DEPARTMENT OF THE ENVIRONMENT AND ENERGY

PDR:19-000158

To: Jo Evans (For Decision)

Through: Kushla Munro

Release of the National Greenhouse Accounts - 2019

Timing: 30 April to be able to complete National Greenhouse Account documents for release

Recommendation:

1. That you note the draft preliminary estimates to be used to finalise the National Inventory Report at **Attachment A**.

Noted / Please discuss

2. That you note our intention to provide you with the UNFCCC *National Inventory Report* (NIR) and related National Greenhouse Accounts for your approval prior to 30 April 2019.

Noted / Please discuss

Signatory: Date:

Comments:

Clearing Officer: Sent ../../..	Rob Sturgiss	Assistant Secretary, NISIR / ICCEID	s22
Contact Officer:	s22	Director, NII ICCEI Division	s22 Mob:

Key Points:

1. Draft preliminary estimates to be used in the NIR are set out in **Attachment A** (NIR Executive Summary).
2. The timeline for formal submission to the UNFCCC of the *National Inventory Report* is the window of 15 April - 26 May 2019.
   a. We will come back to you for your agreement to submit the NIR to the UNFCCC and to publish the other parts of the National Greenhouse Accounts.
3. Emissions are estimated to have increased by 0.8 per cent in 2017.

Method updates

4. All new methods and data must be applied to the entire time series from 1990. Major estimation methodology changes in this report include:
   a. Integration of the modelling of fire (southern temperate, northern savanna and natural disturbances) into FullCAM – historically the fire modelling has been done outside of FullCAM by external consultants (CSIRO);

b. Application of a new ‘standing dead’ pool which enables differentiation between the emission impacts of clearing and of die-back events (allowing for a slow release of emissions associated with die-back events);

c. The application of the ‘managed land proxy’ to the estimation of emissions from soil carbon from agricultural lands; and

d. Sundry tidy-ups and data cleansing activities.

5. The impacts of the soil carbon method changes are the largest. The change in method to apply the ‘managed land proxy’ is desirable:

   i. this approach is unambiguously consistent with the 2006 IPCC Guidelines; whereas

   ii. the previous approach followed the somewhat controversial Canadian concept of trying to isolate the impacts of management changes on soil carbon and reporting these changes only.

b. The upside to the change is that there should be less risk that the method will be unacceptable to the forthcoming UNFCCC review of the inventory scheduled for 2 September;

c. The downside is that the estimates will more readily reflect climatic impacts, which will add some additional variability to the national account.

   i. With carbon budget accounting, and the use of some smoothing techniques in estimation, these climatic impacts are manageable, I believe.

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Sensitivities and Handling

14. Nil

Consultation

15. The methods and data and draft estimates have been shared with the States and Territories, and the User Reference Group (NFF, AFPA, AIGN, CSIRO, Andrew MacIntosh, Hugh Saddler).

ATTACHMENTS

A: National Inventory Report - Executive Summary
B: Evaluation of Outcomes 2018-19

DEPARTMENT OF THE ENVIRONMENT AND ENERGY

FOI 191203
Document 2

PDR: EC19-000354

To: Jo Evans (For Decision)

Release of National Greenhouse Accounts 2017

Timing: 17 May to incorporate any comments prior to National Inventory Report due date.

Recommendations:

1. That you approve the submission of the *National Inventory Report 2017* (NIR) to the UN Framework Convention on Climate Change (UNFCCC) on 24 May 2019.

Approved / Not approved

2. That you approve the release strategy for the National Greenhouse Accounts 2017 and the *Quarterly Update on the National Greenhouse Gas Inventory December 2018,* contained in this brief.

Approved / Not approved

3. That you note our intention to inform the Minister of the National Greenhouse Accounts 2017 submission to the UNFCCC and website publication through the incoming government briefing process.

Noted / Please discuss

Signatory: Date:

Comments:

Clearing Officer: Sent ../../..	Rob Sturgiss	Assistant Secretary, NISIR / ICCEID	s22
Contact Officer:	s22	Director, NII ICCEI Division	s22

Key Points:

1. Your approval is sought to the submission of the Australian Government's *National Inventory Report 2017* (<u>Attachment A</u>) to the UNFCCC.
2. This Report updates the preliminary emission estimates shared with you in EC19-000158.
   a. Final emission estimates do not change the *Evaluation of Outcomes* (<u>Attachment B</u>) previously submitted to you that demonstrates estimates meet the Inventory QA-QC Plan's quality criteria in all material aspects.

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FOI 191203
Document 2a

Australian Government
Department of the Environment and Energy

National Inventory Report 2017

Volume 1

The Australian Government Submission to the United Nations Framework Convention on Climate Change

Australian National Greenhouse Accounts

May 2019

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Volume 1

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Executive Summary

ES.1 Background information on greenhouse gas inventories

This is Australia's *National Inventory Report 2017,* submitted under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP).

The Report contains national greenhouse gas emission estimates for the period 1990-2017, and preliminary estimates for 2018. It has been prepared in accordance with the *Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention* agreed by the Conference of the Parties at its nineteenth session (decision 24/CP.19), and set out in document FCCC/CP/2013/10/Add.3[1], and the supplementary reporting requirements under Article 7 of the KP (decisions 6/CMP.9, 2/CMP.8, 2 and 4/CMP.7, 15/CMP.1, and 2, 3 and 4/CMP.11).

The Report has been compiled using methods which conform to the international guidelines prepared by the Intergovernmental Panel on Climate Change (IPCC) and adopted by the UNFCCC – the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) and the *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (IPCC 2014). The methodologies used to estimate Australia's inventory have been improved over time and will continue to be refined as new information emerges, and as international practice evolves. The impact on greenhouse gas emission estimates of refinements to methodologies adopted for this inventory has been reported in Chapter 10 (Volume 2) and summarised in section 4 of the Executive Summary.

The Report contains net emissions for 2017 compiled using reporting rules applicable to the KP second commitment period (CP2). 2017 is the fifth year of the KP CP2, which is yet to enter into force. Decision 1/CMP.8 provides that, pending entry into force of the KP Doha Amendment that establishes the CP2 (2013-2020), KP Parties will implement their commitments and other responsibilities in relation to the CP2 in a manner consistent with their national legislation or domestic processes. The Australian Government submitted its instrument of acceptance to the Doha Amendment on 9 November 2016.

The responsibility for Australia's greenhouse emissions reporting has been assigned to the Department of the Environment and Energy. The Department undertakes all aspects of activity data coordination, emissions estimation, quality control, preparation of reports and their submission to the UNFCCC on behalf of the Australian Government.

In addition to this Report, the Department publishes a range of supporting emissions estimates that, together, constitute the *Australian National Greenhouse Accounts*, including:

- *Quarterly Updates of Australia's National Greenhouse Gas Inventory*, which provide a summary of Australia's national emissions, updated on a quarterly basis;
- *State and Territory Greenhouse Gas Inventories*; and
- the *National Inventory by Economic Sector,* comprising emission estimates by economic sector rather than by IPCC sectors as in this Report.

These documents are available on the Department's website at http://www.environment.gov.au/climate-change/. They provide additional information with respect to Australia's emissions on both a regional and industry basis.

1 http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf#page=2

ES.2 Summary of the national emission and removal related trends

ES.2.1 Greenhouse gas inventory – UNFCCC classification system (Paris Agreement NDC)

Australia's total greenhouse gas emissions were 534.7 million tonnes (Mt) of carbon dioxide equivalent (CO_2-e) in 2017. This represents an increase of 4.3 Mt CO_2-e, or 0.8 per cent, on net emissions recorded in 2016. Overall, total emissions have decreased by 70.2 Mt CO_2-e, or 11.6 per cent, on net emissions recorded in 1990 (Table ES.01).

Under the UNFCCC Paris Agreement, the Australian Government committed to a quantified economy-wide nationally determined contribution (NDC) to reduce national emissions by between -26 and -28 per cent on 2005 levels by 2030. In its submission to the UNFCCC[2], the Australian Government indicated that it will report progress towards that commitment using estimates of net emissions according to UNFCCC classifications.

To support Australia's Paris Agreement NDC this Report contains greenhouse gas emissions estimates for 2005 and 2017 on the basis of the UNFCCC classification system. That is, this Report includes emissions and removals from the *energy, industrial processes and product use, agriculture, waste* and the *land use, land use change and forestry* sectors. Total net emissions were 534.7 Mt CO_2-e in 2017, which was 12.4 per cent lower than in 2005.

Table ES.01 Net greenhouse gas emissions under the UNFCCC by sector, Australia, 1990, 2005, 2010, 2016 and 2017 (Mt CO_2-e)

UNFCCC classification sector and subsector	Emissions Mt CO_2-e					Change per cent
	1990	2005	2010	2016	2017	2005-2017
1 Energy (combustion + fugitive)	294.0	399.6	420.1	432.1	435.6	9.0
Stationary energy	195.4	278.7	289.0	287.0	285.1	2.3
Transport	61.4	82.2	88.8	96.4	98.7	20.1
Fugitive emissions from fuel	37.2	38.7	42.4	48.7	51.8	34.0
2 Industrial processes and product use	26.0	31.9	35.6	33.0	33.7	5.7
3 Agriculture	80.2	75.9	66.3	69.3	73.0	-3.8
4 Land use, land use change and forestry	184.6	88.8	48.7	-16.3	-19.4	-121.9
5 Waste	20.0	14.4	15.2	12.4	11.8	-18.1
Total net emissions	**604.9**	**610.6**	**586.0**	**530.4**	**534.7**	**-12.4**

2 http://www.environment.gov.au/climate-change/

ES.2.2 Greenhouse gas emissions – Kyoto Protocol classification system (Cancun Agreement QEERT)

Under the UNFCCC Cancun Agreement, the Australian Government committed to a Quantified Economy-wide Emission Reduction Target (QEERT) of -5 per cent on 2000 levels by 2020. In its third Biennial Report[3], the Australian Government indicated that it will report progress towards that commitment based on a carbon budget for the 2013-2020 period and using estimates of net emissions utilising KP classifications.

To support Australia's QEERT, this Report contains greenhouse gas emissions estimates for 2000 and 2017 on the basis of the KP classification system. That is, this Report includes emissions and removals from the *energy, industrial processes and product use, agriculture* and *waste* sectors and the following KP *LULUCF* sub-classifications: *deforestation*, *afforestation*, *reforestation*, *forest management*, *cropland management*, *grazing land management* and *revegetation*. On this basis, total net emissions were 530.8 Mt CO_2-e in 2017, which was 1.8 per cent lower than in 2000.

Table ES.02 Net emissions by KP classification, Australia, 2000 and 2017 (Mt CO_2-e)

KP Classification sector and subsector	Emissions Mt CO_2-e		Change per cent
	2000	2017	2000-2017
1 Energy	364.3	435.6	19.6
2 Industrial Processes and Product Use	26.7	33.7	26.2
3 Agriculture	78.4	73.0	-6.9
4 LULUCF activities	55.4	-23.3	-142.1
5 Waste	15.7	11.8	-24.7
Total	**540.4**	**530.8**	**-1.8**

ES.2.3 Greenhouse gas emissions – Kyoto Protocol second commitment period

In accordance with decision 1/CMP.8, this Report contains net emissions estimates for 2017 compiled using reporting rules applicable to the KP CP2.

Under the KP accounting rules Parties must report net emissions from the *energy, industrial processes and product use, agriculture* and *waste sectors* and from the *deforestation* activity from the *LULUCF* sector. Parties must also include the mandatory Article 3.3 *LULUCF* activities *afforestation* and *reforestation* and, for the CP2, the mandatory Article 3.4 activity *forest management* in their reporting. In addition, Australia accounts for the voluntary Article 3.4 activities *cropland management, grazing land management* and *revegetation.* Australia does not account for *wetland drainage and rewetting* for the CP2.

As shown in Table ES.03, the total net emissions associated with the KP account were 580.2 Mt CO_2-e in 2017. When Removal Units (RMU) from *LULUCF* activities are added, net liabilities in 2017 were 509.5 Mt CO_2-e. Over CP2 to date (2013-17), Australia's net position stands at an estimated net surplus of 2,132,693,045 Kyoto units (Table ES.04). Further detail on the *LULUCF* activities is provided in Chapter 11 of Volume 3. Information on holdings and transactions of Kyoto units in the financial year 2017-18, is provided in Chapter 12 of Volume 3.

3 http://unfccc.int/national_reports/biennial_reports_and_iar/submitted_biennial_reports/items/7550.php

Table ES.03 Emissions and removals associated with Articles 3.1, 3.3 and 3.4 of the Kyoto Protocol, Australia, 2013-2017 (Mt CO_2-e)

Sector and Subsector	Emissions Mt CO_2-e				
	2013	2014	2015	2016	2017
1 Energy	414.5	408.7	420.3	432.1	435.6
2 Industrial processes and product use	31.5	31.2	32.8	33.0	33.7
3 Agriculture	72.1	72.6	70.1	69.3	73.0
5 Waste	12.4	12.5	11.9	12.4	11.8
Deforestation (a)	35.2	36.9	26.7	29.1	26.1
National inventory emissions	**565.7**	**561.9**	**561.9**	**575.9**	**580.2**
RMU credits generated by Article 3.3 and 3.4 activities					
Afforestation/Reforestation (a)	-25.9	-25.9	-25.0	-28.3	-29.4
Article 3.4 activities (a)	-35.0	-37.0	-42.0	-50.8	-41.3
Total RMU credits (b)	**-61.0**	**-62.9**	**-67.0**	**-79.1**	**-70.7**
Kyoto Protocol Total (National inventory emissions plus RMU credits)	**504.7**	**499.0**	**494.9**	**496.8**	**509.5**

(a) Australia has elected to account for Article 3.3 activities on an annual basis, and Article 3.4 activities at the end of CP2.
(b) Accounting quantity in accordance with decisions 2/CMP.7 and 3/CMP.11 and estimates for *Cropland Management and Grazing Management* were adjusted for the emissions reported under Forest Conversion in the UNFCCC in 1990 for conversions up to 31 December 1989, and recorded in the report used to calculate the assigned amount, in order to avoid double counting.

Table ES.04 Kyoto Protocol second commitment period net position, Australia: as at 2017 (t CO_2-e)

Kyoto units		t CO_2-e
CP2 Assigned Amount		4,511,619,826
CP1 Carry over units		
	AAUs	127,650,775
	CERs	21,768,290
CP2 RMUs (2013-2017)		317,178,355
Total Kyoto units (1)		**4,978,217,246**
National inventory emissions		
2013-2017 (2)		2,845,524,201
Net position (1) – (2)		**2,132,693,045**

ES.3 Overview of source and sink category emission estimates and trends

ES.3.1 Greenhouse gas inventory – UNFCCC

The *energy* sector was the largest source of greenhouse gas emissions in 2017 comprising 81.5 per cent (435.6 Mt CO_2-e) of total net emissions. *Energy* emissions increased by 48.2 per cent between 1990 and 2017 and increased by 0.8 per cent between 2016 and 2017.

For the *energy* subsectors in 2017:

- *stationary energy* was the main contributor to total net emissions (53.3 per cent of the total), and decreased by 0.7 per cent between 2016 and 2017;
- *transport* emissions (18.5 per cent of total net emissions) increased by 2.5 per cent between 2016 and 2017; and
- *fugitive emissions from fossil fuels* (9.7 per cent of total net emissions) increased by 6.4 per cent between 2016 and 2017.

Industrial processes and product use made up 6.3 per cent (33.7 Mt CO_2-e) of the total net emissions for 2017 and increased by 2.1 per cent between 2016 and 2017.

Agriculture emissions made up 13.7 per cent (73.0 Mt CO_2-e) of total net emissions in 2017 and increased by 5.4 per cent between 2016 and 2017.

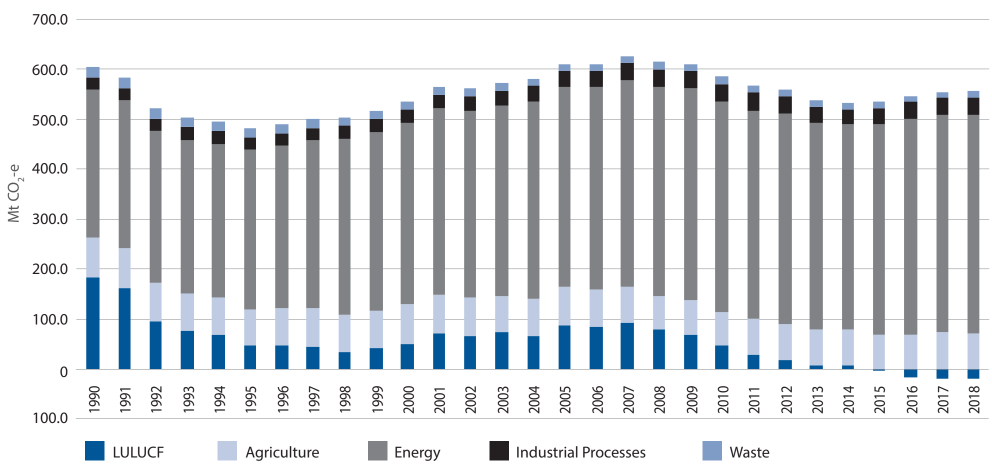
The *waste* sector contributed 2.2 per cent (11.8 Mt CO_2-e) of the total net emissions in 2017 and decreased by 5.0 per cent between 2016 and 2017.

The UNFCCC *LULUCF* sector was a net sink of 19.4 Mt CO_2-e in 2017, equivalent to -3.6 per cent of total net emissions (excluding LULUCF). Net emissions for this sector decreased by 3.1 Mt CO_2-e between 2016 and 2017.

The full time series of the national inventory, including for major sectors and preliminary estimates for 2018, is presented in Figure ES.01. Preliminary estimates for 2018 indicate total net emissions of 537.4 Mt CO_2-e with increases in *stationary energy, transport* and *fugitive* emissions and decreases in emissions from *electricity*.

A full overview of emission estimates by source and sink is given in Chapter 2. More detailed information on the emission results for individual sectors has been reported in the introductions to Chapters 3 – 7.

Figure ES.01 Net greenhouse gas emissions under the UNFCCC, by sector, Australia, 1990-2018 (Mt CO_2-e)



Focus on land sector estimates

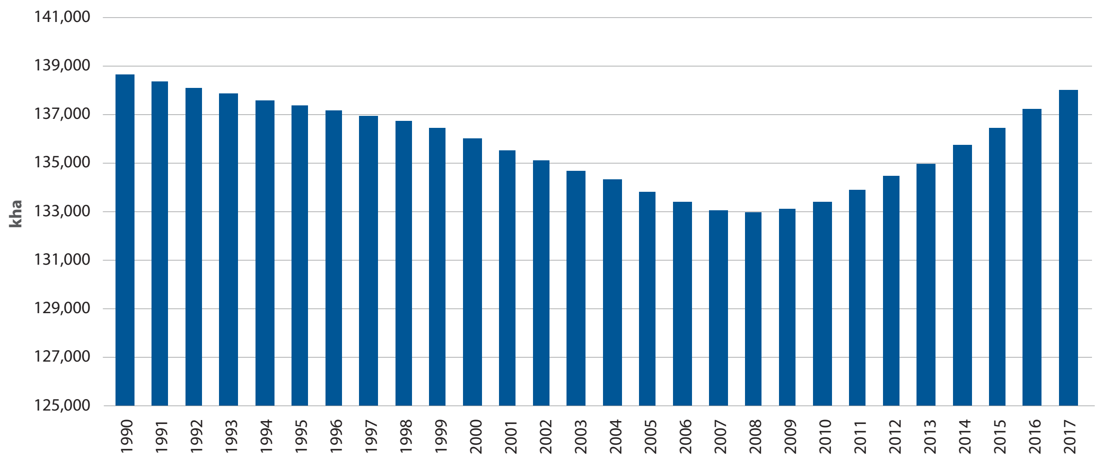
Overall, the forest area of Australia increased by an estimated 772 thousand hectares in 2017, and by 4.6 million hectares since 2010 (Figure ES.02). In 2017, the increase in forest cover from new and emerging forests more than offset losses from an increase in forest land clearing activity.

The increase in forest cover includes establishment of new forests, as well as secondary regrowth on areas where previous land clearing has been observed. Within the *Land converted to forest* category, the area of additional secondary forest regenerating on land previously cleared was 273 thousand hectares in 2017. In net terms, this indicates that forests are re-appearing on land previously cleared faster than land managers are re-clearing that bush encroachment. The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) classifies much of these lands as "grazing native vegetation" (Appendix 6.L), signifying that clearing occurs on lands that attract extensive cyclical clearing management activity by graziers.

The area of primary forest converted to other land uses was estimated to be 46 thousand hectares in 2017 (Figure ES.03) (a decrease of 20 thousand hectares on 2016 levels).

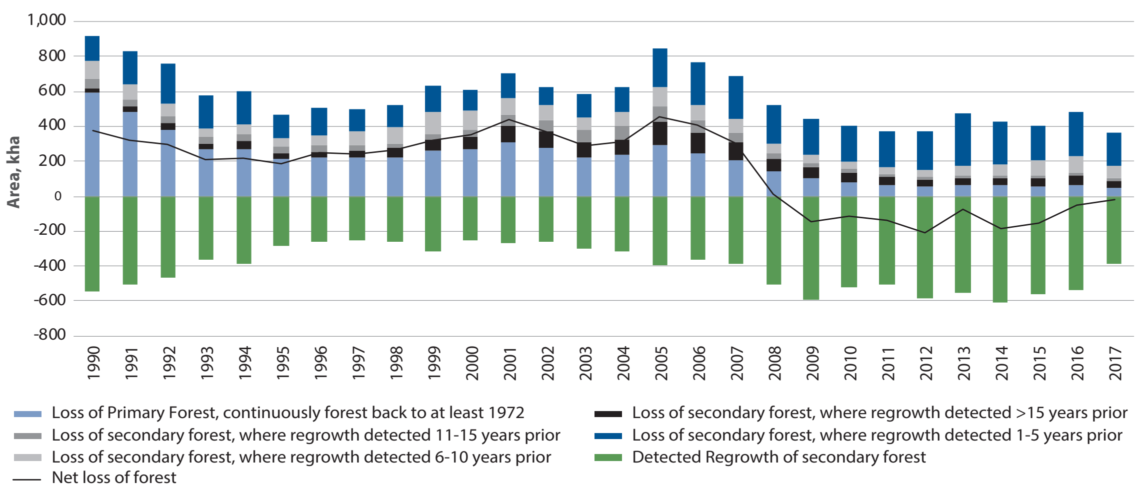
Significantly, most clearing (87 per cent of the total) occurs in secondary regrowth forests. In 2017, this kind of re-clearing was 318 thousand hectares, which was 23 per cent lower than in the previous year (416 thousand hectares). Most of this activity (279,000 hectares or 76 per cent of the total clearing) was the loss of juvenile forests where the forest had been observed to have regenerated less than 15 years previously (Figure ES.03).

Figure ES.02 Forest cover, Australia, 1990-2017 (kha)



Larger areas of gains and losses of sub-forest, sparse woody vegetation are occurring and are reported under *grasslands remaining grassland*. The estimates of sparse vegetation gains and losses may comprise some clearing for pasture as well as the short term effects of climate variability.

Figure ES.03 Forest cover changes on lands with a history of clearing, Australia, 1990-2017 (kha)



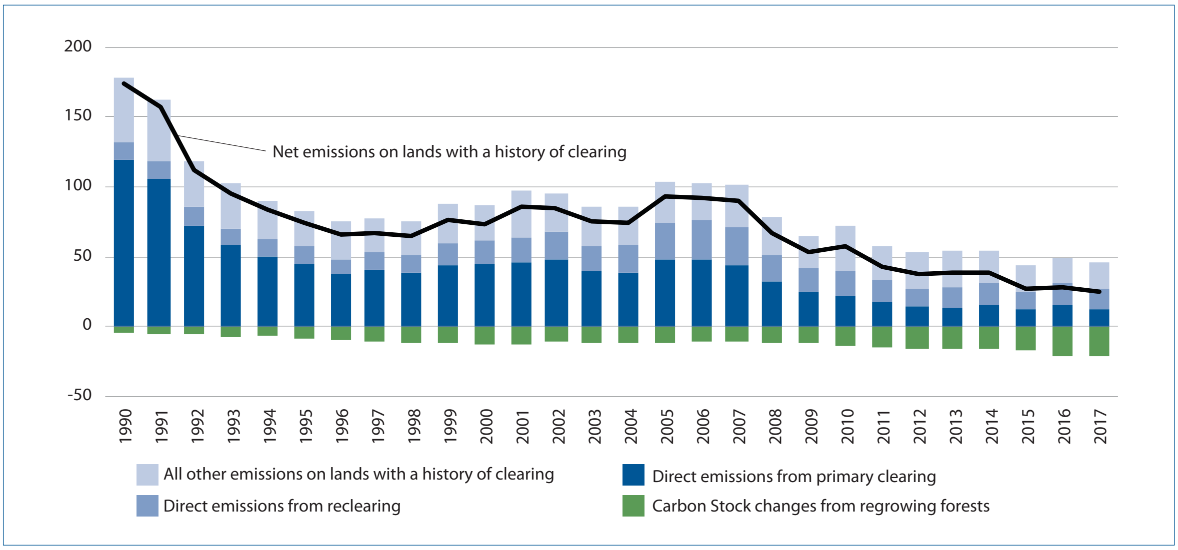
The most important driver of net emissions from the land sector in 2017 has been the conversion of *forest to other land uses* (Figure ES.04) including for agriculture, mining and settlements. The emissions from *forest converted to other land uses* totalled 46.5 Mt CO_2-e in 2017.

Direct emissions from primary forest clearing (from combustion of forest debris following a clearing event) fell in 2017 to 12.5 Mt CO_2-e, down 17 per cent from 2016 levels (15.1 Mt CO_2-e) (see Figure ES.04).

Direct emissions from re-clearing contributed 15.0 Mt CO_2-e in 2017, down 6 per cent from 16.0 Mt CO_2-e in 2016. These practices contribute far fewer net emissions per hectare than the clearing of mature forests on average due to the lower biomass of younger regrowth forests.

For this Report, consistent with UNFCCC ERT recommendations, sequestration from secondary regrowth on areas where previous land clearing has been observed has been classified under *land converted to forest*, contributing a net sink of 21.0 Mt CO_2-e in 2017.

Figure ES.04 Emissions from *forest converted to other land uses*, Australia,1990-2017 (Mt CO_2-e)



The state of carbon stocks on Australia's land is illustrated in Figure ES.05.

Figure ES.05 Carbon stocks, Australia, June 2016 (tC/ha)

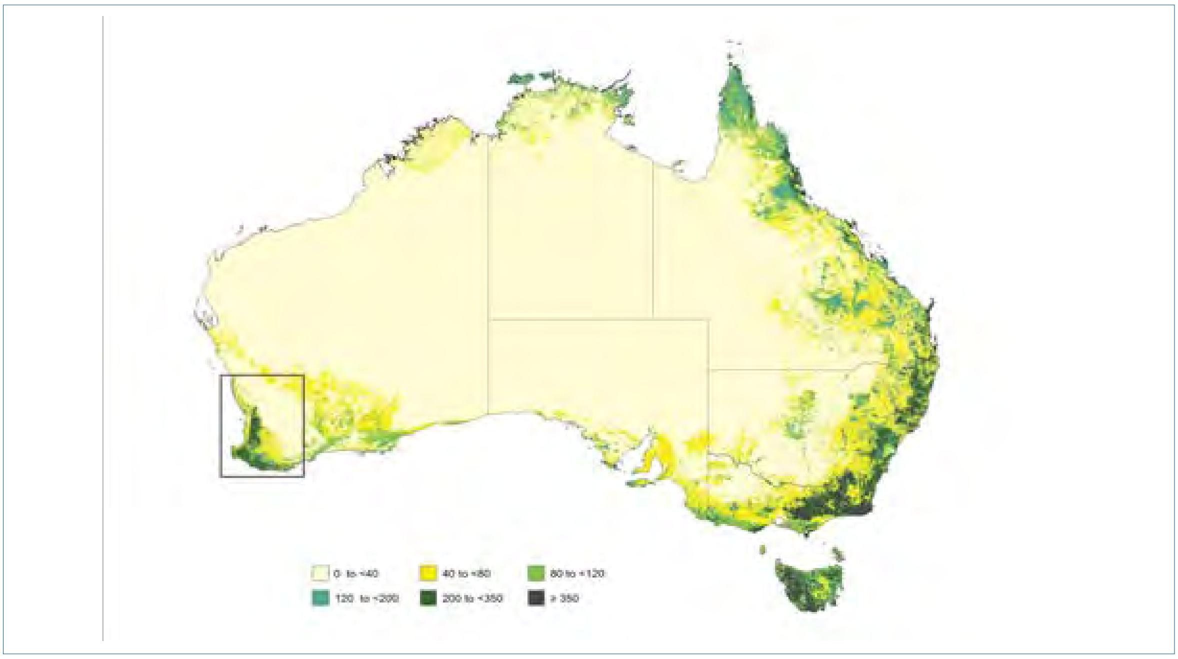
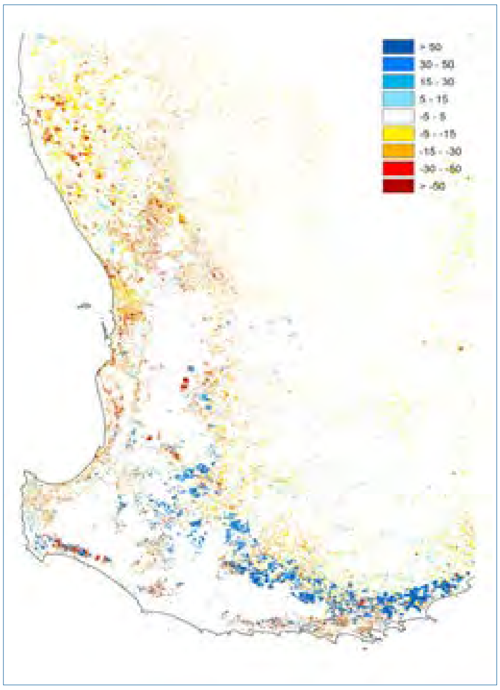


Figure ES.06 shows the changes in forest-related carbon stocks with a focus on South-Western Australia, and reflects losses of carbon stocks due to forest conversion events and gains in carbon stocks due to forest regrowth from natural seed sources and plantations.

Figure ES.06 Carbon stock changes in South-Western Australia due to forest gains and losses, 1990-2016, (t/ha)



The increases in net carbon stock in recent years principally reflect declines in timber harvesting and increasing rates of secondary forest regrowth.

ES.3.2 KP-*LULUCF* Activities

In accordance with decision 1/CMP.8, this Report contains estimates for 2017 from KP *LULUCF* activities (Table ES.03) compiled using reporting rules applicable to the KP CP2.

The *deforestation* activity contributed net emissions of 26.1 Mt CO_2-e in 2017. Under KP accounting rules this estimate would lead to the cancellation of Assigned Amount Units (AAUs) equivalent to this amount.

Under KP accounting rules, the *afforestation/reforestation* activity is estimated to generate RMU credits equivalent to 29.4 Mt CO_2-e in 2017.

Forest management, cropland management, grazing land management and *revegetation* activities are estimated to generate RMU credits of 41.3 Mt CO_2-e in 2017.

Australia accounts for *deforestation* and *afforestation/reforestation* annually in a continuation of the approach selected in the first commitment period.

Australia will account for *forest management* and elected Article 3.4 activities (*cropland management, grazing land management,* and *revegetation)* at the end of the commitment period.

ES.4 Major inventory developments and recalculations

ES.4.1 Australian National Audit Office (ANAO) Performance Audit: 2016-17

The ANAO is an independent office established under the *Auditor-General Act 1997*. Its purpose is to drive accountability and transparency in the Australian Government sector through quality evidence based audit services and independent reporting to Parliament, the Executive and the public, with the result of improving public sector performance.

The ANAO conducts performance audits of government agencies operating under the Standard on Assurance Engagements ASAE 3500 Performance Engagements issued by the Australian Auditing and Assurance Standards Board (AUASB).

ANAO reports are tabled in the Australian Parliament and subject to review by the Joint Committee of Public Accounts and Audit (JCPAA).

The ANAO undertook a performance audit of the national inventory over nine months (August 2016 to April 2017). Its objective was to assess the effectiveness of arrangements for the preparation and reporting of Australia's greenhouse gas emissions estimates in the *National Inventory Report 2014 (revised)* for the year 2014.

Through the course of the audit the ANAO:

- examined Department records relating to the preparation of the estimates, including UNFCCC and departmental guides, implementation plans, quality assurance/quality control documents, and general governance documentation,
- examined ten inventory sectors representing more than 50 per cent of national emissions; comprising over 5250 data points across more than 158 data types contained in spreadsheets supporting the entry of data into the Australian Greenhouse Emissions Information System (AGEIS),
- examined key IT controls supporting AGEIS and FullCAM, and
- interviewed Department staff and sought input from the public and key stakeholders.

The ANAO reported that:

- the Department has established appropriate processes to prepare, calculate and publish Australia's national inventory for the year 2014,
- emissions estimates have been calculated using relevant contemporary data,
- appropriate quality assurance and control procedures are in place for inventory data processing, emissions calculations and reporting, and
- the aggregate impact of data issues identified in the national inventory across the time series 1990-2014 was calculated by the Department as less than 0.1 per cent per year.

All data issues identified by the ANAO have been addressed or corrected. The ANAO also made a number of recommendations relating to improving the data accuracy, security and governance arrangements for the preparation, calculation and publication of the national inventory. Measures to address aspects of these recommendations were implemented through the course of the preparation of the *National Inventory Report 2015*. One such measure was a "Rounding policy for AGEIS inputs" to promote consistent decision making in inventory compilation.

Measures to address outstanding aspects of the ANAO report recommendations have been included in the *National Inventory Improvement Plan*.

ES.4.2 Synthetic greenhouse gas emissions

The major change in the industrial process and product use sector has been in the use of atmospheric measurements to support estimates of HFC emissions for the first time. In this report, the annual operating leakage rates of HFCs have been calibrated to fluctuations in atmospheric concentrations of HFCs measured by CSIRO at Cape Grim in Tasmania. The strength of this approach is that it enables the inventory estimates to better reflect atmospheric measurements which, in turn, capture improvements in industry practice over time in terms of gas handling, equipment maintenance and decommissioning. See section 4.9 of this Report, Volume 1, for further information.

ES.4.3 Land sector improvements

The principal improvements to the estimation of emissions from the land sector relate to the estimation of emissions from fire, from die-back and from soil carbon in agricultural lands.

Emissions from temperate and savanna fires have been estimated using a spatial Tier 3 approach for the first time in this report. The modelling of net emissions from fire has been incorporated into the FullCAM model of carbon stock change across the Australian landscape, integrating the estimation of net emissions from fire with the estimation of net emissions from forest conversion to grass and croplands (land clearing) and forest regrowth.

The inclusion of a standing dead pool of carbon into the FullCAM model has facilitated the symmetric treatment of natural regeneration and the die-back of forests.

Soil carbon emissions from crop and grasslands have been re-calculated in this report using the FullCAM model in conjunction with a conceptually consistent approach to that used for the estimation of soil carbon emissions from *forest conversion* (land clearing) (ie the managed land proxy), replacing the previous approach based on changes in management practices designed to control for inter-annual variability.

ES.4.4 Land sector accuracy, transparency and disaggregation of estimates

The FullCAM model has been designed to comply with IPCC Guidelines and to meet the Australian Government's international treaty estimation and reporting commitments.

FullCAM is designed to fully integrate the estimation of carbon stock changes and related emissions across the Australian landscape and is described in detail in Volume 2.

A comprehensive modelling approach to the estimation of carbon stock changes was originally chosen for the Australian land sector because of the absence of extensive forest inventory or measurement systems, reflecting the circumstance that timber industry activity has been confined in recent times to approximately 10 per cent of Australia's forest.

FullCAM's initial design took advantage of existing carbon model structures, such as the widely used Roth-C for soil carbon.

Model parameterization has been informed by the latest empirical science, including the work of Dr Stephen Roxburgh and Dr Keryn Paul of the CSIRO. For example, the spatial layer of maximum biomass achieved across the Australian landscape for undisturbed forests was re-calibrated for the latest science by the CSIRO (Roxburgh *et al* 2017) based on the library of six thousand measurements held by the TERN/AusCover National Biomass Library (http://www.auscover.org.au/purl/biomass-plot-library).

Spatial datasets for key disturbance events such as land clearing, forest planting and natural regeneration are derived by the Department of Environment and Energy from LandSat satellite imagery held by the GeoScience Australia datacube (Digital Earth Australia) and processed by CSIRO Data61 and are informed by land use and vegetation datasets provided by the Department of Agriculture and Water and the Department of the Environment and Energy.

Spatial data for fire areas are derived from AVHRR satellite imagery.

Figure ES.07 Spatial mapping of forest losses, South-Eastern Queensland 2014-2017

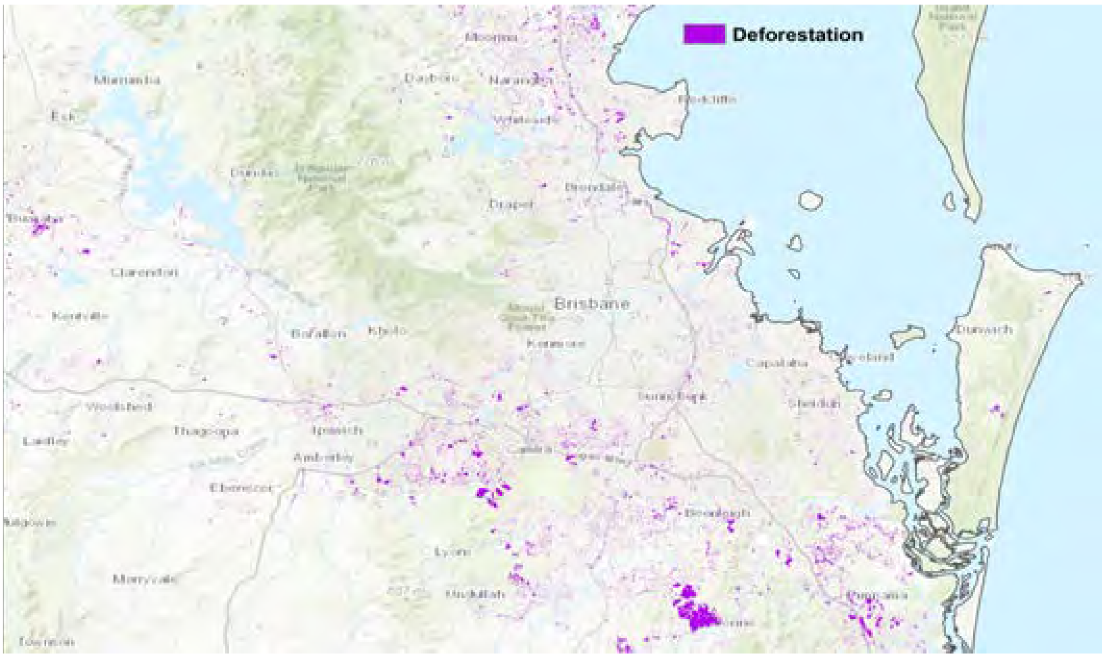
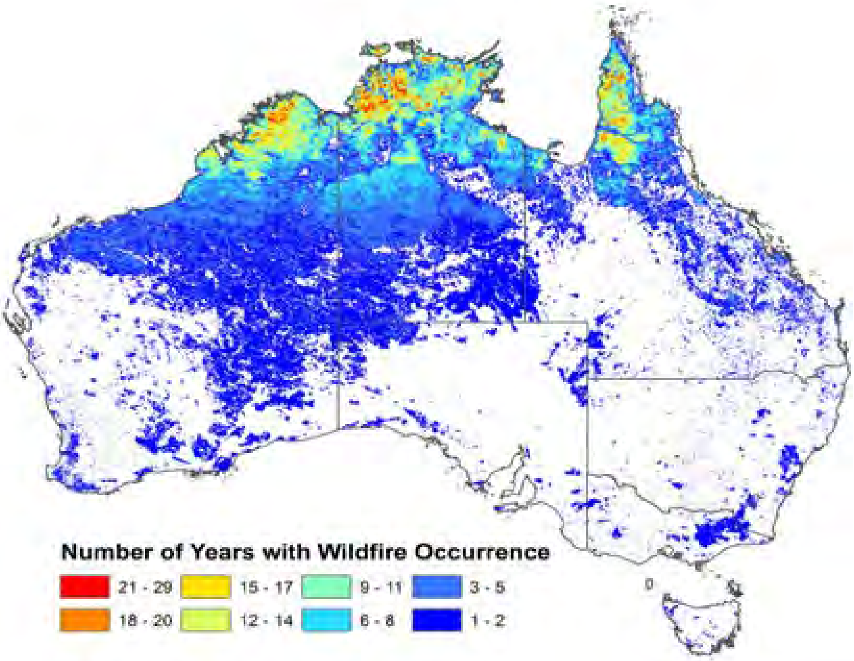


Figure ES.08 Spatial mapping of new plantations, Southern Australia, 1990-2017

Figure ES.09 Spatial mapping of forest and grassland wildfire, 1990-2017



Review and audit

The FullCAM model has been reviewed by UNFCCC on 11 occasions. All recommendations from past UNFCCC ERT reports have been implemented or addressed in this National Inventory Report.

Inventory estimates in this report comply with the National Greenhouse Accounts *Quality Assurance- Quality Control Plan 2018/19*.

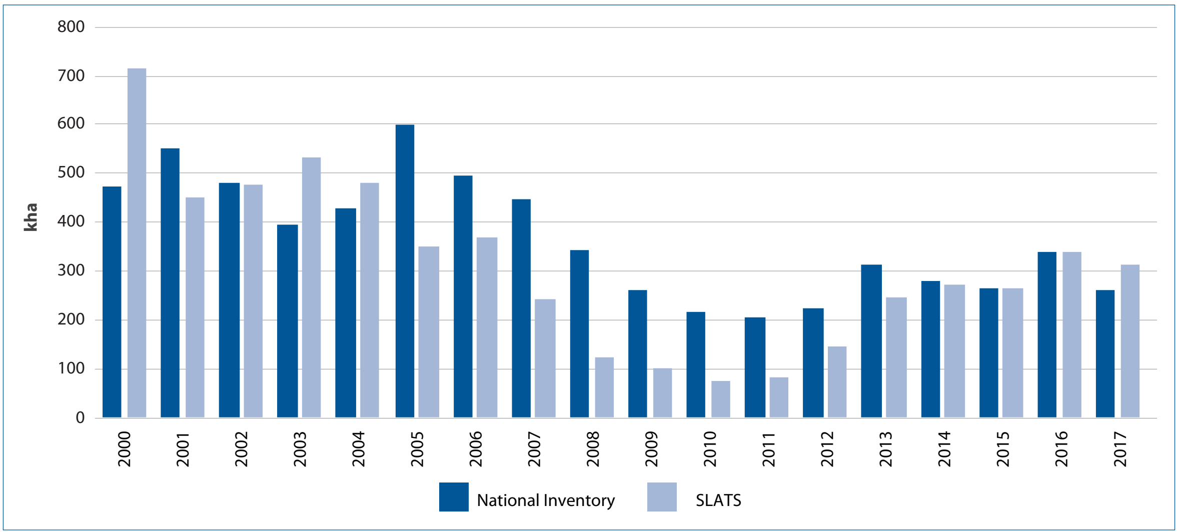
All national inventory systems and data were audited by a $0.5million Australian National Audit Office audit in 2017. No material issues were identified.

Data inputs

One of the key activity data inputs relates to the area of forest cleared for Queensland. The national inventory dataset can be compared with a similar product prepared by the Queensland Government for its monitoring of the Queensland Government *Vegetation Management Act* (see Figure ES.10) (known as SLATs).

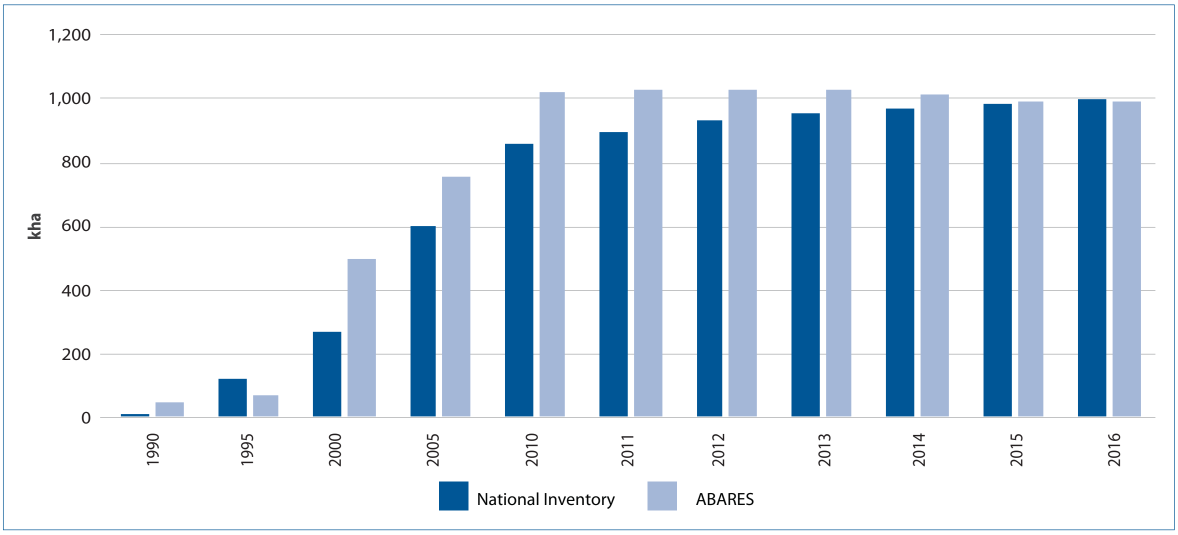
Analysis shows close agreement between the spatial dataset used for the national inventory and the Queensland Government's 'SLATS' estimates for recent years. In the period 2013-2017, the average difference between the two datasets compared on a like-for-like basis is 1 per cent. In the period 2005-2012, the Australian national inventory dataset shows higher clearing rates and for the year 2000 the Australian national inventory dataset is 34 per cent lower. Over the whole period 2000-2017, the national inventory estimates are 15 per cent higher than the Queensland Government's 'SLATs' estimates. Work is ongoing to consider whether greater levels of reconciliation may be able to be achieved for the earlier periods of the time series.

Figure ES.10 Comparison of forest clearing rates in Queensland, 2000-2017 (kha)



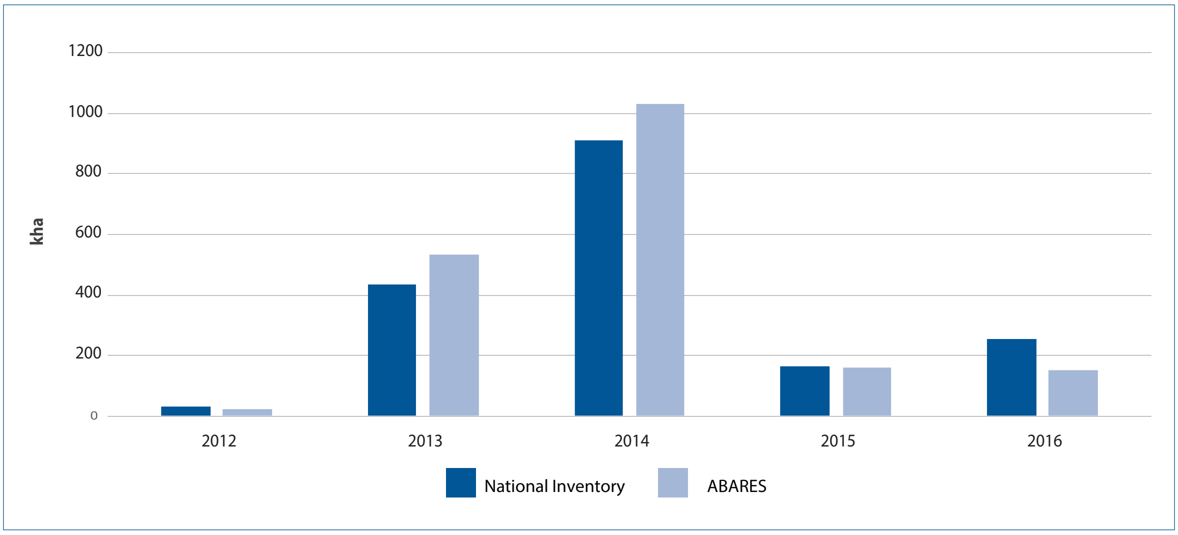
Similarly, the spatial dataset for new plantations used for the national inventory aligns closely with independent published datasets. Cumulatively over the period 1990-2016, the new area under plantations estimated for the national inventory using spatial remote sensing techniques is 1 per cent below the area estimated by ABARES (Figure ES.11).

Figure ES.11 Comparison of cumulative plantation areas, Australia, 1990-2016 (kha)



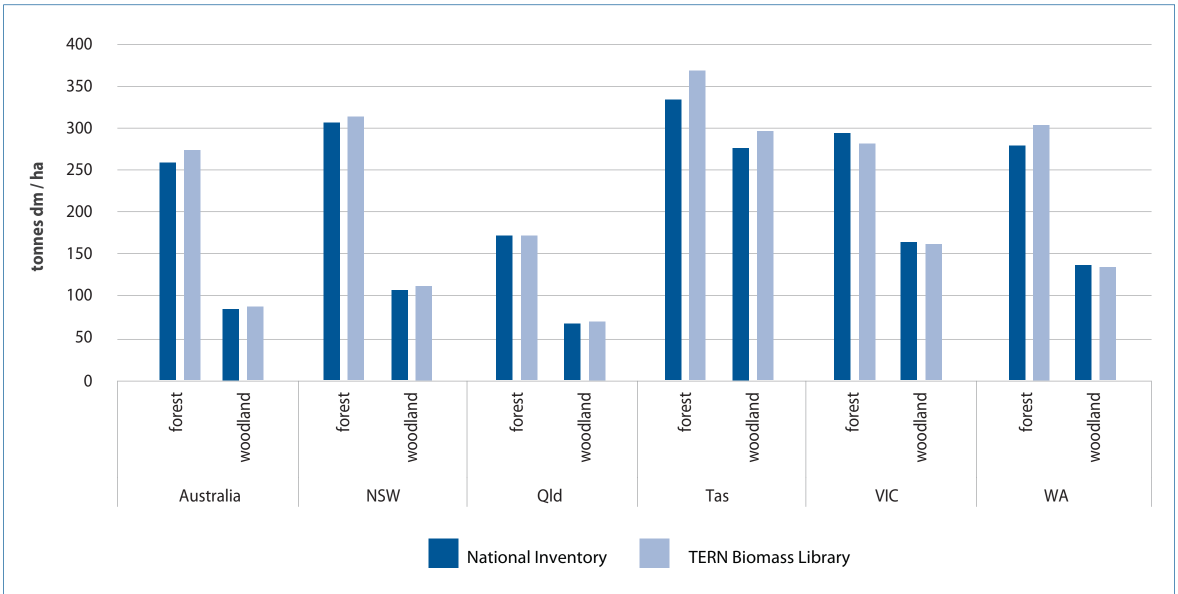
Likewise, spatial datasets for fire disturbances used for the national inventory aligns with independent datasets. Cumulatively over the period 2012-2016, the temperate forest experiencing wildfire estimated for the national inventory using spatial remote sensing techniques is 5 per cent below the area estimated by ABARES in the State of the Forests Report (Figure ES.12).

Figure ES.12 Comparison of annual forest area experiencing wildfire, Australia, 2012-2016 (kha)



The work of Roxburgh (2017) compared the FullCAM modelled maximum biomass estimates with the average maximum biomass data from a sample from the TERN biomass library. He found that for forest cover with more than 50 per cent canopy coverage, at the national level, that the modelled estimates were within 10 per cent of the estimates from the sample from the TERN biomass library. For woodland forests, where the canopy cover was between 20 and 50 per cent, the estimate from the FullCAM model was within 5 per cent of the estimates from the sample from the TERN library (Figure ES.13).

Figure ES.13 Comparison of maximum biomass layer and empirical data, Australia and by State, (tonnes of dry mass/ha)



Transparency

The FullCAM methods and data are documented extensively in Volume 2 of this report.

FullCAM is subject to considerable external usage and scrutiny.

FullCAM is made available to public users as the FullCAM public release (http://www.fullcam.com/FullCAMServer/Help/172_Overview%20of%20FullCAM.htm), enabling public users to model carbon stock changes for any relevant location across Australia using FullCAM.

FullCAM is used by project proponents under the Australian Government's Carbon Farming Initiative to estimate carbon stock changes from forest regeneration projects ensuring integrated, consistent estimates of project and national net emissions.

A FullCAM Research Version is also available on request and is used by many researchers around Australia.

Data and disaggregation

In addition to the data presented in this National Inventory Report, tabular estimates for UNFCCC and Kyoto Protocol classification systems and for related activity data by each of Australia's 8 states and territories is published on the Australian Greenhouse Emissions Information System (AGEIS) (http://ageis.climatechange.gov.au/).

FullCAM outputs are used in the Australian Government State-of-the-Forest and State-of-the-Environment reports and by various State Governments for a variety of purposes.

Gross emissions from land clearing events are reported under *Forest converted to grassland* and *Forest converted to cropland, forest converted to settlements* and *forest converted to wetlands* classifications. Further disaggregation between the emissions for clearing of primary forest, secondary forest and from the lagged effects of clearing in previous years is identified (for example in Figure ES.04 above).

Sequestration from the regrowth of forest on previously cleared lands is disaggregated from forest conversion estimates and reported under the *Land converted to forest* classification.

Data for the Kyoto Protocol classification – *Deforestation* – are reported in net terms in accordance with the rules of the Kyoto Protocol but also with sub-categories disaggregating emission and sequestration processes on previously deforested lands.

Spatial data results are published at disaggregated level in Volume 2 – see Appendix 6., for example, which disaggregates land clearing data by type of land use; by IBRA region and by climate zones for the period.

Spatial data for carbon stock changes are published at https://www.nationalmap.gov.au/ at the ABS Statistical Area Division 2 level.

Future improvements

The *National Inventory Improvement Plan 2019/20-22/23* will be implemented to ensure FullCAM is consistent with Paris Agreement requirements.

Additional disturbance events to be fully incorporated into FullCAM include timber harvesting events in native forests and pre-1990 plantations while an assessment of other degradation or regeneration processes in Forest land remaining forest will be undertaken. Additional modules will be developed to build a Tier 3 approach to sub-forest or sparse vegetation and for the implementation of the *2013 IPCC Wetlands Supplement*.

Executive Summary

FullCAM will be regularly reviewed to ensure that the model parameterisation reflects the latest empirical data and science. For example, it is intended that newly available empirical data in relation to the effects of fire in Northern Australia will inform updated parameterisations of FullCAM for future submissions.

ES.4.5 Implementation of 2013 Wetlands Supplement

The *IPCC 2013 Wetland Supplement* is being progressively implemented into the national inventory. Activity-based net emissions are provided for seagrass, tidal marsh removal, as well as for aquaculture adnd emergence/loss of mangrove forest (reported under forest categories).

ES.4.6 Recalculations

The impact of the recalculations on emission levels for the sectors including core *LULUCF* subsectors was an increase in the estimate of total emissions for the year 1990 of 28.1 Mt and an increase in 2016 of 5.4 Mt in 2016 compared with last year's submission.

More significant recalculations resulted from the implementation of the managed land proxy for estimation of soil carbon emissions under croplands and grasslands remaining.

Taken together the impact of all of the recalculations for the national inventory was an increase of 1.0 per cent in 2005 and an increase of 1.0 per cent also for 2016.

Table ES.05 gives the estimated recalculations for this submission. Further information on recalculations is provided in each sector chapter and in Chapter 10 of Volume 2.

Table ES.05 Estimated recalculations for this submission compared with last year's submission 1990, 2000, 2005, 2010, 2013 –16

Sector	Principal reason	Mt CO_2-e							
		1990	2000	2005	2010	2013	2014	2015	2016
1. A Fuel Combustion	**Activity data**	**0.0**	**-0.3**	**-0.2**	**-0.7**	**-0.7**	**-0.8**	**-1.3**	**-1.1**
1. A.1, 2, 4, 5 Stationary Energy	*Activity data*	*0.0*	*0.0*	*0.0*	*-0.3*	*0.0*	*-0.1*	*-0.4*	*0.0*
1.A.3 Transport	*Activity data*	*0.0*	*-0.3*	*-0.2*	*-0.4*	*-0.7*	*-0.8*	*-0.9*	*-1.1*
1. B Fugitives	**Activity data**	**0.0**	**0.0**	**-0.1**	**-0.2**	**-0.2**	**-0.2**	**-0.3**	**-0.3**
2 Industrial Processes	**Activity data**	**0.0**	**0.0**	**0.0**	**-0.8**	**-1.7**	**-1.4**	**-1.0**	**-1.2**
4 Agriculture	**Activity data**	**0.2**	**0.0**	**-0.2**	**-0.1**	**-0.4**	**-0.1**	**0.0**	**0.1**
6 Waste	**Activity data**	**0.0**	**0.0**	**0.0**	**-0.1**	**0.2**	**0.1**	**0.2**	**0.1**
5 Core Land Use, land use change and forestry (excl. Croplands remaining and Grasslands remaining)	Integration of fire, die-back into FullCAM	*1.3*	*-1.1*	*-2.6*	*6.2*	*7.2*	*2.3*	*9.4*	*2.6*
Sub-Total Recalculation	**Total Inventory (excl. Croplands remaining and Grasslands remaining grasslands)**	**1.5**	**-1.6**	**-3.5**	**3.6**	**3.6**	**-1.0**	**5.6**	**-0.9**
5 Additional LULUCF – Croplands Remaining and Grasslands Remaining	Implementation of the Managed Land Proxy and related changes	26.6	-9.5	9.1	19.7	19.3	12.2	7.4	5.2
Total Recalculation	**Total inventory**	**28.1**	**-10.8**	**5.9**	**24.1**	**23.6**	**12.1**	**14.4**	**5.4**

Acknowledgements

The Department of the Environment and Energy acknowledges the many individuals and organisations that have contributed to the development of the national methods over the years.

National Greenhouse Gas Inventory Committee
National Inventory User Reference Group

The resources and expertise of the following Commonwealth agencies have also significantly contributed to the Report:

Australian Bureau of Agricultural and Resource Economics and Sciences
Australian Bureau of Statistics
Bureau of Meteorology
CSIRO
Department of Industry, Innovation and Science
Department of Agriculture and Water Resources
Department of Infrastructure, Regional Development and Cities
Geoscience Australia

PART 1:

ANNUAL INVENTORY SUBMISSION

1. Introduction and inventory context

1.1 Background information on greenhouse gas inventories

1.1.1 Inventory reporting

The United Nations Framework Convention on Climate Change (UNFCCC) was ratified by Australia in 1992 and entered into force in March of 1994. One of the principal commitments made by the ratifying Parties under the Convention was to develop, publish and regularly update national emission inventories of greenhouse gases.

Australia's *National Inventory Report 2017* (the Report) provides estimates of Australia's net greenhouse gas emissions for the period 1990-2017, and preliminary estimates for 2018. This Report and associated common reporting format (CRF) tables[4] are submitted to the UNFCCC to fulfill Australia's reporting obligations under the UNFCCC.

The Report has been prepared in accordance with the *Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention* agreed by the Conference of Parties at its nineteenth session (decision 24/CP.19), and set out in document FCCC/CP/2013/10/Add.3[5] and the supplementary reporting requirements under Article 7 of the Kyoto Protocol (decisions 6/CMP.9, 2/CMP.8, 2 and 4/CMP7, 15/CMP.1, and 2, 3 and 4/CMP.11).

The emission estimates provided in this Report have been compiled in accordance with the Intergovernmental Panel on Climate Change (IPCC) *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) and the *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (IPCC 2014). The aim is to ensure that the estimates of emissions are accurate, transparent, complete, consistent through time and comparable with those produced in the inventories of other countries.

Australia's ratification of the Kyoto Protocol (KP) came into force in March 2008. In accordance with decision 1/CMP.8, this Report fulfils Australia's reporting obligations under the KP. This Report contains net emissions for 2017 compiled using reporting rules applicable to the KP second commitment period (CP2).

2017 is the fifth year of the KP CP2, which is yet to enter into force. Decision 1/CMP.8 provides that, pending entry into force of the KP Doha Amendment that establishes the CP2 (2013-2020), KP Parties will continue to implement their commitments and other responsibilities in relation to CP2 in a manner consistent with their national legislation or domestic processes. On 9 November 2016, the Australian Government submitted its instrument of acceptance of the Doha Amendment.

1.1.2 Gases

The Report covers sources of greenhouse gas emissions, and removals by sinks, resulting from human (anthropogenic) activities for the major greenhouse gases; carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). Also covered in ancillary fashion for reporting under the UNFCCC are the indirect greenhouse gases; carbon monoxide (CO), oxides of nitrogen (NO_X), and non-methane volatile organic compounds (NMVOCs). Sulphur dioxide (SO_2), an aerosol precursor, is also included because emissions of this gas influence global warming.

4 Australia's complete CRF tables will be made available on the web at http://ageis.climatechange.gov.au/QueryCRFTable.aspx

5 http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf#page=2

The Report presents emissions for each of the major greenhouse gases as carbon dioxide equivalents (CO_2-e) using the 100-year global warming potentials (GWPs) contained in the 2007 *IPCC Fourth Assessment Report* (IPCC 2007)[6]. As greenhouse gases vary in their radiative activity, and in their atmospheric residence time, converting emissions into CO_2-e allows the integrated effect of emissions of the various gases to be compared.

1.1.3 Sectors

Emissions and removals have been grouped under five sectors that have been defined by the IPCC. These represent the main human activities that contribute to the release or capture of greenhouse gases into, or from, the atmosphere:

- *Energy*
- *Industrial processes and product use*
- *Agriculture*
- *Land use, land use change and forestry* (*LULUCF*)
- *Waste*

For the first commitment period of the KP, Australia accounted for the *LULUCF* activities *deforestation*, *afforestation and reforestation* activities that had occurred since 1990 (the mandatory Article 3.3 activities). In accordance with decision 1/CMP.8, Australia has expanded the land sector account in CP2. This expansion includes the mandatory Article 3.4 activity *forest management* and the voluntary Article 3.4 activities, *cropland management, grazing land management* and *revegetation*. Australia does not account for *wetland drainage and rewetting* in CP2, however its estimates relating to wetlands categories are reported in Chapter 6 of Volume 2, and summarised in section 4 of the Executive Summary, on a voluntary basis.

1.1.4 Reporting year

The Australian greenhouse gas inventory is reported for Australian fiscal years as key data sources, such as the National Greenhouse and Energy Reporting (NGER) system, and national energy and agricultural statistics obtained from national statistical agencies, the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), the Department of Industry, Innovation and Science (DIIS), and the Australian Bureau of Statistics (ABS), are published on this basis. The year 2017 refers to the Australian fiscal year from 1 July 2016 to 30 June 2017, and a similar format is used for other years to ensure that time series consistency is maintained. The use of fiscal year data is consistent with the IPCC Guidelines (IPCC 2006) as the use of these data conforms to the normal practice of Australia's national statistical agencies and leads to more accurate emissions estimates.

1.1.5 Structure of the National Inventory Report

The structure of this Report has been organised to conform to the *Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention* (FCCC/CP/2013/10/Add.3), and the supplementary reporting requirements under Article 7 of the KP (decisions 6/CMP.9, 2/CMP.8, 2 and 4/CMP.7, 15/CMP.1 and 2, 3 and 4/CMP.11).

6 GWPs used are, 1 for CO_2, 25 for CH_4, 298 for N_2O, 7,390 for the PFC perfluoromethane (CF4), 12,200 for the PFC perfluoroethane (C2F6), 22,800 for SF6 and 17,200 for nitrogen trifluoride (NF3). The full list of GWPs can be found in Annex III to decision 24/CP.19 (available from the UNFCCC website in document FCCC/CP/2013/10/Add.3). GWPs are not available for the indirect greenhouse gases and in accordance with the UNFCCC reporting guidelines, are reported but are not included in the inventory total.

The Report provides estimates of Australia's total net emissions in 2017, and identifies trends in emissions between 1990 and 2017 for each of the sectors and for the main greenhouse gases. It also provides, *inter alia*, comprehensive information on estimation methodologies and data quality; details of recalculations of emissions estimates and background on the national system and the inventory preparation processes in order to facilitate international review and comparison with the inventories of other countries.

Supplementary Kyoto Protocol reporting requirements

In accordance with decision 1/CMP.8, Chapters 11 to 15 of this Report (Volume 3) contain the supplementary KP reporting information on emissions and removals from the *LULUCF* Article 3.3 and Article 3.4 activities, Kyoto units, minimisation of adverse impacts in accordance with Article 3.14 and changes to the national system and registry.

1.1.6 National system

In accordance with Article 5, paragraph 1 of the KP, Australia has put in place a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. The guidelines for national systems (annex to decision 19/CMP.1 and decision 3/CMP.11) detail the characteristics of a national inventory system (Table 1.1). This chapter describes the main components of Australia's national system.

Table 1.1 Reporting of national system characteristics against the guidelines for national systems (annex to decisions 19/CMP.1 and 3/CMP.11)

General functions

Paragraph number (decision 19/CMP.1)	Description of national inventory system characteristic	Section cross reference
10a	Establish and maintain institutional, legal and procedural arrangements	1.2
12a	Designate a single national entity	1.2
12b	Make available postal and electronic addresses of national entity	1.2
12c	Information on actors, institutional, legal and procedural arrangements	1.2
12d	Elaborate a QA/QC plan	1.2
12e	Establish process for official consideration	1.2
13	Improve quality of the inventory	1.2, 10
14a	Identify key source categories	1.5, Annex 1[1]
14b	Prepare estimates in accordance with methods described by the IPCC	1.4
14c	Collect sufficient activity data to support the methods	1.3, 1.4
14d	Estimate inventory uncertainty	1.6, Annex 2
14e	Information on recalculations	10
14g	Information on general inventory QC (tier 1) procedures in accordance with the QA/QC plan	1.2, Annex 6
15a	Information on specific QC (tier 2) procedures	1.2, Annex 6
15b	Information on QA procedures including provision for basic review of the inventory by personnel not involved in the inventory development	1.2, Annex 6
15c	Information on provision for more extensive review for key source categories	1.5
15d	Information on how 15(b) and 15(c) relate to evaluation of inventory planning process in order to meet quality objectives	1.3
16a	Information on how information is archived	1.3
16b	Information on what information is archived	1.3

1 Annexes are contained in Volume 3.

1.1.7 National Greenhouse Accounts

In addition to this Report, the Department publishes a range of supporting emission estimates that, together, constitute the *Australian National Greenhouse Accounts*. In addition to the *National Inventory Report*, the Department also prepares:

- *Quarterly Updates of Australia's National Greenhouse Gas Inventory*, which provide timely information on emissions trends on a quarterly basis;
- an overview of the *State and Territory Greenhouse Gas Inventories*; and
- the *National Inventory by Economic Sector,* comprising emission estimates by economic sector (rather than by IPCC sectors, as in this Report).

These reports provide additional information with respect to Australia's emissions on both a regional and industry basis and are available on the Department's website:

http://environment.gov.au/climate-change/climate-science-data/greenhouse-gas-measurement/tracking-emissions

1.2 National inventory arrangements

1.2.1 Institutional, legal and procedural arrangements

Single national entity

In accordance with the guidelines for national systems (decision 19/CMP.1 annex paragraph 12(a) and decision 3/CMP.11), the responsibility for Australia's national inventory has been assigned to a single agency, the Department of the Environment and Energy, under the Administrative Arrangements Orders of the Australian Government.

The Department has responsibility for all aspects of activity data co-ordination, emissions estimation, quality control, improvement planning, preparation of reports, and submission of reports to the UNFCCC on behalf of the Australian Government.

The designated representative with overall responsibility for the national inventory is:

Assistant Secretary
National Inventory Systems and International Reporting Branch
Department of the Environment and Energy
Australian Government
GPO Box 787
Canberra ACT 2601
AUSTRALIA
nationalgreenhouseaccounts@environment.gov.au

Capacity for timely performance of the general and specific functions of the national system

The guidelines for national systems (decision 19/CMP.1 annex paragraph 10(b) and decision 3/CMP.11) require that there is sufficient capacity for the timely performance of national inventory system functions. The production of high quality and timely greenhouse gas inventories is a resource-intensive process. To meet these objectives of quality and timeliness Australia has invested significant financial and human resources through the development of capital assets, training of Department staff and the contracting of expert consultants as needed.

IT software systems

Estimation of emissions is conducted by the Department, using the Australian Greenhouse Emissions Information System (AGEIS) and, for the *LULUCF* sector, the Full Carbon Accounting Model (FullCAM) (see Figures 1.1 and 1.2).

The AGEIS has been designed to meet the requirements for national inventory systems and is an integral part of the inventory preparation and publishing processes. In particular, it fully integrates quality control procedures into the compilation process as well as centralising emissions estimation, inventory compilation and reporting, and data storage activities. The AGEIS provides high transparency levels for the inventory, with emissions data for the set of *National Greenhouse Accounts* publicly accessible through an interactive web interface: http://www.environment.gov.au/climate-change/climate-science-data/greenhouse-gas-measurement/ageis.

The AGEIS is continuing to be expanded and refined to support the range of *National Greenhouse Accounts* in accordance with the *AGEIS Strategic Plan*. Recent investment include integration of SO_2, $PM_{2.5}$ and PM_{10} emissions data from the National Pollutant Inventory and addition of of sector calculation modules for Black Carbon emissions.

While the AGEIS is used for final preparation of the *National Greenhouse Accounts*, the inventory uses FullCAM to estimate emissions and removals from the *LULUCF* sector and KP-*LULUCF* activities. FullCAM has been substantially redeveloped to improve its fully spatially explicit, process-based ecosystems modeling capability by applying techniques described in the *2013 Revised Supplementary Methods and Good Practice Guidance for LULUCF Arising from the Kyoto Protocol* (IPCC 2014) as well as significantly updated national datasets. To date, the modeling capability has been completed for conversion of forests to other land uses (e.g. cropping and grazing), *conversion of lands to forest, croplands remaining croplands, cropland management*, and the grassland component of *grasslands remaining grasslands* and *grazing land management*.

Figure 1.1 Department of the Environment and Energy inventory asset structures and relationship

Acronym Key

ABARES	Australian Bureau of Agricultural Resource Economics and Sciences
ABS	Australian Bureau of Statistics
AEC	Australian Energy Council
AGEIS	Australian Greenhouse Emissions Information System
ANREU	Australian National Registry of Emissions Units
APPEA	Australian Petroleum Production and Exploration Association
BoM	Bureau of Meteorology
CER	Clean Energy Regulator
CRC	Cooperative Research Centres
CRF	Common Reporting Format
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DoEE	Department of the Environment and Energy
DIIS	Department of Industry, Innovation and Science
DNRM	Department of Natural Resources and Mining (Queensland)
FullCAM	Full Carbon Accounting Model
NGERS	National Greenhouse and Energy Reporting Scheme
QA	Quality Assurance
QC	Quality Control

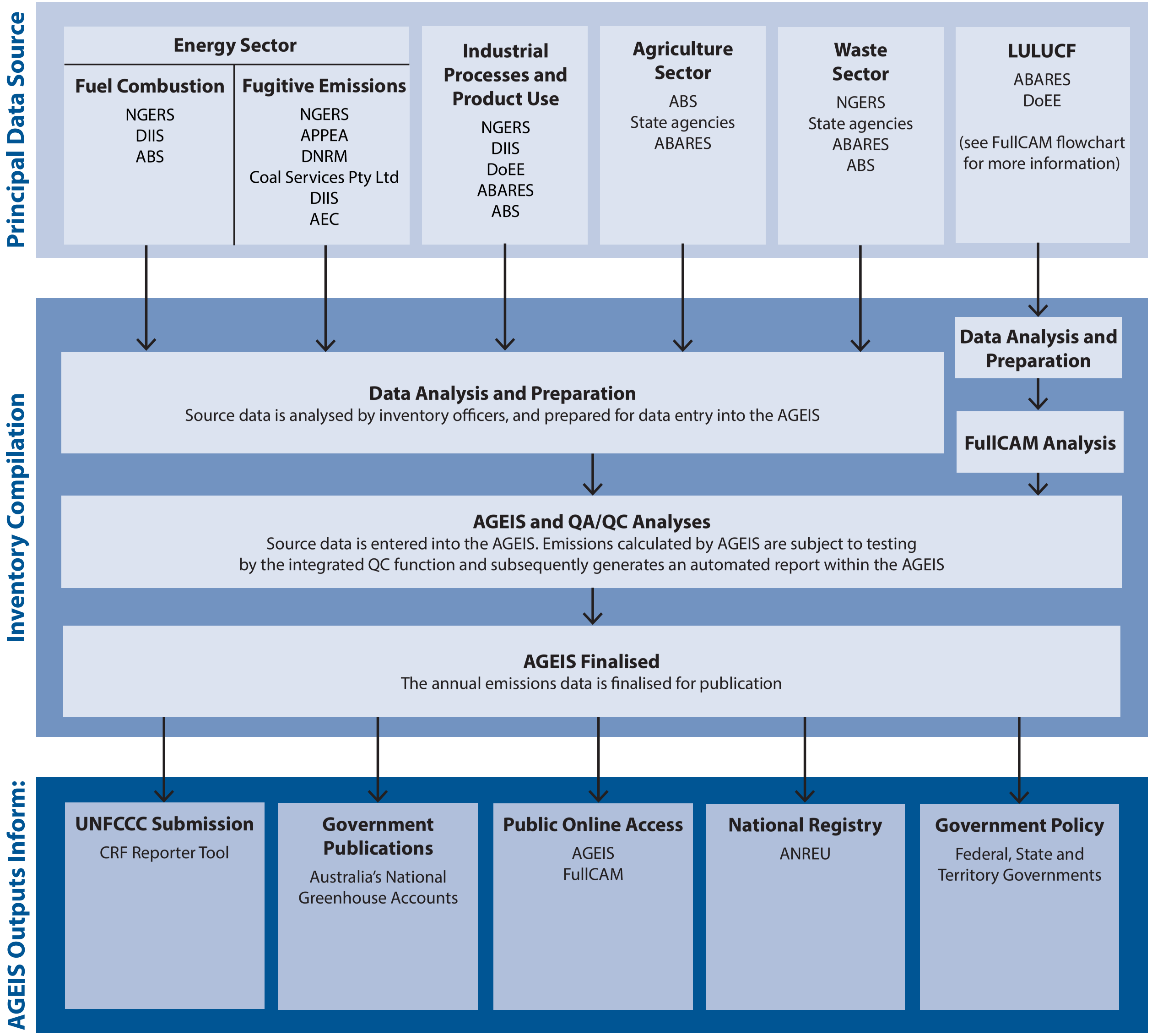
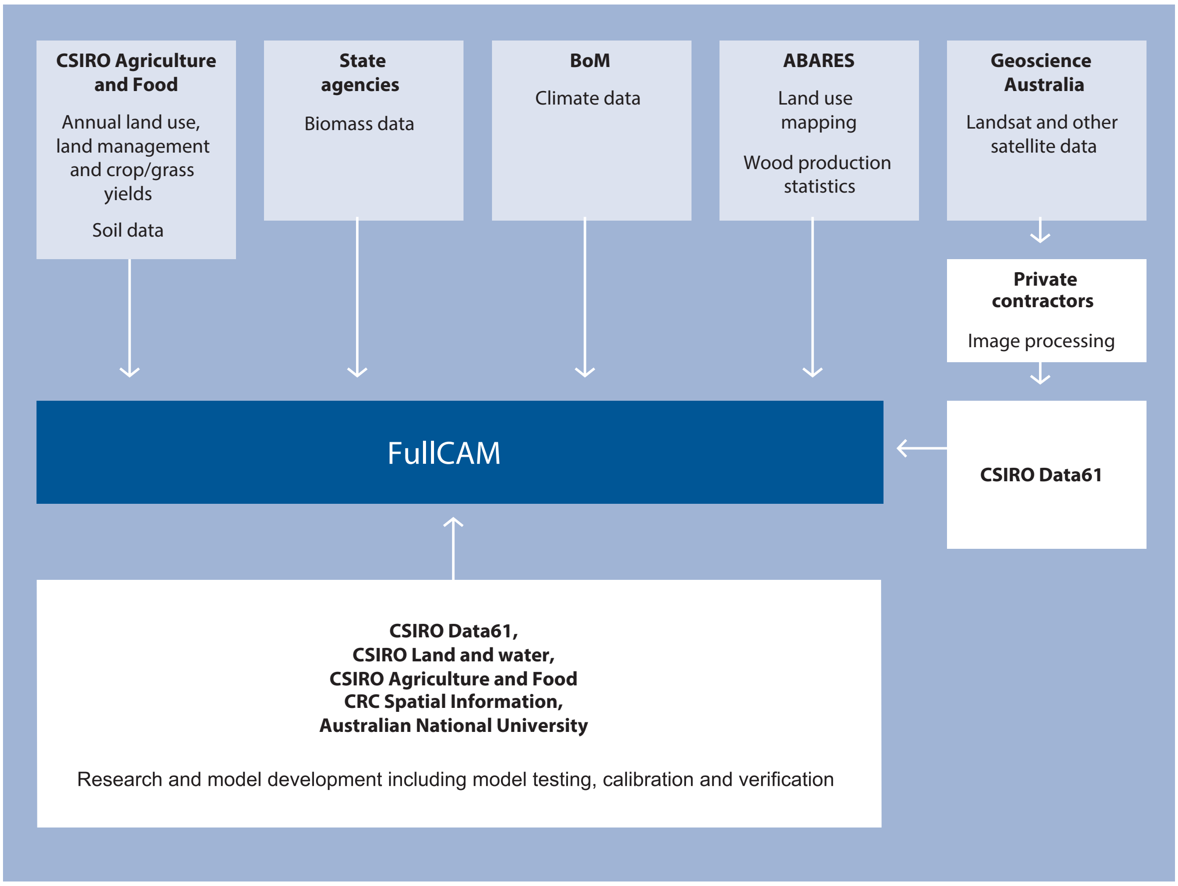


Figure 1.2 FullCAM institutional arrangements



Technical competence of staff

Department of the Environment and Energy staff and external consultants have extensive experience in inventory preparation. The Department aims to maximise the number of staff who have undergone the UNFCCC reviewer training and participated in UNFCCC Expert Review processes. All senior technical staff are qualified reviewers and have been accepted onto the UNFCCC Roster of Experts. Where particular technical expertise is not available within the Department, expert consultants are engaged to undertake analysis and review work.

Process for official consideration and approval of the Inventory

The draft Report is considered by the National Greenhouse Gas Inventory Committee, which comprises representatives of the Australian, state and territory governments. Key domestic users of national inventory data are also engaged in the formal review arrangements through the National Inventory Users Reference Group. This group includes Australia's premier science organisation, academics, sectoral experts from the consulting sector and industry representatives. The National Inventory User Reference Group meets once or twice a year.

The National Greenhouse Gas Inventory Committee and the National Inventory Users Reference Group are the principal mechanisms for formal external review of the Report prior to its release.

Release of each year's inventory and submission to the UNFCCC is approved by the Deputy Secretary of the Department.

1.2.2 Overview of inventory planning, preparation and management

Australia's inventory is prepared following a rigorous annual process which includes planning, methodology improvement, data collection and entry, the implementation of quality control and assurance measures, emission estimation, report preparation, emission and report review and report publication. The 17 steps of a typical annual cycle are described in detail in section 1.3.

National Greenhouse and Energy Reporting (NGER) System

The NGER system is one of the most critical assets in the preparation of the inventory, collecting data on emissions from the *energy, industrial processes and product use* and *waste* sectors.

The legislative framework for the mandatory NGER system was established through the *National Greenhouse and Energy Reporting Act 2007* (Cwlth) (NGER Act). An explicit objective of the NGER Act is to collect information to support the development of the national inventory.

Under the NGER system, companies whose energy production, energy use, or greenhouse gas emissions (from the *energy, industrial processes and product use* and *waste* sectors) meet certain thresholds must report facility-level data to the Clean Energy Regulator (CER). The NGER system provides activity data inputs, such as fuel combustion, emission factors (EF) at facility level and, in some cases, directly measured emissions.

Annual reports have been submitted by companies under the NGER system for Australian financial years since 2008-09. This data has been used in the preparation of this Report.

The rules for the estimation of activity data, EFs and emissions by companies are well specified and set out in the *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (Cwlth) (the Determination). For further detail on the Determination see section 1.4.2.

The estimation methodologies used for company and facility emissions are estimated within the *National Greenhouse Accounts* framework ensuring consistency among the relevant accounts; national, state and territory, industry, company and facility-level inventories. Integration of the estimation methods and data is critical for ensuring that changes in emissions at the facility level are captured efficiently and accurately in the national inventory. The default methods used by companies are derived from the national inventory methods while the default EFs have been derived using the AGEIS.

The CER manages the process of input data collection from companies, data verification/auditing and the dissemination of this data to relevant agencies. The CER's Emissions and Energy Reporting System (EERS) is used for the collection of the input data from companies. Details of the NGER verification and auditing procedures are provided in section 1.2.3.

The Climate Change Authority (CCA) undertook a review of the operation of the *National Greenhouse and Energy Reporting Act 2007* and its supporting legislative instruments in 2018.

The CCA is an independent statutory agency, which provides expert advice to the Australian Government on climate change policy. The Authority is required to review the operation of the National Greenhouse and Energy Reporting legislation every five years.

In coming to its findings, the CCA consulted widely with industry, government agencies and data users and also undertook its own research and analysis.

The CCA found the NGER reporting system is working well, is generally fit for purpose and, in its current form, has strong support from industry, governments and others. More specifically it was found that the NGER system:

- generates a high quality dataset, which is accurate, has broad coverage and compares favourably against international schemes;
- informs government energy and emissions policies, programs and activities at both the Australian and state and territory level;
- uses approaches to measuring energy and emissions that are fit for purpose;
- helps companies better understand their energy and emissions and meet other reporting requirements;
- informs investors and others such as academics and analysts; and
- reduces duplicative reporting of emissions and energy across jurisdictions and has minimised the regulatory burden on businesses.

Recommendations from the review focus on incremental improvements to enhance the efficiency and effectiveness of the reporting scheme, and include that the Government should:

- continue the focus on streamlining requirements for energy and emissions data to reduce costs to government and business;
- seek opportunities to streamline and integrate the administration of related energy and environmental reporting schemes in order to improve efficiency and reduce costs to government and business;
- explore options to expand the emissions coverage of the system, including through voluntary reporting, and increasing transparency; and
- employ administrative systems that continue to target compliance audits in order to reduce costs.

At the time of submission, the Department and the Clean Energy Regulator were considering the review recommendations and preparing a response.

The *Review of the National Greenhouse and Energy Reporting legislation - final report* is publically available on the Climate Change Authority's website at http://climatechangeauthority.gov.au/review-national-greenhouse-and-energy-reporting-legislation-final-report.

Details on other data sources used in the preparation of the inventory are contained in sections 1.2.3, 1.3.2 and 1.7.

1.2.3 Information on the quality assurance/quality control plan

This section outlines the major elements of the quality assurance/quality control plan. Australia's QA/QC plan is documented in full in the *National Inventory Systems: Quality Assurance/Quality Control Plan* (QA/QC plan).

The IPCC defines QC as a system of routine technical activities to measure and control the quality of the inventory as it is being developed. A basic QC system should provide routine and consistent checks to ensure data integrity, correctness, and completeness, identify and address errors and omissions, and document and archive inventory material and record all QC activities.

QA is a planned system of review procedures conducted by personnel not directly involved in the inventory compilation and development process.

The QA/QC processes deployed by the Department aim to conform to the IPCC Guidelines and Supplementary Methodologies (IPCC 2006, 2014). These processes further aim to contribute to the production of inventories which are accurate, in which uncertainties are reduced to the extent practicable, and in which the estimates are transparent, documented, consistent over time, complete, and comparable. The QA/QC plan identifies key risks to the achievement of these objectives and sets out the mitigation strategies employed to ensure that the quality objectives for emission estimates are attained.

Key risks to the attainment of the defined quality objectives are identified at each level of inventory preparation, including the measurement of data at the facility level, the collation of activity and other input data by the Department and other agencies, and the process of emissions estimation.

Principal mitigation strategies are discussed below. A detailed summary of the quality control measures employed in the preparation of Australia's inventory is presented in Annex 6 (Volume 3 of this Report).

Systems have been established to monitor the outcomes of the mitigation strategies and control measures, principally managed through the AGEIS (see below). Each year, an evaluation of the data collected under the monitoring systems is undertaken and documented in the *National Inventory Systems: Evaluation of Outcomes* document. Following consideration of the *Evaluation of Outcomes* document, improvements to the inventory are then effected through the *National Inventory Systems: Inventory Improvement Plan*.

NGER system data – quality control procedures

The principal data source for this inventory is the NGER system. The quality control system for this data is critical for the quality for the inventory as a whole.

Use of Standards

A key mitigation strategy to manage risks associated with measurement error is to ensure that rules for emissions estimation are well specified. Rules for the estimation of emissions by companies have been developed to conform to the *National Greenhouse Accounts* framework and aims to ensure that consistent estimation methods are deployed at the national, state and territory, industry, company and facility level. This consistency is critical to ensure policy efficiency, and to engender confidence in the company estimates by ensuring the methods used are also consistent with IPCC 2006.

The Determination is supplemented by the referencing of standards for sampling and analysis of key data inputs. For example, for the estimation of facility-specific EFs, NGER methods reference relevant Australian, ISO, and equivalent international standards (EU, US) for sampling and analysis of relevant fuel qualities and characteristics (such as carbon content). These standards provide, *inter alia*, sample handling protocols and tolerance levels for precision (repeatability and reproducibility), as well as for the management of bias.

Where possible, the NGER system has been designed to use the data systems that operate to support other regulatory functions such as commercial or taxation activities. In particular, measurement of commercial activity data in Australia is regulated by the *National Measurement Act 1960* and *National Measurement Regulations 1999* and, for utilities, by state government regulations. These legislative instruments underpin the quality of all activity data subject to commercial operation that are used in the *National Greenhouse Accounts*. For example, the *National Measurement Regulations 1999* specify maximum tolerances for measurement error for any amount of solid fuel subject to commercial activity.

Certain data sources are also governed by the regulations of the taxation system. For example, data on liquid fuels are governed by the requirements of the *Excise Tax Act 1901* which places strict tolerance limits on measurement error. To an important extent, the quality of commercial and taxation data in Australia underpins the quality of emissions data reported under NGER system.

Validation of NGER data

In order to facilitate accurate reporting of information, the CER has devoted resources to 'outreach' whereby the CER officials liaise with reporting companies to assist them in the preparation of reports. A validation unit is also deployed by the CER to assist with the initial inspection of reported data, checking for transcription errors and liaising with companies about possible resubmission of estimates.

Independent auditing of NGER data

The NGER Act also provides for a risk-based system for the independent verification of NGER data. Under the Act, the CER has the authority to order a corporation to conduct an external audit on aspects of the corporation's compliance with the Act or with the Regulations. Sections 73 and 74 of the Act define the circumstances under which a greenhouse and energy audit may be initiated and allow for the appointment of Registered Greenhouse and Energy Auditors to undertake audit engagements.

The *National Greenhouse and Energy Reporting (Audit) Determination 2009* (Cwlth) sets out the requirements for preparing, conducting and reporting on greenhouse and energy audits. Greenhouse and energy audits may only be conducted by a greenhouse and energy auditor who has been registered under section 75A of the Act. The purpose of greenhouse and energy audits is to determine the extent to which entities that are required to register and report under the Act have, or have not, complied with its requirements.

The Act empowers the CER to initiate a greenhouse and energy audit, where:

- there are reasonable grounds to suspect that an entity that is required to register and report under the Act has contravened, is contravening, or is proposing to contravene either the Act or the Regulations; or
- it is determined that, for another reason, an audit of an entity's compliance with one or more aspects of the Act or the Regulations is necessary.

Audits may examine:

- emission sources, energy consumption and energy production; and
- the effectiveness of internal controls associated with data collection and reporting processes.

Significant penalties may apply to Chief Executive Officers for contravention of the Act.

Given the risk of a mandatory audit ordered by the CER, and the threat of significant penalty, many companies have voluntarily utilized external auditors to audit their reports prior to submission to the CER in 2009-2017. During the period 1 July 2016 to 30 June 2017 380 audits were completed; including 73 voluntary audits from NGER reporters. Over the same period, 98 per cent of entities submitted their reports on time, the same as the previous year.

Time series consistency with audited data

For the preparation of the national inventory, data collected under the NGER system has been checked for time series consistency with facility data available for previous years either from the NGER system or, in some cases, data collected previously for the inventory, e.g. fuel combustion in the electricity generation sector or other facility reporting programs.

Confidential data

Where reporting at a disaggregated level could lead to the disclosure of confidential information emissions data is treated as confidential and aggregated with other sectors before publication. Confidential data utilised in the national inventory is currently collected from companies under NGER. This data is subject to the *validation, independent auditing* and *use of standards* controls outlined above.

Processes have been put in place to ensure QA/QC is recorded in the Report for confidential emission sectors. For sectors where emissions data is confidential the implied emission factors (IEF) have been published for the relevant sub sectors (see sections 4.3.9, 4.4.10 and 4.5.7). As a quality control, the IEF for Australia are plotted and compared against a distribution of implied emission factors for all other Annex I Parties.

In order to maintain continuity in the compilation of *industrial processes and product use* emissions estimates, the Department engaged the external consultant previously used to collect activity data and EF information to undertake a quality control assessment of the full time series of activity data including confidential data from before the introduction of the NGER system. This work is of particular importance in industrial processes where confidentiality of historical activity data poses some challenges for the assessment of time series consistency.

Other datasets – quality control procedures

Where the inventory uses official national statistics, the quality control of this data is managed by the source agencies. The ABS publishes assessments of data quality and quantitative estimates of sampling errors for transport and agriculture activity data. National level energy activity data are produced by the Department (previously DIIS) through its annual *Australian Energy Statistics* (AES, DoEE 2018). The AES data was reviewed and 'benchmarked' by the ABS in its role of national statistics co-ordinator.

With respect to electricity, explicit reconciliations of energy data are undertaken by comparing data collected under NGER contained in the AES and the estimates produced by the Australian Energy Council (AEC) and the Australian Energy Market Operator (AEMO), which are all undertaken for slightly differing reasons and with slight differences in coverage.

Explicit reconciliations of data are also undertaken with respect to emissions estimates on forest conversion. Geospatial data on forest conversion is compared to independent datasets produced by other agencies, for example the Queensland Department of Science, Information Technology and Innovation (DSITI) and the New South Wales Office of Environment and Heritage (OEH). Information provided by other state agencies in relation to permits issued for land clearing have also been used in assessing the land cover change data obtained from Landsat.

Tier 1 quality control checks – emissions estimation

Emissions estimation is conducted through the use of the AGEIS software (apart from the *LULUCF* sector). Management of the AGEIS is conducted in accordance with the Control Objectives for Information and related Technology (COBIT) framework. The AGEIS is subject to performance audit by the Australian National Audit Office.

For this inventory and associated time series, there are around 3 million data inputs in the non-*LULUCF* sectors. To facilitate the management of such a large amount of data, AGEIS was specifically developed to play a central role in the quality control of the national inventory. Key tier 1 QC controls have been systematically built into the operation of the AGEIS. Auditable checks are undertaken *inter alia* to reduce the risks of errors associated with the input of activity data, missing data, recalculations and the time series consistency of generated emission estimates.

Input data and IEFs are also checked for recalculations and time series consistency prior to submission using AGEIS and the CRF reporter tool. The allocation of roles and responsibilities of staff provide for the separation of data handling and data approval roles within the Department to improve accountability.

Extensive internal verification of emission estimates, as well as external acceptance testing of system integrity and functionality, is undertaken during the development of the AGEIS. Emissions estimated by the AGEIS are compared with those previously reported using traditional spreadsheets to ensure emissions are calculated correctly, that parameter and emission units are correctly recorded, and that data is correctly aggregated from lower to higher reporting levels. Implementation of new estimation methodologies are undertaken using a dual estimation approach, which ensures that AGEIS emission estimates are verified independently.

Australia's QA/QC Plan is designed to align with the requirements of the IPCC Guidelines (IPCC 2006). The set of tier 1 QC procedures for the inventory compilation process specified in the IPCC Guidelines along with the relevant control measure reference in Australia's QA/QC Plan, are identified in Table 1.2.

Table 1.2 Implementation of tier 1 quality control checks

Tier 1 QC activity: Checks [(a)]	Control Measure[(b)]	Implementation / Comment
Assumptions and criteria for the selection of activity data and EFs documented	3.E.1	Documented in the National Inventory Report.
Transcription errors in data input and reference	2.A.1-3, 2.B.2.	Errors checked for using internal AGEIS data verification checks. AGEIS fully integrated with the UNFCCC CRF Reporter Tool removing risk of errors in CRF tables. Error checks are also implemented during the pre-processing of input data. Bibliographical data references checked for correct citation.
	2.A.4	FullCAM inputs database is checked for transcription errors between source documents and database.
Emissions are calculated correctly	3.A, 3.B, 3.C	Extensive testing during AGEIS development phase and when new methods introduced. Selected dual estimation process using traditional spreadsheets.
Parameter and emission units are correctly recorded and that appropriate conversion factors are used	3.A, 3.B, 3.C	Extensive testing during AGEIS development phase and when new methods introduced. Selected dual estimation process using traditional spreadsheets. Extensive testing during development of FullCAM functionality. Ongoing testing undertaken on an operational basis.
Integrity of database files	3.A1-3	Extensive verification/external acceptance testing during the AGEIS development phase. Automated testing of FullCAM database files. Selected dual estimation process using traditional spreadsheets. Database system and operation documentation updated and archived.
	2.A.5	Integrity of FullCAM inputs database files checked.
Consistency in data between source categories	3.A.1-3	Parameters (activity data, constants, EFs) which are common to multiple sources are entered into global or general data tables so data is only entered once into database.
	2.E.1	FullCAM provides a common platform using a common inputs database for *LULUCF* estimates. The FullCAM inputs database is reviewed to ensure that parameters that are common between source categories are not differentiated.
Movement of inventory data among processing steps is correct	3.A.1-3	Extensive testing during AGEIS development phase and when new methods introduced. Standard reconciliation reports are run to ensure correct aggregation of emission estimates. Cross checking data between FullCAM, AGEIS and the CRF for consistency.
Uncertainties in emissions and removals are estimated or calculated correctly		Independent review by CSIRO completed.

Tier 1 QC activity: Checks [(a)]	Control Measure[(b)]	Implementation / Comment
Time series consistency/ Methodological and data changes resulting in recalculations	3.C, 3.D	Where changes are made to methods or activity data the full time series of emissions is recalculated, the AGEIS and FullCAM ensure consistent use of methods across time series.
Completeness	2.B.1-2, 3.B.1-4	Checked through CRF Reporter Tool. Mass balance checks undertaken for fuel, carbonates, biomass and synthetic gases. FullCAM has a mass balance check incorporated at each stage of the model process.
Trend	3.D.1-2	Activity data, emissions and IEFs are compared with the previous year's estimates, and across entire time series, through the AGEIS and CRF Reporter Tool.
Review of internal documentation	3.E 1-3	All activity data, emission factors and algorithms are archived within AGEIS. Past inventories may be reproduced using AGEIS. Electronic and hard copies of each year's NIR and methodology are kept in a safe. All bibliographical data references are archived within the AGEIS and in a hardcopy library. FullCAM software, simulations and activity data are stored on a secure server and include a documented backup service with offsite storage.

(a) Source: IPCC 2006, Table 6.1, page 6.10. (b) References refer to numbering in Australia's QA/QC Plan (see Annex 6).

Table 1.3 Results of reconciliation quality control objectives

Test	Objective (per cent difference)	Result
CM 2.A.1 Accuracy/Completeness: Reconcilation of data submitted into AGEIS and reference data: electricity emission and coal mine fugitve emissions.	< 2 per cent	Achieved
CM 2.B.2 (i) Completeness: Reconciliation of data submitted into AGEIS and reference data: fossil fuels consumption	<0.1	Achieved
CM 2.B.2 (ii) Completeness: Reconciliation of data submitted into AGEIS and reference data: carbonates consumption	<1	Achieved
CM 2.B.2 (iii) Completeness: Reconciliation of data submitted into AGEIS and reference data: biomass consumption	<1	Achieved
CM 2.B.2 (iv) Completeness: Reconciliation of data submitted into AGEIS and reference data: wastewater consumption	<1	Achieved
CM 2.B.2 (vi) Completeness: Reconciliation of data submitted into AGEIS and reference data: synthetic gas consumption	<0.1	Achieved
CM 3.B.1 (i) Carbon balance: Reconciliation of data submitted into the AGEIS and national inventory: fossil fuel consumption	<0.01	Achieved
CM 3.B.1 (ii) Carbon balance: Reconciliation of data submitted into the AGEIS and national inventory: carbonates consumption	<0.01	Acceptable
CM 3.B.1 (iii) Carbon balance: Reconciliation of data submitted into the AGEIS and national inventory: biomass consumption	<0.001	Achieved
CM 3.B.1 (iv) Carbon balance: Reconciliation of data submitted into the AGEIS and national inventory: wastewater consumption	<0.001	Achieved
CM 3.B.1 (vi) Carbon balance: Reconciliation of data submitted into AGEIS and reference data: synthetic greenhouse gases	<0.001	Achieved
CM 3.B.1. (vii) Carbon balance: Reconciliation of data submitted into AGEIS and reference data: forests and soils	<0.001	Planned Improvement

Test	Objective (per cent difference)	Result
CM 3.B.1 (viii) Carbon balance: Reconciliation of carbon in fossil fuels, carbonates, synthetic gases, wastewater data submitted into AGEIS and carbon contained in emissions or stored in products or destroyed.	< 0.001	Acceptable
CM 3.B.2 (i) Reconciliation between national inventory and sum of State and Territory inventories	<0.1	Achieved
CM 3.B.2 (ii) Reconciliation between national inventory and national inventory by economic sector	<0.1	Achieved
CM 3.B.2 (iii) Reconciliation between national inventory and output from the AGEIS	<0.1	Achieved

Tier 2 quality control checks

Category-specific QC (tier 2) checks are conducted for all sectors to test for completeness, international comparability and verification of country-specific parameters.

Completeness and accuracy are tested through the operation of mass balance checks. The application of mass balance constraints for carbon in fuels, carbonates, biomass wastes, and hydrofluorocarbons and nitrogen balances for domestic and industrial wastewater constitute tier 2 quality control measures. All carbon entering the economy in fuels is accounted for, either as emissions from fuel combustion, emissions from the use of fossil fuels as reductants, non-energy uses, use of biomass sources of energy, or international bunkers. Carbon balances for biomass, carbonates and synthetic gas consumption have also been implemented. The results of these checks against the principal quality objectives are set out in Table 1.3. Detailed results of the application of these balances are reported in Annex 6 of Volume 3.

International comparability of emission estimates is systematically tested through comparisons of the IEFs obtained for significant sources of the Australian inventory with the distribution of IEFs for all other Annex I Parties. The results of these analyses are included in the QA/QC discussions of individual sector sources in this Report.

For the *energy, industrial processes and product use* and *waste* sectors, systematic verification tests are undertaken for country-specific parameters, such as EFs utilising data collected under the NGER system. The tests are undertaken in accordance with the decision tree (Figure 1.3). Country-specific parameters are tested against NGER datasets that meet the prescribed conditions. If the mean of the NGER dataset is significantly different to the country-specific parameter, the parameter may be revised to reflect the new information. The results of the test are presented in the *National Inventory Systems: Evaluation of Outcomes* document.

The empirical research program set out in the *National Inventory Improvement Plan* is designed to generate information to provide the basis for verification tests for parameters in either tier 2 or tier 3 methods where private measurement activity is not undertaken (see section 10.5 of Volume 2 for more details).

In addition, country-specific parameters may also be subjected to verification tests on an ad hoc basis as new information is obtained.

Integrated Quality Control: AGEIS

New functionalities have been introduced into the AGEIS to achieve efficiencies in the QC process, mitigate the risk of transcription errors during QC activity checks, and centralise all QC activities for review and archiving. As a result AGEIS can conduct tier 1 and tier 2 quality controls based on user-defined selections of QC activities. It can also populate the *National Inventory Systems: Evaluation of Outcomes* report to record the results of the monitoring program designed to implement the risk mitigation strategies and quality control measures detailed in the QA/QC Plan.

Quality assurance procedures implemented

Australia's QA systems operate at a number of levels. QA controls that are implemented annually include:

- the review of the Report, prior to submission to the UNFCCC, by the National Greenhouse Gas Inventory Committee, which comprises representatives of state and territory governments. This is the principal formal external review mechanism for the report before it is finalised;
- the prioritisation and review of inventory improvements by the National Inventory Users Reference Group;
- review by external consultants for specified sectors;
- QA of remote sensing imagery and data inputs for the *LULUCF* (Chapter 6 Appendix A, Volume 2);
- the inventory is potentially subject to audit by the Australian National Audit Office (ANAO). The ANAO is an independent office established under the *Auditor-General Act 1997*. It conducts performance audits of government agencies operating under the Standard on Assurance Engagements ASAE 3500 Performance Engagements issued by the Australian Auditing and Assurance Standards Board (AUASB). ANAO reports are tabled in the Australian parliament and subject to review by the Joint Committee of Public Accounts and Audit (JCPAA). The ANAO undertook a performance audit of the national inventory in 2009-10 and 2016-17. Further information on the most recent audit is provided below;
- opening the inventory emission estimates and methods for public review through the release of transparent and easily accessible information via the Department and the AGEIS webpage. Industry and public feedback is accepted through the inventory e-mail facility nationalgreenhouseaccounts@environment.gov.au; and
- UNFCCC expert review team processes which aim to review and improve the quality of all Annex I Parties' inventories in an open and facilitative manner. Australia's inventory has been reviewed by in-country teams in 2002, 2005, 2008, 2010 and 2015, by a desk review in 2017, with centralised reviews in other years. Annex 6 (Volume 2) shows outstanding recommendations from the 2016-17 review report have been implemented, or will be addressed in the future. Australia's inventory was not subject to a review in 2018.

Specific reviews of sectoral methodologies that have been performed by expert consultants that are not involved in the inventory preparation process are described in Table 1.4.

Table 1.4 Expert reviews of methodologies and activity data

Year of Review	Categories reviewed
2002-2003	4A Enteric Fermentation and 4B Manure Management. (CSIRO, ASIT Consulting, QDNRME, Hassell and Associates Pty. Ltd) Estimating Greenhouse Gas Emissions from Residential Firewood Use (J.Todd)
2004	Review of Savanna burning (CSIRO)
2005-06	Emission factors for liquid fuels (GHD Pty Ltd) Estimating Greenhouse Gas Emissions from Residential Firewood Use (J.Todd)
2006	Methodologies in the iron and steel and petroleum refining sectors (GHD Pty Ltd) Industrial wastewater and waste incineration methodologies (O'Brien Consulting) Flooded decommissioned coal mines (L. Lunarzewski, Consultant)
2007	Review of Industrial processes and product use sector (M. Tsaranu, international expert from UNFCCC reviewer roster) Review of Waste sector (Hyder Consulting 2007a,b)
2008	Review of key FullCAM model parameters and assumptions in the LULUCF sector (M. Apps, W Kurts, P. Smith and Q. Zhang, international experts from UNFCCC review roster and/or authors of IPCC Guidelines)
2009	Review of waste generation and disposal improvements; and Review of DOC_f values (S. Guendehou, international expert from UNFCCC reviewer roster)

Year of Review	Categories reviewed
2010	Australian National Audit Office (ANAO) audit of the national greenhouse gas inventory program
2011	4E. Review of Prescribed Burning of Savannas (CSIRO Marine and Atmospheric Research) Review of the characteristics of liquid fuels used in the National inventory (Orbital Australia 2011a)
2011	Review of confidential data handling practices, C. O'Keefe, CSIRO 2011 Estimating Greenhouse Gas Emissions from Residential Firewood Use (J.Todd)
2015	Review of Agriculture, Cropland and Grassland methods, FullCAM and Agriculture Advisory Panel
2015	Review of Forest Management, (S. Fedirici international expert from UNFCCC reviewer roster)
2016	Review of deforestation and treatment of natural disturbances under UNFCCC accounting (S. Federici international expert from UNFCCC reviewer roster)
2017	Review and update of key parameters used by FullCAM in modelling carbon fluxes in forests (by CSIRO experts K. Paul and S. Roxburgh)
2017	ANAO audit of the national greenhouse gas inventory program
2018	Climate Change Authority review of the operation of the *National Greenhouse and Energy Reporting Act 2007* and its supporting legislative instruments

Australian National Audit Office (ANAO) Performance Audit: 2016-17

The ANAO is an independent office established under the *Auditor-General Act 1997*. Its purpose is to drive accountability and transparency in the Australian Government sector through quality evidence based audit services and independent reporting to Parliament, the Executive and the public, with the result of improving public sector performance.

The ANAO conducts performance audits of government agencies operating under the Standard on Assurance Engagements ASAE 3500 Performance Engagements issued by the Australian Auditing and Assurance Standards Board (AUASB). ANAO reports are tabled in the Australian Parliament and subject to review by the Joint Committee of Public Accounts and Audit (JCPAA).

The ANAO undertook a performance audit of the national inventory over nine months (August 2016 to April 2017). Its objective was to assess the effectiveness of arrangements for the preparation and reporting of Australia's greenhouse gas emissions estimates in the *National Inventory Report 2014 (revised)* for the year 2014.

Through the course of the audit the ANAO:

- examined Department records relating to the preparation of the estimates, including UNFCCC and departmental guides, implementation plans, quality assurance/quality control documents, and general governance documentation,
- examined ten inventory sectors representing more than 50 per cent of national emissions; comprising over 5250 data points across more than 158 data types contained in spreadsheets supporting the entry of data into AGEIS,
- examined key IT controls supporting AGEIS and FullCAM, and
- interviewed Department staff and sought input from the public and key stakeholders.

The ANAO reported that,

- the Department has established appropriate processes to prepare, calculate and publish Australia's national inventory for the year 2014,
- emissions estimates have been calculated using relevant contemporary data,
- appropriate quality assurance and control procedures are in place for inventory data processing, emissions calculations and reporting, and

- the aggregate impact of data issues identified in the national inventory across the time series 1990-2014 was calculated by the Department as less than 0.1 per cent per year.

All data issues identified by the ANAO have been addressed or corrected. The ANAO also made a number of recommendations relating to improving the data accuracy, security and governance arrangements for the preparation, calculation and publication of the national inventory. Measures to address aspects of these recommendations were implemented through the course of the preparation of the *National Inventory Report 2015*.

One such measure was a "Rounding policy for AGEIS inputs" to promote consistent decision making in inventory compilation. The policy specifies the number of decimal places to be employed for inventory input parameters, molecular factors and activity data used to generate emissions estimates via AGEIS. It has also been incorporated into the *National Inventory Systems: Quality Assurance/Quality Control Plan* (QA/QC plan). Measures to address outstanding aspects have been included in the *National Inventory Improvement Plan*.

Climate Change Authority review of the operation of the National Greenhouse and Energy Reporting Act 2007 and its supporting legislative instruments

The Climate Change Authority (CCA) undertook a review of the operation of the *National Greenhouse and Energy Reporting Act 2007* and its supporting legislative instruments in 2018.

The CCA is an independent statutory agency, which provides expert advice to the Australian Government on climate change policy. The Authority is required to review the operation of the National Greenhouse and Energy Reporting legislation every five years.

In coming to its findings, the CCA consulted widely with industry, government agencies and data users and also undertook its own research and analysis.

The CCA found the NGER reporting system is working well, is generally fit for purpose and, in its current form, has strong support from industry, governments and others.The Authority found that the energy and emissions reporting scheme enjoys broad support from industry, governments and others. It is widely considered to be a best-practice approach to measuring and reporting emissions and energy and compares favourably to schemes in other countries.

The high quality data collected through the scheme is used extensively by governments and others to develop energy and climate change policies. It is also a critical input to meeting Australia's international energy and emissions reporting obligations.

The success of the scheme is underpinned by private investments in mature data collection and reporting systems by companies, and effective administration by the Regulator and the Department. The Regulator's constructive and professional approach to supporting companies to meet their obligations was singled out by many as a key driver of the success of the scheme.

The Authority identified a number of opportunities for improving the reporting scheme. Many of these can reduce costs to businesses or the scheme's administrators, while further enhancing the integrity of the data collected. For example, the Authority has recommended the Government continue to monitor and analyse reporting obligations placed on businesses and ensure they are streamlined where possible. It has also recommended developments to the online reporting system to reduce both the costs associated with reporting and the risk of errors, and recommended work be undertaken to improve the development and use of the measurement determination and related legislation.

The Authority has also made recommendations to extend reporting, on a voluntary basis, to agricultural emissions. While this may impose additional costs on businesses and government, it will build on industry sustainability objectives and enhance the value of the dataset collected.

Finally, the Authority's recommendations aim to improve the usefulness of the dataset generated through the scheme, for government and other users. For example, the Authority has recommended the dataset used by governments be enhanced for time series analysis, and data users' needs be better met through the Regulator publishing more detailed analyses of key findings and trends.At the time of submission, the Department and the Clean Energy Regulator were considering the review recommendations and preparing a response.

The *Review of the National Greenhouse and Energy Reporting legislation - final report* is publically available on the Climate Change Authority's website at http://climatechangeauthority.gov.au/review-national-greenhouse-and-energy-reporting-legislation-final-report.

Verification activities

The CSIRO operates a Baseline Air Pollution Station at Cape Grim in Tasmania. Data on the concentrations of synthetic gases – HFCs and PFCs – have been collected and have been analysed with the aim of providing an independent assessment of emissions of these gases in Australia (see Chapter 4).

The Australian inventory is tested extensively for comparability with the inventories of other Annex I Parties. The IEFs and other key parameters for specified variables are reviewed for comparability against the IEFs for all other Annex I Parties. Specific t-tests are performed to test whether the IEFs derived from the Australian inventory are significantly different to the mean of all other Annex I Parties. The results of these tests are recorded in the *National Inventory Systems: Evaluation of Outcomes* document.

As the Australian inventory has transitioned to tier 3 methods for many sectors, future verification developments will focus on the development of assessments of tier 3 emission outcomes against the results of associated tier 2 models.

1.2.4 Changes in national inventory arrangements

Changes to Australia's national inventory arrangements since the previous national inventory report are detailed in Chapter 13: Information on changes to the national system (Volume 3).

1.3 Inventory preparation and data collection, processing and storage

1.3.1 Inventory preparation

Key steps in the annual inventory preparation process (with indicative dates in parentheses) are determined by the needs of the system and output and quality objectives. The timing is determined by the UNFCCC submission timelines and data availability. Steps 1-17 below provide an overview of a typical inventory cycle. The production of Volume 1 of this Report was accelerated to accommodate business priorities and test the merits of a staggered preparation cycle. The cycle commences with a review of emission estimation methods, allocation of tasks, selection of external consultants, and the preparation of the AGEIS for the compilation of the forthcoming inventory. The cycle is completed by external independent review provided by the UNFCCC Expert Review Teams.

Planning and methodology improvement

1. Preparation of the *Evaluation of Outcomes* document for the previous year (March – April).

2. Preparation of QA/QC and Inventory Improvement plans, taking into account Department of the Environment and Energy review of methodologies and activity data; UNFCCC expert review recommendations and the *Evaluation of Outcomes* document (May).

3. Development of investment and maintenance plan for the AGEIS, incorporating the QA/QC plan (June).

4. Methodology development, review, and incorporation into AGEIS (June – October).

Data collection and entry

5. Activity data collection, conducted annually by the Department. It is heavily reliant on NGER system data, and published data from Australia's economic statistics agencies, and is subject to quality control checks. (June – October)

6. Activity data entry into the AGEIS input database, by the Department, through predefined data entry templates (August – December).

Implementation of quality control measures

7. Activity data verification and quality control - the Department uses the AGEIS to systematically report a range of diagnostic statistics on the activity data to facilitate identification and correction of anomalous entries to ensure time series consistency and consistency across sectoral emissions estimates.

8. A designated analyst (known as a Supervisory user) investigates anomalies and records an assessment of the quality of the activity data in the system.

9. The data quality is checked and internally audited by a designated analyst, known as the Database Operations Manager (DOM), to provide quality control. Only when the DOM is satisfied is the input data transferred to the core database where emissions estimation are undertaken.

Emission estimation

10. The AGEIS is used to generate emission estimates for all inventory years using time series consistent methodologies.

Emission and report review

11. Emissions estimates verification is undertaken by Department analysts repeating the range of tests on emissions estimates generated by the AGEIS to ensure time series consistency, consistency across sectoral emissions estimates, and accuracy of recalculations.

12. Completion of quality control measure tests to ensure estimates meet quality criteria.

13. The compiled inventory is circulated to the National Greenhouse Gas Inventory Committee of state and territory government representatives and the National Inventory Users Reference Group of inventory user representatives for comment prior to public release (February).

Report publication

14. Automated population of CRF tables[7] (February – March).

15. Following approval by the Deputy Secretary of the Department, the inventory is available for public release.

16. Release of Australia's National Greenhouse Accounts and the AGEIS database of emission estimates and background data at http://www.environment.gov.au/climate-change/climate-science-data/greenhouse-gas-measurement/tracking-emissions (April).

17. UNFCCC Expert Review of the Report and CRF tables (August – November).

1.3.2 Data collection, processing and storage

Data collection

Data collection to support the preparation of the *National Greenhouse Accounts* is managed centrally by the Department utilising a mix of approaches to ensure the reliable flow of data from other agencies to support inventory preparation.

The NGER system

As described in section 1.2.2, input data to support the preparation of the *National Greenhouse Accounts* for important elements of the *energy*, *industrial processes and product use* and *waste* sectors are collected using the NGER system.

Other data sources

Where possible, NGER system data sources are used for the *energy, industrial processes and product use* and *waste* sectors, supplemented by the use of other published data sources only where necessary. The collection process for other data is well-integrated with the objectives of other programmes with a strong reliance on data collected and published by Australia's principal economic statistics agencies; the ABS, and the Department's Economics Branch. The Department's Economics Branch (formerly part of DIIS) have collected energy statistics for over 40 years and use these data to meet Australia's reporting commitments to the IEA. The ABS is the national statistical agency with legislative backing for its collection powers. The ABS, in conjunction with ABARES, is the major source of agricultural activity data.

The Department employs consultants to process the satellite imagery used to determine land cover change for the *LULUCF* sector. Satellite imagery is sourced from Geosciences Australia (Australia's principal satellite ground station and data processing facility). Data to support estimates of HFCs are sourced from compulsory reporting by importers under licensing arrangements under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 2003*. Solid waste disposal data are provided by the Stewardship Waste Section of the Department. Disposal data are collected annually as part of the National Waste Reporting initiative.

Data processing

As described in sections 1.2.1 and 1.2.3, the estimation of emissions is conducted by the Department, utilising the AGEIS and, for the *LULUCF* sector, using FullCAM.

7 Australia's complete CRF tables will be submitted and made available on the web at http://ageis.climatechange.gov.au/QueryCRFTable.aspx

Data Storage

The Australian documentation systems aim to both manage and retain all data used in the estimation of emissions to provide a means for knowledge management, ensuring continuity and security of the National Inventory Systems.

The AGEIS is at the heart of Australia's documentation systems. It allows efficient electronic data management and archiving of the significant quantities of data needed to generate an emissions inventory. AGEIS data management functions include:

- archival and storage within the AGEIS database of the emissions estimates of past submissions;
- archival and storage within the AGEIS of past activity data, EF, and other parameters and models;
- archival and storage of data source descriptions, methodology descriptions, and source reference material; and
- integrated access to the documentation of data sources; methodology description and source reference material.

The aims of these systems include giving inventory staff ready access to all related materials that underpin the emissions estimates and to provide the means for replication of emission estimates from past submissions.

The AGEIS functions are supported by some additional and important elements of the documentation system:

- documentation of the inventory's emission estimation methodologies in the Report; and
- maintenance of a National Inventory Library of source material documents.

1.4 Brief general description of methodologies and data sources

1.4.1 Estimation methods

The Australian methodology for estimating greenhouse gas emissions and sinks uses a combination of country-specific and IPCC methodologies and EFs. These methods are consistent with IPCC 2006 and 2014, and are compatible with international practice.

In general, *Australia's National Greenhouse Accounts* utilize a mix of tier 2 and tier 3 estimation methods that incorporate:

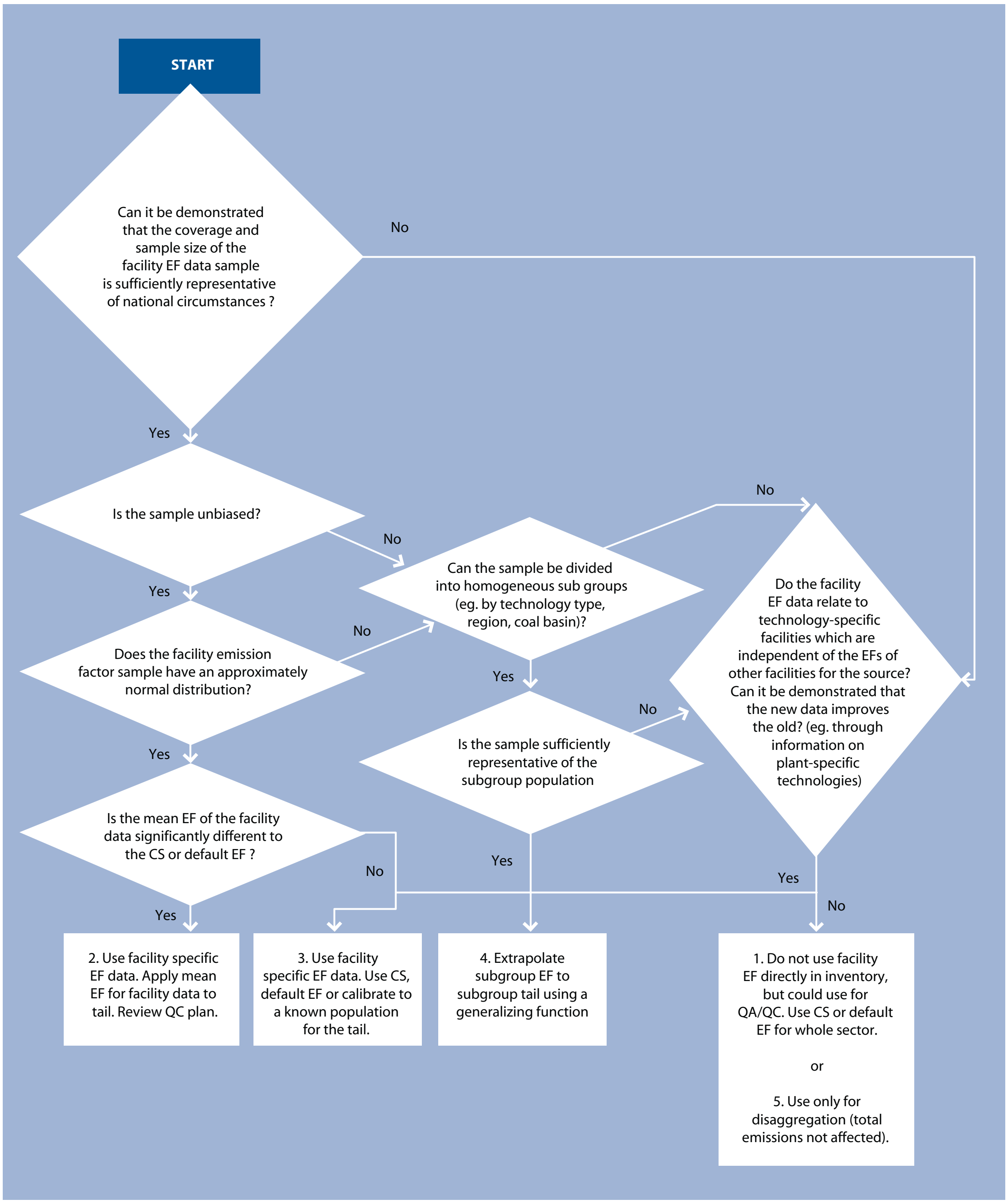
- facility-specific emission estimation processes;
- characterisations of the capital and technology types at the point of emission;
- dynamic relationships that link current emissions outcomes with the activity levels of previous years; and
- spatial differences in emissions processes across Australia.

The additional complexity in the methodology allows emissions to be estimated more accurately. Detailed descriptions of methods chosen are set out in the Chapters 3-7 of this Report.

Tier 3 approaches are in place for fuel combustion in the electricity industry and from fugitive emissions from underground coal mining sources. For a range of additional categories, a mix of tier 2 and tier 3 approaches will continue to be implemented over time as methods for facility-specific measurement of emissions or key data inputs are adopted by reporters under the NGER system and as key pre-conditions for implementation of the new methods are met. These circumstances include: the data must comply with prescribed data standards (in this case, set out in the Determination); there is a timely and comprehensive data collection system in place; and the resulting emission estimates for the source pass the inventory quality criteria set out in the QA/QC plan (for example, in relation to completeness and international comparability).

Consistent decision making with respect to the use of facility specific EFs has been ensured through the application of a decision tree, as set out in Figure 1.3.

Figure 1.3 Consistent decision making in method selection



In particular, tier 3 methods incorporating facility–specific EF data obtained from NGER have been used where the sample size of the available NGER data is sufficiently large and when there is no evidence of bias in the distribution of the NGER EF data. For the balance of a source where there are facilities for which no facility-specific data are available, a country-specific factor is applied.

Tier 3 methods incorporating NGER facility-specific data are also able to be used in two other cases where large samples displaying characteristics of an approximately normal distribution cannot be obtained.

The first additional case relates to the situation where, within one source, a number of homogenous sub-samples can be discerned. Data for facilities with unknown characteristics can be determined by the extrapolation of information from the relatively homogenous sub sample or through calibration to a known, unbiased distribution for the population.

The second additional case relates to the situation where facility data are heavily technology dependent, and where the data for each facility are likely to be independent of one another. In particular, this is the case in the industrial wastewater category where knowledge of the technology deployed at one facility does not affect the likelihood of a certain technology being deployed at another facility where no facility data is available. In these cases, it is possible to use the facility data, where available, and it may not be appropriate to extrapolate information from the NGER sample to the remainder of a particular source. Consequently, in these cases, the original tier 2 EF has been retained for the tail of the source where NGER data has not yet been collected.

1.4.2 Data sources

The inventory is prepared using a mix of sources for activity data, including published data from national statistical agencies. The principal data sources are set out in Table 1.5.

Table 1.5 Principal data sources for the estimation of Australia's inventory

Category (UNFCCC sector)	Principal data sources	Principal collection mechanism
Energy sector (1A1, 1A2, 1A4, 1A5)	Department of the Environment and Energy, NGER	Published, Mandatory data reporting system
Energy sector (1A3)	Department of the Environment and Energy, ABS	Published
Energy sector (1B)	NGER, Coal Services Pty Ltd, QLD DNRM, WA DMP, SA DSD, APPEA, ESAA, DIIS, NSW DIRE, Department of the Environment and Energy	Mandatory data reporting system, published
Industrial processes and product use (2)	NGER	Mandatory data reporting system
	Department of the Environment and Energy	Mandatory reporting of HFCs under import licensing arrangements
Agriculture (3)	ABS	Published
	ABARES	Published
Land use, land use change and forestry (4)	Geosciences Australia	Memorandum of Understanding
	ABARES	Published
	CSIRO	
Waste (5)	NGER	Mandatory data reporting system
	Department of the Environment and Energy	Published

NGER (Measurement) Determination

The NGER system is an integral element of the national inventory system. The rules for estimation of data and emissions at the facility level by companies are set out in the Determination, which is made under subsection 10(3) of the *NGER Act*.

The structure of the Determination is designed to facilitate the integration of corporate and facility level data provided under the *NGER Act* with international data standards on greenhouse emissions.

The scope of the Determination is given by the following categories of emission sources:

- **Fuel combustion** emissions from the combustion of fuel for energy (see Chapter 2 of the Determination);
- **Fugitive emissions** from the extraction, production, flaring, processing and distribution of fossil fuels (see Chapter 3 of the Determination);
- **Industrial processes** and product use emissions where a mineral, chemical or metal product is formed using a chemical reaction that generates greenhouse gases as a by-product (see Chapter 4 of the Determination); and
- **Waste** emissions from waste disposal – either in landfill, as management of wastewater or from waste incineration (see Chapter 5 of the Determination).

The scope of the Determination does not include land based emissions covered by the UNFCCC reporting categories *agriculture* and *LULUCF*. Emissions from fuel combustion for land based industries are, nonetheless, covered by the Determination.

Four estimation methods are provided for under the NGER system ranging from low cost simple default methods to higher order methods requiring sampling and analysis of inputs or direct monitoring of emissions.

In general, reporters may choose the estimation method appropriate to their own circumstances. Some important exceptions relate to reporters in the electricity generation, underground coal mining and aluminium industries which are required to use method 2 or higher (see below) for key components of their emission estimations. These restrictions cover around 60 per cent of emissions reported under the NGER system.

The four NGER estimation methods are:

NGER Method 1: is the *National Greenhouse Accounts* default method. Method 1 specifies the use of designated EFs in the estimation of emissions. These EFs are national average factors determined by the Department using the AGEIS. Although significantly updated, this method is very similar in approach to that used by many corporations for over a decade to voluntarily report emission estimates under the *Greenhouse Challenge Plus* program.

The national inventory only utilises activity data collected from companies that report using this method as no new information is collected in relation to EFs or in relation to other key facility-specific parameters.

NGER Method 2: a facility-specific method using industry sampling and Australian or international standards listed in the Determination or equivalent for analysis of fuels and raw materials to provide more accurate estimates of emissions at facility level. Method 2 enables corporations to undertake additional measurements – for example, the qualities of fuels consumed at a particular facility – in order to gain more accurate estimates for emissions for that particular facility. Method 2 draws on the large body of Australian and international documentary standards prepared by standards organisations in order to provide the benchmarks for procedures for the analysis of, typically, the critical chemical properties of the fuels being combusted. Method 2 was based on existing technical guidelines used by reporters under the *Generator Efficiency Standards* program, which had been in place since 1998.

The national inventory may utilise activity data and EFs or other key facility-specific parameters collected by companies using this method, depending on the analysis of the quality of the data and in accordance with the decision tree set out in section 1.4.1.

NGER Method 3: a facility-specific method using Australian or international standards listed in the Determination or equivalent standards for both sampling and analysis of fuels and raw materials. Method 3 is very similar to method 2, except that it requires reporters to comply with Australian or equivalent documentary standards for sampling (of fuels or raw materials) as well as documentary standards for the analysis of fuels.

NGER Method 4: direct monitoring of emission systems, either on a continuous or periodic basis. Method 4 provides for a different approach to the estimation of emissions. Rather than providing for the analysis of the chemical properties of inputs (or in some case, products), method 4 aims to directly monitor greenhouse emissions arising from an activity. This approach can provide a higher level of accuracy in certain circumstances, depending on the type of emissions process, however, it is more likely to be more data intensive than other approaches.

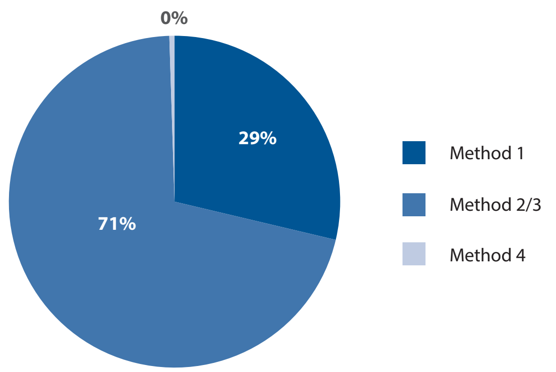
As for methods 2 and 3, there is a substantial body of documented procedures on monitoring practices and state and territory government regulatory experience that provide the principal source of guidance for the establishment of such systems.

The national inventory may use emissions data generated using NGER method 4 depending on the analysis of the quality of the data and in accordance with the decision tree set out in section 1.4.1.

Implementation of the NGER (Measurement) Determination

In the eighth year of implementation of the NGER system (2016-17), 65 per cent of carbon dioxide (CO_2) emissions were estimated using method 2 or 3, i.e. using analysis of carbon content of fuels or other inputs. By comparison, 29 per cent of CO_2 emissions were estimated using method 1. Less than 1 per cent of CO_2 emissions were estimated using method 4 (Figure 1.4). These outcomes reflect the choices determined by companies within the NGER system, and reflect the significance of the source and the likely variability in the carbon content of the source. For example, over 95 per cent of emissions from the combustion of coal were estimated using a higher order method. However, method 1 continued to be used principally for petroleum products, which tend to be homogenous in character and where payoff from additional measurement effort is often limited. Choices made by companies for gas lay somewhere between coal and petroleum products.

Figure 1.4 CO_2 emissions: method selected by NGER reporters



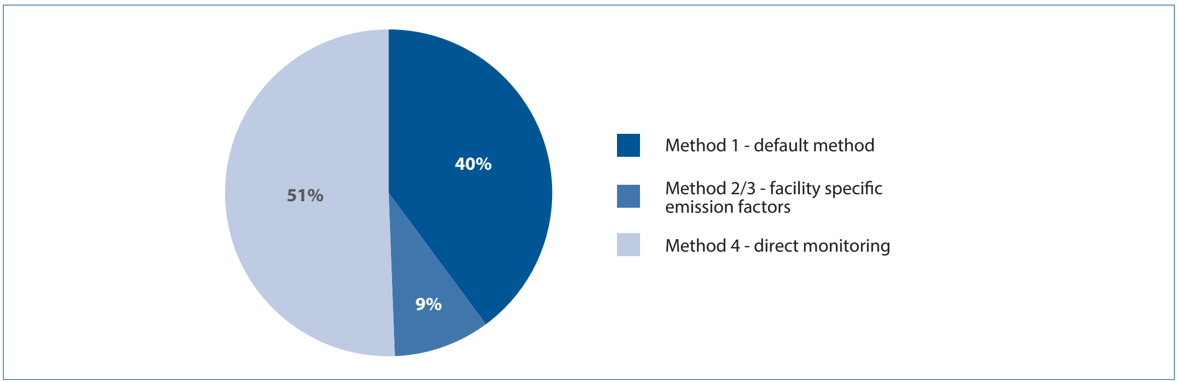
There is a similar story when choices made about estimation methods used for methane are considered (Figure 1.5). Around 51 per cent of CH_4 emissions were estimated using direct monitoring of emissions while 40 per cent of CH_4 emissions were estimated using method 1.

Introduction and Inventory Context

As for CO_2, the choices of the system, and of companies within the system, have resulted in the use of actual measurements from facilities to determine emissions for major sources of CH_4. This outcome relates principally to the choices made by underground coal mines to use directly monitored estimates.

For minor sources of CH_4 and where measurement is difficult, such as CH_4 from combustion of fuels, method 1 has been used by reporting companies under the NGER system.

Figure 1.5 CH_4 emissions: method selected by NGER reporters



The particular use of this NGER data within the national inventory for each category is explained within their respective chapters of this document.

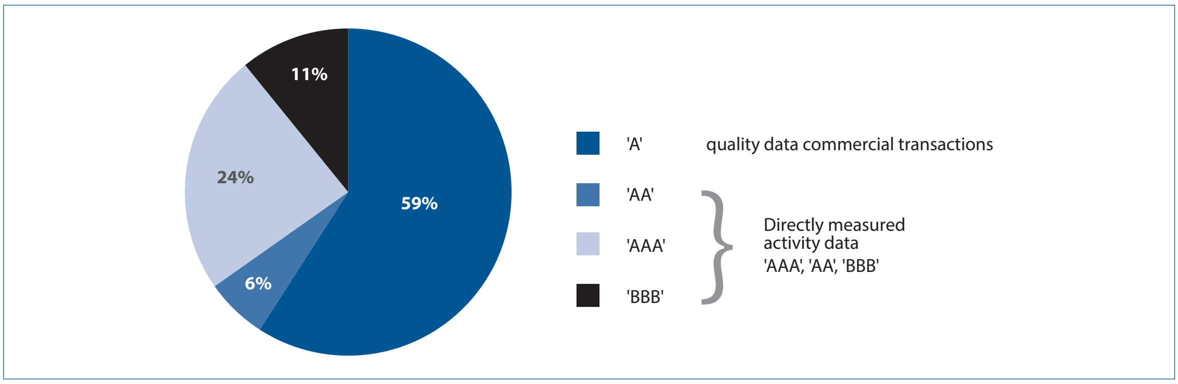
Activity data

The NGER system generates activity data on fuel consumption and key activity data inputs in the *industrial processes and product use* and *waste* sectors for NGER reporters. It also aims to maximise the amount of activity data collected from companies that is used for other regulated purposes, including commercial activity and taxation. This approach both reduces the regulatory burden on companies and ensures consistency across national datasets, also formalising the role of the national measurement systems in the national inventory system.

Activity data is rated 'A' if it is estimated using information used to support commercial transactions such as estimates of the amount of fuel purchased. Activity data is rated 'AA' if companies estimate fuel consumed based on information on the amount of fuel purchased and change in stock at the facility. Activity data is rated 'AAA' if companies directly measure fuel consumed using the same tolerance levels for measurement error that govern commercial transactions. In some cases fuel use is not subject to either commercial or taxation activity (i.e. where a facility both extracts and utilises fuel). In these cases, the quality of the data must be signified by a quality rating (i.e. 'BBB'). All 'quality' data is reported by companies as part of their NGER system reporting obligations.

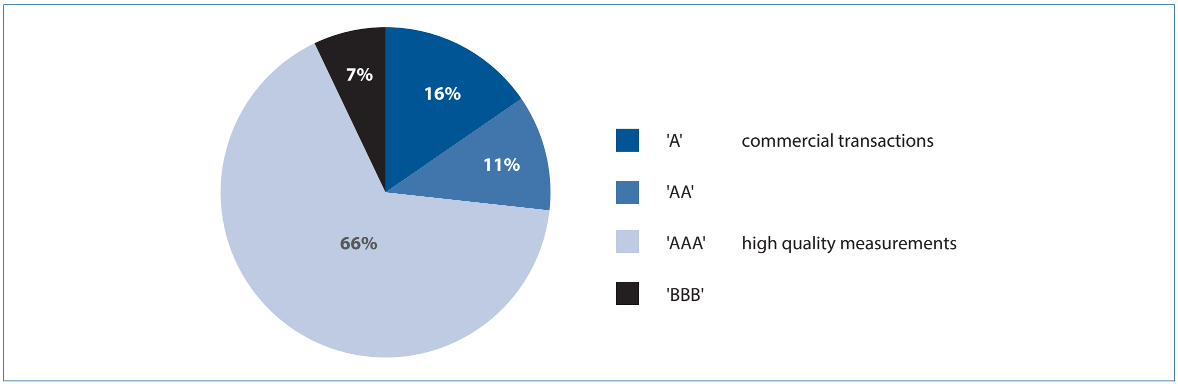
The choices made by companies with respect to the quality of their activity data inputs for 2016-17 are presented in Figure 1.6. Of reported activity data points under the NGER system, 59 per cent is derived from commercial transactions and requires no new measurements to be undertaken by the company in order to meet reporting requirements.

Figure 1.6 Activity data selected by NGER reporters by percentage of data points



However, in terms of CO_2 emissions, companies have tended to choose to use actual measurements of activity to underpin emissions estimates (Figure 1.7). In 2016-17, 66 per cent of emissions were estimated using 'AAA' activity data inputs, i.e. estimates of fuel measured at the point of combustion at an accuracy level consistent with standards required to support commercial activity.

Figure 1.7 Activity data selected by NGER reporters by percentage of emissions



It follows that companies have generally used existing commercial data for relatively minor emission sources. While commercial data accounted for 59 per cent of the data points used in emission estimation processes, these data points only related to 17 per cent of the estimated emissions.

Use of commercial activity data occurs primarily for gas and petroleum products – often minor sources or where uncertainties associated with the use of data on fuels purchased as a proxy for fuels consumed are considered low. It appears that for major emissions sources, Australian companies have chosen to use the most accurate data requiring explicit measurement effort while for minor emission sources they have chosen to use low cost, albeit slightly less accurate data.

NGER data is supplemented where necessary by alternative data sources. Currently national data for the *energy* sector is published in the Department's *Australian Energy Statistics*. *Agriculture* data is obtained by agricultural censuses and surveys conducted by the ABS while *waste* data is principally obtained under State and Territory Government legislation, collected by the Department on an annual basis under the National Waste Reporting initiative.

1.5 Brief description of key source categories

A key source category has a significant influence on a country's total inventory of direct greenhouse gases in terms of absolute level of emissions, the trend in emissions, or both. Australia has identified the key categories for the inventory using the tier 1 level and trend assessments as recommended in the IPCC 2006 and adopted by decision 24/CP.19. This approach identifies sources that together contribute to 95 per cent of the total emissions or 95 per cent of the trend of the inventory in absolute terms.

When the *LULUCF* sector is included in the analysis, Australia has identified *public electricity (solid fuel), road transportation (liquid fuels),* and *land converted to grassland* as the most significant of the key categories (i.e. contributing more than 10 per cent of the level and/or trend) in 2017. When the *LULUCF* sector is excluded from the analysis the most significant key categories in 2017 are *public electricity (solid fuel), road transportation (liquid fuels)* and *enteric fermentation (sheep)*. More details are provided in Annex 1 of Volume 3 of this Report.

The concept of key categories is also used for choosing the good practice estimation methods for emissions and removals due to activities under Articles 3.3 and 3.4 of the KP. The KP-*LULUCF* key categories have been identified as outlined in the IPCC 2014. Australia has identified *deforestation, afforestation/reforestation, and forest management, grazing land management* and *cropland management,* as key categories.

1.6 General uncertainty evaluation

Uncertainty is inherent within any kind of estimation, be it an estimate of the national greenhouse gas emissions, or the national gross domestic product. Managing these uncertainties, and reducing them over time, is recognised by IPCC 2006 as an important element of inventory preparation and development. Uncertainty arises from the limitations of the measuring instruments, sampling processes and the complexity of modelling highly variable sources of emissions over space and time, particularly for some biological sources.

Australia has conducted uncertainty analysis across the sectors of *energy*, *industrial processes and product use*, *agriculture*, *LULUCF* and *waste* in line with IPCC 2006, 2014.

Emission estimate uncertainties typically are low for CO_2 from energy consumption as well as from some industrial process emissions. Uncertainty surrounding estimates of emissions are higher for *agriculture*, *LULUCF* and synthetic gases. A medium band of uncertainty applies to estimates from *fugitive emissions*, most *industrial processes* and non-CO_2 gases in the *energy* sector.

The sectoral estimates presented in Annex 2 of Volume 3 of this Report show that the uncertainty ranges reported for the various components of the Australian inventory are largely consistent with the typical uncertainty ranges expected for each sector, as identified in the IPCC 2006, 2014.

At an aggregate level, using IPCC good practice tier 1 methods, the overall uncertainty surrounding the Australian inventory estimate for 2017 is estimated at ± 6.5 per cent. The reported uncertainty for the trend in emissions is estimated to be ± 4.8 per cent. When the *LULUCF* sector is excluded from the analysis the uncertainty is estimated at ± 5.5 per cent for the 2017 inventory estimate and ± 5.2 per cent for the trend in emissions.

The IPCC approach provides accurate estimates of uncertainty under certain restrictive assumptions that do not always hold for most countries' inventories. Consequently, the Department is conducting further reviews using available NGER system uncertainty data to improve accuracy of the uncertainty estimate for Australia across the sectors of *energy*, *industrial processes and product use* and *waste*.

1.7 General assessment of completeness

The inventory is considered to be largely complete with only a few minor sources not estimated, due to either a lack of available information or methodology in the IPCC 2006, 2014. More information on completeness is available in Annex 5. Table 1.6 summarises how completeness is achieved in those categories where NGER data is not solely used to achieve completeness.

Building on the last Report, Australia has prepared additional estimates for the voluntary reporting category of wetlands. Estimates for the *wetland* categories are reported under a number of sectors in this submission as there is no specific category. This Report captures a subset of activities and affected habitats covered in the *2013 Wetlands Supplement*, with additional estimates to be included in futures submissions, as per planned improvements descried in Chapter 6 of Volume 2. More information on the coverage of *wetland* categories for this submission is available in Annex 5 of Volume 3 of this Report.

Table 1.6 Summary of data sources used to achieve completeness, where NGER data not sole source, by IPCC category

Category	Source
1.A.1a Electricity (gas)	Completeness is achieved through use of data from the Australian Energy Statistics published by the Department. As explained in section 3.3.2 Methodology – Electricity Generation – Activity Data, the energy use of the small power stations, that do not meet the NGER reporting thresholds, are estimated as the difference between the total of reported values under NGER and DIIS energy statistics for ANZSIC subdivision 26. This approach has been adopted throughout the time series. Therefore the improved coverage of power stations under NGER does not alter the method for estimating total fuel consumption in this sector. Further detail at NIR Volume 1 section 3.3.2.
1.A.1a Electricity (liquid)	As above.
1.A.1c Oil and gas extraction	Completeness is achieved through use of data from the Australian Energy Statistics published by the Department. Further detail in NIR Volume 1 section 3.3.1.
1.A.2 Manufacturing	Completeness is achieved through use of energy balance data, by fuel type and subsector from the Australian Energy Statistics published by the Department. Further detail in NIR Volume 1 section 3.4.1.
1.A.3 Transport	Completeness is achieved through use of national transport fuel sales data published by the Department in the Australian Energy Statistics. Further detail is provided in NIR Volume 1 section 3.5.1.
1.A.4 Other sectors	Completeness is achieved through use of energy balance data, by fuel type and subsector from the Australian Energy Statistics published by the Department. Further detail in NIR Volume 1 section 3.6.1.
1.A.5 Other	This category comprises Military transport only. Completeness is achieved for this source through the use of data obtained directly from the Department of Defence. Further detail in NIR Volume 1 section 3.7.
1.B.2 Oil & Gas	NGER data is complemented by a range of data sources to ensure completeness. Further detail in NIR Volume 1 section 3.9.
1.B.C Carbon dioxide transport and storage	Not occurring
2.B.9 Fluorochemical production	Not occurring
3 Agriculture	Completeness is principally achieved through the use of Australian Bureau of Statistics agricultural census data.
4 LULUCF	Completeness is principally achieved through the application of annual wall-to-wall spatial monitoring changes in woody vegetation cover. Completeness is achieved through use of energy balance data, for combusted harvested wood products, from the Australian Energy Statistics published by the Department.

Category	Source
5.A Solid waste	Completeness for solid waste disposal is discussed in NIR Volume 2 Chapter 7 of the NIR. NGER data cover about 70 per cent of total waste disposal in Australia. Solid waste disposal data is also provided by the Stewardship Waste Section of the Department, which collects disposal data from each State and Territory annually as part of the National Waste Reporting initiative. The residual disposal not covered by the NGER system is calculated as the total disposal reported for each state and territory minus the sum of NGER disposal in each State and Territory. Figure 7.4 of NIR Vol 2 shows the relationship between State and Territory reported disposal and disposal reported under NGERS. Methane capture data obtained under NGERS are considered complete as they are supplied by gas capture companies (as distinct from landfill operators) all of which trigger reporting thresholds of NGERS.
5.B Biological treatment of solid waste	Emissions estimates are based on an annual industry survey undertaken by the Recycled Organics Unit at the University of NSW. Refer to Chapter 7 of volume 2 of the NIR for further information.
5.C Waste incineration	Data on the quantities of municipal solid waste incinerated are based upon published processing capacities of the three incineration plants prior to decommissioning in the mid 90s. Data on the quantities of clinical waste incinerated have been obtained from a per-capita waste generation rate derived from data reported under the NGER system, by O'Brien (2006b) and an estimate of State population reported by the Australian Bureau of Statistics. Refer to Chapter 7 of volume 2 of the NIR for further information.
5.D.1 Domestic and commercial wastewater	Major wastewater treatment facilities report under NGERS. NGER reporting requirements include the population serviced by each treatment plant. Population data and per-capita wastewater organic matter and N generation rates are used to determine the residual. Refer to Chapter 7 of volume 2 of the NIR for further information.
5.D.2 Industrial wastewater	Where appropriate, national commodity production statistics are used to ensure completeness of AD for industrial wastewater. Refer to Chapter 7 of volume 2 of the NIR for further information.

Trends in Emissions

1.7.1 Geographical coverage

The Australian inventory covers the six states (New South Wales, Victoria, Queensland, South Australia, Western Australia and Tasmania), the mainland territories (Northern Territory, Australian Capital Territory and Jervis Bay Territory) and the associated coastal islands.

The geographical coverage of the Australian inventory also includes emissions from the following external territories:

- Norfolk Island
- Christmas Island
- Cocos Islands
- Heard and McDonald Islands

Australia's Antarctic Program operations in the Antarctic are also covered.

The following external territories are also covered are included in the state statistical territories by the ABS:

- Coral Sea Islands (Queensland); and
- Ashmore and Cartier Islands (Northern Territory).

The coverage of emissions/removal categories for the external territories is as follows:

- *fuel combustion*, *waste* and HFC emissions associated with refrigeration are estimated;
- *fugitive emissions* and *industrial processes and product use* emissions are assumed to be not occurring; and *agriculture* and *LULUCF* emissions and removals are not estimated but are likely to be negligible.

2. Trends in emissions

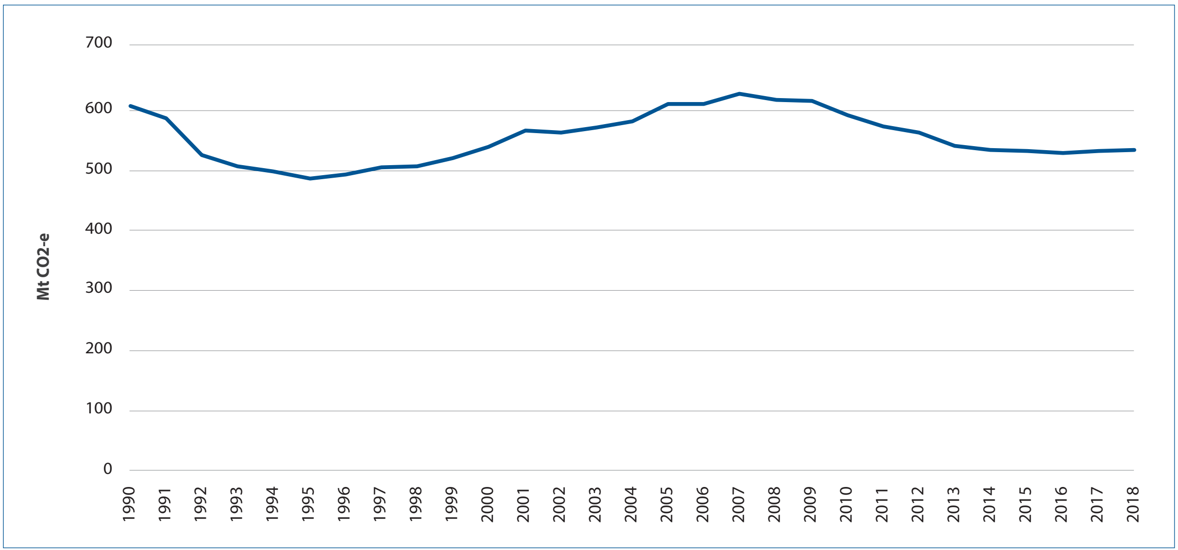
2.1 Emission trends for aggregated greenhouse gas emissions

Australia's total greenhouse gas emissions, excluding the *LULUCF* sector, were 554.1million tonnes (Mt) of carbon dioxide equivalent (CO_2-e) in 2017. This represents an increase of 7.4 Mt CO_2-e (1.3 per cent) on net emissions recorded in 2016, and an increase of 31.8 per cent (133.8 Mt CO_2-e) above 1990 levels.

When the *LULUCF* sector emissions and removals are included in the total, Australia's net greenhouse gas emissions in 2017 were 534.7 Mt CO_2-e (Figure 2.1). This represents a decrease of 70.2 Mt CO_2-e (11.6 per cent), on net emissions recorded in 1990. In 2017, the *LULUCF* sector was a net sink of 19.4 Mt CO_2-e.

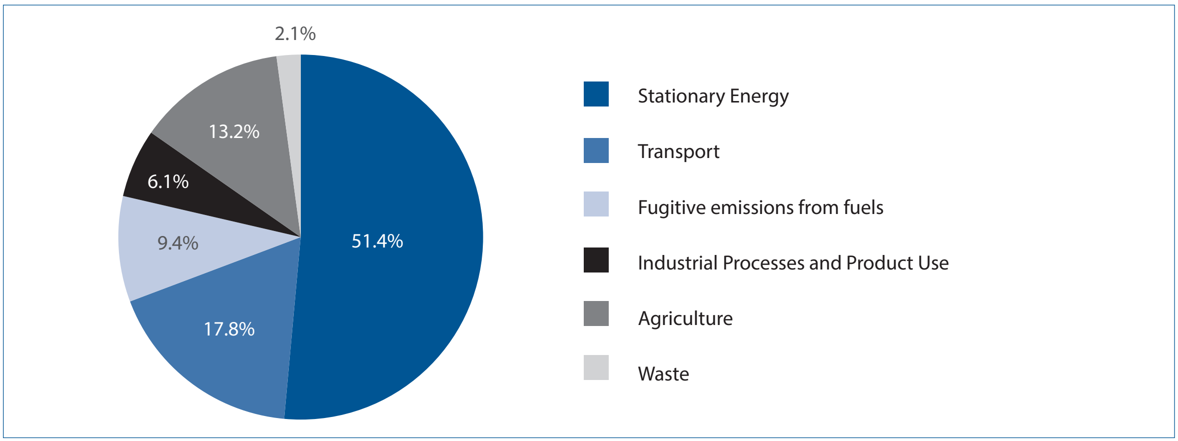
The preliminary estimate for Australia's total greenhouse gas emissions, including the *LULUCF* sector, in 2018 is 537.0 Mt CO_2-e, an increase of 0.4 per cent on 2017 levels.

Figure 2.1 National Inventory trend for aggregated greenhouse gas emissions (including *LULUCF*), Australia, 1990 – 2018



The combined *energy* subsectors (including *stationary energy, transport* and *fugitive* emissions) were the largest source of greenhouse gas emissions in 2017 comprising 78.6 per cent of emissions excluding *LULUCF* (Figure 2.2) followed by the *agriculture* sector (13.2 per cent).

Figure 2.2 Contribution to total net CO_2-e emissions (excluding *LULUCF*) by sector, Australia, 2017

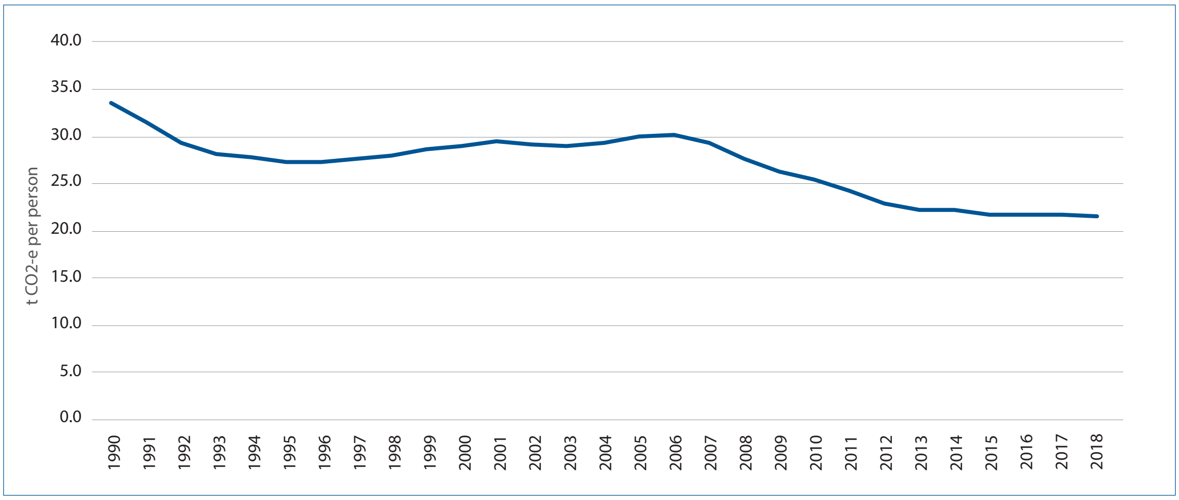


2.2 Emission trends per capita and per GDP

Australia's emissions per capita and per dollar of gross domestic product (GDP) have generally declined over the last twenty years. These declines have resulted from specific emissions management actions across sectors, the large decline in land use change emissions over the period, and structural changes in the economy.

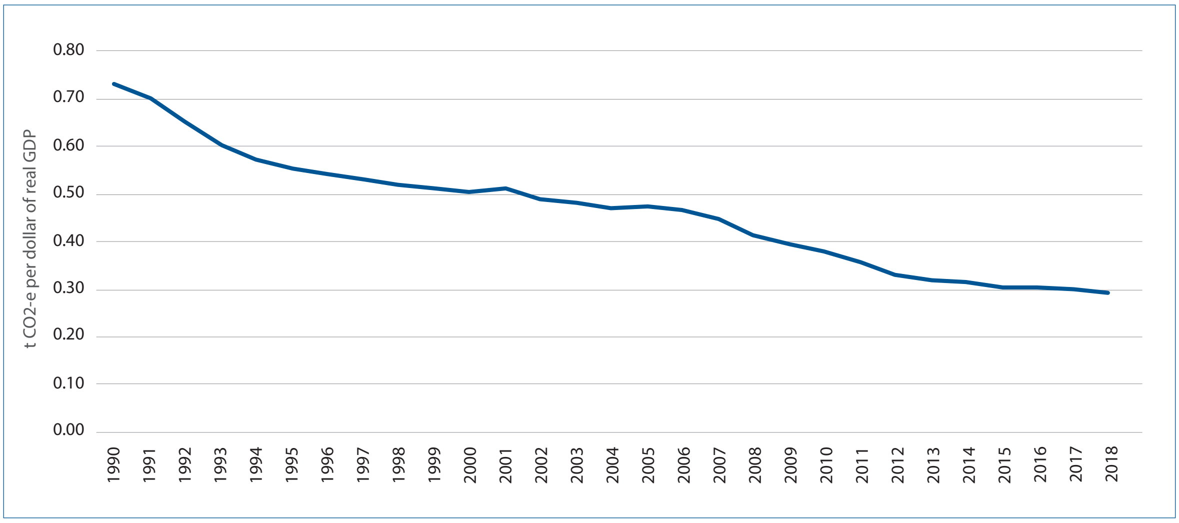
Australia's population grew strongly between 1990 and 2018, from 17.1 million in 1990 to around 25.0 million in 2018 (growth of 45.6 per cent). For the national inventory total (including emissions from the land sector), the 2018 estimate is 21.5 t CO_2-e per person, compared to 33.5 t CO_2-e in 1990, representing a 35.8 per cent decline.

Figure 2.3 Emissions per capita, Australia (t CO_2-e per person)



Australia's GDP also grew over this period, from 782 billion Australian dollars (AUD) in 1990 to over AUD 1,815 billion in 2018 (growth of 131.7 per cent). For the national inventory total (including emissions from *LULUCF*), the 2018 estimate is 0.29 kg CO_2-e per dollar, compared to 0.73 kg CO_2-e per dollar in 1990, which is a decline of 59.8 per cent.

Figure 2.4 Emissions per GDP, Australia (t CO_2-e per dollar of real GDP 2016-17 prices)



Trends in Emissions

2.3 Emission trends by sector

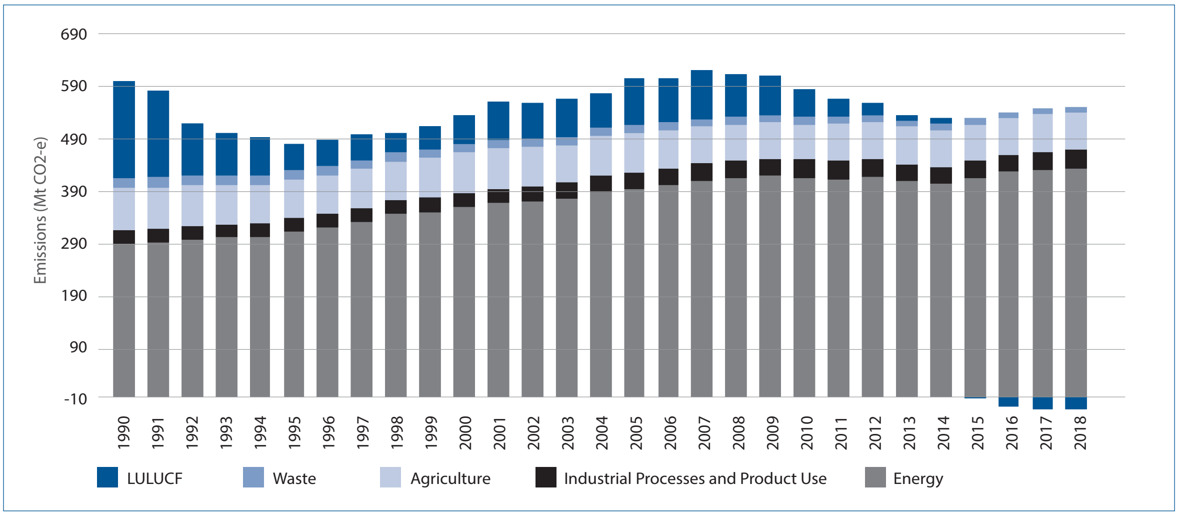
Sectors with increasing emissions over the 1990 to 2017 period included *stationary energy* (45.9 per cent), *transport* (60.8 per cent), *fugitive emissions from fossil fuels* (39.2 per cent) and *industrial processes and product use* (29.4 per cent). Decreased emissions were recorded for *waste* (41.1 per cent), *agriculture* (9.0 per cent) and *LULUCF* (110.5 per cent).

Figure 2.5 shows the emissions for each sector from 1990-2017 (preliminary estimates are also included for 2018). The principal drivers of these emission trends are as follows:

- *Energy*: The largest sectoral increase in greenhouse gas emissions over the 1990 to 2017 period, of 89.7 Mt CO_2-e (45.9 per cent), occurred in the *stationary energy* sector, driven in part by increasing population, household incomes and export increases from the resource sector. The main drivers for the increase in *transport* emissions are continuing growth in the number of passenger vehicles, along with an increase in diesel consumption in heavy vehicles and an increase in air travel. *Fugitive emissions* have increased over the period largely due to increased production from open cut coal mines and increased gas production. The most recent increase, since 2015, is associated with an expansion of LNG exports; annual LNG production increased 41 per cent in 2017 and 18 per cent in 2018;
- *Industrial processes and product use*: The increase in emissions since 1990 is primarily driven by the growth in emissions associated with HFCs, chemical and metals industries;
- *Agriculture*: Between 1990 and 1995 emissions decreased due to falling sheep numbers. From 1995 to 2002 emissions increased due to increased beef cattle numbers and increased emissions from agricultural soils. From 2002 until 2010 emissions declined due to prolonged and widespread drought conditions over southern and eastern Australia which contributed to reductions in animal populations, crop production, fertiliser use, and associated emissions. With the return to wetter conditions emissions have increased as high levels of crop production have been achieved and livestock populations have increased as farmers rebuild their herd. In recent years however (2015 and 2016), high beef prices have led to further destocking in the beef herd. Preliminary data for 2018 show that restocking has recommenced;
- *Waste*: The net emissions from waste have decreased as increases associated with growing populations and industrial production have been offset by increased CH_4 recovery. In recent years, this longer term trend of emissions reductions through increases in CH_4 recovery has stabilized; and
- *LULUCF*: The decreasing trend in emissions from *LULUCF* since 1990 has been mainly driven by the decline in emissions from *forest land converted to cropland* and *grassland,* and in recent years, from the declines in the harvesting of native forests.

Trends in emissions from each sector are discussed further in Chapters 3-8.

Figure 2.5 Net CO_2-e emissions by sector, Australia, 1990-2018



2.4 Analysis of emission trend drivers

An equation based on the Kaya identity (Equation 2.1) supports analysis of the drivers of Australia's emissions trends. The equation expresses CO_2 emissions from fuel combustion and industrial processes and product (IPPU) use as the product of four factors: population; GDP per capita; the energy intensity of the economy and the emissions intensity of energy.

Equation 2.1: CO_2 from fuel combustion and *IPPU* = $P \times \frac{GDP}{P} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$

Where *P* = Population

GDP = Gross domestic product

Energy = Total net energy consumption

CO_2 = CO_2 emissions from fuel combustion and IPPU

Trends in these factors provide insight into how Australia's national circumstances have impacted on CO_2 emissions since 1990. However, it should be noted that each factor is not necessarily independent of each other (i.e. increases in GDP per capita may change the energy intensity of the economy) and an increase in a single factor will not automatically result in a corresponding change in CO_2 emissions (i.e. an increase in population does not automatically result in an equivalent increase in CO_2 emissions).

Between 1990 and 2017, CO_2 emissions from fuel combustion and IPPU increased by 32 per cent (Figure 2.6). Underlying growth factors were a 31 per cent increase in population (light blue line) and a 38 per cent increase in GDP per capita (light grey line). Declining factors were a 52 per cent decline in the energy intensity of the economy (black line) and a 5 per cent decline in the emissions intensity of energy consumption (dark grey line). Over the time series, Australia's CO_2 emissions trended upwards until 2009 before declining over the period to 2017 as the impact of improved energy intensity of the economy and emissions intensity of energy more than offset increases in population and GDP per capita.

Figure 2.6 Growth in CO_2 emissions from fuel combustion and IPPU and underlying drivers, Australia, 1990-2017

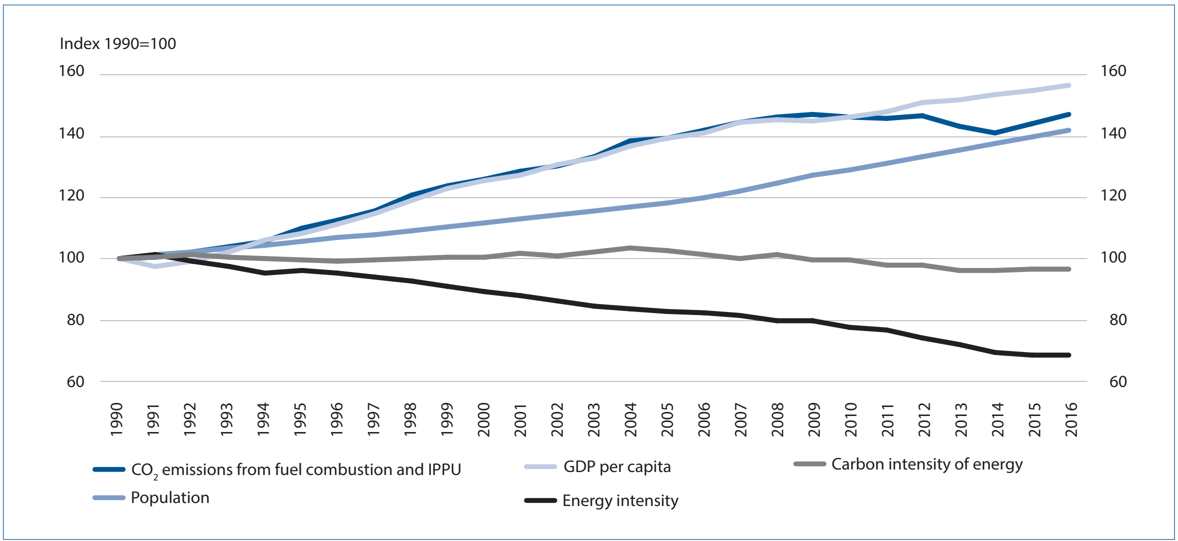
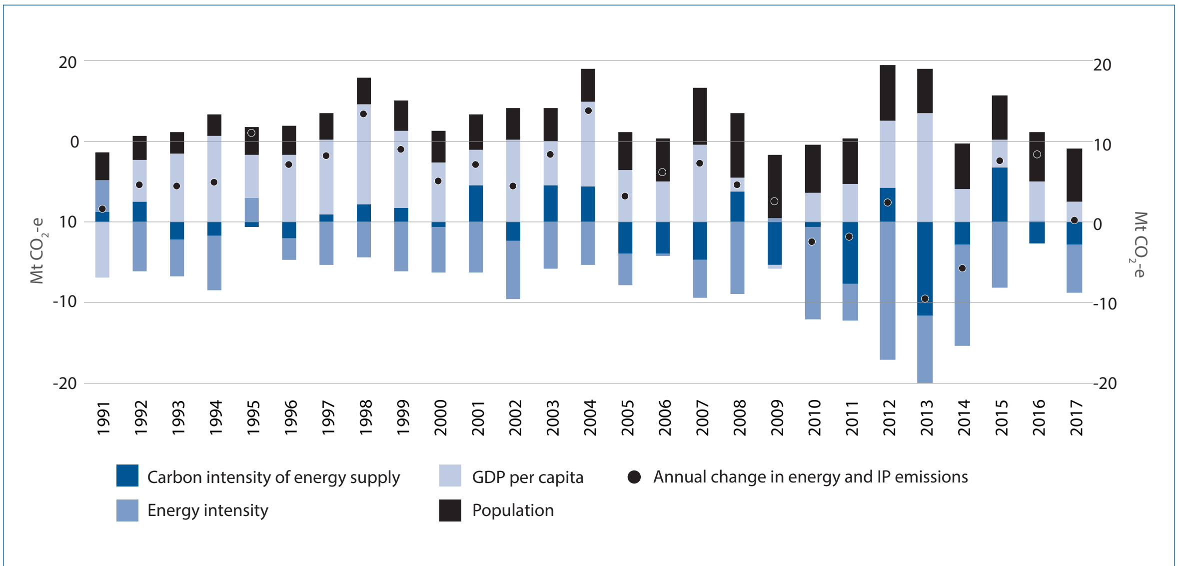


Figure 2.7 attributes annual emission changes (black dot) to the four underlying factors. The combined impact of increases in population (black bar) and GDP per capita (light grey bar) have contributed to increasing emissions in all years.

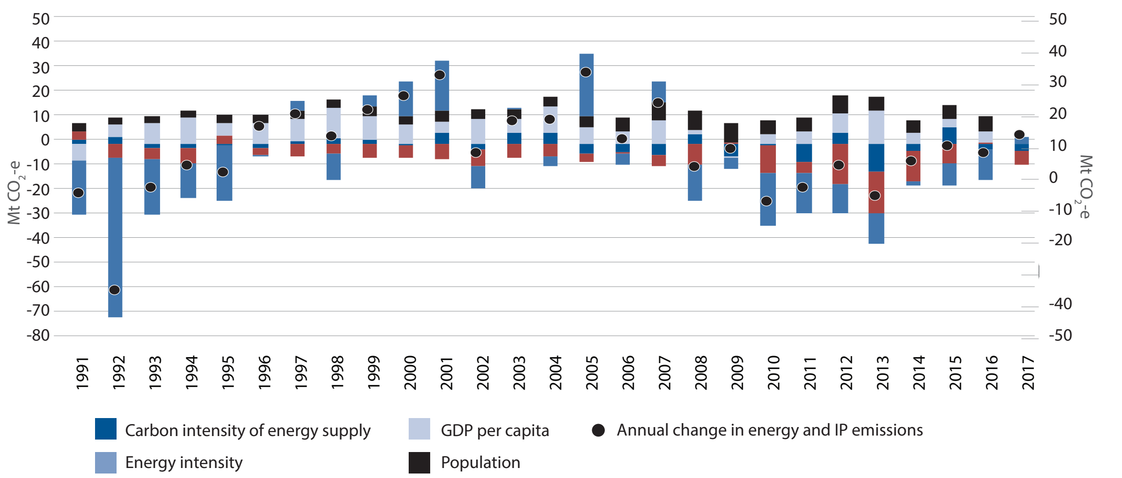
The energy intensity of the economy (light blue bar) decreased in 23 of the 27 years at varying annual rates reflecting energy efficiency improvements and structural change in the economy towards less energy intensive service sectors. The emissions intensity of energy (dark blue bar) has fluctuated over the time series however there has been a declining trend since 2005 as the proportion of electricity generation from coal has declined.

Figure 2.7 Annual change in CO_2 emissions from fuel combustion and IPPU from underlying drivers: Australia1992-2018 (Mt CO_2-e)



This trend is reflected in the choice of fuel for energy consumption (Figure 2.8). Over the period 1990-2009 consumption of coal, oil and natural gas (for fuel combustion) increased. From 2009, oil and gas consumption continued to grow, driven by the *transport* and *electricity* sectors. In contrast coal consumption declined, rebounding somewhat since 2014. In 2017, coal consumption was 18 per cent below its 2009 peak level of 2351 petajoules.

Figure 2.8 Energy consumption by fuel type



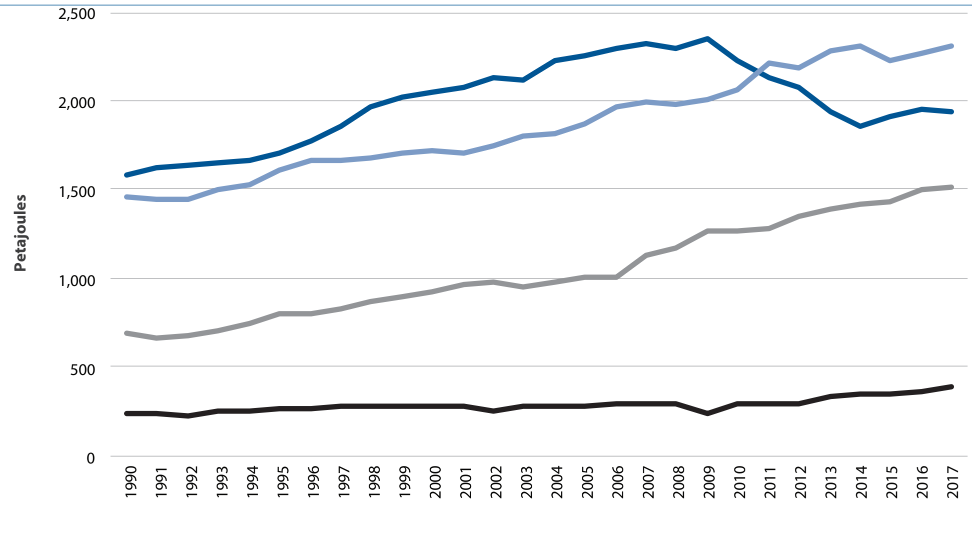
The Kaya analysis considers a subset of Australia's total emissions. At the national level increases in CO_2 emissions from fuel combustion and IPPU have been offset by declines in other emission sources. Figure 2.9 expands the decomposition to include other emission sources as a fifth driver of total emissions (equation 2.2). This analysis does not attempt to break down other emissions into underlying drivers such as energy consumption, population or GDP growth which have less of an effect on these types of emissions.

Equation 2.2: Total emissions = $P \times \frac{GDP}{P} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$ + Other Emission sources

CO_2 from fuel combustion and IPPU — Fugitive emissions, Non-CO_2 fuel combustion, non-CO_2 IPPU, Agriculture, Waste and LULUCF

Changes in other emission sources (light blue bar) generally have a downward impact on total emissions however annual changes are subject to considerable variation.

Figure 2.9 Primary energy consumption, Australia: 1992-2017



Trends in Emissions

2.5 Black carbon Inventory

With an increased global focus on short lived climate forcers and their role in affecting climate, black carbon emissions from combustion processes, has been included for the first time in this Report. This Report provides estimates of black carbon emissions for energy, IPPU, *waste*, *transport*, residential burning and biomass burning for 2008-09 and 2016–17.

As black carbon is not emitted on its own, but as a component of particulate matter with an aerodynamic diameter ≤ 2.5 μm ($PM_{2.5}$), the basis for the black carbon inventory is the $PM_{2.5}$ emitted from combustion processes, multiplied by source specific black carbon ratios. Measured $PM_{2.5}$ data from Australia's Pollutant Release Transfer Register, the National Pollutant Inventory (NPI), has been used to supplement existing greenhouse gas accounting activity data.

Table 2.1 Black carbon emissions from combustion processes 2008-09 and 2016-17 kt

	2009	2010	2011	2012	2013	2014	2015	2016	2017
1 Energy	45.3	49.1	52.1	56.5	58.3	60.2	61.0	63.5	62.6
Fuel Combustion	45.3	49.1	52.1	56.5	58.3	60.2	61.0	63.5	62.6
Energy Industries	5.2	5.3	5.1	7.0	6.9	7.4	6.9	7.1	5.0
Manufacture of Solid Fuels and Other Energy Industries	4.4	4.6	4.4	6.3	6.2	6.7	6.2	6.5	4.5
Petroleum Refining	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.1
Public Electricity and Heat Production	0.7	0.4	0.5	0.5	0.3	0.4	0.4	0.4	0.3
Manufacturing Industries and Construction	6.3	6.0	6.1	7.2	7.5	7.6	7.4	7.4	7.7
Other (not elsewhere classified)	0.2	0.3	0.4	0.3	0.3	0.4	0.3	0.4	0.3
Other Sectors	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4
Transport	33.3	37.5	40.3	41.7	43.3	44.6	46.2	48.2	49.1
2 Industrial Processes	0.4	0.3	0.4	0.3	0.2	0.3	0.3	0.4	0.4
3 Agriculture	4.1	3.6	5.2	5.2	4.9	4.6	4.4	4.0	6.5
4 Land Use, Land-Use Change and Forestry UNFCCC	335.8	312.2	285.3	252.4	254.0	267.1	242.4	257.0	251.9
5 Waste	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.8
Memo Items (including International Bunkers - Marine and Aviation)	18.2	23.4	22.7	24.0	24.7	26.8	26.2	27.5	30.0
Total	**385.6**	**365.3**	**342.9**	**314.4**	**317.5**	**332.2**	**308.2**	**325.0**	**322.1**

Measured data from the NPI for the aerosol particulate matter with an aerodynamic diameter less than 10 μm (PM_{10}) and the precursor SO_2, since 2009-10 for *energy*, *waste* and industrial processes has also been published in this Report.

Table 2.2 National pollutant Inventory measured PM10 data from combustion processes, 2008-09-2016-17 kt

	2009	2010	2011	2012	2013	2014	2015	2016	2017
1 Energy	518.7	521.6	623.3	724.8	812.0	892.6	930.8	944.0	899.0
Fuel Combustion	518.7	521.6	623.3	724.8	812.0	892.6	930.8	944.0	899.0
Energy Industries	245.9	244.1	320.1	354.4	408.7	450.8	432.9	429.7	394.7
Manufacture of Solid Fuels and Other Energy Industries	212.2	219.8	293.0	328.9	386.4	427.7	407.0	405.2	371.3
Petroleum Refining	1.2	1.1	0.8	0.8	1.1	1.0	0.8	0.6	0.6
Public Electricity and Heat Production	32.5	23.2	26.3	24.7	21.2	22.1	25.1	23.8	22.8
Manufacturing Industries and Construction	264.4	264.5	293.7	360.1	394.7	432.4	487.9	501.4	492.2
Other Sectors	8.3	13.1	9.5	10.3	8.5	9.4	10.0	13.0	12.1
2 Industrial Processes	11.3	11.7	12.0	11.2	12.0	13.7	12.8	13.4	13.3
5 Waste	0.3	0.5	0.2	0.2	0.2	0.4	1.4	1.3	4.3
Total	**530.3**	**533.8**	**635.6**	**736.2**	**824.2**	**906.8**	**945.0**	**958.7**	**916.6**

Table 2.3 National pollutant Inventory measured SO_2 data from combustion processes, 2008-09-2016-17 kt

	2009	2010	2011	2012	2013	2014	2015	2016	2017
1 Energy	779.8	761.2	733.9	727.6	700.6	680.0	662.5	644.2	640.8
Fuel Combustion	779.8	761.2	733.9	727.6	700.6	680.0	662.5	644.2	640.8
Energy Industries	649.1	630.1	608.9	601.7	576.0	559.8	559.9	546.5	541.9
Manufacture of Solid Fuels and Other Energy Industries	8.9	11.0	12.1	12.1	13.3	12.5	10.7	11.1	11.3
Petroleum Refining	8.7	9.1	9.8	7.4	7.7	7.2	6.4	5.6	5.4
Public Electricity and Heat Production	631.4	610.1	587.0	582.1	554.9	540.1	542.8	529.7	525.3

Manufacturing Industries and Construction	95.2	95.5	89.8	91.8	93.8	88.3	69.9	64.2	64.3
Other (not elsewhere classified)	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.4	0.3
Other Sectors	7.4	7.4	7.4	7.7	7.7	8.0	8.3	8.8	9.3
Transport	27.9	27.9	27.5	26.2	22.8	23.5	24.1	24.4	24.9
2 Industrial Processes	1820.2	1618.8	1774.0	1791.4	1713.5	1819.4	1723.3	1820.7	1647.7
Total	**2600.0**	**2380.0**	**2507.9**	**2519.1**	**2414.1**	**2499.4**	**2385.9**	**2464.9**	**2288.5**

2.6 Emission trends for Kyoto Protocol –LULUCF inventory

Trends in Emissions

In accordance with decision 1/CMP.8, this section contains emissions and removals associated with Articles 3.1, 3.3 and 3.4 of the KP for the first four years of the CP2.

Under the KP accounting rules Parties must report emissions from the *energy, industrial processes and product use, agriculture* and *waste* sectors as well as the *deforestation* activity from the *LULUCF* sector. For the CP2, Australia accounts for the mandatory activities *afforestation/reforestation* and *forest management* and the voluntary activities *cropland management, grazing land management* and *revegetation*. Australia does not account for *wetland drainage and rewetting* for the CP2.

Table 2.4 Emissions and removals associated with Articles 3.1, 3.3 and 3.4 of the Kyoto Protocol, 2013-2017

Sector and Subsector	Emissions Mt CO_2-e				
	2013	2014	2015	2016	2017
1 Energy	414.5	408.7	420.3	432.1	435.6
2 Industrial processes and product use	31.5	31.2	32.8	33.0	33.7
3 Agriculture	72.1	72.6	70.1	69.3	73.0
5 Waste	12.4	12.5	11.9	12.4	11.8
Deforestation (a)	35.2	36.9	26.7	29.1	26.1
National inventory emissions	**565.7**	**561.9**	**561.9**	**575.9**	**580.2**
RMU credits generated by Article 3.3 and 3.4 activities					
Afforestation/Reforestation (a)	-25.9	-25.9	-25.0	-28.3	-29.4
Article 3.4 activities (a)	-35.0	-37.0	-42.0	-50.8	-41.3
Total RMU credits (b)	**-61.0**	**-62.9**	**-67.0**	**-79.1**	**-70.7**
Kyoto Protocol Total (National inventory emissions plus RMU credits)	**504.7**	**499.0**	**494.9**	**496.8**	**509.5**

(a) Australia has elected to account for Article 3.3 activities on an annual basis, and Article 3.4 activities at the end of CP2.
(b) Accounting quantity in accordance with decisions 2/CMP.7 and 3/CMP.11.

3. Energy

3.1 Overview

Total emissions from the *energy* sector for 2017 were estimated to be 435.7 Mt CO_2-e (Table 3.1). *Energy industries* were the main contributor, accounting for 50.1 per cent of emissions from the *energy* sector. Other significant contributors to total *energy* emissions were *transport* (22.7 per cent), and *manufacturing industries and construction* (9.5 per cent).

Energy sector emissions increased by 48.2 per cent between 1990 and 2017. Annual emissions from 2016 to 2017 increased by 3.6 Mt (0.8 per cent).

Table 3.1 Energy sector CO_2-e emissions, 2017, 2018

Greenhouse gas Source and Sink Categories	CO_2-e emissions (Gg)				
	CO_2	CH_4	N_2O	Total 2017 CO_2-e	Preliminary 2018 estimate CO_2-e
1 ENERGY	394,703	37,680	3,266	435,649	439,200
A. Fuel combustion activities	378,659	1,972	3,178	383,808	382,399
1 Energy industries	216,468	634	962	218,064	212,193
a Electricity and heat production	188,411	606	753	189,771	181,454
b Petroleum refining	2,982	1	2	2,986	3,130
c Manufacture of solid fuels	25,075	26	207	25,308	27,609
2 Manufacturing industries and construction	40,815	61	452	41,328	42,856
3 Transport	96,841	363	1,528	98,732	101,023
a Domestic aviation	8,736	1	20	8,757	8,744
b Road transportation	82,151	234	1,052	83,437	85,074
c Railways	3,486	5	446	3,937	4,232
d Navigation (domestic)	1,804	120	9	1,933	2,306
e Other transportation	664	3	0	668	667
4 Other sectors	23,619	913	227	24,759	25,336
5 Other Mobile (military)	916	1	8	925	991
B. Fugitive emissions from fuels	16,045	35,708	88	51,841	56,801
1 Solid fuels	2,144	23,657	0	25,801	27,006
2 Oil and natural gas	13,901	12,051	88	26,039	29,795

3.1.1 Stationary energy

Stationary energy principally comprises fossil fuel combustion in *electricity and heat production* and *manufacturing and construction industries.* Total estimated emissions from stationary energy combustion were 285.1 Mt CO_2-e in 2017, equal to 51.4 per cent of net national emissions (excluding *LULUCF*).

The *energy industries* subsector includes fuel combustion in electricity generation, petroleum refining, gas production and solid fuel manufacture. *Electricity and heat production* (1.A.1.a) contributed 189.7 Mt CO_2-e or 66.6 per cent of *stationary energy* emissions in 2016. This category includes emissions only from electricity generation because heat production as defined by the IPCC does not occur in Australia. Estimated emissions from the remaining *energy industries* subsectors were 28.3 Mt CO_2-e in 2017.

The *manufacturing industries and construction* subsector (1.A.2) emissions were 41.3 Mt CO_2-e in 2017. This subsector includes direct emissions from fuel combustion in manufacturing industries, ferrous and non-ferrous metals production, plastics production, construction and non-energy mining. These calculations do not fully reflect the greenhouse impact of these industries, as the emissions generated from the production of electricity used in these industries are included under *electricity and heat production* (1.A.1.a).

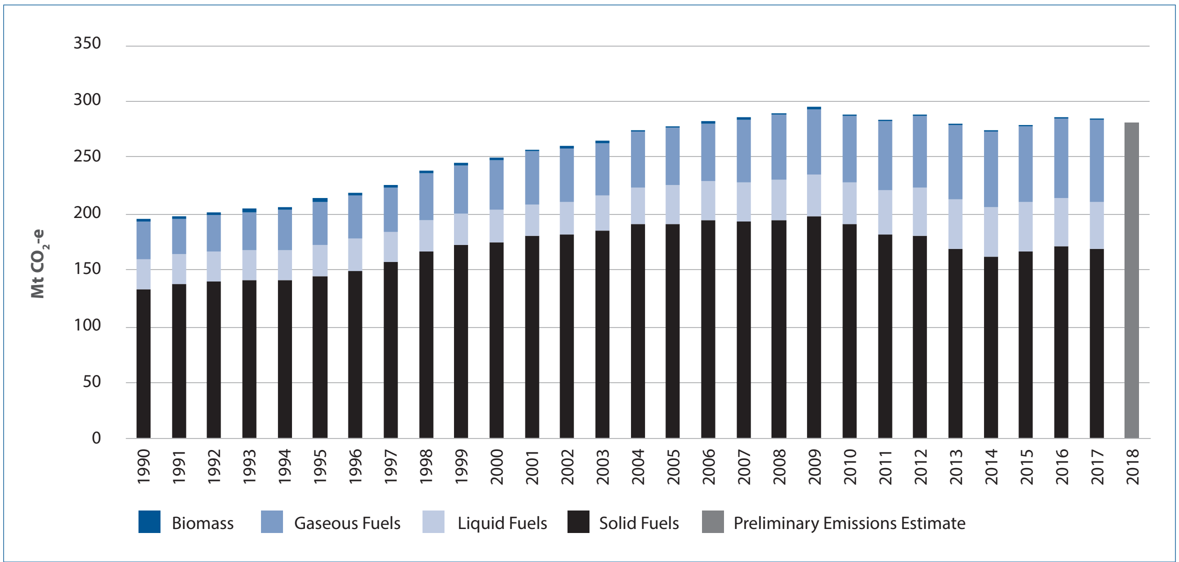
Estimated emissions from *other sectors* (1.A.4) were 24.8 Mt CO_2-e in 2017. This subsector comprises direct fuel combustion in the residential, commercial and institutional sectors, including energy used in mobile equipment in *agriculture*, *forestry* and *fishing* industries. However, as with *manufacturing*, much of the greenhouse impact of these sectors arises from their large consumption of electricity, which is not reflected in this figure alone (reported under 1.A.1.a). *Other* (1.A.5) comprises of emissions from *military transport* (0.9 Mt CO_2-e).

Trends

Emissions from *stationary energy* increased by 45.9 per cent (89.7 Mt CO_2-e) between 1990 and 2017, including an increase in emissions from the combustion of solid fossil fuels of 27.8 per cent (36.8 Mt CO_2-e) in the same period (Figure 3.1). Emissions related to gaseous fossil fuels have shown the largest relative and absolute growth, increasing by 118.8 per cent (39.5 Mt CO_2-e) between 1990 and 2017. Emissions from liquid fossil fuels increased by 54.0 per cent (14.7 Mt CO_2-e) in the same period. Biomass emissions decreased by 51.0 per cent (1.4 Mt CO_2-e) between 1990 and 2017. Between 2016 and 2017, emissions from *stationary energy* decreased by 0.7 per cent (1.9 Mt CO_2-e). The preliminary estimate for Australia's *stationary energy* (excluding electricity) sector in 2018 is 99.9 Mt CO_2-e, a change of 4.8 per cent on 2017 levels.

Energy

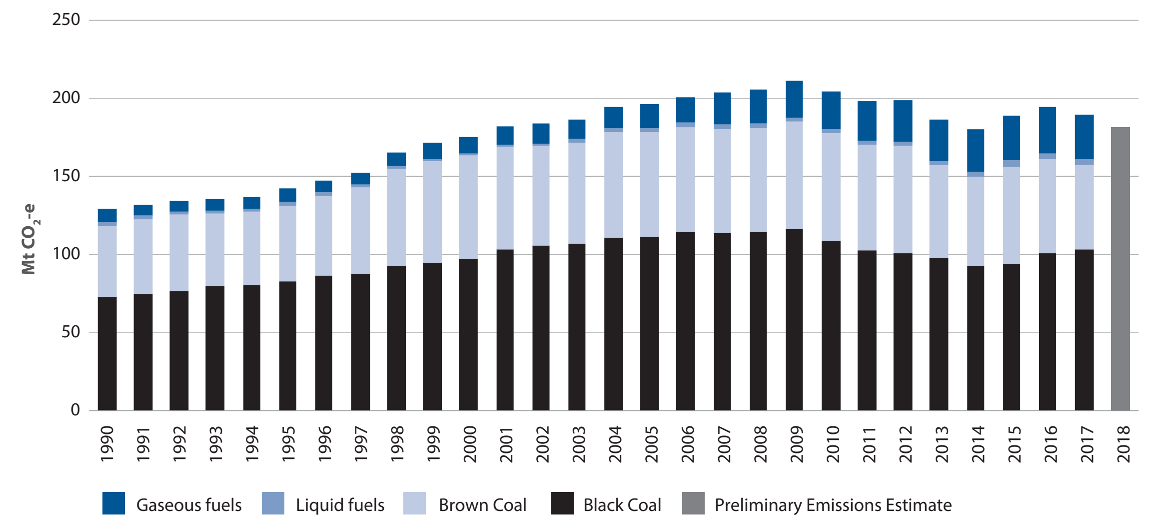
Figure 3.1 Total CO_2-e emissions from stationary energy combustion by fuel, 1990–2017 (preliminary estimates 2018)



Electricity generation emissions decreased by 5.0 Mt (2.6 per cent) from 2016 to 2017, and increased by 60.2 Mt (46.5 per cent) from 1990 to 2017 (Figure 3.2). The 2016 to 2017 electricity generation emissions decrease (2.6 per cent) was primarily due to a decrease in electricity generation. From 2016 to 2017 there was an increase in emissions from black coal of 2.7 percent, while emissions from gas decreased by 4.6 per cent and emissions from brown coal decreased by 10.5 percent.

The preliminary estimate for 2018 is 181.5 Mt an decrease of 4.4 per cent on 2017 levels.

Figure 3.2 CO_2-e emissions from electricity generation by fossil fuels, 1990–2017 (preliminary estimates 2018)



Emissions from *stationary energy* subsectors, other than *electricity generation*, increased by 3.0 Mt CO_2-e (3.3 per cent) between 2016 and 2017, and increased overall by 29.5 Mt (44.8 per cent) from 1990 to 2017. Emissions from the *manufacturing industries and construction* subsector decreased 1.1 per cent (0.4 Mt CO_2-e) between 2016 and 2017 and increased by 14.0 per cent (5.1 Mt CO_2-e) from 1990 to 2017.

3.1.2 Transport

In 2017, *transport* contributed 98.7 Mt CO_2-e or 18.6 per cent of Australia's net emissions (excluding *LULUCF*).

The major source of *transport* emissions in Australia is road transportation, which accounts for 84.5 per cent (83.4 Mt CO_2-e) of *transport* emissions. This outcome is principally driven by the importance of motor vehicles as modes of transportation of passengers and freight in Australia. Passenger cars account for 45.0 Mt CO_2-e and trucks (light and heavy) and buses 22.5 Mt CO_2-e. Other sources are far smaller: domestic aviation contributed 8.9 per cent (8.8 Mt CO_2-e), domestic navigation 2.0 per cent (1.9 Mt CO_2-e), railways 4.0 per cent (3.9 Mt CO_2-e), and pipeline transport 0.6 per cent (0.6 Mt CO_2-e).

Fuel used in *international transport (international aviation* and *marine 'bunkers')* is by international agreement reported separately from the national total net emissions. In 2017, international bunker fuels generated 15.4 Mt CO_2-e of emissions.

Trends

Transport emissions are one of the strongest source of emissions growth in Australia. Emissions from this sector were 60.8 per cent higher in 2017 than in 1990, and on average have increased by around 2.5 per cent annually (Figure 3.3). The preliminary estimate for 2018 is 101.0 Mt CO_2-e, a change of 2.3 per cent on 2017 levels.

Emissions from road transportation increased by 54.9 per cent (29.6 Mt CO_2-e) between 1990 and 2017 (Figure 3.4). Emissions from passenger cars increased by 29.3 per cent (10.2 Mt CO_2-e). Emissions from light commercial vehicles (LCVs) and heavy duty trucks and buses have also grown strongly (109.9 per cent and 97.2 per cent respectively). Emissions from pipeline transport grew very strongly between 1990 and 2017, increasing 136.7 per cent (0.4 Mt CO_2-e).

Figure 3.3 Total transport emissions, 1990–2017 (preliminary estimates 2018)

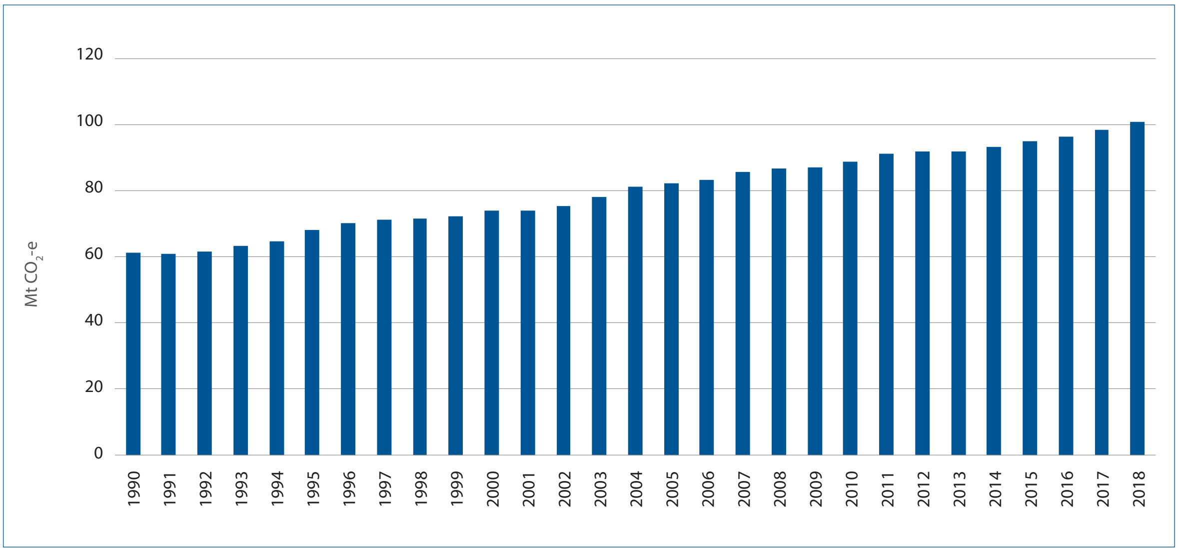
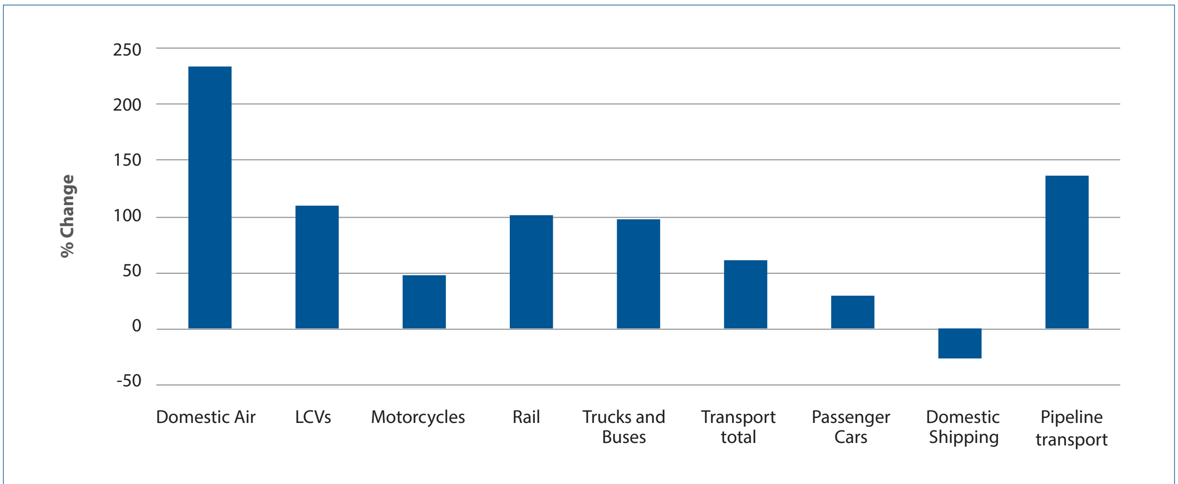


Figure 3.4 Comparison of growth in transport emissions by subcategory, 1990–2017



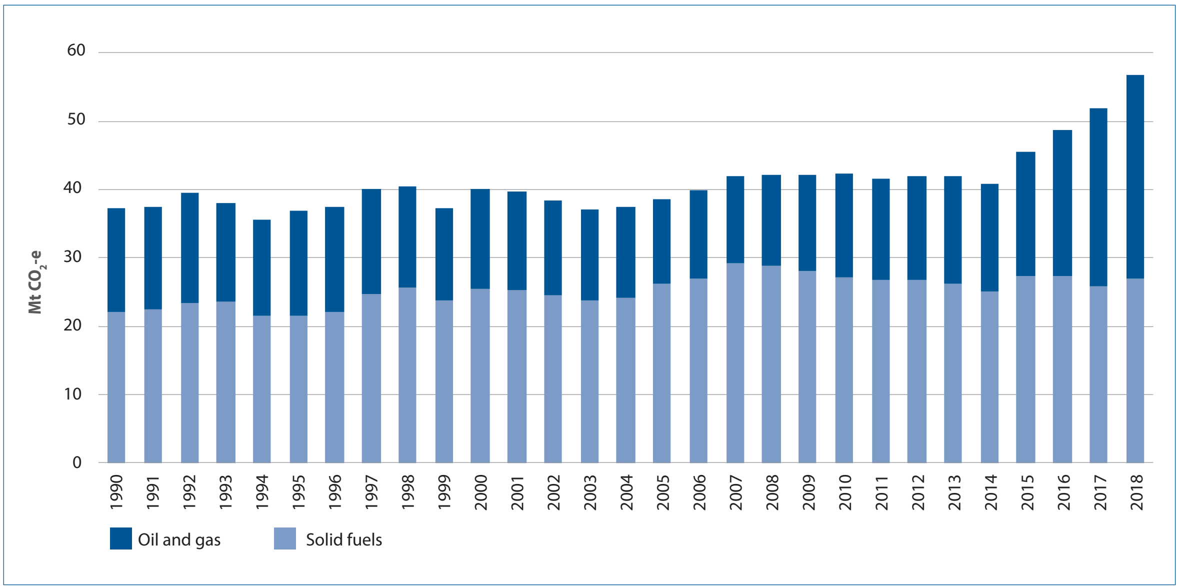
3.1.3 Fugitive emissions

Total estimated *fugitive emissions* for 2017 were 51.8 Mt CO_2-e, representing 9.4 per cent of net national emissions (excluding LULUCF). Net *solid fuel* emissions contributed 49.8 per cent (25.8 Mt CO_2-e) of *fugitive emissions*. *Oil and natural gas production, processing and distribution* account for the remaining 50.2 per cent (26.0 Mt CO_2-e) of *fugitive emissions*. The preliminary *fugitive* emissions estimate for 2018 is 56.8 Mt CO_2-e, an increase of 9.6 per cent on 2017 levels.

Trends

Overall *fugitive emissions* increased 39.2 per cent (14.6 Mt CO_2-e) between 1990 and 2017, and increased by 6.4 per cent (3.1 Mt CO_2-e) from 2016 to 2017 (Figure 3.5). From 1990 to 2017, *fugitive emissions* from *solid fuels* increased by 16.4 per cent (3.6 Mt CO_2-e) and *oil and natural gas* emissions increased by 72.9 per cent (11.0 Mt CO_2-e).

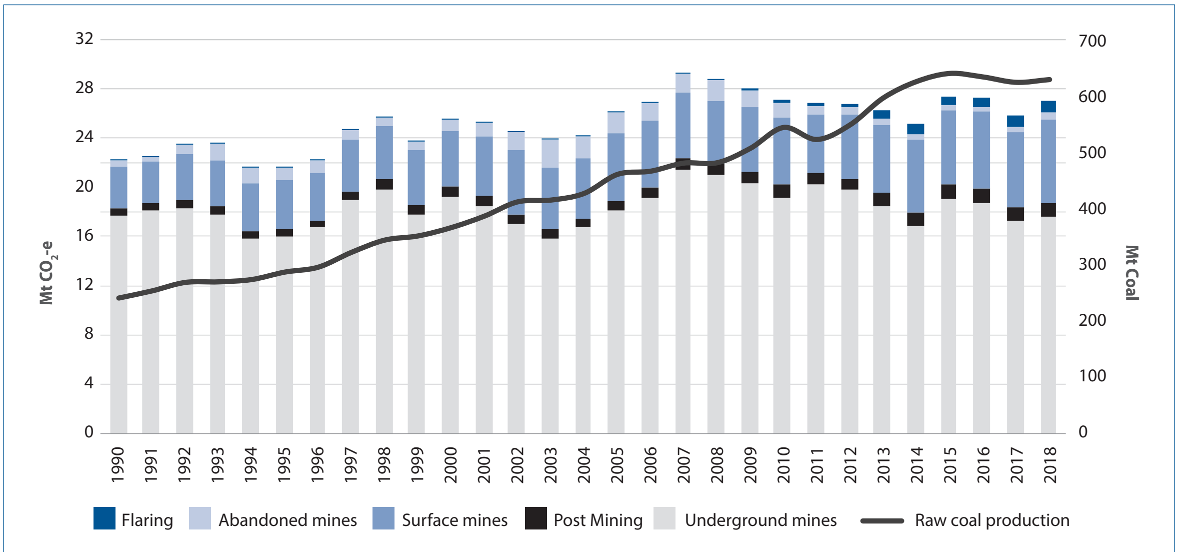
Figure 3.5 CO_2-e fugitive emissions by category, 1990–2017 (preliminary estimates 2018)



Fugitive emissions from solid fuels decreased by 5.5 per cent (1.5 Mt CO_2-e) between 2016 and 2017. Underground mine emissions decreased by 7.7 per cent (1.5 Mt CO_2-e). Emissions from surface mines decreased by 2.0 per cent (0.1 Mt CO_2-e) between 2016 and 2017. Emissions from decommissioned mines have increased 4.0 per cent (0.01 Mt CO_2-e) between 2016 and 2017, and emissions from flaring increased by 17.2 per cent (0.1 Mt CO_2-e).

Emissions tend to fluctuate from year to year depending on the volume of coal mined and the share of production from underground mines of varying gas contents. Mine production of coal has increased from 241.0 Mt in 1990 to 624.0 Mt in 2017, an increase of 159 per cent. Methane emissions have not grown as fast as activity principally because, since 1998, there has been an increasing trend in activity from surface mines compared to that of underground mines (Figure 3.6) and, within underground mines, a decreasing share of production from the gassiest southern coal field. In addition, the flaring of pre-drainage gas and technologies to recover and utilise coal mine waste gas for electricity generation have been increasingly adopted in underground mining, particularly in recent years.

Figure 3.6 Fugitive CO_2-e emissions from coal mining activities, 1990–2017 (preliminary estimates 2018)



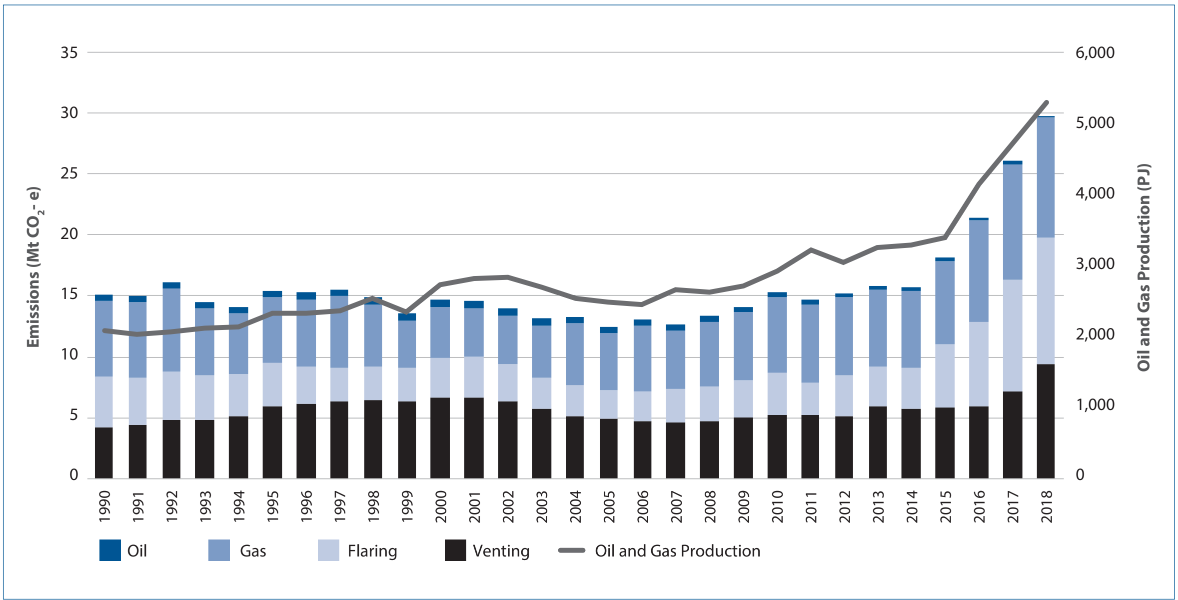
Energy

Oil and natural gas fugitive emissions increased 72.9 per cent (11.0 Mt CO_2-e) between 1990 and 2017 (Figure 3.7). This correlates with a 127.7 per cent increase in production during the same time period. The reduction in emissions intensity for this sector is the result, in particular, of improvements in gas distribution (a reduction of 36.7 per cent in emissions since 1990), large and efficient production, processing, and export facilities coming online (LNG), and an increase in recent years of the flaring to venting ratio (flaring being less emissions intensive per throughput unit as methane is combusted into the less potent greenhouse gas - carbon dioxide).

Between 1990 and 2017, leakage emissions from oil-related activities decreased 45.4 per cent (0.2 Mt CO_2-e) whereas leakage emissions from gas-related activities have increased 52.2 per cent (9.0 Mt CO_2-e). In 2017, leakage emissions from oil-related activities decreased 9.6 per cent (0.02 Mt CO_2-e) whereas leakage emissions from gas-related activities have increased 13.1 per cent (1.1 Mt CO_2-e). Much of the leakage emissions increase has occurred since 2000, with gas-related leakage emissions increasing 128.3 per cent (5.3 Mt CO_2-e) in 2017 when compared with 2000 levels.

Emissions from venting increased 20.6 per cent (1.3 Mt CO_2-e) in 2017 when compared with 2016, and increased 70.6 per cent (6.7 Mt CO_2-e) compared with 1990. Flaring emissions increased 33.0 per cent (2.3 Mt CO_2-e) in 2017 when compared with 2016, and increased 119.8 per cent (5.0 Mt CO_2-e) since 1990.

Figure 3.7 Fugitive CO_2-e emissions from oil and gas production, 1990–2017 (preliminary estimates 2018)



3.2 Overview of source category description and methodology – energy

The *energy* sector includes emissions from the combustion of fossil fuels (1.A.1 *energy industries*; 1.A.2 *manufacturing industries and construction*; 1.A.3 *transport;* 1.A.4 *other sectors*; and 1.A.5 *'other'*) as well as *fugitive emissions from the extraction of fossil fuels* (1.B).

The combustion of solid, liquid and gaseous fuels for energy use has been identified as key sources in Australia's inventory.

The methodology for estimating emissions from fossil fuel combustion in the *stationary energy* sectors is consistent with the IPCC tier 2 approach. Tier 2 methods may be regarded as those dividing fuel consumption on the basis of sample or engineering knowledge between technology types which are sufficiently homogenous to permit the use of representative EFs. Emissions for the *transport* sector have been estimated with a mix of tier 1, tier 2, and tier 3 approaches.

The *Department of the Environment and Energy* compiles the *Australian Energy Statistics* (AES; DoEE 2018) which estimates Australian energy consumption by fuel and economic sector for the purpose of meeting Australia's reporting commitments to the International Energy Agency. National Greenhouse and Energy Reporting System (NGER) data has been adopted as the main energy consumption data source for the AES. Previously, the construction of DIIS historical energy statistics were based on the voluntary *Fuel and Electricity Survey* (FES). With the introduction of the NGER, survey year 2008–09 became the final year that the FES was conducted. For survey year 2009–10 and onwards, NGER data has been used as the primary source of energy consumption data.

The AES provides a comprehensive and detailed 'bottom-up' quantification of energy use in Australia. To ensure internal consistency and completeness, the data are reconciled with 'top-down' statistics on the supply and use of all major fuels in Australia collected from the suppliers of those fuels, i.e. the coal, oil, gas and electricity industries.

3.2.1 CO_2 emissions and emission factors

In general, the estimate of emissions of CO_2 used for each fuel, *k*, in each economic sector, *h*, is estimated by:

$$E_{hk} = (F_{hk} \cdot EF_{hk} \cdot P_{hk}/100) - S_{hk} \cdot 44/12 \qquad (3.1)$$

Where E_{hk} is the amount of CO_2 emitted from fuel k in economic sector h (in Gg);

F_{hk} = the amount of fuel k combusted in sector h (in PJ);

EF_{hk} = the CO_2 Emission factor (EF) (in Gg CO_2/PJ) for fuel k;

P_k = the oxidation factor (in per cent) of fuel k; and

S_{hk} = the amount of carbon sourced from fuel k which is stored in sector h (in Gg).

Emission factors (EF) for CO_2 depend only on the chemical composition of the fossil fuel concerned under IPCC methods. For fuels having well defined and/or stable chemical composition, CO_2 EFs can be specified with considerable accuracy. This is particularly the case for natural gas and for petroleum products, with the exception of fuel oil, which may vary considerably in composition, and to a lesser degree for coals, which can vary in their composition of both combustible components (carbon, volatiles) and non-combustible components (ash, moisture).

Solid fuels

Coal

Approximately 90 per cent of all coal consumed in Australia is used by the electricity generation industry. Under NGER all electricity generators who consume coal as their primary fuel must sample and analyse their coal and report their facility specific CO_2 EF. The reported EFs are illustrated in Figure 3.8. After the electricity industry, the largest user of coal in Australia is the steel industry. The steel industry has provided a representative CO_2 EF of 91.8 Gg/PJ for black coal used in iron/steel/coke production (L. Leung, BHP 2001, pers. comm.). This figure has been further verified by industry data obtained from NGER as being representative. For black coal used in other industries, a representative CO_2 EF of 90.0 Gg/PJ has been derived from NGER data. All EFs are reported in Table 3.2.

A brown coal CO_2 EF of 93.5 Gg/PJ is applied to combustion other than electricity generation. The EF has been derived from facility data obtained from brown coal electricity generators reporting under NGER. The CO_2 EF of 95.0 Gg/PJ for brown coal briquette has also been derived from NGER data.

Coke

The CO_2 EF for coke is derived from a carbon balance conducted on the coke oven subsector. Carbon input into coke ovens is estimated and balanced against carbon contained in the fuel and product outputs from coke ovens. The carbon content of coke is determined as the carbon content required to achieve a carbon balance for the overall coke oven process. The resulting coke EF varies slightly from year to year depending on the balance of inputs and outputs, in a range between 105.6 and 108.9 Gg/PJ which is comparable to the IPCC default factor (Table 3.A.22). The underlying data used to estimate the coke EF is confidential due to the sector being characterised by a limited number of producers.

Coal By-Products

Coal by-product fuels are defined as coke oven gas, coal tar and liquefied aromatic hydrocarbons. They are produced largely as a by-product of coke oven processes, however liquefied aromatic hydrocarbons can also be produced from petroleum refining. An EF of 37 Gg/PJ has been assigned to coke oven gas following advice from the steel industry (Deslandes and Kingston 1997). The steel industry has also advised a representative EF for coal tar of 81.8 Gg/PJ. Liquefied aromatic hydrocarbons consist of compounds such as benzenes, toluene and xylene. Because of their similarities with naphtha and solvents, the same EF of 69.7 Gg/PJ was assigned to these products.

Liquid fuels

Refined Petroleum Products

Energy

Australian oil tends to be of the light crude variety and the petroleum products generated by Australian refineries reflect the characteristics of these supplies. The country-specific EFs for marketable petroleum products for this inventory are taken from GHD Australia (GHD 2006a), which reports the results of a review of Australian petroleum products. EFs are listed in Table 3.2. The EFs for petroleum fuels were further validated as being representative in a more recent review of Australia's liquid fuels characteristics conducted by Orbital Australia (Orbital 2011a). The Orbital review also confirmed the representativeness of the EF for fuel oil which was obtained from large industrial users of fuel oil (J. Le Cornu, pers. comm. 1996, J. Bawdin, pers. comm. 1996).

Other Petroleum Products

In the AES sectors, Basic Chemicals (ANZSIC Subdivisions 17-19), Oil and Gas Mining (ANZSIC Subdivision 07) and Basic Non-Ferrous Metals (ANZSIC Group 213-14) (after excluding petroleum coke from the latter sector), petroleum products not elsewhere classified (nec) consists largely of naphtha. The EF for naphtha of 69.8 Gg CO_2/PJ, (IPCC 2006), was therefore used in these sectors. For all other AES sectors in which petroleum products nec appears as a fuel type, an EF of 69.8 Gg CO_2/PJ is used based on IPCC 2006 default for Refinery Feedstocks and Other Petroleum Products.

Petroleum refining consumes refinery gas/liquids and refinery coke in the process of converting raw crude oil to refined products. EFs of 54.7 Gg CO_2/PJ (refinery gas and liquids) and 92.6 Gg CO_2/PJ (refinery coke) have been adopted from the 2006 *Guidelines* (IPCC 2006). Recycled tyres are combusted for energy within Cement, Lime, Plaster and Concrete (ANZSIC Group 203). An EF of 81.6 Gg CO_2/PJ was sourced from the US Energy Information Administration (GHD 2006b).

Solvents and Bitumen

Australian information on CO_2 EFs for these products is not available. The factor for solvents (69.7 Gg/PJ) and bitumen (80.7 Gg/PJ) are based on the IPCC *Guidelines* (2006).

Gaseous fuels

Natural Gas

A national EF has been estimated for natural gas using data on the composition of natural gas in each pipeline system, as published by the Australian Gas Association (various years), weighted by the volumes of gas consumed from each pipeline system (see Table 3.2).

The CO_2 EF for natural gas varies slightly between States, depending on the composition of the gas supplied to energy users in the State, which in turn depends on the characteristics of natural gas in the fields from which supply is sourced. In these circumstances, use of a single national weighted average EF for all natural gas will not introduce errors at the level of aggregate national energy sector emissions. All emission estimates for natural gas are therefore based on national consumption data and national EFs, except for gas used for electricity generation. Under NGER all electricity generators, that use gaseous fuels as their primary fuel, are required to sample and analyse their natural gas or coal seam methane and report their facility specific EF. The reported EFs are illustrated in Figure 3.8. For small electricity generators who do not meet the reporting thresholds of NGER the national CO_2 EF for natural gas is used.

An additional adjustment is made for natural gas activity data reported in the AES as used by the chemical industry because this includes both natural gas and the separate ethane supply that is used as feedstock. The ethane CO_2 EF used for the inventory was derived based on data within the *ASHRAE Handbook Fundamentals* (2001) and is 56.5 Gg CO_2/PJ. Ethane is the main source of feedstock and fuel supply for the petrochemical industry in Victoria, which is the location for a large proportion of the Australian petrochemical industry.

Town Gas

Town gas is a minor source of emissions and is given the same EF as LPG. It is assumed that in the manufacture of town gas, both carbon content and energy content is reduced in the same proportion, meaning that the carbon EF is unchanged.

Biomass fuels

Emissions of CO_2 from biomass fuels are not included in the national inventory but are required to be reported as a Memo item. The CO_2 EFs for bagasse and wood/woodwaste combusted in commercial and residential sectors are listed in Table 3.2. A detailed explanation of residential wood heater EFs is provided in section 3.6. Factors for bagasse (95.0 Gg/PJ) and ethanol (67.3 Gg/PJ) are based on IPCC 2006.

Table 3.2 Emission factors for CO_2 2017

Fuel Type	Fuel	CO_2 emission factor (Gg CO_2/PJ)
Coal derived fuels	Coal used in public electricity generation [a]	85.6 - 95.9
	Coal used in steel industry [l,a]	91.8
	Black coal used by other industry [a]	90.0
	Brown coal used by industry [a]	93.5
	Coke [m]	108.6
	Coal by-products (coke oven gas) [b]	37.0
	Coal by-products (coal tar) [b]	81.8
	Coal by-products (liquefied aromatic hydrocarbons [e]	69.7
	Brown coal briquettes [a]	95.0

Fuel Type	Fuel	CO_2 emission factor (Gg CO_2/PJ)
Petroleum fuels	LPG (c)	60.2
	Naphtha (e)	69.8
	Automotive gasoline (c)	67.4
	Aviation gasoline (c)	67.0
	Lighting Kerosene (c)	68.9
	Aviation turbine fuel (c)	69.6
	Power Kerosene (c)	68.9
	Heating oil (c)	69.5
	ADO (c)	69.9
	IDF (c)	69.9
	Petroleum products nec (e)	69.8
	Refinery gas and liquids (e)	54.7
	Refinery coke (e)	92.6
	Fuel oil (n)	73.6
	Tyres (k)	81.6
	Solvents (e)	69.7
	Bitumen (e)	80.7
Gases	Natural gas (including coal seam gas) (f)	51.4
	Natural gas (Basic chemicals sector) (f)	51.4
	Ethane (g)	56.5
	Town gas (c)	60.2
Biomass fuels	Wood and wood waste (h)	94.0
	Wood (For Residential subsector) (i)	77.5
	Ethanol (e)	67.3
	Bagasse (e)	95.0

Source: (a) NGER. (b) Deslandes and Kingston 1997. (c) GHD 2006a. (e) IPCC 2006. (f) AGA 2001. (g) ASHRAE 2001.(h) Todd 1993. (i) Todd 2011. (k) GHD 2006b. (l) L.Leung BHP 2001. (m) Derived from carbon balance within coke oven/iron and steel subsectors(n) Industry data confirmed by Orbital 2011a.

Note: All EFs expressed in terms of energy measured as gross calorific equivalents (GCV).

Oxidation Factors for CO2

The oxidation factor is defined as the proportion of carbon contained in a fuel which is oxidised to CO_2. Oxidation factors for fuels used in stationary energy are set at 1 with the exception of the special cases outlined below. An oxidation factor of 1 is consistent with the IPCC 2006 assumption of complete oxidation of carbon contained in fuel.

The IPCC 2006 Guidelines also recommends that where the fraction of non oxidised carbon is known, ie in facility-specific EFs or higher tier methods, then it is good practice to apply those oxidation factors. Data is available for Australia to adopt this approach for stationary energy EFs in the following circumstances:

1.A.1.a Electricity generation – coal fuels: – electricity generators are required to report facility-specific CO_2 EFs for primary fuels using sampling and analysis of their fuel inputs under the NGER Scheme. Coal generators may sample and analyse their carbon in fly ash and furnace ash to determine a facility-specific oxidation factor which is incorporated into their reported emission factor. A detailed discussion on CO_2 EFs used in electricity generation is found at section 3.3.2.

1.A.4.b Residential – Biomass Combustion: – the CO_2 and non CO_2 EFs for residential wood combustion are calculated using a detailed tier 2/3 model based on a large database of emission data and equipment types. The model accounts for all carbon in the fuel as combustion emissions or solid products of incomplete combustion in the form of ash and particulates. A detailed description of the residential biomass combustion method is found at section 3.6.2.

3.2.2 Non-CO_2 emissions

In addition to emissions of CO_2, the combustion of fuel in stationary source results in the emission of CH_4, N_2O, NO_x, CO, and NMVOCs. Of these, CH_4 and N_2O account for around 1 per cent of emissions, on a CO_2-e basis, in this sector. The magnitude of these emissions is dependent on a large number of factors, including fuel type, equipment design, and emission control technology. It is, therefore, inherently more complex and more uncertain than estimates of CO_2 emissions.

For non-CO_2 gases, emissions are estimated by:

$$E_{hkl} = F_{hk} \cdot E_{fhkl} \quad (3.2)$$

Where E_{hkl} = amount greenhouse gas l emitted from combustion of fuel type k, in economic sector h (in Gg);

F_{hk} = amount of fuel type k combusted in sector h (in PJ);

E_{fhkl} = technology weighted EF (in Gg/PJ) for greenhouse gas l, from fuel type k in sector h.

The characteristics of the capital stock are an important determinant of the non-CO_2 emissions generated. The characteristics of the capital stock are an important determinant of the non-CO_2 emissions generated by the combustion of fossil fuels. Consequently, EFs for non-CO_2 are capital–and technology-specific and require capital specific information to be collected, including equipment type, technology, and, in some cases, the age of capital.

The non-CO_2 factors are updated according to the IPCC 2006 and US EPA 2005b default values for uncontrolled emissions from various source categories, corrected for control technologies in use in Australia. In Australia, emissions from stationary fuel combustion source are controlled to varying degrees. The EFs for non-CO_2 greenhouse gases for each sector are summarised in Table 3.A.1. These derived EFs use weightings calculated according to the equipment type shares to reflect the mix of equipment types, including both stationary and mobile equipment, in use for those sectors. In absence of evidence to differentiate gas variations in measured gas concentrations between boilers, differences cannot be attributed either to differences in boiler type – e.g. tangentially-fired, boiler size, boiler load, or combustion modifications – e.g. low NO_X burners, it is assumed that the gas EFs are dependent on fuel type only.

For certain fuel types, due to absence and unavailability of data, industrial default emission factors for stationary combustion are applied to all non-CO_2 gases according to the IPCC 2006 guidelines and US EPA 2005b.

For the other economic sectors not covered by the above analysis fuel use by equipment type and EFs for equipment types were estimated with a range of assumptions. For ANZSIC class Division A (Agriculture, Forestry, Fishing), it was assumed that all diesel is used in mobile equipment. It is assumed that the small quantities of other fossil fuels consumed in Division A are used in the agricultural industry, in miscellaneous small combustion equipment. For Division E (Construction), mobile equipment EFs are used. For Other Transport Services and Storage, 50-53, it was assumed that consumption of gaseous fuels occurs in gas turbines (used to power compressors in gas transmission and distribution systems) and all consumption of liquid fuels occurs in mobile equipment.

In ANZSIC subdivision 26, Electricity generation, data is available on the relevant equipment data for each power station.

3.2.3 SO_2 emissions

Data on EFs was obtained from the following sources:

- Petroleum products: Australian Institute of Petroleum and the National Pollutant Inventory (Department of the Environment and Energy);
- Natural gas and LPG: Australian Gas Association;
- Coal (default values): the former Australian Government Department of Primary Industries and Energy; and
- Electricity industry: specific SO_2 emission data have previously been obtained from power station operators. If historical data is not available defaults are used as listed in Table 3.3. For other sectors, the EFs are derived from data from the Australian Institute for Petroleum, the Australian Gas Association and the Australian Government Department of Energy.

In some cases, data for SO_2 emissions are available directly from reporting by certain facilities under the National Pollutant Inventory. For selected major fuel types, SO_2 emissions are entered directly for those facilities.

Table 3.3 SO_2 emission factors

Fuel	SO_2 emission factors (Gg SO_2/PJ)
Black coal	0.37
Brown coal	0.15
LPG	0.002
Aviation gasoline	0.008
Kerosene	0.057
Heating oil	0.057
ADO	0.057
IDF	0.057
Fuel oil	1.282
Natural gas	0.002

Source: Australian Institute for Petroleum (pers. comm. 1996), National Pollutant Inventory (petroleum refining, DE 1998-2012), Department of Primary Industries and Energy (pers. comm. 1998) (for default coal values) and Annual Gas Industry Statistics (AGA 1988-1994).

For both CO_2 and non-CO_2 gases, total national emissions are calculated by summing the estimated emissions from each fuel in each sector across all fuels and across all sectors.

3.2.4 Activity data

The Australian Energy Statistics (AES, DoEE 2017) of energy use by economic sector and fuel has been compiled since the 1970s. The Department of Environment and Energy has complied the Australian Energy Statistics. This has historically also been compiled by the Office of the Chief Economist of the Department of Industry, Innovation and Science (DIIS) (formerly known as the Bureau of Resource and Energy Economics (BREE), and Department of Industry and Science (DIS), and predecessor organisations.

The statistics provide a comprehensive and detailed 'bottom-up' quantification of energy use in Australia. They are reconciled with 'top-down' statistics of all major fuels in Australia, collected from the suppliers of those fuels, i.e. the coal, oil, gas and electricity industries. These statistics have been historically compiled from an annual fuel and electricity survey supplemented by a variety of other sources of information.

The latest annual update of the Australian Energy Statistics has continued to progressively utilise data collected under NGER as the primary source of energy consumption data. NGER reporting is compulsory for facilities over specified energy and emissions thresholds and provides greater coverage than was previously available from the previous voluntary Fuel and Electricity Survey. Revisions were made by to the to further incorporate NGER data into the time series where appropriate which has resulted in some changes in fuel use in certain subsectors for some years.

Additional work is being considered in future releases of the Australian Energy Statistics to extend the revision associated with NGER data back further through the time series. Those recalculated time series will be incorporated in the inventory when available.

The Department has supplemented NGER data with information from other Australian Government agencies, state-based agencies and industry associations. As in the past, in sectors with low or no NGER coverage (commercial and services, agriculture and residential), energy consumption was estimated using the energy balance process and other estimation techniques. The Australian Energy Statistics provides a comprehensive and detailed 'bottom-up' quantification of energy use in Australia. To ensure internal consistency and completeness, the data are reconciled with 'top-down' statistics on the supply and use of all major fuels in Australia collected from the suppliers of those fuels, i.e. the coal, oil, gas and electricity industries.

The data is presented in common energy units (PJ) on an individual State basis. Historically, the Australian Energy Statistics has also collected statistics of energy use by equipment (technology) type. These have been used to compile the technology weighted sectoral EFs for non-CO_2 greenhouse gases.

Several re-allocations to the Australian Energy Statistics statistics are required in order to:

- break down energy consumption into sub-sectors where this is required to match Common Reporting Format (CRF) table categories;
- identify and allow for stored carbon;
- separate coke production from other parts of the iron and steel industry;
- eliminate double counting of gas leakage from the gas distribution system; and
- allocate fuel use to the industrial process sector for the estimation of emissions from the use of fuels as reductants.

The Australian Energy Statistics undertakes reconciliation at the level of the supply and use of energy in the economy at the level of energy units. The Australian Energy Statistics analysis ensures that all energy entering the economy is accounted for by end-uses.

Activity data for the time series 1990 to 2017, reported by category level and fuel type, are available on the AGEIS website: http://ageis.climatechange.gov.au/QueryAppendixTable.aspx

3.2.5 Feedstock and non-energy fuel use

Activity data and emissions associated with the non-energy use of fuels are not reported within the fuel combustion subsector. In accordance with the 2006 IPCC *Guidelines*, they are reported under the *industrial processes and product use* sector and *fugitive emissions from fuels* sub-sector as follows.

- Reported in *industrial processes and product use:*
- Coke and natural gas where used as a reductant in the integrated coke/iron and steel production – reported in 2.C.1 Iron and Steel Production;
- Pulverised black coal where used as a reductant in the integrated coke/iron and steel production – reported in 2.C.1 Iron and Steel Production;

- Black coal where used as a reductant in synthetic rutile production – reported in 2.B.6 Chemical Industry – Titanium Dioxide Production;
- Black coal, coke, petroleum coke and fuel oil where used as a reductant in base metal production – reported in 2.C.2 Ferroalloys Production and 2.C.7 Other;
- Petroleum coke where used as a reductant in titanium dioxide production – reported in 2.B.6 Chemical Industry – Titanium Dioxide Production;
- Petroleum coke, coal tar and coke used for anodes in aluminium production – reported in 2.C.3 Aluminium Production;
- Natural gas used in Ammonia production – reported in 2.B.1 Ammonia Production;
- Coke where used as a reductant in soda ash production – reported with other emissions from soda ash production in 2.B.7 Soda Ash Production.; and
- Lubricants and grease consumption where used for non-energy purposes– reported in 2.D.1.
  - Reported in *fugitive emissions from fuels*
- Oil refinery flaring – reported in 1.B.2.a. Oil Refining/Storage; and
- Natural gas leakage – reported in 1.B.2.b Natural Gas Distribution.

3.2.6 QA/QC

Energy

The carbon balance

A carbon balance for all years was undertaken in terms of the supply and use of carbon from fuels in the economy. All carbon entering the economy is accounted for—either as emissions from fuel combustion, emissions from the use of fossil fuels as reductants, non-energy uses, use of biomass source of energy and international bunkers. While the predominant outcome of carbon entering the economy is emissions, a small portion of the total is stored in carbon-containing products or non-oxidised as ash.

Tables detailing the results of the carbon balance can be found in Annex 6.

Comparison with international data

IEFs for all major fuels are tested for differences against the mean of the population of all other available Annex I data. For each major fuel, the t-tests conducted show that the implied CO_2 EFs for Australian fuels are not significantly different to the mean of the implied EFs for the Annex I population.

The Australian Energy Statistics is the common source of energy data for the preparation of the national inventory, as well asfor Australia's report to the International Energy Agency (IEA). Some differences occur from year to year between the activity data in the inventory CRF tables, and those data published by the IEA. A project has been undertaken to reconcile the data provided to the IEA with the published Australian Energy Statistics data used in the inventory.

The Department has found that the data reported to the IEA by the DIIS, the Australian Government department previously responsible for publishing the *Australian Energy Statistics*, is consistent with the data published in the *Australian Energy Statistics* (in petajoules units).

The investigation found the following reasons for differences between data reported by Australia in the CRF tables and data published by the IEA:

- The energy conversion used by the IEA is a significant cause of the differences, and that data provided to the IEA has been processed by methods outside of the control of Australia; and
- Coal production data reported in the CRF table are significantly higher (around 13-25 per cent) than those reported to the IEA. The reason for this difference is that the coal production reported to the IEA only comprises black coal production and does not include brown (lignite) coal production. The IEA data does correspond with coal production reported in Australia's CRF table when brown coal production is included.

During July 2014 the IEA conducted a Statistics Mission to Australia. Officers of the Department of the Environment responsible for compiling the National Inventory Report had the opportunity to raise with the IEA the issue of differences between data reported by Australia in the CRF tables and data published by the IEA. The IEA observed that at the higher level, the CRF fuel consumption was generally in good agreement with the IEA. A better understanding as to why differences exist between the IEA/CRF tables for petroleum fuels was established; Australia submits petroleum data on the 5th of each month to the IEA, whereas the CRF tables are based on Australia's official energy statistics which represent the financial year (ie July 2013 to June 2014). Therefore the potential exists for differences due to accounting period inconsistencies and revisions to data published annually in the AES.

3.3 Source Category 1.A.1 Energy industries

3.3.1 Source category description

This category includes emissions from fuel combustion within electricity generation, petroleum refining and other energy manufacturing industries such as coke ovens, briquette production, coal mining, oil and gas extraction, and natural gas production and distribution. The Australian Energy Statistics reports energy consumption for economic sectors defined using the Australia New Zealand Standard Industrial Classification (ANZSIC) developed by Australia's national statistical agency, the Australian Bureau of Statistics. The mapping of data to IPCC classifications from the ANZSIC codes is complete and reported in Table 3.4.

Table 3.4 Relationship between IPCC source categories and ANZSIC sectors: Energy Industries

IPCC Source Category	ANZSIC Subdivision		
	Division	Sub-division	Description
1.A.1 Energy Industries			
a Electricity and heat production [(a)]	D Electricity, Gas and Waste Services	26	Electricity supply
b Petroleum refining	C Manufacturing	1701	Petroleum refining
c Solid fuel transformation and other energy industries	B Mining and C Manufacturing		Coal mining (incl. briquette production)
	B Mining		Oil and gas extraction (incl. gas processing and LNG production)
	C Manufacturing	21	Coke ovens associated with Basic iron and steel manufacturing
	D Electricity, Gas and Waste Services	27	Gas supply

Note: (a) There is no public generation of distributed heat in Australia.

3.3.2 Methodology

In summary, emissions for the *energy industries* category are estimated using tier 2 approaches and country specific factors (Table 3.5).

Table 3.5 Summary of methods and emission factors: Energy Industries

Categories	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A1a Public electricity	T2	PS, CS	T2	CS	T2	CS
1A1b Petroleum refining	T2	CS, PS	T2	CS	T2	CS
1A1c Manufacture of Solid Fuels	T2	CS	T2	CS	T2	CS

Notes: T1 = tier 1. T2 = tier 2. T3 = tier 3. CS= Country-specific. D= IPCC default, PS = Plant Specific.

Electricity Generation (ANZSIC Subdivision 26) (1.A.1.a)

Electricity generation includes power for supply to the grid (whether the power stations are owned by public or private corporations). Public heat production does not occur in Australia.

Choice of emission factors

A tier 2 approach is used for the key category of electricity generation in which EFs for fuels such as coal vary from source to source and over time. The fundamental reporting unit in this sector is the individual power station. Data is collected from power stations through the NGER. Under the NGER, facilities over certain thresholds are required to submit annual data on fuel consumption, fuel energy content, fuel EFs (incorporating oxidation factors), emission estimates and the amount of electricity generated and sent out to the Clean Energy Regulator. Power stations must sample and analyse their primary solid and gaseous fuels in accordance with the requirements and standards listed in the *National Greenhouse and Energy Reporting (Measurement) Determination 1998* (Cwlth). The adoption of these methods and standards ensures accuracy and comparability in the facility specific information reported. This data provides facility specific energy content and EFs for the solid and gaseous fuels consumed in each power station.

When the NGER was established the methods to be used by power stations were aligned with those that applied under the Generator Efficiency Standards program – as detailed in the *Generator Efficiency Standards Technical Guidelines* (AGO 2006a). The Generator Efficiency Standards program had been in place in Australia since 2000 and data collected under this program has been utilised in the national inventory throughout the time series. The adoption of consistent methods in the NGER and the Generator Efficiency Standards program ensured time series consistency in the emission estimates in the national inventory.

Country-specific EFs are utilised for minor (mainly liquid) fuels.

Activity data

NGER data is received from all large and medium sized power stations in Australia. There are around 140 such fossil fuel based power stations in Australia at present. NGER data has resulted in a significant increase in the number of power stations where facility level data is available (increasing from 50-60 to around 140). The energy use of the small power stations, that do not meet the NGER reporting thresholds, are estimated as the difference between the total of reported values under NGER and Australian Energy Statistics for ANZSIC subdivision 26. This approach has been adopted throughout the time series. Therefore the improved coverage of power stations under NGER does not alter the method for estimating total fuel consumption in this sector. The coverage of individual coal power station NGER data is comprehensive and has displaced the necessity to use AES data to inform coal activity data.

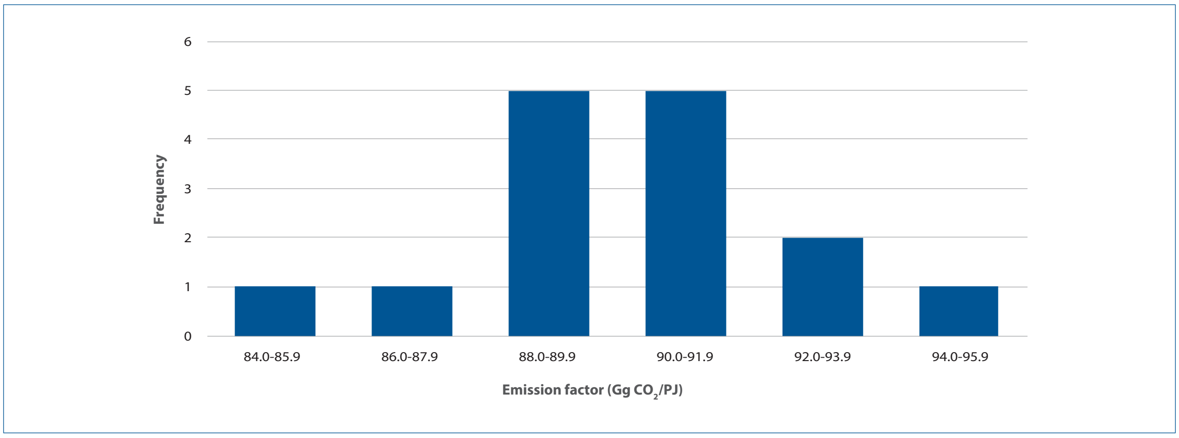
Research conducted by BREE on regional and remote electricity generation in Australia (BREE 2013b) was used in 2013 to validate or update the fuel consumption totals estimated in the *Australian Energy Statistics*. This research surveyed off-grid electricity generated and consumed outside of the major electricity grids of Australia, including the smaller grid systems of the Pilbara, Darwin to Katherine and the Mt Isa areas. The fuels covered in the survey are natural gas, diesel oil and fuel oil.

Under the NGER, oxidation factors and the emissions factors are linked in that coal power station operators report CO_2 EFs including the effects of oxidation based on analysis of ash contents and in accordance with *NGER Measurement Determination 2008* (Cwlth). In such cases applying an additional oxidation factor would double-count the effect of incomplete combustion, so an oxidation factor of 100 per cent is used. The *NGER Measurement Determination 2008* requires emission factors reported by generators to use a default oxidation factor of 100 per cent unless measurements are undertaken to support an alternative value. Figure 3.8 shows the distribution of emission factors reported by electricity generators for major fuel types.

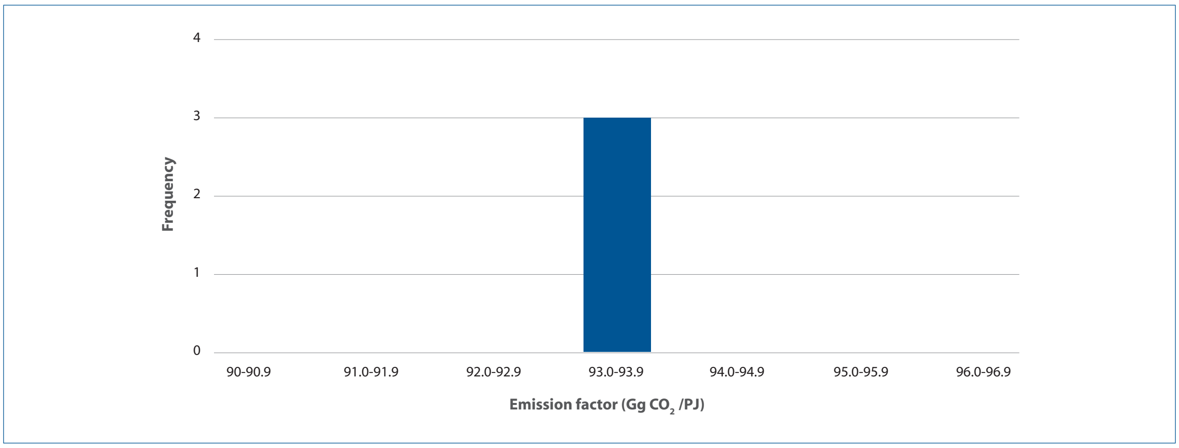
CH_4 and N_2O emissions from landfill gas captured for combustion for electricity generation are reported in this subsector and CO_2 emissions are reported as a memo item.

Figure 3.8 Emission factors for CO_2 in electricity generation, Australia, 2017

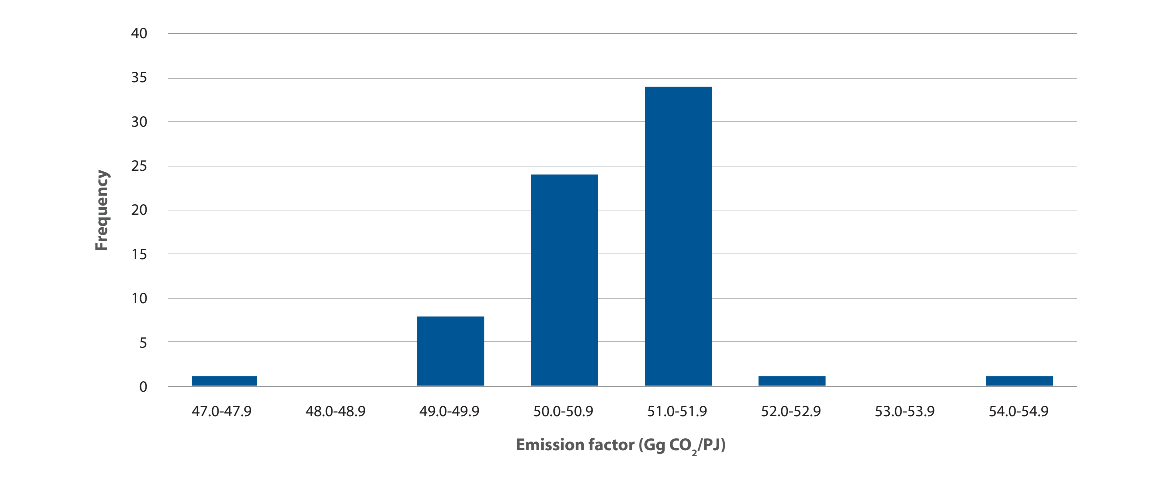
(a) Black Coal power stations



(b) Brown Coal power stations



(c) Natural gas and waste gas power stations



Source: NGER.
Notes: Values incorporate the effect of partial oxidation of fuels.

Petroleum refining (ANZSIC Class 1701) (1.A.1.b)

The main fuels used by petroleum refineries are refinery gas/liquids and natural gas along with some minor use of other liquids fuels. The combustion of refinery coke is also included under Petroleum Refining 1.A.1.b. The *Australian Energy Statistics* reports refinery feedstock, i.e. essentially crude oil, as the major input, together with other undefined petroleum products. The various market petroleum products are shown as energy outputs. The total energy content of the products produced by the sector is less than the energy content of the petroleum input, with the difference being energy consumed by the refining processes (distillation, cracking etc.). The fuel from which this energy is derived is obtained from the crude oil input and is referred to as refinery fuel.

Choice of emission factor

NGER data made available facility-specific EFs for the fuels; refinery gas and liquids, refinery coke and natural gas from several of the petroleum refineries. A decision to utilise these factors for the relevant refineries while maintaining the default factors for the remainder, was made in consultation with the decision tree in section 1.4.1. In doing so, it was recognised that refinery EFs for these fuel types are strongly linked with the specific technology types and process configurations inherent in individual refineries.

Activity data

The refinery fuel balance contained in the AES is analysed using a model that examines the expected refinery plant efficiency in the conversion of crude oil to final products, taking into account factors such as the change to low sulphur diesel. The model is used to derive refinery fuel consumption for the years 2000 to 2008. This is in response to QC analysis demonstrating that the AES petroleum refining data does not provide representative activity data using an input/output balance method for that period.

Detailed fuel consumption data was made available via the NGER for all Australian oil refineries from 2009 to 2016. In particular, NGER data provides details on the refinery fuel use, enabling a split between the combustion of refinery gas/liquids and the burning of refinery coke to restore the activity of the catalyst during the refining process. Given that this component of petroleum refining emissions has previously been included within total refinery fuel combustion, it was decided to continue with this practice for this submission in order to maintain time series consistency. This remains consistent with practice followed by most other countries and the 2006 IPCC *Guidelines* are unclear as to where emissions from this source should be reported. For transparency purposes, these emissions from refinery coke have also been noted in the Fugitives – petroleum refining section of this Report. Refinery flaring is accounted for in the *Fugitive Fuel Emissions* sector.

Manufacture of Solid Fuels and Other Energy industries (1.A.1.c)

The manufacturing of solid fuels and other energy industries sector, 1.A.1c, comprises six ANZSIC sectors:

- Coke Oven Operation (ANZSIC Subdivision 21);
- Briquetting (ANZSIC Subdivision 17);
- Coal Mining (ANZSIC Division B);
- Oil and Gas Extraction (ANZSIC Division B);
- Other Transport Services and Storage, assumed to be gas pipeline transport (ANZSIC Subdivision 50-53); and
- Gas Supply (ANZSIC Subdivision 27).

Estimated emissions are derived from equations 3.1 and 3.2 and the EFs reported in Tables 3.2 and 3.3 and Table 3.A.1.

The *Coke Oven Operation (ANZSIC* Subdivision 21*)* sub-sector is effectively a subsidiary activity of the iron and steel industry but is classified by the IPCC as an energy transformation industry and hence is reported separately. This sub-sector is both a consumer of black coal and coal by-products and a producer of coke and coal by-products. Consequently, fuel combustion is calculated by deducting derived fuels produced by the sector from energy inputs. Following a recommendation by the UNFCCC ERT in 2015, additional information has been provided to improve the transparency of activity data for the black coal/coke oven gas fuel mix consumed in 1.A.1.c Manufacture of Solid Fuels and Other Energy Industries sector. The percentage of black coal/coke oven gas fuel mix is shown in Table 3.6.

Table 3.6 Percentage of black coal and coke oven gas fuel mix in 1.A.1.c

Years	per cent of coal	per cent of coke oven gas
1990	86	14
2000	72	28
2005	66	34
2006	81	19
2007	82	18
2008	82	18
2009	79	21
2010	82	18
2011	82	18
2012	81	19
2013	82	18
2014	81	19
2015	78	22
2016	78	22
2017	76	24

The *Gas Production and Distribution (ANZSIC Subdivision 27)* sector is also one of the energy transformation industries, manufacturing town gas up until 2012 from both natural gas and LPG. Fuel consumption consists of:

- natural gas and LPG used to make town gas; and
- other gas (including both natural gas and town gas) used by the industry for its own purposes.

The quantity of town gas produced is shown as an energy output of the sector in the *Australian Energy Statistics*. It was assumed that all LPG is converted to town gas, and none is combusted in the conversion process. LPG consumption was therefore offset in full against an equal quantity (in terms of energy content) of town gas produced. The remaining town gas production was subtracted from total natural gas consumption.

3.3.3 Uncertainties and Time Series Consistency

The tier 1 uncertainty analysis in Annex 2 provides estimates of uncertainty according to IPCC source category and gas.

Time series variability of GHG IEFs are also likely to be influenced by changes in fuel mix within categories, and changes of facility specific fuel EFs. Notable examples of where such variations occur in 1.A.1 *energy industries* are set out below:

- 1.A.1.c *manufacture of solid fuels and other energy industries* – CO_2 from solid fuels: The IEF declines by 10 per cent between 1990 and 2001. This can be explained by the relative rise of coal by-products—coke oven gas as a fuel (with a relatively low EF of 37 Gg/PJ) at the expense of black coal; and
- 1.A.1.a *public electricity* – CO_2 from biomass: Biomass combustion for electricity consists of a growing proportion of biogas from landfill. Biogas has a relatively low CO_2 emission factor compared to other biomass fuel, hence Australia's CO_2 biomass IEF is relatively low.
- 1.A.1.a *public electricity* – CO_2 from liquid fuels: Variations occur in the IEF over the time series due to changes in the proportions of Fuel Oil and Diesel Oil in the liquid fuel mix. These fuels have consumption variability year on year as they are generally used for unscheduled and off-grid electricity generation.
- 1.A.1.b *petroleum refining* – CO_2 from liquid fuels: Variations in the IEF of around 2 per cent are evident since 2008. The estimation of CO_2 for the petroleum refining sector utilises facility-specific emission factors obtained from the NGER Scheme. The CO_2 IEF will tend to vary depending on the liquid fuel mix used and the refinery processes undertaken in the year. Australia has a limited number of refineries (5 in 2016/17). Therefore changes in fuel mix and qualities in those refineries will tend to result in minor variations in the overall liquid IEF.

3.3.4 Source specific QA/QC

This source category is covered by the general QA/QC measures of the greenhouse gas inventory discussed in Chapter 1. Results for the reference approach for the *energy* sector, reported in Annex 4, and the carbon reconciliation reported in Annex 6, provide quality control checks for this sector.

Fuel and generation data for 1.A.1.a *public electricity* are compiled by the Department from NGER data and from Australian Energy Statistics energy data. Inputs are reconciled and emission data is fully reconciled against the outputs from the AGEIS to ensure the accurate reporting in this sector.

Fuel and generation data are also checked and reconciled against the alternative data source of the Energy Supply Association of Australia (ESAA) and the Australian Energy Market Operator (AEMO). These comparisons confirm the consistency of the estimates to a high level of accuracy and show that all energy/carbon has been accounted for.

A top-down/bottom-up reconciliation and verification using supplementary data was undertaken for natural gas consumption in the inventory, as a means of verifying recalculations for natural gas with 1.A.1 – see section 3.2.6 QA/QC.

Emissions and activity data for coke ovens are estimated within an overarching carbon and energy balance that encompasses the Australian Iron and Steel production sector.

3.3.5 Recalculations since the 2016 Inventory

Recalculations to 1.A.1 energy industries are detailed at the sub-category level in Table 3.7.

Minor recalculations were made to the Australian Energy Statistics to the coal by-product produced from coke oven operations. This contributed to revisions of between -0.4 and 2.9 per cent in the Manufacturing of solid fuels and other energy industries between the period 2009 to 2016.

Table 3.7 1.A.1 Energy Industries: recalculation of total CO_2-e emissions, 1990-2016

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1.A.1.a Electricity and heat production				
1990	129,580	129,580	0	0.0 per cent
2000	175,413	175,413	0	0.0 per cent
2001	182,686	182,686	0	0.0 per cent
2002	183,990	183,990	0	0.0 per cent
2003	186,561	186,561	0	0.0 per cent
2004	194,933	194,933	0	0.0 per cent
2005	196,762	196,762	0	0.0 per cent
2006	201,313	201,313	0	0.0 per cent
2007	204,125	204,125	0	0.0 per cent
2008	205,961	205,961	0	0.0 per cent
2009	211,695	211,695	0	0.0 per cent
2010	205,095	205,095	0	0.0 per cent
2011	198,498	198,498	0	0.0 per cent
2012	199,117	199,117	0	0.0 per cent
2013	187,049	187,049	0	0.0 per cent
2014	180,789	180,789	0	0.0 per cent
2015	188,989	188,989	0	0.0 per cent
2016	194,743	194,743	0	0.0 per cent
1.A.1.b Petroleum refining				
1990	5,527	5,527	0	0.0 per cent
2000	6,169	6,169	0	0.0 per cent
2001	6,282	6,282	0	0.0 per cent
2002	6,208	6,208	0	0.0 per cent
2003	6,062	6,062	0	0.0 per cent
2004	5,537	5,537	0	0.0 per cent
2005	5,479	5,479	0	0.0 per cent
2006	4,921	4,921	0	0.0 per cent
2007	5,335	5,335	0	0.0 per cent
2008	5,125	5,125	0	0.0 per cent
2009	5,199	5,199	0	0.0 per cent

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2010	5,292	5,292	0	0.0 per cent
2011	5,691	5,691	0	0.0 per cent
2012	5,148	5,148	0	0.0 per cent
2013	4,905	4,905	0	0.0 per cent
2014	4,588	4,588	0	0.0 per cent
2015	3,858	3,858	0	0.0 per cent
2016	2,955	2,955	0	0.0 per cent
1.A.1.c Manufacturing of solid fuels and other energy industries				
1990	7,992	7,992	0	0.0 per cent
2000	10,578	10,578	0	0.0 per cent
2001	10,468	10,468	0	0.0 per cent
2002	11,454	11,454	0	0.0 per cent
2003	12,393	12,393	0	0.0 per cent
2004	13,648	13,648	0	0.0 per cent
2005	14,221	14,221	0	0.0 per cent
2006	14,730	14,730	0	0.0 per cent
2007	14,566	14,566	0	0.0 per cent
2008	14,709	14,709	0	0.0 per cent
2009	15,173	14,809	-363	-2.4 per cent
2010	15,724	15,368	-356	-2.3 per cent
2011	16,436	16,442	5	0.0 per cent
2012	17,616	17,424	-193	-1.1 per cent
2013	18,818	18,847	29	0.2 per cent
2014	19,459	19,291	-168	-0.9 per cent
2015	19,151	18,598	-554	-2.9 per cent
2016	22,715	22,232	-483	-2.1 per cent

3.3.6 Planned improvements

The Department has further incorporated into the Australian Energy Statistics improved activity data available under the NGERS into the time series. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period 2003 to 2016. An undesirable outcome of this improved data is that a step change exists in some time series for individual fuel types within certain source categories.

The Department will continue to look at applying revisions through to the earlier part of the time series in future Australian Energy Statistics releases and these revisions will be incorporated into future recalculations of the national inventory when available.

Uncertainty data reported by corporations under the NGER system has been incorporated into the national inventory for the electricity sector. A review of NGER uncertainty data in other fuel combustion sectors will be undertaken with the intention of incorporating these estimates in the uncertainty analysis.

Further facility specific data from NGERS will be incorporated into the activity data. This will reduce differences between the total of reported values under NGERS and the Australian Energy Statistics for ANZSIC subdivision 20.

3.4 Source Category 1.A.2 Manufacturing Industries and Construction

3.4.1 Source category description

This source category includes emissions from fuel combustion in manufacturing, construction and non-energy mining. This includes both stationary and mobile equipment such as earth moving and mining equipment.

The Australian Energy Statistics report energy consumption for economic sectors defined using the Australia New Zealand Standard Industrial Classification (ANZSIC). The mapping of ANZSIC codes against IPCC classifications is complete and given in Table 3.8.

Table 3.8 Relationship between IPCC source categories and ANZSIC sectors: Manufacturing and Construction

IPCC Source Category	ANZSIC Subdivision/Group/Class			
	Division	Sub-division	Group/ Class	Description
2. Manufacturing Industries and Construction				
A Iron and Steel	C Manufacturing	21	211-212	Iron and steel manufacturing (excl. Coke ovens)
B Non-Ferrous Metals	C Manufacturing	21	213-214	Basic non-ferrous metal manufacturing
C Chemicals	C Manufacturing	17	1709	Other petroleum and coal product manufacturing
		18-19		Basic chemical and chemical, polymer and rubber
D Pulp, Paper and Print	C Manufacturing	14		Wood and paper products
		15-16		Pulp, paper and printing
E Food Processing, Beverages and Tobacco	C Manufacturing	11-12		Food, beverages, tobacco
F Non-metallic minerals	C Manufacturing	20	201	Glass and glass products
F Other (part)	C Manufacturing	20	202	Ceramics
	C Manufacturing	20	203	Cement, lime, plaster and concrete
	C Manufacturing	20	209	Other non-metallic mineral products
G Other (Mining (excluding fuels) and quarrying)	B Mining	8-10		Other mining,
G Other (Textile and leather)	C Manufacturing	13		Textiles, clothing , footwear and leather
G Other (All other manuf.)	C Manufacturing	22		Fabricated metal products
		25		Furniture and other manufacturing
G Other (Manufacturing of Machinery)	C Manufacturing	23-24		Machinery and equipment
G Construction	E Construction			Construction

3.4.2 Methodology

The emissions for *manufacturing industries and construction* are estimated using tier 2 approaches. Emissions estimated from activity data are based on the national survey of energy consumption by industry sector and fuel type compiled by the DIS. CO_2 EFs are country-specific and direct industry advice on the use of CO_2 emissions factors has been adopted for the use of coal by-products within 1.A.2.c *chemicals*, black coal within 1.A.2.a *iron and steel*, and natural gas in general. Non-CO_2 EFs have been calculated using a sectoral equipment-weighted average approach and are reported in Table 3.A.2. More detail is provided for the metal and chemicals industries.

Table 3.9 Summary of methods and emission factors: Manufacturing and Construction

Category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A2a Iron and Steel	T2	CS	T2	CS	T2	CS
1A2b Non-Ferrous Metals	T2	CS	T2	CS	T2	CS
1A2c Chemicals	T2	CS	T2	CS	T2	CS
1A2d Pulp, Paper and Print	T2	CS	T2	CS	T2	CS
1A2e Food Processing, Beverages and Tobacco	T2	CS	T2	CS	T2	CS
1A2f Non-metallic minerals	T2	CS	T2	CS	T2	CS
1A2g Other	T2	CS	T2	CS	T2	CS

Notes: T1 = tier 1, T2 = tier 2, T3 = tier 3, CS= Country-specific, D= IPCC default.

Energy

Iron and Steel (ANZSIC Subdivision 21) (1.A.2.a)

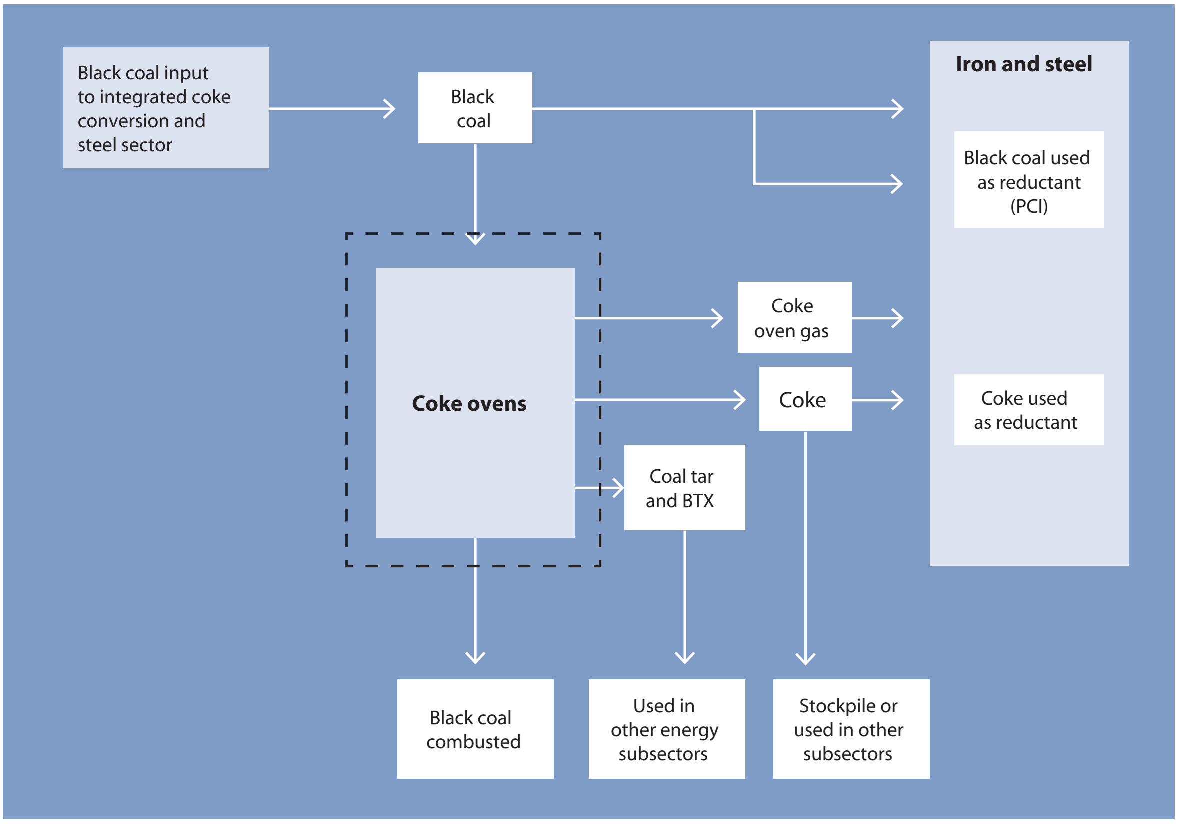
The methodology in the *iron and steel* sub-sector is somewhat more complex than many other sections of the inventory. This complexity arises from a number of factors:

- The operation of Coke Ovens is considered to be an energy transformation industry, and hence must be reported separately to the rest of the iron and steel emissions;
- The production of coke yields a variety of by-products, including coke oven gas, coal and tar;
- Liquefied aromatic hydrocarbons and naphthalene, each having quite different calorific values and EFs. Coke oven gas is used as fuel in coke ovens and adjacent steelworks, while the other products are in general not combusted, but are used as feedstock in the chemical industry;
- Overall, the Coke Ovens sector is a producer of coke, most of which is consumed in the Iron and Steel sector and some of which is exported to other sectors (and other countries);
- The operation of blast furnaces to produce pig iron also produces yet another coal by-product, blast furnace gas, which is a low calorific value fuel consisting mainly of CO (and atmospheric nitrogen), used elsewhere in the steelworks. For the purpose of calculating CO_2 emissions, the production and subsequent combustion of blast furnace gas is ignored, and it is assumed that all coal and coke used in the iron and steel industry undergoes complete oxidation to CO_2, apart from a small adjustment for carbon sequestered in steel;
- The use of coke, as well as natural gas in hot briquetted iron production is regarded primarily as a chemical process rather than fuel combustion under IPCC reporting *guidelines*. Consumption and emissions are therefore reported under the *industrial processes and product use* sector 2.C.3 rather than the *energy* sector;
- Pulverised black coal has been used as a reductant in the production of iron since 2003. Therefore the consumption and emissions are now reported under the *industrial processes and product use* sector in 2.C.1 *metal production* rather than the *energy* sector;

- Although Coke Ovens are in operation in the iron and steel industry, they are considered an energy transformation industry under the IPCC methodology. Therefore, Coke Ovens must be separated from the other parts of the iron and steel industry, so that it can be reported under IPCC category 1.A.1.c;
- The statistics show that production of both coke and coal by-products exceed consumption within the sectors, i.e. the iron and steel industry as a whole is a net producer of coke and coal by-products. Only the estimate of consumption is used to estimate emissions from the Iron and Steel sector. Some of the remaining production may appear elsewhere in the national inventory if it is consumed as fuel by other industries in Australia, in which case the emissions are allocated to the consuming industry; and
- Production consumed elsewhere includes some coke (though in most years the majority of surplus coke produced by the industry is exported from Australia), and surplus coal by-products, most of which are consumed by the Coal and Petroleum Products sector.

A schematic chart showing energy flows within the integrated coke oven/Iron and Steel subsectors is shown in Figure 3.9. Energy and carbon flows are balanced between input and outputs when compiling the inventory as part of the inventory quality controls – See QC control 3.B.1 (i) carbon and energy balances (NIR Volume 3, Table A6.2: Australia's National Carbon Balance and Figure A6.1.) A discrete carbon balance is undertaken around the coke ovens input/output, as defined by dashed lines in Figure 3.9, to determine the carbon content of coke produced as a balancing item. The coke emission factor determined from this balance is shown for all years in Table 3.A.22.

Figure 3.9 Coke Oven and Iron and Steel energy flow chart



Note: The dashed lines define the discrete carbon balance undertaken for the coke oven inputs/outputs to determine the carbon content of the coke produced.

Energy

Non-Ferrous Metals (ANZSIC Group 213-214) (1.A.2.b)

The consumption of petroleum products nec (meaning other, unspecified petroleum products 'not elsewhere classified') in this sector includes petroleum coke and coal tar used to make carbon anodes for aluminium production. CO_2 emitted from oxidation of carbon anodes in aluminium smelters is accounted in UNFCCC category 2.C.3. The quantity of petroleum coke and coal tar consumed in this sector, as advised by industry each year, is therefore subtracted from energy consumption of petroleum products nec and coal by-products, in order to eliminate double counting. It is assumed that the remaining energy consumption of Petroleum Products nec consists of naphtha. Some use of black coal in the production of synthetic rutile as well as black coal, coke, petroleum coke and fuel oil for base metal smelting occurs for reductant purposes. Therefore, these fuel quantities are also deducted from the *energy* sector fuel consumption and reported under the *industrial processes and product use* sector.

Chemicals (1.A.2.c)

This sub-sector spans the following ANZSIC classes:

- Other petroleum and coal product manufacturing (ANZSIC Class 1709); and
- Basic chemical and chemical, polymer and rubber (ANZSIC Subdivision 18-19).

The Chemicals sector is a major energy user. Most of the energy is used by the Petroleum Refining and Basic Chemical Manufacturing sub-categories. Energy use in these two sub-categories is separately reported at the national level.

Non-energy use of natural gas in the production of ammonia is regarded as an industrial process and is therefore reported under the *industrial processes and product use* sector rather than the *energy* sector, in order to prevent double counting. Likewise, the non-energy use of petroleum coke for titanium dioxide production and coke oven coke used in soda ash production are also reported within the *industrial processes and product use* sector.

The calculation of emissions in the Chemicals sector must identify and allow for carbon stored in products. Sequestration takes place in the Other petroleum and coal product manufacturing (ANZSIC Class 1709) and Basic chemical and chemical, polymer and rubber (ANZSIC Subdivision 18-19) sub-categories, where fossil fuels are used as feedstock. Data is also obtained directly from chemical companies in order to estimate the quantity of carbon sequestered in products from feedstocks, with emissions estimates adjusted accordingly.

Coal by-products constitute the largest fuel input into the Other petroleum and coal product manufacturing (ANZSIC Class 1709) sector. It is assumed that these consist of coal tar and liquefied aromatic hydrocarbons and that, in the absence of specific information about this industry sector in Australia, 75 per cent of this fuel is sequestered in long lived coal products, following the default assumption of the IPCC methodology.

The basic chemical and chemical, polymer and rubber (ANZSIC Subdivision 18-19) sub-category includes the major bulk chemical manufacturing enterprises producing fertilisers, other nitrogenous chemicals, polymer resins (plastics) and carbon black. The fossil fuel feedstocks used include natural gas (CH_4), ethane, propane, butane, propylene and naphtha. Ethane, propane and butane may be either 'naturally occurring', i.e. sourced directly from oil and gas fields, or derived from crude oil as by-products of refining. In Australia, all ethane is derived from naturally occurring source, while both naturally occurring and ex-refinery propane and butane are used. Propylene and naphtha are refinery products. The Australian Energy statistics include ethane within the reported total natural gas consumption, after appropriately adjusting for the different energy content of ethane. The Australian Energy Statistics also groups propane and butane together as LPG and group propylene and naphtha as petroleum products nec.

The important outputs of this sector can be classified into two components:

- synthetic resins (polymers); and
- nitrogenous fertilisers and other nitrogenous products.

A third component, carbon black manufacture, uses significant quantities of fossil fuel feedstock as a source of carbon, however relatively little is combusted. A fourth, methanol, has been manufactured in Australia since 1994.

Synthetic Resins

The balance between combustion and storage in products varies greatly between chemical plants, depending on the production processes involved and the configuration of the particular plant. Therefore the quantity of feedstock supplied to chemical plants is not a useful indication of the quantity of stored carbon. The only reliable guidance comes from the quantities of chemical products produced. The major products in which fossil carbon is sequestered include polyethylene, polypropylene, synthetic rubber and styrene. Other bulk plastics are made in Australia from imported monomers, e.g. PVC made from imported vinyl chloride monomer. These imported monomers contain large quantities of fossil carbon, but since this has not been derived from primary fossil fuels (crude oil, petroleum products and natural gas) produced in or imported to Australia, this carbon is not estimated.

The IPCC Methodology assumes that default fractions of specified fossil fuel products, e.g. ethane, naphtha, are sequestered. The national inventory utilises the actual production figures provided by the companies making the products concerned. The analysis is nevertheless relatively complex, because most products are derived from several different feedstocks. The carbon contents of the various feedstocks and basic chemical products used in estimating the carbon sequestration are reported in Table 3.10 and Table 3.11.

The quantities of feedstocks used in the Chemical sub-sector, and the associated amounts of carbon stored in products, are detailed in CRF table 1.A(d) – Feedstocks and non-energy use of Fuels. For 2011, 26.9 PJs of ethane and 8.3 PJs of petroleum (naphtha) feedstocks resulted in the storage of 376 kt and 166 kt of carbon in long life products respectively. The majority of emissions of ethane and naphtha combusted as fuels are reported in the national inventory under 1.A.2c Chemicals. In 2011, net emissions from the combustion of ethane were 0.2 Mt CO_2-e, while 2.5 Mt CO_2-e of naphtha emissions were reported.

Carbon Black

Carbon black is produced in Australia by partial oxidation of petroleum feedstocks and used in a variety of long lived products, including tyres.

Table 3.10 Feedstock assumptions in basic chemicals

Feedstock	Carbon Faction	Calorific Value (GCV)
Ethane	0.80	(a)
Propylene	0.86	52.2
Naphtha (Benzene)	0.84	48.1
Gas Oil (ADO)	0.85	45.6
Carbon Black Feedstock	(a)	(a)

Source: Energy Strategies 2007 Analysis. (a) Data is provided in a confidential manner annually from the relevant companies and hence is not reported here.

Energy

Table 3.11 Product assumptions in basic chemicals

Product	Carbon Faction
Polyethylene	0.86
Polypropylene	0.86
Butadiene Rubber / Styrene-Butadiene Rubber	0.86
Styrene	0.92
Carbon black	1.00

3.4.3 Uncertainties and time series consistency

The tier 1 uncertainty analysis in Annex 2 provides estimates of uncertainty according to IPCC source category and gas.

Revisions to the AES have taken place due to the incorporation of improved activity data available under the NGER. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period of 2003 to 2016. The revisions have improved time series consistency from 2003 onwards, however a step change exists after 2002 in the time series for a small number of fuel types within source categories.

See under Planned Improvements for discussion regarding plans to revise the pre-2003 parts of time series affected by the step change. Time series variability of GHG IEFs are likely to be influenced by changes in fuel mix within categories. Notable examples of where such variations occur in Manufacturing Industries and Construction 1.A.2 are set out below.

1.A.2.a *iron and steel:-* CO_2

Solid fuels

The use of coke in *iron and steel* is reported in *industrial processes and product use* sector in accordance with the 2006 IPCC *Guidelines*. Of the two remaining solid fuels: coal and coke oven gas, the coke oven gas has a relatively low CO_2 EF of 37 Gg/PJ compared to 91.8 Gg/PJ for coal. This tends to lower the overall CO_2 IEF for solid fuels.

Following the recommendation of the 2008 ERT, Australia allocated black coal used for pulverised coal injection (consumed as a reductant) to the industrial processes and product use sector. This has resulted in a reallocation of black coal from 1.A.2.a iron and steel to 2.C.1 metal production from 2003 onwards, when pulverised coal injection was first used in Australia. However, there is some minor use of black coal for combustion purposes remaining in the Energy sector under 1.A.2.a Iron and Steel. This coal is driving the solid IEF to be higher than that of coke oven gas alone, as well as influencing the annual fluctuations observed in the solid IEF from 2003 onwards. Following the 2015 ERT recommendation, Australia provided additional information to improve the transparency on the activity data for black coal and coke oven gas fuel mix consumed in 1.A.2.a iron and steel sector. Table 3.13 show the percentage of black coal/coke oven gas fuel mix within solid fuels.

Table 3.12 Percentage of black coal and coke oven gas fuel mix in 1.A.2.a

Years	per cent of coal	per cent of coke oven gas
1990	10	90
2000	9	91
2005	23	77
2006	14	86
2007	5	95
2008	16	84
2009	40	60
2010	36	64
2011	14	86
2012	34	66
2013	15	85
2014	6	94
2015	16	84

Liquid fuels

The liquid fuel CO_2 IEF is relatively low, driven by the dominant use of LPG (CO_2 EF of 60.2 Gg/PJ) compared to other liquid fuels with higher EFs. However, a sharp increase in the IEF in 2001 was the result of an increase in the use of diesel and fuel oil relative to the consumption of LPG. As LPG has a relatively lower CO_2 EF, the change in fuel mix resulted in an increase in the overall liquid CO_2 IEF.

1.A.2.c *Chemicals*: Emissions and IEFs for *chemicals* are influenced by the mix of end products which sequester carbon. The production mix of the Australian chemicals industry changes over time, resulting in a variable trend.

3.4.4 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1.

3.4.5 Recalculations since the 2016 Inventory

Recalculations to 1.A.2 *manufacturing and construction* are detailed at the sub-category level in Table 3.13.

Revisions to the Australian Energy Statistics:

A key reason for recalculations arises from revisions by DoEE to the Australian Energy Statistics. The revisions to the Australian Energy Statistics are due to the incorporation of improved activity data available under the NGER.

Recalculations were made in response to revisions by the Department in the fuel consumption reported in the Australian Energy Statistics that better aligns with NGER and results in improvements in time series consistency. In 1.A.2.b, the main driver for recalculations for 2012 to 2015 was Australian Energy Statistics revisions to the petroleum product nec fuels.

In 1.A.2.g, the main driver for Australian Energy Statistics revisions were made for 2011 to 2016 the and petroleum product nec fuels.

Table 3.13 1.A.2 Manufacturing and Construction: recalculation of total CO_2-e emissions, 1990-2016

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1.A.2.a Iron and steel				
1990	2,735	2,735	0.0	0 per cent
2000	2,521	2,521	0.0	0 per cent
2001	2,547	2,547	0.0	0 per cent
2002	2,769	2,769	0.0	0 per cent
2003	2,466	2,466	0.0	0 per cent
2004	2,684	2,684	0.0	0 per cent
2005	2,916	2,916	0.0	0 per cent
2006	2,584	2,584	0.0	0 per cent
2007	2,479	2,479	0.0	0 per cent
2008	2,819	2,819	0.0	0 per cent
2009	2,535	2,535	0.0	0 per cent
2010	2,562	2,562	0.0	0 per cent
2011	1,770	1,770	0.0	0 per cent
2012	2,259	2,259	0.0	0 per cent
2013	1,568	1,568	0.0	0 per cent
2014	1,559	1,559	0.0	0 per cent
2015	1,560	1,560	0.0	0 per cent
2016	1,506	1,506	0.0	0.0 per cent
1.A.2.b Non-ferrous metals				
1990	11,193	11,193	0.0	0 per cent
2000	13,310	13,310	0.0	0 per cent
2001	12,537	12,537	0.0	0 per cent
2002	12,741	12,741	0.0	0 per cent
2003	12,472	12,472	0.0	0 per cent
2004	12,783	12,783	0.0	0 per cent
2005	13,775	13,775	0.0	0 per cent
2006	13,920	13,920	0.0	0 per cent
2007	14,197	14,197	0.0	0 per cent
2008	14,808	14,808	0.0	0 per cent
2009	13,637	13,637	0.0	0 per cent
2010	13,058	13,058	0.0	0 per cent
2011	12,090	12,090	0.0	0 per cent
2012	13,271	13,164	-107.0	-0.8 per cent
2013	14,669	14,452	-216.8	-1.5 per cent
2014	15,265	15,079	-185.9	-1.2 per cent
2015	13,295	13,190	-104.7	-0.8 per cent
2016	12,531	12,531	0.0	0 per cent
1.A.2.c Chemicals				
1990	5,661	5,661	0.0	0 per cent
2000	6,064	6,064	0.0	0 per cent
2001	6,674	6,674	0.0	0 per cent
2002	6,160	6,160	0.0	0 per cent
2003	6,852	6,852	0.0	0 per cent

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2004	7,535	7,535	0.0	0 per cent
2005	6,867	6,867	0.0	0 per cent
2006	6,597	6,597	0.0	0 per cent
2007	6,222	6,222	0.0	0 per cent
2008	6,949	6,949	0.0	0 per cent
2009	6,718	6,718	0.0	0 per cent
2010	6,623	6,623	0.0	0 per cent
2011	7,097	7,097	0.0	0 per cent
2012	8,057	8,057	0.0	0 per cent
2013	8,806	8,806	0.0	0 per cent
2014	8,326	8,326	0.0	0 per cent
2015	8,701	8,701	0.0	0 per cent
2016	7,739	7,739	0.0	0 per cent
1.A.2.d Pulp paper and print				
1990	1,327	1,327	0.0	0 per cent
2000	1,494	1,494	0.0	0 per cent
2001	1,505	1,505	0.0	0 per cent
2002	1,506	1,506	0.0	0 per cent
2003	1,553	1,553	0.0	0 per cent
2004	1,669	1,669	0.0	0 per cent
2005	1,819	1,819	0.0	0 per cent
2006	1,825	1,825	0.0	0 per cent
2007	1,766	1,766	0.0	0 per cent
2008	1,713	1,713	0.0	0 per cent
2009	1,704	1,704	0.0	0 per cent
2010	1,737	1,737	0.0	0 per cent
2011	1,506	1,506	0.0	0 per cent
2012	1,396	1,396	0.0	0 per cent
2013	1,588	1,588	0.0	0 per cent
2014	1,436	1,436	0.0	0 per cent
2015	1,388	1,388	0.0	0 per cent
2016	1,366	1,366	0.0	0 per cent
1.A.2.e Food, beverages and tobacco				
1990	3,054	3,054	0.0	0 per cent
2000	3,283	3,283	0.0	0 per cent
2001	2,668	2,668	0.0	0 per cent
2002	2,666	2,666	0.0	0 per cent
2003	3,438	3,438	0.0	0 per cent
2004	3,155	3,155	0.0	0 per cent
2005	3,597	3,597	0.0	0 per cent
2006	3,513	3,513	0.0	0 per cent
2007	3,206	3,206	0.0	0 per cent
2008	3,270	3,270	0.0	0 per cent
2009	3,446	3,446	0.0	0 per cent
2010	3,428	3,428	0.0	0 per cent

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2011	3,571	3,571	0.0	0 per cent
2012	3,350	3,350	0.0	0 per cent
2013	3,333	3,333	0.0	0 per cent
2014	3,335	3,335	0.0	0 per cent
2015	3,240	3,240	0.0	0 per cent
2016	3,173	3,173	0.0	0 per cent
1.A.2.f Non-metallic minerals				
1990	5,517	5,517	0.0	0 per cent
2000	5,046	5,046	0.0	0 per cent
2001	5,411	5,411	0.0	0 per cent
2002	5,495	5,495	0.0	0 per cent
2003	6,478	6,478	0.0	0 per cent
2004	6,508	6,508	0.0	0 per cent
2005	6,268	6,268	0.0	0 per cent
2006	6,141	6,141	0.0	0 per cent
2007	6,797	6,797	0.0	0 per cent
2008	6,852	6,852	0.0	0 per cent
2009	6,464	6,464	0.0	0 per cent
2010	6,618	6,618	0.0	0 per cent
2011	6,679	6,679	0.0	0 per cent
2012	6,113	6,113	0.0	0 per cent
2013	5,581	5,581	0.0	0 per cent
2014	5,305	5,305	0.0	0 per cent
2015	5,272	5,272	0.0	0 per cent
2016	5,186	5,186	0.0	0 per cent
1.A.2.g Other (a)				
1990	6,769	6,769	0.0	0 per cent
2000	7,235	7,235	0.0	0 per cent
2001	7,110	7,110	0.0	0 per cent
2002	7,792	7,792	0.0	0 per cent
2003	6,365	6,365	0.0	0 per cent
2004	6,170	6,170	0.0	0 per cent
2005	6,342	6,342	0.0	0 per cent
2006	6,066	6,066	0.0	0 per cent
2007	6,260	6,260	0.0	0 per cent
2008	6,626	6,626	0.0	0 per cent
2009	7,679	7,679	0.0	0 per cent
2010	7,409	7,409	0.0	0 per cent
2011	8,292	8,245	-47.5	-0.6 per cent
2012	9,706	9,701	-5.0	-0.1 per cent
2013	11,055	11,052	-2.7	0.0 per cent
2014	11,185	11,202	16.6	0.1 per cent
2015	10,496	10,515	18.3	0.2 per cent
2016	10,161	10,273	112.1	1.1 per cent

3.4.6 Planned improvements

In Australian Energy Statistics, the Department has further incorporated improved activity data available under the NGER into the time series.

The Department will continue to look at applying revisions through to the earlier part of the time series in future Australian Energy Statistics releases and these revisions will be incorporated into future recalculations of the national inventory when available.

In response to a recommendation from a previous review report, a study was commissioned by the Department to investigate the appropriateness of the fuel characteristics, including the CO_2 EF, for liquid fuels types. As a result, further analysis of Australian ethanol characteristics will be undertaken to consider whether changes should be made to the EF used to compile the inventory

3.5 Source category 1.A.3 Transport

3.5.1 Source category description

This source category includes emissions from the *transport* sector, comprising the civil aviation, road transportation, marine navigation, railways and 'other' categories.

Activity data on fuel consumption is sourced from the *Australian Energy Statistics 2018* (DoEE 2018). A number of mobile source categories have been allocated to the stationary source inventory because the current national data collection methods do not allocate this fuel to the transport sector but rather to the specific ANZSIC class in which it is used. In particular, emissions from miscellaneous off-road vehicles used in specific ANZSIC classifications (such as tractors and other farm vehicles, forestry vehicles, quarry trucks and front-end loaders, construction equipment, and forklifts) are allocated to the corresponding ANZSIC group and accounted for in sectors 1.A.2 and 1.A.4. It is estimated that these emissions account for approximately 24,241 Gg CO_2-e in 2015. More information on the assumed mobile components of stationary source is at section 3.2.2. Emissions from mobile utility engines (such as lawn-mowers, chain-saws, portable generators and mobile compressors) and military transport are reported in sectors 1.A.4 and 1.A.5 using the methodologies detailed in this sector. Emissions from other off-road mobile source, however, such as unregistered trail bikes, recreation vehicles and competition vehicles are reported under 1.A.3.

3.5.2 Methodology

Like other energy sub-sectors, the methodology for 1.A.3 is based on the application of 'bottom up' approaches to the estimation of emissions. The estimation of non-CO_2 emissions from passenger and light commercial vehicles utilises a Tier 3 approach that depends on data on vehicle kilometres travelled, vehicle fleet characteristics and vehicle operating modes. Non-CO_2 emissions from civil aviation using aviation turbine fuel are estimated using a Tier 2 approach (with a Tier 1 approach applied to estimates of non-CO_2 emissions from domestic aviation using gasoline), which takes account of fuel consumed, landing and take-off cycles and Australian fleet characteristics.

Table 3.14 Summary of methods and emission factors: Transport

Source Category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A3a Civil Aviation	T2	CS	T1/T2	CS/D	T1/T2	CS/D
1A3b Road Transportation – passenger, light commercial and heavy vehicles	T2	CS	T3	CS	T3	CS
1A3b Road Transportation – other	T2	CS	T1	CS	T1	CS
1A3c Railways	T2	CS	T1	D	T1	D
1A3d Water-borne Navigation (Domestic)	T2	CS	T2	CS	T2	CS
1A3e Other Transport	T2	CS	T1	D	T1	D

Notes: T1 = tier 1. T2 = tier 2. T3 = tier 3. CS= Country-specific. D= IPCC default.

General methodology

The emission estimate of a greenhouse gas from fuel combustion in the engines of a mobile source, using a specified fuel type, is calculated by:

$$E(l)_{ijk} = Au_{ijk} \times F(l)u_{ijk} \quad (3.3)$$

Where $E(l)_{ijk}$ is the emission of greenhouse gas l in gigagrams (Gg) from a mobile vehicle and age class i and technology j using fuel type k;

Au_{ijk} is the activity level, where u refers to either energy consumption in petajoules (PJ) or to distance travelled in kilometres (km); and

$F(l)u_{ijk}$ is the EF, in units of grams of gas l emitted per megajoule of energy use (g/MJ) for CO_2 and SO_2, and grams of gas l emitted per kilometre travelled (g/km) for other non-CO_2 gases.

Fuel consumption data for the *transport* sector are taken from *Australian Energy Statistics (DoEE 2017)*. The main adjustments applied to energy consumption data allocates some fuels to off-road, residential and military fuel uses (reported in Table 3.A.13).

The allocations of fuel to military transport in 2008, 2009 and 2010 are informed by direct reporting of fuel consumption by the Australian Department of Defence (2010-2012).

Allocations for 2011, 2012 and 2013 are based on energy use data published by the Australian Government in accordance with its *Energy Efficiency in Government Operations (EEGO) Policy* (AGO 2007). This required the preparation of an annual whole-of-government report on the total energy use and estimated greenhouse gas emissions of Australian Government departments and agencies, and presented in the report *Energy use in the Australian Government's operations* using information reported to the Department of Resources, Energy and Tourism from all government departments and agencies – including the Department of Defence. Allocations for 1995-2007 are linearly extrapolated between the reported data points in 1994 and 2008.

This reporting was discontinued, and the allocations of fuel to military transport in 2014, 2015 and 2016 are informed by direct reporting of fuel consumption by the Australian Department of Defence.

Civil aviation (1.A.3a)

The estimation of CO_2 emissions from civil aviation is undertaken using a Tier 2 methodology and EFs given in Tables 3.2 and 3.3.

Non–CO_2 emissions from domestic civil aviation from fuel use are estimated using both a Tier 1 and a Tier 2 methodology. For larger aircraft operating on aviation turbine fuel, emissions are calculated as a function of both the landing/takeoff cycles (LTOs) and of cruise emissions for both domestic and international aircraft. Small aircraft operating on aviation gasoline make up a small portion of aviation emissions, and are estimated using a Tier 1 approach and IPCC default EFs.

The Tier 2 estimation of emissions from landing and takeoff cycles of larger aircraft operating on aviation turbine fuel requires data on the number of LTO cycles at Australian airports; data on the profile of the Australian aviation capital stock or fleet; and EFs by type of aircraft. The data required for the total yearly LTO for the domestic and international aircraft are available from the Bureau of Infrastructure, Transport and Regional Economics (BITRE 2017) within the Department of Infrastructure and Regional Development (DIRD). The Australian aviation fleet profile is developed using the Australian Aircraft Register which is available from the Civil Aviation Safety Authority (Table 3.19). EFs for each aircraft type are taken from IPCC 2006 and are used to estimate weighted average LTO cycle EFs for the domestic/interstate and international aviation fleets (Table 3.15). These EFs most accurately reflect the technology and aircraft types currently in the Australian aircraft fleet. In a couple of instances EFs are not available for a certain aircraft type. These aircraft are allocated to the aircraft type, for which an EF exists, that most closely reflects the aircraft's engine characteristics.

The estimation of cruise emissions is a function of fuel use, after deduction of fuel consumption required for the LTO cycles, and cruise EFs. Data on the yearly fuel consumption for domestic and international activity are available from DoEE 2017. Cruise EFs are taken from IPCC (2006) (Table 3.21), with N_2O being a weighted average EF for the Australian domestic aircraft fleet.

The methodology is applied to each of the eight Australian states and territories (with the exception of the Australian Capital Territory which due to the unavailability of disaggregated fuel consumption data is included in estimates for the state of New South Wales). Differences in emission estimates across the States principally reflect differences in fuel consumption and both the number of LTO cycles and the relative importance of major interstate movements relative to regional LTO cycles, which impacts on the aircraft type that use State airports. National emissions are estimated as the sum of the State and Territory emissions.

For small piston engine aircraft operating on aviation gasoline fuel, non-CO_2 emissions are estimated using a Tier 1 approach. This method applies default EFs (IPCC (2006) for all fuels and aircraft types) to all aviation gasoline fuel consumed by state (Table 3.20).

Emissions from international aviation are also estimated, but are reported as a Memo item only, by international agreement.

Activity data for international bunkers is estimated by the Department as part of the Australian Energy Statistics. The Department also uses data from the *Australian Petroleum Statistics* (DIIS 1996-2016, DoEE 2017a) which publishes monthly national and state petroleum statistical information while sales of aviation turbine fuel, diesel and fuel oil for domestic and international uses are published on a quarterly basis. The Australian Petroleum Statistics explanatory note, which informs company reporting, states that the dissection of international and domestic fuel consumption is made according to the predominant activity of each operator.

Independent of the national inventory the DIRD has developed a software tool to compute and track the carbon footprint associated with aircraft fuel uplifted in Australia. The DIRD completed an assessment of the robustness of their results by comparing their calculated values with the APS. Their results showed that for domestic aviation, computed CO_2 estimates using the software tool and inventory estimates differed by 0.1 per cent in 2013 for domestic consumption, and 2.1 per cent for international consumption in 2013. This is considered to be an excellent independent verification of the estimates.

DIRD no longer undertakes modeling of aircraft emissions independently. Whilst future comparisons will not be possible, the several years it was possible have served to validate methods that continue to be applied in the inventory.

Table 3.15 The Australian aircraft fleet, 2016, and emission factors by type of aircraft

Type of aircraft	Number	Emission Factors				
		CH_4	N_2O	NO_x	CO	NMVOC
		kg/LTO	kg/LTO	kg/LTO	kg/LTO	kg/LTO
Domestic						
DHC-8-100	10	0.00	0.02	1.51	2.24	0.00
DHC-8-200	10	0.00	0.02	1.51	2.24	0.00
A320	110	0.06	0.10	9.01	6.19	0.51
A330–200/300	34	0.13	0.20	35.57	16.20	1.15
BAE 146	13	0.14	0.00	4.07	11.18	1.27
B717	20	0.01	0.10	10.96	6.78	0.05
B727-200	2	0.81	0.10	11.97	27.16	7.32
B737–300/400/500	10	0.08	0.10	7.19	13.03	0.75
B737–700	2	0.09	0.10	9.12	8.00	0.78
B737–800	155	0.07	0.10	12.30	7.07	0.65
B767–300	2	0.10	0.20	28.19	14.47	1.07
SAAB 340	61	0.00	0.02	1.51	2.24	0.00
SA227	38	0.00	0.02	1.51	2.24	0.00
SA226	7	0.00	0.02	1.51	2.24	0.00
Gulfstream IV	5	0.14	0.10	5.63	8.88	1.23
EMB 110	5	0.06	0.01	0.30	2.97	0.58
EMB 120	14	0.00	0.02	1.51	2.24	0.00
Cessna 525	0	0.33	0.03	0.74	34.07	3.01
Beech 200	64	0.06	0.01	0.30	2.97	0.58
F27	68	0.03	0.02	1.82	2.33	0.26
International						
747–300	0	0.27	0.40	65.00	17.84	2.46
747–400	10	0.22	0.30	42.88	26.72	2.02
777	5	0.07	0.30	52.81	12.76	0.59
A380	12	0.40	0.30	69.31	28.40	2.02
787	17	0.40	0.30	69.31	22.00	2.02

Source: CASA Civil Aircraft Register (2017), International Civil Aviation Organisation, Aircraft Engine Emissions Databank (EASA 2016).

Table 3.16 Weighted average emissions factors per Landing and Take Off cycle

Fleet	CH_4 (kg)	N_2O (kg)	NO_x (kg)	CO (kg)	NMVOC (kg)
Domestic Fleet	0.1	0.1	8.0	6.1	0.5
International Fleet	0.2	0.3	48.0	21.2	1.5

Source: DE estimates.

Table 3.17 Aviation cruise emission factors (grams per tonne of fuel consumed)

Fleet	CH_4 (g/t)[a]	N_2O (g/t)[a]	NO_x (g/t)[b]	CO (g/t)[b]	NMVOC (g/t)[b]
Domestic Fleet	0	0.01	11	7	0.7
International Fleet	0	0.01	17	5	2.7

Source: (a) IPCC (2006) weighted average, (b) IPCC (1997).

Table 3.18 Aviation Tier 1 Non-CO_2 Emission Factors

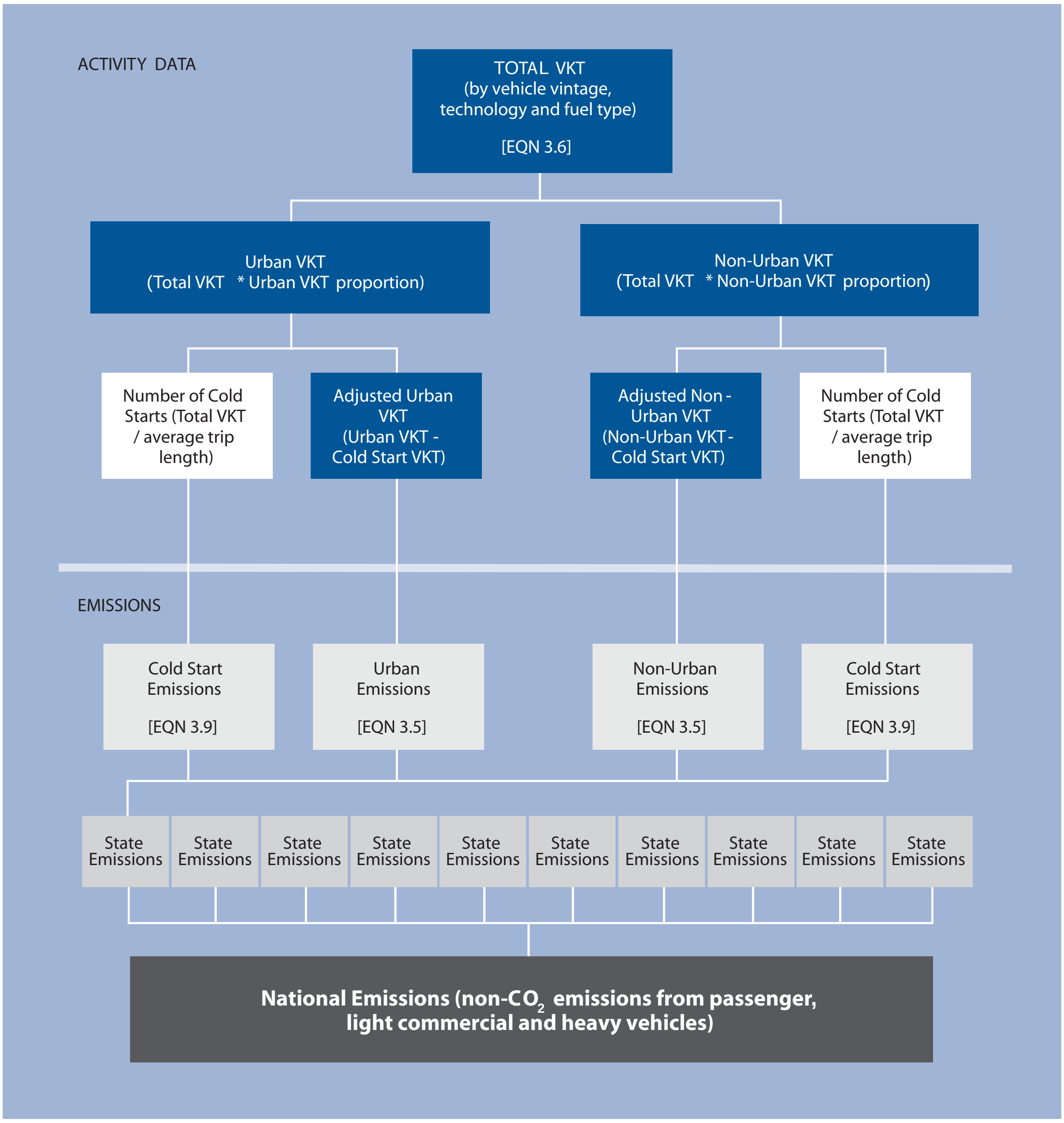
Tier 1 Non-CO_2	CH_4 (kg/TJ)	N_2O (kg/TJ)	NO_x (kg/TJ)	CO (kg/TJ)	NMVOC (kg/TJ
All Fuels	0.5	2	250	0.024	0.00054

Source: IPCC (1997), IPCC (2006).

Road transportation (1.A.3.b)

Like the aviation sector, the estimation of CO_2 emissions from the road transport sector is based on a Tier 2 method with EFs given in Table 3.2. The estimation of non–CO_2 emissions is based on a Tier 3 method, with the emission estimates dependent on the type of vehicle, the age of the vehicle capital stock, technology, operating mode (cold versus hot) and road type (urban versus non-urban). Activity data is expressed in terms of vehicle kilometres travelled and EFs are expressed in g/km. The methodology is applied to each of the eight Australian States and Territories. Differences in emission estimates across the States and Territories principally reflect differences in fuel consumption and the impacts on non-CO_2 emission estimates of differentials in the age distribution of each State and Territory's vehicle fleet. National emissions are estimated as the sum of the State and Territory emissions (see Figure 3.10).

Figure 3.10 Methodology for the estimation of non-CO2 emissions from passenger and light commercial vehicles



Passenger and light commercial vehicles, heavy vehicles and buses (1.A.3.b i-iii)

CO_2 emissions from all vehicle fuel sources have been estimated based on the quantity of fuel consumed by the CO_2 EF specific to that fuel and the proportion of that fuel which is completely oxidised.

$$E_{ijk} = A^{u=1}_{ijk} \times (F(l)_k \times P_k) \quad (3.4)$$

Where $F(l)_k$ is the CO_2 EF applicable to complete oxidation of fuel carbon content for fuel type k (where k=petrol, diesel and LPG);

P_k is the proportion of fuel that is completely oxidised upon combustion; and

A^u_{ijk} is the activity data for vehicle type i with emission control technology j and fuel type k (and where u=1 for fuel consumption in each Australian State)

The CO_2 EFs and oxidation factors for each fuel are summarised in Tables 3.2 and 3.3.

For all vehicles besides motorcycles consuming automotive gasoline, ethanol, diesel and LPG nonCO_2 emissions for each age class are estimated based on vehicle kilometres travelled (VKT) in each State or Territory; the profile and age of the vehicle capital stock in each State; the penetration of catalytic control technology; mode of operation and road type; and vehicle and fuel specific EFs.

It is assumed that all light duty vehicles go through a cold start phase for each trip which is associated with higher emissions due to engine and catalyst temperatures that are below optimum. The number of cold starts is derived from total VKT and an average trip length sourced from Pekol Traffic and Transport (Pekol Traffic and Transport 2017). Average trip length by State and Territory and by vehicle type is estimated for each year throughout the time series. This data replaced static average trip length of 10km that was previously applied across States and Territories and vehicle types. Average trip length data is listed at Appendix Table 3.A.20. A cold-start duration of 3km (as cited in IPCC 2006) is used to determine the total cold start VKT. This is subtracted from total VKT to derive an adjusted total VKT value.

EFs vary by road type (urban versus non-urban) to reflect the different driving conditions and engine operating profiles. Distance travelled is disaggregated into urban and non-urban VKT in each State and Territory and by vehicle type (Pekol Traffic and Transport 2017). The urban VKT proportion data is listed at Appendix Table 3.A.21.

Vehicles using automotive gasoline, ethanol, diesel and LPG are further classified by age of vehicle using data contained in ABS 2017. The divisions in the vehicle fleet enable differences in emissions control technology and differences in fuel efficiency across age classes to be factored into the emissions estimation. Passenger vehicles and light commercial vehicles manufactured and sold in Australia before 1976 are assumed to have no emissions control equipment. The 1976-1985 group uses a variety of non-catalytic control (such as exhaust gas recirculation) and the 1985-1997, 1998-2003, 2004-2005 and the post-2005 groups use catalytic control.

In general, non- CO_2 exhaust emissions from vehicles have been calculated by the following form of equations:

$$E(l)_{ijk} = A^{u=2}_{ijk} \times EF(l)_{ijk} \quad (3.5)$$

Where l = non-CO_2 gases; $A^{u=2}$ for vehicle kilometres travelled and k= automotive gasoline, diesel, and LPG; $EF(l)_{ijk}$ is the exhaust EF for gas l from vehicle type i and age class j using fuel type k for urban and rural operation in each state or territory and where vehicle distances travelled during the hot-engine phase of operation are related to energy consumption levels using:

$$A^{u=2}_{ijk} = A^{u=1}_{ijk} / R_{ik} \times D_k \quad (3.6)$$

Where $A^{u=2}_{ijk}$ is the distance travelled for vehicle type i and age class j, using fuel type k = automotive gasoline, diesel, and LPG; and

R_{ijk} is the average rate of fuel consumption (in l/km, given in Tables 3.A.15-3.A.17) for vehicle type i and age class j, using fuel type k; and

D_k is the energy density of fuel type k (in MJ/L)

and where

$$EF(l)_{ijk} = (ZKL_{ijk} + DR_{ijk} \times CumVKT_{ijk}) \quad (3.7)$$

Where $EF(l)_{ijk}$ is the EF for gas l from each vehicle type i and age class j , using fuel type k=automotive gasoline, diesel, and LPG;

ZKL_{ijk} is the zero kilometre level emissions of a gas l from vehicle type i and age class j;

DR_{ijk} is the deterioration rate for vehicle type i and age class j; and

$CumVKT_{ijk}$ is the cumulative VKT for vehicle type i and age class j, and fuel type k, in each state or territory

and where

$$CumVKT(l)_{ijk} = \Sigma_{t=1-n} A^{u=2}_{ijk} \quad (3.8)$$

Where $A^{u=2}_{ijk}$ is the average distance travelled (in km) by vehicle type i and age class j, using fuel type k=automotive gasoline, diesel, and LPG in each State or Territory summed over time.

Cold start emissions are derived using equation 3.9:

$$Ecs_{ijk} = CS_{ijk} \times EFcs_{ijk} \quad (3.9)$$

Where Ecs_{ijk} are the cold start emissions for vehicle type i and age class j, using fuel type k = automotive gasoline, diesel, and LPG;

CS_{ijk} is the number of cold starts for vehicle type i and age class j, using fuel type k = automotive gasoline, diesel, and LPG;

$EFcs_{ijk}$ is the cold start EF (g/start) for vehicle type i and age class j, using fuel type k = automotive gasoline, diesel, and LPG

Data on fuel consumption for individual vehicle types is derived from DIIS 2013a and ABS (2017a). The data on fuel consumption rates are taken from ABS (2013). The profile and age of the passenger vehicle stock in each State and Territory required for equation 3.7 is taken from ABS (2017a). The vehicle stock from each historical year varies largely due to vehicle sales from each particular year, which in turn is largely driven by the prevailing economic conditions. For example the vehicle stock in 1991 is lower than surrounding years as a result of lower vehicle sales impacted by an economic recession affecting Australia at the time. Data required for estimating VKT for individual vehicle and age classes are given in Tables 3.A.17 to 3.A.19.

Emissions of CH_4 from motor-vehicles are a function of the emission and combustion control technologies present as well as vehicle operating conditions. EFs chosen for passenger and light commercial vehicles were obtained from Australian sources where these were available and applicable to the vehicle fleet and its various modes of operation and fuel types (see Tables 3A.6-3A.8). A major empirical study (*Second National In Service Emissions Study*) of emissions from the operation of light duty petrol vehicles was undertaken in 2009. The results of this study were analysed for the national inventory (Orbital Australia 2010). The study directly measured emissions from 347 petrol passenger vehicles and light commercial vehicles manufactured from 1994-2009. The 347 vehicles represented four ADR (Australian Design Rule, DIRD 1969-1988) age groupings. A petrol Composite Urban Emissions Drive Cycle (CUEDC) was developed as a means of better representing driving under Australian conditions. All vehicles undertook a hot start CUEDC while a subset of the vehicles also undertook a cold start. Emission measurements were allocated to hot urban, non-urban and cold driving conditions. Total hydrocarbon, CO, NO_x, CO_2 and CH_4 emissions were measured from bag samples. EFs (Table 3.A.5) and deterioration rates (3.A.11) were derived for ADR groupings for each gas and each driving condition. Using the EFs and deterioration rates a zero kilometre EF was derived. Results were assessed by cross-referencing the generated results to the zero kilometre capability of the vehicle fleet. This reference point is based on the assumption that at zero kilometres the vehicles were generally in compliance with emission standards of the day and that in general the deterioration over the ADR specified period is indicated to be in line with automotive engineering expectations. Orbital Australia (2010) details these checks.

Orbital Australia (2011b) was used to extend the direct measurement approach outlined above to older vehicles by utilising measurements taken for other studies including the pilot phase of the *Second National In Service Emissions Study* and the *First National In Service Emissions Study*. The outcomes from this report provided updated EFs and deterioration rates for petrol passenger vehicles and light commercial vehicles manufactured between 1986 and 1993. The use of disaggregated, country-specific EFs expressed in terms of emissions per kilometre travelled is consistent with the IPCC Tier 3 methodologies. For vehicles not covered by the studies outlined above the choice of US versus European default factors has been dictated by the exhaust emission standards in the Australian Design Rules (ADR) applicable to each particular vehicle vintage. Australian Design Rules have been harmonised with European Standards since 1996 in heavy duty vehicles. Therefore the IPCC default factors used for post 1995 heavy duty vehicles are based on European data (COPERT IV, EEA 2011). Prior to the harmonisation with European standards, US Federal Test Protocol standards were used as the basis for ADRs. Therefore USEPA default factors cited in IPCC 2006 are used for earlier vehicle vintages where required.

Australian design rules applied to Australia's vehicle fleet, their date of introduction and the European sources for these standards are outlined in Table 3.19. The age-band structure of the motor vehicle emission model is based on the applicability of a given ADR to a given vehicle vintage.

Table 3.19 Australian petrol passenger car exhaust emission standards, Australian heavy duty diesel exhaust emission standards

Petrol passenger vehicles		
Australian Standard	Year introduced	Source standard
ADR 79/00	2004	Euro 2
ADR 79/01	2006	Euro 3
ADR 79/02	2010	Euro 4
ADR 79/03	2013	Euro 5
Heavy duty diesel exhaust		
Australian Standard	Year introduced	Source standard
ADR 70/00	1996	Euro 1
ADR 80/00	2003	Euro 3
ADR 80/02	2008	Euro 4
ADR 80/03	2011	Euro 5

Source: DIRD (2015).

There are no country-specific CH_4 EFs available for heavy-duty vehicles. These EFs have been taken from DCC 2006 or IPCC 2006 as indicated in Appendix 3.A.6. CH_4 EFs for post-2005 vintage vehicles (Euro 3) have been derived based on the Euro 1 COPERT IV EF and an emission reduction factor according to the method in EEA 2009. A summary of the EFs used to estimate CH_4 emissions from the Australian petrol, diesel, LPG and ethanol driven passenger and light commercial vehicle fleets, as well as their respective sources, are presented in Appendix Table 3.A.6.

Emissions of non-CO_2 exhaust gases may increase as the vehicle ages due to the gradual wearing of components, poor maintenance, deactivation of catalyst materials, removal of emission control equipment, oxygen sensor failure, or modification of the engine. The rate of increase in emissions per kilometre per vehicle kilometres travelled is the deterioration rate. Deterioration rates are positive, indicating that emissions increase with mileage. Deterioration rates for each gas, vehicle design category and vehicle type combination are calculated by fitting a linear regression to the scatter of directly measured emissions by vehicle kilometres travelled.

For petrol passenger vehicles and light commercial vehicles manufactured prior to 1986 a study by EPA NSW (1995) analysed the combined emission test databases of EPA NSW and EPA Victoria to determine deterioration rates and zero VKT (i.e. new car) emissions for the two States' combined fleet. For vehicles manufactured from 1986 onwards the deterioration rates are taken from the Orbital Australia 2010 and Orbital Australia 2011b. In this year's inventory the model was updated to allow separate deterioration rates to be applied to passenger vehicles and light commercial vehicles.

The deterioration rates derived in the Orbital reports are based on a study of petrol vehicles. A separate study was undertaken to assess the appropriateness of applying the petrol deterioration rates to other fuels (Orbital Australia 2011c). Limited information was found on the deterioration rates of many vehicles using other fuels however there was evidence that the deterioration rate of diesel passenger vehicles is less than petrol vehicles. Based on the available information Australia has applied the petrol deterioration rates to the diesel and ethanol consumed in passenger and light commercial vehicles which is believed to be a conservative approach. The deterioration rates used to derive EFs for the passenger and light commercial vehicle fleet are shown in Appendix Table 3.A.11. The data shows no evidence of deterioration in the level of N_2O emissions, therefore a deterioration rate of 0 is used.

The majority (345 out of 347) of vehicles tested in the *Second National In Service Emissions* study had a VKT between 0 and 300,000km. Most of the deterioration rates used in the transport model are sourced from this data set. Therefore Australia has applied a limit to the application of the deterioration rate based on total vehicle kilometres travelled. This limit is applied at an accumulated average VKT of 300,000km per vehicle.

N_2O EFs for Australia's petrol-fuelled passenger vehicle fleet are based on CSIRO testing (Weeks *et al.*, 1993) of vehicles of vintage up to 1993, fitted with a range of emissions control technology. Test data on vehicles not fitted with catalysts are used for the pre 1976 and the 1976-85 age groupings and a weighted average of the catalyst equipped emissions used for the 1985-1997 and the post-1997 vehicle fleet. The EFs in Weeks *et al.* are comparable to those reported in IPCC (2000) and by the USEPA and COPERT IV. N_2O EFs for light duty petrol vehicles of vintage 1994 onwards are estimated in the Orbital Australia 2010 report on NISE 2 data.

Australian emissions standards as set out in Australian Design Rules (ADRs) have tended to lag those applied in Europe and the United States (see Table 3.20). Consequently, the types of emissions control technology employed in Australia also tend to lag as these are introduced in order to comply with the emissions standards.

The EFs used to estimate N_2O emissions from the Australian petrol, ethanol, diesel and LPG driven passenger and light commercial vehicle fleets, as well as their respective sources, are presented in Appendix Table 3.A.8.

There are no country-specific N_2O EFs available for heavy-duty vehicles. These EFs have been taken from DCC 2006 and IPCC 2006 as indicated in Appendix Table 3.A.9.

EFs from the *2006 IPCC Guidelines* are used in the road transportation sector when they are the most appropriate factors for the vehicle standards and technology that exist in the Australian road transport fleet.

Australia's IEF for CH_4 from liquid fuels (Fuel Combustion sectoral approach) is most influenced by the contribution of CH_4 emissions for Road Transportation, Cars, and Petroleum. CH_4 implied emission factors for Road Transportation, Cars, and Petroleum have been trending down since the mid-1990s as the inventory reflects improved vehicle emissions control technology performance in the Australian fleet.

The Australian fleet has a relatively high non-CO_2 emissions profile due to the lag behind source emission standards applied in Europe and the United States - Consequently, the types of emissions control technology employed in Australia in the period 1990-2016 also lags as these are introduced in order to comply with the emissions standards. This is compounded in the current fleet by a relatively slow fleet turnover and transition to vehicles with improved emission control technologies.

Motorcycles (1.A.3.b.iv)

The estimation of emissions for motorcycles is given by equations 3.4 and 3.5. Fleet average EFs for motorcycles are provided in appendix Table 3.A.12.

Evaporative fuel emissions (1.A.3.b.v)

Road vehicles using automotive gasoline emit NMVOCs both from the exhaust and through evaporation. The evaporative NMVOC emissions include:

- Running losses resulting from evaporative emissions released during engine operation. Running losses occur when the capacity of the vapour control canister and purge system is exceeded by the vapour generation rate and are greatest at low average vehicle speeds. Running losses vary with the age and type of control system of the vehicle and the trip duration;

- Hot soak losses resulting from evaporation of fuel at the end of each trip. These emissions bear little relation to the VKT for an individual vehicle. A more realistic activity on which to base these emissions is the number of trips an average vehicle would make in a given time period;
- Diurnal losses resulting from vapour being expelled from fuel tanks due to ambient temperature rises. These emissions are strongly dependent on the Reid Vapour Pressure (RVP) of the fuel, the daily ambient temperature changes and where the vehicle is parked during the day. Emissions will vary significantly between identical vehicles in different geographical regions. Diurnal emissions only occur when the temperature is rising; and
- Resting losses resulting through the permeation of fuel through rubber hoses or open bottom carbon canisters. Resting losses have often been included in measurements of hot soak, diurnal and running losses (USEPA, 1991a).

EFs for evaporative emissions for each of the three passenger vehicle age classes have been estimated for average Australian temperatures and fuel properties and are presented in Appendix Table 3.A.19.

Urea-based catalysts (1.A.3.b.vi)

Heavy and passenger vehicles operating on diesel fuel in Australia include later year model vehicles using urea catalyst technology (selective catalyst reduction SCR) to reduce NOx emissions.

Australian emission standards mirror Euro emission limits and approaches and as such not dictate a particular technology with emission standards met by a range of technological approaches which includes SCR both in heavy and passenger transport.

Australia made a preliminary estimate of emissions from Urea based catalysts and considered it to be an insignificant source.

This assessment was made by considering the potential emissions from heavy vehicles. Australia has around 24,000 heavy vehicles operating in 2016 that conform to Euro IV and Euro V – not all of these are known to employ SCR technology (the UK for example assumes 75 per cent are so equipped), but to be conservative it was assumed all 24,000 vehicles use the technology.

The EMEP/EEA Guidebook suggests it is assumed that urea consumption is 3-4 per cent of fuel consumption for a Euro IV HGV and bus and 5-7 per cent for a Euro V HGV and bus – again to be conservative Australia applied 6 per cent to both classes.

With these assumptions, it was estimated that there are 14kt CO_2 attributed to heavy vehicles in Australia (0.003 per cent of the total inventory).

Australia applied Euro emission standards, however there is a lag of several years. Combined with a historically low uptake of diesel for passenger cars compared to European markets, emissions associated with the use of SCR in passenger cars is expected to be a small fraction of that from heavy vehicles.

Railways (1.A.3c)

Emissions are estimated using Tier 2 methods described by equations 3.1 and 3.2. CO_2 EFs are reported in Table 3.2 and non- CO_2 EFs are reported in Table 3.21. Given data on the composition and engine types in the local fleet, an average fleet EF has been calculated using the individual engine EFs in USEPA (1992). Data on fuel consumption is taken from the Australian Energy Statistics.

Table 3.20 Non-CO_2 emission factors for non-road sources

Source Category	CH_4	N_2O	NO_x	CO	NMVOC
	(g/MJ)				
Rail Transport [(a) (c)]					
ADO	0.004	0.03	1.530	0.202	0.071
IDF	0.004	0.03	1.530	0.202	0.071
Coal	0.002	0.001	0.190	0.220	0.260
Marine Transport [(b) (c)]					
Domestic					
Petrol – Small Craft	0.360	0.001	0.254	20.300	3.240
ADO	0.007	0.002	1.105	0.246	0.075
IDF	0.007	0.002	1.580	0.163	0.046
Fuel Oil	0.007	0.002	2.000	0.044	0.063
NG	0.243	0.001	0.243	0.095	0.029
Coal	0.032	0.001	0.190	0.220	0.260
International					
ADO	0.007	0.002	1.580	0.163	0.046
IDF	0.007	0.002	1.580	0.163	0.046
Fuel Oil	0.007	0.002	2.000	0.044	0.063

Source: (a) USEPA (1995a); (b) Lloyd's Register of Shipping (1995, and previous issue); (c) (IPCC 2006).

Water-borne navigation (1.A.3d)

Emissions are estimated using Tier 2 methods described by equations 3.1 and 3.2. CO_2 EFs are reported in Table 3.2 and non-CO_2 EFs are IPCC 2006 Default values or taken from Lloyds Register of Shipping 1995 and are reported in Table 3.21. As discussed in section 3.2.1, where IPCC 2006 defaults are adopted their appropriateness for Australia has been validated by Orbital Australia (Orbital 2011a) and are therefore considered to be country specific emission factors.

Emissions from international bunker fuels are also estimated, but are excluded from national emission inventory aggregates by international agreement. Activity data for international bunkers is estimated by the Department as part of the Australian Energy Statistics. the Department also uses data published in the *Australian Petroleum Statistics* (APS, DIIS 1996-2016) series. Monthly national and state petroleum statistical information are published in the Australian Petroleum Statistics. Sales of aviation turbine fuel, diesel and fuel oil for domestic and international uses are separated on a quarterly basis.

The Australian Petroleum Statistics explanatory note, which informs company reporting, states that the distinction between international and domestic fuel consumption data is undertaken according to the predominant mode of usage by the consumer.

Pipeline transport (1.A.3.e.i)

Australia has an extensive system of long distance natural gas transmission pipelines. As with oil and gas production, emissions may occur as a result of compressor starts (for which gas expansion is typically used to start gas turbine power units), blowdowns for maintenance at compressor stations, maintenance on pipelines, leakage, and accidents.

The Australian high pressure gas transmission system is of relatively recent vintage (the oldest line dates from 1969), has been built to high quality standards and is well maintained. Work undertaken by the Pipeline Authority (the organisation formerly responsible for operation of the Moomba to Sydney pipeline) concluded that losses from a typical gas transmission pipeline in Australia are 0.005 per cent of throughput.

The factor of 0.005 per cent and the throughput data are used in conjunction with national average pipeline gas composition figures for each year, as given in Table 3.42. Throughput data are obtained from the NGERS (2009-2016), the Australian Gas Association (AGA) and the Energy Supply Association of Australia (ESAA). IPCC 2006 recommends an approach where emissions are also linked to the length of pipeline rather than solely using throughput. Consistent with this approach, emissions are calculated for a reference year and emissions for other years scaled against the reference year according to the change in pipeline length.

3.5.3 Uncertainties and time series consistency

The Tier 1 uncertainty analysis in Annex 2 provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by the use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to EFs or methodologies occur, a full time series recalculation is undertaken.

3.5.4 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1 and the fuel combustion specific QA/QC outlined in section 3.2.6.

The primary sources of activity data for this sector are the Department of the Environment and Energy (DoEE) and the Australian Bureau of Statistics (ABS). These two organisations have systematic quality assurance programmes in place. In addition, there are also a number of critical user organisations and alternative data sources available for this sector.

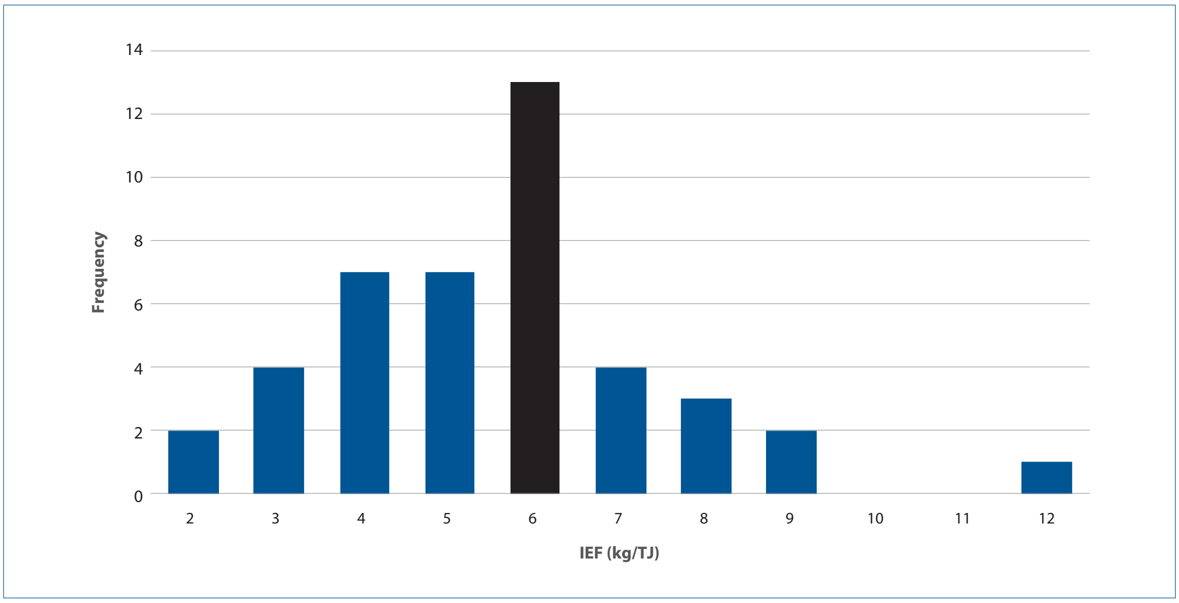
Comparisons of IEFs and with international data sources are conducted systematically for the Australian inventory. In the 2008 inventory submission it was found that the IEF for CH_4 from the combustion of liquid fuels in Australia (18.1 kg CH_4/TJ) was significantly higher than those of other Annex 1 parties (7.5kg CH_4/TJ). The largest contributor to Australia's high EFs was CH_4 emissions from road vehicles.

Three studies (Orbital 2010, 2011b and 2011c) have improved the emission estimates for fuel combusted by Australian passenger vehicles and light commercial vehicles (the largest contributors to CH_4 fuel combustion emissions).

Throughout the time series, Australia has introduced progressively stricter emission standards for new motor vehicles sold in Australia. Over time, the fleet composition reflects the improved performance of larger amounts of vehicles operating with sophisticated catalysts and efficient fuelling systems. The steady rollout of these technologies into the fleet has been reflected in a steady decrease in the emissions of CH_4 and other unburnt hydrocarbons from gasoline engines in particular.

Further improvements will be implemented for the road transport model as outlined in section 3.5.6.

Figure 3.11 2016 methane implied emission factor (IEF) from liquid fuel combustion (kg/TJ) for Annex I countries and 2017 IEF for Australia



Independent emissions modeling

Independent assessments of emissions from air and road transport are undertaken in Australia, providing good independent verification of emission estimates prepared in accordance with IPCC 2006.

The Department of Infrastructure and Regional Development developed a software tool to compute and track the carbon footprint associated with aircraft fuel uplifted in Australia, providing an assessment of the robustness of their results by comparing their calculated values with the APS. Their results showed that computed CO_2 estimates using the software tool and inventory estimates differed by 0.1 per cent in 2013 for domestic consumption, and 2.1 per cent for international consumption in 2013.

Additionally, an Australian specific application of COPERT has been developed by the University of Queensland for use in modeling air quality emissions from the Australian road vehicle fleet. Included in this is the ability to model greenhouse gas emissions.

Emission estimates for CO_2 aligned well with the National Greenhouse Accounts, with less than 4 per cent difference in emissions from road transport.

3.5.5 Recalculations since the 2016 Inventory

Minor recalculations resulted from revised data from the Department of Defence for fuel consumption in military transport. This resulted in a revision of the allocation of total national fuel sales to military use and domestic use in road transport and aviation.

In addition, a minor recalculation for road transport as a result of fleet population.

The effect of the recalculations on 1990 and 2016 is as follows:

- 2018 Submission – 61,395 Gg CO_2-e in 1990, 97,463 Gg CO_2-e in 2016; and
- 2019 Submission – 61,395 Gg CO_2-e in 1990, 96,354 Gg CO_2-e in 2016.

Table 3.21 1.A.3 Transport: recalculation of total CO_2-e emissions, 1990-2016

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1.A.3.a Domestic aviation (a)				
1990	2,624	2,624	0.0	0.0 per cent
2000	4,951	4,951	0.0	0.0 per cent
2001	5,498	5,498	0.0	0.0 per cent
2002	4,943	4,943	0.0	0.0 per cent
2003	4,722	4,722	0.0	0.0 per cent
2004	4,944	4,944	0.0	0.0 per cent
2005	5,375	5,375	0.0	0.0 per cent
2006	5,653	5,653	0.0	0.0 per cent
2007	6,128	6,128	0.0	0.0 per cent
2008	6,637	6,637	0.0	0.0 per cent
2009	6,669	6,669	0.0	0.0 per cent
2010	6,783	6,783	0.0	0.0 per cent
2011	7,584	7,609	25.3	0.3 per cent
2012	7,945	7,945	0.0	0.0 per cent
2013	8,504	8,430	-73.6	-0.9 per cent
2014	8,619	8,525	-94.5	-1.1 per cent
2015	8,628	8,553	-74.9	-0.9 per cent
2016	8,962	8,754	-207.9	-2.3 per cent
1.A.3.b Road Transportation (a)				
1990	53,873	53,873	0.0	0.0 per cent
2000	65,036	64,775	-261.0	-0.4 per cent
2001	64,486	64,263	-223.0	-0.3 per cent
2002	66,428	66,173	-255.0	-0.4 per cent
2003	68,991	68,755	-236.4	-0.3 per cent
2004	71,514	71,271	-242.6	-0.3 per cent
2005	71,805	71,563	-242.0	-0.3 per cent
2006	73,052	72,683	-369.4	-0.5 per cent
2007	73,992	73,689	-303.0	-0.4 per cent
2008	74,829	74,521	-307.6	-0.4 per cent
2009	75,469	75,059	-409.8	-0.5 per cent
2010	76,684	76,271	-413.0	-0.5 per cent
2011	78,624	78,169	-455.3	-0.6 per cent
2012	79,118	78,574	-544.0	-0.7 per cent
2013	78,901	78,271	-630.1	-0.8 per cent
2014	79,972	79,309	-662.0	-0.8 per cent
2015	81,743	80,903	-839.2	-1.0 per cent
2016	82,633	81,732	-901.0	-1.1 per cent
1.A.3.c Railways (a)				
1990	1,962	1,962	0.0	0.0 per cent
2000	1,769	1,769	0.0	0.0 per cent
2001	1,685	1,685	0.0	0.0 per cent

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2002	1,770	1,770	0.0	0.0 per cent
2003	1,851	1,851	0.0	0.0 per cent
2004	2,054	2,054	0.0	0.0 per cent
2005	2,139	2,139	0.0	0.0 per cent
2006	2,147	2,147	0.0	0.0 per cent
2007	2,194	2,194	0.0	0.0 per cent
2008	2,616	2,616	0.0	0.0 per cent
2009	2,716	2,716	0.0	0.0 per cent
2010	2,683	2,683	0.0	0.0 per cent
2011	2,770	2,770	0.0	0.0 per cent
2012	3,067	3,067	0.0	0.0 per cent
2013	3,299	3,299	0.0	0.0 per cent
2014	3,385	3,385	0.0	0.0 per cent
2015	3,658	3,658	0.0	0.0 per cent
2016	3,771	3,771	0.0	0.0 per cent
1.A.3.d Navigation (a)				
1990	2,633	2,633	0.0	0.0 per cent
2000	2,058	2,058	0.0	0.0 per cent
2001	1,959	1,959	0.0	0.0 per cent
2002	1,963	1,963	0.0	0.0 per cent
2003	1,941	1,941	0.0	0.0 per cent
2004	2,115	2,115	0.0	0.0 per cent
2005	2,294	2,294	0.0	0.0 per cent
2006	2,133	2,133	0.0	0.0 per cent
2007	2,920	2,920	0.0	0.0 per cent
2008	2,248	2,248	0.0	0.0 per cent
2009	2,211	2,211	0.0	0.0 per cent
2010	2,420	2,420	0.0	0.0 per cent
2011	2,272	2,272	0.0	0.0 per cent
2012	1,794	1,794	0.0	0.0 per cent
2013	1,545	1,545	0.0	0.0 per cent
2014	1,445	1,445	0.0	0.0 per cent
2015	1,681	1,681	0.0	0.0 per cent
2016	1,601	1,601	0.0	0.0 per cent
1.A.3.e Other Transportation (a)				
1990	303	303	0.0	0.0 per cent
2000	574	574	0.0	0.0 per cent
2001	687	687	0.0	0.0 per cent
2002	776	776	0.0	0.0 per cent
2003	835	835	0.0	0.0 per cent
2004	791	791	0.0	0.0 per cent
2005	841	841	0.0	0.0 per cent
2006	888	888	0.0	0.0 per cent

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2007	921	921	0.0	0.0 per cent
2008	935	935	0.0	0.0 per cent
2009	666	666	0.0	0.0 per cent
2010	620	620	0.0	0.0 per cent
2011	581	581	0.0	0.0 per cent
2012	555	555	0.0	0.0 per cent
2013	606	606	0.0	0.0 per cent
2014	606	606	0.0	0.0 per cent
2015	473	473	0.0	0.0 per cent
2016	495	495	0.0	0.0 per cent
Recalculation explanation				
(a) Activity data revision Revisions to DIS statistics on fuel consumption.				

3.5.6 Planned improvements

A number of mobile source categories are allocated to the stationary source in the inventory because the current national data collection methods do not allocate this fuel to the transport sector but rather to the specific ANZSIC class in which it is used. The Department will continue to monitor the NGER data to investigate the magnitude of these emissions and whether the reliability, completeness and accuracy of the data are adequate to inform a reallocation of these emissions from the stationary sectors to the transport sector.

The Orbital Australia reports (Orbital Australia 2010 and Orbital Australia 2011b) provided detailed vehicle testing data that is at a greater level of disaggregation than is currently supported in the national inventory model. The department plans to investigate and apply updates, as appropriate, to the issues listed below in future inventory submissions:

- Within the passenger vehicle groups, EFs for large SUVs (sport utility vehicles) can vary significantly between specific vehicle make/models depending on the original ADR to which they are certified. These factors are also significantly different to the other vehicle sub-types in the passenger vehicle group. Separate EFs and DRs for SUV-Large are available. The Department will investigate whether all the activity data is available to support further disaggregation of vehicle classifications in the next annual inventory submission; and
- Passenger vehicle and light commercial vehicle EFs from the NISE 2 dataset are available for an additional drive cycle (hot extra urban). The Department will investigate whether the required data is available to support the further disaggregation of drive cycles in the next inventory submission.

The Department will investigate EFs for new petrol passenger vehicles to take account of the latest exhaust emission standards adopted in Australia. This could include a new testing program to examine the real world emissions performance of the Australian vehicle fleet, and provide for the refinement of country specific non-CO_2 emission factors.

The Department has not identified suitable activity data to support the estimation of emissions for IPCC 2006 source category 1.A.3.vi – Urea based catalysts. Australia also has identified this as a common issue with New Zealand during a mutual review undertaken in 2015, and will investigate the availability of activity data in conjunction with New Zealand. Opportunities for data sharing exist given the comparable nature of the diesel powered road transport fleet.

Australia will research methods developed in some European countries for deriving national emission estimates for Urea based catalysts with a view to adopting an appropriate method for the Australian vehicle fleet. Despite the level in Australia being insignificant at present, the expected alignment of Australia emission standards with Europe is likely to significantly increase the numbers of heavy and passenger diesel fueled vehicles operating with SCR emissions reduction technology in the Australian fleet.

3.6 Source category 1.A.4 Other Sectors

3.6.1 Source category description

Source category *1.A.4 other sectors* is an aggregation of the following sources:

- Commercial/Institutional—a diverse category which includes direct emissions from water utilities, accommodation, communications, finance, insurance, property and business services, government and defence, education, health and wholesale and retail trade;
- Residential—emissions from fuel combustion in households, including lawnmowers; and
- Agriculture, forestry and fisheries—emissions from fixed and mobile equipment.

The Australian Energy Statistics report energy consumption for economic sectors is defined using the Australia New Zealand Standard Industrial Classification (ANZSIC). The mapping of ANZSIC codes against IPCC classifications is complete and given in Table 3.23. Only the petroleum from ANZSIC sub-division 50-53 Other transport, services and storage is included in this category. The natural gas consumption is accounted for within the Transport sector (Natural Gas Transmission) sub-category. Similarly, only the natural gas consumption from sub-category 47 Railway Transport is included in this category. Any other fuel consumption within sub-category 47 is assumed to be accounted for within sector 1.A.3.

3.6.2 Methodology

The methodology for this sector consists of tier 2 approaches and country specific CO_2 EFs. Non-CO_2 EFs have been calculated using a sectoral equipment-weighted average approach.

CO_2 emission is reported in Table 3.2. Activity data are taken from the AES published by the Department (DoEE 2017). Non-CO_2 EFs for this sector, by ANZSIC Division, are reported in Appendix Table 3.A.3.

Table 3.22 Relationship between IPCC source categories and ANZSIC sectors: Other Sectors

IPCC Source Category	ANZSIC Category			
	Division	Sub-division	Group/ Class	Description
4. Other Sectors				
A Commercial, Institutional	Division D	281		Water supply, sewerage and drainage services
	Division F			Wholesale trade
	Division G			Retail trade
	Division H, P, Q	57		Accommodation, cultural and personal
	Division I Transport, Postal and Warehousing	50-53		Other transport, services and storage

IPCC Source Category	ANZSIC Category			
	Division	Sub-division	Group/ Class	Description
	Division J			Communication
	Division K, L			Finance, insurance, Property and business
	Division M			Government administration and defence
	Division N, O	84		Education, Health and community services
B Residential	Residential			Residential
C Agriculture, forestry, and fishing	Division A			Agriculture, Forestry and Fishing

Table 3.23 Summary of methods and emission factors: 1.A.4 Other Sectors

Source Category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A4a Commercial/Institutional	T2	CS	T2	CS	T2	CS
1A4b Residential	T2	CS	T2	CS	T2	CS
1A4c Agriculture, Forestry and Fisheries	T2	CS	T2	CS	T2	CS

Notes: T1 = tier 1, T2 = tier 2, T3 = tier 3, CS= Country-specific.

Residential – biomass combustion (1.A.4)

The *Residential* sector also includes specific treatment of the use of firewood and also in the combustion of fuels in mobile equipment such as lawnmowers.

This category is characterised by the use of wood in residential wood heaters. Emissions are modelled using an advanced tier 2 approach which takes into account factors such as wood heater technology and replacement of older models, user operation and Australian wood.

The estimation of emissions from residential firewood use requires a more complex approach to the estimation of emissions from fossil fuels reflecting information on heater design (technology type) and the operation of wood-burning appliances, which influences the mix of emissions per kilogram of firewood consumed.

The proportion of Australian households choosing firewood as their main heating fuel peaked in the early 1990s and has decreased slowly since then. New appliances, with lower emissions of some greenhouse gas species, came on the market in the early 1990s and they have gradually been replacing older, non-certified heater models. Poor user behaviour, which significantly increases emissions of pollutants, has been the target of education campaigns and, in the past few years, programs have been aimed specifically at households with excessive visible smoke. This has led to improved appliance use.

The residential wood heater methodology has been developed for Australian conditions (Todd 2003, 2005 and 2011). This methodology was recently updated (Todd 2011) to account for the latest information and trends. The model was validated against recent field studies of emissions from wood heaters used in Australian household and resulted in a minor increase to the CH_4 EF over the complete time series along with a small decrease in the CO_2 EF. The methodology incorporates factors such as appliance type and certification, wood type and moisture content and user behaviour. The composition of gaseous and particulate emissions when burning eucalypt firewood in typical Australian appliances is based on Gras (2002). A schematic diagram showing the methodology process is shown in Figure 3.13, and is also summarised in the algorithm below:

$$E_{k,n} = F_n \times S \times W \times fn_k\{\Sigma PEF_n\} \quad (3.10)$$

Where $E_{k,n}$ = emission of greenhouse gas k in year n

F_n = amount of fuel combusted (i.e. firewood use) in year n

S = softwood use correction factor

W = wet wood correction factor

fn_k = formula linking the greenhouse gas EF for gas k to the particulate EF.

PEF_n = weighted particulate EF for year n, which is summed over the mix of appliances and operator behaviour for that year, with l = 1 to 8

l(1) certified wood heater correctly operated

l(2) certified wood heater carelessly operated

l(3) certified wood heater very badly operated

l(4) non-certified wood heater correctly operated

l(5) non-certified wood heater carelessly operated

l(6) non-certified wood heater very badly operated

l(7) masonry open fireplace

l(8) factory built (metal) open fireplace

Description of factors

Certified and non-certified heater

- Emission factors

A base CH_4 EF for certified wood heaters of 261.3 Mg/PJ has been developed by Todd (2005). It has been derived from a large database on particulate emissions from heaters meeting the requirements of Australian Standard AS4013. Over 250 different heater models have been tested at the two NATA certified (National Association of Testing Authorities) laboratories in Australia, producing a database of over 2250 individual emission tests (heaters must have three repeat tests at each of high, medium and low burn rates).

A base CH_4 EF of 462.5 Mg/PJ has been applied to non-certified heaters, through the application of a factor of 1.77 to the certified wood heater EF. Todd (2005) based this approach on comparisons between US emission tests of non-certified heaters (referred to as 'Pre-Phase I Non-Catalytic Heaters' in US literature) and certified heaters (referred to as Phase II Non-Catalytic Heaters) (USEPA 1996). The Australian emission test for wood heaters has differences to the US test (both in test fuel, and testing procedure); however, the Australian Standard was cross-checked with two models of heater that had passed both the US (Phase II) and found to be generally similar. Thus the US ratio has been applied to Australian heaters.

- Mix of certified and non-certified heaters and open fireplaces

A survey of households in 2000, carried out as part of a CSIRO study (Gras, 2002), found that 40 per cent of heaters were less than 6 years old (i.e. installed in 1994 or later). Taking into account the number of open fireplaces also in use (derived by Todd 2005 from a 1999 ABS survey), certified wood heaters accounted for 30.6 per cent of all wood-burning appliances in 2000. The population of certified wood heaters has been decreased linearly to 1994, where it is zero (Todd 2005). Todd (2011) extended the time series to 2010 based on data recent wood heater sales numbers from the home heating association.

Operator behaviour

- Emission factors

Three operator classifications have been adopted for these calculations.

a) 'Good' operation means a certified heater will perform as it did in the laboratory test.

b) 'Careless' operation (or poor operation) refers to operators who pay some attention to heater performance, but are not well enough informed. A survey in Tasmania (Todd 2001) suggested at least half the heater owners fall into this category. Careless operation has been assigned EFs 2 times greater than for good operators, applying to both certified and non-certified heaters (expert judgement by Todd 2005).

c) 'Very poor' operation refers to heater operators that regularly run the heater with a slow, smouldering fire. Todd (2001) indicates 10 per cent of households with wood heaters are in this category. The increase in emissions compared to a well-operated heater has been set at a factor of 5 based on a small number of laboratory tests (Todd 2005).

Proportion of well/poorly operated wood heaters

Energy

The proportion of good, careless and very poor wood heater operators for 2000 was set by Todd (2005) and modified by Todd (2011) at 0.5, 0.4 and 0.1 respectively. This is based on surveys in 1999 and 1997 that showed most households thought they operated their heaters correctly, but more detailed questioning showed that few did everything correctly. National TV campaigns (in 1997 'Breathe the Benefits') and a wide range of other education campaigns at state level suggest user behaviour has improved over time, therefore Todd (2005) has used 0.7 (i.e. 70 per cent) for 1990 as the proportion of heaters used carelessly.

The trend in the proportion of households achieving improved wood heater operation evident up to 2000 has slowed based on a recent national survey of wood heater use. From 2001 to 2011 a reduced rate of improved operation has been used.

The very poor operation grouping represents those heaters that regularly emit copious quantities of visible smoke. A 1999 Hobart survey, and feedback from local government officers involved in wood-smoke reduction programs in all states, suggests that about 10 per cent of chimneys/flues smoke excessively. Todd (2005) has allowed for a continuous improvement over the time series, setting 1990 at 0.2, i.e. (20 per cent) of heaters smoked excessively.

The 2007 national survey of wood heater operation and firewood parameters (Todd 2008) identified common operating behaviour that will increase particulate emissions above that found in certification testing. Specifically, 25 per cent of households blocked incoming combustion air by placing logs parallel to the fuel loading door, 17.5 per cent failed to establish a hot fire after refuelling before decreasing the combustion air, and 22.5 per cent used convections fans in ways likely to cause excessive cooling of the firebox. On the positive side 25 per cent of households always established a hot fire before reducing combustion air and 45 per cent of households did not attempt to burn their heaters overnight. The survey supported the earlier estimate that about 10 per cent of households commonly operate their heaters in a manner likely to produce excessive smoke. The survey also suggested at least half the households operated their heaters in a manner that would produce similar emissions to the certified test methods.

Open fireplaces

- Emission factors

No emission testing of masonry open fireplaces has been carried out in Australia. The US (USEPA 1996) value for the particulate EF for masonry open fireplaces (17.3g/kg) has been used by Todd (2005) to derive a base CH_4 EF of 1365.8 Mg/PJ. Even though the wood species used in Australia are different from the US, this is unlikely to have a significant effect on EFs. The CSIRO tests provide particulate EF of 2.3g/kg for factory-built open fireplace (sometimes referred to as heat-recovery fireplaces). This is used by Todd (2005) to derive a base CH_4 EF of 181.6 Mg/PJ. It is assumed that the operator of an open fireplace has little impact on the emissions (on average) and so no correction factors for careless or very poor operation have been used (Todd 2005).

- Proportion of open fireplaces

The proportion of open fireplaces in use is based on the same CSIRO survey and ABS surveys in 1999 and 2001 (Todd 2011).

Softwood fuel and wet wood

- Emission factors

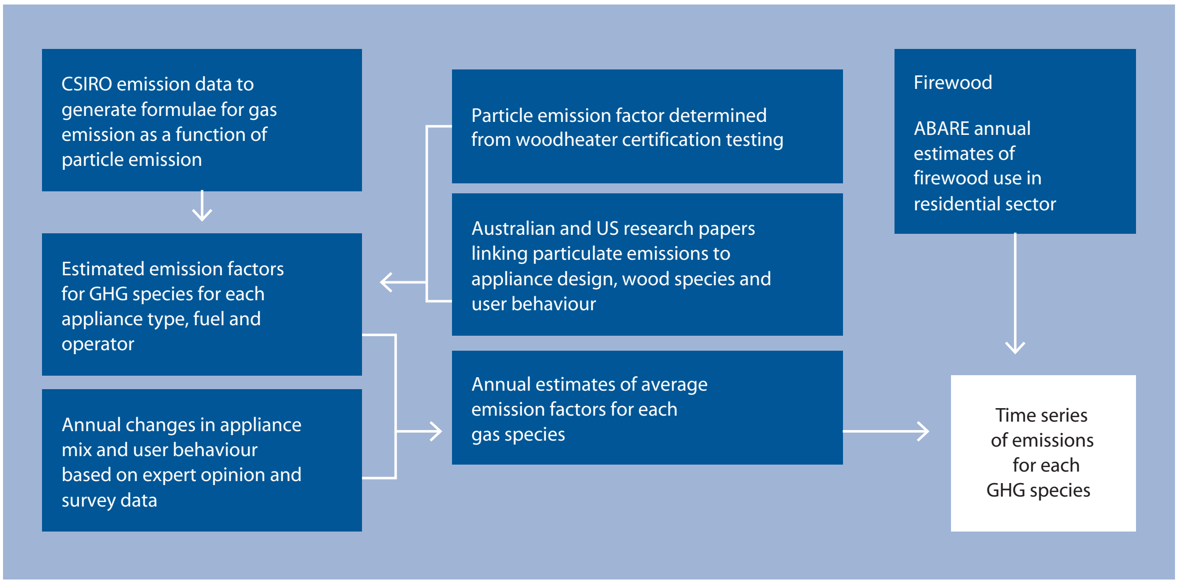
The use of wet firewood is often cited as one of the main reasons for high emissions from wood heaters. However, the CSIRO study, and other Australian studies (e.g. Todd *et al.* 1989a) have consistently shown that only very wet wood (i.e. unseasoned) influences emissions. High burn-rate tests carried out by the CSIRO have shown that very wet wood (moisture greater than 30 per cent) leads to an increase in emissions by a factor of 3.5 (Todd 2005).

The use of softwood fuel in the CSIRO testing led to a large increase in emissions (by a factor of about 3.5). However, other comparative tests of hardwood and softwood emissions (Todd 1991) have shown smaller increases. Therefore, Todd (2005) has adopted a factor of 2.

- Proportion of wet wood and softwood

The 6.25 per cent proportion of households using very wet wood (>30 per cent moisture, wet weight basis) is based on a recent national survey of firewood moisture (Todd 2011). The proportion of softwood used as firewood is based on several surveys (Todd *et al.* 1989b, Driscoll *et al.* 2000, Gras 2002) that consistently show around 5 per cent of firewood consumed is softwood.

Figure 3.12 Schematic diagram of the methodology process for estimation of emissions from wood heaters



Energy

The resulting emissions factor trends are shown below in Table 3.25. With Australian standards for wood heater emissions introduced in 1992, there has been an increasing uptake of certified heaters at the expense of older, non-compliant heaters, as well as open fireplaces. Together with improving user operation, these factors work to produce an overall trend for the more complete and efficient combustion of fuelwood. This is borne out in the increasing CO_2 EF (i.e. more carbon is oxidised under improved combustion conditions) and decreasing CH_4 EF.

As a result, the implied CH_4 EF varies between 1297 Mg/PJ in 1990 and 713 Mg/PJ in 2011. This range is consistent with the 2006 IPCC defaults for residential CH_4 EFs for woodstoves (IPCC 2006, Vol. 2, Table 2.9), taking in account the inherent uncertainty of residential combustion CH_4 EFs of 50 to 150 per cent (IPCC 2006, Vol. 2, Table 2.12).

Table 3.24 Residential biomass emission factors

Inventory Year	Greenhouse Gas Emission Factor (Mg/PJ)						
	CO_2	CH_4	N_2O	CO	NO_x	NMVOC	SO_2
1990	66.7	1,297.0	2.5	13,195.8	14.3	1,642.9	1.1
2000	75.1	844.2	2.0	9,874.9	20.3	1,069.3	1.1
2001	75.3	834.9	2.0	9,806.7	20.4	1,057.5	1.1
2002	75.4	826.0	2.0	9,741.3	20.6	1,046.2	1.1
2003	75.7	814.1	2.0	9,654.3	20.7	1,031.2	1.1
2004	75.8	804.2	2.0	9,581.6	20.9	1,018.6	1.1
2005	76.1	791.3	1.9	9,487.4	21.0	1,002.4	1.1
2006	76.3	778.4	1.9	9,392.5	21.2	986.0	1.1
2007	76.6	765.4	1.9	9,297.2	21.4	969.5	1.1
2008	76.8	752.3	1.9	9,201.2	21.5	952.9	1.1
2009	77.0	739.2	1.9	9,104.8	21.7	936.3	1.1
2010	77.3	725.9	1.9	9,007.8	21.9	919.5	1.1
2011	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1
2012	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1
2013	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1
2014	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1
2015	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1
2016	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1
2017	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1

Emissions from lawnmowers are estimated using tier 2 methods described by equation (3.1). CO_2 EFs are reported in Table 3.2 and non-CO_2 EFs are reported in Table 3.26. There are no fuel consumption statistics for these activities, instead allocation factors are used to derive this data from known consumption statistics. Lawn mowers are powered by small 2-stroke or 4-stroke engines and assumed to be utilised in the ratio of 60:40 (EPA NSW, 1995).

For the *1.A.4.c agriculture, forestry and fisheries category, DoEE* statistics present a single total figure for diesel fuel consumed in agriculture, fisheries and forestry. However, the types of equipment used by these industries vary quite widely (tractors, log skidders, fishing boats etc.), and therefore EFs for non-CO_2 gases also vary widely. It is assumed that the agriculture, fisheries and forestry industries account respectively for 77 per cent, 6 per cent and 17 per cent of total diesel fuel consumption by the sector as a whole. This estimate is based on the relative volumes of diesel fuel for which excise rebates were claimed, as advised by the Australian Customs Service, over the period 1988 to 1994 inclusive, and have been held constant throughout the period.

These ratios were applied to EFs for the different types of diesel engines used in the types of equipment typical of the three sectors, to estimate weighted sectoral EFs (Table 3.25).

Table 3.25 Non-CO_2 emission factors for non-road mobile sources

	CH_4	N_2O	NO_x	CO	NMVOC
			(g/MJ)		
Other Mobile Sources					
Recreational Vehicles					
Petrol	0.03	0.0009	0.37	7	1.08
Industrial Equipment					
ADO	0.0057	0.002	1.006	0.39	0.108
LPG	0.022	0.001	0.437	5.465	0.409
Farm Equipment					
ADO	0.01	0.002	1.36	0.541	0.189
Tractors	0.0096	0.002	1.362	0.543	0.183
Non-Tractors	0.011	0.002	1.351	0.531	0.21
Utility Engines					
Petrol	0.38	0.0009	0.087	13	3.45

Source: IPCC (1997), USEPA (1995a), F. Carnovale pers. comm., 1995.

3.6.3 Uncertainties and time series consistency

The Tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

A revision of the AES was undertaken by DIIS (2016) in response to improved activity data available under the NGER. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period of 2003 to 2014. A consequence of this is a step change exists in some time series for individual fuel types within certain source categories in 2002-2003. See the Recalculations section below in 3.6.5 for a description of these changes and how they affect time series consistency in particular source categories. Note that under 3.6.6 Planned Improvements, any time series inconsistencies are planned to be fixed in future releases of the AES and will be subsequently reflected in the national inventory.

The time series variability of GHG IEFs are likely to be influenced by changes in fuel mix within categories.

3.6.4 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1.

3.6.5 Recalculations since the 2016 Inventory

- Revisions to the Australian Energy Statistics:

Recalculations to 1.A.4 other are detailed at the sub-category level in Table 3.26. Recalculations were made in response to revisions to AES. These revisions were in response to inclusion of improved activity data available under the NGER. In 1.A.4.a, the main driver was the revision in the consumption of natural gas, diesel and petroleum products nec fuels in the Commercial/institutional sector. Minor recalculation were made to increase accuracy and consistency applied to all non-CO_2 emission factors in 1.A.4.b and 1.A.4.c sectors which prompted minor changes to non-CO_2 emissions.

Table 3.26 1.A.4 Other sectors: recalculation of total CO_2-e emissions, 1990-2016

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(per cent)
1.A.4.a Commercial/institutional				
1990	3,614	3,614	0.0	0.0 per cent
2000	4,544	4,544	0.0	0.0 per cent
2001	4,262	4,262	0.0	0.0 per cent
2002	4,401	4,401	0.0	0.0 per cent
2003	4,341	4,341	0.0	0.0 per cent
2004	4,389	4,389	0.0	0.0 per cent
2005	4,456	4,456	0.0	0.0 per cent
2006	4,653	4,653	0.0	0.0 per cent
2007	4,687	4,687	0.0	0.0 per cent
2008	4,804	4,804	0.0	0.0 per cent
2009	4,791	4,825	34.0	0.7 per cent
2010	4,911	4,939	28.0	0.6 per cent
2011	5,070	5,130	59.8	1.2 per cent
2012	5,202	5,347	145.1	2.8 per cent
2013	5,339	5,419	79.5	1.5 per cent
2014	5,695	5,857	161.4	2.8 per cent
2015	5,866	6,002	135.7	2.3 per cent
2016	6,063	6,187	124.6	2.1 per cent
1.A.4.b Residential				
1990	8,526	8,526	0.0	0.0 per cent
2000	9,194	9,194	0.0	0.0 per cent
2001	9,291	9,291	0.0	0.0 per cent
2002	9,144	9,144	0.0	0.0 per cent
2003	9,172	9,172	0.0	0.0 per cent
2004	9,041	9,041	0.0	0.0 per cent
2005	9,048	9,048	0.0	0.0 per cent
2006	9,360	9,360	0.0	0.0 per cent
2007	9,377	9,377	0.0	0.0 per cent
2008	9,541	9,541	0.0	0.0 per cent
2009	9,694	9,694	0.0	0.0 per cent
2010	9,770	9,770	0.0	0.0 per cent
2011	9,950	9,950	0.0	0.0 per cent
2012	10,064	10,064	0.0	0.0 per cent
2013	10,289	10,289	0.0	0.0 per cent
2014	10,381	10,381	0.0	0.0 per cent
2015	10,487	10,487	0.0	0.0 per cent
2016	10,653	10,318	164.7	1.5 per cent

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(per cent)
1.A.4.c Agriculture/fisheries/forestry				
1990	3,464	3,464	0.0	0.0 per cent
2000	4,484	4,484	0.0	0.0 per cent
2001	5,502	5,502	0.0	0.0 per cent
2002	5,586	5,586	0.0	0.0 per cent
2003	6,222	6,222	0.0	0.0 per cent
2004	6,233	6,233	0.0	0.0 per cent
2005	6,573	6,573	0.0	0.0 per cent
2006	6,221	6,221	0.0	0.0 per cent
2007	6,008	6,008	0.0	0.0 per cent
2008	6,076	6,076	0.0	0.0 per cent
2009	6,056	6,056	0.0	0.0 per cent
2010	6,202	6,202	0.0	0.0 per cent
2011	6,234	6,234	0.0	0.0 per cent
2012	6,349	6,349	0.0	0.0 per cent
2013	6,444	6,444	0.0	0.0 per cent
2014	6,398	6,398	0.0	0.0 per cent
2015	6,772	6,772	0.0	0.0 per cent
2016	7,307	7,174	-133.0	-1.8 per cent

3.6.6 Planned improvements

In the *2017 Australian Energy Statistics* (DoEE 2018), DoEE has further incorporated improved activity data available under the NGER into the time series. This has resulted in revisions to fuel consumption and the reallocation of fuel use between source categories for the period 2003 to 2014. An undesirable outcome of this improved data is that a step change exists in some time series for individual fuel types within certain source categories. DoEE is exploring the possibility of extending the revision through to the earlier part of the time series in future AES releases and these revisions will be incorporated into future recalculations of the national inventory when available.

3.7 Source Category 1.A.5 Other (Not Specified Elsewhere)

Emissions from 1.A.5 *other* are estimated using a mix of tier 1 and tier 2 approaches using EFs set out in Table 3.2.

Table 3.27 Summary of methods and emission factors: Other (Not Elsewhere Classified)

Category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1A5b Other (mobile)	T1	CS	T2	CS	T2	CS

Notes: T1 = tier 1, T2 = tier 2, CS= Country-specific.

3.7.1 Source category description

The source category *1.A.5 other* consists of emissions arising from fuel used in mobile equipment within defence operations.

Energy

3.7.2 Methodology

Emissions from military vehicles are estimated using tier 1 methods described by equation 3.3 and 3.4. CO_2 EFs are reported in Table 3.2 and non- CO_2 EFs are reported in Appendix Table 3.A.12.

The allocations of fuel to military transport in 2011, 2012 and 2013 are based on energy use data published by the Australian Government in accordance with the *Energy Efficiency in Government Operations (EEGO) Policy* (AGO 2007). This required the preparation of an annual whole-of-government report on the total energy use and estimated greenhouse gas emissions of Australian Government departments and agencies, and presented in the report *Energy use in the Australian Government's operations* using information reported to the Department of Resources, Energy and Tourism from all government departments and agencies – including the Department of Defence. Allocations for 1995-2007 are linearly extrapolated between the reported data points in 1994 and 2008.

This reporting has now been discontinued, and the allocations of fuel to military transport in 2014 are informed again by direct reporting of fuel consumption by the Australian Department of Defence.

The shares used to allocate fuel consumption are reported in Appendix Table 3.A.13.

3.7.3 Uncertainties and time series consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

3.7.4 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1.

3.7.5 Recalculations since the 2016 Inventory

Recalculations made to *1.A.5 other* are detailed at the sub-category level in Table 3.28.

Table 3.28 1.A.5 Other: recalculation of total CO_2-e emissions (Gg), 1990-2016

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)		(per cent)
1.A.5.b Mobile – Military transport (a) (b)				
1990	423	423	0.0	0.0
2000	635	635	0.0	0.0
2001	639	639	0.0	0.0
2002	591	591	0.0	0.0
2003	561	561	0.0	0.0
2004	583	583	0.0	0.0
2005	623	623	0.0	0.0
2006	6055	6055	0.0	0.0
2007	1,011	1,011	0.0	0.0
2008	1,044	1,045	0.8	0.1
2009	823	823	0.0	0.0
2010	889	889	0.0	0.0

	2018 submission (Gg CO_2-e)	2019 submission (Gg CO_2-e)	Change (per cent)	
2011	933	899	-34	-3.7
2012	881	872	-9	-1.0
2013	842	912	69	8.2
2014	939	1,026	87	9.3
2015	877	946	68	7.8
2016	922	1,124	202	22.0

Military Transport has had minor recalculations for the period 2012–2016 with the inclusion of updated data from the Department of Defence.

3.7.6 Planned improvements

All relevant data are kept under constant review.

3.8 Source Category 1.b.1 Solid Fuels

3.8.1 Source category description

This source category covers fugitive emissions from the production, transport and handling of coal, and emissions from decommissioned mines. It does not include emissions arising from the conversion of coal into coke. Coverage of emissions for 1.B.1 Solid Fuel emission categories are shown in Table 3.29. Both methane and carbon dioxide emissions are reported for both underground and surface coal mines. Estimates for carbon dioxide emissions from decommissioned mines are not currently available, but will be considered for reporting in the inventory as data becomes available under NGER. Carbon dioxide, methane and nitrous oxide emissions are also reported from flaring.

In 2017, there were 44 underground mines and 72 open cut mines operating nationally, while emissions are estimated for 118 decommissioned mines.

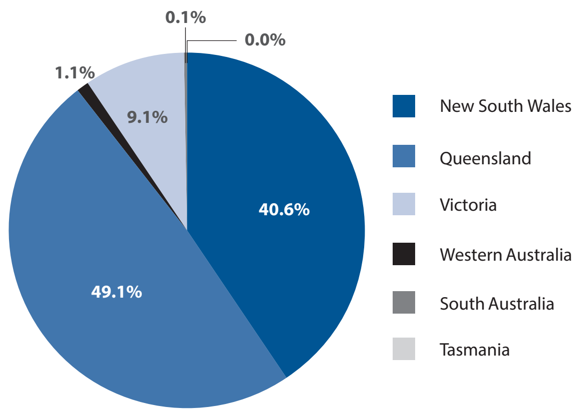
Table 3.29 1.B.1 Solid Fuels – Emissions source coverage

IPCC Category	CO_2 emissions	CH_4 emissions	N_2O Emissions
1.B.1.a.i Underground mines			
Mining	YES	YES	
Post-mining		YES	
1.B.1.a.ii Surface mines			
Mining	YES	YES	
Post-mining		IE (surface mining)	
1.B.1.b Solid fuel transformation		IE (IP – metals)	
1.B.1.c Other			
Decommissioned mines		YES	
Flaring	YES	YES	YES

Energy

The great majority of Australia's resource and production of black coal are located on the east coast of Australia in New South Wales and Queensland. A very small quantity of black coal is also mined in Tasmania. In Victoria, large quantities of brown coal are mined in open cut operations. A relatively small quantity of sub-bituminous coal is mined in Western Australia, and a minor quantity of low rank sub-bituminous coal is mined in South Australia. The share of coal production from Australian states for 2017 is shown in Figure 3.13.

Figure 3.13 Share of coal production from Australian states – 2017



In New South Wales, the principal coal fields are the Southern, Newcastle, Hunter and the Western New South Wales. In Queensland, the main coal fields are the Northern Bowen Basin, the Central Bowen Basin and the Southern Basin. Since 1990 there has been strong growth in production from the Hunter and Bowen Basins and declines from the Southern and Newcastle Basins (see Figure 3.15).

There can be wide variations in both the gas content and the composition of the gas across Australian coal basins, and across coal fields within the basins. The variability and characteristics of coal gas in eastern Australia have been described by Thomson (2010) as a response to a number of distinct geological and biogenic processes, namely:

- the coalification processes;
- tectonic history;
- magmatic activity;
- groundwater flow; and
- biogenesis.

The methane in coal layers has its origins largely in the coalification process that arises from pressure and heat associated with the deep burial of biomass within sedimentary basin deposits. The burial of biomass reached a peak depth during the mid-cretaceous period when it was estimated to be around 2.5 to 4 km deep, resulting in coal layers reaching saturation with thermogenic CH_4. As gas is generated during the coalification process, coal is able to store the gas within its micropore structure. The upper limit of gas able to be held within coal follows an adsorption isotherm, which describes the pressure/temperature relationship at the point where the coal is fully saturated with gas. The isotherm is useful for representing a theoretical cap on the gas content of coal at any given depth. In the Permian coal basins of Australia's east coast, coal layers greater than 500-600m in depth will tend to be close to saturation with thermogenic methane (Thomson 2010).

It is rare, however, for coals saturated with methane to be mined. This is because uplifting and rifting of the strata in geological periods following the coalification process provided opportunities for gas to escape through fracture systems, resulting in the upper coal layers becoming under-saturated with methane. For Australia, this started from the late Cretaceous period with New Zealand rifting away from the Australian east coast, with tthe associated uplifting and subsequent erosion of the coal bearing regions.

The under-saturated coal layers were then receptive to new sources of gas. Extensive magmatism activity in the Tertiary period introduced CO_2 into the upper, under-saturated coal layers. In more recent times, methanogen bearing groundwater flows through the surface fracture system have introduced biogenic methane into the upper coal layers (Thomson 2010).

A generalised model to describe the variation of gas in coal along the east coast coal bearing regions as a result of these processes has been described (Thomson 2010), and is shown in Figure 3.14. Localised geological features can also have a large influence on subsurface gas characteristics at a mine level scale. For example, faults and dykes can provide opportunities for gas to escape or be trapped and influence groundwater flows for biogenesis. In summary, the coal gas type and distribution characteristics of the eastern coalfields can be viewed as a result of the history of large scale processes overlaying localised geological features. Most near surface coal deposits on the east coast are under-saturated, as a function of their geological history. The surface zone is characterised by a very low gas content, predominantly in the form of CO_2.

Coal mining on the west coast of Australia is confined within a small coal field within the Collie basin. The Collie basin coal deposits were formed by the transport of material rather than the bed forming *in situ*. The coal beds are also commonly associated with a sandstone roof providing opportunities for gas to escape over time. The understanding of the geological characteristics, current and historical mining practices, and anecdotal evidence suggested the basin is characterised by low gas content. Mine specific emission data based on measurement is now available through NGER reporting, and is incorporated in this inventory. The data confirms that the Collie Basin coal deposits are characterised by very low gas.

Energy

Figure 3.14 Generalised model of gas variation in the subsurface for east coast Australia

Zone 1	Surface zone to ~ 100m of very low gas – CO_2 dominant
Zone 2	Biogenic zone, 100 to 250/300m Methane increasing with depth
Zone 3	Mixed gas zone. Biogenic and thermogenic undersaturated CH_4 Magmatic CO_2 present
Zone 4	Thermogenic methane, increasing to saturation with depth

Source: Thomson (2010)

3.8.2 Methodology

Fugitive emissions from coal mining activities are estimated using a mix of tier 3 and tier 2 methods. Estimates for underground mines are prepared using a tier 3 method. Data on measured CH_4 emissions for individual mines are obtained from coal mining companies reporting under NGER. For the 2017 year, data on measured CH_4 and CO_2 emissions is available for all 44 underground mines. Time series consistency has been maintained for the underground mine emissions estimates with the use of NGER data (see section 3.8.3).

Fugitive emissions from surface mining are estimated using state-specific default CH_4 emission factors, as well as incorporating facility-specific NGER data for CH_4 and CO_2 emissions, where available and appropriate.

For decommissioned mines, a country-specific tier 2 approach is used with EFs (m³ CH_4/tonne coal produced) derived from measurement data obtained for mines with similar characteristics. Flaring uses a tier 2 approach and a country-specific CO_2 EF.

Table 3.30 Summary of methods and emission factors: 1.B.1 Solid Fuels

Source category	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
Underground mining	T3	PS	T3	PS	NA	NA
Surface mining	T3	PS	T2, T3	CS, PS	NA	NA
Post mining	NA	NA	T2	CS	NA	NA
Decommissioned mines	NA	NA	T2/T3	CS	NA	NA
Flaring	T2	CS	T2	CS	T2	CS

Notes: T2 = tier 2, T3 = tier 3, CS = Country-specific, PS = Plant-specific.

Activity data

Data on coal production provides activity data for the sector and are used as drivers for the estimation of emissions from mines in years where directly measured emissions data is not available. The production data for each mine are published annually in the statistical publications of:

- New South Wales – Coal Services Pty Ltd (2017) (formerly the Joint Coal Board) and NGER data
- Queensland – Department of Natural Resources and Mines (DNRM 2017) and NGER data
- Western Australia – Department of Mines, Industry, Regulation and Safety (DMIRS 2017) and NGER data
- Victoria – NGER data

Underground mining (1.B.1ai)

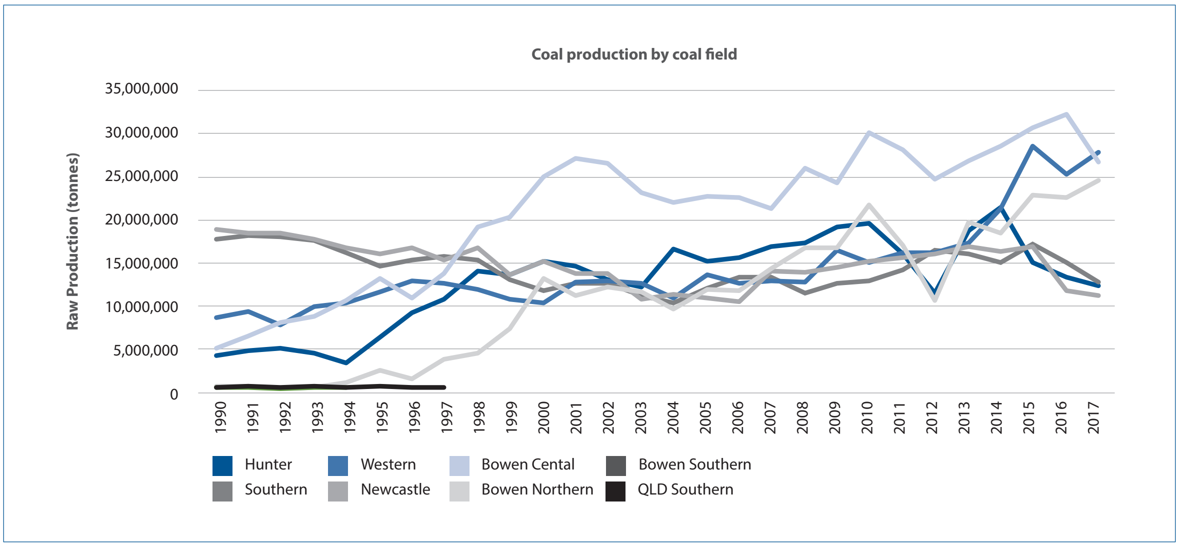
Mining activities

Emissions derived from direct measurement account for the majority of emissions from underground mines reported in the inventory. Emissions are estimated using methods set out in the *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (the Determination) and are based on the measurement of gas concentration and flow within mine ventilation systems. In addition, mines are subject to state government legislation, including the *Coal Mine Health and Safety Act 2002 (NSW), Coal Mine Health and Safety Regulation 2006 (NSW), Coal Mining Safety and Health Act 1999 (Qld)* and the *Coal Mining Safety and Health Regulation 2001 (Qld),* which establish mandatory monitoring regulations for mines. The Determination builds on these existing state regulatory processes.

Coal companies reporting measured CH_4 from underground mines under NGER are also required to measure and report CO_2 emissions. This is significant as, prior to NGER reporting, there was little data available on fugitive CO_2 emissions from Australian coal mining.

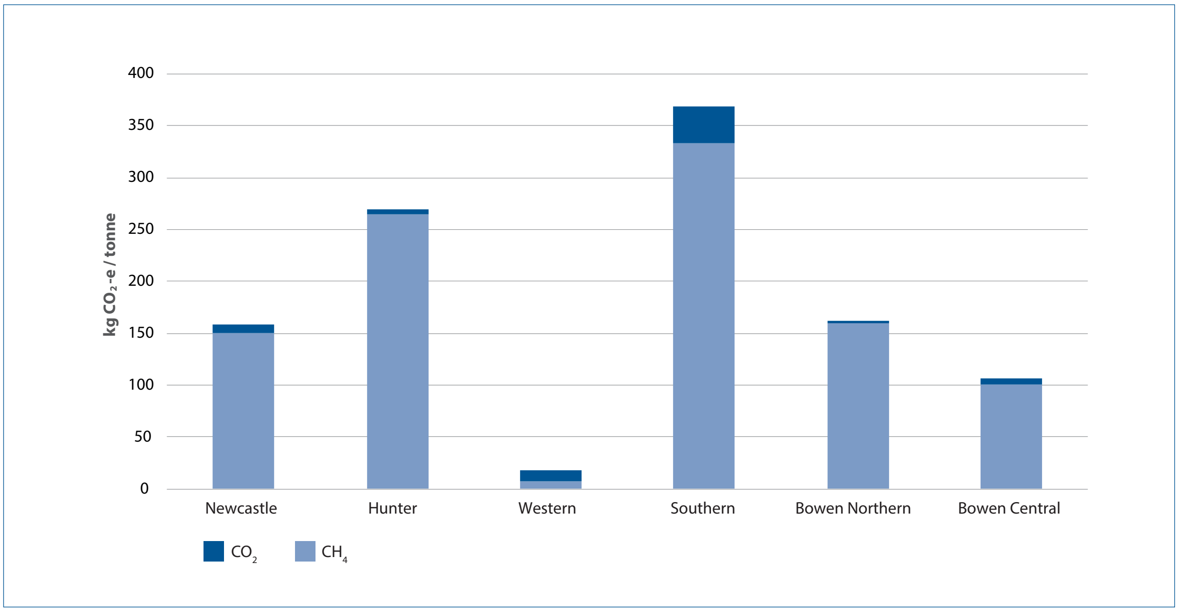
The NGER emission data for underground mine emissions has shown that the gas type and content of different coal fields varies significantly. This is evident in Figure 3.16, which details the average gas content profile of underground production by coal field. The gassiest coal field is the Southern New South Wales, while the least gassy field is the Western New South Wales (which is mainly CO_2).

Figure 3.15 Underground black coal production by coal field



Source: Queensland Department of Natural Resources and Mines (DNRM 2017), Coal Services Pty Ltd (2017).

Figure 3.16 The gas content profile of Australian underground production by coal field



Source: NGER data.

Choice of emission factor

Estimates based on direct measurements were reported for all underground mines under NGER in 2017. Emissions for underground coal mines, which were closed prior to the introduction of NGER, and for which tier 3 data were not available, have been estimated by applying an average IEF for their respective coal fields. This is consistent with the decision tree for use of facility-specific EFs, as set out in section 1.4. In applying the decision tree, it was decided that the NGER data demonstrated that facility-specific EFs, aggregated into subgroups based on spatial correlation (i.e. by coal field), were sufficiently different from the national country-specific EFs and drew on the general understanding that mines within coal fields shared common characteristics due to their shared geological history and structure. Detailed discussion as to how time series consistency has been maintained with the inclusion of NGER data for underground mines is given in section 3.8.3.

Post Mining Activities

Emissions from post mining activities reflect the fugitive escape of gases from the coal after mining, i.e. during preparation, transportation, storage or crushing, and are based on the measurements of Williams *et al.* (1993) and Williams *et al.* (1996). In these studies, the amount of gas retained in coal from gassy underground mines in New South Wales and Queensland, once the coal reached the surface, was analysed. Most of this gas is likely to desorb from the coal before combustion (i.e. during preparation, transportation, storage or crushing) and can therefore be classified as fugitive emissions from post mining activities. These studies related emissions E_{pm} to the quantity of black coal from underground Class A (gassy) mines QTY_a an emission factor EF_{pm} and C_{pm} the volume-to-mass conversion factor for post mine emissions, which equals 0.6767 kg/m^3:

$$E_{pm} = QTY_a \cdot EF_{pm} \cdot C_{pm} \qquad (1B1\_5)$$

The emission factor, E_{pm}, is the average of the results of the two empirical studies. It was found that the amount of gas retained was quite variable, but adopted an average gas EF of 1.7 m^3/t raw coal, of which 75 per cent was CH_4 and 25 per cent CO_2 (Williams *et al.* 1993). An estimated factor, equal to 20 per cent of the *in situ* CH_4 content of coal (6.78m^3/tonne in this case), is applied (Williams *et al.* 1996). It is assumed that post mining emissions are associated only with black coal mined in underground gassy mines, and not with black coal mined in underground Class B (non-gassy) mines.

Surface mining (1.B.1aii)

A mix of tier 3 and country-specific tier 2 methods are used to estimate fugitive methane and carbon dioxide emissions across Australia's regional coal basins.

Table 3.31 Summary of methods and emission factors: 1.B.1 Solid Fuels: Surface mining

Coal field	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
Bowen (Qld)	T3	PS	T2	CS	NA	NA
Surat (Qld)	T3	PS	T2, T3	CS, PS	NA	NA
Hunter (NSW)	T3	PS	T2, T3	CS, PS	NA	NA
Newcastle (NSW)	T3	PS	T2, T3	CS, PS	NA	NA
Western (NSW)	T3	PS	T2, T3	CS, PS	NA	NA
La Trobe (Vic)	NA	NA	T2	CS	NA	NA
South Australia	NA	NA	T2	CS	NA	NA
Collie (WA)	T3	PS	T3	PS	NA	NA

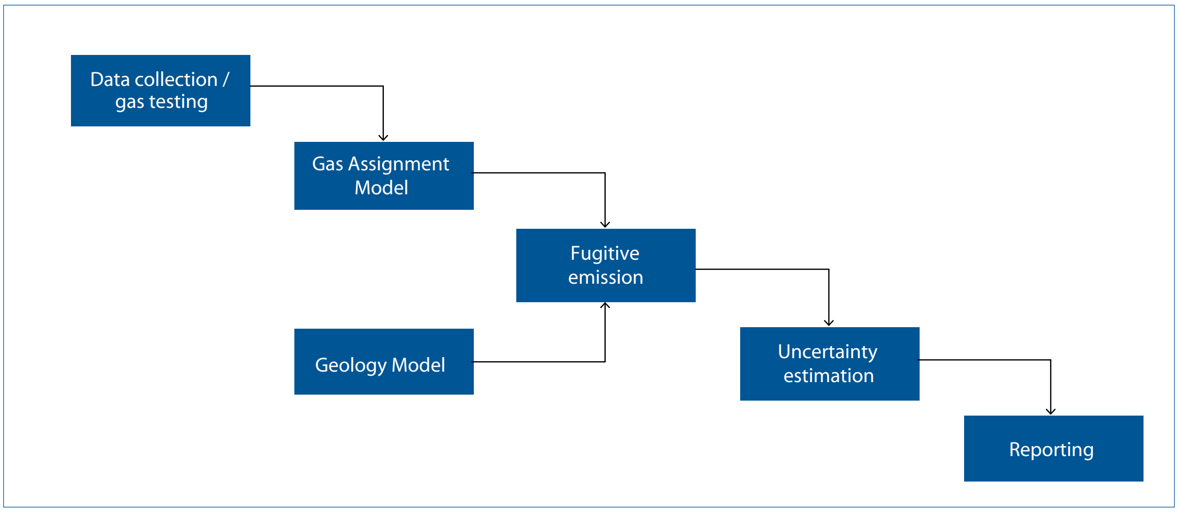
Notes: T2 = tier 2, T3 = tier 3, CS = Country-specific, PS = Plant-specific.

Higher tier, facility-specific, NGER method

The Department of the Environment and Energy has invested in a comprehensive program of measurement technique research and development since 2007 in order to underpin emissions estimation processes under NGER. An important outcome of the program has been the development of guidelines for the application of the existing NGER mine-specific (method 2/3) approach to estimating emissions from open cut mines.

These guidelines have been published by the Australian Coal Association Research Program (ACARP) in December 2011, *Guidelines for the Implementation of NGER Method 2 or 3 for Open Cut Coal Mine Fugitive GHG Emissions Reporting* (C20006). These guidelines have been incorporated into a legislative instrument, the *NGER (Measurement) Determination 2008,* for the application by mines for the estimation of fugitive emissions under NGER. As indicated elsewhere, mine estimates are subject to the full audit and compliance processes that apply for other NGER reports.

Figure 3.17 Surface mines: emissions estimation process flowchart for companies



Source: ACARP 2011.

The key components of the mine-specific method for estimating emissions from open cut mines (Figure 3.17) are:

- a framework for data collection, including borehole sampling and gas testing of coal and gas bearing strata, which ensures representative and unbiased sampling;
- guidelines and standards for data analysis and interpretation;
- an approach for estimating gas in near-surface zones characterised by very low gas contents;
- guidelines on utilising the collected data to produce a model of gas distribution describing the gas content and composition with a defined 3 dimensional volume. This is incorporated within the mine's 3-dimensional geological model to establish the *in situ* gas stock residing within the mine strata (e.g. geological models used for JORC Code [8] resource evaluation, or for mine planning where JORC Code compliance is not applicable, are suitable);
- guidelines on estimating the emissions released from the *in situ* gas stock as blocks of strata within the mine are extracted for coal production; and
- minimum qualifications of persons who are permitted to estimate emissions from an open cut mine using the higher order method.

The NGER (Measurement) Determination 2008 sets out requirements for the sampling and analysis to be undertaken by facilities to determine the gas content contained in rock strata within a coal mine; the parameters for the low gas zone, and the application of a gas distribution model to develop an emissions estimate for a surface mine as well as the determination of a low gas zone.

A description of the conceptual framework supporting the facility-specific NGER method is detailed below.

8 The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves developed by the Joint Ore Reserves Committee (JORC).

Energy

A. For estimating total surface mine fugitive emissions in a year:

$$E_j = \gamma_j \Sigma_z(S_{j,z})$$

Where E_j is the fugitive emissions of gas type (j) that result from the extraction of coal from the mine during the year (CO_2-e tonnes).

γ_j is the factor for converting a quantity of gas type (j) from cubic metres at standard conditions of pressure and temperature to CO_2-e tonnes, as follows:

(a) for methane—$6.784 \times 10^{-4} \times 25$;

(b) for carbon dioxide—1.861×10^{-3}.

$\Sigma_z (S_{j,z})$ is the total of gas type (j) in all gas bearing strata (z) under the extraction area of the mine during the year, in cubic metres.

B. For estimating the total gas contained by gas bearing strata for (A) above

(1) For $S_{j,z}$ for gas type (j) contained in a gas bearing strata (z) under the extraction area of the mine during the year, in cubic metres, is:

$$S_{jz} = M_z \text{ x } \gamma_z \text{ x } GC_{jz} - \Sigma_t Q_{ij, cap, z} - \Sigma t\, Q_{ij,flared,z} - \Sigma_t Q_{ijtr} - \Sigma_t E_{j,vented,z}$$

Where M_z is the mass of the gas bearing strata (z) under the extraction area of the mine during the year, in tonnes.

γ_z is the proportion of the gas content of the gas bearing strata (z) that is released by extracting coal from the extraction area of the mine during the year, as follows:

(a) if the gas bearing strata is at or above the pit floor—1;

(b) for gas released below the pit floor.

GC_{jz} is the content of gas type (j) contained by the gas bearing strata (z) before gas capture, flaring or venting is undertaken at the extraction area of the mine during the year, measured in cubic metres per tonne of gas bearing strata at standard conditions.

$\Sigma Q_{ij,cap,z}$ is the total quantity of gas type (j) in coal mine waste gas (i) captured for combustion from the gas bearing strata (z) at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres.

$\Sigma Q_{ij,flared,z}$ is the total quantity of gas type (j) in coal mine waste gas (i) flared from the gas bearing strata (z) at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres.

ΣQ_{ijtr} is the total quantity of gas type (j) in coal mine waste gas (i) transferred out of the mining activities at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres.

$\Sigma_{Ej,vented,z}$ is the total emissions of gas type (j) vented from the gas bearing strata (z) at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres.

(2) In subsection (1), ΣQ_{ijtr} applies to carbon dioxide only if the carbon dioxide is captured for permanent storage.

(3) For GC_{jz} in subsection (1), the content of gas type (j) contained by the gas bearing strata (z) – see C below.

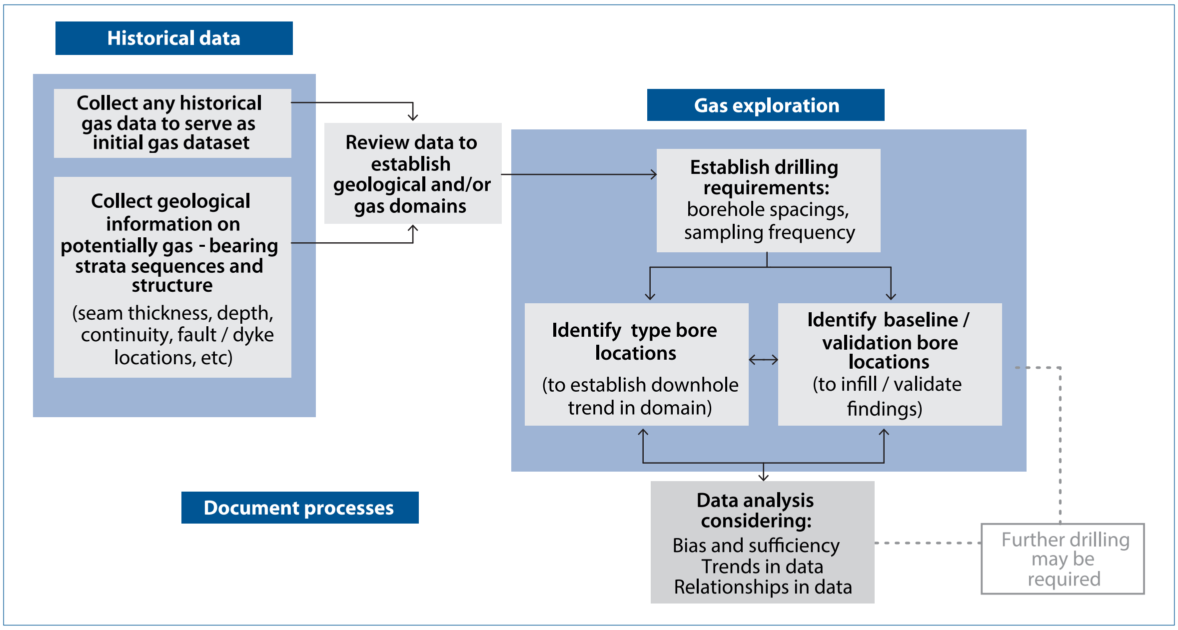
C. For estimating the content of gas type (j) contained by the gas bearing strata (z) total gas contained by gas bearing strata for (B) above:

Data collection and gas testing

A minimum of 3 boreholes that capture the full variance of the gas trends with depth must be located within each gas domain (i.e. area of common gas characteristics). Assessment of the requirement for any additional boreholes is carried out via an iterative process of data review during the gas exploration process to ensure that a sufficient number of unbiased samples have been collected (Figure 3.18).

Sample selection involves the collection of core samples that are representative of the strata that their results will be characterising, and to limit any air contamination both in the field and in the laboratory. Gas testing involves the measurement of each sample's gas content (desorption) and composition according to the Australian Standard AS3980-1999.

Figure 3.18 Surface mine sample collection process flowchart



Source: ACARP 2011.

The low gas zone

In most mine sites, there is a portion of strata immediately below the surface that is lacking in quantifiable quantities of coal seam gases. Gas properties in strata with no or low gas volumes are difficult to measure accurately due to inherent uncertainties associated with sampling and testing processes.

A gas dataset of over 2,000 samples from New South Wales and Queensland were analysed to provide an alternative method for the estimation of emissions from low gas zones in the subsurface. It was found that there is a 'low' or 'no' gas zone present at most open cut coal mines from surface down to a clearly apparent boundary at varying depths. There is a key set of common characteristics observed in these low gas zones:

- over 95 per cent of samples reported gas contents under 0.5 m^3/t;
- over 95 per cent of samples are commonly carbon dioxide (CO_2) and nitrogen (N_2) in gas composition;
- at the horizon where the gas contents increase to over 0.5 m^3/t, the gas compositions simultaneously switch to close to 100 per cent methane (CH_4); and
- this horizon is closely related to the 2 main weathering profiles at the deposit:
  - base of oxidation or water table horizon, and
  - base of weathering (or fresh rock horizon).

Samples within the low gas zone are assigned a default emissions factor. Therefore, all gas bearing strata (i.e. coal and carbonaceous strata with a density less than 1.95 g/cm^3) are assigned default value, obtained from half the measurable quantities of both components observed in this zone: i.e. 0.25 m3/t at 50 per cent CO_2 gas composition.

Energy

Process used for inclusion of NGER surface mine emission data into the national inventory

NGER emissions for surface mines have been incorporated into the national inventory, having regard to the following procedures and issues:

Consistency with the IPCC guidelines and comparison with international practice;

Previous ERT report comments - that have both recommended and encouraged Australia to incorporate NGER emission data for surface mines, when available, into the National Inventory; and

Inventory quality control procedures for data:

- NGER data has been subject to quality control procedures specific to inventory purposes, consistent with the national inventory Quality Assurance/Quality Control Plan, as set out in section 1.6 of the NIR.
- A decision making process with respect to the use of facility specific EFs is set out in section 1.4.1.

The major issue for which the inventory compilation process must control for relates to the question of whether the sample of mines that have estimated emissions using the higher tier methods contains a sampling bias and is not representative of the entire population of coal mines in Australia. At this stage, there is insufficient evidence to indicate that this is the case. This is due to the differing characteristics of individual coal fields, and because companies may select between Method 1 and Method 2/3 when estimating emissions under NGER. Some mines have not estimated emissions using the higher tier methods (non-reporting mines).

Consequently, the reported facility-specific emissions data has been divided into subgroups based on individual coal basins or coalfields with the use of data and approaches to the treatment of non-reported data set out as below.

In Queensland basins, other than Surat, the number of NGER reporters reporting facility – specific emission estimates using higher order NGER methods is considered to be not sufficient for the sample to be representative of the sub-population of the coal basin. In these cases, the facility-specific NGER emission factors for reporting mines may be incorporated into the inventory but the tail of non-estimating mines is constrained such that the total IEF for the coal field is equal to the pre-existing country-specific emission factors. This means that total emissions for these coal fields are not affected by the inclusion of facility–specific data, for this submission.

In the Western, Surat and Collie coal fields – where previously there has been no empirical data available, the number of reporting mines under NGER is much higher and is considered to be sufficiently representative to be included in the inventory. In these cases, facility-specific NGER data have been incorporated into the inventory but the emission factors of these reporting mines have, conservatively, not been extrapolated to the non-reporting mines. In the absence of any pre-existing empirical data for these coal fields the pre-existing country-specific emission factors have been used for the tail of non-estimating mines.

In the case of the Gunnedah Basin, the near universal reporting of higher tier facility data has demonstrated the basin to be significantly different from the existing tier 2 country-specific methane emission factor. Therefore, in this case, a Gunnedah Basin-specific methane emission factor has been developed from facility NGER data and applied to mines in the Gunnedah Basin mine for which high tier methane data are not available.

In practice, the use of facility–specific data have been implemented for the Gunnedah, Western, Surat, Collie, Hunter and Newcastle coal fields. The remaining coal fields in Queensland do not use NGER reported data and retain the use of existing tier 2 country-specific methods (see below).

Black coal mine production

A study of methane flux measurements from open cut coal mines in New South Wales and Queensland (Williams *et al.* 1993) forms the basis for Australia's country-specific, default emission factors. The study used the empirical results to estimate EFs (in m^3/tonne raw coal) applicable to open cut black coal mining, as shown in Table 3.32.

Brown coal (lignite) mine production

Open cut mining of brown coal (lignite) occurs in Victoria for combustion in electricity generation. A methane emission factor for Victorian brown coal mining of 0.0162 m^3 per tonne of raw coal mined is applied. The emission factor is based on a gas measurement program conducted in 2013, which consisted of 96 samples taken from six boreholes across three brown coal mining deposits (HRL 2013).

Surface mining of a low rank sub-bituminous coal occurs in South Australia for combustion in electricity generation. Coal mined in South Australia has an energy content of 13.5 GJ/t. Based on the IEA fuel type classification, which classes non-agglomerating coals under 17.435 GJ/t as being lignite (IEA 2005), the methane EF from open cut brown coal mining of 0.0162 m^3/t (as used for Victorian brown coal) has been applied.

Table 3.32 Tier 2 default CH_4 emission factors for surface mining

State	EF CH_4 m^3/t raw coal mined	Volume-to-mass conversion factor[c] kg/m^3
NSW	3.2 [a]	0.6767
Bowen (Qld)	1.2 [a]	0.6767
Tasmania	1.0 [b]	0.6767
South Australia	0.0162[e]	0.6767
Victoria	0.0162[e]	0.6767

(a) Source: Williams *et al.* (1993) and confirmed by Australian Coal Association.
(b) Source: D Cain, Australian Coal Association, pers. comm. (1993).
(c) These factors are derived by treating CH_4 as an ideal gas, i.e. 16 g (1 gmole) occupies 23.645 at 15 °C and 1 atmosphere.
(d) Source: IPCC 2006.
(e) Source: HRL 2013.

Decommissioned mine emissions (1.B.1.c Other)

Methane emissions are also known to occur under certain conditions following closure of coal mines. Leakage into the atmosphere through fractured rock strata, open vents and seals occurs over daily to decadal timescales.

The Australian methodology is based on the approach developed in the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*. The decline of emissions following mine closure are modelled using emission decay curves (EDCs) for dry gassy and non-gassy mines. In addition, the EDCs are adjusted on a mine–by–mine basis, according to the flooding characteristics of each mine.

Key data required for the approach include:

- mine closure history;
- emissions at time of closure;
- dry mine EDCs for gassy and non-gassy Australian mines;
- mine void size; and
- mine water inflow rates.

Energy

The approach seeks to maximise the use of publicly available data and is best described as a high tier 2 and tier 3 approach. It is consistent with a tier 3 approach in that it estimates emissions on an individual mine basis. However, other mine-specific data characteristic of higher level tier 3 approach are absent, such as characteristics of the mined coal seam, permeability and direct measured emissions.

The EDC methodology used for estimating CH_4 emissions from decommissioned mines can be described as:

$E_{dm} = (E_{tdm} . EF_{dm} . (1 - F_{dm})) - E_{rec}$ .... (1B1_7)

Where E_{dm} is the emissions (Gg methane/year) for a mine at a particular point in time.

E_{tdm} is the annual emission rate of the mine at point of decommissioning (Gg methane/year)

EF_{dm} is the emission factor for a mine at a point in time since decommissioning. It is derived from the EDC (formulae 1B1_8 and _9). The EF is dimensionless.

F_{dm} is the fraction of mine flooded at a point in time since decommissioning.

E_{rec} is the quantity of methane emissions avoided by recovery.

Emission Decay Curves (EDCs)

An EDC describes the decline in fugitive CH_4 emissions over time following mine closure. Hyperbolic curves have been found to function best in portraying the rapid decline in emissions in first few years, followed by a slow decline over time of the remaining emissions.

Australian-specific EDCs were utilised for gassy and non-gassy mines respectively. The EDCs represent the dry mine case and have been developed from studies of long term (1982 -2006) direct gas emission measurements from Australian mines (Lunarzewski 2005 and Armstrong *et al.* 2006). The EDCs are shown in Figure 3.19, and are described in the following formulae:

Gassy mines

$EF_{dm} = (1 + A * T)^b - C$ .... (1B1_8)

Non-gassy mines

$EF_{dm} = (1 + A * T)^b - C$ .... (1B1_9)

Where EF_{dm} is the emission factor (Gg methane/year) for a mine at any point in time since decommissioning (the emission factor is dimensionless).

T is the time (years) elapsed since decommissioning of mine.

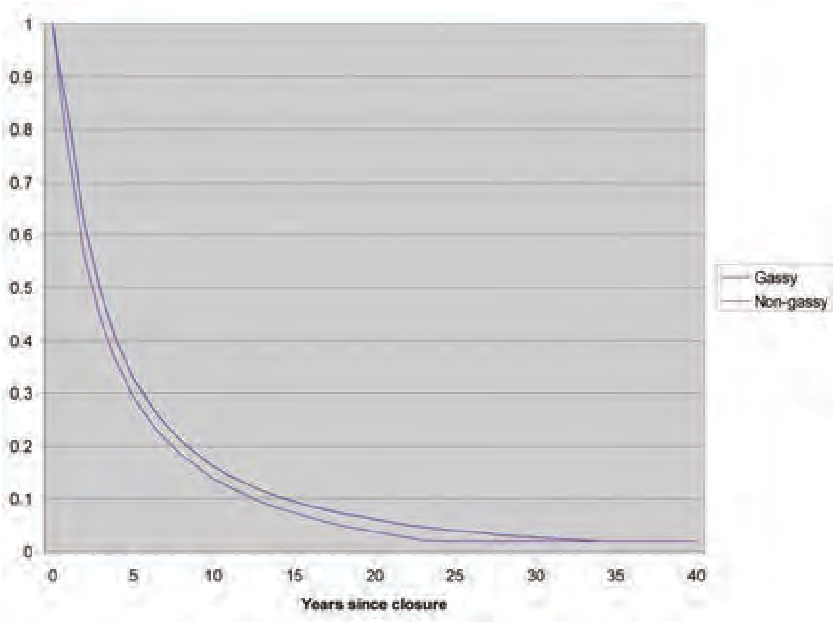
A, b and C are coefficients unique to the decline curves (see Table 3.33).

Table 3.33 Coefficients used in Australian emission decay curves from decommissioned mines

Mine category	Coefficients		
	A	B	C
Gassy Mines	0.23	-1.45	0.0242
Non-Gassy mines	0.35	-1.01	0.0881

Energy

Figure 3.19 Emission decay curves for gassy and non-gassy Australian decommissioned coal mines



Source: Lunarzewski 2005 and Armstrong *et al.* 2006.

Mine Production Data

Mine production data are obtained from:

- Coal Services Pty Ltd (2015), for New South Wales mines from 1972 to 2015; and
- Queensland Department of Natural Resources and Mines (DNRM 2015), Mines and Energy from 1979 to 2015.

In both datasets, details were obtained for mine type (underground/open cut), annual run-of-mine production, and time of closure. Only underground mines were included in the study. Open cut mines were not included in the study as they are associated with relatively low CH_4 emissions. This approach is consistent with that presented in the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*.

Emissions at Closure

In order to estimate the decline of emissions over time following closure, it is first necessary to establish emissions at year zero, i.e. emissions at the point prior to closure. The approach used is consistent with that used to estimate CH_4 emissions from active underground coal mines (see 1.B.1ai). Final mine production at closure is taken as the last full year of production.

Decommissioned mines are defined as Class A (gassy) or Class B (non-gassy) based on existing classifications used to calculate previous *National Greenhouse Gas Inventories*. For earlier mines, for which class tends to be unknown, mines were classified according to their geological proximity to other mines for which class was known.

Adjustment of EDC for flooding mines

It is common for decommissioned mines to become flooded over time. The flooding of mines is known to result in a very rapid decline in the release of CH_4, thus having a substantial impact on the shape of the EDC, and on overall emissions.

The approach uses emission values calculated using dry mine EDCs (formulae 1B1_8 and 1B1 _9) and makes adjustments based on the proportion of the mine flooded at that time. For example, if a mine is 50 per cent flooded 10 years post closure then the emission value derived from the EDC is adjusted at that point in time by 50 per cent.

The following information is required in order to estimate the flooding rate of any particular mine:

- size of the mine void volume; and
- rates of mine water inflow.

Estimating mine void volume

The quantity of run-of-mine coal production removed from the mine is used as a basis for estimating the mine void volume remaining at the time of closure. Total historical mine run-of-mine coal production is converted from tonnes to cubic metres by dividing the total tonnage by 1.425, representing the specific gravity of an average Australian worked coal seam Lunarzewski (2006).

Mine water production data are difficult to obtain on a mine by mine basis, particularly for older, decommissioned mines. The approach taken is to develop a set of basin/state average mine water inflow rates based on available data.

The primary source of mine water production rates for individual mines were obtained from publicly available Environmental Impact Statements (EIS) for mining development projects. EIS provides a good coverage of ground water hydrology, providing data on mine water production rates for proposed mines, extensions, nearby existing mines, and the flooding status of surrounding mines.

Water production rates for three regions were calculated using these data sources. The Southern New South Wales region contained mine water production rates ranging between 1 – 5.0 ML/Day and an average value of 2.5 ML/Day. The Central New South Wales region ranged between 0.4 and 3 ML/Day and an average value of 1.2 ML/Day and Queensland ranged between 0.1 and 0.4 ML/Day and an average value of 0.2 ML/Day.

The following assumptions were necessary in estimating mine water inflow rates:

- the mine floods at a linear rate;
- mine water production is the same for each mine on a basin/state scale; and
- CH_4 is produced evenly throughout the mine and flooding reduces the emissions proportionately to the void volume flooded.

Fully Flooded Mine Emissions

Once a mined void area has been fully flooded, the associated primary gas sources can no longer release gas into the workings. However, remaining free gas in the strata and desorbing gas from unflooded secondary gas sources could continue to leak into the atmosphere (ground surface) via fractured rock strata i.e. geological faults, cracks, and fissures (structurally induced pathways). A constant of 2 per cent of the emissions at the time of mine closure has been adopted to represent emissions once fully flooded (Lunarzewski 2006).

Mine flaring emissions (1.B.1.c. Other)

Data for 2009 to 2017 on the recovery and flaring of CH_4 from coal mines is available from mines reporting under NGER. Time series consistency for coal mine flaring is maintained by the inclusion of flaring data obtained from a 2006 unpublished report on coal mine methane prepared for the Australian Greenhouse Office (AGO 2006b), which provided flared gas quantities by mine for 2005.

For those respective mines, the 2005 flared quantity was then prorated according to the total mine methane emissions for other years to produce a time series. Information regarding when flaring systems were first installed at the respective mines were also taken in to account in producing the time series.

The mine flaring emissions have been reported under 1.B.1.c. Other – Flaring. Although the Solid Fuel CRF Table 1.B.1 does not facilitate the reporting of N_2O emissions from flaring, the UNFCCC reporting tool does allow reporting, and the inclusion of N_2O is evident under Solid Fuels in the CRF Summary Table 2.

The emission estimation methodology utilises a default combustion CO_2 EF of 51.9 Gg/PJ and an energy content of 37.7 GJ/m3 for coal mine waste gas flared, derived from industry data. Facility CO_2 EFs are utilised from NGER data where available. A flaring efficiency factor of 98 per cent is used, consistent with the IPCC *Good Practice Guidance 2000* and 2006 *IPCC Guidelines*.

3.8.3 Uncertainties and time series consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Underground Mines

The transition to the use of NGER data for underground coal mines has had to be carefully managed to ensure that time series consistency has been respected. It is *Good Practice* to perform the splicing using more than one technique before making a final decision and to document why a particular method was chosen. The surrogate method, involving the use of coal production data and an EF derived from actual mine measurements, was chosen as the most appropriate splicing technique. This choice was made because run-of-mine coal production data is available for individual mines for all years and is an underlying activity data parameter that best explains emission trends.

Interpolation was considered as a complementary approach where emissions data are available from non-NGER sources for a previous year and which could be used to provide an EF per unit of coal production for earlier years. In accordance with *Good Practice Guidance* (IPCC 2000), interpolated estimates were compared with surrogate data as a QA/QC check.

For a number of years, data on emissions for certain underground mines have been available from estimates published within company environmental reports or from industry reports to the Australian Greenhouse Office (AGO 2006b). This emissions data has been used for each mine for the years for which they are available. For earlier years, where such emissions data are not available, an EF per unit of production for each mine was established and applied to production levels back through the time series from 1990 to the year when data on emissions first becomes available (Figure 3.20). For the years between the latest company report and the year of the NGER data, the EF for each mine was calculated by interpolating between the EF for the latest year for which company data was available and the EF based on NGER data for the year 2009.

A small number of underground mines closed in the period 1990-2005 for which there are no mine-specific measured data available. Emissions for each year were recalculated using a basin-specific factored, calculated from the NGER data for 2009 and multiplied by production. A similar approach has been adopted for the inclusion of emissions of CO_2 for all mines (Figure 3.20 and Figure 3.21).

Figure 3.20 Time series consistency method for determining underground coal mine emission factors – methane

Methane	1990-2004	2005 Industry survey	2006-2008	2009-16 NGER	2017 NGER	
"Actual" data reported by companies represents the best available and most representative for the year – back cast based on latest available year of actual data. Basin specific factors (based on NGER data) used for mines for which NGER data was not available	EFs held constant	Actual data	Interpolated EFs	Actual data	Actual data	NGER data backcast only until an actual emissions data year is available using interpolation to fill intervening years.

Figure 3.21 Time series consistency method for determining underground coal mine emission factors – CO_2

Carbon dioxide	1990-2008	2009-16 NGER	2017 NGER	
Basin specific factors (based on NGER data) used for mines for which NGER data was not available.	EFs held constant	Actual data	Actual data	Emissions for all earlier years are estimated using the production EF based on mine-specific NGER data.

Surface mines

The introduction of NGER data for surface coal mines in this inventory submission has been undertaken in a manner that maintains time series consistency. A set of rules has been applied that takes into account the new understanding of gas content gained from NGER data and maintains the relevance of the original 1993 study for mines and basins where measurements were previously undertaken.

Where the NGER data is an improvement on the country-specific Tier 2 EF because coal fields are outside the area of the original study (Gunnedah, Western, Surat coal fields), then the earliest NGER facility-specific EF has been applied through the entire time series. Where the new data improves on the old EF because comprehensive NGER measurement provides updated and improved data of the original study area measured in 1993 (Hunter and Newcastle) then, for methane, the earliest NGER facility-specific EF back through the time series by interpolating back until year of original study (1993) or, if mine was not part of original study, then the NGER derived factor is applied to the entire time series.

For carbon dioxide, where no measurements previously exist, then the earliest NGER facility-specific EF is applied to the entire time series.

3.8.4 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1.

Implied emission factors

International comparability

The Department of the Environment and Energy undertook analysis of methane implied emission factors (IEFs) for Australian coal mines to compare statistically with the IEFs reported by other countries in accordance with the Quality Assurance-Quality Control Plan. Overall, it was found that Australia's IEFs for methane emissions were not significantly different to the means of the 2016 IEFs of all other reporting parties. The 2016 data from other reporting parties was used for comparison purposes because 2017 data from key coal producing parties were not available at the time.

Figure 3.22 Implied emission factor (IEF) for methane from solid fuel underground mine (kg/t) for Annex I countries (2016) and IEF for Australia (2017)

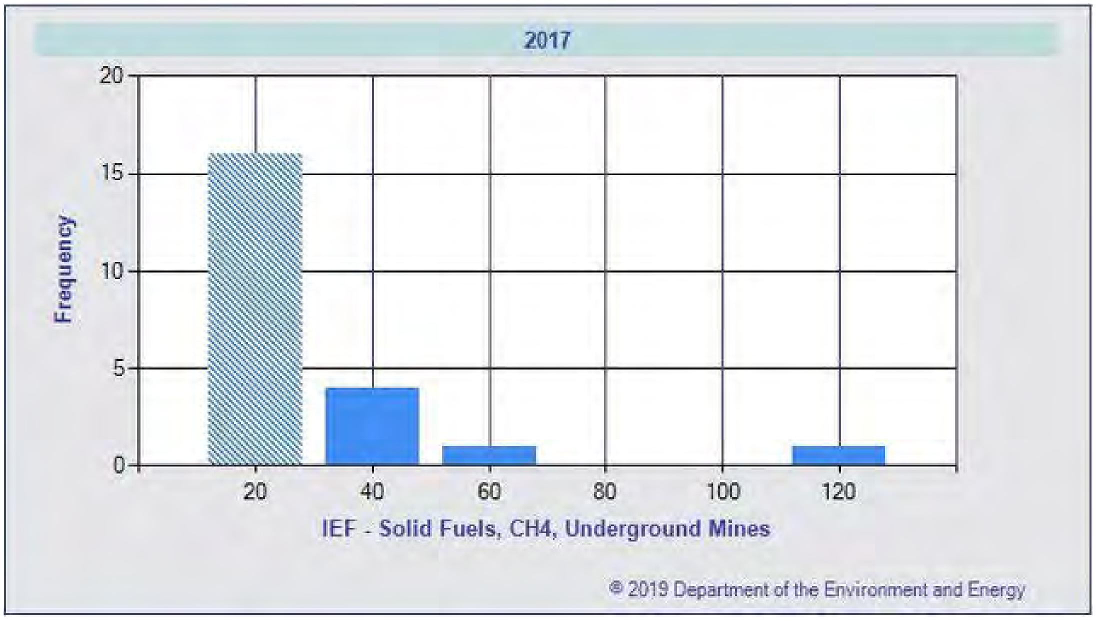
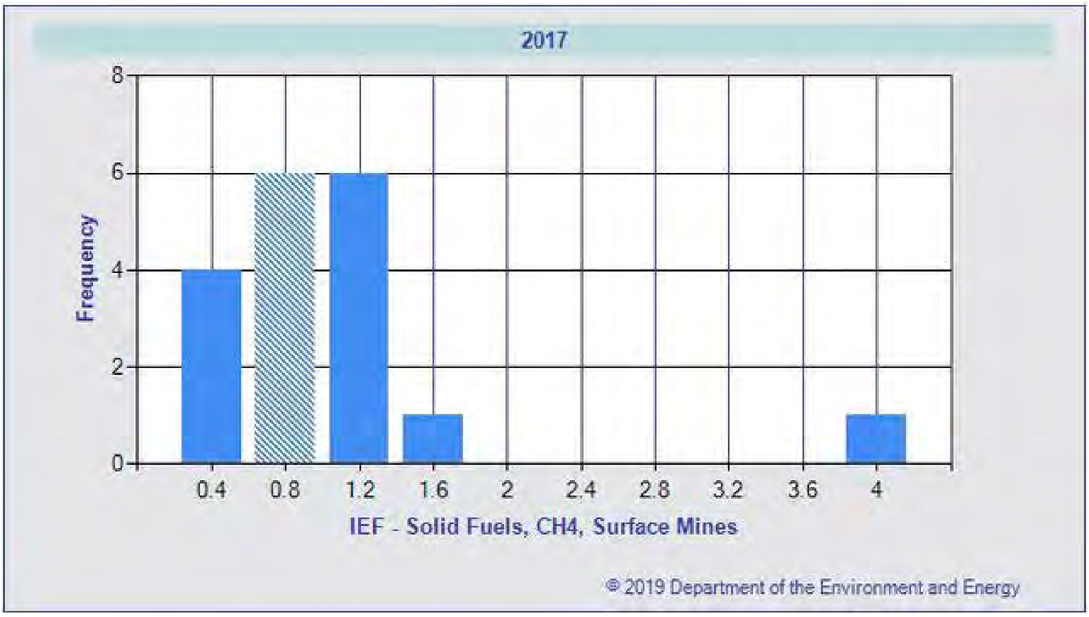


Figure 3.23 Implied emission factor (IEF) for methane from solid fuel surface mine (kg/t) for Annex I countries (2016) and IEF for Australia (2017)



Energy

In 2017, Australia's IEF for methane from underground mines was 5.55 kg CH_4/t compared to 19.56 kg CH_4/t (n = 21) for the 2016 mean of all countries. The result of a t-test comparison of the means showed that the methane IEF from underground mining in Australia is not significantly different to that of the mean IEF for all reporting countries.

Australia's IEF for methane from surface mining in 2017 was 0.47 kg CH_4/t compared to 0.81 (n = 17) for the 2016 mean of countries. The result of a t-test comparison of the means showed that methane IEF from surface mining in Australia is not significantly different to that of the IEF mean for all reporting countries (0.81 kg CH_4/t).

The IEF for carbon dioxide emissions from underground mining in 2017 was 10.12 kg CO_2/t. Statistical comparison with other countries was not possible as very few countries report CO_2 emissions from coal mining. However the figure is comparable to levels of carbon dioxide associated with underground mines in Russia. A study of 16 mines in the Kuznetskiy and Pechorskiy coal basins by Ruban *et al.* (2006) found 11.4 kg CO_2 per tonne of coal produced.

Time series consistency – trends in implied emission factors

Estimates are tested for time-series consistency in accordance with the Quality Assurance – Quality Control Plan. The IEFs from total coal mining activities for Australia are influenced over time by changes in the share of production from mines of varying gas content and gas type and the quantity of methane recovered. This is evident in a declining trend of the methane IEF for underground mines, which reflects a relative increase in production from less gassy mine regions compared to production from high gas coalfields. Figure 3.24 details the declining trend of the underground coal mine IEF since 1990 and the corresponding fall in production from the New South Wales Southern Coalfield, which has the highest IEF of Australian coalfields. In more recent years the increasing use of flaring to combust methane that otherwise would have been vented has acted to reduce the IEF for underground mines in total.

The IEF for all coal mining activities has also declined since 1990 reflecting the additional influence of a relative increase of surface mine production compared to underground production. The trend in production also varies over time, reflecting the effects of opening and closure of large mines, commodity prices and global demand.

The IEF for surface mines also exhibits a decline over time reflecting changes in the relative weight of production from gassy to non-gassy mines between 1990 and 2016.

Measurement audits

The NGER facility-specific method for surface mines involves extensive measurement of in-situ gas within each respective coal mine's coal and carbonaceous rock strata, via borehole drilling and sampling.

All measurements used to support facility-specific estimates of emissions are subject to at least three controls.

First, the NGER legislation sets out minimum qualifications of the estimator of surface mine emissions using the NGER higher tier method. The Estimator is a person, or team of persons, meeting the minimum qualifications described below, who estimates the fugitive emissions from an open cut coal mine.

> *The minimum qualifications of an Estimator are 5 years experience in the assessment of coal deposit continuity and dimensions including the identification of geological features that affect coal seam geometry such as seam splitting, subcrop lines, washouts, and otherwise deterioration in thickness of the coal seams, including (but not limited to) the presence of any adverse structural features (for example faults, folds or igneous intrusions).*

Second, under the carbon price scheme in operation at the time, companies that had an annual emissions that exceeded 125 000 Gg CO_2-e were required to undertake a pre-submission audit report to provide assurance over their NGER emissions report. Audit reports had to have been submitted to the Clean Energy Regulator by the reporting due date of 31 October. The audit had to have been a reasonable assurance engagement, it must have been conducted in accordance with the *National Greenhouse and Energy (Audit) Determination 2009*, and it must have been undertaken by a Category 2 or 3 registered greenhouse and energy auditor.

Third, the Clean Energy Regulator is empowered under the National Greenhouse and Energy Reporting Act to investigate any emission estimates at any time and has a program to undertake a risk-based audit process to provide assurance on the quality of data reported under NGERs.

Use of NGER facility level data in the national inventory

The use of NGER data addresses comments made in previous ERT reports which have both recommended and encouraged Australia to incorporate NGER data for surface mines.

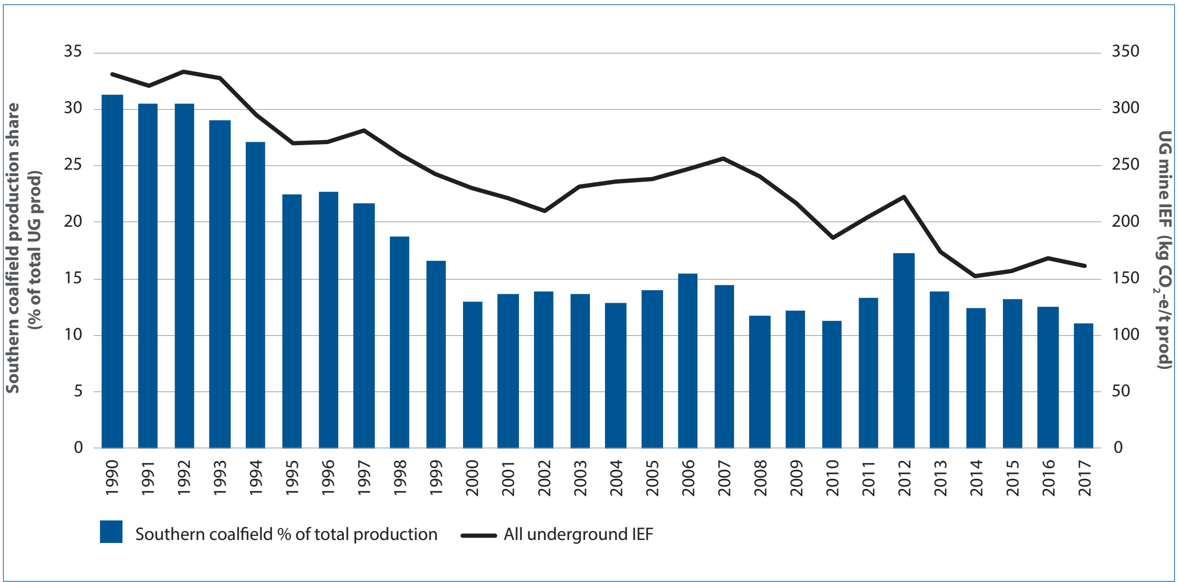
Nonetheless, the application of NGER facility data must be undertaken with care to ensure that issues of selection bias are controlled for. In order to manage these risks, the Department has aggregated the available data into a national account in accordance with principles established in the 2006 IPCC Guidelines and elaborated at the IPCC workshop on the use of facility level data held in Sydney, August 2010 (and as explained in Chapter 1).

In the case of surface mines, not all facilities have undertaken facility specific measurements. In Queensland, apart from the Surat Basin, insufficient facility-specific estimates have been obtained and, in the absence of a sufficient sample of data, the national inventory continues to apply default values for emission factors for coal basins in Queensland (other than the Surat Basin). The cost of measurement of emissions is significant and, as a result, would have ensured that companies were reluctant to undertake measurements. It is not clear, consequently, that the default value used to estimate emissions from Queensland is not an unbiased estimate of emissions. While the effect of selection bias remains possible in this case, this small risk has been mitigated through the country-specific value – 1.2 CH_4 m3/t raw coal mined – which is equivalent to the medium IPCC default value available.

Review of brown coal (lignite) surface mining emission factor

Australia undertook an independent technical review of the new emission factor prior to adoption of greenhouse and inventory reporting. The review found conformity with IPCC guidelines and consistency with other comparable international greenhouse gas inventories. It found the emission factor constituted best practice for estimating emissions from surface coal mining (Pitt and Sherry 2015).

Figure 3.24 Decline of the overall underground coal mine implied emission factor compared with the fall in production from the high gas content Southern Coalfield



Source: Coal Services Pty Ltd 1990-2017 and NGER data.

3.8.5 Recalculations since the 2016 Inventory

Table 3.34 1.B.1 Solid Fuels: recalculation of total CO_2-e emissions (Gg), 1990-2016

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1.B.1.a.i Underground Mines				
1990	18,763	18,763	0.0	0.0 per cent
2000	20,999	20,999	0.0	0.0 per cent
2001	20,420	20,420	0.0	0.0 per cent
2002	19,237	19,237	0.0	0.0 per cent
2003	18,898	18,898	0.0	0.0 per cent
2004	19,159	19,159	0.0	0.0 per cent
2005	20,644	20,644	0.0	0.0 per cent
2006	21,358	21,358	0.0	0.0 per cent
2007	23,770	23,770	0.0	0.0 per cent
2008	23,619	23,619	0.0	0.0 per cent
2009	22,598	22,598	0.0	0.0 per cent
2010	21,370	21,370	0.0	0.0 per cent
2011	21,912	21,912	0.0	0.0 per cent
2012	21,326	21,326	0.0	0.0 per cent
2013	20,057	20,057	0.0	0.0 per cent
2014	18,413	18,413	0.0	0.0 per cent
2015	20,646	20,646	0.0	0.0 per cent
2016	20,236	20,236	0.0	0.0 per cent
1.B.1.a.ii Surface Mines				
1990	3,412	3,412	0.0	0.0 per cent
2000	4,535	4,535	0.0	0.0 per cent

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2001	4,808	4,808	0.0	0.0 per cent
2002	5,246	5,246	0.0	0.0 per cent
2003	4,955	4,955	0.0	0.0 per cent
2004	4,954	4,954	0.0	0.0 per cent
2005	5,477	5,477	0.0	0.0 per cent
2006	5,472	5,472	0.0	0.0 per cent
2007	5,416	5,416	0.0	0.0 per cent
2008	5,094	5,094	0.0	0.0 per cent
2009	5,241	5,241	0.0	0.0 per cent
2010	5,462	5,462	0.0	0.0 per cent
2011	4,716	4,716	0.0	0.0 per cent
2012	5,212	5,212	0.0	0.0 per cent
2013	5,518	5,518	0.0	0.0 per cent
2014	5,916	5,916	0.0	0.0 per cent
2015	6,012	6,012	0.0	0.0 per cent
2016	6,297	6,297	0.0	0.0 per cent
1.B.1.c Decommissioned Mines				
1990	410	470	0.0	0.0 per cent
2000	373	323	0.0	0.0 per cent
2001	832	832	0.0	0.0 per cent
2002	1,395	1,395	0.0	0.0 per cent
2003	1,273	1,273	0.0	0.0 per cent
2004	1,012	1,012	0.0	0.0 per cent
2005	987	987	0.0	0.0 per cent
2006	822	822	0.0	0.0 per cent
2007	688	688	0.0	0.0 per cent
2008	648	648	0.0	0.0 per cent
2009	969	969	0.0	0.0 per cent
2010	1,124	1,124	0.0	0.0 per cent
2011	1,434	1,434	0.0	0.0 per cent
2012	2,287	2,287	0.0	0.0 per cent
2013	1,727	1,727	0.0	0.0 per cent
2014	1,745	1,745	0.0	0.0 per cent
2015	1,412	1,412	0.0	0.0 per cent
2016	1,450	1,450	0.0	0.0 per cent

3.8.6 Planned improvements

Uptake of the higher tier method is expected to continue over future years as new mining areas are opened up, resulting in an increase in mine–specific emission data available for compiling surface mine emissions for the inventory. Complementing this approach, the Department is exploring possibilities to undertake new field work in order to obtain additional measurements for surface mines.

A country-specific method for estimating emissions from decommissioned mines was first introduced in the 2004 NIR. The Department is planning to explore the availability of more recent, facility-specific data, with a view to update the method where appropriate.

The Department is planning to undertake the development of a methodology for estimating emissions from coal exploration boreholes. The method will aim to incorporate country-specific data where possible.

3.9 Source Category 1.B.2 Oil and Natural Gas

3.9.1 Source category description

The IPCC *Guidelines* defines a three level hierarchical structure for source categories related to the oil and gas industries. At the top level of the hierarchy is:

- emissions related to oil (1B2a);
- emissions relating to gas (1B2b); and
- venting and flaring emissions relating to both oil and gas (1B2c).

The 2006 IPCC Guidelines reference the American Petroleum Institute's (API) 2009 *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry definitions*:

- vents are emissions that are the result of process or equipment design or operational practices; and
- leaks are emissions from the unintentional equipment leaks from valves, flanges, pump seals, compressor seals, relief valves, sampling connections, process drains, open-ended lines, casing, tanks, and other leakage sources from pressurised equipment not defined as a vent.

Energy

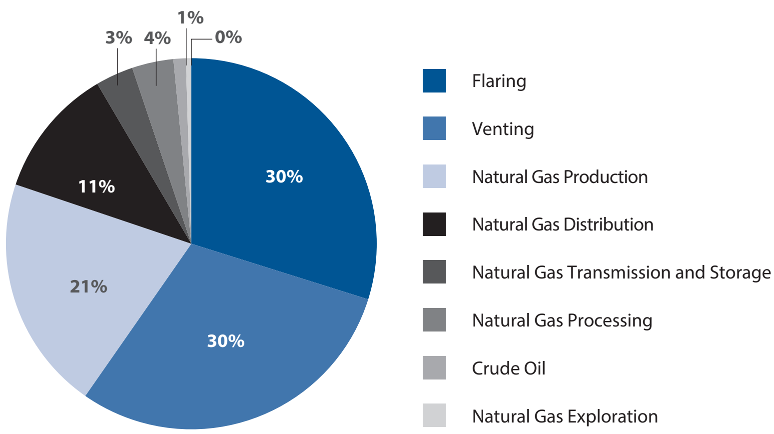
Fugitive emissions associated with various segments of the coal seam gas production chain are reported consistent with UNFCCC reporting requirements, inclusive with emissions from natural gas under 1.B.2.b.1 natural gas exploration, 1.B.2.b.2 natural gas production, 1.B.2.b.3 natural gas processing, and 1.B.2.c venting and flaring.

Fugitive emissions associated with the transportation of coal seam gas are reported, inclusive with emissions from natural gas, under the national inventory reporting source categories of 1.B.2.b.4 natural gas transmission and 1.B.2.b.5 natural gas distribution.

Combustion of raw natural gas used in gas processing, and liquefaction of gas for energy purposes, is reported under stationary energy 1.A.1.C manufacture of solid fuels and other energy industries.

As demonstrated in Figure 3.25, the majority (91.5 per cent) of fugitive emissions from oil and natural gas extraction occur in four source categories: flaring (30 per cent), venting (30 per cent), natural gas production (20 per cent) and natural gas distribution (11 per cent).

Figure 3.25 Fugitive emissions contribution by oil and natural gas sub-sectors, 2017



Descriptions of emission estimation methods are provided in the following section under the respective inventory categories.

3.9.2 Methodology

Oil (1.B.2.a)

The activity data used to calculate emissions from 1.B.2.a oil is documented in Table 3.35.

Table 3.35 Fugitive emissions from oil extraction activity data sources

Inventory Category	Operation/source	Activity Data - Type	Activity Data - Source
1.B.2.a.1 Oil exploration	- Gas flared	Tonnes of gas flared	NGERs facility reports (CER, 2009-2016) and APPEA data (1990-2008)
	- Liquids flared	Tonnes of liquid flared	NGERs facility reports (CER, 2009-2016) and APPEA data (1990-2008)
1.B.2.a.2 Oil production	- Leakage	Tonnes of crude oil produced	NGERs facility reports (CER, 2009-2016) and APPEA data (1990-2008)
1.B.2.a.3 Crude oil transported	- Leakage	Petajoules of crude oil transported	*Australian Energy Statistics* and *Australian Petroleum Statistics* (DIIS) (1990-2016)
1.B.2.a.4 Refining / Storage	- Leakage	Tonnes of crude oil refined	NGERs facility reports (CER, 2009-2015) and APPEA data (1990-2008)
	- Leakage	Tonnes of crude oil stored	NGERs facility reports (CER, 2009-2016) and APPEA data (1990-2008)
1.B.2.a.5 Distribution of oil products	- Leakage	NO	NO
1.B.2.a.6 Other	- Other sources	NO	NO
1.B.2.c Venting and flaring	- Gas vented and flared during oil production and flared during oil refining	See Table 3.45	See Table 3.45

Oil and Gas Exploration (1.B.2.a.1 and 1.B.2.b.1)

Emissions may occur during the process of drilling for oil and gas either during exploration or development drilling, whenever gas or liquid hydrocarbons are encountered. Emission sources include flaring, degassing of drilling muds, and venting during well completions. Emission factors are reported in Table 3.36.

Energy

Table 3.36 Oil and gas exploration flaring, venting, and leakage emission factors

Inventory category	Unit	Factor			
		CO_2	CH_4	N_2O	Source
Offshore/ Onshore testing	tonnes of emissions / tonne of unprocessed gas flared	2.75	0.035	0.000081	APPEA (1998-2006)
	tonnes of emissions / tonne of crude oil flared	3.2	0.00033	0.00022	APPEA (1998-2006)
Drilling	tonnes of emissions / drill day	0.071[(a)]	0.026		API 2009 Table 5.17
Well Completions	tonnes of emissions / event (without fracturing)	0.538[(a)]	0.196		US EPA NIR Table A-134 (2016)
	tonnes of emissions / event (with fracturing and venting)	101.03[(a)]	36.82		US EPA NIR Table A-134 (2016)
	tonnes of emissions / event (with fracturing and flaring)	13.47[(a)]	4.91		US EPA NIR Table A-134 (2016)
	tonnes of emissions / event (with fracturing and green capture)	8.89[(a)]	3.24		US EPA NIR Table A-134 (2016)
Well Workovers	tonnes of emissions / event (without fracturing)	0.013[(a)]	0.0047		US EPA NIR Table A-134 (2016)
	tonnes of emissions / event (with fracturing and venting)	101.03[(a)]	36.82		US EPA NIR Table A-134 (2016)
	tonnes of emissions / event (with fracturing and flaring)	13.47[(a)]	4.91		US EPA NIR Table A-134 (2016)
	tonnes of emissions / event (with fracturing and green capture)	8.89[(a)]	3.24		US EPA NIR Table A-134 (2016)

a) CO_2 EFs were derived from CH_4 EFs using molecular weights (44.01/16.04).

Flaring

Short term testing activities of hydrocarbon flows and pressure may be undertaken following drilling. In the absence of collection infrastructure, which is generally the case in exploration, the hydrocarbons will usually be flared as a means of disposal. CO_2, some unburnt CH_4, and other non-CO_2 gases are released as a result of the flaring.

Drilling Mud degassing

Emissions occur during drilling via the degassing of drilling mud. On drilling through hydrocarbon strata, methane gas can be entrained within the drilling mud and vented at the surface. The 2009 *American Petroleum Institute Compendium* (API) provides emission factors based on specific drilling mud types as follows:

- Water based drilling mud 0.2605 tonnes CH_4/drilling day; and
- Oil based and synthetic mud 0.0586 tonnes CH_4/drilling day.

Source: API 2009, Table 5.-17.

The number of drilling days were estimated using the number of wells drilled for offshore/onshore and coal seam gas type wells, acquired from APPEA (1990-2015), state agencies (DTI 2017 and DNRM 2017b) and industry project sources. The average drill days per well were estimated using APPEA (2009-2015) data utilising the average drilling rate from spud date to target depth, by well type. A factor of 50 per cent was used to represent the portion of a well drill period which encounters hydrocarbons. The proportions of wells drilled with various types of drilling mud were derived from data on mud types used in Western Australia (WA Department of Industry and Resources*; Petroleum Guidelines – Drilling fluid Management 2006*, DIR 2006).

Crude Oil Production (other than venting and flaring) (1.B.2.a.2)

Emissions of CH_4 and NMVOCs may occur during oil production, including field processing, as a result of:

- leakages at seals in flanges, valves, and other components in a variety of process equipment; and
- storage tanks and losses of gases during oil production.

EFs for crude oil production are shown in Table 3.37.

Table 3.37 Oil exploration fugitive emission factors

Inventory Category	Operation/source	Emissions (t) / throughput (kt)					
		CO_2	CH_4	NMVOC	N_2O	NO_x	CO
Crude oil production	Production leaks		0.057				
	Internal floating tank		0.00004	0.0002			
	Fixed roof tank		0.0002	0.112			
	Floating tank		0.0002	0.0009			

Source: APPEA 1998-2006, E and P Forum 1994

Crude Oil Transport (1.B.2.a.3)

The marine, road or rail transport of crude oil results in emissions of NMVOCs, CH_4, and dissolved CO_2. The extent of emissions depends on the gas control technology employed during transfer operations, fuel properties (e.g. vapour pressure and gas composition), ambient temperatures, trip duration, and the leak integrity of tanks.

Emissions associated with the marine transport of crude oil are of three types: loading, transit, and ballasting. From the use of data from the United States Environmental Protection Agency (USEPA), it is estimated that 745 kg CH_4 is emitted per PJ of oil tankered (IPCC, 1997, Volume 3). Using the USEPA finding that CH_4 makes up 15 per cent of the mass of total organic emissions (USEPA, 1995b), the NMVOC EF for marine transport is estimated to be 4,200 kg per PJ of oil tankered.

Fugitive emission estimates are reported for three categories of oil: indigenous crude oil used within Australia, exported crude oil and imported crude oil. Fugitive emissions from the cargoes of ships engaged in international trade are a component of international bunker fuels, which are excluded from national inventories.

The volume of indigenous crude oil transported by ship to Australian refineries is assumed to equal indigenous crude oil production, minus crude oil exports, minus the lesser value of the following:

- Sales of petroleum products in Victoria (DIIS 1996-2016, DoEE 2017a), or
- Production of crude oil in Victoria (DIIS 2016, DoEE 2017a).

The sales data is used when it is lower than the production data because any production exceeding sales in Victoria is assumed to be exported to a different Australian State/Territory. The production of crude oil in Victoria is used when it is lower than sales because any sales exceeding production are assumed to have been imported into the state.

Crude Oil Refining and Storage (1.B.2.a.4)

Crude oil is refined to numerous products via a wide variety of physical and chemical processes. During such processing, fugitive emissions of NMVOCs and CH_4 are generated. Fugitive emission sources at crude oil refineries include valves, flanges, pump and compressor seals, process drains, cooling towers, and oil/water separators.

Crude oil is stored at pipeline pump stations and refineries. During such storage, NMVOCs and CH_4 are emitted from normal processes such as tank breathing, and working and standing losses. Storage or tank losses are a complex function of a number of variables including tank characteristics, fuel properties, meteorological conditions, vapour emission control, and liquid throughput. In the absence of data at the individual refinery level, national CH_4 emissions from crude oil refining and storage may be calculated using default EFs according to IPCC Guidelines. The mid-range IPCC default EFs are adopted for crude oil refining and storage, i.e. 745 kg/PJ for refining and 140 kg/PJ for storage.

Fugitive emissions of NMVOCs resulting from crude oil refining and storage have been estimated for Victoria (Carnovale *et al.* 1991). Based on the Victorian data, it is estimated that the NMVOC EF associated with fugitive and tank storage/loading is 20,000 kg/PJ of oil refined.

The NGER data has provided data on the emissions associated with the burning of refinery coke to restore the activity of the catalyst during the petroleum refining process. Refineries utilised NGER methodologies involving measurement of flue flow rates, flue gas composition and reference to the *Fluid Catalytic Cracking* handbook used in the petroleum refining industry.

Consistent with previous practice, and in order to maintain time series consistency, this source of emissions has continued to be included within total refinery fuel combustion. This remains consistent with practice followed by most other countries. Furthermore, the IPCC *Guidelines* are ambiguous as to whether emissions from this source should be reported as fuel combustion or fugitive emissions.

Oil refinery flaring

The composition of refinery flare feed-gas is highly variable and depends on plant processing, process upsets and flare operation. In this inventory the composition of refinery gas directed to flares is assumed to be 30 per cent CH_4, 30 per cent NMVOCs and 40 per cent H_2 (by volume). An average flare combustion efficiency of 98 per cent is used, based on studies by USEPA (1995b).

For the years 1990 to 2008, the quantity of gas flared is calculated as 0.6 per cent of the total ABARE (1990-2008) annual refinery feedstock as no detailed data has been available on refinery flaring volumes. The methodology considered the range and age of technologies of the Australian refining industry and publicly available information on annual flaring emissions from Australian facilities. These assumptions were reviewed in GHD (2006b).

Facility level data on flaring volumes have become available for the first time in 2009 through NGER. Analysis has shown that the flared quantity based on NGER data is consistent with the assumptions used to derive the activity data prior to 2009. Given that flaring quantities depend on facility-specific technology types and processes, as well as the episodic nature of flaring, it was decided that it was not appropriate to interpolate the NGER activity data back through the time series.

The EFs for flaring are country-specific factors used consistently throughout the time series, and are provided in Table 3.38.

Table 3.38 Emission factors for flaring of gas at oil refineries

Unit	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs
Kg/t gas flared	2,695	6.8	0.081	1.5	8.7	12
Gg/PJ energy flared	47.2	0.12	0.001	0.026	0.15	0.21

Source: DoEE estimates, following methodology of E & P Forum (1994).

Energy

Distribution of oil products (1.B.2.a.5)

The distribution of petroleum products represents a significant source of fugitive NMVOC emissions. Emission sources include motor vehicle refuelling, service station tank filling and breathing losses, major fuel-terminal storage, tank filling losses, refuelling of aircraft, and other mobile sources.

The NMVOC EFs for fuel storage tanks are a complex function of a number of variables and are shown in Table 3.39 on the basis of emissions per sales volumes of each product distributed in Australia. These EFs are calculated from a weighted average analysis of fuel transfer and storage regulations in different regions of Australia (see Appendix 3.A.23 and 3.A.24).

Table 3.39 NMVOC emission factors for petroleum product distribution (kg/kl distributed)

Emission sources	Emission factor (kg/kl distributed)		
	Petrol	Diesel	Avgas
Motor Vehicle/Equipment Refuelling	1.40[a]	0.084[b]	N/A
Service Station/Premises, Storage/Transfer	0.66[c]	0.006[d]	N/A
Bulk Fuel Terminal, Storage/Transfer	1.08[c]	0.009[d]	N/A
Aircraft, Refuelling/Storage	N/A	N/A	2.69[e]
Total all sources	3.14	0.099	2.69

Source: (a). USEPA (1995b) Uncontrolled refuelling and spillage.
(b). USEPA (1992) Uncontrolled refuelling and spillage.
(c). See Appendix Table 3.A.23 and 3.A.24.
(d). Scaled according to ratio of diesel/petrol emission rate for tank breathing and emptying as reported in USEPA (1992).
(e). Australian Environment Council (AEC 1988).

A number of assumptions were made in compiling these EFs. Emissions from refined petroleum products in storage and in transit are assumed to be negligible, meaning that all emissions are associated with transfer and fueling operations. Emissions associated with the normal distribution of LPG are also assumed to be negligible (EPA Victoria 1991; EPA NSW 1995). From a consideration of EFs (USEPA 1992), and the predominant modes of distribution of aviation turbine fuel and fuel oil, emissions of NMVOCs from the distribution of these fuels are estimated to be negligible.

Natural gas (1.B.2.b)

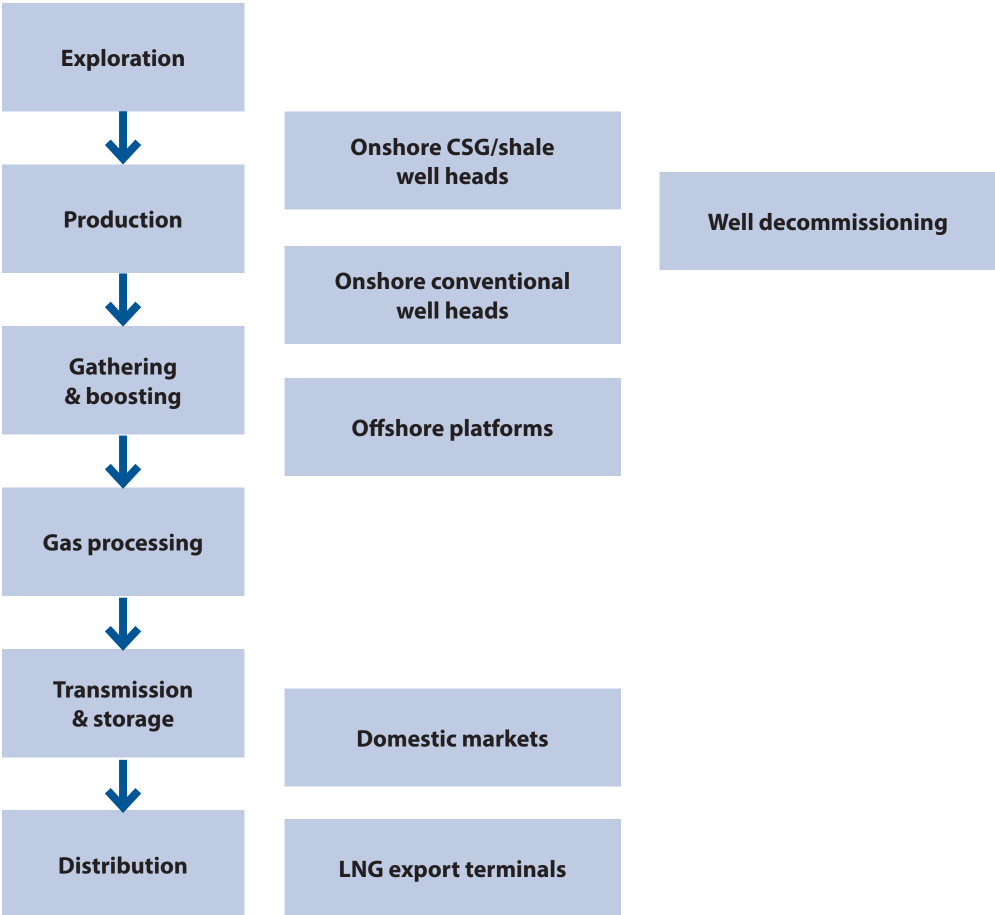
Natural gas production is generated from both onshore and offshore fields. Onshore fields comprise natural gas (mainly South Australia and the Northern Territory) and coal seam gas production (mainly in Queensland). Liquefaction of natural gas for export takes place at the North West Shelf and Pluto liquefied natural gas (LNG) plants near Dampier in Western Australia, Darwin in the Northern Territory and near Gladstone in Queensland.

The major sub-categories of fugitive emissions of methane and carbon dioxide associated with gas supply relate to:

- Natural gas exploration (see 1.B.2.b.1) which includes emissions from drilling, flaring during exploration and emissions from well completions and workovers;
- Natural gas production (1.B.2.b.2) which includes leakages from onshore wells and well-pad operations; onshore gas gathering and boosting equipment and stations, including compressors, dehydrators, pipelines and treatment plants; offshore gas platforms leakages; and leakages from industrial plants and power stations obtained from the NGER system;
- Natural gas processing plant leakages (1.B.2.b.3)
- Natural gas transmission and storage leakages (1.B.2.b.4); and
- Natural gas distribution leakages (1.B.2.b.5) including emissions from residential and commercial sectors.

Fugitive emissions of both methane and carbon dioxide from venting and flaring from gas production and processing steps are described and reported under 1.B.2.c.

Figure 3.26 Emission estimation segments for the gas supply chain



Source: Department of the Environment and Energy.

The emission factors for leakages are derived from the following sources:

1. Australia-specific factors derived from research by the CSIRO, where available;
2. Application of more complex NGERs methods – 'method 2', where appropriate using factors taken from API 2009, consistent with IPCC default factors;
3. Factors derived from US and international research that update or supplement factors in API 2009:
    a. Well completions for fractured wells (US EPA 2016);
    b. Offshore gas platforms (US EPA 2016);
    c. Gathering and boosting stations (Mitchell *et al.* 2015);
    d. Gas processing plants (Mitchell *et al.* 2015); and
    e. Storage and export terminal infrastructure (US EPA 2016).

The activity data used to calculate emissions from 1.B.2.b natural gas is documented in Table 3.40.

Table 3.40 Fugitive emissions from gas extraction activity data sources

Inventory Category	Operation/source	Activity Data - Type	Activity Data - Source
1.B.2.b.1 Gas exploration	- Gas flared	Tonnes of gas flared	NGERs facility reports (CER, 2009-2016) and APPEA data (1990-2008)
	- Drilling leakage	Number of drilling days	Derived from NOPTA and APPEA data (1990-2016)
	- Well completions leakage	Number of wells drilled	NOPTA and APPEA data (1990-2016)
	- Well workovers leakage	Number of well workovers	Derived from APPEA data (1990-2016)
1.B.2.b.2 Gas production	- Wells and well pads leakage	Tonnes of crude oil produced	NGERs facility reports (CER, 2009-2016) and APPEA data (1990-2008)
	- Produced water leakage	Megalitres of water produced	APPEA data (1990-2016)
	- Offshore gas platforms leakage	Number of platforms operating in a year	Geoscience Australia (1990-2016)
	- Gathering and boosting compressor stations leakage	Tonnes of gas throughput	NGERs facility reports (CER, 2009-2016), APPEA data (1990-2008), and Queensland Government CSG production data (1990-2016)
	- Gathering and boosting pipeline leakage	Kilometres of pipeline	Derived using the *Australian Energy Statistics* (DIIS, Petajoules of Production, 1990-2016), Table 6 of *U.S. GHG Emissions and Sinks 1990-2014: Revision to Gathering and Boosting Station Emissions* (2016), and miles of pipe per compressor station in the US 2013 *National Inventory Report* (2016).
1.B.2.b.3 Gas processing	- Leakage	Tonnes of gas throughput	NGERs facility reports (CER, 2009-2016) and AES production data (1990-2016)
1.B.2.b.4 Transmission and storage	- Transmission leakage	Length of high pressure pipeline	*Electricity Gas Australia* (AEC 2017)
	- Gas storage leakage	Number of gas storage stations operating in a year	Australian Energy Market Operator (1990-2016)
	- LNG storage leakage	Number of LNG storage stations operating in a year	Department of the Environment and Energy (1990-2016)
	- LNG terminals leakage	Number of LNG terminals operating in a year	Department of the Environment and Energy (1990-2016)
1.B.2.b.5 Distribution	- Leakage	Terajoules of gas sales	NGERs facility reports (CER, 2009-2016) and AES production data (1990-2016)
1.B.2.b.6 Other	- Other sources	NO	NO
1.B.2.c Venting and flaring	- gas vented and flared from gas production and condensate production	See Table 3.45	See Table 3.45

Gas Exploration (1.B.2.b.1)

Emission factors relating to gas exploration are reported under *Oil and Gas exploration (1.B.2.a.1 and 1.B.4.a.1)* in Table 3.36. Methods for mud degassing are described under *Oil (1.B.2.a).*

Well completions and workovers

Methane emissions occur in association with final well clean-ups, production testing and well stimulation associated with the transition of a well to gas production. The emission factors for well completions and workovers are technology – specific. The factor for well completions without the stimulation of fracking is derived from a study of Australian well completions by Day *et al.* 2017. The factor is 0.196 tonnes of methane per well completion.

In cases of well completions where stimulation of production though fracking occurs, the factors in US EPA 2016 are applied in the absence of any IPCC default factors for these types of events. The factors applied are:

- 36.8 tonnes of methane for a well completion event with fracking;
- 3.2 tonnes of methane for a well completion event with fracking and where a green capture completion is performed; and
- 4.9 tonnes of methane for a well completion event with fracking and where flaring is performed.

The number of well completions was derived from production well activity data obtained from APPEA, state agencies and industry project sources and includes coal seam gas and shale gas wells. The number of well completions by year is provided in Table 3.41. The sharp recent expansion of the coal seam gas industry is evident in the sharp increase in the number of production wells since 2008.

Table 3.41 Well completion activity data for onshore (including CSG) and offshore wells

Year	Number of well completions
1990	125
1991	130
1992	95
1993	124
1994	118
1995	139
1996	117
1997	169
1998	159
1999	144
2000	112
2001	159
2002	176
2003	198
2004	316
2005	326
2006	371
2007	593
2008	646
2009	1039
2010	936
2011	592

Year	Number of well completions
2012	814
2013	1468
2014	1724
2015	983
2016	709
2017	542

Source: APPEA, State agencies and published industry project data.

Natural Gas Production (other than venting and flaring) (1.B.2.b.2)

This category represents leakage emissions from natural gas production, and includes emissions from the unintentional equipment leaks from valves, flanges, pump seals, compressor seals, relief valves, sampling connections, process drains, open-ended lines, casing, tanks, and other leakage sources from pressurised equipment not defined as a vent.

Emission Factors for natural gas production and processing leaks are shown in Table 3.43.

Onshore coal seam gas wells

The leakage rate for operating coal seam gas wells is derived from Day *et al.* 2014. This study collected field data measurements from 43 coal seam gas wells in coal seam gas producing states in Australia and found the mean emission leakage rates from gas producing wells corresponded to an emission factor of 0.000047 tonnes of methane per tonne of gas production.

Produced water disposal

The produced water associated with coal seam gas production as a result of pumping is managed through treatment tanks and dams to enable, generally, the water to be used for some alternative purpose. Residual dissolved methane in the produced water will escape to the atmosphere throughout the treatment process.

The leakage rate, of 0.31 tonnes of methane per million litres of produced water, is taken from API, 2009, Table 5-10, and is the factor cited in the 'method 2' of natural gas production and processing source in the NGERs Measurement Determination. In 2016, there were 60,740 million litres of water produced across Australia.

Onshore natural gas wells

In the absence of a country specific factor for onshore natural gas wells, leakage rates for onshore natural gas wells are derived from onshore coal seam gas well measurements published in Day *et al.* 2014. This study collected field data measurements from 43 coal seam gas wells in coal seam gas producing states in Australia and found the mean emission leakage rates from gas producing wells corresponded to an emission factor of 0.000047 tonnes of methane per tonne of gas production.

Offshore platforms

Offshore natural gas production is any platform structure that houses equipment to extract hydrocarbons from the ocean and that processes and/or transfers such hydrocarbons to storage, transport vessels, or onshore. Emission factors are taken from the US EPA 2016 in the absence of Australian data or IPCC default factors. For shallow water platforms (less than 200 metres of water), the emission factor is 62.6 tonnes of methane per platform per year while for deep water platforms, the factor is 661.1 tonnes of methane per platform per year. In 2017, there were 51 shallow platforms and 7 deep water platforms in Australian waters.

Table 3.42 Fugitive emission factors for natural gas

Inventory category	Unit	Factor		
		CO_2	CH_4	Source
Onshore Natural Gas wells	tonnes of emissions / tonne of gas throughput	0.00013 (a)	0.000047	CSIRO 2014
Offshore natural gas platforms (shallow water)	tonnes of emissions / platform	171.8 (a)	62.6	US EPA
Offshore natural gas platforms (deep water)	tonnes of emissions / platform	1,813.9 (a)	661.1	US EPA
Onshore coal seam gas wells	tonnes of emissions / tonne of gas throughput	0.00013 (a)	0.000047	CSIRO 2014
Produced water	tonnes of emissions / Megalitre of water produced		0.31	NGER Method 2 (API 2009)
Gathering and boosting stations	tonnes of emissions / tonne of gas throughput	0.0041 (a)	0.0015	Mitchell *et al.* 2015
	tonnes of emissions / pipeline kilometre	0.63 (a)	0.23	NGER Method 2 (API 2009)
Gas processing plants	tonnes of emissions / tonne of gas throughput	Modelled	Modelled	Mitchell *et al.* 2015
Natural Gas Transmission and Storage	tonnes of emission / kilometre of pipeline	0.02	0.41	NGER Method
	tonnes of emission / storage station		370	US EPA NIR Table A-134 (2016)
Natural Gas Distribution	Various	Various	Various	See Table 3.43
	tonnes of emission / LNG storage station	2,527.0	921	US EPA NIR Table A-134 (2016)
	tonnes of emission / LNG terminal	3,042.8	1,109	US EPA NIR Table A-134 (2016)

Gathering and boosting stations

The emission factor for gathering and boosting stations is derived from Mitchell *et al.* 2015, who collected measurements from 114 gathering and boosting stations across the United States. Mitchell's sample data has been adjusted for Australian conditions, removing from the sample outliers and data points where the authors were not able to construct a confidence interval. The emission factor for gathering and boosting pipelines is based on factors in API 2009, 6.1.2, Table 6.4 and as cited in NGER method '2'.

Gas Processing (1.B.2.b.3)

The emission factor function for gas processing plants is derived from Mitchell *et al.* 2015, whose data for gas processing plants confirms that those facilities with the highest emission rates tend to be those with the smallest gas throughputs. Analysis of Mitchell's data indicates a non-linear, negative relationship between emission rates and the size of gas processing throughput - in general, higher emission rates are experienced by plants with lower gas throughput and lower emission rates for plants with high gas throughput (Figure 3.27).

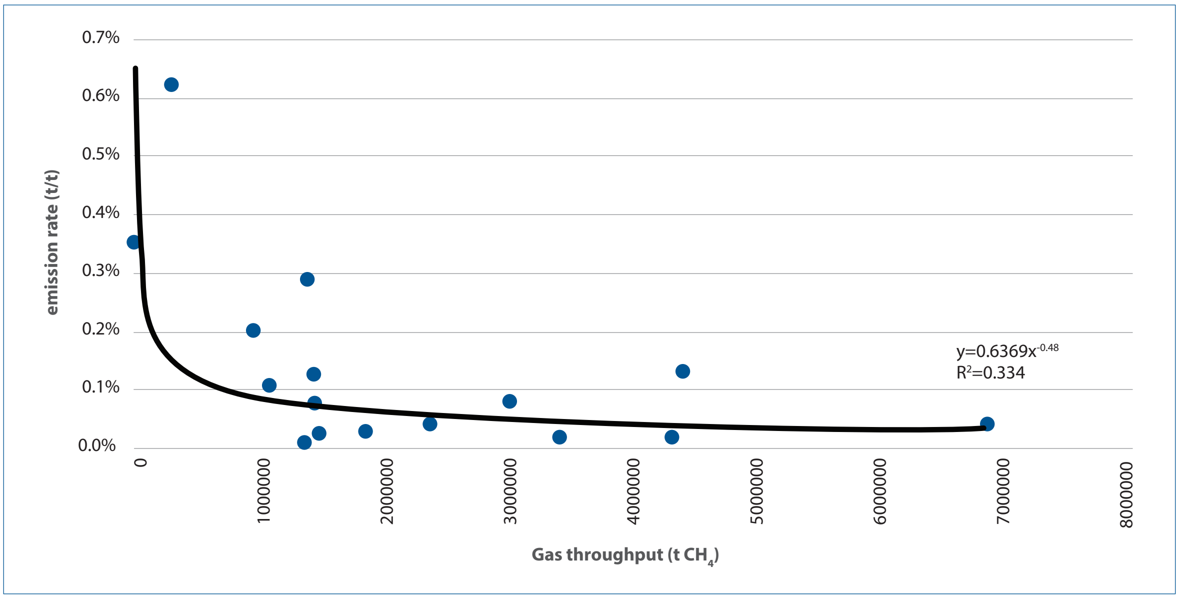
$$Y = 0.6369 . X ^\wedge -0.48$$

Where Y = emission rate in tonnes of emissions per tonne of gas throughput; and

X = gas throughput in tonnes.

Energy

Figure 3.27 Gathering and boosting stations with reported high emission rates are likely to have negligible gas throughputs



Source: Derived from Mitchell *et al.* (2015).

Using this equation, the modelled emission rate for the smallest plant was 0.0065 tonnes per tonne of gas throughput and the modelled emission rate for the largest, 0.0004 tonnes per tonne of gas throughput. These estimates suggest that there are emissions benefits from additional scale in plant design. In 2017, in Australia there were an estimated 43 gas processing plants.

Natural Gas Transmission and Storage (1.B.2.b.4)

Natural gas transmission

Australia has an extensive system of long distance natural gas transmission pipelines. As with oil and gas production, emissions may occur as a result of compressor starts (for which gas expansion is typically used to start gas turbine power units), blowdowns for maintenance at compressor stations, maintenance on pipelines, leakage, and accidents.

The Australian high pressure gas transmission system is of relatively recent vintage (the oldest line dates from 1969), has been built to high quality standards and is well maintained. Work undertaken by the Pipeline Authority concluded that losses from a typical gas transmission pipeline in Australia are 0.005 per cent of throughput.

The factor of 0.005 per cent and the throughput data are used in conjunction with national average pipeline gas composition figures for each year, as given in Table 3.43. Throughput data are obtained from NGER (2009 onwards), the Australian Gas Association (AGA) and the Energy Supply Association of Australia (ESAA). *IPCC Good Practice Guidance (2000)* recommends an approach where emissions are also linked to the length of pipeline rather than solely using throughput. Consistent with this approach, emissions are calculated for a reference year and emissions for other years scaled against the reference year according to the change in pipeline length.

Natural gas storage

Natural gas storage sites are an increasingly important component of the Australian gas marketplace. Natural gas storage emission factors are taken from US EPA (2016), in the absence of IPCC default factors, and set at 370 tonnes of methane per facility per year. In 2016, there were 8 gas storage facilities in operation in Australia.

Natural Gas Distribution (1.B.2.b.5)

There is currently an eight year data overlap between the total annual gas utility sales (AES, DoEE 2018) and the quantity of natural gas distribution reported under NGERs (CER, 2017). The high level, total annual gas utility sales have been used historically in lieu of direct data relating to natural gas distribution. By removing components of these high level estimates that are known to be used in other sectors (i.e. Divisions A, B, D and I of the AES data), it was assumed that the remainder of gas sales fell under the natural gas distribution sector.

Conversely, the NGERs facility data of gas sales directly attributed to natural gas distribution has now been reported for seven years. All of the natural gas distributors of Australia appear to be captured under NGERs, and these data provide a consistently lower time series than the AES data.

The overlap method specified in Chapter 5.3.3.1 on *Time Series Consistency – Overlap* in the 2006 *IPCC Guidelines* was used to splice the series together – specifically by comparing the difference between the two data sources during overlapping years, taking the average proportion of difference, and applying it through the AES time series.

Liquified Natural Gas Storage and Export (1.B.2.b.5)

Liquified natural gas export terminal emission factors are taken from US EPA (2016), in the absence of IPCC default factors, and set at 1109 tonnes of methane per facility per year. In 2017, there were 7 LNG export terminals in Australia. Liquified natural gas storage emission factors are taken from US EPA (2016) in the absence of IPCC default factors, and set at 921 tonnes of methane per facility per year. In 2017, there were an estimated 9 LNG storage stations in operation in Australia.

The boundary between natural gas transmission and distribution is generally taken to be the city gate regulator stations at which gas pressures are reduced from transmission pressures (up to about 15 MPa) to sub-transmission pressures. Most of the gas lost from gas transmissions and distribution systems is by way of leakage from the low-pressure network. The amount of leakage depends on the number and condition of joints in the pipes. The high pressure and trunk main pipes are welded steel, so flanged joints are typically only at valves and compressors. Pressures are so high that any major leaks that might occur are obvious, dangerous and quickly attended.
Other causes of fugitive emissions from gas distribution systems (up to and including customer meter) are:

- third party damage (e.g. excavators);
- purging of new mains;
- unburnt gas from gas compressors (if there are any on the distribution system);
- gas lost to atmosphere on start-up and shut down of compressors; and
- regulating and relief valves.

There are no Australian data on fugitive emissions from the customer side of the meter, but these may arise from such sources as:

- leaking lines at fittings;
- purging of lines during appliance installation and maintenance;
- leaking appliance valves;
- extinguished pilot lights without automatic cut-off; and
- leakage when intermittently operated appliances (e.g. cookers) are ignited and extinguished.

Emissions from the distributor side of the meter are not measured directly, but must be based on estimates of unaccounted for gas (UAG). Components of UAG include: leakage emissions, meter inaccuracies, use of gas within the system itself, theft of gas, variations in temperature and pressure and differences between billing cycles and accounting procedures between companies delivering and receiving the gas.

The ratio of emissions to UAG for Australian utilities has been estimated at 80 per cent (Dixon 1990) and 70–80 per cent (Hutchinson *et al.* 1993). A leakage component for UAG of 90 per cent is used for 1990 (NGGIC 1994), reflecting an additional allowance for the additional emissions from the customers side of the meter, which were not covered in the two studies. An analysis of industry data on the progressive upgrade of the gas distribution infrastructure in response to a variety of drivers, including greenhouse gas emissions concerns, concluded that a figure in the range of 50–60 per cent is more realistic for current circumstances (Energy Strategies 2005). Accordingly, the estimate for leakage under UAG adopts a figure of 55 per cent from 2003 onwards.

The data sources necessary to calculate emissions from natural gas distribution are:

- estimates of UAG as a percentage of gas issued annually by gas utilities in each State, published in the Energy Supply Association of Australia series; *Electricity, Gas Australia* (ESAA 2005-2014, AEC 2017);
- annual gas utility sales in each State and Territory, published in the Energy Supply Association of Australia series; *Electricity, Gas Australia* (ESAA and AEC 2005 onwards); this figure is sales through the low pressure distribution system, and excludes sales made through high pressure mains to electricity generators and large industrial customers;
- NGER data for 2009 onwards, which includes the facility-specific data for natural gas distribution throughput and associated emissions data for all natural gas distributors in Australia; and
- the composition of pipeline gas supplied in each State and Territory pipeline system (Table 3.43).

Table 3.43 Natural gas composition and emission factors

Pipeline	Longford, Melbourne (Victoria)	Moomba, Sydney, Adelaide (NSW, SA)	Roma, Brisbane (Qld)	Denison, Gladstone (Qld)	Dampier, Perth (WA)	Dongarra, Perth (WA)	Amadeus, Darwin (NT)	Australia (weighted average)
kg CO_2/GJ	0.9	0.8	0.8	0.7	1.0	1.5	0.0	0.88
kg CH_4/GJ	15.5	15.6	15.0	16.0	13.9	16.2	12.6	14.9
kg NMVOC/GJ	2.5	2.4	3.2	1.8	4.3	1.8	5.8	3.2
Weighted state averages:								
kg CO_2/GJ			0.8		1.1			
kg CH_4/GJ			15.1		14.3			
kg NMVOC/GJ			3.1		3.9			

Oil and gas production venting and flaring (1.B.2.c)

Venting refers to emissions that are the result of process or equipment design or operational practices. Venting at oil and gas processing facilities is mainly associated with the release of CO_2, which is extracted from the raw gas stream in the course of gas processing. Because separation of the other components of the gas stream from the CO_2 is incomplete, the vented CO_2 contains small quantities of CH_4. The quantities of CO_2 and CH_4 vented will depend on the concentration of CO_2 in the raw gas, which varies significantly between gas fields, and on the mode of operation and efficiency of the CO_2 stripping plant. Gas processing facilities monitor the volumes of the vent gas and CO_2 and CH_4 concentrations as a part of routine plant operation. The venting of CH_4 also occurs from gas assisted pumps and cold process vents.

Flaring refers to the controlled combustion of a mixed flammable gas stream. At oil and gas processing plants, flared gas may arise from crude oil processing or natural gas processing. Where there is no market for gas separated from the wellhead production stream, the gas is reinjected or flared. With the growth in markets for natural gas and an increase in its value, some Australian petroleum production facilities now operate as combined oil and gas facilities, with both oil and gas as marketable products. At such facilities, smaller quantities of gas are flared as part of normal operation of the various processing units. Typically, gas sent to flare is mostly CH_4 with smaller concentrations of other volatile hydrocarbons and is usually different in composition to pipeline gas.

The activity data used to calculate emissions from 1.B.2.c venting and flaring is documented in Table 3.44.

Table 3.44 Fugitive emissions from venting and flaring activity data sources

Inventory Category	Operation/source	Activity Data - Type	Activity Data - Source
1.B.2.c.1.i Oil venting	- Gas vented during oil production	IE - 1.B.2.c.1.ii Gas venting	IE - 1.B.2.c.1.ii Gas venting
1.B.2.c.1.ii Gas venting	- Gas vented during oil production	Tonnes of gas vented	NGERs facility reports (CER, 2009-2017) and APPEA data (1990-2008)
	- Gas vented during gas production	Tonnes of gas vented	NGERs facility reports (CER, 2009-2015) and APPEA data (1990-2008)
	- Gas vented during condensate production	Oil barrels (bbl)	APPEA data (1990-2015) APS data (DIIS, DoEE 2017a onwards)
1.B.2.c.2.i Oil flaring	- Crude oil flared during oil production	Tonnes of liquid flared	NGERs facility reports (CER, 2009-2017) and APPEA data (1990-2008)
	- Gas flared during oil refining	Tonnes of gas flared	NGERs facility reports (CER, 2009-2017) and APPEA data (1990-2008)
	- Gas flared during oil refining	Tonnes of gas flared	NGERs facility reports (CER, 2009-2017) and APPEA data (1990-2008)
1.B.2.c.2.ii Gas flaring	- Gas flared during gas production	Tonnes of gas flared	NGERs facility reports (CER, 2009-2017) and APPEA data (1990-2008)

Venting – Gas

From 1990 to 2008, estimates of emissions are based on APPEA 2008 data. The APPEA data consists largely of direct monitored emissions associated with control vent releases, equivalent to a *tier 3* estimation, as well as estimates of emissions from cold process vents. The NGER approach for 2009 onwards has enhanced the methodologies available for technology types by utilising the American Petroleum Institute Compendium (API 2009) methodologies for vents.

Methane vented from condensate production is estimated from the average factor in the United States, US EPA (2017), and from production published by APPEA.

Flaring – Oil and Gas

EFs can be found in Table 3.45 and are country-specific, sourced from the APPEA industry inventory. The NGER EFs are consistent with those used for the APPEA inventory, thus ensuring time series consistency between the time series.

Energy

Prior to 2009, the APPEA data did not provide splits for flaring between oil and gas sources and, therefore, flaring emissions were reported in the oil/gas combined category. With the introduction of the NGER for the inventory year 2009, separate emissions data has been available for the individual oil and gas flaring categories and therefore the flaring emissions have been reported for 2009 onwards in those respective categories.

In response to ERT recommendation E.13 (2016), a method was implemented in Australia's *National Inventory Report 2014* for splitting oil and gas flaring in 1990-2008. The reporting of a full time series for oil flaring was achieved by calculating the average implied emissions per petajoule of crude oil and ORF (oil refinery fuel) produced (from the *Australian Energy Statistics*) for NGER years (2009 onwards) and applying this factor back through the production time series (1990-2008). These derived oil flaring emissions were subtracted from the combined total of oil and gas flaring emissions, resulting in no net change in emissions from flaring.

Table 3.45 Venting and flaring emission factors

Inventory category	Unit	Factor			
		CO_2	CH_4	N_2O	Source
Gas vented during oil production	NA	Various	Various	Various	NGER
Gas vented during oil production	NA	Various	Various	Various	NGER
Gas vented during gas production	NA	Various	Various	Various	NGER
Gas vented during condensate production	Tonnes of emission / barrel of condensate	0.007	0.0025	-	US NIR 2017
Crude oil flared during oil production	Tonnes of emission / tonne of oil flared	3.2	0.035	0.000081	APPEA 2000
Gas flared during oil refining	Tonnes of emission / tonne of gas flared	2.9	0.0014	0.00022	APPEA 2000
Gas flared during oil refining	Tonnes of emission / tonne of gas flared	2.695	0.0068	0.000081	AGO 2008
Gas flared during gas production	Tonnes of emission / tonne of gas flared	2.7	0.00476	0.000097	NGER

3.9.3 Uncertainties and time series consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Time series consistency is maintained through the use of consistent methodologies and data over time across multiple datasets.

3.9.4 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1.

Leakage rates for the Australian gas supply chain have been compared with rates reported in the United States. The estimated fugitive emissions of methane and carbon dixiode together, are within 15-20 per cent of the estimate for the United States when expressed as a ratio of t CO_2-e/t gas produced. Differences in leakage rates arise from i) differences in industry structure with a) more coal seam gas and less shale gas in Australia and b) more deep water offshore platforms; ii) differences in gas composition - coal seam gas fields in Australia are very high in methane, although one important offshore conventional gas field, Gorgon, is high in carbon dioxide; iii) differences in infrastructure as, for example, US evidence shows that larger gas processing plants have lower emission rates than smaller plants – a shift towards larger plants has been a trend in Australia in recent years; iv) differences in the age of infrastructure - US fields are typically much more mature than Australian fields; and v) differences in corporate and regulatory culture.

The methods used to estimate fugitive emissions in Australia are anchored in methods used for the United States. There are now available numerous national 'top-down' studies based on satellites, flux towers and aircraft measurements for the United States that broadly support estimates prepared by the US EPA using 'bottom up' emission factor approaches of around 1.3 per cent loss of gas throughput. When considered together, neither substantial omissions of emission sources or under-estimates of particular sources in the US inventory are indicated by these 'top-down' studies.

Turner *et al.* 2015, Peischl *et al.* 2014, Miller *et al.* 2013 and Karion *et al.* 2015 provide top-down empirical studies based on measurements taken from satellites and aircraft that underpin confidence in the US EPA estimates for the United States gas industry as a whole.

Analysing GOSAT satellite imagery for 2009-2011, Turner *et al.* 2015 estimate methane emissions from the oil and gas industry for the United States of 8.8-13.2 Tg / yr (22-31 per cent of 40.2-42.7 Tg/year). The most recent US EPA estimate for oil and gas fugitive emissions was within that range at 8.8 Tg/ yr in 2010.

Using aircraft measurements across the Haynesville, Fayetteville and Marcellus regions, Peischl found that the production-weighted loss rate from the three regions was 1.1 per cent of gas throughput – a rate similar to a [then estimated] 1.0 per cent loss rate derived from the 2012 EPA GHG emissions inventory for natural gas systems. The fields of their study account for around 50 per cent of US shale gas production.

Miller *et al.* 2013 reported that estimates from the 2013 US EPA inventory underestimated methane emissions nationally by 25–30 per cent (for 1990–2011). Since their publication, the US EPA has increased its estimate of fugitive methane emissions from the gas fields for 2010 by 23.4 per cent.

Using shares of methane sources attributed to the oil and gas industry by Turner *et al.*, Miller's estimated average methane emissions range for the industry could be put at 7.0 to 10.8 Tg a year for 2007 and 2008. Current US EPA estimates for 2008 are consistent with Miller's estimates being within Miller's range, at 7.6 Tg a year.

Some US studies identify pockets of regionalised hotspots of emissions. In, for example, Utah, a small field accounting for 1.0 per cent of production, emission rates were recorded at 6.2-11.7 per cent (Karion *et al.* 2013). Similar results were recorded for north-western Colorado (Petron 2012) and for an embryonic Marcellus shale region (Caultron 2014). These estimates, while potentially applicable to specific regions, reflecting local hotspots, cannot be meaningfully extrapolated nationally.

Some studies have reported anomalies in larger fields, albeit with large uncertainty. Schneising, of the University of Bremen, and co-authors using the now defunct Sciamachy satellite, estimated loss rates for Bakken 10.1 per cent ±7.3 per cent and Eagleford 9.1 per cent ±6.2 per cent regions but did not report estimates for the Marcellus region which were considered too unreliable. Significant uncertainties present in Karion *et al.* 2013 stem from the authors' inability to use data from more than one monitoring flight out of twelve attempts, underlining the finicky nature of some of these estimation process. These results of these latter studies should be interpreted with caution given the large uncertainties present in the estimation process.

Key segments of the US gas supply chain have also been subject to new empirical estimates: for wells and fracked well completion events, emissions were estimated at 0.4 per cent of gas throughout (Allen *et al.* 2015); for gas gathering and boosting stations, 0.2 per cent (Mitchell *et al.* 2015); for gas processing plants, 0.1 per cent (Mitchell *et al.* 2015); and from transmission and storage systems, 0.2 per cent (Zimmerle *et al.* 2015).

The national estimates for these segments of the gas supply chain, when added together, are broadly consistent with both US EPA estimates of 1.4 per cent of emission losses and the validating top-down national studies.

Some of these 'bottom up' studies identify that the distribution of measured emission rates at individual facilities is often highly skewed, with a small number of facilities recording much higher emission rates. In the majority of measurements at downstream facilities, the identification of extreme leakage rates at individual gas gathering facilities – in the range of 2-17 per cent - proved to be are an artefact of very small, unrepresentative gas throughputs at those stations. Mitchell *et al.*, for example, reports a small number of facilities with loss rates of 17 per cent, and higher, but these are all estimated at gas facilities with negligible amounts of gas throughput.

More generally, Mitchell *et al.* found that a segment of sites did perform less well than other sites. The emission rate for the best performing 90 per cent of the gas gathering equipment in their sample was 0.15 per cent of gas throughput. Of these, the very best performing stations had emission rates around 0.01 per cent of gas throughput. The remaining stations, accounting for the last 5 per cent of gas throughput and largely based in one State, Oklahoma, raised the average emission rate for the whole US industry to 0.2 per cent.

With wells, there is also evidence of irregular emitting behaviour on the part of a small number of wells. Day *et al.* 2014, for example, observed the highest emitting 5 per cent of wells were responsible for 75 per cent of the sample's emissions.

Nevertheless, on balance, data available to date on emissions from wells, while reflecting a distribution of emitting behaviour that is highly skewed, do not indicate that instances of irregular, high emission outcomes on the part of some wells are outweighing the effects of the vast majority of wells with negligible emissions in ways that significantly affect the overall emissions profile.

Energy

3.9.5 Recalculations since the 2016 inventory

The recalculations since the 2018 submission were undertaken to incorporate updated activity data relating to Natural Gas Distribution.

1.B.2.b Natural gas

Revised natural gas sales figures relating to natural gas distribution was provided in the *Australian Energy Update 2018* (DoEE 2018), which resulted in recalculations for estimates of emissions for *1B2biii5 Distribution*.

Recalculations are quantified in Table 3.46.

Table 3.46 1.B.2 Oil and gas: recalculation of total CO_2-e emissions (Gg), 1990-2017

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(per cent)
1.B.2.a Oil - Total				
1990	474	474	0.0	0.0 per cent
2000	559	559	0.0	0.0 per cent
2001	583	583	0.0	0.0 per cent
2002	591	591	0.0	0.0 per cent
2003	564	564	0.0	0.0 per cent
2004	526	526	0.0	0.0 per cent
2005	507	507	0.0	0.0 per cent
2006	475	475	0.0	0.0 per cent

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(per cent)
2007	511	511	0.0	0.0 per cent
2008	496	496	0.0	0.0 per cent
2009	389	389	0.0	0.0 per cent
2010	380	380	0.0	0.0 per cent
2011	387	387	0.0	0.0 per cent
2012	354	354	0.0	0.0 per cent
2013	357	357	0.0	0.0 per cent
2014	294	294	0.0	0.0 per cent
2015	304	304	0.0	0.0 per cent
2016	236	236	0.0	0.0 per cent
1.B.2.b Natural gas - Total				
1990	6,211	6,211	0.0	0.0 per cent
2000	4,141	4,141	0.0	0.0 per cent
2001	3,972	3,972	0.0	0.0 per cent
2002	3,998	3,998	0.0	0.0 per cent
2003	4,414	4,286	-127.9	-2.9 per cent
2004	5,186	5,064	-122.1	-2.4 per cent
2005	4,811	4,693	-117.8	-2.4 per cent
2006	5,378	5,378	0.0	0.0 per cent
2007	4,894	4,748	-146.4	-3.0 per cent
2008	5,362	5,362	0.0	0.0 per cent
2009	5,801	5,643	-158.0	-2.7 per cent
2010	6,372	6,218	-154.0	-2.4 per cent
2011	6,670	6,479	-191.1	-2.9 per cent
2012	6,565	6,387	-178.2	-2.7 per cent
2013	6,435	6,257	-177.9	-2.8 per cent
2014	6,455	6,304	-150.9	-2.3 per cent
2015	7,066	6,807	-259.0	-3.7 per cent
2016	8,673	8,360	-312.9	-3.6 per cent
1.B.2.c Venting and Flaring - Total				
1990	8,372	8,372	0.0	0.0 per cent
2000	9,949	9,949	0.0	0.0 per cent
2001	10,012	10,012	0.0	0.0 per cent
2002	9,392	9,392	0.0	0.0 per cent
2003	8,308	8,308	0.0	0.0 per cent
2004	7,698	7,698	0.0	0.0 per cent
2005	7,288	7,288	0.0	0.0 per cent
2006	7,204	7,204	0.0	0.0 per cent
2007	7,397	7,397	0.0	0.0 per cent
2008	7,529	7,529	0.0	0.0 per cent
2009	8,049	8,049	0.0	0.0 per cent
2010	8,665	8,665	0.0	0.0 per cent
2011	7,849	7,849	0.0	0.0 per cent

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(per cent)
2012	8,454	8,454	0.0	0.0 per cent
2013	9,217	9,217	0.0	0.0 per cent
2014	9,097	9,097	0.0	0.0 per cent
2015	11,057	11,057	0.0	0.0 per cent
2016	12,831	12,831	0.0	0.0 per cent

3.9.6 Planned improvements

Future improvements will focus on:

- reviewing new empirical data and methods on fugitive emission leakages and methods as they emerge;
- reviewing NGER data on vents and flaring; and
- development of methods for decommissioned wells.

Development of a method for decommissioned wells and wells where production has been temporarily suspended will take account of the empirical data outlined below.

Kang *et al.* 2015, in a study of US decommissioned wells, reports estimates equivalent to average annual emission rates of 1.66 kg of methane for decommissioned oil wells, 0.473kg of methane for a decommissioned plugged gas well and 657kg of methane for an unplugged gas well. In a later 2016 study, Kang confirms that high emitting abandoned wells are best predicted as unplugged gas wells and appear to be unrelated to the presence of underground natural gas storage areas or unconventional oil/gas production. Repeat measurements over 2 years show that flow rates of high emitters are sustained through time, at least in the short term. Plugged/vented gas wells in coal areas - where venting might be a safety issue – require careful consideration to ensure appropriate classification.

In a study of decommissioned UK oil and gas wells ranging between 8 and 79 years old, Boothroyd *et al.* 2016 found evidence of surface emissions at 30 per cent of wells, with estimated emissions on average of 14.6 kg of methane per year. In one case, where an older well had not been appropriately decommissioned, the estimated emissions were 344 kg of methane per year.

Kell *et al.* 2012 studies well integrity failures in Oklahoma, reporting a failure rate of 0.06 per cent of wells. King and King 2012 identify age as a factor in the decline of well integrity given improvements in technology and decommissioning practices. They report well integrity failures in Texas and Oklahoma at 0.004 per cent of modern wells and 0.02 per cent in older wells.

Townsend-Small *et al.* 2016 found, of 138 oil and gas wells,that most abandoned wells do not emit methane, but that 6.5 per cent of wells had measurable emissions. Twenty-five percent of wells visited that had not been plugged emitted more than 5 grams of methane per hour. Townsend-Small *et al.* estimates that abandoned wells make a small contribution (<1 per cent) to regional methane emissions in their study areas.

Watson and Bacchu 2009 identify changes in regulation as an important factor (Alberta, since 1995) which affects the quality of the well abandonment process. They found up to 4.6 per cent of wells with evidence of leaks either at surface casing (3.9 per cent) or from gas migration (0.6 per cent). Sy *et al.* 2007 also identify changes in regulation as an important factor (France, since 2000) which affects the quality of the well abandonment process.

Davies *et al.* 2014 survey international literature and put possible well integrity failures at 1 per cent and wells with evidence of well deterioration across a very broad range (1.9-75 per cent). Ptil 2012, in a North Sea study, found that 0.5 per cent of wells had had well integrity failures and a further 8.7 per cent of wells had some defects. Vignes 2012, also a North Sea study, found, in a survey of temporarily plugged wells, that 1 per cent of wells had had well integrity failures and a further 18.7 per cent of wells had had at least one defect and needed remediation.

3.10 Source Category 1.C Carbon Capture and Storage

3.10.1 Source category description

The IPCC Guidelines defines Carbon Capture and Storage (CCS) as a chain subdivided into four systems – Capture and compression, Transport, Injection, and Geological Storage.

Australia does not currently have any Carbon Capture and Storage (CCS) projects operating.

Planned CCS projects

Chevron Australia's Gorgon LNG project is expected to commence CCS operations at Barrow Island in Western Australia in the near future in accordance with approvals under the project specific legislative instrument the Barrow Island Act 2003 (WA). CO_2 will be separated from the natural gas, captured and injected into a saline aquifer at 2km depth.

The Gorgon LNG project is developing the Gorgon and Jansz-Io gas fields, located within the Greater Gorgon area, between 130 and 220 kilometres off the northwest coast of Western Australia. It includes the construction of a 15.6 million tonne per annum liquefied natural gas (LNG) plant on Barrow Island and a domestic gas plant.

The CO_2 will be captured at the Barrow Island gas processing plant, and transported by a 7km pipeline to the injection site – the Dupuy saline aquifer, 2.3 km beneath Barrow Island. The project involves nine injection wells, and includes long-term monitoring with a number of surveillance wells and seismic surveying.

CCS Research project

An existing CCS demonstration and research project in Australia is the CO_2 CRC Otway Project in Victoria.

This demonstration project however does not constitute a CCS activity in accordance with IPCC guidance.

Naturally occurring CO_2 is extracted from a geological reservoir CO_2, and hence is not captured for abatement purposes. The CO_2 is dried and purified, and transported by a short 2km pipeline for reinjection into a nearby depleted natural gas field and a deeper saline aquifer.

From its commencement in 2006, the project has injected trial volumes of around 65,000 tonnes of CO_2. This research project is reinjecting negligible amounts of naturally occurring reservoir CO_2 that has been extracted from nearby geological formation, and does not involve capture or abatement. A negligible amount of fugitive emissions would be associated with the processing, transport and reinjection – these emissions are not estimated.

3.10.2 Methodology

For the Gorgon and future commercial CCS projects, the Department of the Environment and Energy will derive estimates of fugitive emissions of greenhouse gases associated with the capture, transport, injection and long term geological storage of greenhouse gases from data collected under the National Greenhouse and Energy Reporting Scheme (NGERS).

Appendix 3.A Additional information on activity data

Table 3.A.1 Non-CO_2 Emission Factors 1.A.1 Energy Industries

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
1.A.1.b Petroleum Refining (ANZSIC Class 1701)						
Natural Gas	1.0	0.4	605.1	47.2	1.5	2.3
Crude Oil	1.7	0.5	349.8	49.4	0.8	57.0
Kerosene	2.9	0.6	323.4	49.7	0.7	57.0
ADO	0.7	0.5	323.4	49.7	0.7	57.0
Fuel Oil	1.7	0.5	349.8	49.4	0.8	1,282.1
LPG	0.9	1.8	325.6	58.1	2.3	2.3
Naphtha	0.7	0.5	323.4	49.7	0.7	57.0
Refinery Gas and Liquids	1.0	0.1	349.8	49.4	0.8	2.3
Refinery Coke	1.0	0.1	349.8	49.4	0.8	370.0
1.A.1c Coke Oven Operation (ANZSIC Subdivision 21)						
Black Coal	1.0	0.8	425.0	113.6	1.0	370.0
Coke Oven Gas	1.0	0.6	495.5	68.8	1.6	370.0
Fuel Oil	2.0	0.5	217.8	92.2	0.9	1,282.1
Briquette Manufacture (ANZSIC Subdivision 17)						
Brown Coal	1.0	0.7	110.5	88.6	0.8	150.0
Coal Mining (ANZSIC Division B)						
Brown Coal Briquettes	1.0	0.8	307.7	92.1	1.0	150.0
Natural Gas	2.0	0.9	107.1	19.3	1.6	2.3
Automotive Gasoline	47.6	1.9	1,095.2	7,000.0	1,080.0	15.0
ADO	3.6	3.6	3,681.2	1,132.8	505.6	57.0
LPG	1.2	1.4	902.5	177.0	50.1	2.3
Petroleum products nec	1.1	0.9	901.5	173.3	49.4	57.0
Ethanol	2.9	0.6	667.4	405.4	859.8	0
Oil and Gas Extraction (ANZSIC Division B)						
Natural Gas	2.0	0.9	107.1	19.3	1.6	2.3
Ethane	1.0	0.1	112.2	20.2	1.6	2.3
ADO	3.2	3.1	3,227.9	976.4	431.2	57.0
Fuel Oil	1.5	0.8	913.4	173.1	49.4	1,282.1
LPG	1.2	1.4	902.5	177.0	50.1	2.3
Petroleum products nec	1.9	0.9	905.1	299.7	68.5	57.0

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Other Transport, Services and Storage (Natural Gas Transmission) (ANZSIC Subdivision 50-53)						
Natural Gas	1.0	0.9	65.9	9.6	2.1	2.3
Gas Production and Distribution (ANZSIC Subdivision 27)						
Natural gas	3.4	0.9	120.6	30.0	0.9	2.3
LPG	3.6	1.2	126.1	33.6	1.2	2.3

Source: Derived from Table 3.A.4.

Table 3.A.2 Non-CO_2 Emission Factors 1.A.2 Manufacturing and Construction

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Iron and steel (ANZSIC Group 211-12)						
Black coal	1.0	0.8	425.0	113.6	1.0	370.0
Natural Gas	0.9	0.6	499.5	69.4	1.5	2.3
Coke Oven Gas	1.0	0.6	523.2	72.7	1.6	370.0
ADO	1.8	1.8	1,617.4	522.4	209.1	57.0
LPG	47.6	1.9	2,645.7	3,968.6	3571.4	2.3
1.A.2.b Non-Ferrous Metals (ANZSIC Group 213-14)						
Black Coal	1.0	0.7	191.0	91.2	0.9	370.0
Coke	1.0	0.7	191.0	91.2	0.9	370.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	1.0	0.6	452.7	36.2	1.7	2.3
ADO	3.3	3.3	3,323.6	1,020.0	453.3	57.0
Fuel Oil	1.7	0.5	355.8	50.6	0.8	1,282.1
Naphtha	0.6	0.5	327.3	51.0	0.7	57.0
Other Petroleum and Coal Product Manufacturing (ANZSIC Class 1709)						
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Natural Gas	0.9	0.9	83.5	10.4	2.1	2.3
ADO	3.7	3.7	3,809.5	1,177.1	526.7	57.0
Fuel Oil	2.9	0.3	128.6	13.3	0.8	1,282.1
Liquefied Aromatic Hydrocarbons	0.2	0.4	59.0	14.3	0.6	57.0
LPG	47.6	1.9	2,645.7	3,968.6	3,571.4	2.3
Basic Chemical Manufacturing (ANZSIC Subdivision 18-19)						
Black Coal	1.0	0.7	110.5	88.6	0.8	370.0
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Natural Gas	1.0	0.5	489.3	38.8	1.5	2.3
Ethane	1.0	0.1	512.6	40.7	1.6	2.3
ADO	0.6	0.5	302.8	50.7	4.1	57.0
Liquefied Aromatic Hydrocarbons	0.6	0.5	280.0	43.4	0.7	57.0
LPG	11.6	2.0	821.0	945.3	815.8	2.3
Naphtha	0.6	0.5	280.0	43.4	0.7	57.0
Petroleum products nec	0.6	0.5	280.0	43.4	0.7	57.0

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Chemicals, Rubber and Plastic Products (ANZSIC Subdivision 18-19)						
Black Coal	1.0	0.7	110.5	88.6	0.8	370.0
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Natural Gas	1.0	0.5	489.3	38.8	1.5	2.3
ADO	0.7	0.7	434.8	93.1	23.8	57.0
LPG	14.0	2.0	944.2	1,149.5	1,001.9	2.3
1.A.2.D Pulp, Paper and Print (ANZSIC Subdivisions 14-16)						
Black coal	1.0	0.7	110.5	88.6	0.8	370.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	92.8	11.1	2.0	2.3
ADO	0.5	0.5	101.4	14.8	0.7	57.0
LPG	0.9	2.6	104.9	28.2	3.2	2.3
Petroleum products nec	0.5	0.5	101.4	14.8	0.7	57.0
1.A.2.E Food Processing, Beverages, Tobacco (ANZSIC subdivision 11-12)						
Black coal	1.0	0.7	119.2	92.1	0.8	370.0
Brown coal briquettes	1.0	0.7	119.2	92.1	0.8	150.0
Wood and Wood waste	9.2	5.8	175.8	215.0	6.1	0
Bagasse	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.2	9.1	2.0	2.3
ADO	3.2	3.2	3,205.1	989.1	441.6	57.0
Fuel Oil	2.6	0.3	133.6	13.6	0.8	1,282.1
LPG	0.9	3.4	78.1	33.5	4.3	57.0
Ethanol	2.9	0.6	667.4	405.4	859.8	2.3
Textile, Clothing, Footwear and Leather (ANZSIC Subdivision 13)						
Black Coal	1.0	0.7	110.5	88.6	0.8	370.0
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Natural Gas	0.9	0.8	64.0	9.2	2.0	2.3
Fuel Oil	2.6	0.4	134.9	14.5	0.8	1,282.1
Petroleum products nec	0.5	0.4	79.3	15.3	0.6	57.0
Fabricated Metal Products (ANZSIC Subdivision 22)						
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
ADO	0.8	0.8	586.7	145.7	48.5	1,282.1
LPG	47.6	1.9	2,645.7	3,968.6	3,571.4	2.3
Machinery and Equipment (ANZSIC Subdivision 24)						
Natural Gas	0.9	0.8	169.1	16.5	2.0	2.3
ADO	3.7	3.7	3,809.5	1,177.1	526.7	57.0
LPG	47.6	1.9	2,645.7	3,968.6	3,571.4	2.3
Furniture and Other Manufacturing (ANZSIC Subdivision 25)						
Natural gas	0.9	0.8	159.4	15.8	2.0	2.3
1.A.2.F(II) Construction (ANZSIC Division E)						
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Kerosene	2.9	0.6	59.1	14.3	0.6	57.0
ADO	3.7	3.7	3,809.5	1,177.1	526.7	57.0

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Fuel Oil	2.9	0.6	913.4	173.1	49.4	1,282.1
LPG	1.0	0.1	64.8	36.2	4.8	2.3
Glass and Glass Products (ANZSIC Group 201)						
Natural Gas	1.0	0.1	1,010.0	75.0	1.1	2.3
LPG	0.9	0.8	507.5	76.9	1.0	2.3
Ceramics (ANZSIC Group 202)						
Black coal	1.0	0.8	525.9	78.6	1.0	370.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	1.0	0.1	1,000.5	74.4	1.1	2.3
ADO	3.7	3.7	3,809.5	1,177.1	526.7	57.0
Fuel Oil	1.0	0.6	515.2	76.7	0.8	1,282.1
LPG	17.0	1.1	1,249.8	1,418.7	1,232.1	2.3
Petroleum products nec	1.0	0.6	515.2	76.7	0.8	57.0
Cement, Lime, Plaster and Concrete (ANZSIC Group 203)						
Black coal	1.0	0.8	525.9	78.6	1.0	370.0
Coke	1.0	0.8	525.9	78.6	1.0	370.0
Tyres	0.7	0.5	323.8	7.6	0.9	57.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	1.0	0.1	953.0	71.1	1.1	2.3
Coke Oven Gas	1.0	0.1	998.4	74.5	1.2	370.0
ADO	3.5	3.4	3,503.9	1,078.4	480.9	57.0
Fuel Oil	1.3	0.6	307.5	41.1	0.8	57.0
Solvents	0.8	0.6	295.0	41.2	0.8	57.0
LPG	47.0	1.9	2,616.7	3,920.1	3,527.4	2.3
Petroleum products nec	0.8	0.6	295.0	41.2	0.8	57.0
Other Non-Metallic Mineral Products (ANZSIC Group 209)						
Black coal	1.0	0.8	343.1	83.0	0.9	370.0
Coke	1.0	0.8	343.1	83.0	0.9	370.0
Natural Gas	1.0	0.2	620.4	48.3	1.2	2.3
ADO	3.7	3.7	3,809.5	1,177.1	526.7	57.0
Fuel Oil	1.6	0.5	398.8	57.7	0.8	1,282.1
LPG	42.6	1.9	2,401.5	3,548.2	3,187.0	2.3
Petroleum products nec	0.7	0.5	376.5	58.0	0.8	57.0
1.A.2.F(iv) Mining (non-Energy Minerals (ANZSIC subdivisions 08-10)						
Black coal	1.0	0.8	307.7	92.1	1.0	370.0
Coke	1.0	0.8	307.7	92.1	1.0	370.0
Natural Gas	2.0	0.9	107.1	19.3	1.6	2.3
Coke Oven Gas	2.1	0.9	112.2	20.2	1.6	370.0
ADO	3.6	3.6	3,735.0	1,151.4	514.4	57.0
Fuel Oil	1.5	0.8	913.4	173.1	49.4	1,282.1
LPG	1.2	1.4	902.5	177.0	50.1	2.3
Petroleum products nec	1.1	0.9	901.5	173.3	49.4	57.0

Source: Derived from Table 1-16.

Table 3.A.3 Non-CO_2 Emission Factors: Other Sectors

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
281 Water, Sewerage and Drainage						
Natural Gas	0.9	0.9	59.1	14.3	2.1	2.3
Kerosene	2.9	0.6	59.0	14.3	0.6	57.0
ADO	3.7	3.7	3,809.5	1,177.1	526.7	57.0
50-53 Other Transport, Services and Storage (part)						
ADO	3.7	3.7	3,809.5	1,177.1	526.7	57.0
Div. F, G Wholesale and Retail Trade						
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Town Gas	0.9	0.9	64.5	9.1	2.1	2.3
ADO	0.7	0.4	59.0	14.3	0.6	57.0
Fuel Oil	1.3	0.3	128.6	13.3	0.8	1282.1
LPG	0.9	3.8	64.8	36.2	4.8	2.3
Div. H, P, Q Accommodation, Cultural and Personal						
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
ADO	0.7	0.4	59.0	14.3	0.6	57.0
LPG	0.9	3.8	64.8	36.2	4.8	2.3
Div. J Communication						
Natural Gas	1.0	1.0	67.6	9.5	2.2	2.3
Kerosene	2.9	0.6	59.0	14.3	0.6	57.0
ADO	0.7	0.4	59.0	14.3	0.6	57.0
Div. K, L Finance, Insurance, Property and Business						
Natural Gas	1.0	1.0	67.6	9.5	2.2	2.3
Div. M Government Administration and Defence						
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Kerosene	2.9	0.6	59.0	14.3	0.6	57.0
ADO	0.7	0.4	59.0	14.3	0.6	57.0
LPG	0.9	3.8	64.8	36.2	4.8	2.3
Div. N, O Education, health and community services						
Black Coal	1.0	0.7	110.5	88.6	0.8	370.0
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Town Gas	0.9	0.9	64.5	9.1	2.1	2.3
Kerosene	2.9	0.6	59.0	14.3	0.6	57.0
ADO	0.7	0.4	59.0	14.3	0.6	57.0
LPG	0.9	3.8	64.8	36.2	4.8	2.3
Residential						
Wood and Wood Waste [(a)]						
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3

Energy

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Town Gas	0.9	0.9	64.5	9.1	2.1	2.3
ADO	0.7	0.6	59.0	14.3	0.6	57.0
LPG	1.0	0.6	64.8	36.2	4.8	2.3
1.A.4.c Agriculture, Forestry & Fisheries: (ANZSIC Division A)						
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Gasoline	47.6	1.9	1,095.2	7,000.0	1,080.0	15.0
ADO	3.7	3.7	3,809.5	1,177.1	526.7	57.0
LPG	0.9	3.8	64.8	36.2	4.8	2.3

(a) See Table 1-17 for Residential biomass EFs.

Table 3.A.4 Derivation of non-CO_2 emission factors for stationary energy

Sector	Fuel	Equipment	Emission Factors[(a)] (Mass/Gross Energy Use)				
			CH_4	N_2O[a]	NO_X	CO	NMVOC
			Mg/ PJ				
Utility excl. Electricity Generation							
1	Residual Fuel Oil	Boiler[b]	0.8	0.3	128.6	13.3	0.8
2	Gas/Diesel Oil	Boiler[c]	0.9	0.4	59.0	14.3	0.6
3	Black Coal	Dry Bottom, Wall Fired Boilers[d]	0.7	0.5	323.8	7.6	0.9
4	Black Coal	Overfeed Stoker Boilers[e]	1	0.7	110.5	88.6	0.8
5	Natural Gas	Boiler[f]	0.9	0.9	71.8	31.8	2.1
6	Gas-Fired Gas Turbines >3MW	NA[g]	3.6	0.9	125.5	31.8	0.8
Industrial							
7	Residual Fuel Oil	Boiler[h]	2.9	0.3	128.6	13.3	0.8
8	Gas/Diesel Oil	Boiler[i]	0.2	0.4	59.0	14.3	0.6
9	Large Stationary Diesel Oil Engines >600 hp (447kW)	NA[j]	3.8	3.7	1,805.7	388.6	142.9
10	Liquefied Petroleum Gases	Boiler[k]	0.9	3.8	64.8	36.2	4.8
11	Black Coal	Dry Bottom, Wall Fired Boilers[l]	0.7	0.5	323.8	7.6	0.9
12	Black Coal	Overfeed Stoker Boilers[m]	1.0	0.7	110.5	88.6	0.8
13	Natural Gas	Boiler[n]	0.9	0.9	64.5	9.1	2.1
14	Gas-Fired Gas Turbines >3MW	NA[o]	3.6	0.9	125.5	31.8	0.8
15	Wood/Wood Waste	Boilers[p]	9.2	5.8	175.8	215	6.1
Kilns, Ovens, and Dryers							
16	Cement, Lime	Kilns – Natural Gas[q]	1.0	0.1	1,010.0	75.0	1.1
17	Cement, Lime	Kilns – Oil[r]	1.0	0.6	525.9	78.6	0.8
18	Cement, Lime	Kilns – Coal[s]	1.0	0.8	525.9	78.6	1.0
19	Coking, Steel	Coke Oven[t]	1.0	0.8	300.7	210.6	1.0

Sector	Fuel	Equipment	Emission Factors [(a)] (Mass/Gross Energy Use)				
			CH_4	N_2O^a	NO_X	CO	NMVOC
			Mg/ PJ				
20	Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer – Natural Gas[u]	1.0	0.1	58.0	10.0	1.1
21	Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer – Oil[v]	1.0	0.6	167.6	15.7	0.8
22	Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer – Coal[w]	1.0	0.8	225.2	178.1	1.8
Residential							
23	Residual Fuel Oil	Combustors[x]	1.3	0.3	128.6	13.3	0.8
24	Gas/Diesel Oil	Combustors[y]	0.7	0.6	59.0	14.3	0.6
25	Liquefied Petroleum Gases	Furnaces[z]	1.0	0.6	64.8	36.2	4.8
26	Natural Gas	Boilers and Furnaces[aa]	0.9	0.9	64.5	9.1	2.1
Commercial/Institutional							
27	Residual Fuel Oil	Boilers[ab]	1.3	0.3	128.6	13.3	0.8
28	Gas/Diesel Oil	Boilers [ac]	0.7	0.4	59.0	14.3	0.6
29	Liquefied Petroleum Gases	Boilers [ad]	0.9	3.8	64.8	36.2	4.8
30	Black Coal	Dry Bottom, Wall Fired Boilers[ae]	0.7	0.5	323.8	0.9	0.9
31	Black Coal	Overfeed Stoker Boilers[af]	1.0	0.7	110.5	0.8	0.8
32	Natural Gas	Boiler[ag]	0.9	0.9	64.5	2.1	2.1
33	Gas-Fired Gas Turbines >3MW	NA[ah]	3.6	1.3	125.5	31.8	0.8
34	Wood/Wood Waste	Boilers[ai]	9.2	5.8	175.8	215.0	6.1

Source:

[a] IPCC (2006, Volume 2) Net calorific values for CH_4 and N_2O outlined in the IPCC (2006, Volume 2) were converted to gross calorific values by assuming that net calorific values are 5 per cent lower for coal and oil, 10 per cent lower for natural gas and 20 per cent lower for dry wood (Forest Product Laboratory).

[b] USEPA (2005b) Pg 1.3-11 to 1.3-14. Uncontrolled emissions of NO_x and CO from residual oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) residual oil (No. 6 oil) fired industrial boilers (normal firing).

[c] USEPA (2005b) Pg 1.3-11 to 1.3-14. Uncontrolled emissions of NO_x and CO from distillate oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) distillate oil (No. 6 oil) fired industrial boilers (normal firing).

[d] USEPA (2005b) Pg 1.1-16 to 1.1-41 Uncontrolled emissions of NO_x and CO from pulverised coal fired dry bottom configuration (wall fired boiler). NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal fired dry bottom configuration (wall fired boiler).

[e] USEPA (2005b) Pg 1.1-16 to 1.1-41 Uncontrolled emissions of NO_x and CO from pulverised coal fired overfeed stoker. NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal overfeed stoker.

[f] USEPA (2005b) Pg 1.4-5 and 1.4-6. Uncontrolled emissions for NO_x, CO and NMVOC from natural gas fired large wall fired boilers (>100).

[g] USEPA (2005b) Pg 3.1-10 to 3.1-11 Uncontrolled emissions for NO_x, CO and NMVOC from large stationary natural gas fired turbines.

[h] USEPA (2005b) Pg 3.1-3 and 3.1-5. Pg 1.3-11 to 1.3-14. Uncontrolled emissions of NO_x and CO from residual oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) residual oil

(No. 6 oil) fired industrial boilers (normal firing).

[i] USEPA (2005b) Pg 1.3-11 to 1.3-14. Uncontrolled emissions of NO_x and CO from distillate oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) distillate oil (No. 6 oil) fired industrial boilers (normal firing).

[j] USEPA (2005b) Pg 3.3-6. Uncontrolled emissions for NO_x, CO and NMVOC from diesel oil industrial engines.

[k] USEPA (2005b) Pg 1.5-3 Uncontrolled emissions for NO_x and CO from butane emission factor for industrial boilers. NMVOC emissions estimated from Total Organic Compounds (TOC) from butane emission factor for industrial boilers.

[l] USEPA (2005b) Pg 1.1-16 to 1.1-41 Uncontrolled emissions of NO_x and CO from pulverised coal fired dry bottom configuration (wall fired boiler). NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal fired dry bottom configuration (wall fired boiler).

[m] USEPA (2005b) Pg 1.1-16 to 1.1-41 Uncontrolled emissions of NO_x and CO from pulverised coal fired overfeed stoker. NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal overfeed stoker.

[n] USEPA (2005b) Pg 1.4-5 and 1.4-6. Uncontrolled emissions for NO_x, CO and NMVOC from natural gas fired tangentially fired boilers (all size).

[o] USEPA (2005b) Pg 3.1-10 to 3.1-11 Uncontrolled emissions for NO_x, CO and NMVOC from large stationary natural gas fired turbines.

[p] USEPA (2005b) Pg 1.6-8 to 1.6-11Uncontrolled emissions for NO_x and CO from dry wood fired boilers. NMVOC emissions estimated from average emission factor for Volatile Organic Compound (VOC).

[q] Assume 10 per cent increase in natural gas fired kilns EFs for NO_x, CO and NMVOC from IPCC (1995b).

[r] Assume 10 per cent increase in fuel oil fired kilns EFs for NO_x, CO and NMVOC from IPCC (1995b).

[s] Assume 10 per cent increase in pulverised coal fired kilns EFs for NO_x, CO and NMVOC from IPCC (1995b).

[t] Assume 10 per cent increase in pulverised coal fired coke oven EFs for NO_x, CO and NMVOC from IPCC (1995b).

[u] Assume 10 per cent increase in natural gas fired dryers EFs for NO_x, CO and NMVOC from IPCC (1995b).

[v] Assume 10 per cent increase in fuel oil fired dryers EFs for NO_x, CO and NMVOC from IPCC (1995b).

[w] Assume 10 per cent increase in pulverised coal fired dryers EFs for NO_x, CO and NMVOC from IPCC (1995b).

[x] USEPA (2005b) Pg 3.1-3 and 3.1-5. Pg 1.3-11 to 1.3-14. Uncontrolled emissions of NO_x and CO from residual oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) residual oil (No. 6 oil) fired industrial boilers (normal firing).

[y] USEPA (2005b) Pg 1.3-11 to 1.3-14. Uncontrolled emissions of NO_x and CO from distillate oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) distillate oil (No. 6 oil) fired industrial boilers (normal firing).

[z] USEPA (2005b) Pg 1.5-3 Uncontrolled emissions for NO_x and CO from butane emission factor for industrial boilers. NMVOC emissions estimated from Total Organic Compounds (TOC) from butane emission factor for industrial boilers.

[aa] USEPA (2005b) Pg 1.4-5 and 1.4-6. Uncontrolled emissions for NO_x, CO and NMVOC from natural gas fired tangentially fired boilers (all size).

[ab] USEPA (2005b) Pg 3.1-3 and 3.1-5. Pg 1.3-11 to 1.3-14. Uncontrolled emissions of NO_x and CO from residual oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) residual oil (No. 6 oil) fired industrial boilers (normal firing).

[ac] USEPA (2005b) Pg 1.3-11 to 1.3-14. Uncontrolled emissions of NO_x and CO from distillate oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) distillate oil (No. 6 oil) fired industrial boilers (normal firing).

[ad] USEPA (2005b) Pg 1.5-3 Uncontrolled emissions for NO_x and CO from butane emission factor for industrial boilers. NMVOC emissions estimated from Total Organic Compounds (TOC) from butane emission factor for industrial boilers.

[ae] USEPA (2005b) Pg 1.1-16 to 1.1-41 Uncontrolled emissions of NO_x and CO from pulverised coal fired dry bottom configuration (wall fired boiler). NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal fired dry bottom configuration (wall fired boiler).

[af] USEPA (2005b) Pg 1.1-16 to 1.1-41 Uncontrolled emissions of NO_x and CO from pulverised coal fired overfeed stoker. NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal overfeed stoker.

[ag] USEPA (2005b) Pg 1.4-5 and 1.4-6. Uncontrolled emissions for NO_x, CO and NMVOC from natural gas fired tangentially fired boilers (all size).

[ah] USEPA (2005b) Pg 3.1-10 to 3.1-11 Uncontrolled emissions for NO_x, CO and NMVOC from large stationary natural gas fired turbines.

[ai] USEPA (2005b) Pg 1.6-8 to 1.6-11Uncontrolled emissions for NO_x and CO from dry wood fired boilers. NMVOC emissions estimated from average emission factor for Volatile Organic Compound (VOC).

Table 3.A.5 Non CO_2 emission factors for stationary energy – electricity

Basic Technology	Emission Factors (Mg/PJ energy input)				
	CH_4	N_2O	NO_X	CO	NMVOC
Liquid Fuels					
Fuel Oil [a]	0.8	0.3	186.0	14.0	2.1
Diesel [b]	0.9	0.4	64.0	13.0	1.4
Large diesel Oil Engine [c]	3.8	0.9	1,322.0	349.0	45.0
Other Liquids [d]	0.8	0.3	54.0	383.8	0.8
LNG [e]	234.5	0.9	1,331.0	340.0	80.0
Solid					
Pulverised Wall [f]	0.7	0.5	462.0	11.0	1.7
Tangentially Fired (black coal) [g]	0.7	1.3	306.0	11.0	1.7
Tangentially Fired (brown coal) [h]	0.7	1.3	136.0	17.0	1.7
Fluidised Bed [i]	0.9	58.1	54.6	11.0	1.7
Natural Gas					
Boilers [j]	0.9	0.9	226.0	16.0	0.6
Gas fired turbine [k]	3.6	0.9	190.0	46.0	2.4
Internal Combustion [l]	234.5	0.9	1,331	340.0	80.0
Combined cycle [m]	0.9	2.7	226.0	16.0	0.6
Biomass					
Wood waste boilers [n]	10.5	6.7	75.0	680.0	6.8
Bagasse boiler [o]	10.5	6.7	84.0	1,625.0	16.3

[a] CH_4 and N_2O IPCC (2006, Volume 2) value for residual oil boiler. USEPA (1995b) Pg 1.3-2 to 1.3-6. Uncontrolled emissions of CO, NO_x, and NMVOC from residual oil (No. 4 – 6) fired utility boilers (normal firing).

[b] CH_4 and N_2O IPCC (2006, Volume 2) value for gas/diesel oil boiler. CO, NO_x, NMVOC Distillate oil fired utility boiler data not available. Assume emissions equal those of residual oil fired utility boiler scaled by relative emissions of industrial boiler category (USEPA, 1986, Pg 1.3-2).

[c] CH_4 and N_2O IPCC (2006, Volume 2) value for large diesel oil engine. CO, NO_x, NMVOC USEPA (1995b) Pg 3.4-3

[d] CH_4 and N_2O IPCC (2006, Volume 2) value residual fuel oil/shale oil boiler.

[e] CH_4 and N_2O IPCC (2006, Volume 2) value for residual fuel oil/shale oil. CO, NO_x, NMVOC USEPA (1995b) Pg 3.4-3. Assume dual fuel EFs.

[f] CH_4 and N_2O IPCC (2006, Volume 2) value for pulverised coal fired dry bottom configuration CO, NO_x, NMVOC USEPA (1995b) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for pulverised coal fired dry bottom configuration.

[g] CH_4 and N_2O IPCC (2006, Volume 2) assume value for pulverised coal fired dry bottom configuration CO, NO_x, NMVOC USEPA (1995b) Pg 1.1-6 and 1.1-22. Uncontrolled emissions for pulverised coal fired dry bottom configuration (tangentially fired boiler).

[h] CH_4 and N_2O IPCC (2006, Volume 2) assume value for pulverised coal fired dry bottom configuration Assume $CH_{4\text{ and}}$ N_2O and NMVOC EFs identical to black coal combustion. CO and NO_x EFs based on average of SECV data (1994).

[i] CH_4 and N_2O IPCC (2006, Volume 2) assume value for pulverised coal fired dry bottom configuration

[j] CH_4 and N_2O IPCC (2006, Volume 2) value for natural gas boiler. CO, NO_x, NMVOC USEPA (1995b) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, and NMVOC from natural gas fired 'commercial' boilers (0.1-2.9 MW).

[k] CH_4 and N_2O IPCC (2006, Volume 2) assume value for natural gas gas-fired turbine>3MW. USEPA (1995b) Pg 3.1-3 and 3.1-5. Uncontrolled emissions of CO and NO_x for large stationary natural gas turbines. NMVOC emissions estimated from ratio of NMHC: to Total Organic Compounds for selective catalytic reduction controlled turbines.

[l] CH_4 and N_2O IPCC (2006, Volume 2) assume value for natural gas Large Dual-fuel engine. CO, NO_x, NMVOC USEPA (1995b) Pg 3.4-3. Assume dual fuel EFs.

[m] CH_4 and N_2O IPCC (2006, Volume 2) assume value for natural gas combined cycle. CO, NO_x, NMVOC USEPA (1995b) Pg 1.4-4 to 1.4-6. Uncontrolled emissions of CO, NO_x, and NMVOC from natural gas fired 'commercial' boilers (0.1-2.9 MW).

[n] CH_4 and N_2O IPCC (2006, Volume 2) value for wood/wood waste boiler. CO, NO_x, NMVOC USEPA (1995b) Pg 1.6-6 to 1.6-7. Uncontrolled emissions from wood waste combustion in stoker boiler. Assume wood moisture content of 50 per cent as recommended by USEPA.

[o] CH_4 and N_2O IPCC (2006, Volume 2) value for wood/wood waste boiler. CO, NO_x IPCC (1997a) data for NO_x and CO converted to gross calorific equivalent by dividing by 1.05. NMVOC emission rates estimated by scaling relative to wood boiler data (see [n]).

Table 3.A.6 Passenger and light commercial vehicles: CH_4, NO_x and CO emission factors split by urban/non-urban road conditions and hot/cold operation at vehicle group's average VKT

	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
Fuel type	**EF (g/km)**	**Source**	**EF (g/start)**	**Source**	**EF (g/km)**	**Source**	**EF (g/km)**	**Source**	**EF (g/start)**	**Source**	**EF (g/km)**	**Source**
Petrol												
Post-2008	0.001		0.029		0.001		0.002		0.073		0.003	
2006-2007	0.002	Orbital Australia 2010	0.053	Orbital Australia 2010	0.001	Orbital Australia 2010	0.002	Orbital Australia 2010	0.073	Orbital Australia 2010	0.003	Orbital Australia 2010
2004-2005	0.005		0.073		0.002		0.017		0.138		0.013	
1998-2003	0.003		0.098		0.000		0.013		0.155		0.000	
1994-1997	0.076		0.228		0.049		0.054		0.384		0.012	
1985-1993 (3-way cat)	0.052	Orbital Australia 2011(b)	0.336	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)
1985-1993 (2-way cat)	0.014		0.207		0.010		0.000		0.000		0.000	
1976-1985	0.125	Carnovale 1991	0.434	USEPA (as cited in IPCC 2006)	0.065	Carnovale 1991	0.140	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.487	USEPA (as cited in IPCC 2006)	0.087	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
Pre-1976	0.133		0.461		0.112		0.150		0.521		0.100	
LPG												
Post-2005	0.080	COPERT IV	0.240	COPERT IV (converted to a per start EF)	0.025	COPERT IV (Highway)	0.080	Petrol LCV EF x Pass car LPG to petrol ratio	0.240	Petrol LCV EF x Pass car LPG to petrol ratio	0.025	Petrol LCV EF x Pass car LPG to petrol ratio
2004-2005	0.080		0.240		0.025		0.080		0.240		0.025	

	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
Fuel type	**EF (g/km)**	**Source**	**EF (g/ start)**	**Source**	**EF (g/km)**	**Source**	**EF (g/km)**	**Source**	**EF (g/ start)**	**Source**	**EF (g/km)**	**Source**
1998-2003	0.024	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.096	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.011	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.024	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.096	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.011	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985-1997 (3-way cat)	0.024		0.096		0.011		0.024		0.096		0.011	
1985-1997 (2-way cat)	0.033		0.131		0.014		0.033		0.131		0.014	
1976-1985	0.031		0.125		0.014		0.031		0.125		0.014	
Pre-76	0.032		0.126		0.014		0.032		0.126		0.014	
ADO												
Post-2008	0.002	COPERT IV	0.008	COPERT IV (converted to a per start EF)	0.000	COPERT IV (Highway)	0.003	COPERT IV	0.021	COPERT IV (converted to a per start EF)	0.000	COPERT IV (Highway)
2006-2007	0.003		0.021		0.000		0.003		0.021		0.000	
2004-2005	0.007		0.018		0.002		0.007		0.018		0.002	
1998-2003	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.003	USEPA (as cited in IPCC 2006)	0.000	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.003	USEPA (as cited in IPCC 2006)	0.000	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985-1997 (3-way cat)	0.001		0.003		0.000		0.001		0.003		0.000	
1985-1997 (2-way cat)	0.001		0.004		0.001		0.001		0.004		0.001	
1976-1985	0.001		0.004		0.001		0.001		0.004		0.001	
Pre-76	0.001		0.004		0.001		0.001		0.004		0.001	

	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
Fuel type	**EF (g/km)**	**Source**	**EF (g/start)**	**Source**	**EF (g/km)**	**Source**	**EF (g/km)**	**Source**	**EF (g/start)**	**Source**	**EF (g/km)**	**Source**
Ethanol[a]												
Post-2005	0.037	USEPA (as cited in IPCC 2006) - mid-point of reported range	NA		0.049	Hot EF x Petrol Non-urban to Hot Urban ratio	0.037	Passenger car EF x LCV to car ratio	NA		0.049	Ethanol car hot EF x LCV non-urban to petrol hot urban ratio
2004-2005	0.037		0.049			0.037			0.049			
1998-2003	0.037		0.025			0.053			0.048			
1985-1997 (3-way cat)	0.206	Post 97 EF x earlier petrol age class relativity	0.158			0.211			0.159			
1985-1997 (2-way cat)	0.592		0.331			0.581			0.449			
1976-1985	0.661		0.344			0.740			0.460			
Pre-1976	0.703		0.592			0.793			0.529			

Note: As deterioration rates are assumed to be 0 for N_2O the EF at the vehicles group's average VKT is the same as at 0 VKT.
The cold start EFs are reported in the table above as g/km.
Source: Orbital Australia 2010 and Orbital Australia 2011 (c).

Table 3.A.7 Passenger and light commercial vehicles: Zero kilometre CH_4 emissions factors split by urban/non-urban road conditions and hot/cold operation

	Medium Duty Truck				Heavy Duty Truck				Bus			
	Urban		Non-urban		Urban		Non-urban		Urban		Non-urban	
Fuel type	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source
Petrol												
Post 2002	0.078	COPERT IV (x EF reduction per cent)	0.062	COPERT IV (x EF reduction per cent)	0.078	COPERT IV (x EF reduction per cent)	0.062	COPERT IV (x EF reduction per cent)	0.078	COPERT IV (x EF reduction per cent)	0.062	COPERT IV (x EF reduction per cent)
1996 - 2002	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV
Pre 1996	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV
LPG												
Post 2002	0.123	DCC 2006	0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.123	DCC 2006	0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.067	DCC 2006	0.029	Passenger car LPG COPERT IV non-urban to urban ratio
1996 - 2002	0.220	DCC 2006	0.096	Passenger car LPG COPERT IV non-urban to urban ratio	0.220	DCC 2006	0.096	Passenger car LPG COPERT IV non-urban to urban ratio	0.120	DCC 2006	0.053	Passenger car LPG COPERT IV non-urban to urban ratio
Pre 1996	0.220	DCC 2006	0.096	Passenger car LPG COPERT IV non-urban to urban ratio	0.220	DCC 2006	0.096	Passenger car LPG COPERT IV non-urban to urban ratio	0.120	DCC 2006	0.053	Passenger car LPG COPERT IV non-urban to urban ratio
ADO												
Post-2010	0.0025		0.0051		0.00525		0.0042		0.00525		0.0021	
2008-2010	0.0025		0.0051		0.00525		0.0042		0.00525		0.0021	
Post 2003 - 2007	0.046	COPERT IV (x EF reduction per cent)	0.07735	Hot urban EF x COPERT IV non-urban to urban ratio	0.098	COPERT IV (x EF reduction per cent)	0.0637	Hot urban EF x COPERT IV non-urban to urban ratio	0.10325	COPERT IV (x EF reduction per cent)	0.0413	Hot urban EF x COPERT IV non-urban to urban ratio
1996 - 2002	0.157	COPERT IV	0.037	Hot urban EF x COPERT IV non-urban to urban ratio	0.157	COPERT IV	0.07	Hot urban EF x COPERT IV non-urban to urban ratio	0.157	COPERT IV	0.0628	Hot urban EF x COPERT IV non-urban to urban ratio
Pre 1996	0.157	COPERT IV	0.037	Hot urban EF x COPERT IV non-urban to urban ratio	0.157	COPERT IV	0.063	Hot urban EF x COPERT IV non-urban to urban ratio	0.157	COPERT IV	0.0628	Hot urban EF x COPERT IV non-urban to urban ratio

(a) raw ethanol content of blended fuel.
Source: (as indicated in table):FORS (1996); Carnovale *et al.* (1991); IPCC (2006); Orbital Australia (2010); Orbital Australia (2011b).

Table 3.A.8 Medium and heavy duty trucks and buses: Zero kilometre CH_4 emissions factors split by urban/non-urban road conditions and hot/cold operation

	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold			Hot			Cold			
Fuel type	**EF (g/km)**	**Source**	**EF g/start**	**Source**	**EF (g/km)**	**Source**	**EF g/start**	**Source**	**EF g/start**	**Source**	**EF (g/km)**	**Source**
Petrol												
Post-2008	0.001		0.020		0.001		0.003		0.144		0.001	
2006-2007	0.004		0.037		0.001		0.003		0.144		0.001	
2004-2005	0.008	Orbital Australia 2010	0.121	Orbital Australia 2010	0.009	Orbital Australia 2010	0.006	Orbital Australia 2010	0.087	Orbital Australia 2010	0.009	Orbital Australia 2010
1998 - 2003	0.030		0.332		0.029		0.041		0.156		0.029	
1994 – 1997	0.037		0.231		0.012		0.025		0.137		0.012	
1985 – 1993 (3-way cat)	0.057	Orbital Australia 2011(b)	0.194	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)	0.002	Orbital Australia 2011(b)	0.005	Orbital Australia 2011(b)	0.000	Orbital Australia 2011(b)
1985 – 1993 (2-way cat)	0.000		0.000		0.000		0.000		0.000		0.000	
1976 – 1985	0.004		0.041		0.005		0.005		0.047		0.005	
Pre 76	0.003	Weeks *et al.* 1993	0.036	USEPA (as cited in IPCC 2006)	0.002	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.003	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.041	USEPA (as cited in IPCC 2006)	0.002	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio

	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
Fuel type	EF (g/km)	Source	EF g/start	Source	EF (g/km)	Source	EF g/start	Source	EF g/start	Source	EF (g/km)	Source
LPG												
post 2005	0.005	COPERT IV	0.027	COPERT IV (converted to a per start EF)	0.001	COPERT IV (Highway)	0.008	Petrol LCV EF x Pass car LPG to petrol ratio	0.081	Petrol LCV EF x Pass car LPG to petrol ratio	0.003	Petrol LCV EF x Pass car LPG to petrol ratio
2004-2005	0.013		0.069		0.002		0.026		0.178		0.018	
1998 - 2003	0.016	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.048	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.006	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.016	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.048	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.006	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.006		0.017		0.001		0.006		0.017		0.001	
1985 – 1997 (2-way cat)	0.003		0.008		0.002		0.003		0.008		0.002	
1976 – 1985	0.003		0.008		0.000		0.003		0.008		0.000	
Pre 76	0.002		0.005		0.000		0.002		0.005		0.000	
ADO												
Post-2008	0.003	COPERT IV	0.023	COPERT IV (converted to a per start EF)	0.002	COPERT IV (Highway)	0.009	COPERT IV	0.045	COPERT IV (converted to a per start EF)	0.004	COPERT IV (Highway)
2006-2007	0.009		0.045		0.004		0.009		0.045		0.004	
2004-2005	0.004		0.045		0.006		0.004		0.045		0.006	

Energy

	Passenger Car							LCV						
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
Fuel type	EF (g/km)	Source	EF g/start	Source	EF (g/km)	Source	EF g/start	Source	EF g/start	Source	EF (g/km)	Source
1998 - 2003	0.003	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.010	USEPA (as cited in IPCC 2006)	0.001	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.003	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.010	USEPA (as cited in IPCC 2006)	0.001	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985 – 1997 (3-way cat)	0.001		0.003		0.002		0.001		0.003		0.002	
1985 – 1997 (2-way cat)	0.001		0.002		0.001		0.001		0.002		0.001	
1976 – 1985	0.001		0.002		0.000		0.001		0.002		0.000	
Pre 76	0.000		0.001		0.000		0.000		0.001		0.000	
Ethanol[a]												
post 2005	0.030	USEPA (as cited in IPCC 2006) - mid-point of reported range	NA		0.015	Post 97 hot Ef x Petrol Non-urban to Hot Urban ratio	0.049	Passenger car EF x LCV to car ratio	NA		0.049	ethanol car hot EF x LCV non-urban to petrol hot urban ratio
2004-2005	0.030		0.007			0.059			0.059			
1998 - 2003	0.030		0.025			0.082			0.082			
1985 – 1997 (3-way cat)	0.030	Post 97 EF x earlier petrol age class relativity	0.029			0.049			0.049			
1985 – 1997 (2-way cat)	0.012		0.011			0.015			0.015			
1976 – 1985	0.004		0.010			0.005			0.005			
Pre 76	0.003		0.010			0.003			0.002			

Table 3.A.9 Passenger and light commercial vehicles: Zero kilometre N_2O emissions factors split by urban/non-urban road conditions and hot/cold operation

	Medium Duty Truck				Heavy Duty Truck				Bus			
	Urban		Non-urban		Urban		Non-urban		Urban		Non-urban	
fuel type	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
Petrol												
Post 2002	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV
1996 - 2002	0.006		0.006		0.006		0.006		0.006		0.006	
Pre 1996	0.006		0.006		0.006		0.006		0.006		0.006	
LPG												
Post 2002	0.020	DCC 2006	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.020	DCC 2006	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.011	DCC 2006	0.011	Hot urban EF x COPERT IV non-urban to urban ratio
1996 - 2002	0.020		0.020		0.020		0.020		0.011		0.011	
Pre 1996	0.020		0.020		0.020		0.020		0.011		0.011	
ADO												
Post-2011	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio	0.021	COPERT IV	0.017	Hot urban EF x COPERT IV non-urban to urban ratio	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio
2008-2010	0.030		0.030		0.021		0.030		0.030		0.030	
2003-2007	0.030		0.030		0.030		0.030		0.030		0.030	
1996 - 2002	0.030		0.030		0.030		0.030		0.030		0.030	
Pre 1996	0.030		0.030		0.030		0.030		0.030		0.030	

(a) raw ethanol content of blended fuel.
Source (as indicated in table): Weeks *et al.* (1993), IPCC (2006), Orbital Australia (2010); Orbital Australia (2011b).

Table 3.A.10 Medium and heavy duty trucks and buses: Zero kilometre N_2O g/km emission factors split by urban/non-urban road conditions and hot/cold operation

	Passenger Car			LCV			Medium Duty Truck			Heavy Duty Truck			Bus		
Fuel type	NO_x	CO	NMVOC	NO_x	CO	NMVOC	NO_x	CO	NMVOC	NO_x	CO	NMVOC	NO_x	CO	NMVOC
Petrol															
post 2005	0.044	0.108	0.077	0.139	0.047	0.236	2.52	10.87	1.04	2.52	10.87	1.04	3.91	48.61	3.47
2004-2005	0.075	0.399		0.275	0.669										
1998 - 2003	0.167	0.037		0.820	1.664										
1994 – 1997	0.498	6.906		1.456	10.108										
1985 – 93 (3-way cat)	0.669	10.378	0.294	0.000	0.000	0.236									
1985 – 93 (2-way cat)	0.619	0.083	0.260	0.000	0.000	0.791									
1976 – 1985	1.400	14.900	1.419	2.853	25.977	4.314									
Pre 76	2.460	24.000	2.275	5.014	41.842	6.914									
LPG															
Post 97	0.472	2.327	0.199	0.472	2.327	0.199	4.83	24.00	4.21	4.83	10.87	4.21	2.76	24.00	2.41
1985 – 97 (3-way cat)	0.942	10.305	0.755	0.942	10.305	0.755									
1985 – 97(2-way cat)	1.947	14.614	0.669	1.947	14.614	0.669									
1976 – 1985	2.931	39.881	3.647	2.931	22.875	3.647									
Pre 76	5.150	64.238	5.846	5.150	36.846	5.846									
ADO															
Post 97	0.250	0.116	0.062	0.250	0.116	0.062	5.20	6.44	1.15	5.20	24.00	1.15	4.90	2.88	1.56
1985 – 97 (3-way cat)	0.500	0.515	0.237	0.500	0.515	0.237									
1985 – 97 (2-way cat)	1.034	0.731	0.210	1.034	0.731	0.210									
1976 – 1985	1.556	1.994	1.144	1.556	1.994	1.144									
Pre 76	2.734	3.212	1.833	2.734	3.212	1.833									

Table 3.A.11 Vehicle emission factors for indirect gases by year of vehicle manufacture (g/km)

	Vehicle Age Class							
	Pre-1979[c]	1980-85[c]	1985-93[ac]	1985-93 [bd]	1994-97[e]	1998-03[e]	2004-05[e]	2006-current[e]
Passenger Cars								
CH_4	6.35E-07	4.76E-07	3.85E-07	5.85E-07	2.5E-08	1.38E-07	1.52E-07	1.54E-07
N_2O	0	0	0	0	0	0	0	0
CO	1.45E-04	1.27E-04	4.71E-05	1.06E-04	4.31E-06	1.43E-05	5.83E-06	4.74E-06
NO_x	0.00E+00	6.48E-06	1.54E-06	2.98E-06	1.54E-06	1.76E-06	2.73E-07	3.04E-07
NMVOCd	9.95E-06	7.45E-06	4.42E-06	7.83E-06	4.42E-06	4.42E-06	4.42E-06	4.42E-06
Light Commercial Vehicles								
CH_4	0	0	0	0	2.35E-07	2.08E-07	1.46E-07	1.55E-07
N_2O	0	0	0	0	0	0	0	0
CO	0	0	0	0	2.22E-05	2.29E-05	1.35E-06	6.23E-06
NO_x	0	0	0	0	1.49E-06	4.46E-06	0	1.08E-07
NMVOCd	9.95E-06	7.45E-06	4.42E-06	7.83E-06	4.42E-06	4.42E-06	4.42E-06	4.42E-06

Note: For light duty vehicles hot urban EFs are reported in the table above.

Table 3.A.12 Passenger and light commercial vehicles: non-CO_2 emission factor deterioration rates (g/km/km)

	Vehicle Age Class							
	Pre-1979[c]	1980-85[c]	1985-93[ac]	1985-93 [bd]	1994-97[e]	1998-03[e]	2004-05[e]	2006-current[e]
Passenger Cars								
CH_4	6.35E-07	4.76E-07	3.85E-07	5.85E-07	2.5E-08	1.38E-07	1.52E-07	1.54E-07
N_2O	0	0	0	0	0	0	0	0
CO	1.45E-04	1.27E-04	4.71E-05	1.06E-04	4.31E-06	1.43E-05	5.83E-06	4.74E-06
NO_x	0.00E+00	6.48E-06	1.54E-06	2.98E-06	1.54E-06	1.76E-06	2.73E-07	3.04E-07
NMVOC[d]	9.95E-06	7.45E-06	4.42E-06	7.83E-06	4.42E-06	4.42E-06	4.42E-06	4.42E-06
Light Commercial Vehicles								
CH_4	0	0	0	0	2.35E-07	2.08E-07	1.46E-07	1.55E-07
N_2O	0	0	0	0	0	0	0	0
CO	0	0	0	0	2.22E-05	2.29E-05	1.35E-06	6.23E-06
NO_x	0	0	0	0	1.49E-06	4.46E-06	0	1.08E-07
NMVOC[d]	9.95E-06	7.45E-06	4.42E-06	7.83E-06	4.42E-06	4.42E-06	4.42E-06	4.42E-06

Notes: a 3-way catalyst; b 2-way catalyst.
Source: (c) EPA NSW 1995 (d) Orbital Australia (2011c) (e) Orbital Australia (2010).

Table 3.A.13 Road transport: non-CO_2 emission factors

Source Category		Emission Factor (g/km)				
Sector	Fuel Type	CH_4 [a]	N_2O [b]	NO_x [c]	CO [c]	NMVOC [c]
Medium Trucks	NG [e]	0.101	0.001	1.200	0.200	0.010
Heavy Trucks	NG [e]	0.101	0.001	1.200	0.200	0.010
Buses	NG [e]	0.101	0.001	1.200	0.200	0.010
Motorcycles	Petrol	0.150	0.002	0.210	19.270	4.580
Passenger Cars	NG [e]	0.261	0.001	0.190	0.110	0.020
Light Commercial Vehicles	NG [e]	0.261	0.001	0.190	0.110	0.020

Source: (a) Hoekman (1992); (b) Weeks *et al.* (1993); (c) Carnovale *et al.* (1991); (d) EPA NSW (1995); (e) de Maria (1992).

Table 3.A.14 Shares used to allocate DIIS fuel consumption to unlisted categories 2017

ANZSIC category fuel consumption reported by OCE	General use	Military	Small marine craft	Off-road vehicles	Utility engines
Road transport automotive gasoline	97.2 per cent	0.0 per cent	2.0 per cent	0.1 per cent	0.6 per cent
Road transport ADO	99.9 per cent	0.1 per cent			
Water transport ADO	68.9 per cent	31.1 per cent			
Water transport fuel oil	100 per cent				
Air transport aviation gasoline	99.8 per cent	0.2 per cent			
Air transport aviation turbine fuel	93.1 per cent	6.9 per cent			

Source: Derived from Farrington 1988, ABS 2006 and Department of Industry 2013.

Table 3.A.15 Shares of total road fuel consumption by vehicle and fuel type 2015

Vehicle Type	Fuel Type			
	Automotive Gasoline	ADO	LPG	NG [(a)]
Passenger cars	88.1 per cent	17.1 per cent	53.5 per cent	0.8 per cent
Light commercial vehicles	10.9 per cent	27.0 per cent	26.0 per cent	1.1 per cent
Medium duty trucks	0.1 per cent	21.1 per cent	8.5 per cent	1.8 per cent
Heavy duty trucks	-	30.8 per cent	5.3 per cent	-
Buses	0.2 per cent	4.0 per cent	6.7 per cent	96.3 per cent
Motor cycles	0.7 per cent	-	-	-

Source: (a) ABS 2017. (b) Pekol Traffic and Transport 2017.

Table 3.A.16 Australian petrol-fuelled vehicle stock age distribution and fuel consumption rates: 2017

	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Passenger cars: year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2017[b]	340,952	0.104	7,598	0.126	70	0.202	23	0.202	250	0.172
2016	758,799	0.104	20,540	0.126	0	0.202	25	0.202	524	0.172
2015	755,614	0.104	18,606	0.126	124	0.202	27	0.202	696	0.172
2014	698,979	0.104	20,131	0.126	125	0.202	26	0.202	648	0.172
2013	735,328	0.104	26,983	0.126	183	0.202	42	0.202	560	0.172
2012	692,426	0.104	31,738	0.126	182	0.202	36	0.202	646	0.172
2011	632,268	0.104	34,296	0.126	176	0.202	15	0.202	958	0.172
2010	672,550	0.107	43,789	0.134	247	0.158	21	0.205	860	0.147
2009	592,128	0.107	45,834	0.134	180	0.158	21	0.205	802	0.147
2008	633,705	0.107	56,124	0.134	258	0.158	41	0.205	1,137	0.147
2007	672,668	0.107	58,304	0.134	476	0.158	110	0.205	1,016	0.147
2006	622,487	0.107	54,355	0.134	536	0.158	49	0.205	1,049	0.147
2005	626,223	0.107	79,818	0.134	434	0.158	39	0.205	745	0.147
2004	567,494	0.107	73,420	0.134	470	0.158	41	0.205	418	0.147
2003	526,261	0.107	66,317	0.134	332	0.158	33	0.205	780	0.147
2002	426,713	0.107	50,829	0.134	413	0.158	20	0.205	661	0.147
2001	371,878	0.107	43,871	0.134	318	0.158	14	0.205	479	0.147
2000	338,881	0.109	39,797	0.133	216	0.353	12	0.304	750	0.143
1999	276,911	0.109	39,742	0.133	197	0.353	12	0.304	536	0.143
1998	247,946	0.109	34,140	0.133	260	0.353	24	0.304	552	0.143
1997	176,600	0.109	25,984	0.133	213	0.353	11	0.304	495	0.143
1996	122,969	0.109	22,651	0.133	177	0.353	11	0.304	387	0.143
1995	102,407	0.109	19,946	0.133	160	0.353	11	0.304	345	0.143
1994	83,463	0.109	18,560	0.133	163	0.353	34	0.304	273	0.143
1993	63,721	0.109	13,919	0.133	151	0.353	15	0.304	223	0.143
1992	50,055	0.109	13,462	0.133	196	0.353	3	0.304	195	0.143
1991	40,548	0.109	10,573	0.133	157	0.353	3	0.304	151	0.143
1990	40,178	0.109	11,510	0.133	213	0.353	6	0.304	156	0.143
1980 – 1989 a	122,367	0.109	47,149	0.133	2,604	0.353	80	0.304	503	0.143
1979 and earlier	162,991	0.109	38,494	0.133	12,549	0.353	159	0.304	160	0.143

Notes: (a) Fuel consumption rates average for period 1980–89. (b) Assumes new cars on road for average of 6 months in the first year.
Source: Department of the Environment and Energy estimates derived from ABS 2013, ABS 2014a.

Table 3.A.17 Australian diesel-fuelled vehicle stock age distribution and fuel consumption rates: 2017

	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Passenger cars: year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2017[b]	71,213	0.101	88,460	0.111	11,536	0.305	2,850	0.574	1,919	0.268
2016	171,362	0.101	186,525	0.111	23,290	0.305	4,883	0.574	3,854	0.268
2015	162,317	0.101	173,783	0.111	22,237	0.305	4,965	0.574	4,064	0.268
2014	153,773	0.101	159,492	0.111	20,591	0.305	5,810	0.574	4,233	0.268
2013	162,481	0.101	165,189	0.111	19,649	0.305	6,093	0.574	3,888	0.268
2012	159,553	0.101	160,444	0.111	21,054	0.305	5,572	0.574	4,607	0.268
2011	126,613	0.101	117,866	0.111	15,502	0.305	3,223	0.574	4,674	0.268
2010	120,907	0.094	118,032	0.113	23,765	0.272	5,409	0.556	4,296	0.285
2009	86,804	0.094	96,913	0.113	18,384	0.272	2,987	0.556	3,579	0.285
2008	86,481	0.094	105,551	0.113	22,171	0.272	3,818	0.556	4,623	0.285
2007	64,742	0.094	80,849	0.113	27,852	0.272	7,621	0.556	3,371	0.285
2006	50,199	0.094	70,486	0.113	20,868	0.272	4,316	0.556	3,002	0.285
2005	36,106	0.094	54,173	0.113	20,901	0.272	4,435	0.556	2,949	0.285
2004	30,593	0.094	47,227	0.113	19,561	0.272	4,134	0.556	2,106	0.285
2003	25,640	0.094	38,096	0.113	14,280	0.272	3,419	0.556	1,938	0.285
2002	21,081	0.094	33,902	0.113	16,090	0.272	2,575	0.556	1,880	0.285
2001	17,209	0.094	23,770	0.113	11,052	0.272	1,816	0.556	1,825	0.285
2000	15,583	0.122	27,280	0.119	10,774	0.260	1,865	0.537	2,360	0.297
1999	12,392	0.122	24,776	0.119	10,666	0.260	1,997	0.537	1,971	0.297
1998	11,552	0.122	21,951	0.119	10,293	0.260	2,185	0.537	1,989	0.297
1997	10,179	0.122	18,074	0.119	8,046	0.260	1,723	0.537	1,571	0.297
1996	8,730	0.122	15,559	0.119	6,959	0.260	1,388	0.537	1,437	0.297
1995	8,623	0.122	13,898	0.119	7,438	0.260	1,581	0.537	1,567	0.297
1994	8,786	0.122	13,743	0.119	7,948	0.260	1,642	0.537	1,534	0.297
1993	7,910	0.122	11,461	0.119	6,060	0.260	1,028	0.537	1,185	0.297
1992	9,348	0.122	10,044	0.119	5,854	0.260	540	0.537	1,091	0.297
1991	8,008	0.122	7,151	0.119	4,803	0.260	369	0.537	802	0.297
1990	7,323	0.122	8,497	0.119	7,220	0.260	838	0.537	741	0.297
1980 – 1989 a	24,813	0.122	25,138	0.119	47,397	0.260	5,668	0.537	2,295	0.297
1979 and earlier	697	0.122	1,294	0.119	9,201	0.260	1,806	0.537	212	0.297

Notes: (a) Fuel consumption rates average for period 1980–89. (b) Assumes new cars on road for average of 6 months in the first year.
Source: Department of the Environment and Energy estimates derived from ABS 2013, ABS 2014a.

Table 3.A.18 Australian LPG-fuelled vehicle stock age distribution and fuel consumption rates: 2017

	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Passenger cars: year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2017[b]	273	0.100	53	0.13	49	0.146	20	0.530	10	0.200
2016	867	0.100	479	0.13	60	0.146	6	0.530	35	0.200
2015	1,813	0.100	809	0.13	24	0.146	0	0.530	66	0.200
2014	3,290	0.100	1,186	0.13	30	0.146	6	0.530	69	0.200
2013	4,117	0.100	1,665	0.13	36	0.146	3	0.530	43	0.200
2012	4,780	0.100	2,592	0.13	70	0.146	5	0.530	42	0.200
2011	3,902	0.100	1,253	0.13	53	0.146	8	0.530	192	0.200
2010	7,561	0.098	4,083	0.142	73	0.248	16	0.640	264	0.431
2009	8,835	0.098	4,795	0.142	44	0.248	8	0.640	377	0.431
2008	10,480	0.098	7,000	0.142	45	0.248	3	0.640	481	0.431
2007	10,193	0.098	5,968	0.142	55	0.248	15	0.640	319	0.431
2006	11,362	0.098	7,240	0.142	73	0.248	3	0.640	285	0.431
2005	11,785	0.098	6,241	0.142	70	0.248	9	0.640	196	0.431
2004	12,724	0.098	5,668	0.142	67	0.248	0	0.640	121	0.431
2003	14,350	0.098	5,712	0.142	56	0.248	3	0.640	65	0.431
2002	12,078	0.098	5,122	0.142	67	0.248	6	0.640	94	0.431
2001	10,920	0.098	5,102	0.142	38	0.248	0	0.640	261	0.431
2000	11,433	0.160	5,078	0.156	26	0.630	0	0.432	155	0.600
1999	11,957	0.160	4,241	0.156	21	0.630	0	0.432	121	0.600
1998	9,994	0.160	3,382	0.156	16	0.630	0	0.432	43	0.600
1997	10,914	0.160	2,690	0.156	23	0.630	0	0.432	38	0.600
1996	8,845	0.160	2,385	0.156	20	0.630	0	0.432	19	0.600
1995	5,896	0.160	2,071	0.156	20	0.630	0	0.432	63	0.600
1994	4,764	0.160	1,879	0.156	17	0.630	3	0.432	112	0.600
1993	4,269	0.160	1,384	0.156	15	0.630	0	0.432	58	0.600
1992	3,965	0.160	1,199	0.156	32	0.630	0	0.432	28	0.600
1991	3,323	0.160	970	0.156	30	0.630	0	0.432	23	0.600
1990	2,164	0.160	1,205	0.156	28	0.630	0	0.432	35	0.600
1980 – 1989 a	7,751	0.160	5,356	0.156	548	0.630	3	0.432	69	0.600
1979 and earlier	6,106	0.160	4,350	0.156	1,154	0.630	111	0.432	17	0.600

Notes: (a) Fuel consumption rates average for period 1980–89. (b) Assumes new cars on road for average of 6 months in the first year.
Source: Department of the Environment and Energy estimates derived from ABS 2013, ABS 2014a.

Table 3.A.19 Average rate of fuel consumption for road vehicles by vehicle and fuel type

Vehicle Type	Fuel Type		
	Automotive Gasoline (L/km)	ADO (L/km)	LPG / NG (L/km)
Passenger cars	a	a	a
Light commercial vehicles	a	a	a
Medium duty trucks	a	a	a
Heavy duty trucks	a	a	a
Buses	a	a	a
Motor Cycles	0.059	NA	NA

Source: ABS 2017. (a) Refer to Table 3.A.15 - 3.A.17.

Table 3.A.20 Evaporative emission factors for road vehicles using automotive gasoline

Vehicle Type	Emission Factor (g/km)	
	Hot Soak and Diurnal Emissions (FH_{ij}) [a]	Running Losses (FR_{ij}) [b]
Passenger Cars[c]		
Post 1985	0.38	0.9
1976–1985	0.96	0.9
Pre-1976	1.92	0.9
Light Commercial Vehicles	1.13	0.19
Medium Trucks	2.24	0.26
Heavy Trucks	2.75	0.29
Buses	2.24	0.20
Motorcycles	0.76	0.0

Source: (a) Carnovale *et al.* (1991).
(b) OECD (1991).
(c) Calculated with an RVP (Reid Vapor Pressure) of 11.0 psi (pound-force per square inch).

Table 3.A.21 Average Trip Length by State and Territory, by vehicle type, 2016

	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Passenger Cars	12.53	11.95	16.52	14.32	11.58	12.02	12.13	13.36
Light Commercial Vehicles	16.55	15.24	27.16	15.18	17.09	12.83	16.63	16.34
Medium Trucks	26.00	23.70	40.00	24.92	20.64	15.69	16.87	19.43
Heavy Trucks	123.57	79.65	125.21	102.74	76.90	81.98	65.92	69.62
Buses	24.95	28.19	51.47	30.87	30.53	21.06	19.21	22.11

Source: Pekol Traffic and Transport 2018

Table 3.A.22 Carbon dioxide emission factor for coke

Year	Emission Factor (CO_2 Gg/ PJ)
1990	103.79
1991	103.81
1992	103.84
1993	103.87
1994	103.83
1995	103.84
1996	103.82
1997	103.89
1998	103.88
1999	103.87
2000	103.83
2001	103.82
2002	104.48
2003	104.16
2004	105.38
2005	106.41
2006	106.62
2007	107.06
2008	107.05
2009	107.84
2010	106.65
2011	106.50
2012	106.76
2013	106.15
2014	106.91
2015	108.20
2016	108.19

Source: Determined using a carbon balance of the coke oven process.

Table 3.A.23 NMVOC emission factors for service station storage and transfer operations

Region	Population (million)[(a)]	Emission factor (kg per kl distributed)[(b)]
Sydney Statistical Region*(c)*	3.67	0.16
Port Phillip Control Region*(d)*	3.39	0.16
Other	10.22	1.00
Australia*(e)*	17.28	0.66

Source: (a) Australian Bureau of Statistics, Census (ABS 1991b).
(b) Filling losses and underground-tank breathing.
(c) Environment Protection Authority NSW (EPA 1995).
(d) Melbourne, Geelong and Westernport Regions, Environment Protection Authority Victoria (EPA 1991).
(e) Population weighted average, all years 1988-1994.

Table 3.A.24 NMVOC emission factors for bulk fuel storage facilities

Region	Population (million)[(a)]	Emission factor (kg per kl distributed)[(b)]
Melbourne/Sydney Region[(c)]	7.06	0.48
Other[(d)]	10.22	1.49
Australia[(e)]	17.28	1.08

Source: (a) Australian Bureau of Statistics, Census (ABS 1991b).
(b) Storage and working losses
(c) Assume emission factors in Melbourne (Environment Protection Authority Victoria, (EPA 1991) and Sydney are similar because control regulations are identical
(d) From Australian Environment Council (AEC 1988) data for regions outside Melbourne and Sydney.
(e) Population weighted average, all years 1988-1994.

4. Industrial Processes and Product Use

4.1 Overview

Total net emissions estimated from *industrial processes and product use* were 33.7 Mt CO_2-e in 2017, or 6.1 per cent of net national emissions (excluding *LULUCF*) (Table 4.1).

Table 4.1 Industrial processes and product use sector CO_2-e emissions, 2017, 2018

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)					
	CO_2	CH_4	N_2O	HFC/PFC/SF_6	Total 2017 CO_2-e	Preliminary 2018 estimates CO_2-e
2 INDUSTRIAL PROCESSES AND PRODUCT USE	19,446	73	1,536	12,632	33,686	34,432
A Mineral Industry	5,600	NA	NA	NA	5,600	5,460
B Chemical Industry	3,074	14	1,519	NA	4,607	5,098
C Metal Industry	10,374	59	17	203	10,653	10,915
D Non-energy products from fuels and solvent use	184	NA	NA	NA	184	184
E. Electronics Industry	NA	NA	NA	NE	NE	-
F Product uses as substitutes for Ozone Depleting Substances	NA	NA	NA	12,253	12,253	12,377
G Other product manufacture and use	NA	NA	NA	176	176	178
H Other	213	NA	NA	NA	213	219

The *metal industry* contributed 31.6 per cent (10.7 Mt CO_2-e) of the sector's emissions, The *mineral industry* contributed 16.6 per cent (5.6 Mt CO_2-e), *chemical industries* contributed 13.7 per cent (4.6 Mt CO_2-e), the *product uses as substitutes for ozone depleting substances* contributed 36.4 per cent (12.3 Mt CO_2-e), *Other (food and drink)* contributed 0.6 per cent (0.2 Mt CO_2-e) and *other product manufacture and use* contributed 0.5 per cent (0.2 Mt CO_2-e).

The main gas emitted by *industrial processes and product use* is CO_2, contributing 57.7 per cent (19.4 Mt CO_2-e) of the sector's emissions in 2017. PFCs contributed 0.6 per cent (0.2 Mt CO_2-e), HFCs contributed 36.4 per cent (12.3 Mt CO_2-e), SF_6 contributed 0.5 per cent (0.2 Mt CO_2-e), N_2O contributed 4.6 per cent (1.5 Mt CO_2-e), and CH_4 0.2 per cent (0.1 Mt CO_2-e).

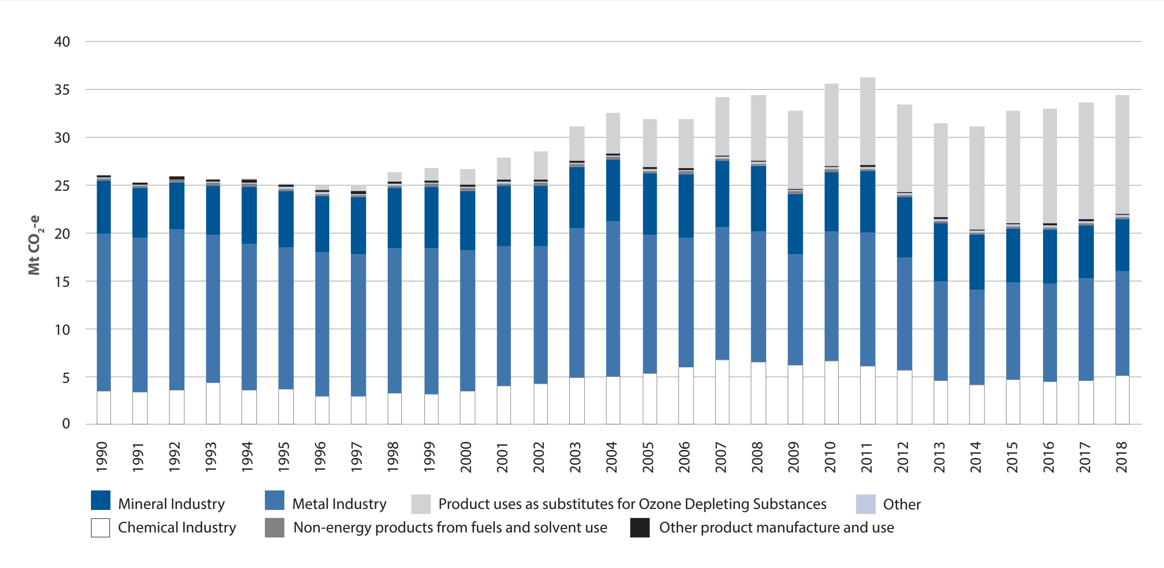
Trends

Net emissions from *industrial processes and product use* increased by 29.4 per cent (7.7 Mt CO_2-e) from 1990 to 2017, and increased by 2.1 per cent (0.7 Mt CO_2-e) between 2016 and 2017. The preliminary estimate for 2018 is 34.4 Mt CO_2-e, a change of 2.2 per cent on 2017 levels.

The increases in sectoral emissions observed over the longer term are principally due to growth in emissions associated with the manufacture of chemical products and *Product uses as substitutes for Ozone Depleting Substances*. The decrease in emissions from 2010 to 2011 predominantly reflects declines in metal production associated with the permanent closure of a blast furnace in late 2011.

Each source category's contribution to total emissions and to sectoral trends within the *industrial processes and product use* sector between 1990 and 2018 is shown in Figure 4.1.

Figure 4.1 Emissions from industrial processes and product use by subsector, 1990–2018



Cement production

Emissions of CO_2 for this source category are dependent on the quantity of cement produced and this in turn is closely tied to annual growth in the Australian economy. Emissions of CO_2 from cement production in 2017 were 3,019 kt CO_2-e, a 12.8 per cent decrease from 1990, while production has decreased by 10.1 per cent over the same period. Improvements in industry practices such as the recycling of cement kiln dust have resulted in lower emissions per unit production.

Year on year fluctuations in emissions from cement production is variable and matches fluctuations in cement production very closely.

Lime production

Emissions of CO_2 from the production of lime vary year to year according to the quantities of commercial and in-house lime produced. The quantities of lime produced are dependent on the demand for lime within the Australian economy. Total lime production in 2017 was 1,516 kt compared with 1,546 kt in 2016 representing a decrease in production of 1.8 per cent. Lime production levels are sensitive to levels of demand in the resources sector as evidenced by the decline in lime production of 16.7 per cent observed in 2000 and a 13.0 per cent decline in 2009. The decline in 2000 is attributed to the fall in demand for minerals processing particularly in the gold sector while the 2009 decline is associated with the general economic downturn also affecting other industrial processes.

Limestone and dolomite use

The total CO_2 emissions reported in this source category include emissions from the consumption of carbonates in (calcite, magnesite, dolomite, sodium bicarbonate, potassium carbonate, barium carbonate, lithium carbonate and strontium carbonate), magnesia production, zinc production, ferroalloys production, iron and steel production, ceramics (including clay bricks) and glass production, soda ash use and production and miscellaneous uses of carbonates. The trend in emissions is heavily influenced by the consumption of limestone which is consumed in greater quantities than any other carbonate. In 2017, total carbonate consumption had increased by 10.6 per cent from 1990. The year on year growth in carbonate consumption, however, has varied from positive to negative throughout the time series with the decrease of 8.5 per cent observed between 2016 and 2017 predominantly reflecting decreases in ceramics and 'other' production in Australia.

Soda ash production and use

Soda ash is produced in Australia by only one company, Alcoa. A second producer, Penrice Soda Products, which ceased operations in late 2013. Soda ash is now predominantly imported into Australia. More than half the soda ash produced is consumed by glass manufacturers, with other important users of soda ash including manufacturers of detergents, soaps and chemicals and the metals and mining industries. Production of soda ash remained relatively constant while imports of soda ash have experienced large fluctuations and an overall increase in quantities. Emissions for soda ash production in historical years are confidential and are reported under 2.B chemical industry.

Chemical industry

In 2009, there was a scaling back of chemical products manufacture reflecting in combination the effects of the international economic downturn and a gas explosion in Western Australia in October 2008 which affected natural gas supplies for ammonia production in that part of the country. A decline of 23.9 per cent from 2011 has been observed through to 2017 reflecting a similar decline in ammonia production associated with temporary plant shut downs and improvements in nitric acid emissions control.

Iron and steel production

Emissions per tonne of iron and steel produced vary according to changing quantities of reductants used. Emissions from iron and steel production in 2017 were 7.5 per cent higher than in 2016.

A notable decline of emissions from iron and steel production in 2012 was a 21.3 per cent reduction on 2011. This decrease in emissions reflected a decrease in the coke consumption in iron and steel production reported under the NGER System, and was associated with the closure of the No.6 blast furnace at the Port Kembla steelworks in October 2011.

The down-turn in emissions during 2005 occurred due to the blast-furnace re-lining activities at the Whyalla steel works. There has been a general declining trend in the Iron and Steel CO_2-e IEF due to the increased use of pulverised coal injection in lieu of coke. *Aluminium production*

Emissions from the production of aluminium were 5.2 per cent lower in 2017 than 2016 owing to a decrease in production levels and the associated consumption of coal tar, petroleum coke and other inputs to the anode production process.

The 29.3 per cent downward trend in CO_2-e emissions per tonne of aluminium produced since 1990 has occurred as a result of improvements in process control and the resultant reduction in PFC emissions. Any fluctuations in IEFs occurring in the latter part of the time series are the result of small fluctuations in the number of anode effects in the production process occurring due to electricity supply disruptions and potline maintenance. The fall in the PFC IEF between 2005 and 2007 occurred as a result of a smelter upgrade at Hydro Kurri Kurri (conversion of Potline No 1 from side-work to centre-work) and an enhanced emissions performance at the Tomago smelter (AAC 2007).

Consumption of halocarbons and SF_6

Emissions from the consumption of halocarbons and SF_6 are increasing steadily on 1990 levels with a growing stock of gas and low levels of destruction and recycling. HFC refrigerants were first used in Australia in 1994 and have been increasing in use since that time as ozone depleting refrigerants are phased out under the Montreal Protocol. SF_6 has been in use in electricity supply and distribution and miscellaneous uses throughout the time series.

4.2 Overview of source category description and methodology – Industrial Processes and Product Use

The *industrial processes and product use* sector includes emissions generated from a range of production processes involving *inter alia* the use of carbonates (i.e. limestone, dolomite, magnesite, etc.); carbon when used as a chemical reductant (e.g. iron and steel or aluminium production); chemical industry processes (e.g. ammonia and nitric acid production) and the production and use of synthetic gases such as halocarbons. Key categories for Australia include emissions from cement production, iron and steel production, aluminium production and the consumption of halocarbons.

For some industries, for example the iron and steel industry, reported emissions are split between the *industrial processes and product use* sector and the *energy* sector depending on the type of process within the industry that generated the emissions.

The Australian methodology for *industrial processes and product use* contains both country specific and IPCC default methodologies and EFs (Table 4.2). The use of tier 2 methods indicates a higher level of complexity, data requirements and in-principle accuracy than a tier 1 method.

In certain sub sectors within *industrial processes and product use*, activity data are commercial-in-confidence and, due to the direct relationship between activity and emissions, emissions estimates by gas species are also confidential. Where this is the case, it is necessary to aggregate sub-sectoral emission estimates in order to preserve confidentiality.

Emissions of CO_2 from *magnesia production* (2.A.4.c) have been aggregated with CO_2 from *other product uses of carbonates* (2.A.4). *CO2 emissions from carbide production* (2.B.5) and *soda ash production* (2.B.7) have been aggregated under 2.B.10 – *confidential chemical industry emissions*. Emissions of N_2O from the u*se of N2O in anesthesia and aerosols* (2.G.3) have been aggregated with N_2O from *nitric acid production* (2.B.2). This aggregate is reported under 2.B.2 *nitric acid production.* Emissions from *iron and steel production* (2.C.1) are aggragated with emissions from the production of *ferroalloys* and *other metals* (2.C.2 and 2.C.7).

Table 4.2 Summary of methods and emission factors: Industrial processes and product use

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
2. Industrial Processes and Product Use												
A. Mineral Industry	T2	CS	NA	NA	NA	NA						
1. Cement Production	T2	CS	NA	NA	NA	NA						
2. Lime Production	T2	CS	NA	NA	NA	NA						
3. Glass Production	T2	CS	NA	NA	NA	NA						
4. Other Process Uses of Carbonates	T2	CS	NA	NA	NA	NA						
7. Other												
B. Chemical Industry	T2,T3	CS,D	T2	CS/D	T3	CS	NA	NA	NA	NA	NA	NA
1. Ammonia Production [b]	T2/3	CS,D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2. Nitric Acid Production [b]	NA	NA	NA	NA	T3	CS	NA	NA	NA	NA	NA	NA
3. Adipic Acid Production	NA	NA	NA	NA	NA	NA						
4. Caprolactuam, Glyoxal and Glyoxix acid Production	NA	NA	NA	NA	NA	NA						
5. Carbide Production	T2	CS	NA	NA	NA	NA						
6. Titanium Dioxide Production	T2	CS	NA	NA	NA	NA						
7. Soda Ash Production	T2/3	CS, D	NA	NA	NA	NA						
8. Petrochemical and Carbon Black Production	NA	NA	T2	CS/D	NA	NA						
9. Fluorochemical Production	NA	NA	NA	NA	NA	NA						
10. Other	NA	NA	NA	NA	NA	NA						
C. Metal Industry	T2/3	CS	T2	CS	T2	CS			T2/3	CS	T2	CS
1. Iron and Steel Production	T2/3	CS	T2	CS	T2	CS			NA	NA	NA	NA
2. Ferroalloys Production	T2	CS	NA	NA	NA	NA			NA	NA	NA	NA
3. Aluminium Production	T2/3	CS	NA	NA	NA	NA			T2/3	CS	NA	NA
4. Magnesium Production	NA	NA	NA	NA	NA	NA			NA	NA	T2	CS

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
5. Lead Production	T2	CS	T2	CS	T2	CS			NA	NA	NA	NA
6. Zinc Production	T2	CS	T2	CS	T2	CS			NA	NA	NA	NA
7. Other	T2	CS	T2	CS	T2	CS			NA	NA	NA	NA
D. Non-Energy Products from Fuels and Solvent Use	T2	CS							NA	NA	NA	NA
1. Lubricant Use	T2	CS										
2. Parrafin wax Use												
3. Solvent Use												
4. Other												
E. Electronics Industry									NA	NA	NA	NA
1. Integrated Circuit or Semiconductor									NA	NA	NA	NA
2. TFT Flat Panel Display									NA	NA	NA	NA
3. Photovoltaics									NA	NA	NA	NA
4. Heat Transfer Fluid									NA	NA	NA	NA
5. Other												
F. Product Uses as Substitutes for Ozone Depleting Substances							M	D/CS	NA	NA	T1,T2	CS
1. Refrigeration and Air Conditioning							M	D/CS	NA	NA	NA	NA
2. Foam Blowing							M	D/CS	NA	NA	NA	NA
3. Fire Protection							M	D/CS	NA	NA	NA	NA
4. Aerosols							M	D/CS	NA	NA	NA	NA
5. Solvents							M	D/CS	NA	NA	NA	NA
6. Semiconductor Manufacture							NA	NA	NA	NA	NA	NA
7. Electrical Equipment							NA	NA	NA	NA	T2	CS
8. Other Applications (d)							NA	NA	NA	NA	T1	CS
G. Other Product Manufacture and Use					T2	CS	NA	NA	NA	NA	NA	NA
1. Electrical Equipment					NA	NA	NA	NA	NA	NA	NA	NA

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
2. SF_6 and PFCs from Other Product Uses					NA	NA	NA	NA	NA	NA	NA	NA
3. N_2O from Product Uses					T2	CS	NA	NA	NA	NA	NA	NA
4. Other					NA	NA	NA	NA	NA	NA	NA	NA
H. Other	CS	CS	NA	NA	NA	NA						
1. Pulp and Paper Industry	NA	NA	NA	NA	NA	NA						
2. Food and Beverage Industry	CS	CS	NA	NA	NA	NA						
3. Other	NA	NA	NA	NA	NA	NA						

Notes: EF = Emission Factor, T1 = tier 1, T2 = tier 2, T3 = tier 3, CS= Country-specific, D= IPCC default, NE = not estimated, NA= not available, NO = not occurring, IE = included elsewhere.
(a) Emissions reported under 2.A.3 *limestone and dolomite use*; (b) Emissions reported under 2.B.6 *confidential chemical industry emissions*; (c) Methods for acetylene use and from use of N_2O (3D), methods for other components identified separately; (d) Other uses of SF_6

Data sources

The inventory for the *industrial processes and product use* sector relies primarily on data collected under the National Greenhouse and Energy Reporting System. The following table summarises the data source used in compiling the inventory for industrial processes and product use.

Table 4.3 Summary of principal data sources for Industrial Processes and Product Use 2017

Industrial processes and product use sector	Method of data collection	Activity data
2.A.1. Cement cement	NGER	Cement Australia, Boral, Adelaide Brighton
2.A.2. Lime production	NGER	Boral, Adelaide Brighton, Cement Australia, Sibelco Pacific, Alcan and Queensland Alumina
2.A.4. Limestone and dolomite and other carbonates	NGER	Alcan Gove, Alcoa, Amcor, Arrium, BGC Australia, BlueScope Steel, Boral, Bradken, Brickworks, CSR, Fletcher Building, FMQ Australia, Glencore Investment, Heathgate Resources, Incitec Pivot, Kalgoorlie consolidated gold mines, Nyrstar Australia, Owens Illinois, Redbank Energy, Rio Tinto, Silbelco, Sun Metals, Thales Australia, Wesfarmers, Orora, Tarac Australia, Norton Goldfields
2.A.6. Bitumen	Published statistics	ABARES Commodity Statistics
2.B.1. Ammonia	NGER	Incitec, Orica, Wesfarmers CSBP, BHP Billiton, Queensland Nitrates, Burrup Fertlisers
2.B.2. Nitric acid	NGER	Orica, Wesfarmers CSBP, Queensland Nitrates
2.B.6 Synthetic Rutile and Titanium Dioxide	NGER	Tiwest, Iluka Resources, Milenium Chemicals
2.B.7. Soda ash production	NGER	Penrice Soda Products, Alcoa
2.B.8. Petrochemical and carbon black production	Company Census	Dynea W.A, Borden Chemicals, Orica, BP, Shell, Huntsman Chemicals, Dow Chemicals, Qenos, ExxonMobil, Continental Carbon, Cabot Australia, Australian Vinyl, BOC Gases, Air Liquide, Caltex, Coogee Chemicals
2.C.1. Iron and steel	NGER	BlueScope Steel, Arrium
2.C.2 Ferroalloys production	NGER	TemCo
2.C.3. Aluminium	NGER	Alcoa, Rio Tinto, Hydro Kurri Kurri, Tomago Aluminium
2.C.5 – 7. Lead, Zinc and Other metals	NGER and published statistics	Billiton Manganese, BHP Billiton, Simcoa ABARES Commodity Statistics for various metals
2.F.6 Other – SF_6 use in electrical transmission and distribution	NGERS	Multiple NGERS entities consuming SF_6 in electrical switchgear and circuit breaker applications
2.F. 1- 5 Product uses as substitutes for ODS	Import licence reporting	Bulk import and pre-charged equipment data reported to the former Department of Sustainability, Environment, Water, Population, Arts and Community (now DE) under the regulations applying under the Ozone Protection and Synthetic Greenhouse Gas Management Act 2003 SF_6 stock data and EFs obtained from NGER reporting entities.
2.G.3 N_2O from product uses	Company survey	BOC, Air Liquide
2.H.2. Food and drink	NGER and published statistics	ABS apparent consumption data, Penrice Soda Products, Air Liquide, BOC, Hunstman Chemicals, Incitec, Orica.

Industrial Processes and Product Use

4.3 Source Category 2.A Mineral Industry

4.3.1 Cement production (2.A.1)

Source category description

Cement clinker production is a key category for Australia. CO_2 is produced during the manufacture of portland clinker, which is an intermediate product in the production of cement. CO_2 emissions are essentially proportional to the lime content of the clinker. On exit from the cement kiln, and after cooling, the clinker is ground to a fine powder and up to 5 per cent (by weight) of gypsum or natural anhydrite (that is, forms of calcium sulphate) added to control the setting time of the cement. The finished product is referred to as 'portland' cement.

There are three clinker producers in Australia; Adelaide Brighton, Blue Circle Southern Cement (Boral) and Cement Australia. The production of blended cements, incorporating waste materials from other industries (e.g. slag, fly ash and silica fume), represents a significant portion (approximately 20 per cent) of the total cement manufacturing market in Australia. According to the Cement Industry Federation (CIF 2003), the proportion of waste materials added to cement varies significantly and may range from 10 per cent to 80 per cent (by weight). Blending waste materials with cement significantly reduces the CO_2 emissions per unit of cement produced.

The production of clinker in Australia responds to market conditions. Competition with imported products has become a significant issue for domestic production, especially in recent years. In 2012, one clinker production facility ceased operation.

Methodology

Calcium carbonate ($CaCO_3$) from calcium rich raw materials such as limestone, chalk and natural cement rock is heated at temperatures of approximately 1500° C in cement kilns to form lime (CaO) and CO_2 in a process known as calcination.

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

Emissions from clinker production are estimated using a tier 2 method.

$$E_{cl} = [EF_{cl} \cdot A_{cl} + EF_{cl} \cdot F_{ckd} \cdot A_{ckd} + EF_{toc} \cdot (A_{cl} + A_{ckd})] \cdot 10^{-6}$$

CO_2 emissions from clinker manufacture are estimated by the application of a country – specific emission factor EF_{cl}, in kilograms of CO_2 released per tonne of clinker produced, to the annual national clinker production A_{cl}.

The country – specific EF is the product of the fraction of lime used in the clinker and a constant reflecting the mass of CO_2 released per unit of lime produced. This factor was derived using the World Business Council for Sustainable Development (WBCSD 2005) methodology. Assuming CaO and MgO proportions of 0.66 and 0.015 respectively, based on Ryan and Samarin 1992, leads to an EF of 534 kg CO_2 per tonne of clinker.

In addition to the emissions associated with the lime used in the clinker, the methodology accounts for emissions associated with the calcination of cement kiln dust (A_{ckd}) and the quantity of total organic carbon expressed as a proportion of total clinker produced (TOC). F_{ckd} is the degree of calcination of cement kiln dust (ranging from 0 per cent to 100 per cent) and is assumed to be 100 per cent in Australia such that $F_{ckd} = 1$ (following WBCSD 2005). A_{ckd} is the quantity of cement kiln dust (CKD) produced annually. The EF for TOC is taken from WBCSD 2005 (equivalent to 10kg CO_2 per tonne of clinker).

Choice of emission factor

From 2016, two cement production facilities have reported facility-specific EFs based on the CaO and MgO contents of their cement. The remaining facilities continue to use the CS factor as described above as this factor best represents their particular product specifications. The CS EF is used for all facilities from 1990-2015 as adopted by all cement producers under NGERS prior to 2016.

Activity data

Data for cement production for individual facilities were obtained from the NGER System for 2009 onwards and the reporting mechanisms of the former Emissions Intensive, Trade Exposed Industries assistance program (EITEIs – subsequently known as the Jobs and Competitiveness Program) for 2007 and 2008. Data for the period 1990-2006 were obtained by industry survey undertaken by the Cement Industry Federation (CIF). In all cases, all producers of cement have been captured throughout the time-series.

Table 4.4 Australian cement clinker production and emissions 1990, 2000–2017

Year	Clinker production (kt)	Cement Kiln Dust (kt)	Emissions (Gg CO_2)
1990	6,205	160	3,463
2000	6,557	99	3,621
2001	6,425	84	3,541
2002	6,354	58	3,488
2003	6,566	22	3,584
2004	6,492	42	3,555
2005	6,657	79	3,664
2006	7,076	72	3,888
2007	7,254	47	3,972
2008	7,053	48	3, 863
2009	6,986	52	3,829
2010	6,470	53	3,549
2011	6,374	55	3,496
2012	6,425	45	3,518
2013	6,019	52	3,294
2014	5,739	41	3,138
2015	5,632	35	3,076
2016	5,476	29	2,931
2017	5,579	20	3,019

Source: GHD 2009c, DCCEE EITEIs Program 2009, NGER 2009 to date

4.3.2 Lime production (2.A.2)

Source category description

Lime is an important chemical having major uses in metallurgy (steel, copper, gold, aluminium and silver), other industrial applications (water softening, pH control, sewage sludge stabilisation), and construction (soil stabilisation, asphalt additive and masonry lime). The producers of commercial lime in Australia include Cement Australia, Boral Cement , Adelaide Brighton Cement, Sibelco Pacific,. Rio Tinto Alcan also produces in-house lime intermittently for alumina production.

Methodology

CO_2 is produced when either high calcium lime (CaO) or dolomitic lime (CaO.MgO) are manufactured by the calcination of calcium rich raw materials (limestone or dolomite) in a kiln.

$CaCO_3$ (limestone) + heat → CaO (high calcium lime) + CO_2
$CaCO_3.MgCO_3$ (dolomite) + heat → CaO.MgO (dolomitic lime) + 2 CO_2

Emissions from lime production are estimated using a tier 2 method.

Total CO_2 emissions E_q associated with lime production A_q are estimated as the sum of emissions by facility according to:

$$E_q = \Sigma A_q . EF_q$$

The EF for lime produced is estimated for each facility from a consideration of the molecular weights (56 for CaO, 44 for CO_2) and the composition of the lime products.

Choice of emission factor

Selection of EFs was undertaken in accordance with the decision tree in section 1.4.1.

Information important to the derivation of lime production emission factors as been obtained under the former EITIEs program and the NGER System from 2007 onwards where available. Emission factors are derived under 2 different scenarios:

a) where facility-specific lime product composition information is available:

Where lime producers have information on the specifications of their product, they are able to derive facility-specific emission factors on the basis of pure calcium carbonate (CaO) and magnesium carbonate (MgO) content of their product. The pure carbonate emission factors used to derive facility-specific emission factors are as follows:

- 0.785 t CO_2 x the fraction of pure CaO in the lime
- 1.092 t CO_2 x the fraction of pure MgO in the lime

The following equation is applied to derive a facility-specific emission factor:

EF = 0.785 t CO_2 x the fraction of pure CaO in the lime + 1.092 t CO_2 x the fraction of pure MgO in the lime

It follows therefore that where lime producers manufacture lime with a high MgO content, their facility-specific emission factor will be higher than the default case.

From 2007 onwards, facility-specific emission factor information related to commercial lime production became available. The weighted average of these emission factors for all facilities producing commercial lime (including those who did not provide facility-specific emission factors) was 0.751 in 2007 – based on the relative contributions to total production of all commercial lime producers. This weighted value applies only to manufacturers of commercial lime and is higher than the commercial lime CS EF because it reflects the non-standard specifications of producers with commercial lime with a high MgO content. To date, no facility level information on in-house lime production has been available.

b) where facility-specific lime product composition information is not available:

Under this scenario, Australia provides country-specific emission factors for the use of lime manufacturers reporting under the NGER System. These are based upon assumed fractional purities of commercial and in-house lime and are calculated according to the equation:

$$EF = F \times (44.01/56.08)$$

Where F is the fractional purity of lime produced

44.01 is the molecular weight of CO_2

56.08 is the molecular weight of CaO

The CS emission factors are as follows:

- 0.675 t CO_2 / t commercial lime produced

Based on a fractional purity of lime of 0.86

- 0.730 t CO_2 /t in-house lime produced

Based on a fractional purity of lime of 0.93

As outlined above, facilities that do have product composition information, have reported facility-specific emission factors. The average emission factor for all facilities weighted on the basis of relative levels of production is 0.751 t CO_2/t lime.

Country-specific emission factors for commercial and in-house lime are applied to facilities which do not have information on the composition of their product:

- 0.675 t CO_2 / t commercial lime produced
- 0.730 t CO_2 /t in-house lime produced

The following timeline sets out the application of each of the emission factors:

<table>
<tr><th></th><th>1990</th><th>2006</th><th>2007</th><th>2017</th></tr>
<tr><td rowspan="2">Commercial lime</td><td rowspan="2" colspan="2">Weighted average EF 0.751 t CO_2/ t lime</td><td colspan="2">Facility specific Efs</td></tr>
<tr><td colspan="2">Default CS EF-0.675 t CO_2/t lime</td></tr>
<tr><td>In-house lime</td><td colspan="4">Default CS EF-0.675 t CO_2/t lime</td></tr>
</table>

The fluctuation in the implied emission factor year on year reflects the relative proportions of commercial and in-house lime production as well as the relative proportions of production of individual lime producers from 2007 onwards where facility level emission factors are used.

Time series consistency is maintained through the use of a weighted average EF of 0.751 t CO_2/t lime produced for the years when individual facility data are not available (1990 – 2006). It is assumed for the years 1990-2006 that lime producers continued to produce lime in the same relative proportions as observed in 2007 when facility-level data first became available.

For in-house lime, as no producers have composition information, the CS emission factor is applied for all years where in-house lime production occurs.

Activity data

Data on lime production (including data on the amount of lime produced in-house) have been collected under the NGER System for 2009 onwards and the reporting mechanisms of the former EITEIs Program for 2007 and 2008.

Data for the period 1990-2006 were obtained by industry census undertaken by the National Lime Association up to 2000 and various consultants from 2001 to 2006 (For example, GHD 2009c). The census and NGER collection mechanisms have enabled complete coverage of lime producers throughout the time-series.

Table 4.5 Lime production emissions 1990, 2000–2017

Year	Total Lime production (kt)[(a)]	Emissions (Gg CO_2)
1990	1,036	775
2000	1,278	957
2001	1,535	1,150
2002	1,570	1,176
2003	1,595	1,194
2004	1,625	1,217
2005	1,618	1,213
2006	1,468	1,102
2007	1,633	1,225
2008	1,760	1,320
2009	1,531	1,152
2010	1,633	1,231
2011	1,635	1,244
2012	1,601	1,305
2013	1,641	1,257
2014	1,548	1,186
2015	1,570	1,169
2016	1,543	1,051
2017	1,516	1,031

Source: GHD 2009c, DCCEE EITEIs Program 2009, NGER System 2009 to date
(a) includes quantities of in-house lime production

4.3.3 Glass production (2.A.3)

Source category description

CO_2 emissions associated with the production of glass are included in section 6.13.4 Other Process uses of carbonates (2.A.4)

4.3.4 Other process uses of carbonates (2.A.4)

Source category description

Apart from use in cement and lime production, limestone ($CaCO_3$), magnesite ($MgCO_3$) and dolomite ($CaCO_3.MgCO_3$) are basic raw materials that have commercial applications in a number of industries including metallurgy (for example, iron and steel), glass manufacture, ceramics and clay bricks, agriculture, construction, magnesia production and environmental pollution control.

All CO_2 emissions associated with the consumption of carbonates, with the exception of the emissions reported under soda ash, cement and lime production, are accounted for under Other Process uses of Carbonates. This includes emissions from the use of limestone by the iron and steel, ferroalloys, magnesia, zinc, glass, ceramics and clay brick production. Emissions from the use of limestone in cement and lime production are accounted for under 2.A.1 and 2.A.2 respectively.

Emissions associated with the use of carbonates for soda ash production are accounted for under 2.B.7 Soda Ash Production.

Companies using carbonates in their production processes include Owens-Illinois, CSR, Amcor, Qmag, Causmag, OneSteel, BlueScope Steel, Rio-tinto, Billiton Manganese, Bradken, Sun Metals, BHP Billiton, Xstrata, Nyrstar, Incitec Pivot, Minara Resources, Fletcher Insulation, Thales Australia, and Penrice.

To protect confidentiality, the emissions from the production of soda ash (2.B.7) have been aggregated with this source category (2.A.4). The confidentiality provisions of the NGERS Act under which facility specific data is obtained do not allow reporting the use of carbonates in the category in which they are used.

To improve the completeness of the inventory emissions from other carbonates known to be supplied to the Australian economy have also been included in this source category (2.A.4). These include sodium bicarbonate, potassium carbonate, barium carbonate, lithium carbonate and strontium carbonate.

Methodology

A tier 2 method is utilised for the Australian inventory. The mass of CO_2 emitted per unit of limestone EF_{ls}, dolomite EF_d and other carbonates use EF_o is estimated from a consideration of the purity of the raw materials and the stoichiometry of the chemical processes (44 for CO_2; 100 for limestone; 184 for dolomite, 84 for magnesite, 106 for soda ash and 114 for the remaining carbonates). Only the amount of carbonate material used in an application which generates CO_2 is used in the estimation of CO_2 emitted.

Total CO_2 emissions, E, are estimated by summing over each facility the quantity of limestone, $A_{ls,}$ dolomite, A_d, and other carbonate use, $A_{o,}$ multiplied by their respective country-specific fractional purities and EFs derived from stoichiometry:

$$E = A_{ls} . F_{ls} . EF_{ls} + A_d . F_d . E_{Fd} + A_o . F_o . E_{Fo}$$

The fractional purities are country specific and include limestone, F_{ls}, 0.90, dolomite $F_{d,}$ 0.95, and for all other carbonates, 1.00. The EFs are derived from stoichiometry and are 0.396 t CO_2/t limestone, 0.522 t CO_2/t magnesium carbonate, and 0.453 t CO_2/t dolomite.

Emissions from the manufacture of clay bricks

Emissions from carbonate consumption associated with the manufacture of clay bricks have been included for the first time in this submission. Emissions are based upon the quantities of clay bricks produced annually as recorded by the Australian Bureau of Statistics (ABS 1991a, 2000 and 2012) and a country-specific EF derived from data provided by the peak industry body representing Australian clay brick and paver manufacturers, Think Brick.

Choice of Emission Factor

No facility-specific data on EFs were obtained under NGER. Country–specific CO_2 fractional purities and stoichiometric EFs were applied for all facilities and for all years.

Activity data

Limestone and dolomite consumption data have been collected under the NGER System from 2009 and the reporting mechanisms of former EITEIs Program for 2007 and 2008.

Data for the period 1990-2006 were obtained by a combination of industry survey (for example GHD 2009c) and back casting of production based on NGER data.

The coverage of companies for this source was expanded in the 2011 submission due to the mandatory reporting by all companies with emissions above the NGER System reporting thresholds whereas previous voluntary surveys had not identified all consumers of limestone. Where data for a particular facility collected under the NGER System was not available in GHD 2009c, time series consistency was maintained by the interpolation of consumption rates reported under the NGER System for 2009 to the period between the commencement date for the facility and 2008. These facilities include Bradken, Incitec Pivot, Rio Tinto, Fletcher Insulation, Thales, Sun Metals and Minara Resources.

Table 4.6 Carbonate consumption and emissions 1990, 2000–2017

Year	Limestone Use (kt) [(a)]	Dolomite and Other Carbonate Use (kt) [(b)]	Total emissions from the consumption of carbonates (Gg CO_2)
1990	2,176	778	1,251
2000	2,800	1,169	1,654
2001	2,506	1,170	1,548
2002	2,577	1,219	1,628
2003	2,606	1,270	1,651
2004	2,557	1,235	1,617
2005	2,506	1,232	1,601
2006	2,641	1,284	1,679
2007	2,905	1,255	1,789
2008	2,736	1,279	1,715
2009	2,420	948	1,427
2010	2,548	1,077	1,525
2011	2,563	1,404	1,699
2012	2,357	1,323	1,590
2013	2,225	1,327	1,555
2014	1,691	1,792	1,462
2015	1,638	1,768	1,394
2016	1,788	1,784	1,705
2017	1,727	1,539	1,550

Source: EnerGreen Consulting 2009, DCCEE EITEIs Program 2009, NGER System 2009 to date.
(a) Excludes limestone consumption for the production of soda ash.
(b) Includes magnesite, barium carbonate, lithium carbonate, potassium carbonate, strontium carbonate and sodium bicarbonate

Soda Ash Consumption

A tier 2 method is utilised for the Australian inventory. CO_2 emissions are associated with the use of soda ash where it is assumed that for each mole of soda ash use, one mole of CO_2 is emitted. The mass of CO_2 emitted from the use of soda ash E_{sau} may be estimated from a consideration of the consumption data A_{sau} and the stoichiometry of the chemical process (where 44.01 is the molecular weight of CO_2 and 105.99 is the molecular weight of Na_2CO_3).

$$E_{sau} = 0.415 \text{ kg/tonne } Na_2CO_3 \,.\, \Sigma A_{sau}$$

Data on soda ash consumption were collected under the NGER System for 2009 onwards and the reporting mechanisms of the former EITEIs Program for 2007 and 2008. Data for soda ash consumption for the period 1990-2006 were obtained by industry survey (Energreen 2009) and data on soda ash imports taken from ABS 2015.

Table 4.7 Soda ash use and emissions

Year	Soda ash use (kt)	Emissions (Gg CO_2)
1990	450	187
2010	380	158
2011	361	150
2012	353	146
2013	340	141
2014	317	131
2015	271	113
2016	300	124
2017	277	115

Source: EnerGreen Consulting 2009, NGER System 2009 to date.

4.3.8 Uncertainties and time series consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Time series consistency for all sources has been maintained in accordance with the principles established in section 1.4.1.

Activity data obtained under the NGER (2009-onwards) System was compared with activity data obtained from the former EITEIs Program for each facility and with data obtained from GHD and Energreen consulting to ensure the consistent classification of sources and consistency of data.

Where facilities were newly identified from NGER (2009-onwards) System data as emitting facilities, in category 2.A.4, activity data was interpolated to the facility's commencement date – assuming that consumption of limestone and dolomite in previous years was equal to the consumption of limestone and dolomite in 2009 for the each of the new facilities.

Where facility-specific EFs were identified from NGER (2009-onwards) System data for particular facilities, in category 2.A.2 and 2.A.4, the observed EFs were interpolated using a national weighted average EF for all years 1990-2006.

4.3.9 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1. Additional source specific quality control checks were undertaken to assess completeness and international comparability.

In order to maintain continuity in the compilation of *industrial processes and product use* emissions estimates, the Department engaged the external consultant previously used to collect activity data and EF information to undertake a quality control assessment of the full time series of activity data, EFs and emissions estimates. This work is of particular importance in industrial processes where confidentiality of historical activity data poses some challenges for the assessment of time series consistency.

Reconciliation between sources of carbonate supply and use in the Australian economy are undertaken to ensure completeness (see Table 4.8). This reconciliation includes limestone used in soda ash production as well as consideration of dolomite, soda ash use, magnesite and other carbonates (barium, lithium, potassium, strontium and sodium bicarbonate).

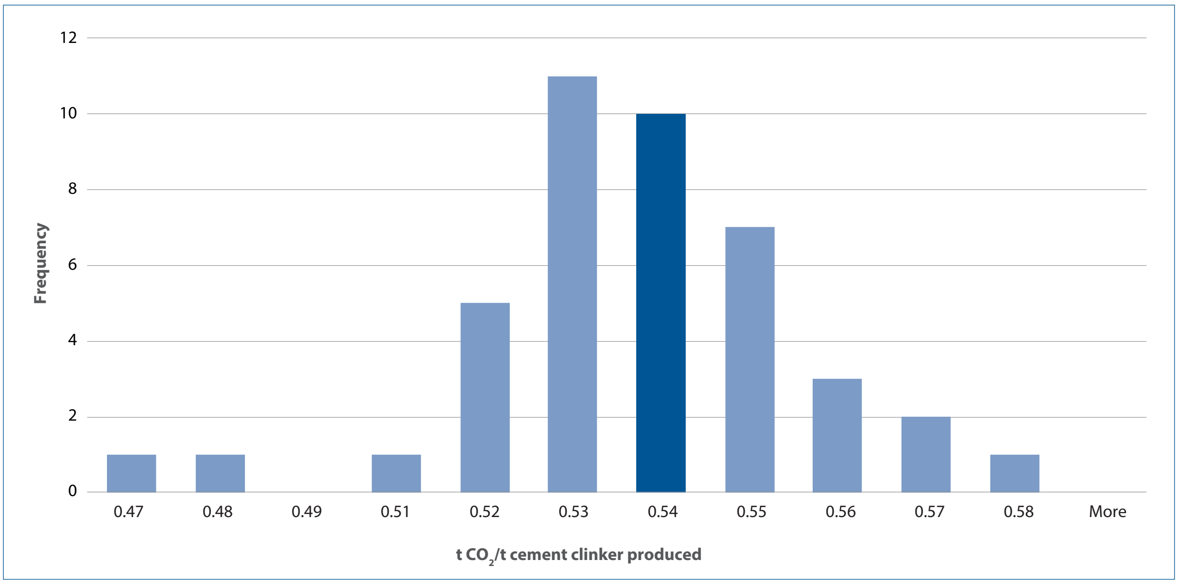
Table 4.8 Reconciliation of limestone, dolomite, soda ash, magnesite and other carbonates supply and use in the Australian economy, 2017

	Raw material[(d)] (kt)	Emissions (Gg CO_2)	Carbon (kt)
Use			
2.A.1 Cement production	6,838	3,019	824
2.A.2 Lime production	2,295	1,031	281
2.A.3 Glass Production	178	79	22
2.A.4 Other process uses of carbonates	3,123	1,356	370
2.B.7 Soda Ash Production	-	-	-
3.C.2 Agricultural Liming	3,312	1,318	360
Change in stocks, statistical discrepancy, and residual available for non-pyro processes	2,261	-	-
Total Use [(a)]	**18,007**	6,804	1,857
Supply			
Production	17,217		
Imports	792		
Exports	2		
Total supply [(b)]	**18,007**		

Source: (a) DoEE. (b) ABS 2018. (c) Cement emissions excluding those from the calcination of magnesium carbonates.
(d) Includes tonnes of limestone, dolomite, soda ash, magnesite and other carbonates.

Comparisons of IEFs and activity data with international data sources are conducted systematically for the Australian inventory.

Figure 4.2 Cement production implied emission factors for Annex I countries (2016 Inventory) and Australia (2017 Inventory)

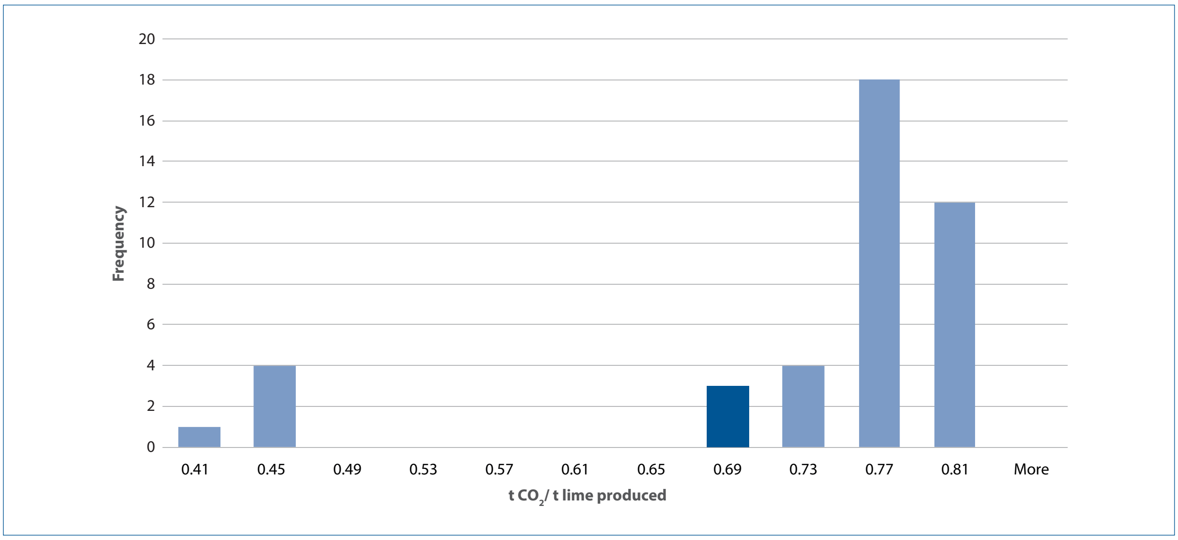


Note: In the figure above, Australia's IEF is located within the dark range.

Australia's IEF for cement clinker production at the national level ranges between 0.535 t CO_2/tonne of cement clinker produced and 0.560t CO_2/tonne of cement clinker produced. The IEF fluctuates year on year according to the relative contributions of product from each facility with their own particular product specifications reflecting the use of different types of carbonates as well as the relative proportions of CaO and MgO as well as the degree of CKD recirculation.

Statistical analysis indicates that the IEF for cement clinker production for Australia (included in the dark shaded column above) is not significantly different to the factors reported by other Annex I parties. Australia's IEF is higher than the IPCC 2006 tier 1 default EF of 0.52 t CO_2/t cement clinker produced. This is due to the relative proportions of CaO and MgO in Australia's cement clinker and the incorporation of emissions from CKD recirculation in Australia's IEF.

Figure 4.3 Lime production implied emission factors for Annex I countries (2016 Inventory) and Australia (2017 Inventory)



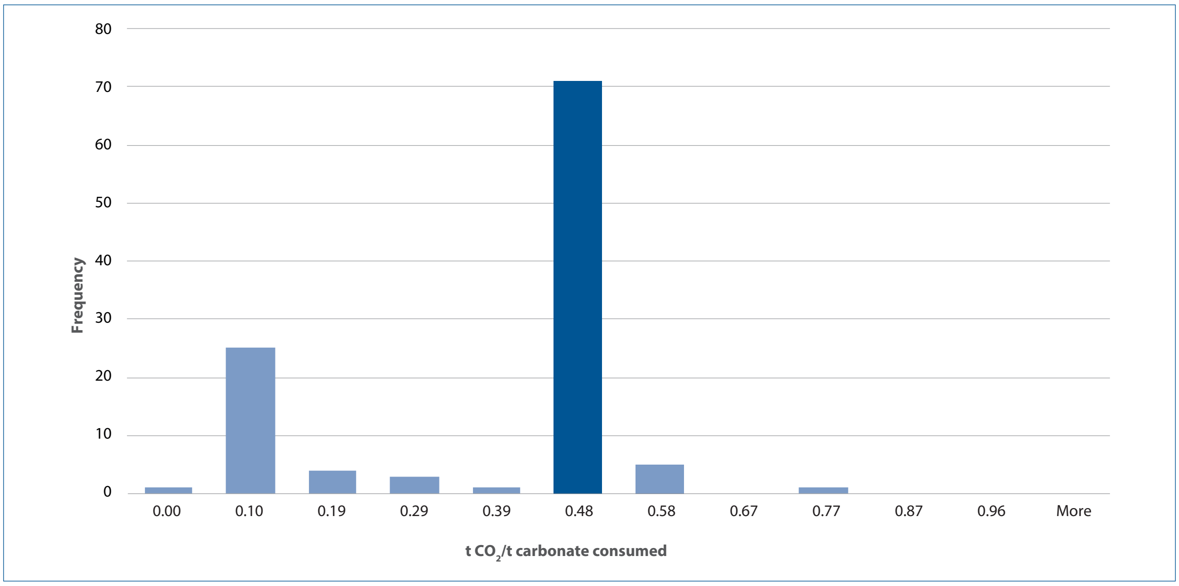
Note: In the figure above, Australia's IEF is located within the marked range.

Australia's IEF for lime production at the national level ranges between 0.68 t CO_2/tonne of lime produced and 0.82t CO_2/tonne of lime produced. The IEF fluctuates year on year according to the relative contributions of product from each facility with their own particular product specifications reflecting the use of different types of carbonates as well as the relative proportions of commercial and in-house lime produced and lime kiln dust recirculation. The IEF for 2017 is 0.68 t CO_2/t lime produced and reflects relatively low levels of LKD calcination reported under the NGER system.

Statistical analysis indicates that the IEF for lime production for Australia (included in the light shaded column above) is not significantly different to the factors reported by other Annex I parties. Australia's IEF is lower than the *IPCC 2006* tier 1 default EF of 0.75 t CO_2/t high calcium quicklime produced. This is due to a lower fractional purity compared with the IPCC (0.86 compared with 0.95) and the incorporation of a portion of dolomitic lime production in the default EF. In years where dolomitic lime production is reported, Australia's IEF is similar or higher than the IPCC default EF.

The IEF for *Other Process Uses of Carbonates* (2.A.4) for Australia is also reported with the distribution of IEF values for other Annex I countries. Results are shown in Figure 4.4.

Figure 4.4 Other Process Uses of Carbonates implied emission factors for Annex I countries (2016 Inventory) and Australia (2017 Inventory)



Note: In the figure above, Australia's IEF is located within the dark range.

Australia's carbonates IEF ranges between 0.371 t CO_2/t carbonate consumed and 0.433 t CO_2/t carbonate consumed. With the availability of facility level data, the national IEF fluctuates according to changes in the relative proportions of each carbonate consumed by individual facilities from year on year.

Statistical analysis indicates that the IEF for limestone and dolomite use for Australia (included in the dark shaded column above) is not significantly different to the factors reported by other Annex I parties. Australia's IEF is within the range of IPCC default EFs 0.380 t CO_2/t carbonate and 0.521 t CO_2/t carbonate. The *2006 IPCC Guidelines* suggest the use of a fractional purity of 1 in the absence of country-specific information. In Australia's case, fractional purities of 0.9 for limestone and 0.95 for dolomite are used.

International comparison of mineral products activity data is also undertaken. Reported cement production is consistent with cement production for Australia reported by the United Nations given the high level of use of supplementary cementitious materials (fly ash and granulated blast furnace slag) in Australian cement.

The *Mineral Industry* sector was reviewed independently by an international expert (Tsaranu) in 2007.

The review was undertaken applying the same principles governing regular UNFCCC inventory desktop reviews. A number of minor refinements were made to the Mineral Industry chapter in response to recommendations made in this review.

4.3.10 Recalculations since the 2016 Inventory

Note that the data presented in Table 4.11 includes soda ash production, which is allocated to 2.B.7 soda ash production in accordance with the *2006 IPCC Guidelines*.

There were no recalculations undertaken in the Mineral Products sector in this submission.

Table 4.9 2.A.1 Cement production: recalculation of CO_2-e emissions (Gg), 1990-2016

	2018 Submission Gg CO_2-e	2019 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
2.A.1 Cement Production				
1990	3,463	3,463	-	0.00 per cent
2000	3,621	3,621	-	0.00 per cent
2001	3,541	3,541	-	0.00 per cent
2002	3,488	3,488	-	0.00 per cent
2003	3,584	3,584	-	0.00 per cent
2004	3,555	3,555	-	0.00 per cent
2005	3,664	3,664	-	0.00 per cent
2006	3,888	3,888	-	0.00 per cent
2007	3,972	3,972	-	0.00 per cent
2008	3,863	3,863	-	0.00 per cent
2009	3,829	3,829	-	0.00 per cent
2010	3,549	3,549	-	0.00 per cent
2011	3,496	3,496	-	0.00 per cent
2012	3,518	3,518	-	0.00 per cent
2013	3,294	3,294	-	0.00 per cent
2014	3,138	3,138	-	0.00 per cent
2015	3,076	3,076	-	0.00 per cent
2016	2,931	2,931	-	0.00 per cent

Table 4.10 2.A.2 Lime production: recalculation of CO_2-e emissions (Gg), 1990-2016

	2018 Submission	2019 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	per cent
2.A.2 Lime Production				
1990	775	775	-	0.00 per cent
2000	957	957	-	0.00 per cent
2001	1,149	1,149	-	0.00 per cent
2002	1,176	1,176	-	0.00 per cent
2003	1,194	1,194	-	0.00 per cent
2004	1,217	1,217	-	0.00 per cent
2005	1,213	1,213	-	0.00 per cent
2006	1,102	1,102	-	0.00 per cent
2007	1,225	1,225	-	0.00 per cent
2008	1,320	1,320	-	0.00 per cent
2009	1,152	1,152	-	0.00 per cent
2010	1,231	1,231	-	0.00 per cent
2011	1,244	1,244	-	0.00 per cent
2012	1,305	1,305	-	0.00 per cent
2013	1,256	1,256	-	0.00 per cent
2014	1,186	1,186	-	0.00 per cent
2015	1,169	1,169	-	0.00 per cent
2016	1,051	1,051	-	0.00 per cent

Table 4.11 2.A.3&4 Other process uses of carbonates: recalculation of CO_2-e emissions (Gg), 1990-2016

	2018 Submission	2019 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	per cent
2.A.3&4 Other process uses of carbonates				
1990	1,251	1,251	-	0.00 per cent
2000	1,654	1,654	-	0.00 per cent
2001	1,548	1,548	-	0.00 per cent
2002	1,628	1,628	-	0.00 per cent
2003	1,651	1,651	-	0.00 per cent
2004	1,617	1,617	-	0.00 per cent
2005	1,601	1,601	-	0.00 per cent
2006	1,679	1,679	-	0.00 per cent
2007	1,789	1,789	-	0.00 per cent
2008	1,715	1,715	-	0.00 per cent
2009	1,427	1,427	-	0.00 per cent
2010	1,525	1,525	-	0.00 per cent
2011	1,699	1,699	-	0.00 per cent
2012	1,590	1,590	-	0.00 per cent
2013	1,555	1,555	-	0.00 per cent
2014	1,462	1,462	-	0.00 per cent
2015	1,394	1,394	-	0.00 per cent
2016	1,705	1,705	-	0.00 per cent

(a) Includes 2.B.7 soda ash production.

4.3.11 Planned improvements

The methodology and emission factors used for the estimation of emissions from *mineral products* will be kept under review.

4.4 Source Category 2.B Chemical Industry

4.4.1 Ammonia production (2.B.1)

Source category description

The overall process of producing ammonia involves a series of stages to remove impurities such as sulphur, carbon monoxide, carbon dioxide and water from the natural gas feedstock and the generation and reaction of hydrogen and nitrogen. The multi stage process involved in ammonia production (from natural gas feedstock) results in the industrial process emissions of CO_2, NMVOC, and CO in addition to ammonia and sulphur compounds.

Carbon dioxide emissions from ammonia reflect the use of natural gas for both energy and feedstock uses. In Australia's inventory, only emissions from the use of natural gas as a feedstock are reported in the *industrial processes and product use* sector. An appropriate deduction has been made in natural gas consumption in the *stationary energy* sector to remove the possibility of double-counting.

A portion of carbon dioxide emissions arising from the production of ammonia are principally recovered for use in the production of urea and food and drink products. Emissions from the production and use of urea are reported under 3.H *Urea Applicaiton*. Emissions from the use of carbon dioxide derived from ammonia production in the food and drink industry are reported under 2.D.2 *food and drink*. The emissions from the ammonia category are aggregated with emissions from the use of acetylene and the production of synthetic rutile and titanium dioxide and included under *2.B.6 confidential chemical industry emissions.* In 2012, ammonia production contributed around two-thirds of total CO_2 emissions under 2.B Chemicals.

Ammonia is produced in seven plants operated by six producers in Australia; Incitec, Orica, Wesfarmers, BHP-Billiton, Queensland Nitrates and Burrup fertilisers. All companies provided natural gas consumption and CO_2 recovery data (where appropriate) for this Inventory under the NGER System.

Industrial Processes and Product Use

Methodology

A tier 1b method is utilised for the Australian inventory. Ammonia is manufactured by the catalytic steam reforming of natural gas. Hydrogen from the reformed natural gas and nitrogen from air are compressed at reduced temperatures to form ammonia:

$$3H_2 + N_2 \rightarrow 2NH_3$$

The overall manufacturing process for ammonia production involves a series of stages to remove impurities such as sulphur, carbon monoxide, carbon dioxide and water from the natural gas feedstock and the generation and reaction of hydrogen and nitrogen.

The manufacture of ammonia from the catalytic steam reforming of natural gas is documented to result in emissions of CO_2, NMVOC and CO. While the CO_2 equivalent emissions associated with the use of natural gas are accounted for, data on emissions of NMVOC and CO are not currently available. It is assumed that carbon in natural gas feedstock is converted entirely to CO_2.

The general method for deriving emissions relates a country-specific emission factor EF_i (reported in Table 3.2) to plant specific natural gas consumption data A_i:

$$E_a = \Sigma A_i \, . \, EF_i \, \_ \, R$$

R is CO_2 captured and sold for use in the food and drink industry and urea production. Carbon dioxide is captured and used in either the production of urea or the manufacture of food and drink products. The CO_2 recovered for use in urea production is deducted from CO_2 emissions from ammonia production and CO_2 emissions associated with the consumption of urea on agricultural land is reported under 3.H *Urea Application.*

The quantity of CO_2 recovered for use in food and drink applications is derived from data reported under the NGER System. Ammonia producers are required to report the quantity of CO_2 recovered and used in urea production and it is assumed that CO_2 recovered and not used in urea production is sold to the food and drink industry. Emissions associated with CO_2 use in the food and drink industry are reported under 2.H Other.

Choice of emission factor

A facility-specific EF for the consumption of natural gas for one facility reported under the NGER System was used for 2009 onwards. This particular facility has reported a facility-specific natural gas EF throughout the time series.

For the remaining six facilities, no facility-specific EF information was available. Therefore the country-specific EF for the consumption of natural gas as listed in Table 3.2 of the NIR was used.

Emissions estimates for ammonia production for all facilities (including the facility reporting a facility-specific emission factor) assume 100 per cent oxidation of natural gas takes place in line with GPG recommendations.

Facility specific emission factors for overall ammonia production plants are not available through NGERS. However, the average implied emission factor for Australian ammonia production ranges is 1.06 tonnes CO_2/tonnes NH_3 – this lower than the 2.1 tonnes CO_2/tonnes NH_3 IPCC default value, reflecting modern practices in Australian ammonia production. Facility specific EFs are confidential.

Activity data

Data on fuel consumption, ammonia production and CO_2 capture were obtained under the NGER System for 2009 onwards. Data for consumption of fuels were derived from data on production for the period 1990-2008 provided by Energreen 2009 and constant consumption to production factors in order to ensure time series consistency. Complete coverage of all ammonia producers has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

Production and emissions from *ammonia production* are shown in Table 4.12.

Table 4.12 Production and emissions from the production of ammonia

	Production (kt)	Emissions (Gg CO_2-e)
1990	448	544
1991	470	560
1992	438	514
1993	422	492
1994	483	554
1995	521	619
1996	511	601
1997	487	572
1998	562	643
1999	538	619
2000	569	651
2001	677	784
2002	734	889
2003	967	1,231
2004	1,179	1,401
2005	1,231	1,476
2006	1,432	1,935
2007	1,708	2,352
2008	1,395	1,895
2009	1,364	1,727
2010	1,896	2,391
2011	1,855	2,337
2012	1,917	1,992
2013	2,092	2,139
2014	2,037	2,235
2015	2,464	2,433
2016	2,529	2,370
2017	2,416	2,271

Source: Energreen 2009, NGERS 2009 Onwards

4.4.2 Nitric acid production (2.B.2)

Source category description

The manufacture of nitric acid (HNO_3) generates N_2O as a by-product of the high temperature catalytic oxidation of ammonia (NH_3). Nitric acid is used as a raw material mainly in the manufacture of nitrogenous agricultural fertiliser.

Nitric acid is produced by three producers in Australia; Wesfarmers, Orica and Queensland Nitrates.

Emissions for the nitric acid category are reported as 'included elsewhere' where the estimates are aggregated with emissions from the use of N_2O in anaesthesia and aerosols and included under *2.B.6 confidential chemical industry emissions*.

Methodology

A tier 3 method is utilised for the Australian inventory. Nitric acid production involves three distinct chemical reactions. These are summarised as follows:

$$4\,NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$
$$2NO + O_2 \rightarrow 2NO_2$$
$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

Nitric oxide (NO), an intermediate in the manufacture of nitric acid, is documented to readily decompose to N_2O and nitrogen dioxide (NO_2) at high pressures for temperatures in the range of 30 to 50°C.

Facility-specific EFs for N_2O from nitric acid production EF_n are based on periodic measurements of the off-gas emitted at nitric acid production plants in the Australia. These EFs are confidential.

The emissions of N_2O, E_n, from the manufacture of nitric acid production A_n is calculated according to:

$$E_n = A_n \,.\, EF_n$$

Choice of emission factor

The selection of EFs was undertaken in accordance with the decision tree in section 1.4.1.

The EFs for nitric acid production are facility-specific and obtained under the NGER System for 2009 onwards. The majority of nitric acid production plants apply NGER method 4, which prescribes periodic or continuous measurement. Other facilities applied NGER method 2, which prescribes periodic updated EFs.

Individual plant specific emission factors reported under NGERS are not provided due to confidentiality restraints.

For earlier years, incomplete data on facility-specific EFs were available from Energreen 2009.
Where facility-specific factors were not available, no information about the factors applicable to the remaining facilities were inferred from the Energreen data on the assumption that factors applicable to each facility are technology-specific and independent of each other. In these cases, IPCC good practice default factors were applied in accordance with information available on the applicable technologies (Energreen 2009).

Time series consistency is maintained by the interpolation of the available facility-specific EFs to the most recent year for which data were available.

Activity data

Data on nitric acid production for individual facilities were collected under the NGER System from 2009 onwards.

Data for nitric acid production for the period 1990-2008 were provided by Energreen 2009.

Complete coverage of all nitric acid producers has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

NGERS methods provide reporters methods for reporting plant specific variables such as emission factors. Consistent with IPCC 2006, NGERS methods are able to account for operational conditions during a reporting year such as temporary losses of N_2O destruction capability.

Production and emissions from *nitric acid production* are shown in Table 4.13.

Table 4.13 Production and emissions from the production of Nitric Acid (including medical N_2O use)

	Production (kt)	N_2O Emissions (Gg CO_2-e)
1990	297	995
1991	243	823
1992	332	1,089
1993	444	1,383
1994	441	1,365
1995	444	1,366
1996	491	1,529
1997	501	1,578
1998	527	1,678
1999	506	1,629
2000	536	1,734
2001	657	2,083
2002	713	2,213
2003	748	2,490
2004	756	2,462
2005	858	2,660
2006	915	2,624
2007	992	2,740
2008	1,082	3,092
2009	1,222	3,001
2010	1,286	3,137
2011	1,269	2,554
2012	1,284	2,407
2013	1,336	1,470
2014	1,466	1,399
2015	1,545	1,545
2016	1,630	1,416
2017	1,630	1,519

Source: Energreen 2009, NGERS 2009 Onwards

4.4.3 Adipic acid production (2.B.3)

There is no adipic acid production occurring in Australia.

4.4.4 Caprolactuam, glyoxal and glyoxix acid production (2.B.4)

There is no Caprolactuam, Glyoxal and Glyoxix Acid production occurring in Australia.

4.4.5 Carbide production (2.B.5)

Silicon carbide and calcium carbide are not produced in Australia. Minor quantities of acetylene are produced from imported calcium carbide and used in welding applications. Data are reported by one company, BOC. Emissions for this category are reported as 'included elsewhere' where the estimates have been aggregated with emissions from *soda ash production* included in *2.B.10 confidential chemical industry emissions*.

4.4.6 Other (2.B.6) Titanium dioxide production

Source category description

Rutile (titanium dioxide) is naturally occurring in Australia. Synthetic rutile can be produced from naturally occurring ilmenite using coal reductant. The rutile is then refined using petroleum coke reductant to produce titanium dioxide (TiO_2).

Titanium dioxide is a white pigment which is used in paint manufacture, paper, plastics, rubber, ceramics, fabrics, floor covering, printing ink, and other miscellaneous uses). Titanium dioxide products are referred to generically as titanium dioxide unless there is a need to make a distinction between the products.

Synthetic rutile is produced in Australia by Iluka Resources and Tiwest whilst TiO_2 is produced by Tiwest and Millennium Chemicals.

The use of coal and petroleum coke as reductants in the synthetic rutile and TiO_2 production processes are accounted for in the *industrial processes and product use* sectors. These reductant quantities have been removed from the stationary energy sector to eliminate the possibility of a double-count.

Methodology

A tier 2 method is utilised for the Australian inventory. The processes that are used in the production of TiO_2 in Australia that lead to process greenhouse gas emissions are synthetic rutile production using the Becher process, and rutile TiO_2 production via the chloride route.

The Becher process reduces the iron oxide in ilmenite to metallic iron and then reoxidises it to iron oxide, and in the process separates out the titanium dioxide as synthetic rutile of about 91 per cent to 93 per cent purity. Rutile TiO_2 is produced through the carbothermal chlorination of rutile ore or synthetic rutile to produce titanium tetrachloride ($TiCl_4$) and oxidation of the $TiCl_4$ vapours to TiO_2 according to the following reactions (Kirk-Othmer, 1999; p.2017):

$$2TiO_2 + 4Cl_2 + 3C \rightarrow 2TiCl_4 + 2CO + CO_2$$
$$TiCl_4 + O_2 \rightarrow TiO_2 + 2Cl_2$$

Based on stoichiometry and assuming complete conversion of the input C to CO_2 through further conversion of CO in excess air, the CO_2 EF cannot be less than 0.826 tonnes of CO_2 per tonne of TiO_2 (based on 1.5 moles of CO_2 per mole of TiO_2).

Emissions from rutile and TiO_2 respectively may be calculated by:

$$CO_2 \text{ Emissions} = \sum EF_i \cdot A_i$$

Where EF_i is the EF for fuel type i and A_i is the quantity of fuel type i consumed as a reductant.

Choice of EF

No facility-specific information on EFs from the NGER System has been used in this inventory. Country-specific EFs are applied to the quantities of black coal and petroleum coke consumed in the synthetic rutile and titanium dioxide production processes.

Activity data

Data on synthetic rutile and TiO_2 production, black coal and petroleum coke consumption were obtained under the NGER System from the three manufacturers, Illuka, Tronox and Cristal. For the inventory years 2007 and 2008, activity data collected under the former EITEIs Program has been used.

Data for consumption of coal and petroleum coke were derived from data on production for the period 1990-2006 provided by Energreen 2009 and constant consumption to production factors in order to ensure time series consistency.

Complete coverage of all synthetic rutile and titanium dioxide producers has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

Aggregated emissions from *synthetic rutile production* and *titanium dioxide production* are shown in Table 4.14.

Table 4.14 Aggregated emissions from the production of synthetic rutile and TiO2

	Emissions (Gg CO_2)
1990	415
1991	405
1992	505
1993	594
1994	564
1995	665
1996	692
1997	700
1998	784
1999	802
2000	920
2001	1,049
2002	975
2003	990
2004	998
2005	1,078
2006	1,331
2007	1,487
2008	1,390
2009	1,282
2010	1,016
2011	1,030
2012	1,014
2013	850
2014	526
2015	718
2016	675
2017	787

Source: Energreen 2009, EITIEs 2007-2009, NGERS 2009 Onwards

4.4.7 Soda ash production (2.B.7)

Source category description

A tier 3 method is utilised for the Australian inventory. Soda ash (sodium carbonate, Na_2CO_3) is used as a raw material in a large number of industries including glass manufacture, soap and detergents, pulp and paper manufacture and water treatment.

The majority of soda ash was produced by one company, Penrice Soda Products, located in South Australia, using the Solvay process. This production has now ceased and the facility converted for import and distribution. The majority of soda ash consumed in Australia is now imported primarily from the United States of America. There remains one company in Australia producing soda ash for its own in house use.

The method is described below for completeness and to describe the estimation of historical emissions associated with Soda Ash production in Australia,

Emissions of CO_2 are generated from both the consumption and production of soda ash. To protect confidentiality, these emissions are aggregated with emissions from *acetylene* under 2.B.10.

Emissions from the production of soda ash include emissions from the coke used as a reductant. This quantity of coke is deducted from the energy sector as it is a non-energy use of coke and ensures there is no double-counting. Limestone is also consumed in the manufacture of soda ash and both the emissions from the calcination of limestone and the coke used as a reductant are accounted for under *Chemical Industry* (2.B).

Sodium bicarbonate ($NaHCO_3$) is also produced in the Solvay process for soda ash production. When heated or reacted with a weak acid, sodium bicarbonate generates CO_2.

Emissions from the use of sodium bicarbonate in applications where CO_2 is generated have been included in the inventory under Food and Beverages Industry (2.H.2). CO_2 emissions for this sector are derived as a function of sodium bicarbonate supplied to the economy and a known proportion being used for emissive purposes.

Methodology

Soda Ash Production

In the Solvay process, sodium chloride brine, limestone, coke and ammonia are the raw materials in a series of reactions leading to the production of soda ash, sodium bicarbonate and waste products containing calcium carbonate. Ammonia, however, is recycled and only a small amount is lost.

The series of reactions involved in the Solvay process may be simply expressed as:

$$CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$$

The CO_2 generated in pyrolysis processes is captured, and directed to Solvay precipitating towers for consumption in a mixture of brine (aqueous NaCl) and ammonia. The Solvay process itself is in theory stoichiometrically neutral in relation to CO_2 gas (that is, generation equals uptake), however, in practice a greater amount of CO_2 is generated than can be absorbed in order to optimise the production process.

Emissions from soda ash production are estimated using a tier 2 method.

The estimation of the CO_2 emissions from a standalone soda ash plant should be based on an overall balance of CO_2 around the whole chemical process. To estimate the excess CO_2 generated during production the carbon in the products and waste materials is deducted from the carbon in the raw materials leaving the excess carbon which is assumed to be entirely converted to CO_2 gas.

Industrial Processes and Product Use

$$E_s = [\Sigma_f CC_f . A_f + CC_l . A_l - \Sigma_p CC_p . A_p . - \Sigma_w CC_w . A_w] . 3.664$$

Where E_s is the emissions of CO_2 from the production of soda ash and sodium bicarbonate

CC_f is the carbon content of the fuel consumed

A_f is the mass of fuel consumed (coke)

CC_l is the carbon content of the limestone consumed

A_l is the mass of limestone consumed

CC_p is the carbon content of a product

A_p is the mass of product (soda ash and sodium bicarbonate)

CC_w is the carbon content of the waste products

A_w is the mass of waste product (brine mud)

In the first step of the Solvay process limestone is calcined to form lime which is then mixed with water to produce slaked lime for the ammonia recovery step. Any limestone that is not calcined is removed as waste (backstone and grits) from the process and this is deducted from the mass of limestone consumed A_l in the emissions estimate.

A relatively small amount of waste material containing carbon in the form of calcium carbonate is also deducted from the carbon in the raw materials. The calcium carbonate waste is produced during a brine purification process where calcium and magnesium salts are removed from the brine feedstock. The purification of the brine is achieved through a reaction of soda ash and sodium hydroxide with the calcium and magnesium salts in the brine forming the solids, calcium carbonate and magnesium hydroxide. Calcium carbonate is also formed in the manufacture of the sodium hydroxide used in these reactions.

Soda ash is taken from the product stream and diverted to the brine purification process where it reacts with the calcium salts (calcium sulphate) to form calcium carbonate and sodium sulphate:

$$Na_2CO_3 + Ca(OH)_2 \rightarrow 2\ NaOH + CaCO_3$$

Sodium hydroxide is manufactured using soda ash (also diverted from the product stream) and slaked lime with calcium carbonate as a waste by-product:

$$MgSO_4 + 2\ NaOH \rightarrow Mg(OH)_2 + Na_2SO_4$$

The sodium hydroxide manufactured is then fed into the brine purification process where it reacts with the magnesium salts (magnesium sulphate) to form magnesium hydroxide and sodium sulphate.

$$MgSO_4 + 2\ NaOH \rightarrow Mg(OH)_2 + Na_2SO_4$$

In this way the CO_2 absorbed into the soda ash product is then diverted for use in the brine purification process and the manufacture of sodium hydroxide is converted into calcium carbonate. The carbon in the calcium carbonate formed in these reactions is deducted from the raw materials in the calculation of the emissions estimate. The soda ash product used in the brine purification process and manufacture of sodium hydroxide is essentially a non-emissive use of soda ash and the amount used is not included in the total soda ash produced for sale.

Sodium Bicarbonate Consumption

Sodium bicarbonate ($NaHCO_3$) is also produced in the manufacture of soda ash using the Solvay process. Sodium bicarbonate has a wide range of applications some of which result in the release of CO_2. When sodium bicarbonate is heated or reacted with a weak acid CO_2 is released. Uses of sodium bicarbonate in which CO_2 is generated include leavening agents, pharmaceuticals, stock feed buffer and effervescent salts and beverages.

Energreen Consulting 2009 indicates that the proportion of sodium bicarbonate consumption resulting in emissions of CO_2 is 80 per cent. This proportion is used to estimate the amount of CO_2 emissions from consumption of sodium bicarbonate. It is assumed that the sodium bicarbonate thermally decomposes in the following reaction:

$$2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

The mass of CO_2 emitted from the use of sodium bicarbonate E_{sbu} is estimated using consumption data A_{sbu}, the proportion resulting in emissions and the stoichiometry of the chemical process (where 44.01 is the molecular weight of CO_2 and 84.01 is the molecular weight of $NaHCO_3$).

$$E_{sbu} = 0.8 \,.\, A_{sbu} \,.\, 0.262 \text{ kg/tonne } NaHCO_3$$

Choice of emission factor

Soda Ash Production

The selection of EFs was undertaken in accordance with the decision tree in section 1.4.1.

The EFs for limestone consumption and coke consumption are facility-specific and obtained under NGER for 2009 onwards and under the former EITEIs Program for 2007 and 2008. As there is only one producer, complete coverage for the sector was achieved.

Time series consistency for the entire period 1990-2006 is maintained by the application of the facility-specific factors, obtained for the period 2007-2008, to years when no facility data are available.

Activity data

Soda Ash Production

Data on limestone and coke consumption for the purpose of soda ash production were collected under the NGER System for 2009 onwards and the reporting mechanisms of the former EITEIs Program for 2007 and 2008.

Data for limestone and coke consumption for the period 1990-2006 were derived from data for soda ash production obtained by industry survey (Energreen 2009). Time series consistency was maintained by the application of constant factors of limestone and coke consumption per unit of soda ash production estimated from data available for the period 2007-2009.

4.4.8 Petrochemical and carbon black production (2.B.8)

Source category description

The manufacture of organic chemicals results in process emissions of NMVOC. Other gases such as CO_2, CH_4, N_2O, NO_x and CO may also be generated depending on the manufacturing process.

Complete time series of emissions of CH_4 and NMVOCs are included in the inventory for methanol, butadiene, carbon black, ethyl benzene, ethylene, ethylene oxide, formaldehyde, HDPE, LDPE, LLDPE, propylene, polypropylene, polystyrene, styrene, polyvinyl chloride, and styrene butadiene rubber. Disaggregated production and emissions data for these sources are confidential. Emissions estimates are aggregated at the polymers and other chemicals source category level.

There are approximately 15 companies producing a large range of polymers and other chemicals in Australia. Companies include Dynea W.A, Borden Chemicals, Orica, BP, Shell, Huntsman Chemicals, Dow Chemicals, Qenos, ExxonMobil, Continental Carbon, Koppers, Australian Vinyl, BOC Gases, Airliquide, Caltex, and Nuplex.

Methanol is produced by one plant owned by Coogee Chemicals which has been operating since 1994 with an annual production capacity of 80 kt (see Coogee Chemicals website http://www.coogee.com.au/op_meth.html).

Dichloroethylene is used to produce vinyl chloride monomer (VCM) which is used to produce polyvinyl chloride (PVC) resin. All PVC resin manufactured in Australia is produced from imported VCM. (http://www.vinyl.org.au/Manufacturingprocess). Dichloroethylene production does not occur in Australia.

Methodology

A tier 2 method is utilised for the Australian inventory, incorporating emission factors derived from plant specific data (EnerGreen 2009). Emissions from miscellaneous organic chemical manufacture are dependent on the level of activity and extent of emission control and estimated according to equation:

$$E_{ij} = (A_j \times EF_{ij})/10^6$$

Where E_{ij} is the process emission (Gg per year) of gas i from industrial sub-sector j

A_j is the amount of activity (production or consumption) of material in industrial sector j (tonnes per year unless)

EF_{ij} is the EF associated with gas i per unit of activity in industrial sector j (kg per tonne) – see Table 4.15

The divisor 10^6 is a factor for converting kg to Gg (kt) (1,000,000kg = 1 Gg)

Table 4.15 Emission factors for organic chemicals

Subsector	CO_2 (kg/tonne)	CH_4 (kg/tonne)	NMVOC (kg/tonne)
Acetylene [(a)]	3 384 kg CO_2 per tonne C_2H_2 used		
Butadiene			1.5
Carbon black		0.11	0.5
Ethyl benzene			0.03
Ethylene		0.03	0.25-1.5
Ethylene oxide			0.069
Formaldehyde			9.2
HDPE			1.5
LDPE and LLDPE			1.5
Methanol [(b)]		0.002	
Propylene			1.5
Polypropylene			1.5
Polystyrene [(b)]			0.1 - 5.4
Styrene [(b)]		4	18
Styrene butadiene rubber		1.5	1.5
Polyvinyl chloride		8.5	8.5

Source: EnerGreen 2009. (a) Based on stoichiometry. (b) IPCC 1997.

Industrial Processes and Product Use

4.4.9 Uncertainties and time series consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Activity data obtained under NGER was compared with activity data obtained from the former EITEIs Program for each facility and with data obtained from GHD and Energreen consulting to ensure the consistent classification of sources and consistency of data.

No facilities were newly identified from NGER data as emitting facilities for this category.

Where facility-specific EFs were identified from NGER data for particular facilities, in category 2.B.2, the reported EFs for 2007, 2008 and 2009 were interpolated for each facility to the most recent year for which data were available.

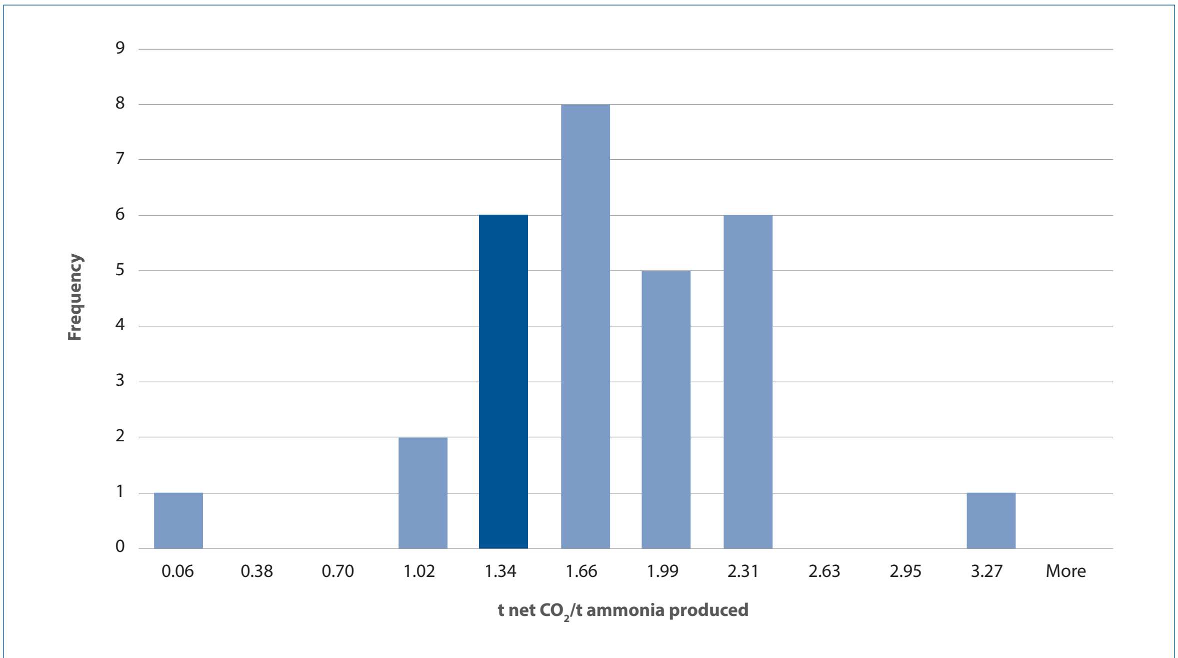
4.4.10 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1. Additional source specific quality control checks were undertaken to assess international comparability.

The IEF per unit of production for Australia's inventory was compared with the IEFs for other Annex I parties in the cases of ammonia and nitric acid production. The factors for Australia were found to be not significantly different to the factors reported by other Annex I parties. The results of this comparison are presented below.

The quantity of CO_2 generated per tonne of ammonia produced has been compared with that of Annex I parties reporting emissions from ammonia production. The results of this comparison are shown in Figure 4.5.

Figure 4.5 Ammonia implied emission factors for Annex I countries (2016 Inventory) and Australia (2017 Inventory)



Note: In the figure above, Australia's IEF is located within the dark range.

The IEF for ammonia production for Australia ranges between 1.073 t CO_2 generated per tonne of ammonia produced and 1.552 t CO_2 generated per tonne of ammonia produced. The IEF fluctuates year on year according to fluctuations in ammonia production levels of individual facilities.

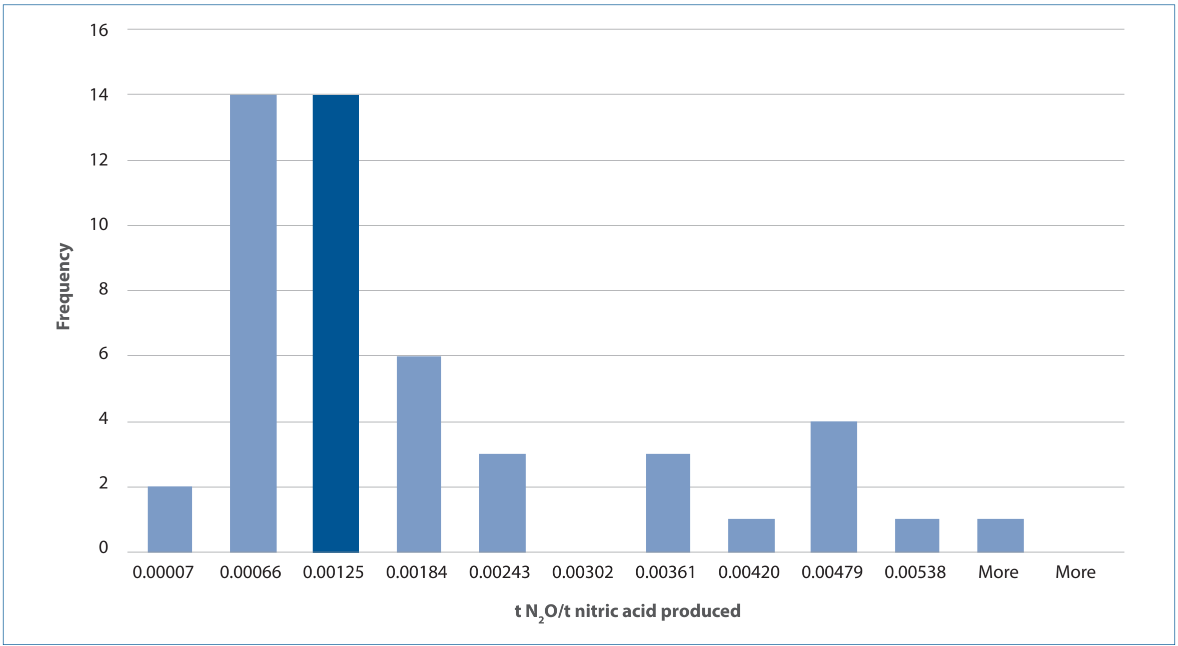
In general, Australia's IEF is generally lower than the default values listed in the 2006 IPCC *Guidelines* of 1.666 – 3.273 t CO_2/t ammonia. The *2006 IPCC Guidelines* lists a range of default "total fuel requirements" (including natural gas consumed for energy purposes as well as chemical feedstock) by production process ranging between 29.7 GJ fuel/t NH_3. Under the NGER System, Australian ammonia facilities must report feedstock and fuel use separately and it is only the feedstock quantity that is used in the estimation of CO_2 emissions. Australia's feedstock fuel requirements range between 21.30 and 30.16 GJ fuel/t NH_3 produced.

This specific IP / non-IP split in activity data explains the difference between Australia's IEF and the IPCC defaults. The specific ammonia production technology mix in Australia will also cause differences between parties and the default IPCC values.

Statistical analysis indicates that the IEF for ammonia production for Australia is not significantly different to the factors reported by other Annex I parties.

The quantity of N_2O emitted per tonne of nitric acid produced has also been compared with that for Annex I parties. The results of this comparison are shown in Figure 4.6.

Figure 4.6 Nitric acid implied emission factors for Annex I countries (2016 Inventory) and Australia (2017 Inventory)



Note: In the figure above, Australia's IEF is located within the dark range.

The IEF for nitric acid production for Australia ranges between 0.0007 t N_2O per tonne of nitric acid produced and 0.0030 t N_2O per tonne of nitric acid produced. The IEF fluctuates year on year according to fluctuations in nitric acid production levels at individual facilities. Emissions at individual facilities are highly technology-specific with three main types of production plants and differing levels of abatement technology in place.

Statistical analysis indicates that the IEF for nitric acid production for Australia is not significantly different to the factors reported by other Annex I parties.

In 2011, the Department engaged a consultant to review N_2O emissions control in the nitric acid industry (EnerGreen Consulting 2011). This review found that a number of facilities were either trialing N_2O emissions reduction technology or monitoring developments domestically and internationally with a view to retrofitting existing plants or integrating abatement technology into future expansions.

Plant-level EFs have been declining since 1990 and more recent reductions have come about as a result of the introduction of continuous monitoring of N_2O emissions and an associated improvement in management of process catalysts.

The *chemical products* category was reviewed independently by an international expert (Tsaranu) in 2007. The review was undertaken applying the same principles governing regular UNFCCC inventory desktop reviews. A number of minor refinements were made to the *chemical products* chapter in response to recommendations made in this review.

4.4.11 Recalculations since the 2016 Inventory

There were no recalculations undertaken in the Chemical Industry sector in this submission.

Recalculations are presented in Table 4.16.

Table 4.16 2.B Chemicals: recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2018 Submission	2019 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	per cent
2.B Chemicals				
1990	3,485	3,485	-	0.00 per cent
2000	3,445	3,445	-	0.00 per cent
2001	4,053	4,053	-	0.00 per cent
2002	4,216	4,216	-	0.00 per cent
2003	4,851	4,851	-	0.00 per cent
2004	5,002	5,002	-	0.00 per cent
2005	5,355	5,355	-	0.00 per cent
2006	6,033	6,033	-	0.00 per cent
2007	6,723	6,723	-	0.00 per cent
2008	6,518	6,518	-	0.00 per cent
2009	6,153	6,153	-	0.00 per cent
2010	6,690	6,690	-	0.00 per cent
2011	6,057	6,057	-	0.00 per cent
2012	5,606	5,606	-	0.00 per cent
2013	4,576	4,576	-	0.00 per cent
2014	4,184	4,184	-	0.00 per cent
2015	4,730	4,730	-	0.00 per cent
2016	4,493	4,493	-	0.00 per cent

4.4.13 Planned improvements

Previous Expert Review Teams have encouraged Australia to explore the possibility of disaggregating emissions from ammonia production.

Confidentiality continues to be a concern in the chemicals sector where there are only a small number of companies in operation. The confidentiality provisions of the NGER Act under which chemical industry data are obtained are explicit and restrict publication of such confidential data. In recent years, Australia has invested effort in providing as much information as it can within the restrictions of the NGER Act, including provision of implied emission factor information and discussions of comparisons with other Annex 1 parties. Australia remains committed to enhancing the transparency of the chemicals sector estimates and will continue to explore additional options within the confidentiality restrictions of the NGER Act. It should be noted however, that most of these options have been implemented. Further options to report disaggregated data are limited.

4.5 Source Category 2.C Metal Industry

4.5.1 Iron and steel production (2.C.1)

Source category description

Iron and Steel production is a key source in the Australian inventory. Emission sources relate to the in-house production of metallurgical coke and lime, the use of limestone and dolomite as flux in iron, steel and ferro-alloy production and fugitive gas leaks associated with the distribution of coke oven gas and other products within industrial premises. In-house lime production as well as limestone and dolomite use is accounted for under 2.A.2.

Metallurgical coke is an essential material in iron and steel production where it serves a number of major functions including the provision of a porous support for furnace ingredients, as a combustion ingredient producing the reducing atmosphere required for ore refinement and as a chemical reductant. Since 2003, pulverised coal has also been used in Australian iron and steel production to improve the performance of the blast furnace. Emissions from the use of coke and pulverised coal as a reductant are reported in this category. Emissions from the production of coke are reported under category1.A.1 while the emissions generated by the combustion of coke oven gas to produce energy are reported under the stationary energy category 1.A.2.

There are two major producers of iron and steel in Australia; Arrium and Blue Scope. Integrated iron and steel production occurs primarily in New South Wales and South Australia. A hot briquetted iron (HBI) plant that used natural gas as a reductant in Western Australia between 2000 and 2005 is also included in the estimates from 2.C.1 *iron and steel production*.

Emission from *iron and steel production* are reported as “included elsewhere” where estimates are aggregated with emissions from *ferroalloys production* and *other metals production*, and included under 2.C.7 *other.*

Methodology

A tier 1b method is utilised for CO_2 and tier 2 for non-CO_2 in the Australian inventory. The manufacture of iron involves the high temperature reduction of iron-bearing materials in a blast furnace. The blast furnace is essentially a large chemical reactor charged with iron ore, coke and limestone/dolomite to produce hot metal or ‘pig iron’ which is converted into steel typically by injecting oxygen gas through a charge of scrap and the molten iron. During the process, lime is added to remove impurities and provide a slag of the desired basicity.

The chemical reactions that occur in the blast furnace to produce molten iron (Fe as shown in the equations) may be summarised as follows:

$2C\ (coke) + O_2 \rightarrow 2CO$
$C + H_2O \rightarrow CO + H_2$
$FeyOz + zCO \rightarrow yFe + zCO_2$
$FeyOz + zH_2 \rightarrow yFe + zH_2O$
$CaCO_3\ (limestone) \rightarrow CaO + CO_2$
$CaCO_3.MgCO_3\ (dolomite) \rightarrow CaO.MgO + 2CO_2$

Coke

The emissions from the use of coke as a reductant are estimated according to equations 3.1 and 3.2 reported in Chapter 3.

The CO_2 EF used to compile the emission estimate for coke consumption (shown in Table 4.17) is derived from a carbon mass balance calculation conducted for the coke oven process. A full time series of coke emission factors is provided in Table 3.A 23 in the NIR.

A schematic diagram of the carbon balance used to derive the coke emission factor is provided in section 3.4.2 of the NIR. This balance is performed to ensure carbon inputs into the coke oven are balanced with all known outputs. In the case of coke ovens, the input is black coal and outputs are coke oven gas, coal tar and coke. All outputs are reported in Australia's energy statistics in the form of energy. With emission factors for black coal, coke oven gas and coal tar known, a balance is achieved through the derivation of an appropriate coke emission factor. This balance is performed each year with each new release of the *Australian Energy Statistics* (DoEE 2018a).

Table 4.17 Carbon dioxide emission factors for iron and steel

Fuel Type	P Oxidation Factor (per cent)	F Emission Factor (Gg/PJ)
Coke	100[(a)]	108.6[(c)]
Natural Gas	100[(b)]	51.4[(c)]

Notes: (a) IPCC (2006) default value. (b) IPCC (2006) default value. (c) the CO_2 EF for coke is derived from a carbon balance calculation conducted for the coke oven process. The natural gas EF is provided by the Australian Gas Association.

Table 4.18 Non-carbon dioxide emission factors for iron and steel

Fuel Type	F: Emission Factors (Mg/PJ)					
	CH_4	N_2O	CO	NO_x	NMVOC	SO_2
Coke	0.95	0.71	91.25	190.99	0.86	370
Natural Gas	0.95	0.55	69.4	499.45	1.49	2.3

The raw steel produced contains carbon, the ultimate source of which is fossil carbon from the coal input to coke ovens. Since steel is a long-lived product, this is a form of carbon sequestration. The carbon content of steel is reported directly by iron and steel producers under the NGER system. The reported carbon contents of steel across all producers between 0.16 per cent and 0.19 per cent.

Fugitive Emissions

In addition to the estimation of emissions from the use of coke and gas as reductants, a process EF is established for CH_4 from integrated iron and steel production (0.44 kg CH_4/tonne of crude steel produced) to reflect mainly sources of fugitive emissions. The estimated CH_4 EF is based on experimental data and engineering calculations conducted at the plant owned by BlueScope Steel by BHP (pers. comm. 2000) for its major Australian integrated iron and steelworks. Process emission sources considered include the in-plant distribution of coke oven gas and natural gas, leakage from coke ovens and the bleeding of unflared blast furnace gas to the atmosphere. By comparison with fugitive emissions from the in-plant distribution of coke oven gas, emissions of CH_4 associated with leakage from coke ovens and the bleeding of unflared gas from blast furnaces are estimated to be of minor significance.

Activity data

Activity data for coke consumption in the production of iron and steel are obtained from DoEE *Australian Energy Statistics* (DoEE 2018) for inventory years up to 2009 and the NGER (2009-2012) System from 2009 onwards. Crude steel production has been sourced directly from companies (Energreen 2009 and the NGER 2009-2012 System). Data on pulverised coal consumed in the blast furnace have been obtained from investor reports published by Bluescope Steel (Bluescope 2014). In 2009, NGER crude steel production reporting under the NGER System was incomplete and was derived by indexing the crude steel production in 2008 to the changes in coke consumption in 2009. This is not the case in subsequent years where crude steel production reporting was complete.

Complete coverage of all iron and steel production has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

Table 4.19 Production and aggregated emissions from the production of Iron and Steel, Ferroalloys and Other Metals

Year	Steel production (kt) a	Hot Briquetted Iron production (kt) b	Natural Gas consumption (PJ) b	Refined Lead production (kt) a	Refined Nickel production (kt) a	Refined Zinc production (kt) a	Refined Silver production (kt) a	Refined Copper (kt) a	Manganese alloy production (kt) c	Aggregated emissions from Iron and Steel, Ferroalloys and Other metals production (Gg CO2-e)
1990	6,223	NO	NO	200	44	295	0.4	265	NA	9,808
2000	6,345	558	6	233	97	405	0.5	477	NA	10,649
2001	6,027	1,223	22	215	113	534	0.5	517	NA	9,890
2002	5,933	1,142	23	275	124	572	0.6	561	NA	9,665
2003	6,282	1,670	34	267	129	571	0.7	537	NA	10,841
2004	6,312	1,592	32	247	124	499	0.6	458	NA	11,450
2005	5,977	NO	NO	234	126	464	0.7	486	NA	9,528
2006	6,560	NO	NO	234	115	446	0.7	461	NA	9,717
2007	6,600	NO	NO	191	118	496	0.6	435	NA	10,103
2008	6,597	NO	NO	203	121	507	0.6	444	NA	9,959
2009	5,529	NO	NO	213	111	506	0.8	499	NA	8,071
2010	6,867	NO	NO	189	120	515	0.7	395	NA	9,996
2011	7,333	NO	NO	190	101	499	0.7	485	NA	10,462
2012	5,357	NO	NO	174	123	505	0.8	486	NA	8,285
2013	4,749	NO	NO	159	131	496	1.1	454	NA	7,407
2014	4,446	NO	NO	183	137	492	1.1	500	387	6,971
2015	4,776	NO	NO	169	145	501	1.0	450	413	7,458
2016	4,945	NO	NO	191	142	459	1.3	514	224	7,671
2017	5,198	NO	NO	172	112	466	1.0	448	220	*8,253*

Sources: a Resources and Energy Quarterly (DIIS 2017), b Energreen 2009, c South32 Annual Reports

4.5.2 Ferroalloys production (2.C.2)

Source category description

Emissions from the consumption of fossil fuels when used as reductants, or when used to produce carbon anodes on-site, or as carbon anodes are estimated under this category. There is one company producing ferroalloys in Australia consuming black coal, coking coal, coke oven coke, petroleum coke and limestone in the process.

The availability of NGER System data on reductant consumption in the production of ferroalloys has enabled reductant emissions from this source to be estimated for the first time in this submission. These emissions are reported under 2.C.7 '*Other Metals*' to protect confidentiality of data. An equivalent deduction has been made in stationary energy to ensure there is no double counting or omission of emissions. The use of limestone in the production of ferroalloys is reported under 2.A.4 '*Other Process Uses of Carbonates*.

Methodology

Emissions from the consumption of reductants in the production of ferro-alloy metals have been estimated using a tier 2 method. Emissions from the use of reductants in the production of ferroalloys are estimated by the application of a country-specific EFs in Table 3.2 and the oxidation factors in Table 3.3 to the quantity of each reductant used.

Choice of emission factor

EFs have been selected in accordance with the decision tree in section 1.4.1. No information on facility-specific EFs were available under the NGER System. Time series consistency has been maintained by the application of values for EFs for 2009 for the period 1990-2008.

Activity data

Data on fuel consumed as reductants for the purpose of production of ferro-alloy metals have been collected under the under the NGER System from 2009 onwards. For the years 1990-2008, this level of fuel consumption has been assumed to be constant. While the approach to estimating pre-NGER activity data introduces a degree of uncertainty, there are presently no other data sources on which to base historical ferroalloy estimates.

4.5.3 Aluminium production (2.C.3)

Source category description

Aluminium is a key source in the Australian inventory. Emissions from the consumption of fuels in the production of carbon anodes on-site, or as carbon anodes, are estimated for this source. Additional perfluorocarbon emissions resulting from process upsets are also reported under this category.

Aluminium is produced by the electrolysis of alumina in a series of complex electrode reactions. The overall reaction results in aluminium being produced at the cathode and carbon dioxide at the anode:

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$$

The electrolysis process is conducted in carbon-lined steel pots containing high purity carbon anodes. The cell electrolyte consists of a molten bath of cryolite (Na_3AlF_6) to which varying proportions of aluminium fluoride, calcium fluoride or lithium fluoride may be added to lower the melting point, decrease the density of the electrolyte and improve energy efficiency.

Carbon dioxide is primarily formed by the chemical reaction of oxygen (produced in the electrolysis process) with the carbon anode. During the electrolysis of alumina to aluminium, some of the CO_2 formed at the anode may be reduced to CO by a secondary reaction involving particles of aluminium or sodium.

Grjotheim and Welch (1980) report that for a typical 150kAmp pre-baked cell, the anode gas consists of 70–85 per cent CO_2 with the balance (15–30 per cent) as CO. Measurements conducted by the ADC at several Australian smelters indicate that approximately 10 per cent of the anode gas (by weight) consists of CO. On contact with air, the majority of the CO in anode gas is burnt to CO_2 immediately above the electrolyte.

The perfluronated carbon compounds (PFC), tetraflurornethane (CF_4) and hexafluroethane (C_2F_6) are powerful greenhouse gases which are generated during the so-called anode effect in the production of aluminium. The anode effect is characterised by an increase in cell voltage as a result of the cryolite bath becoming deficient in alumina.

There are four companies operating aluminium smelters in Australia; Alcoa, Tomago Aluminium Rio Tinto and Hydro Kurri Kurri.

In Australia, bauxite is refined to alumina in Western Australia (WA), Queensland (Qld) and the Northern Territory (NT). The in-house production of lime at alumina refineries in Qld and NT represents an industrial process source of CO_2 emissions, which are accounted for under 2.A.2.

Methodology

CO_2 emitted during the consumption of carbon anodes is reported as if all the carbon is oxidised to CO_2. Emissions from the production of carbon anodes for use in aluminium production are estimated on the basis of the quantities of coal tar, petroleum coke and coke oven coke consumed in the production process and plant-specific EFs. CO_2 emissions are derived using the equation:

$$E_{al} = A_i \cdot EC_i \cdot EF_i$$

Where A_i is the quantity of fuel type i consumed in the production of anodes

EC_i is the energy content of each fuel type i

EF_i is the CO_2 EF for each fuel type i

Facility specific PFC EFs have been estimated in accordance with accepted international measurement protocols (International Aluminium Institute (2006), *The Aluminium Sector Greenhouse Gas Protocol, Addendum to the WRI/WBCSD GHG Protoco*l, USEPA, International Aluminium Institute (2008), *Protocol for Measurement of Tetrafluoromethane (CF_4) and Hexafluoroethane (C_2F_6) Emissions from Primary Aluminium Production*).

Choice of emission factor

CO_2 EFs have been applied to the quantities of fuels used in the production of anodes. One NGER reporting facility has derived facility-specific CO_2 EFs for coal tar and petroleum coke. It was assumed that the fuel specifications measured at this facility were equally applicable to all facilities.

The facility-specific fuel consumption EFs for anode production are confidential, however, the implied total CO_2 EF per unit of aluminium produced is shown in Table 4.17 and confirms that these values are within the historical range of IEFs and not significantly different to the mean of the values reported between 1990 and 2010.

In the case of emissions of perfluorocarbons, facility-specific EFs at all facilities have been estimated and sourced from the NGER System from 2009 onwards. National average factors for previous years have been supplied by the Australian Aluminium Council based on collected information on individual facility factors.

Activity data

Data on coke oven coke, petroleum coke and coal tar consumption for the purpose of production of aluminium have been collected under the NGER System from 2009 onwards. For the years 1990-2008 coal tar and petroleum coke consumption are derived from the carbon in the reported emissions and the typical composition of carbon anodes used in the aluminium production process.

Data on aluminium for the purposes of estimating emissions of PFCs has been obtained under the NGER System for 2009 onwards and ABARES *Commodity Statistics* (various years) for 1990-2008.

Complete coverage of all aluminium producers has been maintained through the data collection mechanisms utilised throughout the time-series as listed above.

Table 4.20 Emission factors: kg per tonne of aluminium production 1990, 2000–2017

Year	CO_2 [(a)]	CF_4	C_2F_6
1990	1,666	0.416	0.054
2000	1,616	0.082	0.011
2001	1,633	0.112	0.015
2002	1,694	0.106	0.014
2003	1,668	0.101	0.013
2004	1,636	0.102	0.013
2005	1,641	0.106	0.014
2006	1,615	0.040	0.005
2007	1,638	0.033	0.004
2008	1,620	0.025	0.003
2009	1,584	0.020	0.002
2010	1,630	0.017	0.002
2011	1,651	0.018	0.002
2012	1,644	0.017	0.002
2013	1,560	0.012	0.001
2014	1,520	0.012	0.001
2015	1,501	0.012	0.001
2016	1,396	0.015	0.002
2017	1,446	0.012	0.004

Source: NGER 2009-onwards, Beyond Neutral 2008, GHD 2009c. (a) IEF including production and consumption of anodes.

The carbon anode consumed in aluminium smelting is approximately 3 per cent sulphur by weight. Based on the assumption that 413 kg of carbon from the carbon anode is oxidised (consumed) for each tonne of aluminium produced, this implies that approximately 12.77 kg of sulphur and 25.54 kg of sulphur dioxide are oxidised per tonne of aluminium produced.

Table 4.21 Aluminium: production and emissions 1990, 2000–2017

Year	Aluminium production (kt) [(a)]	Emissions [(b)] (Gg CO_2-e)
1990	1,235	6,665
2000	1,742	4,102
2001	1,788	4,721
2002	1,809	4,791
2003	1,855	4,778
2004	1,877	4,784
2005	1,890	4,893
2006	1,912	3,775
2007	1,954	3,783
2008	1,965	3,629
2009	1,980	3,495
2010	1,926	3,423
2011	1,943	3,510
2012	1,943	3,489
2013	1,786	2,979
2014	1,778	2,895
2015	1,649	2,646
2016	1,652	2,530
2017	1,520	2,400

Source: (a) ABARES /NGER 2009-onwards. (b) Beyond Neutral 2008, GHD 2009c;

4.5.4 Magnesium production (2.C.4)

The inventory includes experimental quantities of SF_6 used between 1996 and 2000 as a cover gas in magnesium foundries preparatory to the development of a commercial magnesium casting plant (which was not, ultimately, commercially viable). The data on SF_6 use for this experimental foundry was supplied by CSIRO.

4.5.5 Lead production (2.C.5), zinc production (2.C.6), other (2.C.7)

Source category description

In Australia the Lead Production, Zinc Production and Other source categories includes emissions from the production of lead, zinc, copper , nickel, and silver. There are 10 major companies involved in the production of Lead, Zinc and other metals in Australia. In Australia, the major zinc refinery, in Hobart, uses an electrolytic process, which is non-emissive. The major lead refinery, at Port Pirie, which also refines a small amount of zinc, uses blast furnace technology.

CO_2 emissions from the use of fossil fuels as reductants, or in the production of carbon anodes on-site, or as carbon anodes in these refineries are reported under this category. An equivalent deduction has been made from fuel consumption in stationary energy to ensure there is no double-count of fuels in the inventory.

CO_2 emissions from the consumption of limestone in the production of other metals are reported under 2.A.3.

Australia's metal ores are predominantly sulphide ores leading to the generation of SO_2 as a by-product of metal production. SO_2 emissions from metal production are reported under this category.

Methodology

Emissions from the consumption of reductants in the production of lead, zinc and other metals have been estimated using a tier 2 method. Emissions are estimated using country-specific energy contents and CO_2 EFs for relevant fuels or, in certain cases, based on facility-specific EFs.

Ore composition and stoichiometric relationships have been used to derive sulphur dioxide emission estimates for copper, lead, nickel, zinc, and silver. The general approach is illustrated using the example of zinc. Zinc occurs either as sulphide ores (ZnS) or carbonate ores ($ZnCO_3$). Australia's zinc production is predominantly from sulphide ores. The objective of the refining process to obtain primary refined zinc is to break the compound ore down by separating the sulphur from the zinc. Based on atomic and molecular weights, 0.980 tonnes of SO_2 will be released per tonne of primary refined zinc. EFs for other metals, based on stoichiometry relationships, are given in the Table 4.22.

Table 4.22 Sulphur dioxide emission factors for refined metals

Metal	Tonnes SO_2 per tonne of refined metal
Lead	0.3
Zinc	1.0
Nickel	1.1
Silver	0.3
Copper	2.0

Choice of emission factor

EFs have been selected in accordance with the decision tree in section 1.4.1.

In the case of one company, a facility-specific CO_2 EF has been used for the consumption of petroleum coke. This EF is confidential. In all other cases, the factors are taken from Table 3.2.

Time series consistency has been maintained by the application of values for EFs for 2009 for the period 1990-2008.

Activity data

Data on fuel consumed as reductants for the purpose of production of other metals have been collected under the NGER System from 2009 onwards.

For the years 1990-2008, this level of reductant consumption has been assumed to be constant for metals where activity data relating to reductant use is unavailable.

For silver and nickel production, activity data for the pre-NGERS period has been derived using metal production statistics from the Bureau of Resource and Energy Economics (BREE 2014), which covers the period up until 2013.

4.5.6 Uncertainties and time series consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas.

Activity data obtained under the NGER System was compared with activity data obtained from the former EITEIs Program for each facility and with data obtained from GHD and Energreen consulting to ensure the consistent classification of sources and consistency of data.

Where facilities were newly identified from NGER data as emitting facilities for a category, estimates of fuel consumption were interpolated through the time period from the most recent year for which data was available to the year of commencement of the facility based on metal production estimates.

Where facility-specific EFs were identified from NGER data for particular facilities, in category 2.C.4, the reported EFs for 2007, 2008 and 2009 were interpolated for each facility between 2006 and the most recent year for which data were available.

4.5.7 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1. Additional source specific quality control checks were undertaken to assess international comparability.

The Metal Products sector was reviewed independently by an international expert (Tsaranu) in 2007. The review was undertaken applying the same principles governing regular UNFCCC inventory desktop reviews. Small refinements were made to the iron and steel non-CO_2 methodology and general refinements made to the metal products chapter in response to recommendations made in this review.

Iron and steel

The consumption of coke as a reductant which is used as the basis of emissions from iron and steel can be compared between the primary data source under the NGER system and the *Australian Energy Statistics* (DoEE 2018a). A secondary source of trend comparison is the production of crude steel.

It is apparent from this comparison that NGER coke consumption tracks very closely with crude steel production levels while DoEE coke data appear not to reflect the increase in crude steel production observed in 2010-11. As a result of this QC measure, and in consultation with DIS, it was determined that NGER data were best to use for this particular source.

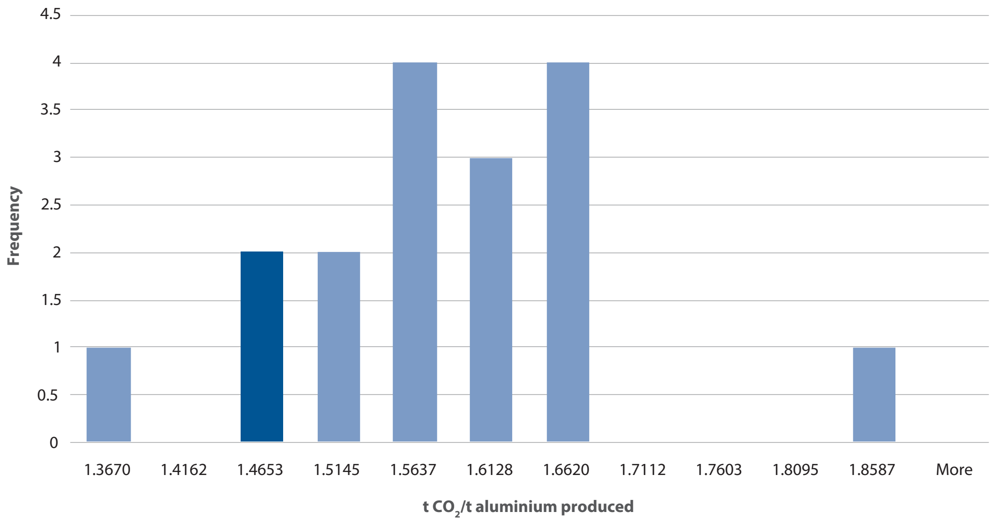
Aluminium

Emissions of PFCs by the Australian aluminium industry are a key category under both the level and trends analyses. Consequently, additional analysis has been performed to provide a comparison of Australian emission trends with those worldwide. The results of the comparison show that the trend in emissions per unit of production in Australia is very close to that observed worldwide. The decline in PFC emissions per unit of aluminium production in Australia since 1990 has mirrored the decline internationally (75 per cent), whereas the International Aluminium Institute (2005) reports a decline of 73 per cent between 1990 and 2003 worldwide. Emissions per unit of production reported by Australia are lower than the global averages, reflecting relatively modern plant and efficient operation, although this difference has narrowed slightly over time.

Monitoring of PFC concentrations occurs at the Cape Grim Baseline Air Pollution Station in Tasmania. Analysis of the observed atmospheric data has been undertaken by the CSIRO and compared to the emissions estimates in the inventory. Estimates of CF_4 and C_2F_6 emissions based on the measured data are in good agreement with inventory estimates for 2010 (CSIRO 2011).

The quantity of CO_2 per tonne of aluminium produced has been compared with that from other Annex I parties reporting emissions from this source. The results of this comparison are shown in Figure 4.7.

Figure 4.7 Aluminium production implied emission factors for Annex I countries (2016 Inventory) and Australia (2017 Inventory)



Note: In the figure above, Australia's IEF is located within the dark range.

The CO_2 IEF for aluminium production for Australia ranges between 1.395 t CO_2/t aluminium produced and 1.779 t CO_2/ t aluminium produced. IEFs fluctuate observed year on year according to the quantities of carbon-based fuels used to produce anodes.

Statistical analysis indicates that the IEF for aluminium production for Australia (in the dark shaded column above) is not significantly different to the factors reported by other Annex I parties.

In order to maintain continuity in the compilation of industrial processes emissions estimates, the Department engaged the external consultant previously used to collect activity data and EF information to undertake a quality control assessment of the full time series of activity data, EFs and emissions estimates. This work is of particular importance in *industrial processes and product use* where confidentiality of historical activity data pose some challenges for the assessment of time series consistency.

4.5.8 Recalculations since the 2016 Inventory

There were no recalculations undertaken in the Metal Industry sector in this submission.

The impact of these revisions is set out in Table 4.23 below.

Table 4.23 2.C Metal Industry: recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2018 Submission Gg CO_2-e	2019 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
2.C Metals				
1990	16,473	16,473	-	0.00 per cent
2000	14,753	14,753	-	0.00 per cent
2001	14,612	14,612	-	0.00 per cent
2002	14,456	14,456	-	0.00 per cent
2003	15,620	15,620	-	0.00 per cent
2004	16,234	16,234	-	0.00 per cent
2005	14,421	14,421	-	0.00 per cent
2006	13,492	13,492	-	0.00 per cent
2007	13,885	13,885	-	0.00 per cent
2008	13,588	13,588	-	0.00 per cent
2009	11,566	11,566	-	0.00 per cent
2010	13,419	13,419	-	0.00 per cent
2011	13,972	13,972	-	0.00 per cent
2012	11,774	11,774	-	0.00 per cent
2013	10,386	10,386	-	0.00 per cent
2014	9,866	9,866	-	0.00 per cent
2015	10,104	10,104	-	0.00 per cent
2016	10,202	10,202	-	0.00 per cent

4.5.9 Planned improvements

All acivity data, methodologies and emission factors are kept review.

4.6 Source Category 2.D Non-Energy Products from Fuels and Solvent Use

Source category description

Activities in the *Non-Energy Products from Fuels and Solvent Use* source category consist of CO_2 emissions arising from the oxidation of lubricants, as well as emissions of NMVOCs from solvent use, road paving and other activities.

Total net emissions estimated from *Non-Energy Products from Fuels and Solvent Use* were 184.0 Gg CO_2 and 189.1 Gg NMVOC in 2017 (Table 4.24), The main determinant of *Non-Energy Products from Fuels and Solvent Use* emissions from year to year is the quantity of the relevant product that is produced or used.

Table 4.24 Non-Energy Products from Fuels and Solvent Use NMVOC emissions 2017

Greenhouse Gas Source and Sink Categories	CO_2 Emissions (Gg	CH_4 Emissions (Gg	N_2O Emissions (Gg)	NMVOC emissions (Gg)
2D Non-Energy Products from Fuels and Solvent Use				
2.D.1 Lubricant Use	184.0			
2.D.2 Paraffin Wax Use	NE			
2.D.3 Solvent Use				109.7
2.D.4 Other				79.4

Lubricant Use was the source of 184.0 Gg CO_2, a reduction of 38 per cent on 1990.

Emissions from *Solvent Use* decreased by 3.3 Gg (5 per cent) between 1990 and 2017. Reductions in emissions from paint application have been offset by increases in emissions from degreasing and dry cleaning and other.

Surface coating operations involve the application of paint, varnish, lacquer or paint primer for decorative or protective purposes. Thinning solvents are normally used to dilute surface coating formulations or for cleaning purposes. Surface cleaning or degreasing operations involve the removal of materials such as oils, grease, waxes and moisture from surfaces. Chemical products manufacture and processing covers paint and ink manufacturing. General solvent use and consumer cleaning by the domestic and commercial sectors covers a large range of products including Domestic and Commercial Aerosol Products; Other Domestic and Commercial Products; and Consumer Cleaning Products.

Cutback bitumen is the most common form of primer used in Australia to protect roads from excessive wear. Cutback bitumen primers and primer binders are manufactured from refined bitumen which are 'cutback' (i.e. blended) with petroleum solvents. NMVOC emissions occur during the mixing of bitumen batches, stockpiling, application and curing of the road surface.

No consumption of Paraffin Wax is reported by DoEE due to only trivial amounts being consumed in Australia – emissions are not estimated.

Methodology

Lubricant Use

Lubricants, together with bitumen and solvents, are non-fuel products of crude oil, which are included in the energy statistics compiled by DIS. It is assumed that 60 per cent of lubricants are not oxidised during engine operation, i.e. not actually combusted (Australian Institute of Petroleum, pers. comm. 1996). Therefore the stated DoEE consumption of lubricants and greases is reduced by 60 per cent before emissions are estimated. Emissions of gases other than CO_2 are included with the emissions arising from fuel combustion in the engine type concerned in the relevant sector. Some lubricants may be incinerated subsequent to use. Any emissions from this source are included in the Waste sector.

Road paving with asphalt

According to Treadrea (1995), for a system in equilibrium where the quantity of NMVOC used is constant each year and the average temperature conditions do not vary significantly from year to year, the quantity of flux and cutter lost to the atmosphere will be approximated by the quantity used each year.

It is assumed that the quantity of fluxed bitumen is negligible; the fraction of total bitumen consumption used in cutback bitumen is approximately 42 per cent (Australian Asphalt Pavement Association, pers. comm., 1995); and, the quantity of cutter added to the bitumen used in cutback bitumen is equal to 5.4 per cent (Treadrea 1995). Bitumen data are sourced from *Australian Energy Statistics* (DoEE 2018).

NMVOC emissions from general solvent use and consumer cleaning

In accordance with IPCC 2006, per-capita EFs from the *EMEP/EEA air pollutant emission inventory guidebook 2016* have been adopted for estimating NMVOC emissions from Other Domestic/Commercial products and Consumer Cleaning Products. NMVOC emissions from general solvent use and consumer cleaning products are reported in Table 4.25. The mean population for the financial year is multiplied by the EF and the result is expressed in gigagrams (Gg). EFs are expressed in terms of per capita use per year.

EFs for general solvent use and consumer cleaning products are presented in Table 4.25.

Table 4.25 Emission factors for general solvent use and consumer cleaning products

Product	Emission Factor kg NMVOC/capita/yr
Domestic/Commercial Aerosol Products [(a)]	
Household (cleaning) products	0.201
Care car products	0.161
Cosmetics and toiletries	0.355
Sub Total	0.717
Other Domestic/Commercial Products [(b)]	
DIY/buildings	0.522
Car care products	0.303
Cosmetics and toiletries	0.733
Pharmaceutical products	0.048
Pesticides	0.076
Sub Total	1.682
Household Cleaning Products [(b)]	
Non-aerosol	0.252
Other products	0.054
Sub Total	0.306
Total	2.40

Source: (a) Aerosol Association of Australia (pers. comm., 1994). (b) *EMEP/EEA* (2016)

4.6.1 Uncertainties and time series consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates.

4.6.2 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1.

4.6.3 Recalculations since the 2016 Inventory

No recalculations were undertaken in the Non-Energy Products from Fuels and Solvent Use sector in this submission as set out in Table 4.26.

Table 4.26 2.D Non-Energy Products from Fuels and Solvent Use: recalculation of total CO_2-e emissions (Gg), 1990-2016

	2018 submission	2019 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(per cent)
2D Non-Energy Products from Fuels and Solvent Use				
1990	280	280	-	0.00 per cent
2000	284	284	-	0.00 per cent
2001	294	294	-	0.00 per cent
2002	299	299	-	0.00 per cent
2003	308	308	-	0.00 per cent
2004	334	334	-	0.00 per cent
2005	254	254	-	0.00 per cent
2006	244	244	-	0.00 per cent
2007	227	227	-	0.00 per cent
2008	235	235	-	0.00 per cent
2009	237	237	-	0.00 per cent
2010	247	247	-	0.00 per cent
2011	232	232	-	0.00 per cent
2012	188	188	-	0.00 per cent
2013	185	185	-	0.00 per cent
2014	181	181	-	0.00 per cent
2015	175	175	-	0.00 per cent
2016	173	173	-	0.00 per cent

4.6.7 Planned improvements

All activity data, methodologies and EFs are kept under review.

4.7 Source Category 2.E Electronics Industry

Source category description

Whilst there is some small scale manufacture of electronics in Australia, in accordance with UNFCCC inventory reporting guidelines emissions associated with the use of fluorinated compounds in the electronics industry are considered negligible and are not estimated.

Australia has identified a small amount of specialty electronic components manufacturing, consuming around 20kg of NF_3 which is destroyed in the process.

It is also understood that negligible amounts of electronics cooling fluids containing NF_3 are consumed in Australia, confined to consumer use in personal computers and hobby applications.

4.8 Source Category 2.F Product Uses as Substitutes for Ozone Depleting Substances

4.8.1 Source category description

This sub-sector comprises emissions of synthetic gases from the use of halocarbons in refrigeration and air conditioning, foam blowing, fire extinguishers, aerosols/metered dose inhalers, solvents and SF_6 in electrical equipment and other miscellaneous applications.

The methodology used for compiling emissions estimates from this range of sources relates emissions to the stock and vintage of halocarbon (HFC) gases in various equipment end-use categories and is described below under the heading "Methodology". Where equipment stock data are available (in the case of domestic refrigeration and air conditioning, motor vehicle air conditioning and metered dose inhalers), information on the vintage and lifetimes of the capital stock of appliances have been used to estimate emissions on a bottom up basis. Where these stock data are not available, a top-down approach has been used.

The method relies primarily on inputs of data on HFC imports (an estimate of potential emissions – there is no export or local production of HFCs in Australia) reported to the Department of the Environment and Energy under the *Ozone Protection and Synthetic Greenhouse Gas Management Act, 2003*. As part of the licensing conditions specified in the *Act*, quantities of gas imported in bulk and in pre-charged equipment are reported to the Department of the Environment and Energy and these data are used for emissions estimation.

4.8.2 Methodology

Consistent with IPCC good practice, the methodology uses specified equations to estimate HFC emissions for each equipment type for three separate processes a) initial losses that occur at the initial charging of the equipment; b) emissions from leakages during the life of the equipment and c) the emissions from the disposal of the equipment. Initial losses occur when an amount of bulk imported gas (Mb_{ijkt}) is allocated to a specific equipment type j. Emissions during the life of the equipment depend, in the first year, on the amount of imported bulk gas allocated to the equipment type j and the amount of gas in imports of precharged equipment of type j (Mpc_{ijkt}) and, for every year thereafter, on the opening stock of gas in the equipment type (S_{ijkt}) plus any replenishments of gas (R_{ijkt}) in the equipment type that may have occurred in that year. Emissions at disposal depend upon the closing stock of gas of vintage k in year t (S_{ijkt}), the proportion of the capital stock retiring in each year, αK_{jkt}, and the quantity of gas recovered for destruction, D_{ijkt}.

The following equations set out the general process for estimating emissions of HFCs:

$$E_{ijkt} = Mb_{ijkt} * IL_{ijkt} + (S_{ijkt-1} + Mb_{ijkt} + Mpc_{ijkt} + R_{ijkt}) * (EF_{ij}) + (\alpha\, K_{jkt} * S_{ijkt} - D_{ijkt})$$
$$S_{ijkt} = S_{ijkt-1} + Mb_{ijkt} + Mpc_{ijkt} + R_{ijkt} - E_{ijkt} - D_{ijkt}$$
$$R_{ijkt} = \Sigma_{t-1,\, t-z}\, E_{ijkt}$$
$$D_{ijktbase} = \alpha\, K_{jkt} * S_{ijkt} * DF_{ijk}$$
$$D_{ijkt} = D_{ijktbase} / \Sigma_j\, \Sigma_k\, D_{ijktbase} * DTOT_t$$

and

$$E_t = \Sigma_i \Sigma_j \Sigma_k E_{ijkt}$$

Where E_t is the sum of emissions of all gases of type i from all equipment types j and vintages k in year t

E_{ijkt} is the emissions of gas i from equipment type j and vintage k in year t

S_{ijkt-1} is the opening stock of gas i from equipment type j and vintage k in year t

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S_{ijkt} is the closing stock of gas i from equipment type j and vintage k in year t

Mb_{ijkt} is the quantity of bulk import of gas i allocated to equipment type j for vintage k if k = year t, else = 0;

Mpc_{ijkt} is the quantity of gas i in imports of pre-charged equipment type j for vintage k if k= year t, else =0;

R_{ijkt} is the amount of replenishment of the stock of gas i for equipment type j and vintage k in year t

EF_{ijkt} is leakage rate of gas i from equipment type j and vintage k in year t (in the first year of operation, EF is divided by 2 – assuming equipment is in operation for an average of 6 months)

IL_{ijkt} is the initial loss rate of gas i from equipment type j and vintage k in year t

αK_{jk} is the proportion of the capital stock of equipment type j and vintage k retired in year t

$\Sigma_{t-z\,t,}\,E_{ijkt}$ is the sum of initial and annual emissions from t-z to t where t is the current year and z is the number of years between replenishments

D_{ijkt} is the amount of gas i destroyed from equipment type j and vintage k in year t

DF_{ijkt} is the base destruction factor for gas i destroyed from equipment type j and vintage k in year t

$D_{ijktbase}$ is estimated base amount of gas i destroyed from equipment type j and vintage k in year t

$DTOT_t$ is the actual total gas destroyed reported by Refrigerant Reclaim Australia.

The initial loss rate (IL_{ijkt}) applied to each vintage of each equipment type are a mix of IPCC 2006 defaults (the mid-point of specified ranges) and country specific factors. The IPCC 2006 default factors have been chosen as they reflect the most recently available knowledge on refrigerant losses from refrigeration and air conditioning equipment most commonly in use in Australia. The annual leakage rates (EFijkt) are based on a mix of IPCC 2006 and country-specific factors adjusted for annual fluctuations in atmospheric observations of F-gases measured at the CSIRO monitoring station in Cape Grim Tasmania.

Calibration of annual leakage rate with atmospheric observations

The annual loss EF from 2006 onwards has been adjusted in line with changes in atmospheric concentrations measured at the Cape Grim monitoring station in Tasmania (CSIRO 2018). CSIRO has used inverse modelling techniques to derive an estimate of national HFC emissions based on atmospheric measurements of HFC concentrations. The base EF is indexed to the changes in the national estimate developed by CSIRO (averaged over a period of 3 years).

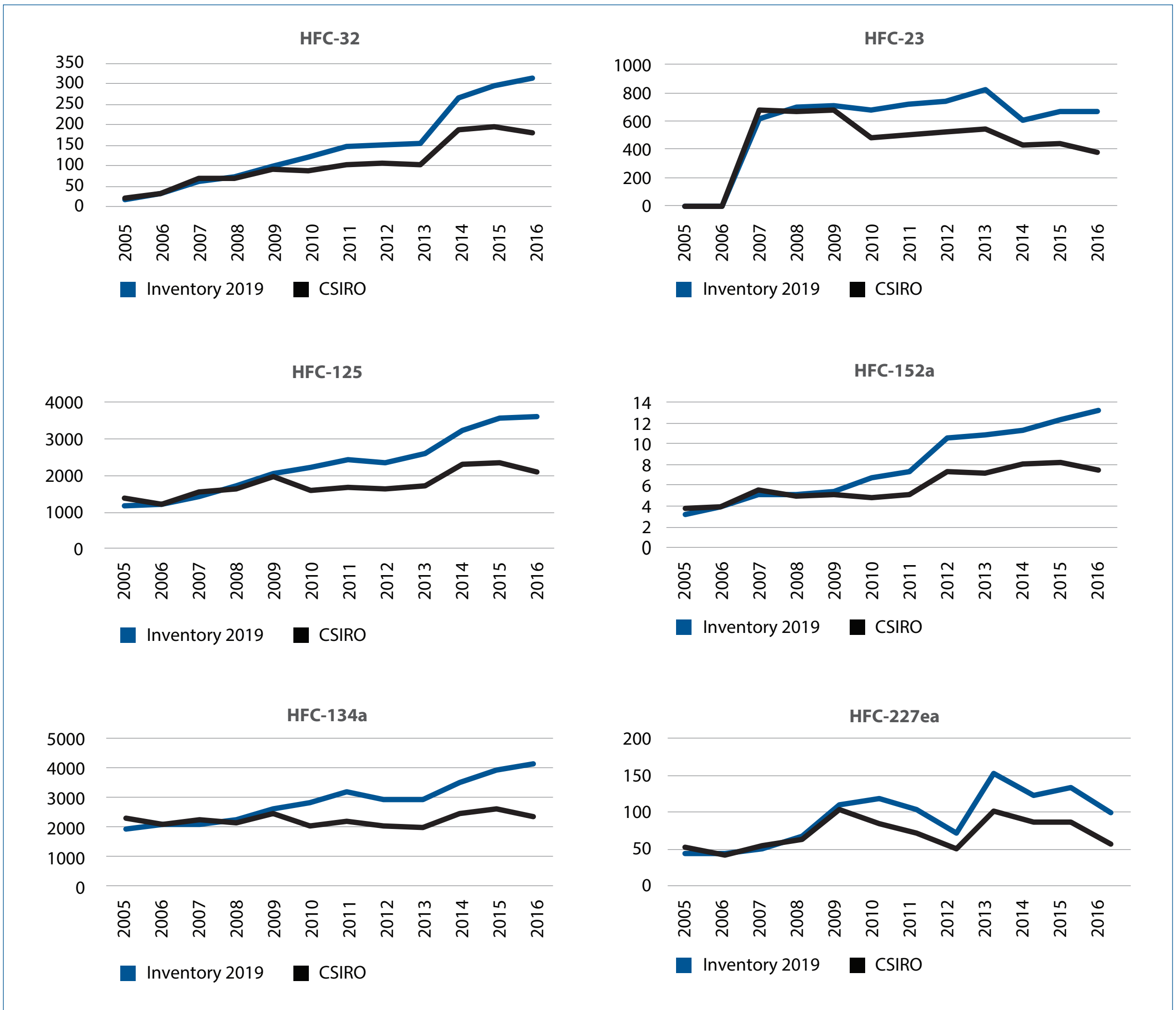
F-gases are considered to be ideal to use inverse modelling techniques to derive national estimates. The 2006 IPCC Guidelines identify fluorinated gases as being among the most suitable for which inverse modelling could provide verification of emissions estimates (p 6.21). As inverse modelling can be prone to natural source interference, F-gases are well suited to this approach as they have no natural sources. The remote location of the Cape Grim monitoring station also reduces the likelihood of measurement error from international sources. Additionally, there are no sinks for F-gases and therefore changes in concentrations reflect changes in emissions.

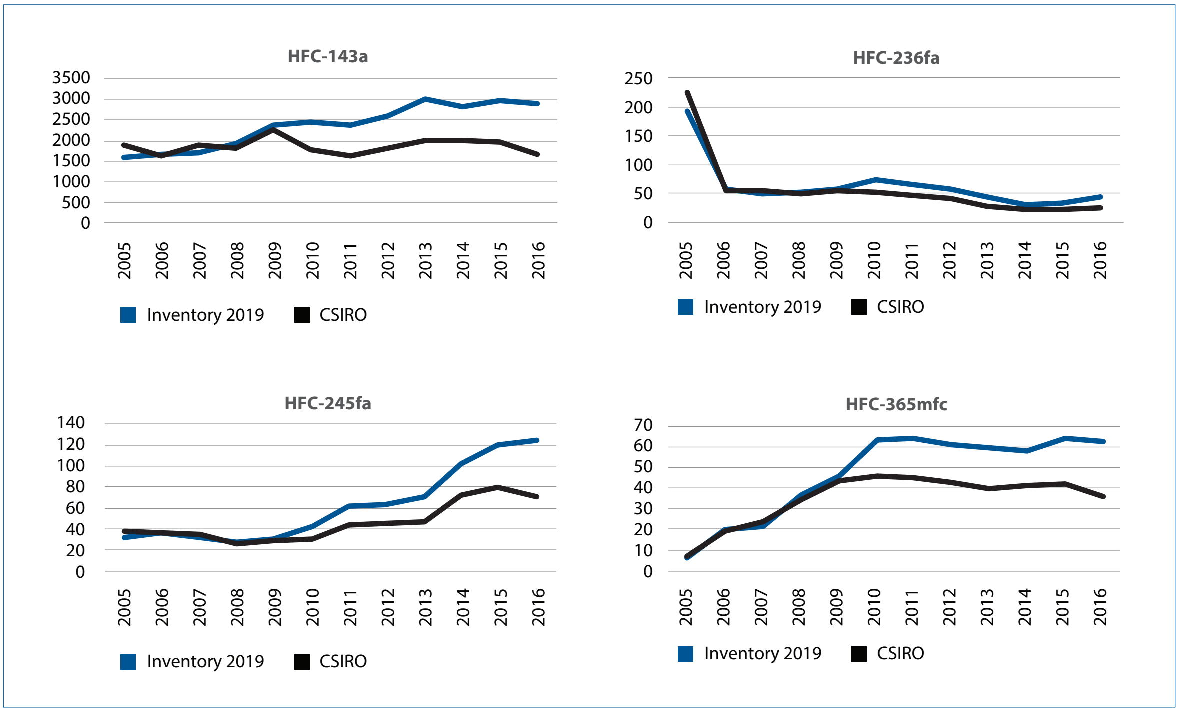
IPCC 2006 recommends a comparison of the uncertainty between the calculated inventory estimates and the inverse model-derived estimates when considering the use of independent emissions estimates based inverse modelling. Where the uncertainty of the model results is less than the calculated inventory uncertainty, the model can be used to improve the inventory. Inventory uncertainty for HFC emissions is estimated at ±27 per cent which is comparable with uncertainty estimated for the modelled emissions by CSIRO which averages at ±20 per cent.

As the 2006 guidelines does not provide any advice on the direct use of inverse modelled emissions estimates, Australia has opted to use the fluctuations in the modelled estimates to adjust the annual leakage rate. This ensures the trend in atmospheric observations is replicated in the inventory. As the inventory model is based on assumptions about changes in capital stocks that are applied consistently year on year, the inverse modelled emission estimates provide a check on these assumptions. The strength of this approach is that it enables the inventory estimates to better reflect improvements in industry practice in terms of gas handling, equipment maintenance and decommissioning. This approach is consistent with the case study presented in section 6.10.2 of the 2019 IPCC Guidelines for National Greenhouse Gas Inventories for Australia's calibration of SF_6 emissions.

In addition to the calibration of annual EFs, gas species fluctuations observed at Cape Grim are also used to calibrate gas speciation in the HFC emissions model. Figure 4.8 shows the post-calibration comparison between CSIRO and DoEE speciation from 2005 to 2017.

Figure 4.8 Post-calibration comparison of HFC emissions by species





Source: DoEE 2019

The amount of gas allocated to the replenishment of the stock of HFC gas and for each equipment type and vintage during the year (R_{ijkt}) is equal to the amount of gas leaked over the life of the equipment to that point and the frequency of replenishment undertaken by the operators of the equipment. Little information is available on this use of bulk imports of gas. Nonetheless, it is assumed that all commercial refrigeration and air-conditioning and fire protection systems are well maintained and subject to regular gas replenishment every 2 years of operation. Light vehicles are assumed to undergo a single gas re-charge at the mid-point of each unit's life. Sensitivity testing of the impact of these assumptions on emissions is provided in the QA/QC section. Lifetime emissions are not affected by these assumptions, while the time profile of emissions is considered to be not significantly sensitive to these assumptions.

Average equipment lifetimes are IPCC defaults. A constant proportion of the equipment stock (αK_{jk}) is assumed to be disposed over a period of time, centred on the midpoint of the average equipment lifetime. For example, the disposal of the refrigerator and air conditioning stocks is assumed to occur over a period from age five to a final date that ensures that the midpoint is centred on the average age of equipment life.

Disposal losses reflect the residual charge or closing stock of gas in the equipment at the time of disposal (S_{ijkt}) and gas recovery for destruction undertaken at time of disposal. Data ($DTOT_t$) on recovery for destruction are supplied by Refrigerant Reclaim Australia (RRA), the sole entity responsible for the recovery and destruction of refrigerants in Australia. The RRA data are used to re-calibrate the recovery for individual equipment types estimated using base destruction factors or IPCC default disposal recovery rates (DF_{ijkt}). In effect, total recovery for destruction for the inventory as a whole is determined by data supplied by RRA, while the allocation of that total amount of destruction to the various equipment types is effectively determined by the relative IPCC default destruction rates.

Using data on rates of disposal and destruction with estimates for emissions using the vintage stock model, implied emission factors are derived for product manufacturing, operation and disposal.

Table 4.27 Halocarbons: key assumptions concerning average equipment life, initial and annual losses and replenishment rates, by equipment type 2017

End Use Category	Average equipment life [a,b]	Loss on initial charge [a]	Annual loss [a][e]	Replenishment [c]	Emissions Estimation Method
	Years	per cent	per cent		
Commercial refrigeration					
Stand-alone commercial applications	12.5	1.75	8.8 [d]	Full replenishment every 2 years	Method 3
Medium and large commercial applications	11	1.75	15.1 [d]	Full replenishment every 2 years	Method 3
Industrial commercial applications	22.5	1.75	22.0 [d]	Full replenishment every 2 years	Method 3
Domestic refrigeration	15	0.6	0.4	No replenishment	Method 2
Transport refrigeration	7.5	5.1	25.2 [d]	Full replenishment every 2 years	Method 3
Light vehicle air conditioning	12	0.4	18.9	Full replenishment at 6 years	Method 1
Heavy vehicle air conditioning	12.5	0.4	12.6 [d]	Full replenishment every 2 years	Method 3
Domestic stationary air conditioning					
Refrigerated portable air conditioners	15	0.6	6.9	No replenishment	Method 2
Split system air conditioners	15	0.6	6.9	No replenishment	Method 2
Packaged air conditioners	15	0.6	6.9	No replenishment	Method 2
Commercial air conditioners	22.5	5.1	7.6 [d]	Full replenishment every 2 years	Method 3
Foams (closed cell)	20	10.0	2.8	No replenishment	Method 4
Aerosols	2	0.0	63.0	No replenishment	Method 4
Fire	10	0.4	6.3	Full replenishment every 2 years	Method 4
Metered Dose Inhalers	2	0.0	63.0	No replenishment	Method 3

Source: (a) IPCC 2006.
(b) Burnbank 2002.
(c) DoEE
(d) Expert Group 2013.
(e) calibrated to Cape Grim atmospheric observations

Bulk gas activity data allocation methods

Bulk imported HFC gas allocations to equipment types are undertaken in 3 ways depending on what information is available about equipment stocks and production levels. These are identified below as methods 1 to 3. Bulk gas demand is first estimated for classes of equipment where data on equipment stocks is available, then the residual bulk gas is allocated to the remainder of equipment types.Method 1 covers the allocation of bulk gas to light vehicle air conditioning. Vehicle stocks by vintage in each inventory year are available from data underpinning the estimation of emissions from road transport. The following equation is used:

$$G_{demmv} = G_{dpmv} + G_{drmv}$$
$$G_{dpmv} = (New_{mv} - Imp_{mv}) \times Chg_{mv}$$

Industrial Processes and Product Use

Where G_{demmv} is total gas demand for production and replenishment for motor vehicle air conditioners

G_{dpmv} is gas demand for domestic production for motor vehicle air conditioners

G_{drmv} is the gas demand for replenishment for motor vehicle air conditioners – assumed to be total replacement of lost gas in the 5th year of operation.

New_{mv} is new additions to the motor vehicle stock – based on motor vehicle census data used for the estimation of emissions for the transport sector

Imp_{mv} is imports of pre-charged motor vehicle air conditioners

Chg_{mv} is the unit charge of motor vehicle air conditioners

Method 2 covers the allocation of bulk gas to domestic refrigeration and air conditioning. Total stocks of domestic refrigerators and air conditioners are tracked based on data available from the Australian Bureau of Statistics. To achieve mass balance, the method includes a 'stock in storage' factor, where a proportion of imported units are held over for installation in a following year. The following equation is used:

$$G_{demdrac} = G_{dpdrac} + G_{drdrac}$$
$$G_{dpdrac} = (Exp_{drac} - Imp_{domrac} + Ret_{drac} + \Delta S_{drac}) \times Shr_{hfc} \times Chg_{drac}$$

Where $G_{demdrac}$ is total gas demand for production and replenishment for domestic refrigerators and air conditioners

G_{dpdrac} is gas demand for domestic production for domestic refrigerators and air conditioners

G_{drdrac} is the gas demand for replenishment for domestic refrigerators and air conditioners – no replenishment assumed

Exp_{drac} is the exports of domestic refrigerators and air conditioners

Ret_{drac} is the retirements of domestic refrigerators and air conditioners - based on assumptions about the operational life of each equipment type

ΔS_{drac} is the change in stock of domestic refrigerators and air conditioners calculated according to:

$CS_{drac} - OS_{drac}$

Where CS_{drac} is the closing stock of domestic refrigerators and air conditioners

OS_{drac} is the opening stock of domestic refrigerators and air conditioners

Imp_{drac} is the imports of domestic refrigerators and air conditioners adjusted for stock in storage = $Imp_{pcedrac} \times P_{inst}$

Where $Imp_{pcedrac}$ is total imports of pre-charged domestic refrigerators and air conditioners

P_{inst} is the proportion of pre-charged domestic refrigerators and air conditioners installed in the year of import.

Shr_{hfc} is the share of domestic production using HFCs

CHG_{drac} is the unit charge of domestic refrigerators and air conditioners

Bulk gas demand is summed for method 1 and 2 equipment types as follows:

$$G_{demtotal} = G_{demmv} + G_{demdrac}$$

Where $G_{demtotal}$ is total demand for gas for production and replenishment for motor vehicle air conditioners and domestic refrigeration and air conditioners

G_{demmv} is total gas demand for production and replenishment for motor vehicle air conditioners

$G_{demdrac}$ is total gas demand for production and replenishment for domestic refrigerators and air conditioners

After bulk gas demand for method 1 and 2 equipment types is allocated, the residual gas is allocated to method 3 and 4 equipment types.

Method 3 covers commercial refrigeration and air conditioning, and metered dose inhalers. Method 4, is a simplified version of Method 3 which does not account for equipment level data and covers foams, aerosols and fire protection equipment. There is no equipment stock information available for these equipment types. Gas is allocated to these equipment types according to the following equation:

$$G_{res} = G_{bulk} - G_{demtotal}$$
$$G_{resi} = G_{res} \times Shr_{resi}$$

Where G_{res} is the residual gas available to commercial refrigeration and air-conditioning, metered dose inhalers, foams, aerosols and fire protection equipment

G_{bulk} is total bulk gas imported available to all equipment

G_{demmv} is total gas demand for production and replenishment for motor vehicle air conditioners

$G_{demdrac}$ is total gas demand for production and replenishment for domestic refrigerators and air conditioners

G_{resi} is the residual gas available to equipment type i

Shr_{resi} is the share of residual gas used in equipment type i – this value is based upon end use data provided annually by the Department of the Environment and Energy

Activity data: HFC gas imported into Australia in 2017

Data on imports of HFC gases are reported to the Department under licensing arrangements operating under the *Ozone Protection and Synthetic Greenhouse Gas Management Act, 2003*. Imports of bulk gas are allocated initially to individual end uses on the basis of a consideration of the amount of gas required for domestic production and replenishment/servicing and retrofitting for the sources which are estimated on a bottom-up basis (gas demand in domestic refrigeration, packaged, split and refrigerated portable air-conditioning and light vehicle air conditioning). After this initial gas demand is satisfied, the residual bulk gas is allocated to the remaining end use categories in proportion to the information on use as reported by licensees under the Act. The sensitivity of these allocations on emissions estimates has been tested and the results are reported in the QA/QC section. The results show that lifetime emissions are not affected by these assumptions, and that the time profile of emissions – whilst impacted – is not considered sensitive to these assumptions.

Quantities of gas imported in bulk and contained in pre-charged equipment by end-use category are shown in Table 4.28.

Table 4.28 End-use allocation of imports of bulk and pre-charged HFC gas 2017

End Use Breakdown	Bulk Imports (Mt CO_2-e)	Pre-charged imports (Mt CO_2-e)	Total (Mt CO_2-e)
Refrigeration	**3.84**	**0.37**	**4.22**
Transport refrigeration	0.31	0.13	0.45
Commercial refrigeration	3.53	0.19	3.72
Domestic refrigeration and freezers	-	0.05	0.05
Stationary air-conditioning	**2.78**	**4.39**	**7.17**
Chillers	0.31	0.83	1.15
Refrigerated portable	-	0.12	0.12
Split systems	2.47	3.26	5.73
Packaged systems	-	0.18	0.18
Mobile air-conditioning	**0.93**	**0.81**	**1.73**
Cars	0.70	0.72	1.42

End Use Breakdown	Bulk Imports ($Mt\ CO_2$-e)	Pre-charged imports ($Mt\ CO_2$-e)	Total ($Mt\ CO_2$-e)
Trucks	0.23	0.08	0.31
Foam	0.00	-	0.00
Aerosols/solvents	0.01	0.20	0.20
Fire equipment	0.04	0.00	0.04
Metered dose inhalers	-	0.13	0.13
TOTAL	**7.60**	**5.89**	**13.49**

Source: DoEE

Backcasting

Collection of data on HFC imports under the *Act* commenced in the 2005 financial year. There are no data available on the import of HFCs for years prior to 2005. It is therefore necessary to backcast import data to enable an estimate of the bank of gas and associated emissions. For each of the end-use categories information on the transition from the use of CFC refrigerants to HFC refrigerants provided in Burnbank 2002 has been used to determine a time series of HFC imports up to 2005 when actual import data are available.

Breakdown of gas species (i)

The bulk gas import data collected under the *Act* are disaggregated into HFC 134a, 'Other HFCs' and 'Exotic HFCs'. The 'Other' gas category comprises a known group of gases but is reported as an aggregated CO_2-e value, whilst the constituent gases in the 'Exotic' gas category are not reported but are provided as an aggregated CO_2-e value. Gas imported in pre-charged equipment is disaggregated into the following equipment types:

Stationary air conditioners;

- Chillers – High pressure
- Chillers – Low pressure
- Air conditioner – Other
- Packaged – Air cooled
- Packaged – Water cooled
- Packaged – Window
- Refrigerated portable
- Split system – Multi head/ variable refrigerant flow
- Split system – Single head

Refrigeration; and

- Commercial refrigerated cabinets
- Domestic refrigerator and equipment
- Other commercial refrigeration
- Portable refrigerators (commercial)
- Self powered refrigerator (transport)
- Vehicle powered refrigerator

Mobile air conditioners.

- Vehicles weighing less than 3.5 tonnes Gross Vehicle Mass (cars and light commercial vehicles)
- Vehicles weighing more than 3.5 tonnes Gross Vehicle Mass (heavy vehicles)

The pre-charged equipment data are also disaggregated by the refrigerant they contain. The refrigerants that are reported are as follows: HFC-125; HFC-134a; HFC-404a; HFC-407a; HFC-407b; HFC-407c; HFC-410a; HFC-413a; HFC-417a; HFC-507a. The speciated gases in pre-charged equipment are calibrated each year from 2006 onwards based fluctuations in individual F-gas species observed at the Cape Grim atmospheric monitoring station and are used to disaggregate the final emissions estimates in each end use category into individual HFC species for reporting in the CRF tables.

Overview of the stocks of gas in operating equipment

The allocation of total gas imports to individual end use categories determines the relative sizes of gas stocks contained in equipment and the time profile of gas losses from the stock. Figure 4.9 shows the growth in the stock of synthetic gas in operating equipment. The chart shows significant growth in gas contained in commercial refrigeration systems, motor vehicle air conditioners and split system air conditioners. The general growth in the stock of gas in operating equipment reflects the transition from CFC to HFC refrigerant use associated with the Montreal Protocol controls on CFC use. In addition to the transitional trend, the recent strong growth in commercial refrigeration systems reflects similar growth in Australia's economy, whilst the growth in motor vehicle air conditioning and residential split systems reflects declines in relative prices of imported residential air conditioning systems as well as a transition in the vehicle fleet to more modern air conditioned vehicles. The total stock and emissions from the consumption of halocarbons is shown in Table 4.29.

Figure 4.9 Growth in the bank of HFC gas in operating equipment 1990–2017 (Mt CO_2-e)

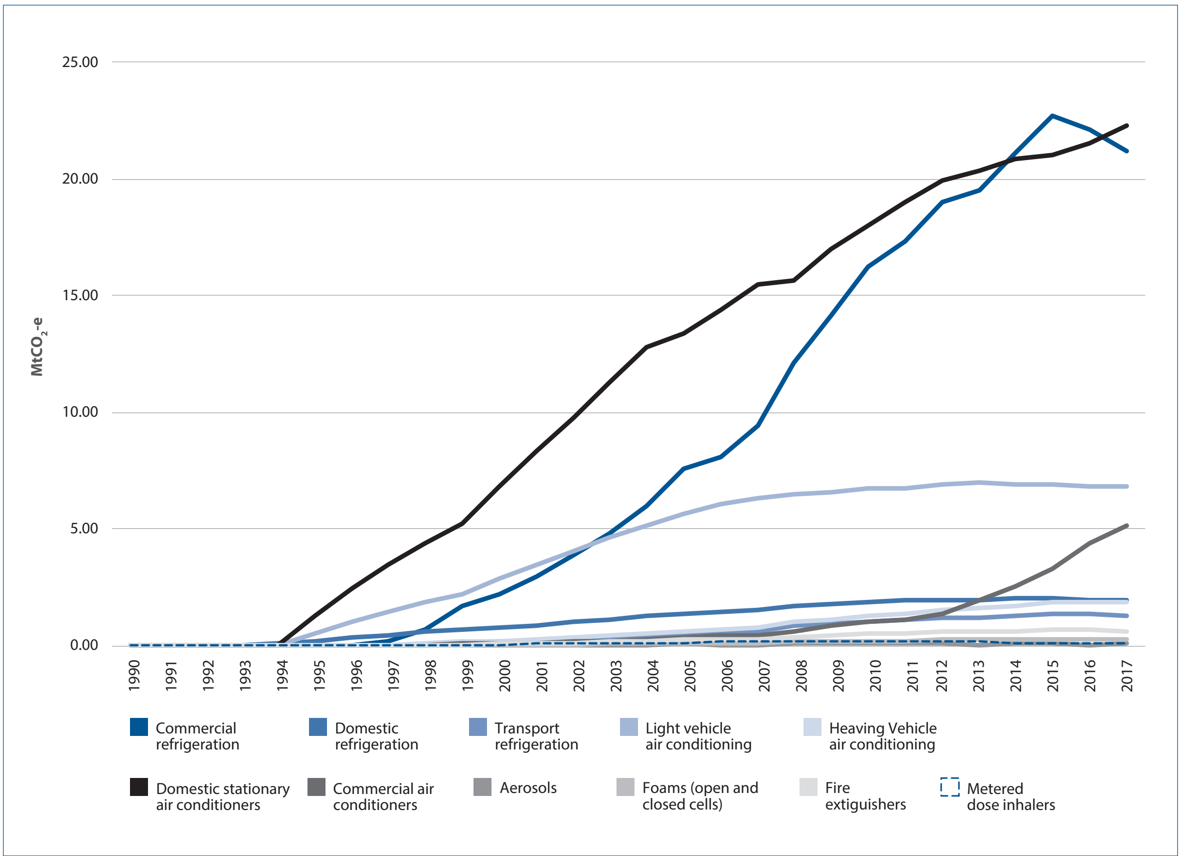


Table 4.29 Halocarbons: estimated stock and emissions: all equipment types

Year	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1990	-	-
1991	-	-
1992	-	-
1993	-	-
1994	0.11	0.00
1995	2.11	0.09
1996	3.87	0.41
1997	5.63	0.71
1998	7.79	1.00
1999	10.28	1.37
2000	13.33	1.61
2001	16.50	2.31
2002	19.79	2.93
2003	23.20	3.58
2004	26.71	4.27
2005	30.07	5.00
2006	32.16	5.17
2007	35.24	6.07
2008	39.29	6.86
2009	43.35	8.11
2010	47.09	8.61
2011	49.72	9.15
2012	53.02	9.06
2013	54.64	9.87
2014	57.52	10.78
2015	60.34	11.80
2016	61.11	11.98
2017	61.67	12.25

Refrigeration and air conditioning (2.F.1)

The refrigeration and air-conditioning sector accounts for the majority of HFC consumption in Australia. Emissions from any piece of equipment include both the amount of chemical leaked during initial charging of equipment and the amount emitted during service life. Emissions also occur at equipment disposal. The disposal emission equation assumes that a certain percentage of the chemical charge will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of the quantity of chemical contained in the retiring equipment and the proportion of chemical released at disposal. The rate at which equipment is retired is based on IPCC default average service-lives for the various types of equipment.

Domestic Refrigeration and freezers

A bottom-up capital stock model has been used to determine a time series for the stock of gas contained in domestic refrigeration and freezers. The estimates are based on data on the number of households and the numbers of domestic fridge freezers found in each household in Australia (ABS 2008a and ABS 2008b) and pre-charged equipment import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act*.

Average charges per unit for domestic refrigerators are based on the pre-charged equipment data collected under the *Act* and were 0.198 kg in 2017. It is assumed that all new equipment and imports from 1994 onwards contain HFC refrigerants (Burnbank 2002). Service life emissions are derived using the IPCC default leakage rates calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station.

Unit disposals are based on an average lifetime of 15 years with the first units in each vintage retiring after 5 years (Burnbank 2002). Under these assumptions the last units in each vintage are retired after 25 years.

Domestic production of household refrigerators no longer takes place in Australia with the last producer Fisher and Paykel completing the relocation of their remaining production facility to Thailand in August 2009[9]. It is assumed that no replenishment of gas losses from domestic refrigerators takes place as the units contain small well-sealed charges of gas. Upon disposal, a base assumption of 8 per cent of total HFC retiring gas in each year is recovered for destruction (which equates to 30 per cent for domestic refrigeration and freezers). Actual recovery for destruction is estimated by calibrating the results of these assumptions with data on actual total recovery obtained for destruction from RRA.

Table 4.30 shows the capital stocks, HFC stock and emissions from domestic refrigeration from 1995 to 2016. Comparison of refrigerator stocks and household numbers shows that there has been a trend toward the use of more than one refrigerator in the home.

Unit disposals are based on an average lifetime of 15 years with 5 per cent of units in each vintage retiring after 5 years (Burnbank 2002). Under these assumptions the last units in each vintage are retired after 25 years. The base assumption is made that 70 per cent of each unit's residual charge is emitted upon disposal (although this is calibrated for actual data on total recovery for destruction).

Table 4.30 Halocarbons: estimated stock and emissions: domestic refrigerator/freezers

Year	Domestic refrigerator stock[a]	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1994	8,382,254	0.11	0.00
1995	8,578,471	0.22	0.00
1996	8,774,688	0.34	0.00
1997	8,970,905	0.45	0.00
1998	9,167,123	0.57	0.00
1999	9,363,340	0.68	0.01
2000	9,538,827	0.79	0.01
2001	9,714,313	0.89	0.02
2002	9,937,512	1.00	0.02
2003	10,226,951	1.12	0.03
2004	10,518,356	1.23	0.03
2005	10,811,949	1.35	0.03
2006	11,045,172	1.42	0.04
2007	11,514,381	1.55	0.04
2008	11,850,689	1.67	0.05
2009	12,182,534	1.79	0.05
2010	12,283,818	1.85	0.06
2011	12,322,307	1.92	0.06

9 http://www.fisherpaykel.com/global/investors/Investors-DFs/Annual per cent20Reports/Annual per cent20Review per cent20Year per cent20Ended per cent2031 per cent20March per cent202010.pdf

Year	Domestic refrigerator stock[(a)]	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
2012	12,372,914	1.95	0.06
2013	12,423,522	1.98	0.07
2014	12,474,129	1.99	0.07
2015	12,474,129	2.02	0.07
2016	11,850,423	1.97	0.07
2017	11,151,546	1.93	0.07

Source: (a) ABS 2008b Includes stocks not containing HFC refrigerants.

Domestic air conditioning

Stationary air conditioning comprises refrigerated portable, split and packaged systems. Emissions from this sub category are estimated on a bottom-up basis using equipment population estimates based on numbers of households and white-goods data provided in ABS 2008c, and pre-charged equipment import data. Table 4.31, Table 4.32 and Table 4.33 show the capital stocks, HFC stocks and emissions from the three types of air conditioning equipment from 1995 to 2016.

A mix of country-specific and IPCC default leakage rates are applied to each gas vintage calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 15 years. The first disposals of gas are assumed to occur after 5 years of operation continuing until the last units are retired after 25 years. Upon disposal, a base assumption of 5 per cent of retiring gas in each year is recovered for destruction. Actual recovery for destruction is estimated by calibrating the results of these assumptions with data on actual total recovery obtained for destruction from RRA.

Table 4.31 Halocarbons: estimated stock and emissions: split system stationary airconditioners

Year	Split system air conditioner stock[(a)]	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	664,300	0.78	0.03
1996	709,650	1.41	0.22
1997	755,000	1.92	0.37
1998	800,350	2.35	0.50
1999	845,700	2.72	0.61
2000	1,146,548	4.21	0.72
2001	1,447,395	5.61	1.10
2002	1,748,243	6.95	1.42
2003	2,075,944	8.36	1.73
2004	2,403,645	9.72	2.08
2005	2,731,346	10.45	2.37
2006	3,062,064	11.57	2.49
2007	3,549,559	12.62	2.81
2008	3,723,500	12.76	3.04
2009	4,106,477	13.80	3.16
2010	4,437,195	14.60	3.39
2011	4,767,913	15.52	3.54
2012	5,098,631	16.40	3.61
2013	5,429,349	16.79	3.92

Year	Split system air conditioner stock[(a)]	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
2014	5,760,067	17.20	4.11
2015	6,090,785	17.32	4.19
2016	6,713,882	18.02	4.26
2017	7,257,270	18.87	4.48

Source: (a) ABS 2008b; Includes stocks not containing HFC refrigerants

Table 4.32 Halocarbons: estimated stock and emissions: packaged air conditioners

Year	Packaged air conditioner stock[(a)]	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	1,582,177	0.53	0.02
1996	1,643,545	1.06	0.05
1997	1,704,215	1.57	0.08
1998	1,764,251	2.04	0.11
1999	1,823,714	2.49	0.13
2000	1,807,716	2.60	0.15
2001	1,791,754	2.68	0.18
2002	1,775,404	2.76	0.20
2003	1,767,740	2.86	0.23
2004	1,759,693	2.95	0.25
2005	1,746,587	2.80	0.26
2006	1,703,566	2.65	0.24
2007	1,660,699	2.63	0.25
2008	1,618,530	2.64	0.25
2009	1,674,441	2.87	0.28
2010	1,730,352	2.92	0.29
2011	1,786,263	2.91	0.28
2012	1,842,174	2.94	0.26
2013	1,898,085	2.97	0.27
2014	1,953,995	2.97	0.28
2015	2,009,906	2.94	0.30
2016	2,009,906	2.79	0.30
2017	2,009,906	2.67	0.29

Source: (a) ABS 2008b; Includes stocks not containing HFC refrigerants

Table 4.33 Halocarbons: estimated stock and emissions: refrigerated portable air conditioners

Year	Refrigerated portable system stock[(a) (b)]	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	160,971	0.00	0.00
1996	155,350	0.00	0.00
1997	149,730	0.01	0.00
1998	144,109	0.01	0.00
1999	138,488	0.02	0.00
2000	141,998	0.03	0.00
2001	145,508	0.04	0.00

Year	Refrigerated portable system stock[(a) (b)]	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
2002	149,019	0.05	0.00
2003	177,029	0.09	0.00
2004	205,040	0.12	0.01
2005	233,050	0.14	0.01
2006	215,967	0.14	0.01
2007	198,883	0.21	0.01
2008	181,800	0.27	0.02
2009	270,000	0.36	0.03
2010	358,200	0.50	0.03
2011	446,400	0.58	0.04
2012	446,400	0.60	0.04
2013	446,400	0.64	0.05
2014	446,400	0.69	0.06
2015	446,400	0.73	0.07
2016	446,400	0.75	0.08
2017	446,400	0.79	0.08

Source: (a) ABS 2008b; Includes stocks not containing HFC refrigerants.

Mobile air-conditioning (Passenger Cars)

Emissions from the use of air conditioners in passenger cars and light commercial vehicles (vehicles under 3.5 tonnes gross vehicle mass) are also estimated on a bottom-up basis. Data on the stock of motor vehicles obtained from the ABS *Motor Vehicle Census* (ABS 2018) have been used to construct a capital stock model. In Table 4.34 the stock of light vehicles, the stock of HFC gas contained in motor vehicle air-conditioners and the associated emissions are reported. It is assumed that all new units manufactured from 1995 onwards contain HFC-134a.

Table 4.34 Halocarbons: estimated stock and emissions: light vehicle air conditioners

Year	Light vehicle stocks [(a)]	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	9,710,640	0.56	0.05
1996	10,106,055	1.00	0.14
1997	10,249,706	1.41	0.22
1998	10,438,519	1.90	0.28
1999	10,735,002	2.18	0.34
2000	11,103,805	2.92	0.33
2001	11,441,871	3.49	0.47
2002	11,722,502	4.03	0.58
2003	12,017,165	4.63	0.68
2004	12,329,726	5.10	0.77
2005	12,701,059	5.67	0.83
2006	13,168,195	6.06	0.84
2007	13,453,049	6.30	1.01
2008	13,803,497	6.52	1.07

Year	Light vehicle stocks [(a)]	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
2009	14,121,275	6.54	1.26
2010	14,756,042	6.72	1.22
2011	15,029,781	6.76	1.23
2012	15,395,828	6.93	1.17
2013	15,797,245	7.01	1.22
2014	16,148,719	6.92	1.32
2015	16,450,349	6.87	1.41
2016	16,798,405	6.80	1.41
2017	17,146,500	6.80	1.40

Source: (a) ABS 2017; Includes stocks not containing HFC refrigerants

The stock of gas has been compiled using the ABS data on light vehicle stocks, assumptions about proportions of each vintage with air-conditioning and an average charge per unit of 0.810 kg of HFC-134a (derived from import data). Assumptions needed on the percentage of pre-1995 vehicles retrofitted with HFC-134a units to estimate an addition to the stock of gas have been taken from Burnbank 2002.

Analysis has shown that the charge in pre-filled units does not significantly differ between model years in the fleet, indicating that despite a general trend of increasing vehicle sizes, there is not an increase in air-conditioning equipment charge due to being offset by more efficient equipment.

Equipment disposals are based on the IPCC default average life-span of 12 years with the first units of each vintage retiring after 5 years of operation. Under these assumptions, the last units of each vintage would be retired after 19 years. It is assumed that between 1995 and 2000, an initial base assumption that 40 per cent of the remaining charge contained in disposed units is recovered for destruction. From 2000 onwards, the assumed base rate of recovery is assumed to grow at 1 per cent per year. The quantity of gas not recovered is emitted to the atmosphere at disposal. These assumptions are consistent with Burnbank 2002. Actual recovery for destruction is estimated by calibrating the results of these assumptions with data on actual total recovery obtained for destruction from RRA.

Mobile air conditioning (heavy vehicles)

This source category comprises emissions from air conditioning units in vehicles over 3.5 tonnes gross vehicle mass.

The quantities of imported gas are allocated to heavy vehicle air conditioning on the basis of pre-charged equipment as reported under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas required for loss replenishment needs is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

A mix of country specific and IPCC default leakage rates are applied to each gas vintage calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 12.5 years and the assumption that gas losses are replenished after every 2 years of a unit's life. The first disposals of gas occur after 5 years of operation continuing until the last units are retired after 20 years. Upon disposal, a base calculation of 8 per cent of retiring gas in each year is recovered for destruction. Actual recovery for destruction is estimated by calibrating the results of these assumptions with data on actual total recovery obtained for destruction from RRA.

Table 4.35 Halocarbons: estimated stock and emissions: heavy vehicle air conditioners

Year	Imports of gas ($Mt CO_2$-e)	Stock of gas in operating equipment ($Mt CO_2$-e)	Emissions ($Mt CO_2$-e)
1995	0.00	0.00	0.00
1996	0.01	0.01	0.00
1997	0.02	0.03	0.00
1998	0.05	0.07	0.01
1999	0.08	0.15	0.01
2000	0.06	0.19	0.02
2001	0.09	0.26	0.02
2002	0.11	0.34	0.03
2003	0.12	0.42	0.04
2004	0.15	0.52	0.05
2005	0.19	0.64	0.07
2006	0.12	0.68	0.07
2007	0.20	0.79	0.09
2008	0.30	0.99	0.11
2009	0.29	1.13	0.15
2010	0.32	1.28	0.16
2011	0.30	1.39	0.18
2012	0.34	1.54	0.18
2013	0.29	1.61	0.21
2014	0.37	1.74	0.24
2015	0.42	1.87	0.28
2016	0.32	1.88	0.29
2017	0.31	1.88	0.30

Source: DoEE – HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003)

Transport refrigeration

Transport refrigeration comprises vehicle and self-powered refrigeration units used in commercial vehicles.

Quantities of imported gas are allocated to transport refrigeration on the basis of pre-charged equipment as reported under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas demand for loss replenishment is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

A mix of country-specific and IPCC default leakage rates are applied to each gas vintage calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 7.5 years and the assumption that gas losses are replenished after every 2 years of a unit's life up to the year of disposal. It is assumed that the first disposals of gas occur after 5 years of operation and continue until the last units are retired after 10 years. Upon disposal, a base assumption of 9 per cent of retiring gas is assumed to be recovered for destruction.

Table 4.36 Halocarbons: estimated stock and emissions: transport refrigeration

Year	Imports of gas ($Mt\ CO_2$-e)	Stock of gas in operating equipment ($Mt\ CO_2$-e)	Emissions ($Mt\ CO_2$-e)
1995	0.00	0.00	0.00
1996	0.00	0.00	0.00
1997	0.01	0.01	0.00
1998	0.05	0.05	0.01
1999	0.10	0.13	0.02
2000	0.07	0.17	0.03
2001	0.10	0.22	0.05
2002	0.13	0.30	0.06
2003	0.14	0.35	0.08
2004	0.18	0.42	0.10
2005	0.25	0.54	0.13
2006	0.16	0.56	0.14
2007	0.24	0.62	0.17
2008	0.41	0.82	0.21
2009	0.39	0.92	0.28
2010	0.43	1.03	0.30
2011	0.40	1.10	0.33
2012	0.43	1.19	0.32
2013	0.39	1.19	0.37
2014	0.52	1.28	0.42
2015	0.59	1.37	0.47
2016	0.45	1.33	0.47
2017	0.45	1.29	0.47

Source: DoEE – HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003).

Commercial refrigeration

Commercial refrigeration comprises stand-alone, medium and large and industrial refrigeration units and is the most significant user of synthetic gases in Australia.

The quantities of imported gas are allocated to commercial refrigeration on the basis of pre-charged equipment imports and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas required for loss replenishment needs is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

A mix of country-specific and IPCC default leakage rates are applied to each gas vintage calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 12.5 years for stand-alone units, 11 years for medium and large applications and 22.5 years for industrial systems and the Department's assumption that gas losses are replenished after every 2 years of a unit's life. It is assumed that the first disposals of gas occur after 5 years of operation and continue until the last units are retired after 20 years for stand-alone units, 17 years for medium and large applications and 40 years for industrial systems. Upon disposal, a base assumption of 10 per cent of retiring gas is recovered for destruction.

Table 4.37 Halocarbons: estimated stock and emissions: commercial refrigeration

Year	Imports of gas ($Mt\ CO_2$-e)	Stock of gas in operating equipment ($Mt\ CO_2$-e)	Emissions ($Mt\ CO_2$-e)
1995	0.01	0.01	0.00
1996	0.02	0.03	0.00
1997	0.17	0.18	0.02
1998	0.58	0.69	0.07
1999	1.19	1.69	0.19
2000	0.75	2.17	0.27
2001	1.14	2.93	0.37
2002	1.45	3.90	0.48
2003	1.54	4.80	0.64
2004	1.96	5.96	0.79
2005	2.70	7.58	1.06
2006	1.68	8.13	1.11
2007	2.69	9.40	1.40
2008	4.52	12.15	1.74
2009	4.49	14.16	2.43
2010	4.77	16.20	2.68
2011	4.27	17.37	3.03
2012	4.76	19.06	2.98
2013	3.85	19.49	3.33
2014	5.48	21.08	3.79
2015	6.18	22.69	4.41
2016	4.14	22.15	4.51
2017	3.72	21.20	4.51

Source: DoEE – HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003)

Commercial air conditioning

Commercial air conditioning covers the use of chiller units used in commercial buildings.

Quantities of imported gas are allocated to commercial refrigeration on the basis of pre-charged equipment imports and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas demand for loss replenishment is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

A mix of country-specific and IPCC default leakage rates are applied to each gas vintage calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 22.5 years and the assumption that gas losses are replenished after every 2 years of a unit's life up to the year of disposal. The first disposals of gas occur after 5 years of operation continuing until the last units are retired after 40 years. Upon disposal, a base assumption of 16 per cent of retiring gas is recovered for destruction.

Table 4.38 Halocarbons: estimated stock and emissions: commercial air conditioners

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	0.00	0.00	0.00
1996	0.01	0.01	0.00
1997	0.01	0.03	0.00
1998	0.02	0.05	0.00
1999	0.03	0.08	0.00
2000	0.03	0.10	0.01
2001	0.04	0.14	0.01
2002	0.05	0.18	0.01
2003	0.06	0.22	0.01
2004	0.07	0.27	0.02
2005	0.10	0.36	0.02
2006	0.07	0.40	0.02
2007	0.09	0.46	0.03
2008	0.22	0.64	0.04
2009	0.27	0.85	0.06
2010	0.21	0.98	0.07
2011	0.22	1.12	0.08
2012	0.30	1.34	0.09
2013	0.70	1.91	0.12
2014	0.80	2.54	0.17
2015	1.04	3.33	0.24
2016	1.33	4.35	0.31
2017	1.14	5.11	0.39

Source: DoEE – HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003).

Foam Blowing Agents (2.F.2)

The quantities of imported gas are allocated to foam on the basis of a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning.

IPCC default leakage rates are applied to each gas vintage calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 20 years. The first disposals of gas occur after 5 years of operation continuing until the last units are retired after 35 years. There is no recovery or replenishment assumed in foams.

Foams are given emission profiles depending on the foam type (open cell or closed cell). Open cell foams are assumed to be 100 per cent emissive in the year of manufacture. Closed cell foams are assumed to emit a portion of their total HFC content upon manufacture, a portion at a constant rate over the lifetime of the foam, and a portion at disposal. Emissions from both open and closed cell foams are estimated as one source using the vintage stock model with an average initial charge and annual operation leakage rate.

Table 4.39 Halocarbons: estimated stock and emissions: foam

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	-	-	-
1996	-	-	-
1997	0.00	0.00	0.00
1998	0.02	0.01	0.01
1999	0.04	0.02	0.02
2000	0.01	0.03	0.01
2001	0.03	0.04	0.02
2002	0.03	0.05	0.02
2003	0.03	0.06	0.02
2004	0.04	0.07	0.03
2005	0.07	0.10	0.04
2006	0.02	0.10	0.01
2007	0.06	0.12	0.04
2008	0.10	0.15	0.06
2009	0.09	0.18	0.06
2010	0.07	0.21	0.05
2011	0.07	0.22	0.05
2012	0.06	0.24	0.05
2013	0.04	0.24	0.03
2014	0.08	0.26	0.06
2015	0.10	0.29	0.07
2016	-	0.27	0.01
2017	0.00	0.26	0.02

Source: DoEE – HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003).

Fire Protection (2.F.3)

The quantities of imported gas are allocated to fire extinguishers on the basis of pre-charged equipment imports and a proportion of bulk gas adjusted for gas demand in domestic refrigeration and air conditioning and mobile air conditioning. Once the gas required for loss replenishment needs is satisfied, the remaining bulk gas is allocated to charging new locally produced units.

IPCC default leakage rates are applied to each gas vintage calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station. Quantities of residual gas disposed in each vintage are based on the IPCC average equipment life of 10 years and the assumption that gas losses are replenished after every 2 years of a unit's life. The first disposals of gas occur after 5 years of operation continuing until the last units are retired after 15 years. Upon disposal, approximately 26 per cent of retiring gas in each year is recovered for destruction.

The UNFCCC expert review of Australia's 2008 submission recommended that the completeness of the *industrial processes and product use* estimates be improved by inclusion of estimates of emissions from PFC use in fire extinguishers. In response, the Australian Fire Protection Association (FPA) was consulted and they confirmed that the ozone depleting or synthetic greenhouse fire fighting gases most common in Australia are: FE 227 (HFC 227ea), FM 200 (HFC 227ea), NAF-S-III (HCFC Blend A) and NAF-P-III (HCFC Blend C). The use of other gases is considered quite rare. On this basis, PFC use in fire extinguishers is considered to be 'Not Occurring'.

Table 4.40 Halocarbons: estimated stock and emissions: fire protection equipment

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	-	-	-
1996	-	-	-
1997	0.00	0.00	0.00
1998	0.02	0.02	0.00
1999	0.04	0.05	0.00
2000	0.02	0.07	0.00
2001	0.03	0.10	0.00
2002	0.04	0.12	0.01
2003	0.04	0.15	0.01
2004	0.05	0.19	0.01
2005	0.07	0.24	0.02
2006	0.03	0.25	0.02
2007	0.07	0.30	0.02
2008	0.11	0.38	0.03
2009	0.11	0.45	0.03
2010	0.10	0.51	0.04
2011	0.09	0.55	0.04
2012	0.09	0.59	0.04
2013	0.07	0.60	0.05
2014	0.11	0.64	0.06
2015	0.13	0.69	0.06
2016	0.04	0.65	0.06
2017	0.04	0.61	0.06

Source: DoEE – HFC import data collected under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003).

Aerosols/Metered Dose Inhalers and Solvents (2.F.4 and 2.F.5)

Emissions from these sectors come from two sources: product use and fugitive emissions associated with product manufacture. Emissions from solvent and aerosol product use can be assumed to be 100 per cent of the charge size (e.g. 100 per cent of consumption over the life of the product).

The quantities of bulk gas imported into Australia and allocated for use in aerosols and solvents is based on the proportion of reported end use adjusted for gas requirements in domestic refrigerator and air conditioning and mobile air conditioning. There are no imports of pre-charged equipment in Australia and no replenishment is assumed to occur. Therefore all gas imported in bulk goes into charging domestically produced stock.

The complete charge of gas from an aerosol application is assumed to be lost at a base rate of 50 per cent per year, calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station, with any residual charge being completely emitted in the third year of operation.

There is no domestic production of metered dose inhalers (MDIs) in Australia. *Imports of metered dose inhalers containing HFCs* are not covered by the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003) *so that data on HFC consumption of metered dose inhalers cannot be derived from this source.* Consequently, emissions of HFCs from the use of metered dose inhalers are estimated on a bottom up basis. Estimates of the imports of gas contained in metered dose inhalers is based on information supplied by SEWPaC on the number of MDIs imported into Australia in 2009 and a per-capita based estimation of imports up to that year. Assumptions about the penetration of HFC propellants in imported MDIs are based on information in Burnbank 2002. On average, each imported unit is pre-charged with 14 grams of HFC-134a based on information supplied from SEWPaC (Annie Gabriel, pers. comm.).

Emissions from MDIs are estimated according to the same assumptions used for aerosols and solvents.

Table 4.41 shows the growth in imports and the bank of HFC in metered dose inhalers along with the associated emissions from this bank.

Table 4.41 Halocarbons: estimated stock and emissions: metered dose inhalers

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)	Emissions (Mt CO_2-e)
1998	0.01	0.01	0.00
1999	0.03	0.03	0.01
2000	0.04	0.04	0.03
2001	0.06	0.06	0.04
2002	0.08	0.08	0.06
2003	0.09	0.10	0.08
2004	0.11	0.12	0.09
2005	0.13	0.14	0.11
2006	0.15	0.17	0.12
2007	0.17	0.18	0.15
2008	0.19	0.20	0.17
2009	0.21	0.21	0.20
2010	0.21	0.21	0.20
2011	0.21	0.22	0.21
2012	0.15	0.18	0.19

Year	Imports of gas ($Mt CO_2$-e)	Stock of gas in operating equipment ($Mt CO_2$-e)	Emissions ($Mt CO_2$-e)
2013	0.14	0.15	0.17
2014	0.13	0.14	0.15
2015	0.12	0.12	0.14
2016	0.12	0.12	0.13
2017	0.13	0.12	0.12

Source: DoEE Estimates.

Table 4.42 shows the growth in imports and the bank of HFC in aerosols and solvents along with the associated emissions from this bank.

Table 4.42 Halocarbons: estimated stock and emissions: aerosols/solvents

Year	Imports of gas ($Mt CO_2$-e)	Stock of gas in operating equipment ($Mt CO_2$-e)	Emissions ($Mt CO_2$-e)
1998	0.02	0.02	0.01
1999	0.04	0.03	0.02
2000	0.02	0.02	0.03
2001	0.03	0.03	0.03
2002	0.03	0.03	0.03
2003	0.04	0.04	0.04
2004	0.04	0.04	0.04
2005	0.08	0.07	0.05
2006	0.02	0.03	0.06
2007	0.07	0.06	0.04
2008	0.11	0.10	0.07
2009	0.11	0.09	0.11
2010	0.08	0.08	0.10
2011	0.08	0.07	0.09
2012	0.07	0.06	0.07
2013	0.05	0.05	0.07
2014	0.09	0.07	0.06
2015	0.11	0.09	0.09
2016	-	0.01	0.07
2017	0.20	0.14	0.08

Source: DoEE Estimates.

4.9 Source Category 2.G Other product manufacture and use

Electrical Equipment (2.G.1)

Australia has implemented the IPCC tier 2a method to estimate emissions of SF_6 from the electricity supply and distribution network.

Equation 3.16
Total Emissions = Manufacturing Emissions + Installation Emissions
+ Use Emissions + Disposal Emissions

Australia has chosen this method in accordance with the IPCC *good practice guidance* decision tree because:

SF_6 is used in electrical equipment in Australia;

This is not a key source for Australia; and

Activity data and EFs are available from data reported under the NGER System.

Country specific emission factor (use of equipment)

With the availability of facility-level leakage rates from 2010 onwards under the NGER System, Australia has developed a country-specific EF for the operation of electricity supply and distribution equipment.

A base country-specific EF has been estimated using data obtained from over 300 facilities reporting under the NGER System estimated consistent with the IPCC tier 3b method (IPCC GPG 3.56). This base factor is then calibrated each year from 2010 onwards in line with atmospheric SF6 concentrations measured at the CSIRO Cape Grim monitoring station.

Since the 2009 reporting year, amendments have been made to the *National Greenhouse and Energy Reporting Measurement Determination 2008* (Cwlth), which provide for utilities to estimate their emissions from their own data using mass-balance and 'top-up' approaches.

Under these approaches, surveyed utilities track their total consumption of SF_6 for refilling of equipment, the total nameplate capacity of their equipment, the quantity of SF_6 recovered from retiring equipment, and the nameplate capacity of their retiring equipment in the principle method. The approaches are consistent with those set out in the *Electricity Networks Association Industry Guideline for SF_6 Management,* ENA Doc 022-2008.

For the reporting year 2010, 15 companies, with stocks of 5.2 Mt of SF_6 as CO_2-e, elected to utilise one of the new EF methods to estimate losses, including the two largest users of SF_6 in Australia.

The weighted average emission rate derived from these 15 NGER reports is estimated at 0.0078 tonnes of SF_6 per tonne of stock of SF_6 per year.

In 2011, the average emission rate derived from these 15 NGER reporters (with stocks of 5.2 Mt in 2011) is estimated at 0.01 tonnes of SF_6 per tonne of stock of SF_6 per year.

The fluctuation in leakage rates between to two reporting years is attributed to differing service intervals and equipment retirement and replacement schedules. This fluctuation has been smoothed by taking a weighted average of the two years leakage rates to derive a leakage rate of 0.0089 tonnes of SF_6 per tonne of stock of SF_6 per year.

Around 40 per cent of the national SF_6 stock is contained in equipment operated by companies that elected to utilise their own data on emission rates to estimate their SF_6 emissions.

The reported EF obtained from facilities under the NGER System incorporates emissions from the operation of equipment and also emissions from disposal. A separate estimate of emissions from disposal is not available. Nonetheless, emissions from disposal are included with the EF from operation or use of the equipment – refer to *Energy Networks Australia, ENA Industry Guidelines for* SF_6 *Management*, ENA Doc 022-2008.

Calibration of annual leakage rate with atmospheric observations

As with annual EFs for HFCs., the annual loss SF_6 from 2010 onwards has been adjusted in line with changes in atmospheric concentrations measured at the Cape Grim monitoring station in Tasmania (CSIRO 2018). CSIRO has used inverse modelling techniques to derive an estimate of national SF_6 emissions based on atmospheric measurements of SF_6 concentrations. The base EF is indexed to the changes in the national estimate developed by CSIRO.

SF_6 is also considered to be an ideal gas to use inverse modelling techniques to derive national estimates, as there are no sinks for SF_6 and therefore changes in concentrations reflect changes in emissions.

Inventory uncertainty for SF_6 emissions is estimated at ±30 per cent which is comparable with uncertainty estimated for the modelled emissions by CSIRO which averages at ±28 per cent.

The calibration of leakage rates with atmospheric observation data ensures the trend in atmospheric observations is replicated in the inventory. As the inventory model is based on assumptions about changes in capital stocks that are applied consistently year on year, the inverse modelled emission estimates provide a check on these assumptions. The strength of this approach is that it enables the inventory estimates to better reflect improvements in industry practice in terms of gas handling, equipment maintenance and decommissioning.

Table 4.43 shows the annual leakage rate applied for each inventory year from 2010 onwards. As national emission estimates derived from atmospheric observations show a degree of volatility, a 3-year average has been used to derive the adjusted annual leakage rate for each inventory year. For the most recent inventory year, as CSIRO data are not yet available, the previous inventory year's leakage rate is retained. This factor will be revised based on observation data in the next submission.

Industrial Processes and Product Use

Table 4.43 Annual SF_6 leakage rates derived from CSIRO estimates

Inventory year	CSIRO national SF_6 emissions estimate (t SF_6)	Annual leakage rate (t SF_6/t stock)
2010	25	0.0085
2011	24	0.0082
2012	22	0.0086
2013	22	0.0080
2014	17	0.0088
2015	20	0.0085
2016	18	0.0093
2017[a]	18	0.0093

Source: CSIRO 2018

a) 2017 values not yet available - have been held constant on 2016 levels.

This factor has been applied to the total stock of SF_6 gas in the electricity supply and distribution network in accordance with the decision tree at section 1.4.

Stock of SF_6 *held by electrical equipment users*

Data on SF_6 stocks held by users of electrical equipment for 2009 onwards included in the National Inventory

Report are taken from data gas stock data reported under the NGER System.

Historical stocks of gas have been derived based on a consideration of equipment stock changes between 1972 and 2008. Critical to this process is a consideration of equipment lifetimes in Australia.

There is no comprehensive data available to the Department on the retirement of equipment using SF_6 in Australia. However, evidence on the retirements of circuit breaker stock that utilise SF_6 can be obtained from data published by Transgrid – the major network in the largest State, New South Wales in *Transgrid, Network Management Plan 2011*, February 2011. The characteristics of Trangrid's operations are likely to be similar to those of other large utilities in Australia and mainly reflect the operation of high voltage transmission lines.

Figure 4.10 Illustration of Transgrid's network

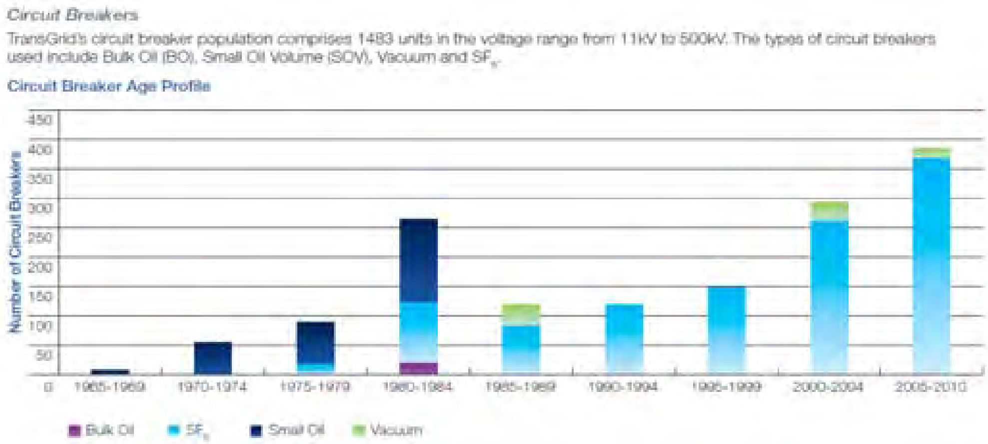
Source: Transgrid Network Management Plan 2011-2016.

Confirmation of the general age profile of Transgrid's circuit breaker assets is provided in the Transgrid *Network Management Plan 2011, page 45.*

According to Transgrid 2011 the first time SF_6 was used in equipment in Australia was in the period 1975-79.

Analysis of the change in the age profile of the stock of circuit breakers using SF_6 based on changes in the asset register between 2002 and 2010 provides a basis for an estimated retirement rate of around 0.4 per cent of the stock each year since 2003 (i.e. after equipment reached approximately 28 years). Transgrid also identifies plans to phase out certain classes of circuit breakers using SF_6 over the next decade. Based on Transgrid's announced plans (Transgrid 2011, page 59), the retirement rate will increase to around 1 per cent of stock by 2019.

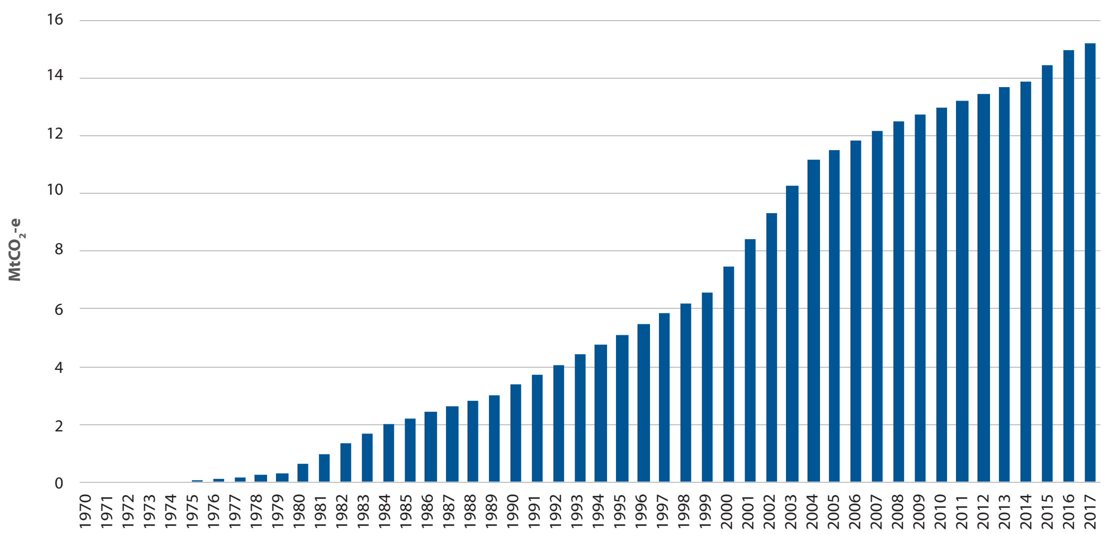
Figure 4.11 Age profile of Transgrid's circuit breaker assets, by type of equipment



The 2006 IPCC *Guidelines* provide additional relevant information in relation to typical equipment lifetimes. In particular, the 2006 IPCC *Guidelines* indicate that equipment lifetimes containing SF_6 are 'more than 30 to 40 years'. Providing a default factor of >35 years, the range of likely outcomes reported by the IPCC is -10 per cent – +40 per cent (2006 IPCC Volume 3, Chapter 8, page 8.21) – i.e. retirement is most likely to occur within the range of 31 years to 49 years.

Taking into account the above information, the oldest equipment containing SF_6 in the Transgrid stock in 2020 is expected to be 40 years old.

Figure 4.12 Estimated stock of SF_6 in Australia 1970-2016 (tonnes of CO_2-e)



Estimation of emissions of SF6 from the manufacture of switchgear and circuit breakers in Australia.

In addition to emissions from the operation and disposal of electricity supply and distribution equipment, Australia also estimates emissions associated with the manufacture of electricity supply and distribution equipment.

Many major international suppliers of electrical equipment operate in Australia – ABB, Siemens, Mitsubishi etc. Currently no data are collected under the NGER System from the manufacturers of electrical equipment in Australia about their use of SF_6 or their emissions of SF_6. In addition, no information is available at this time to indicate the quantities of gas imported to fill new equipment in Australia prior to sale relative to the quantities of gas imported in pre-charged equipment.

To prepare an estimate of emissions from this source requires an assumption in relation to the proportion of pre-charged imported equipment relative to equipment charged with gas domestically using imported gas.

For these estimates it is assumed that half of all equipment used in Australia was either manufactured in Australia or that, if imported, the equipment was charged with SF_6 in Australia. To proxy this outcome, the amount of SF_6 required for charging of new equipment in Australia was assumed to be equal to half of the sum of the change in stock of SF_6 in use recorded during the year and estimated emissions from use in stock. The application of this assumption yields an estimate of 176,626 tonnes of SF_6 in CO_2-e filled in new electrical equipment in 2016.

The IPCC 2006 does not report a default emission rate for global manufacturing. It does report factors taken from studies in Europe, which put leakage rates between 7 per cent for sealed pressure units and 8.5 per cent for closed pressure units. Much higher rates are assumed for Japan (29 per cent).

On the other hand, New Zealand reports a leakage rate associated with charging of units during manufacturing in 2009 of 0.79 per cent. The major manufacturer of this equipment in New Zealand, ABB, is also a significant supplier in Australia and, as Australian and New Zealand economies are highly integrated and reflect related political and cultural histories, it could be appropriate to consider the country-specific data from New Zealand.

Given the range of factors available, Australia has assumed that the IPCC 2006 rates identified for European closed pressure units, which lie around the mid-point of the range, are applicable in Australia from 1996 onwards and the pre-96 GPG factor of 15 per cent prior to 1996.

The application of this leakage rate to Australia's derived estimate of 176,626 tonnes of SF_6 in CO_2-e filled into new equipment results in emissions of 15,013 tonnes of CO_2-e in 2016. While this estimate is only a small proportion of total emissions from electricity supply and distribution, it is important to ensure that Australia's estimate of emissions is complete.

Time series consistency

The construction of a time series of emissions estimates requires:

a. estimates of stocks of SF_6 over time;

b. EFs over time; and

c. emissions from disposals of equipment containing SF_6.

Time series of stocks of SF_6 1972-2017

Data on stocks of SF_6 are not available prior to 2009. To fill the gap, a time series of the stock of SF_6 was derived from:

i) Data on the age profile of equipment

Data on the age profile of the circuit breaker stock using SF_6 was constructed from data on circuit breakers used by Transgrid – the major network in the largest State, New South Wales (*Transgrid, Network Management Plan 2011*, February 2011). Information is available by manufacturer, type of unit (SF_6 or oil), marquee and date of installation. SF_6 was used in equipment in Australia for the first time in the period 1975-79.

ii) Retirements

Retirements of circuit breaker stock using SF_6 were calculated from the change in the age profile of the stock based on changes in the asset register between 2002 and 2010. Retirements are estimated at around 0.4 per cent of the stock for each year since 2003 (after equipment reached approximately 28 years) with the retirement rate reaching 1 per cent of stock by 2020.

iii) additions of new electrical equipment containing SF_6

Estimates of the additions to the stock of circuit breakers using SF_6 were determined from the change in the stock of circuit breakers and estimated retirements.

New equipment NC = observed (i.e., net) increase in the total equipment NC

+ decreases in the equipment NC due to retirements.

iv) extrapolation of Transgrid age profile and management regime to the rest of Australia

The time profile of the stock of Transgrid's circuit breakers was used to derive an estimate of the stock of SF_6 held by Transgrid using the application of a constant assumed charge per circuit breaker unit. Estimates of a time series of stock of SF_6 for Australia for 1990-2008 were derived by splicing the stock of SF_6 held by Transgrid to the national stock of SF_6 held in electrical equipment in 2009 according to data obtained from the NGER System. This approach is consistent with the approaches described in the IPCC GPG for extrapolation of data to ensure time series consistency.

Emission factors 1972-2017

The IPCC GPG notes that it is not good practice to apply recently calculated EFs to leakages from earlier periods (IPCC GPG 3.60), (2006 IPCC volume 3, 8.20). In the absence of country specific information, Australia has developed a time series of EFs for use of electrical equipment derived from the following assumptions:

a) application of the IPCC GPG global default factor for 1990-1995 of 5 per cent (IPCC GPG 3.58);
b) application of IPCC GPG global default factor for the year 2000 of 2 per cent (IPCC GPG 3.58);
c) country-specific factor for 2009 onwards – 0.89 per cent adjusted according to inverse modelled estimates in CSIRO 2018;
d) interpolation of EFs between the above point estimates;
e) the above emission rates include disposal emissions.

In the absence of country specific information, Australia has developed a time series of EFs for manufacture or on-site filling of imported electrical equipment derived from the following assumptions:

f) application of the IPCC GPG global default factor for 1990-1995 of 15 per cent (IPCC GPG 3.58);

g) application of IPCC GPG global default factor for the year 2000 of 8.5 per cent per cent (IPCC 2006 Table 8.3);

The decline in leakage rates over time reflects improved awareness and training of personnel in the handling of SF_6 as reflected in industry initiatives both globally, through CIGRE, or nationally – for example as reflected in the development of an Australian Standard AS2791/1996, *Use and handling of* SF_6 *in high voltage switchgear and control gear* (1996) and industry guidelines as in the Energy Networks of Australia, *Industry Guideline for* SF_6 *Management* (2008).

Emissions 1972-2017

The stock of SF_6 and SF_6 emissions between 1972 and 2017 are presented in Table 4.44.

Table 4.44 Stocks and emissions of SF_6: Australia: 1972-2017

Year	Stock of SF_6 in electrical equipment				Manufacturing of electrical equipment			TOTAL
	National stock		Emission factor	Emissions	Quantity	Leakage rate	Emissions	Emissions
	t CO_2-e	per cent growth	t/t	t CO_2-e	t CO_2-e	t/t	t CO_2-e	t CO_2-e
1972	-	0.0500	-	0.1500				
1973	-	0.0500	-	0.1500				
1974	-	0.0500	-	0.1500				
1975	57,675	0.0500	2,884	30,279	0.1500	4,542	7,426	
1976	115,349	100.0	0.0500	5,767	31,721	0.1500	4,758	10,526
1977	173,024	50.0	0.0500	8,651	33,163	0.1500	4,974	13,626
1978	230,698	33.3	0.0500	11,535	34,605	0.1500	5,191	16,726
1979	288,373	25.0	0.0500	14,419	36,047	0.1500	5,407	19,826
1980	634,420	120.0	0.0500	31,721	188,884	0.1500	28,333	60,054
1981	980,467	54.5	0.0500	49,023	197,535	0.1500	29,630	78,654
1982	1,326,514	35.3	0.0500	66,326	206,186	0.1500	30,928	97,254
1983	1,672,561	26.1	0.0500	83,628	214,838	0.1500	32,226	115,854
1984	2,018,608	20.7	0.0500	100,930	223,489	0.1500	33,523	134,454
1985	2,220,469	10.0	0.0500	111,023	156,442	0.1500	23,466	134,490
1986	2,422,330	9.1	0.0500	121,117	161,489	0.1500	24,223	145,340
1987	2,624,191	8.3	0.0500	131,210	166,535	0.1500	24,980	156,190
1988	2,826,052	7.7	0.0500	141,303	171,582	0.1500	25,737	167,040
1989	3,027,913	7.1	0.0500	151,396	176,628	0.1500	26,494	177,890
1990	3,373,960	11.4	0.0500	168,698	257,373	0.1500	38,606	207,304
1991	3,720,007	10.3	0.0500	186,000	266,024	0.1500	39,904	225,904
1992	4,066,054	9.3	0.0500	203,303	274,675	0.1500	41,201	244,504
1993	4,412,101	8.5	0.0500	220,605	283,326	0.1500	42,499	263,104
1994	4,758,149	7.8	0.0500	237,907	291,977	0.1500	43,797	281,704

Year	Stock of SF_6 in electrical equipment				Manufacturing of electrical equipment			TOTAL
	National stock		Emission factor	Emissions	Quantity	Leakage rate	Emissions	Emissions
	t CO_2-e	per cent growth	t/t	t CO_2-e	t CO_2-e	t/t	t CO_2-e	t CO_2-e
1995	5,118,614	7.6	0.0500	255,931	308,198	0.1500	46,230	302,160
1996	5,479,080	7.0	0.0440	241,080	300,773	0.0850	25,566	266,645
1997	5,839,546	6.6	0.0380	221,903	291,184	0.0850	24,751	246,653
1998	6,200,012	6.2	0.0320	198,400	279,433	0.0850	23,752	222,152
1999	6,560,478	5.8	0.0260	170,572	265,519	0.0850	22,569	193,142
2000	7,483,270	14.1	0.0200	149,665	536,229	0.0850	45,579	195,245
2001	8,406,063	12.3	0.0188	157,786	540,289	0.0850	45,925	203,711
2002	9,328,855	11.0	0.0175	163,637	543,215	0.0850	46,173	209,811
2003	10,251,647	9.9	0.0163	167,220	545,006	0.0850	46,326	213,545
2004	11,174,440	9.0	0.0151	168,533	545,663	0.0850	46,381	214,914
2005	11,506,068	3.0	0.0139	159,387	245,508	0.0850	20,868	180,256
2006	11,837,697	2.9	0.0126	149,427	240,528	0.0850	20,445	169,872
2007	12,169,326	2.8	0.0114	138,651	235,140	0.0850	19,987	158,637
2008	12,500,954	2.7	0.0102	127,059	229,344	0.0850	19,494	146,553
2009	12,760,489	2.1	0.0089	114,008	186,772	0.0850	15,876	129,883
2010	13,001,364	2.1	0.0085	110,463	175,668	0.0850	14,932	125,394
2011	13,223,778	2.1	0.0082	109,070	165,742	0.0850	14,088	123,158
2012	13,446,193	2.1	0.0086	115,195	168,805	0.0850	14,348	129,544
2013	13,668,607	1.9	0.0080	109,477	165,946	0.0850	14,105	123,583
2014	13,891,022	1.6	0.0088	122,007	172,211	0.0850	14,638	136,645
2015	14,461,063	4.1	0.0085	122,707	346,374	0.0850	29,442	152,149
2016	14,977,118	3.6	0.0093	138,928	327,492	0.0850	27,837	166,765
2017	15,207,217	1.5	0.0093	141,063	185,581	0.0850	15,774	156,837

Other uses of SF_6 (2.G.2)

An estimate of SF_6 emissions from other applications including eye surgery, tracer gas studies, magnesium casting, plumbing services, tyre manufacture and industrial machinery equipment has been made on the basis of a per-capita emissions value derived from the National Inventory of New Zealand. An average per-capita emission rate of 0.001 tonne of SF_6 per person per year has been applied to Australia's total population to derive a time series of emissions from this source.

Australia commenced procurement of a number of Boeing E7A Wedgetail airborne early warning and control (AEWC) aircraft in 2010 with the sixth and final unit delivered in June 2014. The Wedgetail aircraft is one of the most advanced aircraft of its kind in operation. The IPCC Guidelines note that AEWC aircraft are a potential user and emitter of SF_6 gas where this gas is used as an insulating medium in high voltage radar units. The IPCC guidelines cite an emission factor referenced in Schwarz 2005. This emission factor is based upon the Boeing E-3A aircraft operating a large rotating radar unit. Importantly, it is noted that the radar units on these aircraft operate at voltages larger than 135kv. It is this high voltage operation that necessitates the use of SF_6 to prevent flashovers in antenna conductors. It is also noted in the reference that "All other radar systems for aircraft, be it ground or aircraft radar, primary or passive, are operated at lower voltages (up to 30 kV), so that no SF_6 is necessary, oil (silicone oil) sufficing".

The Boeing E-3A aircraft first entered service in the late 1970's. By contrast, Australia's E-7A wedgetail aircraft are a new advanced design and operate the modern Multi-Role Electronically Scanned Array (MESA) surveillance radars. These types of radar systems operate at lower voltages than the older type radar systems employed in the E-3A – http://www.ausairpower.net/aesa-intro.html.

Enquiries with Boeing, the manufacturer of the 737 airframe; Northrop Grumman, the manufacturer of the MESA radar and the Royal Australian Air Force who operate the aircraft have all confirmed that no SF_6 gas is used in any capacity in the Wedgetail aircraft.

N_2O from product uses (2.G.3)

Emissions of N_2O from aerosol products and anesthesia are based on production data provided by the industrial gas manufacturers (BOC and Air Liquide) up to the year 2008. From 2008 onwards, N_2O consumption is indexed to population growth. These data and the resultant emissions estimates are confidential and are included in the 2.B.2 Nitric acid production emissions.

From 2003 onwards, one of the two N_2O producing plants in Australia ceased production and imports of N_2O commenced. For 2003 onwards, N_2O emissions from product uses are estimated based on imports in addition to domestic production.

4.9.1 Uncertainties and Time Series consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to EFs or methodologies occur, a full time series recalculation is undertaken.

4.9.2 Source specific QA/QC

Source specific QA/QC focuses on a range of measures undertaken to ensure methods, EFs and activity data are selected and applied appropriately. Section 4.9.2.1 deals with the QA/QC measures associated with the consumption of halocarbons such as independent review, mass balance, sensitivity testing and independent verification. Section 4.9.2.2 focuses on specific QA/QC measures associated with SF_6 use in electricity supply and distribution.

This source category is also covered by the general QA/QC of the greenhouse gas inventory in Chapter 1.

4.9.2.1 Source specific QA/QC: consumption of halocarbons

Data are obtained by the Department from companies under licensing arrangements established under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003) and is subject to verification against known published sources (the Australian Bureau of Statistics data on imports of HFC-134a).

The Consumption of Halocarbons and SF_6 sector has been reviewed independently by an international expert (Tsaranu 2007). The review was undertaken applying the same principles governing regular UNFCCC inventory desktop reviews. The emissions model was reviewed previously by Burnbank consulting. The outputs of the domestic refrigeration and mobile air-conditioning components of the model have been cross-checked against those reported in Burnbank 2002 with close agreement between the two sets of estimates.

Mass balances

An additional comprehensive review of this source was undertaken during 2009 in which HFC balances were completed to ensure that:

- all imported gas in bulk and pre-charged equipment is assigned to an appropriate end-use category, and
- stock changes and emissions and gas destruction were fully tracked and accounted for.

The results of these allocation and stock balances are presented in Table 4.45.

Checks are undertaken to ensure that the sum of bulk gas demand for domestic production and replenishment of leaked gas equals total bulk imports. This check revealed an issue with the bulk gas allocation process in the previous submission which resulted in some bulk gas not being accounted for in charging domestically produced units or replenishing lost stock. Table 4.47 shows this new gas balance check.

Table 4.45 Halocarbons: balance sheet – allocations of imported gas (Mt CO_2-e)

	Backcast import data											Import data reported by SEWPaC												
Gas Imported	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Bulk gas imported	**0.07**	**1.93**	**1.95**	**2.17**	**2.78**	**3.39**	**3.99**	**4.60**	**5.21**	**5.82**	**6.42**	**7.03**	**6.31**	**6.01**	**7.10**	**8.29**	**7.84**	**7.27**	**7.52**	**7.52**	**9.00**	**10.12**	**8.03**	**7.60**
Gas imported in pre-charged equipment	0.04	0.16	0.22	0.30	0.39	0.48	0.69	0.89	1.07	1.27	1.47	1.48	1.15	3.38	4.07	4.24	4.87	4.95	5.45	4.47	5.16	5.19	5.43	5.89
Total gas imported	0.11	2.10	2.17	2.47	3.17	3.86	4.68	5.50	6.27	7.08	7.90	8.51	7.46	9.38	11.17	12.53	12.70	12.22	12.96	12.00	14.16	15.31	13.46	13.49
Allocations to end use																								
Transport refrigeration	-	0.00	0.00	0.01	0.05	0.10	0.07	0.10	0.13	0.14	0.18	0.25	0.16	0.24	0.41	0.39	0.43	0.40	0.43	0.39	0.52	0.59	0.45	0.45
Commercial refrigeration	-	0.01	0.02	0.17	0.58	1.19	0.75	1.14	1.45	1.54	1.96	2.70	1.68	2.69	4.52	4.49	4.77	4.27	4.76	3.85	5.48	6.18	4.14	3.72
Domestic refrigeration and freezers	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.13	0.15	0.15	0.16	0.11	0.18	0.17	0.17	0.13	0.13	0.11	0.10	0.09	0.12	0.04	0.05
Chillers	-	0.00	0.01	0.01	0.02	0.03	0.03	0.04	0.05	0.06	0.07	0.10	0.07	0.09	0.22	0.27	0.21	0.22	0.30	0.70	0.80	1.04	1.33	1.15
Refrigerated portable	-	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.04	0.04	0.03	0.01	0.08	0.08	0.11	0.17	0.12	0.07	0.09	0.11	0.10	0.10	0.12
Split systems	-	0.80	0.85	0.89	0.93	0.98	2.24	2.52	2.81	3.22	3.53	3.24	3.78	4.03	3.38	4.44	4.44	4.78	4.91	4.65	4.83	4.73	5.38	5.73
Packaged systems	-	0.55	0.58	0.58	0.58	0.58	0.25	0.26	0.28	0.33	0.34	0.12	0.10	0.23	0.27	0.53	0.35	0.28	0.30	0.30	0.30	0.29	0.16	0.18
Cars	-	0.61	0.58	0.64	0.76	0.63	1.05	1.04	1.12	1.28	1.24	1.39	1.22	1.27	1.31	1.30	1.41	1.27	1.38	1.32	1.24	1.38	1.37	1.42
Trucks	-	0.00	0.01	0.02	0.05	0.08	0.06	0.09	0.11	0.12	0.15	0.19	0.12	0.20	0.30	0.29	0.32	0.30	0.34	0.29	0.37	0.42	0.32	0.31
Foam	-	-	-	0.00	0.02	0.04	0.01	0.03	0.03	0.03	0.04	0.07	0.02	0.06	0.10	0.09	0.07	0.07	0.06	0.04	0.08	0.10	-	0.00
Aerosols/Solvents	-	-	0.00	0.01	0.03	0.07	0.06	0.09	0.11	0.13	0.16	0.21	0.17	0.24	0.30	0.32	0.30	0.29	0.22	0.19	0.22	0.23	0.12	0.33
Fire equipment	-	-	-	0.00	0.02	0.04	0.02	0.03	0.04	0.04	0.05	0.07	0.03	0.07	0.11	0.11	0.10	0.09	0.09	0.07	0.11	0.13	0.04	0.04
Total gas allocated	0.11	2.10	2.17	2.47	3.17	3.86	4.68	5.50	6.27	7.08	7.90	8.51	7.46	9.38	11.17	12.53	12.70	12.22	12.96	12.00	14.16	15.31	13.46	13.49
Balance against total gas imported	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.46 Halocarbons: Supply – use balance sheet (Mt CO_2-e)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gas supply	**0.11**	**2.10**	**2.17**	**2.47**	**3.17**	**3.86**	**4.68**	**5.50**	**6.27**	**7.08**	**7.90**	**8.51**	**7.46**	**9.38**	**11.17**	**12.53**	**12.70**	**12.22**	**12.96**	**12.00**	**14.16**	**15.31**	**13.46**	**13.49**
Pre-charged Imports	0.04	0.16	0.22	0.30	0.39	0.48	0.69	0.89	1.07	1.27	1.47	1.48	1.15	3.38	4.07	4.24	4.87	4.95	5.45	4.47	5.16	5.19	5.43	5.89
Bulk gas used in production & retrofit	0.07	1.93	1.95	2.17	2.74	3.25	3.36	3.98	4.24	4.83	5.11	5.72	4.55	4.55	4.70	5.88	4.28	4.11	3.60	3.96	4.75	5.55	2.62	2.72
Bulk gas used in replenishment	-	-	0.00	0.01	0.04	0.14	0.64	0.62	0.97	0.99	1.32	1.31	1.76	1.46	2.40	2.40	3.56	3.16	3.92	3.57	4.25	4.56	5.41	4.87
Gas use/losses	**0.11**	**2.10**	**2.17**	**2.47**	**3.17**	**3.86**	**4.68**	**5.50**	**6.27**	**7.08**	**7.90**	**8.51**	**7.46**	**9.38**	**11.17**	**12.53**	**12.70**	**12.22**	**12.96**	**12.00**	**14.16**	**15.31**	**13.46**	**13.49**
Emissions	0.00	0.09	0.41	0.71	1.00	1.37	1.61	2.31	2.93	3.58	4.27	5.00	5.17	6.07	6.86	8.11	8.61	9.15	9.06	9.87	10.78	11.80	11.98	12.25
Recovery for destruction	-	-	0.00	0.00	0.00	0.01	0.01	0.02	0.06	0.09	0.12	0.16	0.21	0.23	0.27	0.35	0.35	0.45	0.60	0.51	0.49	0.69	0.71	0.68
Stock change	0.11	2.00	1.75	1.76	2.17	2.48	3.06	3.17	3.29	3.41	3.51	3.36	2.09	3.09	4.04	4.07	3.74	2.62	3.30	1.62	2.88	2.82	0.77	0.56
Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.47 Halocarbons: Imports – demand balance sheet (Mt CO_2-e)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Total bulk imports	0.35	1.89	1.91	2.17	2.78	3.39	3.99	4.60	5.21	5.82	6.42	7.03	6.31	6.01	7.10	8.29	7.84	7.27	7.52	7.52	9.00	10.12	8.03	7.59
Bulk gas demand for production	0.07	1.93	1.95	2.17	2.74	3.25	3.36	3.98	4.24	4.83	5.11	5.72	4.55	4.55	4.70	5.88	4.28	4.11	3.60	3.96	4.75	5.55	2.62	2.72
Bulk gas demand for replenishment	-	-	0.00	0.01	0.04	0.14	0.64	0.62	0.97	0.99	1.32	1.31	1.76	1.46	2.40	2.40	3.56	3.16	3.92	3.57	4.25	4.56	5.41	4.87
Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Sensitivity testing

In addition to the HFC balances documented above, sensitivity analysis was undertaken to assess the impacts of changes to the allocation of bulk gas to end use as well as changes to the assumptions about replenishment rates in equipment. These two elements of the HFC model are where critical assumptions are made about the areas of consumption of imported gas and the servicing/replenishment habits of the consumers of this gas.

The effect of end use allocation on total emissions was tested by altering the percentage of bulk gas allocated to domestic, commercial and transport refrigeration (which is the biggest user of imported bulk gas) by 1 per cent, 5 per cent, 10 per cent and 20 per cent in all years with the residual gas allocated equally among the other end-use categories. In addition to this change in allocation, all gas imports are ceased after 2009.

Table 4.48 Halocarbons: results of sensitivity testing of allocation assumptions (Mt CO_2-e)

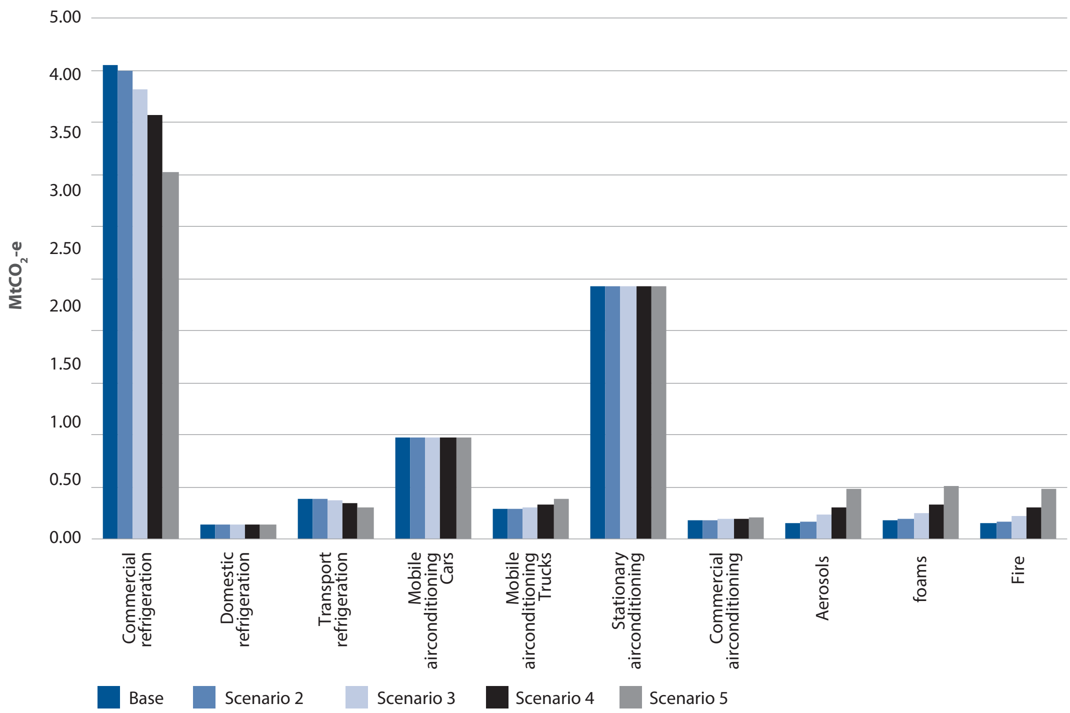
	Allocation assumptions (per cent of total bulk imports)				
End use allocation	**Base**	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Aerosols/solvents	2 per cent	2 per cent	3 per cent	4 per cent	5 per cent
Domestic/Commercial/ Transport refrigeration	60 per cent	59 per cent	55 per cent	50 per cent	40 per cent
Fire	2 per cent	2 per cent	3 per cent	4 per cent	5 per cent
Foam	2 per cent	2 per cent	3 per cent	4 per cent	6 per cent
Mobile air conditioning	25 per cent	25 per cent	26 per cent	27 per cent	28 per cent
Mobile OEM	1 per cent	1 per cent	2 per cent	3 per cent	5 per cent
Stationary air conditioning	8 per cent	8 per cent	8 per cent	9 per cent	11 per cent
Emissions in 2008 (Mt CO_2-e)					
Commercial refrigeration	3.23	3.19	3.06	2.89	2.50
Domestic refrigeration	0.04	0.04	0.04	0.04	0.04
Transport refrigeration	0.31	0.31	0.30	0.28	0.24
Mobile air conditioning cars	0.86	0.86	0.87	0.87	0.87
Mobile air conditioning trucks	0.19	0.19	0.20	0.22	0.25
Stationary air conditioning	0.62	0.62	0.62	0.62	0.62
Commercial air conditioning	0.06	0.06	0.06	0.06	0.07
Aerosols	0.13	0.15	0.20	0.27	0.43
Foams	0.13	0.14	0.18	0.24	0.37
Fire	0.05	0.06	0.08	0.11	0.18
Metered dose inhalers	0.14	0.14	0.14	0.14	0.14
Total	**5.75**	**5.75**	**5.74**	**5.73**	**5.70**
per cent change in total emissions compared with emissions in the base case		**-0.04 per cent**	**-0.19 per cent**	**-0.40 per cent**	**-0.86 per cent**

The results show that even with a 33 per cent change in bulk gas allocation from domestic, transport and commercial refrigeration to other end use categories, total emissions in 2008 are changed by only 0.9 per cent. This suggests that the estimate of emissions in any given year is relatively insensitive to changes in the allocation of bulk gas.

Figure 4.13 shows gas imports under the base end use assumption and each of the re-allocation assumptions. It can be seen that the gas diverted from domestic, commercial and transport refrigeration is re-allocated primarily to aerosols, foams, and fire protection. In total however, gas imports are unchanged as a result of the re-allocation.

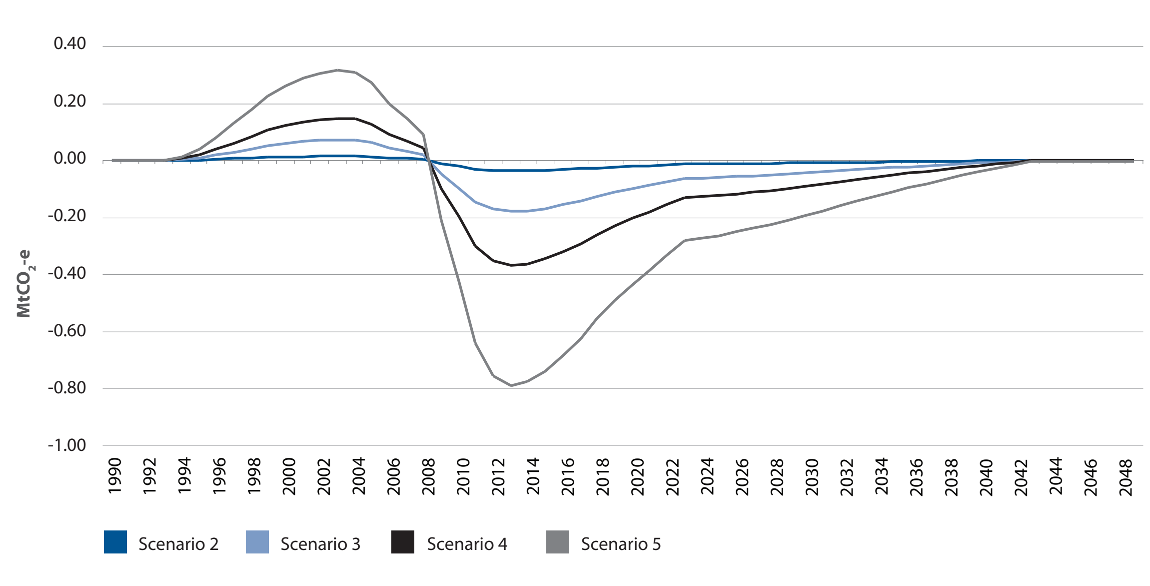
Under scenario 5 (a 33 per cent re-allocation from domestic, commercial and transport refrigeration), approximately 1 million tonnes is re-directed in equal proportions towards aerosols, foam and fire protection. This results in a reduction in emissions of 0.79 million tonnes CO_2-e in domestic, commercial and transport refrigeration and a corresponding increase of 0.66 million tonnes in aerosols, foams and fire protection. The residual gas is accounted for as gas recovered and destroyed and stock change in the bank of gas in operating equipment.

Figure 4.13 Halocarbons: results of sensitivity testing of allocation assumptions: 2008 (Mt CO_2-e)



Total cumulative differences in emissions and destruction under each allocation scenario between 1990 and 2050 (where the last of the current stock of operating equipment is retired) are shown in Figure 4.14. The chart shows that while differences occur in emissions in individual years the total gas either emitted or destroyed is unchanged over the life of each equipment type. The gas end-use re-allocation results in an increase in emissions for years where imports are occurring (up to 2009 in the case of this test), followed by a decrease in emissions relative to the base assumption from 2009 onwards.

Figure 4.14 Halocarbons: results of sensitivity testing of allocation assumptions: 1990–2050 (Mt CO_2-e)



As information about servicing and replenishment practices is limited, the replenishment assumptions have been devised by Department.

The effect of assumptions about gas replenishment was tested by reducing the replenishment rates for all sources where replenishment occurs by 10 per cent, 20 per cent, 30 per cent and 50 per cent.

As with bulk gas allocation, the total emissions estimate was found to be insensitive to changes in assumed replenishment rates with a 50 per cent reduction in replenishment resulting in only a 0.25 per cent change in total emissions in 2008. The effects of changes to the replenishment assumptions on total emissions within the model, while minimal, are complex. The total gas allocated to equipment is unchanged under these scenarios such that when less gas is allocated to replenishment, more is available to be allocated to new equipment.

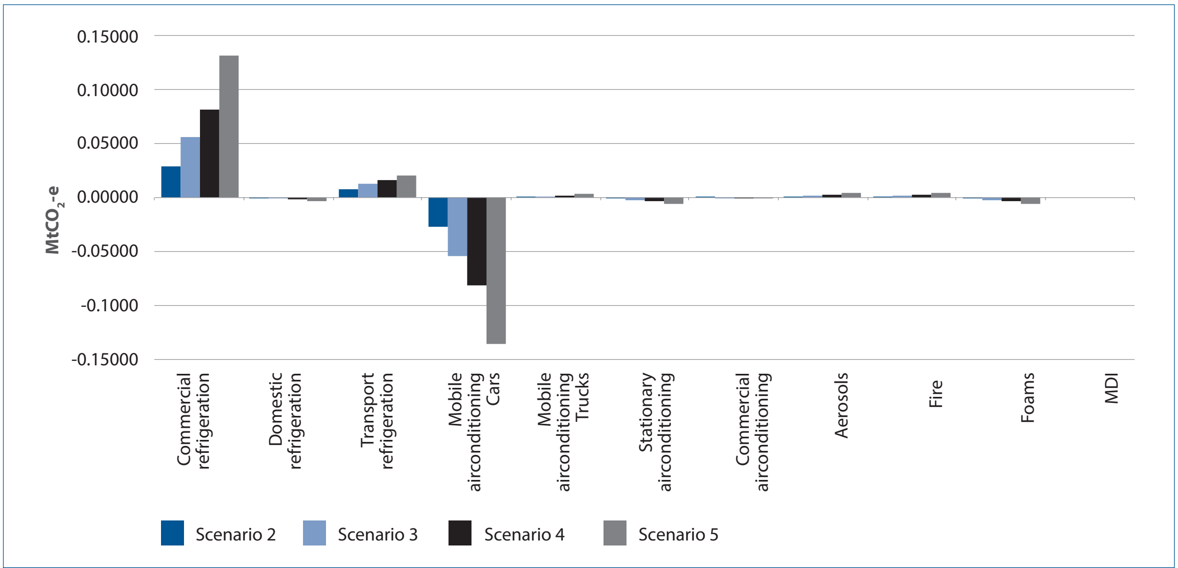
Figure 4.15 shows that emissions from commercial refrigeration increase as a result of a reduction in the general rates of replenishment as more gas is allocated to new equipment for this category. However, for domestic refrigeration, mobile air conditioning in cars and domestic stationary air conditioning the gas stocks are affected by the quantity of gas being replenished and thus, as a result of less gas being replenished, the gas bank and therefore emissions are lower for these categories.

Table 4.49 Halocarbons: results of sensitivity testing of replenishment assumptions (Mt CO_2-e)

	Replenishment assumptions				
	Base	Case 1	Case 2	Case 3	Case 4
Replenishment rate	**100 per cent**	**90 per cent**	**80 per cent**	**70 per cent**	**50 per cent**
Emissions in 2008 (Mt CO_2-e)					
Commercial refrigeration	3.23	3.26	3.28	3.31	3.36
Domestic refrigeration	0.04	0.04	0.04	0.04	0.04
Transport refrigeration	0.31	0.32	0.32	0.33	0.33
Mobile air conditioning cars	0.86	0.84	0.81	0.78	0.73
Mobile air conditioning trucks	0.19	0.19	0.19	0.19	0.19
Stationary air conditioning	0.62	0.61	0.61	0.61	0.61

	Replenishment assumptions				
	Base	Case 1	Case 2	Case 3	Case 4
Commercial air conditioning	0.06	0.06	0.06	0.06	0.06
Aerosols	0.13	0.14	0.14	0.14	0.14
Foams	0.13	0.13	0.13	0.13	0.13
Fire	0.05	0.05	0.05	0.05	0.05
Metered dose inhalers	0.14	0.14	0.14	0.14	0.14
Total	**5.75**	**5.76**	**5.77**	**5.77**	**5.77**
per cent change on base case		**0.17 per cent**	**0.24 per cent**	**0.25 per cent**	**0.25 per cent**

Figure 4.15 Halocarbons: results of sensitivity testing of replenishment assumptions – change in emissions 2008 (Mt CO_2-e)

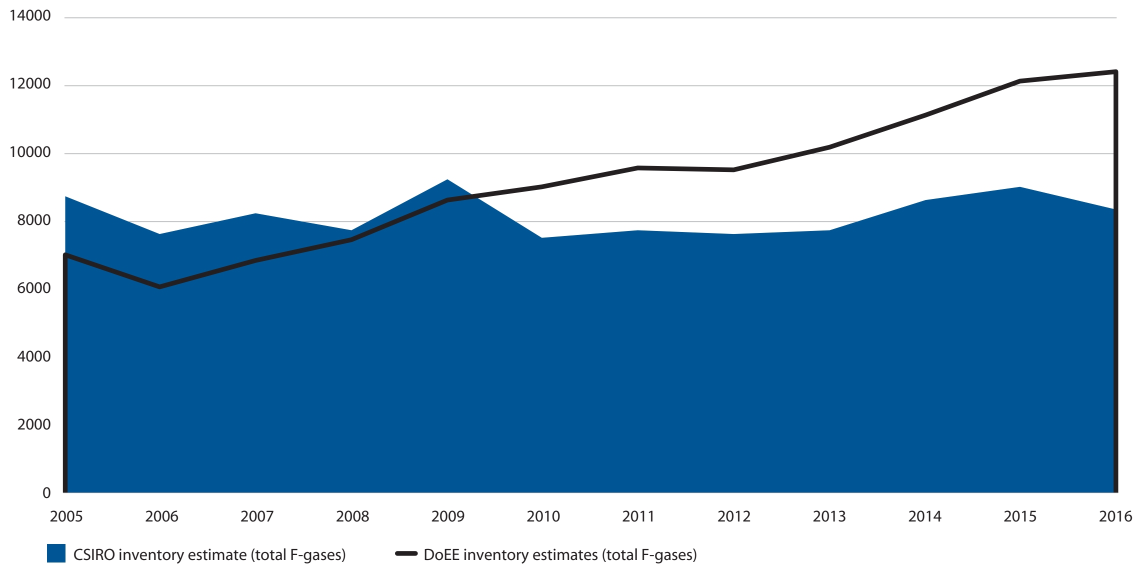


External verification through atmospheric testing

Monitoring of atmospheric HFC concentrations has been undertaken by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) at the Cape Grim Baseline Air Pollution Station in Tasmania since the mid 1990's. The department has commissioned CSIRO to verify its annual estimates of HFC emissions in the Inventory.

The verification process undertaken independently by CSIRO lags the official inventory submission by one year and confirms that total HFC, SF_6 and PFC emissions in the Inventory are 22 per cent higher than estimates based on Cape Grim data over the period 2005–2016 (CSIRO 2018). This comparison does not take into account the introduction of the leakage rate calibration process introduced in this submission. Total F-gas emissions for 2016 (2019 submission) when compared against the CSIRO estimates of 2016 (2018 report) now show a difference of 12 per cent. Figure 4.16 shows the comparisons of estimates based on Cape Grim measurements with inventory estimates for the time-series up to 2016 for this submission.

Figure 4.16 Comparison of Inventory estimates (NGGI 2016) with estimates derived from Cape Grim measurement data (ISC and NAME)



4.9.2.2 Source Specific QA/QC: SF_6 use in electricity supply and distribution

Australia applies six tests to consider the reasonableness of its estimates of SF_6 emissions from the electricity supply and distribution industry:

1) Comparison of the country specific emission factor with the IPCC default.

The IPCC GPG provides a global default factor of 2 per cent (IPCC GPG 3.57). Australia has applied this factor for 1995, while noting that the IPCC itself is somewhat cautious about the validity of these estimates presenting an uncertainty range of ±30 per cent indicating an IPCC range of 1.33 per cent – 2.6 per cent.

The *2006 IPCC Guidelines*, page 8.17, indicates that it would be good practice to select factors from countries with similar equipment designs and handling practices. In Australia, and based on the purchasing patterns of Transgrid, the dominant source of equipment are European manufacturers, although with an increasing supply from Japanese manufacturers in recent years.

Industrial Processes and Product Use

Table 4.50 2006 IPCC Guidelines default factors for Europe and Japan:

	Default	Uncertainty	Range (higher)	Range (lower)
	Tonnes of SF_6 emissions per tonne (nameplate)	per cent	Tonnes of SF_6 emissions per tonne (nameplate)	Tonnes of SF_6 emissions per tonne (nameplate)
euro closed pressure	0.026	±30 per cent	0.0338	0.0182
Japan closed pressure	0.007	±30 per cent	0.0091	0.0049
euro sealed pressure	0.002	±20 per cent	0.0024	0.0016
Japan sealed pressure	0.007	±30 per cent	0.0091	0.0049

The IPCC notes that the defaults are those documented for 1995 – before any special industry actions for emission reduction were implemented (IPCC 2006, page 8.15). This makes validity of comparison for any year after 1995 difficult.

However, it can be noted that the national factor estimated for Australia for 2010 (0.0089) – which is an average factor applied across the full range of equipment types in use in Australia (and typically sourced from Europe or Japan) – falls within the range presented in the 2006 IPCC *Guidelines* (0.0016 to 0.0338) – that should be applied for the year 1995 (and before any emission reduction actions were undertaken by industry).

Since 1995, Australia has had active programs in place to reduce emissions from this source typified by the industry action documented in Electricity Networks Association, *Electricity Networks Association Industry Guideline for* SF_6 *Management*, ENA Doc 022-2008. From 2015, SF_6 will be covered by Australia's carbon price mechanism, and from that data all importers of SF_6 will be levied a carbon price on import. While this is a future action, it underlines the comprehensive approach to mitigation action undertaken by the Australian government.

Australia has assessed the consistency of the emission estimates presented in this document with those of other countries – see below. The time profile of Australia's emission estimates is consistent with the time profiles of the major economies in Annex I.

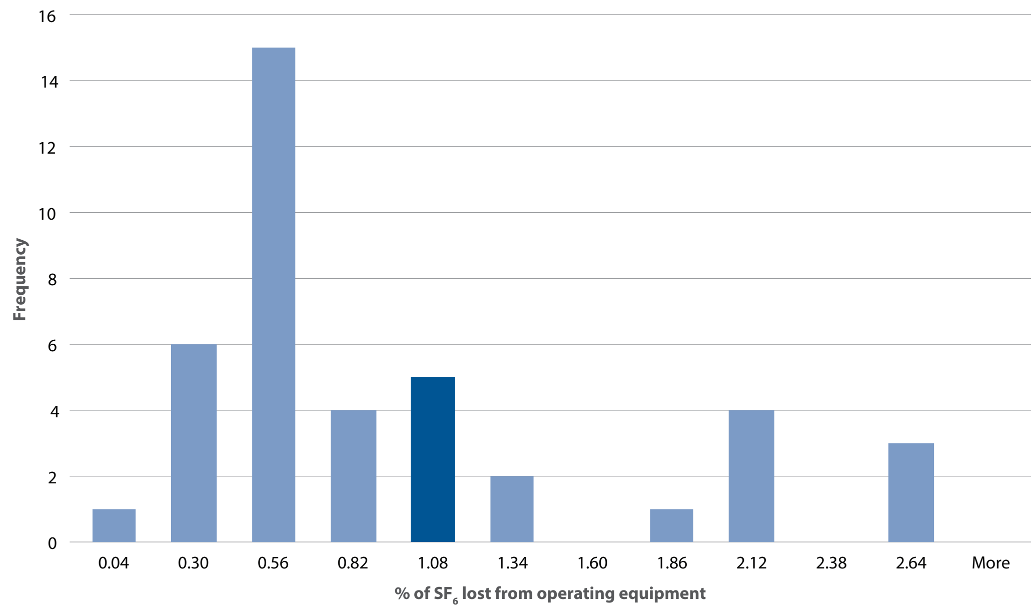
Consequently, Australia's assessment is that the country specific base EF, 0.0089 tonnes of SF_6 emission per tonne of SF_6 stock, is consistent with the information presented by the IPCC.

2) Comparison of the country specific emission factor with the factors of similar countries.

The estimated country specific EF for Australia has been compared with factors developed by the IPCC and factors used by a control group of Western European and other OECD countries. Australia's new EF is higher than the factors used in most Annex I parties. Five other countries share a factor in the range 0.82-1.08 reported in the histogram plot and 10 other parties have higher EFs in the group. 26 parties have EFs below Australia's country specific factor.

Consequently, Australia's national EF is considered to be consistent with those applied by other countries, with a tendency to the high side of reported EF estimates.

Figure 4.17 Histogram of reported product life factors (per cent) by Annex I parties (Western Europe and other OECD) (Australia in marked column)



Data available for Transgrid on equipment retirements are also consistent with the retirement information of other Annex I parties of similar circumstances and recent history. Of the group of major Annex I parties from Western Europe and other OECD countries (20 countries), around seven parties have identified an estimate for emissions from disposal; five indicate that disposal is 'not occurring' while the balance do not report.

3) Assessment of the time series consistency of Australia's estimates

Australia's emission estimates are considered to be time series consistent. Checks have been made in relation to the time series of both emission estimates and the time series of stocks.

4) Assessment of the time series consistency of Australia's estimates with IPCC default growth rates

Trend data were tested for consistency with IPCC GPG expectations for growth based on global growth data. The time series of the stock of SF_6 was checked against the increase in stocks cited as a *good practice* default growth rate for the period 1990-1996 of 6 per cent (IPCC GPG 3.60).

The calculated time series shows the stock of SF_6 in Australia grew by 7 per cent in 1996 and is comparable with IPCC default data.

5) Assessment of the time series consistency of Australia's estimates with the time series profile of other countries

The time profile of Australia's emission estimates presented in this document may be compared with the time profiles of emissions estimates presented by major economies within Annex I.

From this data, it can be observed that the time profile of emissions for Australia is similar to the time profile for of the parties, but has a slower rate of emission reduction than three of the parties. From this data, it can be concluded that the time profile of Australia's emissions are broadly consistent with the time profiles of major Annex I parties.

6) Comparison of NGER facility level emission factors with the NGER default emission factor

Overall, the weighted average emission rate of NGER reporters using their own data is 79 per cent higher than the NGER default factor of 0.005 tonnes of SF_6 per tonne of stock of SF_6 On average, then, reporters that choose to use their own data do so even though the factor to be utilized is higher than the national NGER default factor. Consequently, there is no evidence from the available data that selection bias has been an issue.

4.9.3 Recalculations since the 2016 Inventory

Recalculations have occurred throughout the time-series as a result of:

- The calibration of annual leakage rates for HFC emitting equipment from 2006 onwards
- The correction to the unit charge of split systems from 2006 onwards
- The revision to the method for aerosol emissions to ensure all charge is lost over 3 years
- Updates to CSIRO atmospheric SF6 observation data from 2010 onwards

Table 4.51 shows the impact of these recalculations.

Table 4.51 2.F Consumption of halocarbons and SF_6: recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2018 Submission	2019 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	per cent
2.F Consumption of halocarbons and SF_6				
1990	221	221	-	0.00 per cent
2000	1,823	1,824	0.75	0.04 per cent
2001	2,525	2,526	1.18	0.05 per cent
2002	3,152	3,151	-0.83	-0.03 per cent
2003	3,807	3,808	0.55	0.01 per cent
2004	4,498	4,498	0.22	0.00 per cent
2005	5,199	5,199	0.28	0.01 per cent
2006	5,545	5,353	-192.11	-3.46 per cent
2007	6,549	6,241	-308.03	-4.70 per cent
2008	7,647	7,022	-624.89	-8.17 per cent
2009	8,502	8,256	-245.77	-2.89 per cent
2010	9,559	8,753	-806.05	-8.43 per cent
2011	10,385	9,289	-1,095.82	-10.55 per cent
2012	10,986	9,208	-1,778.00	-16.18 per cent
2013	11,684	10,009	-1,674.97	-14.34 per cent
2014	12,376	10,940	-1,436.00	-11.60 per cent
2015	12,984	11,973	-1,010.95	-7.79 per cent
2016	13,348	12,168	-1,179.06	-8.83 per cent

4.9.4 Planned improvements

The department has introduced improvements to the bottom-up estimation of HFC and SF_6 emissions through the use of top-down estimates based on CSIRO atmospheric observation data to calibrate annual leakage rates in this submission. The department considers this the initial phase of this improvement programme and plans to continue the development of more sophisticated approaches to calibration of bottom-up estimates. Areas of further refinement include:

- Analysis of the use of specific gas species in specific equipment types to better target calibration of leakage rates.
- Consultation with CSIRO and other industry experts to better understand the specific causes for fluctuations in atmospheric observations.
- Consultation with experts and data providers to better understand trends in equipment stocks

Australia will investigate obtaining separate production and operational emissions for the category metered dose inhalers F.4.1.

4.10 Source Category 2.H Other

4.10.1 Food and beverage industry (2.H.2)

Source Category Description

The supply of CO_2 gas for use in the food and drink industry is provided from three main sources in Australia. Three ammonia producers sell a proportion of the CO_2 generated as a by-product of the ammonia production process to the food and drink industry. Gas is also obtained from two natural CO_2 wells located at Caroline in South Australia (commissioned in 1967) and Boggy Creek in Victoria (commissioned in 1995). The third source is by product CO_2 from an ethylene oxide plant located in Botany in New South Wales.

In the case of the CO_2 wells and the ethylene oxide plant, some CO_2 sold is also used for medical and other purposes (such as use in fire extinguishers). However, all CO_2 sold by these operators is reported under 2.D.2 *Food and drink.*

A small source of CO_2 emissions also derives from the use of sodium bicarbonate in food production. These emissions are also reported under 2.D. Sodium bicarbonate is a by-product of the production of soda ash.

The manufacture of beer, wine, alcoholic spirits, and bread involve the use of fermentation processes. The IPCC (1997) indicate the fermentation of sugar by industry is not considered to be a net source of CO_2 emissions, consistent with the IPCC *Guidelines*, Australia does not estimate CO_2 emissions from this source. NMVOC emissions from food and drink production, however, are included in the inventory. Production data for meat and poultry, beer and wine are obtained from ABS. Production data for sugar are obtained from ABARE (2009b).

Methodology

Emissions of CO_2 from food and drink are derived based on the assumption that all CO_2 gas used is emitted in the year of production.

CO_2 generated in the production of ammonia and then captured for consumption in the food and drink industry is described in the method for the estimation of emissions from ammonia production (2.B.1). The quantity of CO_2 supplied from the two gas wells is derived based on published production capacity. The quantity of CO_2 supplied from the ethylene oxide plant is derived based on the production capacity of the plant and a CO_2 EF of 0.45 tonnes of CO_2 per tonne of ethylene oxide produced taken from the Netherlands National Inventory Report (no IPCC default factor is provided and the Netherlands is the only party to report emissions from this source). It is assumed that all CO_2 generated is sold for use in food and drink production.

The method for the calculation of emissions from the use of sodium bicarbonate is provided with the method for the estimation of emissions from soda ash (2.A.4).

Emissions of NMVOCs from food and drink production are based on tier 2 methods and IPCC default EFs. Generally the methods involve multiplying the product activity level data (the amount of material produced or consumed) by an associated EF per unit of production or consumption. The NMVOC EFs used are as follows:

- Beer 0.035 (kg NMVOC/hl beverage produced);
- Red Wine 0.08 (kg NMVOC/hl beverage produced);
- White Wine 0.035 (kg NMVOC/hl beverage produced);
- Bread 1.66 (kg NMVOC/t food produced);
- Sugar 10 (kg NMVOC/t food produced); and
- Meat and Poultry 0.3 (kg NMVOC/t food produced).

4.10.2 Uncertainties and time series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to EFs or methodologies occur, a full time series recalculation is undertaken.

4.10.3 Source specific QA/QC

This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1.

4.10.4 Recalculations since the 2016 Inventory

No recalculations were undertaken in the Other sector in this submission as shown in Table 4.52.

Table 4.52 2.D Food and Drink: recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2018 Submission	2019 Submission	Change	Change
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	per cent
2.D Other Production				
1990	83	83	-	0.00 per cent
2000	145	145	-	0.00 per cent
2001	147	147	-	0.00 per cent
2002	150	150	-	0.00 per cent
2003	152	152	-	0.00 per cent
2004	165	165	-	0.00 per cent
2005	167	167	-	0.00 per cent
2006	160	160	-	0.00 per cent
2007	148	148	-	0.00 per cent
2008	163	163	-	0.00 per cent
2009	161	161	-	0.00 per cent
2010	231	231	-	0.00 per cent
2011	262	262	-	0.00 per cent
2012	218	218	-	0.00 per cent
2013	240	240	-	0.00 per cent
2014	202	202	-	0.00 per cent
2015	240	216	-	0.00 per cent
2017	273	273	-	0.00 per cent

4.10.5 Planned improvements

Activity data and EFs will be kept under review.

5. Agriculture

5.1 Overview

Agriculture produced an estimated 73.0 Mt CO_2-e emissions or 13.2 per cent of net national emissions (excluding *LULUCF*) in 2017 (Table 5.1).

Enteric fermentation was the main source of *agriculture* emissions contributing 70.6 per cent (51.5 Mt CO_2-e) of the sector's emissions. The next largest source was *agricultural soils* (19.4 per cent), followed by *manure management* (5.0 per cent). *Liming* and *urea application* contribute 3.9 per cent of the sector's emissions with *rice cultivation* and *field burning of agricultural residues* contributing the remainder.

Table 5.1 Agriculture sector CO_2-e emissions, 2016, 2017

Greenhouse Gas Source and Sink Categories	CO_2-e emissions (Gg)				
	CO_2	CH_4	N_2O	Total 2017 CO_2-e	Preliminary 2018 estimates CO_2-e
3 AGRICULTURE	2,862	54,765	15,377	73,004	70,787
A Enteric fermentation	NA	51,544	NA	51,544	50,812
B Manure management	NA	2,626	1049	3,675	3,744
C Rice cultivation	NA	285	NA	285	208
D Agricultural soils	NA	NA	14,170	14,170	12,838
E Prescribed burning of savannas	NA	IE	IE	IE	IE
F Field burning of agricultural residues	NA	310	158	468	323
G Liming	1,318	NA	NA	1,318	1,318
H Urea application	1,543	NA	NA	1,543	1,543

Trends

Emissions from *agriculture* decreased by 9.0 per cent (7.2 Mt CO_2-e) between 1990 and 2017 and increased by 5.4 per cent (3.7 Mt CO_2-e) between 2016 and 2017 (Figure 5.1).

Preliminary estimates of Agriculture sector emissions for 2018 are 70.8 Mt CO_2-e. This estimate is prepared using preliminary activity data and leading indicators and will be subject to revision in the official inventory submission in 2020.

Enteric fermentation emissions declined by 20.2 per cent (13.1 Mt CO_2-e) between 1990 and 2017. The decline in emissions in the early 1990s was principally driven by a fall in sheep numbers. However, by the late 1990s the emissions had begun to increase as the numbers of beef cattle began to rise, reflecting changing relative returns to each industry.

Between 2016 and 2017, emissions from *enteric fermentation* increased by 3.1 per cent (1.6 Mt CO_2-e), mainly due to an increase in the beef cattle population, reflecting herd rebuilding, lower cattle turn-off and an increase in calf additions.

Figure 5.1 CO_2-e emissions from agriculture, 1990–2018

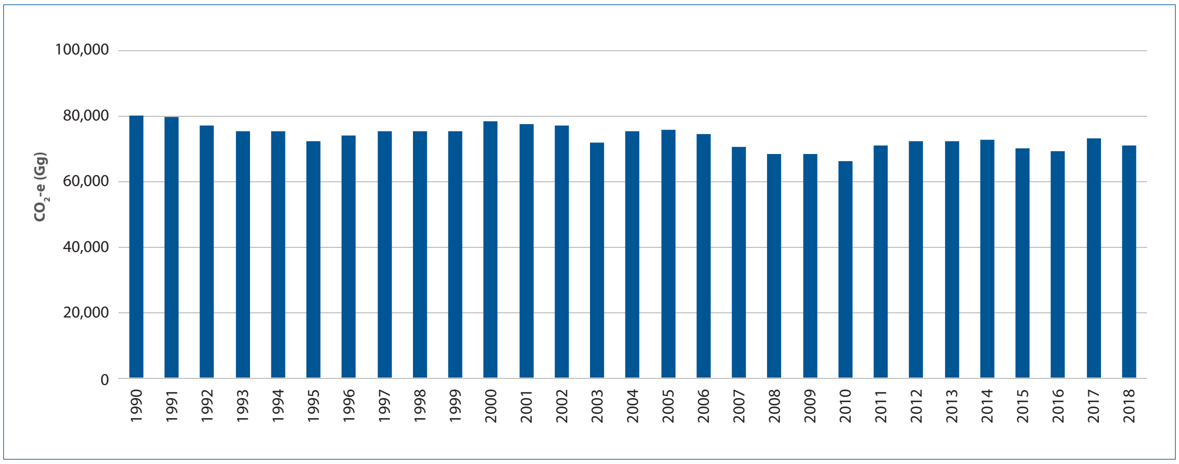
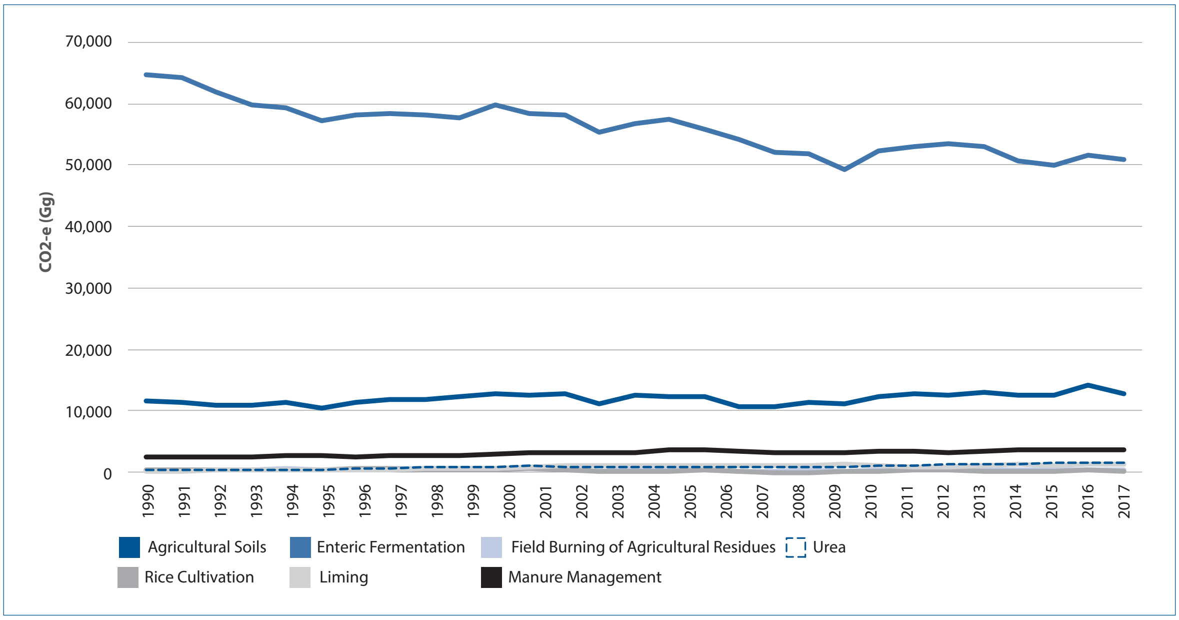


Figure 5.2 CO_2-e emissions from agriculture, by sub-sector, 1990–2018



Manure management emissions have increased by 47.6 per cent (1.2 Mt CO_2-e) between 1990 and 2017 due to the strong growth in the intensive feedlot cattle industry over this period. Manure management emissions increased by 2.8 per cent (0.1 Mt CO_2-e) between 2016 and 2017.

As all *rice cultivation* in Australia is flood irrigated, this industry is highly responsive to water availability. Emissions from *rice cultivation* in 2017 were 28.2 per cent (0.1 Mt CO_2-e) lower than in 1990 and 209.6 per cent (0.2 Mt CO_2-e) higher than in 2016. The increase in CH_4 emissions from rice cultivation observed in 2011 occurred as a result of an increase in the area of rice cultivation after a period of prolonged drought and water policy reform. From around 2003, there was a sharp decline in rice cultivation as water resources became scarcer. The end of the millennium drought around 2009 saw rice cultivation increase again although not to the levels observed prior to the onset of the drought.

Agricultural soils emissions have increased by 20.9 per cent (2.4 Mt CO_2-e) between 1990 and 2017, and increased by 11.8 per cent (1.5 Mt CO_2-e) between 2016 and 2017. Contributing to the change since 1990 has been an overall increase in agricultural fertiliser use and increased retention of crops residues. As crop production, animal populations and fertiliser use was reduced during the recent drought, emissions declined between 2001 and 2009. The return to better conditions has seen emissions increase more recently.

Emissions from *field burning of agricultural residues* have increased by 8.6 per cent (0.04 Mt CO_2-e) between 1990 and 2017 and by 62.7 per cent (0.2 Mt CO_2-e) between 2016 and 2017. This trend is a result of favourable seasonal conditions supporting above average to exceptional yields in much of the Australian cropping region. However, the 2016-17 figures are not representative of the long-term trend. The long term trend reflects a reduction in emissions from *field burning of agricultural residues* due to the reduction of stubble retention practices. Sugar cane burning has also reduced as the industry has shifted to green cane harvesting and use of trash blankets.

Emissions from liming and urea application have increased by 1.1 Mt CO_2-e and 1.2 Mt CO_2-e respectively since 1990. Between 2016 and 2017 liming emissions increased by 0.2 Mt CO_2-e while urea application emissions also increased by 0.03 Mt CO_2-e.

5.2 Overview of source category description and methodology – agriculture

The *agriculture* sector includes emissions of CH_4 and N_2O from livestock industries (enteric fermentation (3A) and manure management (3B)). In Australia, the principal species comprise cattle and sheep, with breeds chosen to operate within pasture and paddock management systems and, in many cases, in semi-arid or tropical and sub-tropical climatic conditions. Typical animal performance, as a consequence, tends to vary significantly from those of other Annex I countries.

Other agricultural sources include CH_4 emissions from rice cultivation (3C), N_2O emissions from agricultural soils (3D), and agricultural crop residues (3F), and CO_2 from the application of lime and urea to agricultural soils.

Emissions of non-carbon dioxide gases from the burning of tropical forests and tropical and semi-arid grasslands in Northern and Central Australia (previously called 'savanna burning') are reported under Land Use, Land Use Change and Forestry, along with emissions of carbon dioxide, and consistent with the structure of the 2006 IPCC Guidelines, under category 4.A Forest lands and category 4C Grasslands.

The Australian agriculture methodology contains both country specific and IPCC default methodologies and EFs (Table 5.2).

Table 5.2 Summary of methods and emission factors: Agriculture (CH_4 and N_2O)

Greenhouse Gas Source and Sink Categories		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor
A	Enteric Fermentation				
1	Cattle				
	a. Dairy Cattle	CS, T2	CS		
	b. Beef Cattle – Pasture	CS, T2	CS		
	c. Beef Cattle – Feedlot	CS, T2	CS		
2	Sheep	CS, T2	CS		

Agriculture

Greenhouse Gas Source and Sink Categories		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor
3	Swine	CS, T2	CS		
4	Other				
	a. Poultry [a]	NE	NE		
	b. Alpacas, Buffalo, Deer, Goats, Horses, Camels, Donkeys, Ostriches and Emus	T1	IPCC, CS		
B	**Manure Management**				
1	Cattle				
	a. Dairy Cattle	CS, T2	IPCC, CS	CS, T2	IPCC
	b. Beef Cattle – Pasture	CS, T2	CS	NA	NA
	c. Beef Cattle – Feedlot	CS, T3	IPCC, CS	CS, T3	IPCC
2	Sheep	CS, T2	CS	NA	NA
3	Swine	CS, T3	IPCC, CS	CS, T3	IPCC
4	Other				
	a. Poultry	CS, T3	IPCC,CS	CS, T3	IPCC
	b. Alpacas, Buffalo, Deer, Goats, Horses, Camels, Donkeys, Ostriches and Emus	CS, T2	CS	NA	NA
5	Indirect Emissions			CS, T2	IPCC,CS
C	**Rice Cultivation**	T1	IPCC		
D	**Agricultural Soils**				
1	Direct Emissions				
	a. Inorganic Fertilisers			T2	CS
	b. Animal Wastes Applied to Soils			T2	IPCC
	c. Sewage Sludge Applied to Land			T2	CS
	d. Other Organic Fertilisers[b]			NE	NE
	e. Urine and Dung Deposited by Grazing Animals			T2	CS
	f. Crop Residues			T2	IPCC
	g. Mineralisation due to loss of Soil C			T2	CS
	h. Cultivation of Histosols			T1	IPCC
2	Indirect Emissions				
	a. Atmospheric Deposition			T1	CS
	b. Leaching and Run-off			CS, T2	IPCC
E	**Prescribed Burning of Savannas**	NA	NA	NA	NA
F	**Field Burning of Agricultural Residues**	CS	CS	CS	CS
G	**Liming**	CS	IPCC		
H	**Urea Application**	T1	IPCC		
I	**Other Carbon-Containing Fertilisers**[a]	NE	NE		

(a) Not estimated as IPCC (2006) provides no methods or EF for this source.
(b) Not estimated as the source is considered insignificant (<0.05 per cent of national total) and data is difficult to collect (see Annex 5).
CS = country specific, IPCC = IPCC defaults, T1 = Tier 1, T2 = Tier 2, T3 = Tier 3 and NE = not estimated

The agriculture inventory is compiled on a State basis with State emission totals then aggregated to give national totals. The inventory is compiled in this way to reduce errors associated with averaging input data across areas with large physical and management differences. Australia has a land area of 769 million hectares which covers a wide range of climate zones, soil and vegetation types (see Section 6.2.1 for more details). These large physical differences lead to significant differences between States in such things as fuel loads for fires, the quality and availability of feed, and the performance of animals throughout the year. For example, in northern Australia there are two distinct seasons – wet and dry. During the dry season (winter-spring) the quality and availability of fodder is significantly reduced leading to weight loss in cattle, while in the southern states pasture growth and availability is lower during the colder autumn-winter months. As the climate ranges from warm to cool, methane conversion factors for manure management systems can also vary significantly between the States.

5.2.1 Data sources

The inventory for the *agriculture* sector relies primarily on livestock numbers and crop production statistics from the ABS (census/survey data collected on 30 June in the relevant year) and data provided by industry associations. Table 5.3 summaries the data Source. The annual activity data used to estimate the emissions are published on the AGEIS (http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/ageis).

Other primary data used in the algorithms (liveweights, liveweight gains, pasture digestibility, allocation to manure management systems, etc) are based on reviews of published data and expert assessments. This additional data is documented in Appendix 5.

Table 5.3 Summary of principal data source for Agriculture

Agriculture Sector	Activity Data
3A Enteric Fermentation 3B Manure Management	*Animal Numbers* ABS Agricultural Commodities; Australian Lot Feeders Association (ALFA); ABS meat chicken slaughter statistics; *Other Production Statistics* Dairy Australia; ABARES; Wool International.
3C Rice Cultivation	ABS Agricultural Commodities and Industry Associations
3D Agricultural Soils	
Inorganic Fertiliser	Fertilizer Australia
Sewage Sludge	NGER System and DCC (2009)
Crop Residues	ABS Agricultural Commodities (crops) and FullCAM (pasture)
N Mineralised due to loss of soil C	Soil C changes from *cropland remaining cropland* (see section 6.8)
Cultivated histosols	CSIRO – derived from the areas of organosols (http://www.clw.csiro.au/aclep/asc_re_on_line/or/orgasols.htm)
3E Savanna Burning	NA – reported under 4.A Forest lands and 4.C Grasslands
3F Field burning of Ag. Residues	ABS Agricultural Commodities, sugar industry associations
3G Liming	ABS Land Management and Farming in Australia survey
3H Urea Application	Fertilizer Australia

Process for eliciting expert assessments

Given the extensive nature of most of Australia's agricultural production there are few if any comprehensive State databases of information such as animal and feed characteristics. As this data is required to estimate emissions it has been necessary to use expert assessments to determine appropriate country specific information. The pasture based beef cattle and sheep categories contain a number of expert assessments and these values were reviewed in 1995 (documented in *Workbook for Livestock 6.1* (NGGIC 1996) and again in 2000-01 (documented in Howden *et al.* 2002 and White 2002). In each case consultants were used to coordinate the review. The consultant elicited expert assessments either through round table meetings with the experts or through surveys. These assessments were then compiled by the consultants and an agreed value recirculated to experts for final comment.
The consultants also undertook a number of reality checks on the expert assessments to ensure that correlated values such as seasonal liveweights and daily liveweight gains, and pasture digestibility and crude protein contents were internally consistent (White 2002). Expert assessments are also used in the dairy and feedlot cattle, pig and poultry categories. The data for these categories were reviewed in 2014-15 with the outcomes document in Wiedemann *et al.* (2014) and Dairy Technical Working Group (2015).

Expert judgements are provided in Table 5.4.

Comparison with international data

The ABS annually reports agricultural data to the Food and Agriculture Organization (FAO) of the United Nations. Some divergence occurs between the activity data in the inventory CRF tables and those published by the FAO. The reasons for these differences are as follows:

a) Beef cattle numbers reported in the CRF will differ from those reported to the FAO as they are the ABS numbers adjusted for annual equivalent number of animals held on feedlots (this applies to all years). Poultry numbers will differ as the meat chicken numbers used in the inventory are annual equivalents derived from the slaughter statistics rather than the static populations reported to FAO.

b) Over the time frame of the inventory the ABS has changed the threshold of the Estimated Value of Agricultural Operations (EVAO) used to determine which agricultural operations are included in the census/survey. In the years 1989 to 1993 ABS used EVAO's of $20-25,000 which is considerably higher than the $5000 used from 1994 until 2015. From 2016, the EVAO was again revised to $40,000. To ensure time series consistency in the data, a multiplier is applied to adjust the animal numbers to reflect the smaller farms that will have been left out of the 1989-1993 and 2016 censuses. This approach has been reviewed by the ABS who found the approach taken by the DoEE to be appropriate to ensure time-series consistency in activity data.

c) For the 2005-06 census the ABS introduced a new survey frame sourced from the Australian Taxation Office's Australian Business Register (ABR). Due to the progressive deterioration of the previous frame (based on a register of agricultural establishments maintained by ABS) the coverage of the two frames differed. To ensure time-series consistency, bridging estimates developed by ABS were used to revise animal numbers for dairy cattle, range kept cattle, sheep and pigs from 2002 to 2005.

Table 5.4 Documentation of expert judgements

Category	Activity Data CH4 emission factor for enteric fermentation – cattle	Revisions of Methods and Data – feedlot cattle, poultry and pigs	Methods and EFs used to estimate emissions from inorganic fertiliser	Implementation of a mass flow approach to manure management system
Submission Year	2016	2015	2015	2015
Name(s) of experts involved	Author: Dr Ed Charmley et al Expert Advisory Panel.	Authors: Wiedemann, SG, Sullivan, T and McGahan, EJ 2014 Expert Advisory Panel.	Authors: P. Grace and I. Scherback Expert Advisory Panel	Authors: Wiedemann, SG, Sullivan, T and McGahan, EJ 2014 Expert Advisory Panel
Experts' background	Authors: Agriculture; Beef production, measurement of animal and environmental variables, methane emissions from grazing systems, improving feed efficiency of ruminants. Expert Advisory Panel: Various backgrounds related to agricultural science	Authors: Agricultural scientist; greenhouse gas emission research Expert Advisory Panel: Various backgrounds related to agricultural science	Authors: Sustainable management and simulation of soil carbon, nitrogen and water in agroecosystems, the role of soils in the mitigation of greenhouse gases and adaptation to climate change. Expert Advisory Panel: Various backgrounds related to agricultural science	Authors: Agricultural scientist; greenhouse gas emission research Expert Advisory Panel: Various backgrounds related to agricultural science
The quantity being judged	Calculation of enteric fermentation emissions from cattle	Revision of methods and data for feedlot cattle, pigs and poultry	Methods and emission factors used to estimate emissions from inorganic fertiliser.	Manure management emissions – implementing a mass flow approach
The logical basis for judgement	The methods for estimating methane emissions from enteric fermentation in cattle as used in the Australian national inventory are based on older data that have now been superseded by more recent data.	Out-of-date methods and data for these livestock categories Changes required to reflect new international reporting requirements	To provide country specific methods and emission factors that reflect Australia's production systems and fertiliser use.	Manure from intensive livestock industries may pass through multiple treatment stages and therefore, inputs and losses should be calculated at each stage to avoid double counting.

Category	Activity Data CH4 emission factor for enteric fermentation – cattle	Revisions of Methods and Data – feedlot cattle, poultry and pigs	Methods and EFs used to estimate emissions from inorganic fertiliser	Implementation of a mass flow approach to manure management system
The result (activity value, emission factor etc.)	There is a close relationship between dry matter intake (DMI) and methane (CH4) production and Charmley recommends using a unified relationship (20.7g CH4/kg DMI) for dairy and beef cattle.	Several revisions to feedlot cattle, pigs and poultry data and methods. For specific data please refer to document 'GHG Prediction methods for feedlots, poultry and pigs'	There is a correlation between the emission factors and nitrogen use. Emission factors in some production systems increase with nitrogen application rates. Therefore, a two component model has been developed to take this into account (linear+exponential). eg. Cotton = 0.29 per cent+ (0.007(e0.037*N application rate -1)/N application rate.	A new mass flow approach will be implemented which estimates the inputs (volatile solids and N) and losses (CH4, N2O, NH3) at each treatment stage. Inputs into the secondary stage takes into account losses form the primary stage. This was advocated for based on research in Wiedemann et al (2014)
Result of any external review	Charmley et al's work was reviewed by the Expert Advisory Panel and approved for use in Australian Inventory – see section 5.2.1 of the NIR. A peer reviewed journal article was also published: Charmley et al 2015. 'A universal equation to predict methane production of forage-fed cattle in Australia' (CSIRO Publishing)	Wiedemann's work was reviewed by the EAP and approved for use in Australian NIR	Grace and Scherback's work was reviewed by the Expert Advisory Panel and approved for use in Australian NIR.	Mass flow approach was reviewed by the EAP and approved for use in the Australian NIR
Approved by inventory compiler (submission year and person)	2016, Penny Reyenga	2015, Penny Reyenga	2015, Penny Reyenga	2015, Penny Reyenga

5.3 Source Category 3.A Enteric Fermentation

5.3.1 Source category description and methodology

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which plant material consumed by an animal is broken down by bacteria in the gut under anaerobic conditions. A portion of the plant material is fermented in the rumen to simple fatty acids, CO_2 and CH_4. The fatty acids are absorbed into the bloodstream, and the gases vented by eructation and exhalation by the animal. Unfermented feed and microbial cells pass to the intestines.

Australia has identified enteric fermentation as a key source category using the tier 1 level and trend assessments as recommended in the IPCC Guidelines (IPCC 2006). In accordance with IPCC good practice requirements tier 2 methods are therefore used, to estimate enteric fermentation emissions from the major livestock sub-categories.

5.3.2 Cattle (3.A.1)

Pasture fed (dairy and beef)

Emissions from dairy and pasture fed beef cattle are estimated based on Charmley *et al.* (2015) who report a close relationship between dry matter intake and methane production. The relationship of Charmley *et al.* (2015) was derived from an analysis of Australian respiration chamber data of dairy and beef (southern and northern) cattle fed diets of >70 per cent forage.

A country-specific method (Minson and McDonald 1987) based on research in Australia is used to estimate intake. Minson and McDonald (1987) have derived an equation that estimates feed intake relative to liveweight and liveweight gain of cattle.

The large volumes of milk produced by dairy cattle under modern management regimes, requires that the lactating cow consume considerably more feed than an equivalent non-lactating cow. The increased energy requirements needed to produce this milk is estimated based on the average daily milk production per head of milking cows (Appendix 5.A.10) and the relationships presented by the Standing Committee on Agriculture (SCA 1990).

Lot fed

Emissions from lot fed beef cattle are estimated based on Moe and Tyrrell (1979). Moe and Tyrrell (1979) relate methane production to the intake of three components of the dietary carbohydrate – soluble residue, hemicellulose and cellulose. The relationship was derived from dairy cattle fed diets consisting mostly of high digestibility grains and concentrates and high quality forages. As feedlot cattle in Australia are fed diets consisting of high digestibility grains and concentrates, the Moe and Tyrrell (1979) equation was considered the most appropriate for estimating emissions.

The IPCC (2006) simplified tier 2 method for estimating intake from growing and finishing cattle is used for feedlot cattle as it has been found to perform well against known feed intake values from commercial feedlots.

5.3.2.1 Dairy cattle (3.A.1.a)

Table 5.5 Symbols used in algorithms for dairy cattle

State (i)	Dairy Cattle Classes (age) (j)
1 = ACT	1 = Milking Cows[a]
2 = Northern Territory	2 = Heifers > 1 year
3 = NSW	3 = Heifers < 1 year
4 = Queensland	4 = Bulls > 1 year
5 = Tasmania	5 = Bulls < 1 year
6 = South Australia	
7 = Victoria	
8 = Western Australia	

(a) Includes cows used for milk production but not currently lactating.

The equation presented in Minson and McDonald (1987) calculates feed intake of non-lactating cattle from liveweight and liveweight gain data. For lactating cattle the additional intake for milk production (MI_{ij}) is included to give total intake (I_{ij} kg dry matter/head/day):

$$I_{ij} = (1.185 + 0.00454W_{ij} - 0.0000026W_{ij}^2 + 0.315LWG_{ij})^2 \times MR_l + M_{lij} \quad \text{(3A.1a\_1)}$$

Where W_{ij} = weight in kg (Appendix 6.A.1)

LWG_{ij} = liveweight gain in kg/day (Appendix 6.A.2)

MR_l = increase in metabolic rate when producing milk (SCA 1990) 1.1 for milking and house cows and 1 for all other classes

The additional intake required for milk production (MI_{ij} kg DM/head/day) is calculated by:

$$MI_{ij} = MP_{ij} \times NE / k_l / q_{m,ij} / 18.4 \quad \text{(3A.1a\_2)}$$

Where MP_{ij} = milk production (kg/head/day) from Dairy Australia State[10] statistics

NE = 3.054 MJ net energy/kg milk (SCA 1990)

k_l = 0.60 efficiency of use of metabolizable energy for milk production (SCA 1990)

$q_{m,ij}$ = metabolizability of the diet. This is the ratio of metabolizable energy (ME) to gross energy (GE) in the diet (i.e. ME / GE). Metabolizable energy content is related to digestibility of dry matter (DMD_{ij}). So using the equation of Minson and McDonald (1987), $q_{m',ij}$ = 0.00795 DMD – 0.0014; (where DMD is expressed as a per cent).

The total daily production of methane (M_{ij} kg CH_4/head/day) is given by Charmley *et al.* (2015) as:

$$M_{ij} = 20.7 \times I_{ij} / 1000 \quad \text{(3A.1a\_3)}$$

Dairy calves are generally fully weaned to pasture at 12 weeks. Until this time calves will primarily consume milk or milk replacer, pellets and hay which results in lower emissions. The daily CH_4 production for pre-weaned dairy calves (MPW) is given in Appendix 5.A.5. Annual Australian methane production (Gg) for all classes of dairy cattle across all states can then be calculated as:

$$E = \Sigma_i \Sigma_j ((N_{ij=1,2,4} \times M_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times M_{ij=3,5} \times 281) + (N_{ij=3,5} \times MPW_{ij=3,5} \times 84)) \times 10^{-6} \quad \text{(3A.1a\_4)}$$

10 Litres of milk is multiplied by 1.03 to convert to kg of milk.

Where N_{ij} = numbers of dairy cattle in each class for each State and season

M_{ij} = methane production (kg/head/day)

MPW_{ij} = methane production for pre-weaned calves (kg/head/day)

5.3.2.2 Beef Cattle on Pasture (3.A.1.b)

Table 5.6 Symbols used in algorithms for beef cattle on pasture

State (i)	Regions (j)	Season (k)	Beef Cattle Classes (l)	Beef Cattle Subclass(n)[(a)]
1 = ACT	1 = ACT	1 = Spring	1 = Bulls < 1 year	1 = Bulls < 1 year
2 = Northern Territory	2a = Alice Springs	2 = Summer	2 = Bulls > 1 year	2 = Bulls > 1 year
	2b = Barkly	3 = Autumn	3 = Cows < 1 year	3 = Cows < 1 year
	2c = Northern	4 = Winter	4 = Cows 1 – 2 year	4 = Cows 1 – 2 year
3 = NSW			5 = Cows > 2 year	5a = Cows 2-3 year
4 = Queensland	4a = High		6 = Steers < 1 year	5b = Cows > 3 year
	4b = High/Moderate		7 = Steers > 1 year	6 = Steers < 1 year
	4c = Moderate/Low			7a = Steers 1-2 year
	4d = Low			7b = Steers 2-3 year
5 = Tasmania				7c = Steers >3 year
6 = South Australia				
7 = Victoria				
8 = Western Australia	8a = South West			
	8b = Pilbara			
	8c = Kimberley			

(a) Beef cattle subclasses (n) only apply to NT and QLD cattle.

The equation presented by Minson and McDonald (1987) calculates feed intake (I_{ijkl} kg dry matter/head/day) from liveweight and liveweight gain:

$$I_{ijkln} = (1.185 + 0.00454W_{ijkln} - 0.0000026\, W_{ijkln}{}^{2} + 0.315\, LWG_{ijkln})^{2} \times MA_{ijkl=5} \quad (3A.1b\_1)$$

Where W_{ijkln} = liveweight in kg (Appendix 5.B.1)

LWG_{ijkln} = live weight gain in kg/head/day (Appendix 5.B.2)

Feed intakes can increase by up to 60 per cent during lactation (ARC 1980). For this study, the intake of all breeding cattle was increased by 30 per cent during the season in which calving occurs and by 10 per cent in the following season based on relationships presented in SCA (1990).

The additional intake for milk production ($MA_{ijkl=5}$) is calculated by:

$$MA_{ijkl=5} = (LC_{ijkl=5} \times FA_{ijkl=5}) + ((1-LC_{ijkl=5}) \times 1) \quad (3A.1b\_2)$$

Where $LC_{ijkl=5}$ = proportion of Cows >2 lactating

$FA_{ijkl=5}$ = feed adjustment (Appendix 5.B.5)

The total daily production of methane (M_{ijkl}, kg CH_4/head/day) is given by Charmley *et al.* (2015) as:

$$M_{ijkl} = 20.7 \times I_{ijkln} / 1000 \quad (3A.1b\_3)$$

Agriculture

To calculate the beef cattle emissions it is necessary to first subtract feedlot cattle numbers from beef cattle numbers to ensure that feedlot cattle are not double counted. Because feedlot cattle, on average, spend between 70 and 250 days on feedlots prior to slaughtering, an annual equivalent number is derived using an approach consistent with equation 10.1 in the 2006 IPCC Guidelines and subtracted from beef cattle numbers. Feedlot cattle are assumed to originate entirely from the steers > 1 year old beef cattle class. This assumption is provided in Table 5.7. The emissions from the feedlot cattle are calculated in next section.

The approach is represented in the following equation:

$$N_{ijkl} = N_{ijk(l=1, l=2, l=3^{*} l=6, [(l=7) - \text{total feedlot numbers}])} \quad \text{(4A.1b\_4)}$$

Where N_{ijkl} = numbers of non-feedlot beef cattle in each State, region, season and class.

$N_{ijkl=1, l=2, l=3^{*} l=6}$ = number of cattle in State i, region j, season k and class l.

$_{(l=7) - \text{total feedlot numbers}}$ = from Table 5.6, l=7 corresponds with steers >1 year old. In order to calculate total beef cattle numbers in this class, total annual equivalent feedlot numbers must be subtracted from l =7. For WA 99 per cent of feedlot cattle are assumed to be sourced from the South-West region and the balance from the Pilbara and Kimberley.

Annual Australian methane production (Gg) for all classes of beef cattle across all seasons can then be calculated as:

$$E = \Sigma_i \Sigma_j \Sigma_k \Sigma_l \Sigma_n (91.25 \times N_{ijkln} \times M_{ijkln}) \times 10^{-6} \quad \text{(4A.1b\_5)}$$

Where N_{ijkln} = numbers of beef cattle in each State, region, season and class

M_{ijkln} = methane production (kg/head/day)

91.25 = number of days in each season

5.3.2.3 Beef cattle in feedlots (3.A.1.c)

Table 5.7 Symbols used in algorithms for feedlot cattle

State (i)	Feedlot Cattle Classes (duration of stay) (j)
1 = ACT	1 = Domestic (70-80 days)
2 = Northern Territory	2 = Export mid-fed (80-200 days)
3 = NSW	3 = Export long-fed (200+ days)
4 = Queensland	
5 = Tasmania	
6 = South Australia	
7 = Victoria	
8 = Western Australia	

Feed intake (I_j kg dry matter/head/day) of feedlot cattle is estimated using the IPCC (2006) simplified tier 2 method.

$$I_j = W_j^{0.75} [(0.2444 \times NE_{ma,j} - 0.0111 \times NE_{ma,j}^{2} - 0.472) / NE_{ma,j}] \quad \text{(3A.1c\_1)}$$

Where W_j = liveweight (kg) (Appendix 5.C.1)

$NE_{ma,j}$ = Dietary net energy concentration (MJ/kg) (Appendix 5.C.2).

Agriculture

The equation developed by Moe and Tyrrell (1979) to predict daily methane yields (Y_j MJ CH_4/head/day) is:

$$Y_j = 3.406 + 0.510SR_j + 1.736H_j + 2.648C_j \quad (3A.1c\_2)$$

Where SR_j = intake of soluble residue (kg/day)

H_j = intake of hemicellulose (kg/day)

C_j = intake of cellulose (kg/day)

SR_j, H_j and C_j are calculated from the total intake of the animal (as calculated above) and the proportion of the intake of each class of animal that is soluble residue, hemicellulose and cellulose (Appendix 5.C.2)

The total daily production of methane (M_j kg CH_4/head/day) is thus:

$$M_j = Y_j / F \quad (3A.1c\_3)$$

Where F = 55.22 MJ/kg CH_4 (Brouwer 1965)

Methane production (Gg) for all classes of feedlot cattle across all States can then be calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_j) \times 10^{-6} \quad (3A.1c\_4)$$

Where N_{ij} = numbers of feedlot cattle as an annual equivalent in each class in each State

M_j = methane production (kg/head/day)

5.3.3 Sheep (3.A.2)

Emissions from sheep are estimated based on Howden *et al.* (1994) who report a close relationship between dry matter intake and methane production based on an analysis of Australian respiration chamber experiments (Margan *et al.* 1985, 1987, 1988 and Graham 1964a,b, 1967, 1969). Howden *et al.* (1994) found that feed intake alone explained 87 per cent of the variation in methane production.

The Agriculture and Food Research Council (AFRC 1990) equation for intake is used here, as it corresponded well with intakes reported by State experts for seasonal feed digestibilities common in their State. The CS approach to estimating feed intake for sheep implicitly takes account of all net energy requirements for activities such as wool production, grazing in large areas and growth.

Table 5.8 Symbols used in algorithms for sheep

State (i)	Season (j)	Sheep Classes (k)
1 = ACT	1 = Spring	1 = Rams
2 = Northern Territory	2 = Summer	2 = Wethers
3 = NSW	3 = Autumn	3 = Maiden Ewes (intended for breeding)
4 = Queensland	4 = Winter	4 = Breeding Ewes
5 = Tasmania		5 = Other Ewes
6 = South Australia		6 = Lambs and Hoggets
7 = Victoria		

The potential, or maximum, intake of feed by sheep occurs when feed is abundant and of high quality. Potential intake is determined largely by body size and the proportion of the diet that is able to be metabolised by the animal. Potential intake (PI_{ijk} kg DM/head/day) is given by AFRC (1990) as:

$$PI_{ijk} = (104.7\ q_{m,ijk} + 0.307\ W_{ijk} - 15.0)\ W_{ijk}^{0.75} / 1000 \qquad (3A.2\_1)$$

Where W_{ijk} = liveweight (kg) (Appendix 5.D.1)

$q_{m,ijk}$ = metabolizability of the diet. This is the ratio of metabolizable energy (ME) to gross energy (GE) in the diet (i.e. ME / GE). Metabolizable energy content is related to digestibility of dry matter (DMD_{ijk}) so, using the equation of Minson and McDonald (1987), $qm,_{ijk}$ = 0.00795 DMD – 0.0014 (DMD is expressed as a per cent)

However, the actual feed intake of animals is often less than the potential intake. This can be caused by many factors, especially by low feed availability. Relative intake is defined as the proportion of potential intake that the animal will consume. The relative intake due to feed availability is given by White *et al.* (1983) as:

$$RI_{ijk} = 1 - \exp(-2(DMA_{ijk})^2) \qquad (3A.2\_2)$$

Where DMA_{ijk} = dry matter availability tonnes/hectare (Appendix 5.D.3)

Note: Actual feed intake will be less than potential intake only when feed availability is less than 1.63 tonnes/hectare.

The actual intake (I_{ijk} kg DM/head/day) of a sheep is thus:

$$I_{ijk} = PI_{ijk} \times RI_{ijk} \times MA_{ijk=4} \qquad (3A.2\_3)$$

Where $MA_{ijk=4}$ = additional intake for milk production

Feed intakes can increase by up to 60 per cent during lactation (ARC 1980). For emissions estimates, the intake of all breeding ewes was assumed to increase by 30 per cent during the season in which lambing occurs, based on relationships presented in SCA (1990).

The additional intake for milk production ($MA_{ijk=4}$) is calculated by:

$$MA_{ijk=4} = (LE_{ijk=4} \times FA_{ijk=4}) + ((1-LE_{ijk=4}) \times 1) \qquad (3A.2\_4)$$

Where $LE_{ijk=4}$ = proportion of breeding ewes lactating, calculated as the annual lambing rates x proportion of lambs receiving milk in each season (Appendix 5.D.6)

$FA_{ijk=4}$ = feed adjustment (assumed to be 1.3)

Methane production (M_{ijk} kg/head/day) is calculated using daily intake figures (I_{ijk}) via the relationship of Howden *et al.* (1994):

$$M_{ijk} = I_{ijk} \times 0.0188 + 0.00158 \qquad (3A.2\_5)$$

The annual methane production (in Gg) of Australian sheep is calculated as:

$$E = \Sigma_i \Sigma_j \Sigma_k\ (91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6} \qquad (3A.2\_6)$$

Where N_{ijk} = numbers of sheep in each class for each season and state

M_{ijk} = methane production (kg/head/day)

Agriculture

5.3.4 Pigs (3.A.3)

Pigs are non-ruminant animals, and convert a smaller proportion of feed energy intake into methane than do ruminants. Whittemore (1993) suggests that the output of methane by a 60 kg pig is about 0.2 MJ/day. Assuming that, on average, a 60 kg pig consumes 1.95 kg DM/day of a diet containing 18.6 MJ GE/kg, the GE intake was 36.3 MJ GE. Thus pigs would convert around 0.6 per cent of gross energy into methane. Other values in the literature suggest methane conversions of 1.2 per cent of gross energy (Christensen and Thorbek 1987), 0.6 to 0.8 per cent of gross energy (Moss 1993) and 0.4 per cent gross energy (Kirchgessner *et al.* 1991).

A methane conversion of 0.7 per cent of gross energy intake is used for Australia.

Table 5.9 Symbols used in algorithms for pigs

State (i)	Pig Classes (j)
1 = ACT	1 = Boars
2 = Northern Territory	2 = Sows
3 = NSW	3 = Gilts
4 = Queensland	4 = Others
5 = Tasmania	
6 = South Australia	
7 = Victoria	
8 = Western Australia	

The relationship for enteric fermentation in pigs gives the total daily production of methane (M_{ij} kg CH_4/head/day) as:

$$M_{ij} = I_{ij} \times 18.6 \times 0.007 / F \qquad (4A.3\_1)$$

Where I_{ij} = intake (kg DM/day) (Appendix 5.E.1)

F = 55.22 MJ/kg CH_4 (Brouwer 1965)

18.6 = MJ GE/kg feed DM

The annual production of methane (Gg) for all classes of pigs is calculated as:

$$E = \Sigma_i\Sigma_j(N_{ij} \times M_{ij} \times 365) \times 10^{-6} \qquad (4A.3\_2)$$

Where N_{ij} = the number of pigs in each class for each State

M_{ij} = methane production (kg/head/day)

5.3.5 Other livestock (3.A.4)

The contribution of other livestock to total methane production is comparatively small. As such, a simplified methodology, based on the IPCC (2006) tier 1 method, using aggregated numbers of the various livestock types and an annual methane emissions factor is used. The annual emission factors used are based on IPCC (2006) defaults and country specific estimates (Table 5.11).

Table 5.10 Symbols used in algorithms for other livestock

State (i)	Other Livestock Types (j)	Digestive Type
1 = ACT	1 = Buffalo	ruminant
2 = Northern Territory	2 = Goats	ruminant
3 = NSW	3 = Deer	ruminant
4 = Queensland	4 = Camels	quasi-ruminant
5 = Tasmania	5 = Alpacas	quasi-ruminant
6 = South Australia	6 = Horses	non-ruminant (equine)
7 = Victoria	7 = Donkeys/Mules	non-ruminant (equine)
8 = Western Australia	8 = Emus/Ostriches	non-ruminant
	9 = Poultry	non-ruminant

By applying the EF to the number of each species in each State, total methane production (Gg) from the enteric fermentation of minor livestock types can be calculated as follows:

$$E = \Sigma_i(N_{ij} \times M_j \times 10^{-6}) \quad \text{(4A.10\_1)}$$

Where N_{ij} = numbers of 'other livestock' types in each State

M_j = methane EF (kg/head/year) (Table 5.11)

Table 5.11 'Other livestock' – enteric fermentation emission factors (kg CH_4/head/year)

Livestock Type	EF	Source
Buffalo	55	IPCC (2006)
Goats	5	IPCC (2006)
Deer	20	IPCC (2006)
Camels	46	IPCC (2006)
Alpacas	8	IPCC (2006)
Horses	18	IPCC (2006)
Donkeys /Mules	10	IPCC (2006)
Emus/ Ostriches	2.5	Equivalent to half of goat EF [(a)]
Poultry	NE	not estimated by IPCC (2006)

(a)Equivalent to half of goat EF based on animal size and anatomy.

5.3.6 Uncertainties and time series consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for enteric fermentation were estimated to be in the order of 22 per cent. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

5.3.7 Source specific QA/QC

5.3.7.1 Activity data

The Australian Bureau of Statistics (ABS) is the national statistical agency of Australia and is the key provider of activity data for this source category. ABS has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated.

Data quality used in the inventory is also kept under review by the Department. This source category is also covered by the general QA/QC procedures detailed in Chapter 1.

Inverse modelling of cattle and sheep populations have been undertaken to ensure consistency with reported populations. These studies show no apparent bias in the sheep numbers (Howden 2001) but possible differences in cattle numbers in the order of 3-4 per cent (Howden and Barrett 2003). It is important to note that, with the limited datasets available for this study, the parameter solutions were non-unique and it is possible that there were no systemic differences in the numbers. Given the size of the possible differences and the inherent uncertainty in animal numbers it was agreed with ABS to incorporate this information into the uncertainty estimates rather than adjust activity data.

5.3.7.2 Implied emission factors

As country specific tier 2 methods are used to estimate emissions from cattle, sheep and pigs, the IEFs have been compared with the IPCC defaults (Table 5.12). The IEFs for pasture based beef cattle and pigs are generally consistent with the IPCC defaults.

The dairy cattle IEF is similar to the IPCC default for Oceania (90 kg/head/year). Differences with IPCC default values are due to the use of a more detailed age and animal class structure for Australia's dairy cattle herd than that assumed in IPCC 2006. Beef cattle IEFs also differ for the same reasons. The feedlot cattle IEF differs from the defaults due to differences in intake (Section 5.3.7.3). The lower IEFs for sheep primarily reflect the inclusion of an age structure in the Australian method and difference in the intakes and methane conversion rates for sheep.

Table 5.12 Implied emission factors – enteric fermentation (kg CH_4/head/year)

Livestock Type	Australia	IPCC Default (a)
Dairy Cattle	92	90
Beef Cattle – Pasture	51	60
Beef Cattle – Feedlot	67	60
Sheep	6.7	8
Swine	1.6	1.5

Source: (a) IPCC 2006

5.3.7.3 Feed intake

As Australia uses country specific tier 2 methods for estimating feed intake, intakes have been checked for reasonableness and have been compared with average intakes reported by other Parties.

Cattle

For dairy cattle, average herd intakes are within the range reported by other Parties (Table 5.13). The intakes of Australian dairy cattle are in the order of 1-3 per cent of live weight (range from 1.5 per cent to 3.16 per cent) as recommended by the IPCC (2006).

Comparison of beef cattle between Parties is complicated by the fact that animals kept under feedlot conditions have not been reported separately from pasture based animals as is done in the Australian inventory. The average herd intake for pasture based animals is slightly lower to that reported by other Parties, while that for lot fed animals is higher (Table 5.13).

Intake estimates for feedlot cattle have been based on the IPCC feed intake model, which was verified by comparison with industry practices. Intakes range from 2-2.1 per cent of live weights. Gross energy intake (GEI) for feedlot cattle was predicted using a diet GE of 19.2 MJ/kg DM based on the proportions of carbohydrate, protein and fat.

Table 5.13 Average herd intake (MJ GEI/head/day)

	Australia		Other Parties	
Livestock Type	**Range**	**Mean**	**Range**	**Mean**
Dairy cows (dairy herd)	266-327 (81-321)	301 (160)	162-536	286
Non-dairy cattle			92-339	137
Beef Cattle -Pasture	81-181	123		
Beef Cattle – Feedlot	152-226	196		
Sheep	10-26	19	10-46	21

Source: Other Parties herd intake from UNFCCC locator tool

Sheep

The country specific method used to estimate intake from Australian sheep produces lower average intakes than that reported by other Parties (Table 5.13). However, an analysis of intake as percentage of liveweight shows that intakes are in the order of 1-3 per cent (range from 1.0 per cent to 2.7 per cent) as recommended by IPCC (2006).

In Australia actual feed intake is often less than potential intake due to low feed availability. The Australian method calculates the proportion of the potential intake that the animal will actually consume (potential intake is restricted when feed availability is less than 1.63 tonnes/hectare). Restricted feed conditions occur in one or more seasons in all States with animals experiencing weight loss over the season. When intakes are not limited, estimated intakes (average 20 MJ/day) are similar to levels reported by other Parties.

5.3.7.4 Methane conversion rates

As Australia uses country specific methods for estimating methane emissions, methane conversion rates (Ym) have been compared against IPCC defaults.

Cattle

The conversion rates for dairy and beef cattle on pastures (6.1-6.2 per cent) are consistent with the IPCC (2006) default (6.5 per cent).

The IPCC (2006) indicates that animals fed diets containing 90 per cent concentrates should use Ym values ranging from 2.0-4.0 per cent. The Australian methodology for feedlot cattle accounts for the different proportion of grain and forage in diets, which are lower than the 90 per cent concentrates value associated with the IPCC default. The Australian methodology estimates conversion rates of 4.9-5.2 per cent or an average of 183 g CH_4/head/day. Kurihara *et al.* (1999, corrected by Hunter 2007) found similar conversion rates (5.6 per cent) for cattle fed on high grain (75 per cent) plus lucerne diets, measured using calorimetry chambers. Open path laser measurements of methane (enteric and manure) from Australian feedlots by McGinn *et al.* (2008) and Loh *et al.* (2008) have estimated enteric fermentation emissions of 161 g/head/day which is slightly lower than the estimated emissions.

Sheep

The herd average Ym for Australian sheep is 6.2 per cent which is within the range of the IPCC (2006) default (6.5 per cent).

The methodology for estimating emissions from sheep has been independently verified. Leuning *et al.* (1999) found close agreement between the methane emissions estimated by the inventory methods and direct field measurements made using micrometeorological mass-balance and SF_6 tracer techniques. Using the inventory methods and default livestock characterisation Leuning *et al.* (1999) estimated CH_4 emissions to be 12.6 g/head/day compared with 11.9 (±1.5) and 11.7 (±0.4) g/head/day measured by the mass-balance and SF_6 tracer techniques respectively. When the actual experimental livestock characterisation was used with the inventory methods, CH_4 emissions were estimated to be 11.1 g/head/day.

In addition, an analysis of Australian respiration chamber experiments by Williams and Wright (2005) showed a very similar relationship between methane output and dry matter intake (CH_4 = 0.0187 x DMI – 0.0003) to that reported in Howden *et al.* (1994) (CH_4 = 0.0188 x DMI + 0.00158).

5.3.7.5 External Review

Comprehensive expert peer review of the methodologies, activity data and livestock characterisation data were conducted for sheep in 2000-01; dairy and feedlot cattle, pigs and poultry in 2014; and QLD/NT beef cattle on pastures in 2015 (Bray *et al.* 2015). These reviews involved agricultural experts from industry, government and academia.

5.3.8 Recalculations since the 2016 Inventory

Recalculations of enteric fermentation have occurred due to:

- a revision of the milk production data for 2012, 2013, 2014, 2015 and 2016.
- a revision of the regional breakdowns of beef cattle pasture for 2012, 2013, 2014, 2015, and 2016
- a revision of 'other livestock' population numbers for 2016
- a revision of sheep population numbers for 2016
- a revision of swine population numbers for 2016

Table 5.14 shows the impact of these recalculations.

Table 5.14 Enteric fermentation (3A): recalculation of total CO_2-e emissions, 1990-2016

Year	2018 submission	2019 submission	Change	
	($Gg\ CO_2$-e)		($Gg\ CO_2$-e)	(per cent)
1990	64,626	64,626	-	0.0 per cent
2000	59,896	59,896	-	0.0 per cent
2005	57,361	57,361	-	0.0 per cent
2008	52,155	52,155	-	0.0 per cent

Year	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2009	51,761	51,761	-	0.0 per cent
2010	49,337	49,337	-	0.0 per cent
2011	52,268	52,268	-	0.0 per cent
2012	53257	53,105	-153	-0.3 per cent
2013	53,637	53,485	-152	-0.3 per cent
2014	53,097	52,955	-142	-0.3 per cent
2015	50,848	50,798	-189	-0.4 per cent
2016	49,699	49,977	278	0.6 per cent

5.3.9 Source specific planned improvements

The inventory improvement plan for the agriculture sector identified areas which require updating or review over the next two years. Areas for improvement are identified through the UNFCCC expert reviews, domestic QA/QC process or the expected availability of new data or empirical studies which could improve accuracy of the inventory.

For enteric fermentation the following areas have been identified for review and/or change

1. *Sheep* – Since the CS method was developed there has been additional measurement data collected in Australia through programs such the Reducing Emissions from Livestock Research Program. Over the next two years the available measurement data will be reviewed, analysed and compared with the existing method.
2. *Pre-weaning emissions* – For the 2015 submission separate emission estimates for pre-weaned dairy calves has been implemented to better reflect the effects of milk intake on CH_4 and N_2O emissions. Over the next two years the methods for beef calves and lambs will be reviewed.
3. *Feed and animal characteristics* – As these characteristic can change as industry practices change over time, the current values need to be reviewed periodically. The beef cattle on pasture in southern states and sheep industries have been identified as the next priorities for review.
4. *Cattle herd characteristics* – a dynamic livestock model will be developed which estimates livestock numbers based on births, deaths and other stock changes. The DoEE will also investigate the availability of improved liveweight data.
5. *Emu and Ostrich CH_4 enteric fermentation emission factor* - Australia uses a country specific CH_4 enteric fermentation emission factor for emus and ostriches. Australia will undertake a review of this emission factor and provide documentation regardng the justification of its methodology.

5.4 Source Category 3.B Manure Management

5.4.1 Source category description and methodology

Methane is produced from the decomposition of the organic matter remaining in the manure under anaerobic conditions. These conditions occur when large numbers of animals are managed in a confined area where manure is typically stored in large piles or lagoons.

Direct N_2O emissions from manure management systems (MMS) can occur via combined nitrification and denitrification of ammoniacal nitrogen contained in the wastes. The amount released depends on the system and duration of waste management. Indirect N_2O emissions also occur via runoff and leaching, and the deposition of N volatilised from the manure management systems.

As manure from intensive livestock industries may pass through multiple treatments stages, Australia applies a tier 3 mass flow approach to estimating emissions where by the volatile solid and nitrogen inputs and losses are estimated at each treatment state. Inputs into the secondary treatment stage takes into account losses from the primary stage (see Figure 5.3).

Subscripts for the algorithms are the same as used for calculating enteric fermentation with an additional manure management system (Table 5.15).

Figure 5.3 Mass flow method of estimating manure management emissions – feedlot cattle example

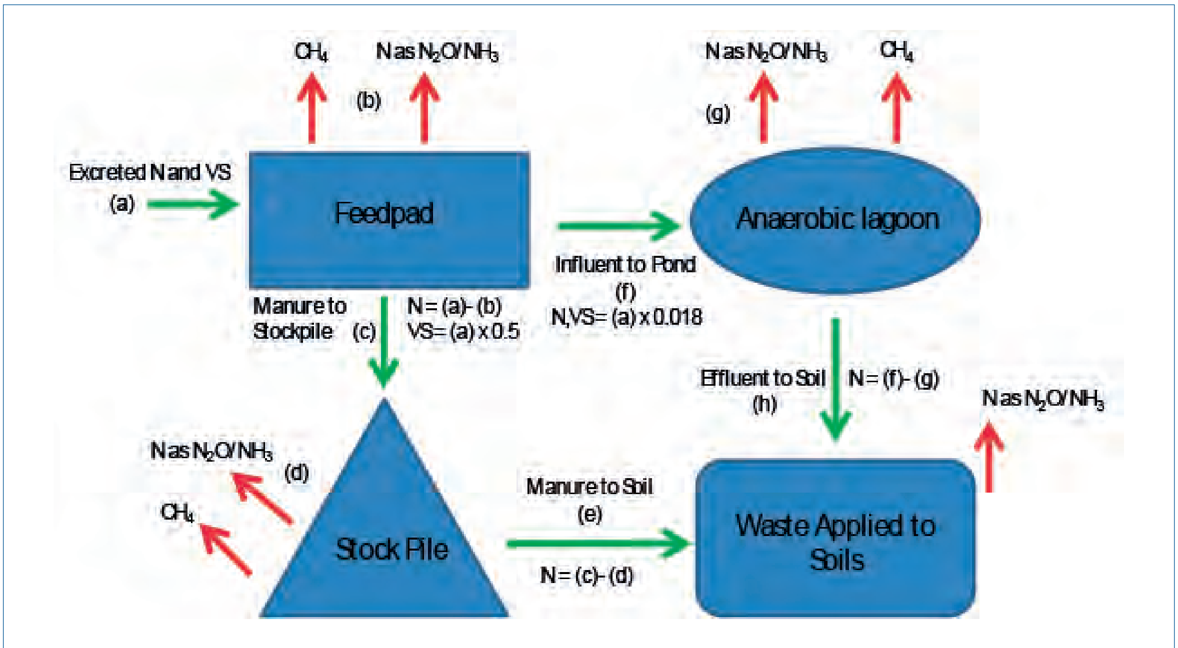


Table 5.15 Symbols used in algorithms for manure related emissions

Manure Management Systems (MMS)	
1 = Anaerobic lagoon	8 = Deep litter
2 = Liquid systems	9 = Pit storage
3 = Daily spread	10 = Poultry manure with bedding
3a = Sump and dispersal system	11 = Poultry manure without bedding
3b = Drains to paddock	11a = Belt manure removal
4 = Solid storage	11b = Manure stored in house
5 = Drylot	12 = Direct Processing
6 = Composting (passive windrow)	13 = Direct Application
7 = Digester / covered lagoons	14 = Pasture range and paddock

5.4.1.1 Methane

Methane production from the manure of dairy cattle, feedlot cattle, pigs and poultry are calculated based on the volatile solids entering the MMS and CS and default IPCC methane conversion factors (MCF). An integrated methane conversion factor (iMCF) has been calculated taking into account the proportion of manure managed in each system, the MCF of each system, and VS losses from earlier stages in the MMS. The specific allocations of manure to the different MMS, the VS loss assumptions, and the applied MCFs are documented in Appendix 5.

Australian experts considered that methane production is likely to be negligible in the manure of range-kept livestock (e.g. pasture based beef cattle, sheep, goats etc). There was agreement that the generally high temperatures, high solar radiation and low humidity environments of Australia would dry manure rapidly. In combination with scarab (or dung) beetles that rapidly infest manure in most Australian environments, there was considered to be little likelihood of anaerobic conditions and hence little methanogenesis in the manure of range-kept animals. This is supported by González-Avalos and Ruiz-Suárez (2001) who recorded negligible amount of methane from the manure of cattle kept under conditions similar to those experienced in Australia. The González-Avalos and Ruiz-Suárez (2001) methodology is, therefore, used to estimate methane emissions from range-kept livestock manure.

Gonzalez-Avalos and Ruiz-Suarez (2001) calculate their methane emissions factor (M_{ijk} kg/head/year) as follows:

$$M_{ijk} = (\text{kg } CH_4 / \text{ kg DM fresh manure}) \times (\text{kg fresh manure/day}) \times (\text{ per cent DM}) \times 365$$

The second and third term on the right hand side of the equation quantify the amount of dry matter (DM) in manure. This can be calculated for beef cattle and sheep using estimates of Intake and DMD to estimate DM manure (kg/head/day):

$$DMM_{ijk} = I_{ijk} \times (1 - DMD_{ijk})$$

Gonzalez-Avalos and Ruiz-Suarez (2001) do not document EFs in kg CH_4/kg DM fresh manure. However, this can be calculated from the data in their paper using their Extensive Dual Purpose (temperate and warm) categories. The manure emission factors are:

Temperate (EFT) — 1.4×10^{-5} kg CH_4/kg DM manure

Warm (EFW) — 5.4×10^{-5} kg CH_4/kg DM manure

5.4.1.2 Nitrous oxide

Nitrogen excretion from cattle, sheep, swine and poultry are estimated using country specific tier 2 mass balance approaches where N excretion = N input – N retention. For other livestock, country specific excretion rates are applied. The N_2O emission factors and volatilisation factors are based on a combination of IPCC (2006) default and country specific values.

Where multiple manure treatment stages occur an integrated nitrous oxide emission factor (iNOF) and an integrated volatilisation factor ($iFracGASM_{MMS}$) has been calculated taking into account the proportion of manure managed in each system, the N_2O EF and $FracGASM_{MMS}$ of each system, and N losses from earlier stages in the MMS (see Appendix 5).

To estimate atmospheric deposition emissions country specific EFs are used. As the highest ammonia deposition rates (kg/ha) are found within a few hundred meters of the emission source, the fertiliser EFs of neighbouring production systems were considered to provide a more accurate estimate of emissions than the IPCC default EF. While the majority of volatilised N is advected away from the MMS, it undergoes significant dilution and is deposited to the wider landscape at very low rates (Dr Matt Redding, per. comm., QLD DAFF, 2014).

5.4.2 Dairy cattle (3.B.1.A)

5.4.2.1 Methane

Dairy cattle are generally kept in higher rainfall areas than other Australian livestock. This, and the disposal of excreta washed from milking sheds, gives opportunities for the generation of methane. However, only a small fraction of the potential methane emissions appears to be released. Williams (1993) measured methane production from dairy cattle manure under field conditions in Australia and found that only about 1 per cent of the methane production potential was achieved. On this basis the temperate MCF for manure voided in the field was reduced to 1 per cent from the IPCC (2006) default of 1.5 per cent.

Methane from manure is formed from the organic fraction of the manure (volatile solids). Volatile solid production for dairy cattle (VS_{ij} kg/head/day) was estimated using the data developed to calculate enteric methane production as this included information on intakes and dry matter digestibility. For dairy cattle, volatile solids were calculated as:

$$VS_{ij} = (I_{ij} \times (1 - DMD_{ij}) + (0.04 \times I_{ij})) \times (1 - A) \quad \text{(3B.1a\_1)}$$

Where I_{ij} = dry matter intake calculated in Section 5.3.2.1

DMD_{ij} = dry matter digestibility expressed as a fraction (Appendix 5.A.4)

A = ash content expressed as a fraction (assumed to be 8 per cent of faecal DM)

Methane production from manure (M_{ij} kg/head/day) is then calculated as:

$$M_{ij} = VS_{ij} \times B_o \times iMCF_i \times \rho \quad \text{(3B.1a\_2)}$$

Where B_o = emissions potential – 0.24m^3 CH_4/kg VS (IPCC 2006)

$iMCF_i$ = integrated methane conversion factor (Appendix 5.A.6)

ρ = density of methane (0.6784 kg/m^3) – Taken from the National Greenhouse and Energy Reporting (Measurement) Determination (DoEE 2016)

The methane produced by pre-weaned calves (MPW) is given in Appendix 5.A.5.

The annual methane production (Gg) from the manure of dairy cattle is calculated as:

$$Total = \Sigma_i \Sigma_j (N_{ij=1,2,4} \times M_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times M_{ij=3,5} \times 281) + (N_{ij=3,5} \times MPW_{ij=3,5} \times 84)) \times 10^{-6} \quad \text{(3B.1a\_3)}$$

Where N_{ij} = numbers of dairy cattle in each State, class and season

M_{ijk} = methane production (kg/head/day)

MPW_{ij} = methane production for pre-weaned calves (kg/head/day) (Appendix 5.A.5)

5.4.2.2 Direct nitrous oxide emissions

The methodology for calculating the excretion of nitrogen from dairy cattle makes use of the following algorithms to calculate crude protein input (CPI_{ij}) and N retention (NR_{ij}) and from these the output of nitrogen in the faeces and urine.

The crude protein intake CPI_{ij} (kg/head/day) of dairy cattle is calculated thus:

$$CPI_{ij} = I_{ij} \times CP_{ij} \quad \text{(3B.1a\_4)}$$

Where I_{ij} = dry matter intake (kg/day) as calculated in Section 5.3.2.1

CP_{ij} = crude protein content of feed intake expressed as a fraction (Appendix 5.A.4)

The amount of nitrogen that is retained by the body (NR_{ij} kg/head/day) is calculated as the amount of nitrogen retain in milk and body tissue such that:

$$NR_{ij} = (0.032 \times MP_{ij\,/\,6.38}) + \{\{0.212 – 0.008(L_{ij} – 2) – [(0.140 - 0.008(L_{ij} – 2)) / (1+\exp(–6(Z_{ij} – 0.4)))]\} \times (LWG_{ij} \times 0.92)\}/6.25 \quad (3B.1a\_5)$$

Where MP_{ij} = milk production in kg/head/day (Appendix 5.A.10)

L_{ij} = Intake relative to that needed for maintenance. Calculated as actual intake divided by maintenance intake (i.e. intake of non-lactating animal with LWG set to zero calculated by equation 3A.1a_1)

Z_{ij} = relative size (liveweight / standard reference weight (Appendix 5.A.1 and 5.A.3))

LWG_{ij} = liveweight gain (kg/day) (Appendix 5.A.2)

Nitrogen excreted in faeces (F_{ij} kg/head/day) is calculated, using functions developed by the SCA (1990) and Freer *et al.* (1997), as the indigestible fraction of the undegraded protein from solid feed and the microbial crude protein plus the endogenous faecal protein, such that:

$$F_{ijk} = \{0.3(CPI_{ij} \times (1-[(DMD_{ij}+10)/100])) + 0.105(ME_{ij} \times I_{ij} \times 0.008) + (0.0152 \times I_{ij})\}/6.25 \quad (3B.1a\_6)$$

Where DMD_{ij} = dry matter digestibility expressed as a per cent (Appendix 5.A.4)

ME_{ij} = metabolizable energy (MJ/kg DM) calculated as: 0.1604 DMD_{ij} – 1.037 (Minson and McDonald 1987)

I_{ij} = dry matter intake (kg/day)

Nitrogen excreted in urine (U_{ij} kg/head/day) is calculated by subtracting NR_{ij}, F_{ij} and dermal protein loss from the nitrogen intake such that:

$$U_{ij} = (CPI_{ij}/6.25) – NR_{ij} – F_{ij} – [(1.1 \times 10^{-4} \times W_{ij}^{0.75})/6.25] \quad (3B.1a\_7)$$

Where W_{ij} = liveweight (Appendix 5.A.1)

Pre-weaned dairy calves are usually removed from their mothers and receive milk or milk replacer and feed pellets. The nitrogen excreted in the faeces (FPW) and urine (UPW) of pre-weaned calves is given in Appendix 5.A.5.

The total annual faecal (AF_{jk} Gg) and urinary (AU_{jk} Gg) nitrogen excreted is calculated as:

$$AF_{ij} = \Sigma_j((N_{ij=1,2,4} \times F_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times F_{ij=3,5} \times 281) + (N_{ij=3,5} \times FPW_{ij=3,5} \times 84)) \times 10^{-6} \quad (3B.1a\_8a)$$

$$AU_{ij} = \Sigma_j((N_{ij=1,2,4} \times U_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times U_{ij=3,5} \times 281) + (N_{ij=3,5} \times UPW_{ij=3,5} \times 84)) \times 10^{-6} \quad (3B.1a\_8b)$$

Where N_{ij} = the number of dairy cattle in each State and class

The annual faecal (FN_{ijMMS} Gg) and urinary (UN_{ijMMS} Gg) nitrogen in the different manure management systems can then be calculated as follows:

$$FN_{ijMMS} = (AF_{ij} \times MMS) \quad (3B.1a\_9a)$$

$$UN_{ijMMS} = (AU_{ij} \times MMS) \quad (3B.1a\_9b)$$

Where MMS = the fraction of nitrogen that is managed in the different manure management systems (Appendix 5.A.8).

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The total emissions of nitrous oxide from the different manure management systems can then be calculated as follows:

$$Faecal_{ijMMS} = (FN_{ijMMS} \times EF_{(MMS)} \times C_g) \quad (3B.1a\_10a)$$

$$Urine_{ijMMS} = (FN_{ijMMS} \times EF_{(MMS)} \times C_g) \quad (3B.1a\_10b)$$

$$Total_{MMS} = \Sigma_i \Sigma_j (Faeca_{lijMMS} + Urine_{ijMMS}) \quad (3B.1a\_10c)$$

Where $EF_{(MMS)}$ = emission factor (N_2O-N kg/ N excreted) for the different manure management systems (Appendix 5.A.9)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.4.2.3 Indirect nitrous oxide emissions

Atmospheric Deposition

The mass of dairy waste volatilised from the manure management systems is calculated as:

$$MNATMOS_i = \Sigma_j \Sigma_{MMS} ((FN_{ijMMS} + UN_{ijMMS}) \times FracGASM_{MMS}) \quad (3B.5a\_1)$$

Where $FracGASM_{MMS}$ = the fraction of N volatilised for dairy MMS (Appendix 5.A.9)

Atmospheric deposition emissions from dairy manure management systems is calculated as:

$$E = \Sigma_{i(}MNATMOS_i \times EF \times C_g) \quad (3B.5a\_2)$$

Where E = annual emissions from atmospheric deposition (Gg N_2O)

$MNATMOS_i$ = mass of N volatilised (Gg N)

EF = 0.004 (Gg N_2O-N/Gg N) (Inorganic Fertiliser EF for irrigated pasture – Table 5.24)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Leaching and Runoff

Emissions associated with leaching and runoff are only estimated for the solid storage manure management system. Leaching and runoff from dairy effluent ponds is considered negligible and leaching and runoff from waste deposited on pasture or distributed to pasture through drains or sump dispersal systems is estimated and reported in the agricultural soils section.

The amount of N available for leaching and runoff is calculated as:

$$MNLEACH = \Sigma_i \Sigma_j ((FN_{ijMMS=4} + UN_{ijMMS=4}) \times FracWETMMS_i \times FracLEACH) \quad (3B.5a\_3)$$

Where FN and $UN_{ijMMS=4}$ = mass of nitrogen in solid storage.

$FracWETMMS_i$ = fraction of N available for leaching and runoff (Appendix 5.J.2)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

Annual leaching and runoff emissions from dairy manure management systems are calculated as:

$$E = MNLEACH \times EF \times C_g \quad (3B.5a\_4)$$

Where E = annual emissions from leaching and runoff (Gg N_2O)

MNLEACH = mass of N lost through leaching and runoff (Gg N)

EF = 0.0075 (Gg N_2O-N/Gg N) IPCC (2006) default EF

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.4.3 Beef cattle – pasture (3.B.1.B)

5.4.3.1 Methane

Methane production from the manure (M_{ijkl} kg/head/day) of pasture based beef cattle is calculated as:

$$M_{ijkl} = I_{ijkln} \times (1 - DMD_{ijk}) \times ((PW_j \times EFW) + (PT_j \times EFT)) \quad (3B.1b\_1)$$

Where I_{ijkln} = dry matter intake calculated in Section 5.3.2.2

DMD_{ijk} = dry matter digestibility (expressed as a fraction) (Appendix 5.B.3) EFW = warm emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001)

EFT = temperate emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001)

PW_j = proportion of animals in warm climate region (Appendix 5.B.7)

PT_j = proportion of animals in temperate climate region (Appendix 5.B.7)

The annual methane production (Gg) from the manure of free-range beef cattle is calculated as:

$$Total = \Sigma_i\Sigma_j\Sigma_k\Sigma_l (N_{ijkl} \times M_{ijkl} \times 91.25) \times 10^{-6} \quad (3B.1b\_2)$$

Where N_{ijkl} = numbers of beef cattle in each State, class and season

M_{ijkl} = methane production (kg/head/day)

5.4.3.2 Nitrous oxide emissions

As the manure of pasture based beef cattle is deposited direct to "pasture range and paddock" there are no direct or indirect manure management N_2O emissions. The nitrogen voided in dung and urine of grazed livestock, as calculated in this section provides the basis of calculating nitrous oxide emissions from agricultural soils in source category 3D.

The amount of nitrogen that is retained by the body (NR_{ijkl} kg/head/day) is calculated as the amount of nitrogen retained as milk and body tissue such that:

$$NR_{ijkln} = (0.032 \times MP_{ijkl} /6.38) + \{\{0.212-0.008(L_{ijkln} - 2) - [(0.140-0.008(L_{ijkln} -2)) / (1+\exp(-6(Z_{ijkln} - 0.4)))]\} \times (LWG_{ijkln} \times 0.92)\}/6.25) \quad (3B.1b\_3)$$

Where MP_{ijkln} = milk production (kg/head/day) calculated as: proportion of cows lactating (LC_{ijkl}) x milk production. In areas where Brahman cross breeds are dominant (NT, Qld and Kimberly WA) milk production is 4 kg/day for cows >2 years old in the first season after calving and 3 kg/day in the second season. In other areas where Hereford or Shorthorn breeds are dominant (all other States) considered to be 6 and 4 kg/day (Appendix 5.B.5)

L_{ijkln} = Intake relative to that needed for maintenance. Calculated as actual intake divided by maintenance intake (i.e. intake of non-lactating animal with LWG set to zero calculated by equation 3A.1b_1)

Z_{ijkln} = relative size (liveweight / standard reference weight (Appendix 5.B.6))

LWG_{ijkln} = liveweight gain (kg/day) (Appendix 5.B.2)

Nitrogen excreted in faeces (F_{ijkl} kg/head/day) is calculated, using equations developed by the SCA (1990) and Freer *et al.* (1997), as the indigestible fraction of the undegraded protein from solid feed, microbial crude protein and milk protein plus the endogenous faecal protein, such that:

$$F_{ijkln} = (\{0.3((I_{ijkln} \times CP_{ijk}) \times (1-[(DMD_{ijk}+10)/100])) + 0.105(ME_{ijk} \times I_{ijkln} \times 0.008) + (0.0152 \times I_{ijkln})\}/6.25) + (0.08(0.032 \times MC_{ijkl})/6.38) \quad (3B.1b\_4)$$

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Where I_{ijkl} = dry matter intake (kg/head/day) as calculated in Section 5.3.2.2

CP_{ijkl} = crude protein content of feed dry matter expressed as a fraction (Appendix 5.B.4)

DMD_{ijkl} = dry matter digestibility (expressed as a per cent) (Appendix 5.B.3)

ME_{ijkl} = metabolizable energy (MJ/kg DM) calculated by Minson and McDonald (1987) as: $ME = 0.1604\ DMD_{ijk} - 1.037$; (DMD expressed as per cent)

I_{ijkl} = feed intake (kg DM/head/day)

MC_{ijkl} = milk intake (kg/head/day). In areas where Brahman cross breeds are dominant (NT, Qld and Kimberly WA) milk intake is 4 kg/day for animals in the first season after birth and 3 kg/day in the second season. In other areas where Hereford or Shorthorn breeds are dominant (all other States) intake is 6 and 4 kg/day (Appendix 5.B.5)

Nitrogen excreted in urine (U_{ijkl} kg/head/day) is calculated by subtracting NR_{ijkl}, F_{ijkl} and dermal protein loss from the nitrogen intake such that:

$$U_{ijkln} = (I_{ijkln} \times CP_{ijk} / 6.25) + (0.032 \times MC_{ijkl} / 6.38) - NR_{ijkl} - F_{ijkl} - [(1.1 \times 10^{-4} \times W_{ijkl}^{0.75}) / 6.25] \quad (3B.1b\_5)$$

Where W_{ijkl} = liveweight (Appendix 5.B.1)

The total annual faecal (AF_{ijkl} Gg) and urinary (AU_{ijkl} Gg) nitrogen excreted to "pasture range and paddock" is calculated as:

$$AF_{ijkln\ MMS=14} = (N_{ijkln} \times F_{ijkln} \times 91.25) \times 10^{-6} \quad (3B.1b\_6a)$$

$$AU_{ijkln\ MMS=14} = (N_{ijkln} \times U_{ijkln} \times 91.25) \times 10^{-6} \quad (3B.1b\_6b)$$

Where N_{ijkln} = the number of beef cattle adjusted for feedlot cattle in each State, region, season and class

5.4.4 Beef cattle – feedlot (3.B.1.C)

5.4.4.1 Methane

The high density of animals in feedlots results in high concentrations of manure from which methane can be produced when the dung pack becomes moistened and anaerobic microsites occur. Emissions may also arise from compacted manure stockpiles which are typically anaerobic, and from effluent storage ponds built to contain runoff. These storage ponds are usually anaerobic, providing conditions conducive to methane production. However, because most manure is handled in drylot and solid storage, only a small fraction of the potential methane emissions is generated.

Volatile solid production for beef cattle in feedlots (VS_j kg/head/day) was estimated using the calculation from the mass balance model developed for Australian feedlots — BeefBal (McGahan *et al.* 2004) and the intakes developed to calculate enteric methane production:

$$VS_j = I_j \times (1 - DMD_j) \times (1 - A) \quad (3B.1c\_1)$$

Where I_j = dry matter intake as calculated in section 5.3.2.3

DMD_j = digestibility expressed as a fraction (Appendix 5.C.2)

A = ash content expressed as a fraction (16 per cent) – The use of the ash content of 16 per cent used in BeefBal is based on measured data from Australia. Data presented in Gopalan *et al.* (2013) confirm VS fractions in fresh manure of between 79 per cent and 88 per cent with an average of 83 per cent. These results support the use of an ash content of manure of 16 per cent.

Methane production from the manure management (M_j kg/head/day) is then calculated as:

$$M_j = VS_j \times B_o \times iMCF_i \times \rho \qquad (3B.1c\_2)$$

Where B_o = emissions potential (0.19m^3 CH_4/kg VS (IPCC 2006))

Australia's B_O value is based on independent research measuring average B_O values in Australian feedlots. Results obtained were very similar to the IPCC default values for North America, and therefore it was recommended that the North American B_O value be applied to Australia (*Wiedemann et al* 2014). These findings constitute an independent validation of the use of the default value for North America as a country specific value.

$iMCF_i$ = integrated MCF for feedlot cattle in each state (Appendix 5.C.3).

ρ = density of methane (0.6784 kg/m^3) – Taken from the National Greenhouse and Energy Reporting (Measurement) Determination (DoEE 2016)

The annual methane production (Gg) from the manure of beef cattle in feedlots is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_j \times 10^{-6}) \qquad (3B.1c\_3)$$

Where N_{ij} = Annual equivalent numbers of beef cattle in feedlots

M_j = methane production (kg/head/day)

5.4.4.2 Direct nitrous oxide emissions

The excretion of nitrogen from feedlot cattle is estimated from the nitrogen intake (NI_j) and the fraction retained (NR_j).

The nitrogen intake NI_{ij} (kg/head/day) of feedlot cattle is calculated by:

$$NI_j = I_j \times CP_j / 6.25 \qquad (3B.1c\_4)$$

Where I_j = dry matter intake as calculated in section 5.3.2.3)

CP_j = crude protein content of feed expressed as a fraction (Appendix 5.C.2)

6.25 = factor for converting crude protein into nitrogen

Nitrogen excretion NE_j (kg/head/day) is calculated by:

$$NE_j = NI_j \times (1 - NR_j) \qquad (3B.1c\_5)$$

Where NR_j = nitrogen retention expressed as a fraction of intake (Appendix 5.C.1)

The annual nitrogen excretion (AE_{ij} Gg/year) from feedlot cattle is calculated as:

$$AE_{ij} = N_{ij} \times NE_j \times 365 \times 10^{-6} \qquad (3B.1c\_6)$$

Where N_{ij} = Annual equivalent numbers of beef cattle in each class in each State

The total direct emissions of nitrous oxide from feedlot cattle (Gg) can be calculated as follows:

$$Total_{MMS} = \Sigma_i \Sigma_j (AE_{ij} \times iNOF \times C_g) \qquad (3B.1c\_7)$$

Where iNOF = integrated N_2O emission factor for each feedlot class and state (Appendix 5.C.3)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.4.4.3 Indirect nitrous oxide emissions (3.B.5)

Atmospheric Deposition

Integrated $FracGASM_{MMS}$ values (Appendix 5.C.3) based on IPCC (2006) default and Australian research values (Appendix 5.C.7) are used to estimate N volatilisation.

The mass of feedlot waste volatilised is calculated as:

$$MNATMOS_{ij} = \Sigma_i \Sigma_j (N_{ij} \times AE_{ij} \times iFracGASM_{MMS}) \quad (3B.5c\_1)$$

Where AE = mass of nitrogen excreted as calculated in equation 3B1c_6.

$iFracGASM_{MMS}$ = integrated fraction of N volatilised from feedlot cattle (Appendix 5.C.3).

Annual atmospheric deposition emissions from manure management systems are calculated as:

$$E = MN_{ATMOS} \times EF \times C_g \quad (3B.5c\_2)$$

Where E = annual emissions from atmospheric deposition (Gg N_2O)

MNATMOS = mass of N volatilised (Gg N)

EF = 0.002 (Gg N_2O-N/Gg N) (Inorganic fertiliser EF for non-irrigated cropping – Table 5.24)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Leaching and Runoff

Australian feedlots are managed with strict environmental controls on leaching, requiring the use of an impermeable barrier depending on underlying strata (MLA, 2012, Skerman, 2000). Leaching is therefore assumed to be zero. Runoff from feedlots is captured in effluent ponds. The emissions associated with the waste runoff are therefore included in the direct emission estimates.

5.4.5 Sheep (3.B.2)

5.4.5.1 Methane

Methane production from the manure (M_{ijk} kg/head/day) of sheep is calculated as:

$$M_{ijk} = I_{ijk} \times (1 - DMD_{ijk}) \times EFT \quad (3B.2\_1)$$

Where I_{ijk} = dry matter intake calculated in Section 5.3.3

EFT = temperate emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001).

The annual methane production (Gg) from the manure of sheep is calculated as:

$$Total = \Sigma_i \Sigma_j \Sigma_k (N_{ijk} \times M_{ijk} \times 91.25) \times 10^{-6} \quad (3B.2\_2)$$

Where N_{ijk} = numbers of sheep in each State, class and season

M_{ijkl} = methane production (kg/head/day)

Agriculture

5.4.5.2 Nitrous oxide emissions

As the manure of sheep is deposited direct to "pasture range and paddock" there are no direct or indirect manure management N_2O emissions. The nitrogen voided in dung and urine of grazed livestock, as calculated in this section provides the basis of calculating nitrous oxide emissions from agricultural soils in source category 3D.

The methodology for calculating the excretion of nitrogen from sheep makes use of the following algorithms to calculate crude protein input (CPI_{ijk}) and N retention (NR_{ijk}) and from these the output of nitrogen in the faeces and urine.

The crude protein intake CPI_{ijk} (kg/head/day) of sheep is calculated thus:

$$CPI_{ijk} = I_{ijk} \times CP_{ijk} + (0.045 \times MC_{ijk}) \quad (3B.2\_3)$$

Where I_{ijk} = feed intake (kg DM/head/day) as calculated in Section 5.3.3

CP_{ijk} = crude protein content of feed intake expressed as a fraction (Appendix 5.D.4)

MC_{ijk} = milk intake (kg/head/day) calculated as: proportion of lambs receiving milk in each season x milk intake (Appendix 5.D.6). Milk intake assumed to be 1.6 kg/day for the first three months after the birth of lambs

The amount of nitrogen retained by the body (NR_{ijk} kg/head/day) is calculated as the nitrogen retained in milk, wool and body tissue such that:

$$NR_{ijk} = \{(0.045 \times MP_{ijk}) + (WP_{ijk} \times 0.84) + \{[(212- 4\{[(EBG_{ijk} \times 1000)/(4 \times SRW_{ijk}^{0.75})] - 1\}) - (140 - 4\{[(EBG_{ijk} \times 1000)/(4 \times SRW_{ijk}^{0.75})] - 1\}) / \{1+\exp(-6(Z_{ijk}-0.4))\}] \times EBG_{ijk}\}/1000\} /6.25 \quad (3B.2\_4)$$

Where MP_{ijk} = milk production (kg/day) calculated as: proportion of ewes lactating (LE_{ijk}) x milk production. Milk production is considered to be 1.6 kg/day for breeding ewes in the first three months after the birth of lambs.

WP_{ijk} = clean wool production (kg/day) based on ABS average greasy wool production per head multiplied by State average clean yield percentage. Wool production may be reduced by 50 per cent for lactating ewes (SCA 1990). Accordingly, wool production of ewes was apportioned pro rata to give recorded annual average wool production. It is assumed that clean wool consists of 16 per cent water and 84 per cent protein.

EBG_{ijk} = empty body gain which is equivalent to LWG_{ijk} x 0.92

SRW_{ijk} = standard reference weight (SCA 1990) in Appendix 5.D.7

Z_{ijk} = relative size (liveweight / standard reference weight)

Nitrogen excreted in faeces (F_{ijk} kg/head/day) is calculated, using functions developed by the SCA (1990) and Freer *et al.* (1997), as the indigestible fraction of the undegraded protein from solid feed, the microbial crude protein and milk protein plus the endogenous faecal protein, such that:

$$F_{ijk} = \{0.3(CPI_{ijk} \times (1-[(DMD_{ijk}+10)/100])) + 0.105(ME_{ijk} \times I_{ijk} \times 0.008) + 0.08(0.045 \times MC_{ijk}) + 0.0152 \times I_{ijk}\}/6.25 \quad (3B.2\_5)$$

Where DMD_{ijk} = digestibility expressed as a percentage (Appendix 5.D.2)

ME_{ijk} = metabolizable energy (MJ/kg DM) calculated as 0.1604 DMD_{ijk} −1.037 (Minson and McDonald 1987)

MC_{ijk} = milk intake (kg/day) calculated as: proportion of lambs receiving milk in each season x milk intake (Appendix 5.D.6). Milk intake assumed to be 1.6 kg/day for the first three months after the birth of lambs

1/6.25 = factor for converting crude protein into nitrogen

Nitrogen excreted in urine (U_{ijk} kg/head/day) is calculated by subtracting the nitrogen retained (NR_{ijk}) and the nitrogen excreted in the faeces (F_{ijk}) from the nitrogen intake such that:

$$U_{ijk} = (CPI_{ijk} / 6.25) - NR_{ijk} - F_{ijk} \quad \text{(3B.2\_6)}$$

The annual faecal (AF_{ijk} Gg) and urinary (AU_{ijk} Gg) nitrogen excreted to "pasture range and paddock" is calculated as:

$$AF_{ijk\ MMS=14} = (N_{ijk} \times F_{ijk} \times 91.25) \times 10^{-6} \quad \text{(3B.2\_7a)}$$

$$AU_{ijk\ MMS=14} = (N_{ijk} \times U_{ijk} \times 91.25) \times 10^{-6} \quad \text{(3B.2\_7b)}$$

Where N_{ijk} = the number sheep in each State, season and class

5.4.6 Pigs (3.B.3)

5.4.6.1 Methane

In Australia, pigs are generally housed and the liquid waste slurry produced during cleaning is often channeled into lagoons. These lagoons tend to create anaerobic conditions, resulting in a high proportion of the volatile solids being fermented with the formation of methane.

A significant proportion of feed given to pigs can be wasted (ranging from 5-20 per cent). This waste feed also contributes volatile solids to the manure management system and will result in methane emissions. For completeness, emissions are estimated from all waste entering the manure management system.

PIGBAL (Skerman *et al.* 2013) is a nutrient balance model for intensive piggeries in Australia. By entering typical animal characteristic, intakes, diet compositions and wastage rates, the model calculates the volatile solids (VS_{ij} kg/head/day) in the animal manure and waste feed (Appendix 5.E).

Using this information CH_4 production from the wastes (M_{ij} kg/head/day) can thus be calculated as:

$$M_{ij} = VS_{ij} \times B_o \times iMCF_i \times \rho \quad \text{(3B.3\_1)}$$

Where VS_{ij} = volatile solids production (kg/head/day) (Appendix 5.E.3)

B_o = methane emission potential (0.45m³ CH_4/kg VS – IPCC 2006)

$iMCF_i$ = integrated methane conversion factor based on the proportion of different manure management regimes (Appendix 5.E.4)

ρ = density of methane (0.6784kg/m³) – Taken from the National Greenhouse and Energy Reporting (Measurement) Determination (DoEE 2016)

The annual methane production (Gg) from the wastes of Australian pigs is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_{ij} \times 10^{-6}) \quad \text{(3B.3\_2)}$$

Where N_{ij} = numbers of pigs in each class for each State

M_{ij} = methane production (kg/head/day)

Agriculture

5.4.6.2 Direct nitrous oxide emissions

Pigs are fed high quality diets with high levels of crude protein. The rapid growth rates of most pigs result in a relatively high proportion of this nitrogen being retained in the body. Pigs may excrete between 45 and 65 per cent of nitrogen consumed in feed (King and Brown 1993, King *et al.* 1993).

Wasted feed also contributes nitrogen to the manure management systems and is included in the estimation of emissions for completeness. The nutrient balance model PIGBAL (Skerman *et al.* 2013) is used to estimate total nitrogen in wastes based on typical animal characteristics, intakes, feed types and wastage rates (Appendix 5.E).

The annual nitrogen (AE_{ij} Gg/year) from pig manure and waste feed is calculated as:

$$AE_{ij} = N_{ij} \times E_{ij} \times 10^{-6} \quad \text{(3B.3\_3)}$$

Where N_{ij} = numbers of pigs in each class in each State

E_{ij} = nitrogen in waste (kg/head/year) as calculated by PIGBAL (Appendix 5.E.3)

The total emissions of nitrous oxide from the different manure management systems (Gg) can then be calculated as follows:

$$Total_{MMS} = \Sigma_i \Sigma_j (AE_{ij} \times iNOF \times C_g) \quad \text{(3B.3\_4)}$$

Where iNOF = the integrated nitrous oxide emission factor for pigs in each state (Appendix 5.E.4).

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.4.6.3 Indirect nitrous oxide emissions

Atmospheric Deposition

Australia has developed integrated $FracGASM_{MMS}$ values (Appendix 5.E.4) for pigs based on default IPCC (2006) and country specific values (Appendix 6.E.8).

The mass of piggery waste volatilised is calculated as:

$$M_{ATMOS} = \Sigma_i \Sigma_k (N_{ij} \times AE_{ij} \times iFracGASM_{MMS}) \quad \text{(3B.5c\_1)}$$

Where AE_{ij} = mass of nitrogen excreted as calculated in equation 3B3_3.

$iFracGASM_{MMS}$ = the integrated fraction of N volatilised for the pig industry (Appendix 6.E.4)

Annual indirect nitrous oxide production from pig manure management systems is calculated as:

$$E = MN_{ATMOS} \times EF_{ijk} \times C_g \quad \text{(3B.5c\_2)}$$

Where E = annual emissions from atmospheric deposition (Gg N_2O)

MN_{ATMOS} = mass of N volatilised (Gg N)

EF_{ij} = 0.002 (Gg N_2O-N/Gg N) (Inorganic Fertiliser EF for non-irrigated cropping – Table 5.24)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Agriculture

Leaching and Runoff

Leaching and runoff from piggery facilities (with the exception of outdoor piggeries) is considered negligible because of strict environmental regulations in all states of Australia. The emissions associated with leaching and runoff are therefore only estimated for the drylot manure management system.

$MNLEACH_{ij} = \Sigma_i \Sigma_k (N_{ij} \times AE_{ij} \times MS_{iMMS=5} \times FracWETMMS_i \times FracLEACH)$ ...... (3B.5c_3)

Where AE_{ij} = mass of nitrogen in waste as calculated in equation 3B3_3.

$MS_{iMMS=5}$ = fraction was waste handled through drylot (Appendix 5.E.5)

$FracWETMMS_i$ = fraction of N available for leaching and runoff (Appendix 5.J.2)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

Annual leaching and runoff emissions from pig manure management systems are calculated as:

$E = MNLEACH_{ij} \times EF \times C_g$ ...... (3B.5c_4)

Where E = annual emissions from leaching and runoff (Gg N_2O)

$MNLEACH_{ij}$ = mass of N lost through leaching and runoff (Gg N)

EF = 0.0075 (Gg N_2O-N/Gg N) IPCC (2006) default EF

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.4.7 Poultry (3B.4.G)

Table 5.16 Symbols used in algorithms for poultry

State (i)	Poultry Classes (j)	Poultry subclass
1 = ACT	1 = Layer	
2 = Northern Territory	2 = Meat	2a = Meat Chicken Growers
3 = NSW		2b = Meat Chicken Breeders
4 = Queensland		2c = Other
5 = Tasmania		
6 = South Australia		
7 = Victoria		
8 = Western Australia		

5.4.7.1 Methane

The majority of Australia's poultry population are housed indoors which promotes conditions for the concentration and concentrated treatment of faecal wastes. Methane from manure is formed from the organic fraction of the manure (volatile solids). Volatile solid production (VS_{ij} kg/head/day) for poultry was estimated using information on intakes and dry matter digestibility:

$VS_{ij} = I_{ij} \times (1 - DMD_{ij}) \times (1 - A)$ ...... (3B.4g_1)

Where I_{ij} = dry matter intake (Appendix 5.F.1)

DMD_{ij} = digestibility expressed as a fraction (Appendix 5.F.1)

A = ash content of manure expressed as a fraction (Appendix 5.F.1)

Methane production from the manure (M_{ij} kg/head/day) can then be calculated as:

$$M_{ij} = VS_{ij} \times B_o \times iMCF_{ij} \times \rho \quad (3B.4g\_2)$$

Where B_o = emission potential (0.36 m^3 CH_4/kg VS for meat and 0.39 m^3 CH_4 / kg VS for layers (IPCC 2006))

$iMCF_{ij}$ = Integrated methane conversion factor (Appendix 5.F.2)

ρ = density of methane (0.6784 kg/m^3) – Taken from the National Greenhouse and Energy Reporting (Measurement) Determination (DoEE 2016)

The annual methane production (Gg) is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_{ij} \times 10^{-6}) \quad (3B.4g\_3)$$

Where N_{ij} = number of birds in each class and state

M_{ij} = methane production (kg/head/day)

5.4.7.2 Direct nitrous oxide emissions

The methodology for calculating the excretion of nitrogen from meat and layer birds makes use of the following algorithms to calculate nitrogen intake (NI_{ij}) and retention (NR_{ij}) and from these the output of nitrogen in the manure.

The nitrogen intake NI_j (kg/head/day) of poultry is calculated by:

$$NI_j = I_j \times CP_j / 6.25 \quad (3B.4g\_4)$$

Where I_j = dry matter intake in kg/day (Appendix 5.F.1)

CP_j = dietary crude protein expressed as a fraction (Appendix 5.F.1)

6.25 = factor for converting crude protein into nitrogen

Nitrogen excretion (NE_{ij}) (Gg/head/year) is calculated by:

$$NE_j = NI_j \times (1-NR_j) \times 365 \times 10^{-6} \quad (3B.4g\_5)$$

Where NR_j = nitrogen retention as a proportion of intake (Appendix 5.F.1)

The total emissions of nitrous oxide from the different manure management systems (Gg) can then be calculated as follows:

$$Total_{MMS} = \Sigma_i \Sigma_j (N_{ij} \times NE_j \times iNOF_j \times C_g) \quad (3B.4g\_6)$$

Where N_{ij} = annual equivalent number of birds in each class and state

NE_{ij} = N excretion (Gg/head/year)

$iNOF_j$ = the integrated nitrous oxide emission factor (Appendix 6.F.2).

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.4.7.3 Indirect nitrous oxide emissions

Atmospheric Deposition

Integrated FracGASM values (Appendix 6.F.2) based on default IPCC (2006) and country specific values (Appendix 6.F.8) are used to estimate N volatilisation from poultry.

The mass of poultry waste volatilised is calculated as:

$M_{ATMOS} = \Sigma_i\Sigma_j (N_{ij} \times NE_{ij} \times iFracGASM_{MMSj})$ .... (3B.5d_1)

Where NE = mass of nitrogen excreted (Gg/head/year) as calculated in equation 3B4g_5.

$iFracGASM_{MMSj}$ = the integrated fraction of N volatilised for the meat and layer industries (Appendix 6.F.2)

Annual indirect nitrous oxide production from poultry manure management systems is calculated as:

$E = MN_{ATMOS} \times EF_{ijk} \times C_g$ .... (3B.5d_2)

Where E = annual emissions from atmospheric deposition (Gg N_2O)

MN_{ATMOS} = mass of N volatilised (Gg N)

EF_{ij} = 0.002 (Gg N_2O-N/Gg N) (Meat = Inorganic fertiliser EF for non-irrigated pastures; Layers = Inorganic Fertiliser EF for non-irrigated cropping – Table 5.24)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Leaching and Runoff

Leaching and runoff from poultry facilities (with the exception of free range operations and manure stockpiles) is considered negligible. The emissions associated with the waste leaching and runoff are therefore only estimated for manure stockpiles. Emission from free range operations are estimated in the Agricultural Soils category 3D.

$MN_{LEACH} = \Sigma_i\Sigma_j (N_{ij} \times NE_{ij} \times MS_{iMMS=4-5} \times FracWET_{MMS_i} \times Frac_{LEACH})$ .... (3B.5d_3)

Where NE_{ij} = mass of nitrogen excreted (Gg/head/year) as calculated in equation 3B4g_5.

$MS_{iMMS=4-5}$ = fraction was waste handled through drylot and solid storage (Appendix 5.F.3)

$FracWET_{MMS_i}$ = Fraction of N available for leaching and runoff (Appendix 5.J.2)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

Annual leaching and runoff emissions from poultry manure management systems are calculated as:

$E = \Sigma_i\Sigma_j (MN_{LEACH_{ij}} \times EF \times C_g)$ .... (3B.5d_4)

Where E = annual emissions from atmospheric deposition (Gg N_2O)

$MN_{LEACH_{ij}}$ = mass of N lost through leaching and runoff (Gg N)

EF = 0.0075 (Gg N_2O-N/Gg N) IPCC (2006) default EF

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.4.8 Other livestock (including 3.B.4. A-F,H and I)

5.4.8.1 Methane

Goats, deer, buffalo, camels, alpaca, horses, donkeys, mules, emus and ostriches are range-kept livestock and hence, manure deposition typically occurs in a dispersed fashion. Little is known about the amount of manure produced by the livestock types in this group. In the absence of adequate information, it was assumed that the rates of manure production (DMM_{ij} kg DM/head/year) can be scaled to those calculated for either sheep or beef cattle based on the comparative size of the animals (Appendix 5.G.1). For example, the IPCC default weight for horses (377 kg) and buffalo (380 kg) are consistent with the average weight of beef cattle (380 kg) while the default weight of donkeys (130 kg) and goats (38.5 kg) are consistent with one third of beef cattle (127 kg) and sheep (45 kg) weights respectively.

Methane production from the manure (M_{ij} kg/head/day) is calculated as:

$$M_{ij} = (DMM_{ij} \times PW_i \times EFW) + (DMM_{ij} \times PT_i \times EFT) \quad (3B.4\_1)$$

Where DMM_{ij} = dry matter in manure (Appendix 5.G.1)

EFW = warm emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001).

EFT = temperate emission factor (kg CH_4 / kg DM Manure) (Gonzalez-Avalos and Ruiz-Suarez 2001).

PW_i = proportion of animals in warm climate region (Appendix 5.G.3)

PT_i = proportion of animals in temperate climate region (Appendix 5.G.3)

The annual methane production (Gg) from the manure of other livestock is calculated as:

$$Total = \Sigma_i \Sigma_j (N_{ij} \times M_{ij}) \times 10^{-6} \quad (3B.4\_2)$$

Where N_{ij} = numbers of animals in each State

M_{ij} = methane production (kg/head/day)

5.4.8.2 Nitrous oxide emissions

As the manure of these other livestock is deposited direct to "pasture range and paddock" there are no direct or indirect manure management N_2O emissions. The nitrogen voided in dung and urine of grazed livestock, as calculated in this section provides the basis of calculating nitrous oxide emissions from agricultural soils in source category 3D.

In the absence of adequate species specific information, it was assumed that the rates of nitrogen excretion (E_{ij} kg/head/year) can be scaled to those calculated for either sheep or beef cattle based on the comparative size of the animals (Appendix 5.G.2).

The annual nitrogen (AE_{ij} Gg/year) excreted to "pasture range and paddock" is calculated as:

$$AE_{ijMMS=14} = (N_{ij} \times E_{ij}) \times 10^{-6} \quad (3B.4\_3)$$

Where N_{ij} = numbers in each State

E_{ij} = nitrogen excreted (kg/head/year) (Appendix 5.G.2)

Agriculture

The annual nitrogen excreted in faeces (AF) and Urine (AU) excreted to "pasture range and paddock" is calculated as:

$$AF_{ij\,MMS=14} = \Sigma_j\,(AE_{ij\,MMS=14} \times PMF) \quad (3B.4\_4)$$

$$AU_{ij\,MMS=14} = \Sigma_j\,(AE_{ij\,MMS=14} \times PMU) \quad (3B.4\_5)$$

Where PMF = the proportion of waste that is faeces. Assumed to be 0.29 (based on average of cattle and sheep).

PMU = the proportion of waste that is urine. Assumed to be 0.71 (based on average of cattle and sheep).

5.4.9 Uncertainties and time series consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for manure management were estimated to be in the order of 37-55 per cent. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

5.4.10 Source specific QA/QC

5.4.10.1 Activity data

The Australian Bureau of Statistics (ABS) is the national statistical agency of Australia and is the key provider of activity data for this source category. ABS has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values.

Data quality used in the inventory is also kept under review by the Department. This source category is also covered by the general QA/QC procedures detailed in Chapter 1. The QC procedure "ensuring consistency in data between categories" is of specific importance for this category. The AGEIS ensures that activity and livestock characterisation data used across multiple categories is entered only once and that intakes or emissions calculated in one category form the input for other categories.

5.4.10.2 Implied emission factors

Comparison with IPCC defaults

As country specific tier 2 methods are used to estimate emissions from cattle, sheep, pigs and poultry, the IEFs have been compared with the IPCC defaults (Table 5.17).

Table 5.17 Implied emission factors – Methane manure management (kg/head/year)

Livestock Type	Australia	IPCC Default (Oceania)
Dairy Cattle	15	23-31
Beef cattle		
Pasture	0.02	1-2
Feedlot	3.5	1-2
Sheep	0.0015	0.19-0.37
Swine	23.30	11-24
Poultry	0.04	0.02-1.4

Source: IPCC 2006, CS = country specific; EF = emission factor; VS = volatile solids

The IEFs for dairy cattle differ from the IPCC defaults because of the allocation of waste to difference MMS. Australia assumes that 80-88 per cent of waste is voided at pasture compared with 76 per cent in the IPCC default.

The IEFs for range-kept beef cattle, sheep and all other range kept animals are significantly lower than the IPCC defaults because of the country specific EF used (Section 5.4.1.1). The pig IEF is on the high end of the IPCC range. The IPCC default assumes that 50 per cent, of manure passes through an anaerobic pond, while Australian management practices see this elevated to ~70 per cent.

The IPCC default Bo value for North America has been chosen for beef cattle based on the recommendations contained in Wiederman *et al*. 2014. The following excerpt (from p7 of the document) explains the choice: "The default methane potential (Bo) in the IPCC (2006) for Oceania is 0.17. Gopalan *et al*.(2013b) measured the Bo of fresh feedlot manure from four Australian feedlots and showed an average Bo of 0.3, declining to 0.205 for manure collected from the feed pad, and to 0.14 for manure in stockpiles. The value measured for feedlot pad manure corresponded closely to the IPCC default for North America. As there are few supporting studies, we recommend applying the IPCC default for North America which approximates the Australian value for manure on the feed-pad."

5.4.10.3 Volatile solids

The major Source of methane emissions from manure management are from the intensive livestock industries. As the intake calculation for cattle and the volatile solid calculations for pigs and poultry differ from the IPCC tier 2 methodologies the estimated volatile solids were compared against the IPCC defaults. These were found to be comparable for dairy cattle, pigs and poultry (Table 5.18). The volatile solid production of feedlot cattle was lower than the IPCC (2006) defaults an ash content of 16 per cent is used compared with the default of 8 per cent. The slightly higher values reported for pigs are likely the consequence of including VS from feed waste.

Table 5.18 Volatile solids (kg/head/day)

Livestock Type	Australia	IPCC Default
Dairy Cows	3.4	2.9-5.4
Beef Cattle – Feedlot	1.9	2.4-3.0
Pigs		
Breeders	0.43-0.57	0.46-5
Other Pigs	0.39	0.27-0.3
Poultry		
Layers	0.014	0.02
Meat	0.016-0.017	0.01-0.02

Source: IPCC 2006

5.4.10.4 Nitrogen excretion

The country specific estimates of nitrogen excretion were compared against the IPCC defaults (Table 5.19). Feedlot cattle, sheep and poultry excretion rates are consistent with the IPCC (2006) defaults.

For other animals excretion rates differ from the IPCC defaults. Unfortunately, unlike volatile solids, the IPCC *Guidelines* do not provide the data on which the default excretion/retention rates are based, so it is impossible to determine whether it is the assumption regarding feed quality causing the difference in excretion rates. Dairy cattle excretion rates are significantly higher than the IPCC defaults. The CS method was compared with excretion rates generated by the IPCC tier 2 and New Zealand methods and was found to give comparable results. Excretion rates for mature animals were almost identical while for growing animals (< 1 year old) the CS method estimated slightly lower N retention and hence higher N excretion that the other methods. Excretion rates for pasture fed beef cattle are just outside the range given by the IPCC. Australia would expect to be at the low end of the range of excretion rates due to the quality of pasture fed to range-kept cattle.

Pig N excretion rates were higher (grower pigs), which could be the result of different feed intake, crude protein intake or N retention assumptions compared to the IPCC.

Table 5.19 Nitrogen excretion rates (kg/head/year)

Livestock Type	Australia	IPCC Default
Dairy cattle (455 kg)	124	58-80
Beef cattle		
Pasture (378 kg)	39	43-69
Feedlot (524 kg)	78	60-96
Sheep (43 kg)	7	5-8
Pigs		
(Sows 188 kg)	18	21-34
(Growers 39 kg)	11	4-7
Poultry	0.6-0.7	0.6-1.0

Source: IPCC 2006

5.4.10.5 External review

Comprehensive expert peer review of the methodologies, activity data and livestock characterisation data were conducted for sheep in 2000-01; dairy and feedlot cattle, pigs and poultry in 2014; and QLD/NT beef cattle on pastures in 2015. The reviews involved agricultural experts from industry, government and academia.

5.4.11 Recalculations since the 2016 Inventory

Recalculations of Manure Management have occurred due to:

- a revision of the milk production data for 2012, 2013, 2014, 2015, and 2016
- a revision of the regional breakdowns of beef cattle pasture for 2012, 2013, 2014, 2015, and 2016
- a revision of 'other livestock' population numbers for 2016
- a revision of sheep population numbers for 2016
- a revision of swine population numbers for 2016

Table 5.20 shows the impact of these recalculations.

Table 5.20 Manure Management (3.B): recalculation of total CO_2-e emissions: 1990-2016

Year	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	2,490	2,490	-	0.0 per cent
2000	2,940	2,940	-	0.0 per cent
2005	3,654	3,654	-	0.0 per cent
2008	3,166	3,166	-	0.0 per cent
2009	3,153	3,153	-	0.0 per cent

Year	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2010	3,282	3,282	-	0.0 per cent
2011	3,371	3,371	-	0.0 per cent
2012	3,351	3,353	1.6	0.05 per cent
2013	3,299	3,300	1.6	0.05 per cent
2014	3,459	3,462	3.2	0.09 per cent
2015	3618	3,618	0.8	0.02 per cent
2016	3575	3,576	0.7	0.02 per cent

5.4.12 Source specific planned improvements

The inventory improvement plan for the agriculture sector identified areas which require updating or review over the next two years. Areas for improvement are identified through the UNFCCC expert reviews, domestic QA/QC process or the expected availability of new data or empirical studies which could improve accuracy of the inventory.

For manure management the following areas have been identified for review and/or change:

1. *Emission Factors (CH_4, N_2O and Volatilisation of N)* – Many of the IPCC defaults are based on limited data. Many countries including Australia have started to undertake additional research in this area. New research on pig and poultry emissions is currently underway in Australia through the National Agricultural Manure Management Program and is expected to deliver results in mid-2015. Over the next two year the EF will be kept under review and will be updated as new data becomes available.

2. Drylot N_2O EF – Recent Australian research (Redding *et al.* (2015); Shorten and Redding (Submitted)) directly measured emissions from the manure layers on several feedlot surfaces using a large chamber. A key finding of this research was that there was no significant relationship between manure N-mass and N_2O emission, contrary to the IPCC (2006) approach. N_2O emissions were observed to be controlled by moisture, temperature, and pen surface area exposed. Nitrate concentration of the manure had a lesser influence. Researchers concluded that the supply of nitrogen in all measured feed-pad manure samples was in excess of that required by the microbial N_2O emission processes, and as a result did not limit emission. Shorten & Redding (submitted) also predicted significantly lower N_2O emissions (0.31 kg N_2O/animal/year) than the IPCC (2006) approach (3.0 kg N_2O/animal/year).

   A second Australian research project using open path FTIR is currently underway with the University of Melbourne to investigate nitrous oxide and ammonia emissions from feedlot feed pads. Preliminary findings from this project support the central finding by Redding *et al.* (2015) that nitrous oxide emissions are not strongly related to N excretion but are related to factors such as moisture and temperature (D. Chen pers. comm., University of Melbourne, June 2014). When data from the additional studies become available the N_2O EFs will be reviewed.

3. Methane Capture and Destruction – a number of piggeries are now capturing and destroying methane from digesters/covered lagoons. Those farms who have participated in the Carbon Farming Initiative have now reported data to the Clean Energy Regulator. This data will be reviewed to determine if it can be used to develop a more accurate MCF based on measurement data.

4. Pre-weaning animal classes – In the 2015 submission separate emission estimates for pre-weaned dairy cattle has been implemented to better reflect the effects of milk intake on CH_4 and N_2O emissions. Over the next two years the methods for beef calves and lambs will also be reviewed.

5. Manure manage system allocations / feed and animal characteristics – As these allocations and characteristic can change as industry practices change over time the current values need to be reviewed periodically. The beef cattle on pasture and sheep industries have been identified as the next priorities for review.

6. *Dairy Cattle and Swine CH_4 B_O value* - Australia currently applies 2006 IPCC default CH_4 B_O values to dairy cattle to dairy cattle and swine. Australia will consider efforts to obtain a country specific value for this parameter in the future.

5.5 Source Category 3.C Rice Cultivation

5.5.1 Source category description

Methane is generated during rice growing from the decomposition of plant residues and other organic carbon material in the soil. This generation occurs through microbial action under anaerobic conditions following flooding of the rice crop.

Methane emission rates vary widely, both diurnally in response to immediate environmental factors such as temperature, and also throughout the season in response to crop development and accompanying changes in soil condition. Emission rates are also dependent on more stable factors including soil type and cultivation method (e.g. irrigation regimes, fertiliser application).

All Australian rice is grown under flooded cultivation and production is highly influenced by availability of water for irrigation. Australian rice cultivation does not have large inputs of organic matter as rice stubble is usually burnt and urea fertilisers are used rather than manures.

Most of the rice grown in Australia is concentrated in the Murrumbidgee and Murray valleys of southern New South Wales. Small areas of rice are also grown in north-eastern Victoria. These climates are considered temperate.

There has also been very small amounts of rice grown in the warmer areas of northern Queensland and Northern territory since 2010. According to the Ricegrowers Association of Australia, rice is a summer cereal crop. Once Australian ricegrowers harvest their rice, they use subsoil moisture remaining to plant either wheat or pasture for animals (http://www.rga.org.au/the-rice-industry.aspx).

5.5.2 Methodology

The IPCC default baseline EF of 1.3 kg CH_4/ha/day with appropriate scaling factors applied for a continuously flooded water regime SF_w = 1 and a non-flooded pre-season of > 180 days SF_p = 0.68 . Over the average 150 day growing season this gives an emission rate for Australia of 132.6 kg CH_4/ha as per equation 5.2 in IPCC 2006:

$$\text{Rice EF} = EFc \times SFw \times SFp \times SFo \times SFs,r$$

Where EFc is the baseline EF for continuously flooded fields without organic amendments (1.3 kg CH_4/ha/day)

SFw is the scaling factor to account for the differences in water regime during the cultivation period (1 for irrigated, continuously flooded production systems)

SFp is the scaling factor to account for the differences in water regime in the pre-season before the cultivation period (0.68 for a non-flooded pre-season > 180 days)

SFo is the scaling factor for organic amendments (as fertiliser is used rather than manure, this factor is not applied)

SFs,r is the scaling factor for soil type, rice cultivar, etc., if available (this information is not available for Australia)

Australia 's Rice EF = 1.3 x 150 x 1 x 0.68.

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Table 5.21 Symbols used in algorithms for rice cultivation

State (i)
1 = ACT
2 = Northern Territory
3 = NSW
4 = Queensland
5 = Tasmania
6 = South Australia
7 = Victoria
8 = Western Australia

Annual production of methane from rice cultivation is calculated as:

$$E_i = A_i \times EF \times 10^{-6} \quad (3C\_1)$$

Where E_i = annual emission (Gg)

A_i = area under rice cultivation (ha).

EF = emission factor integrated over the whole season (132.6 kg CH_4/ha).

5.5.3 Uncertainties and time series consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for rice cultivation were estimated to be in the order of 11 per cent. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use the same methods and data Source for the full time series.

5.5.4 Source specific QA/QC

This source category is covered by the general QA/QC procedures detailed in Chapter 1.

5.5.5 Recalculations since the 2016 Inventory

There were no recalculations affecting this subsector in the 2019 submission.

Table 5.22 Rice Cultivation (3.C): recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	397	397	0	0.0 per cent
2000	434	434	0	0.0 per cent
2005	171	171	0	0.0 per cent
2008	7	7	0	0.0 per cent
2009	24	24	0	0.0 per cent
2010	63	63	0	0.0 per cent
2011	251	251	0	0.0 per cent
2012	342	342	0	0.0 per cent
2013	377	377	0	0.0 per cent
2014	254	254	0	0.0 per cent
2015	231	231	0	0.0 per cent
2016	92	92	0	0.0 per cent

5.5.6 Planned Improvements

All data and methodologies are kept under review.

5.6 Source Category 3.D Agricultural Soils

5.6.1 Source category description and methodology

The emissions of nitrous oxide from soils arise from microbial and chemical transformations that produce and consume nitrous oxide in the soil. The transformations involve inorganic nitrogen compounds in the soil, namely ammonium, nitrite and nitrate. The nitrogen compounds can be added to the soil through the following processes:

a) the application of nitrogen fertilisers
b) the application of animal wastes and sewage sludge to pastures
c) the application of crop residues
d) mineralisation due to cultivation of organic soils
e) mineralisation due to loss of soil carbon
f) atmospheric nitrogen deposition

There is a further source of nitrous oxide associated with the leaching from soils and surface runoff of nitrogen and subsequent denitrification in rivers and estuaries.

5.6.2 Methodology inorganic fertiliser (3.D.A.1)

A country specific method is used to estimate emissions from inorganic fertilisers. The emission factors are based on analyses of Australian measurement studies (Scherbak and Grace 2014; Scherback *et al.* 2014), including those undertaken through programs such as the Nitrous Oxide Research Program (NORP) and the National Agricultural Nitrous Oxide Research Program (NANORP).

This experimental work on the application of fertilisers to different production systems in Australia has shown large variations from the IPCC default EF of 1 per cent across different classes of crop and pasture systems. Variation in EFs with region and production system is to be expected. For example the majority of Australian grain production is from rain-fed cultivation in relatively low rainfall areas where lower rates of nitrogen fertiliser inputs, lower decomposition rates and lower levels of microbial activity (Barton *et al.* 2008) contribute to a lower denitrification potential.

It is also now becoming apparent that the EFs in some productions systems increase with nitrogen applications rates. For example, Scherback *et al.* (2014) have developed a two component (liner + exponential) model for cotton which gives EF (per cent) = 0.29 + (0.007($e^{0.037*N\ application\ rate}$-1)/N application rate.

The emission factors used in the inventory are summarised in Table 5.24.

Calculation of fertiliser applied to each production system

Total fertiliser use in each State is provided by Fertilizer Australia. The fraction of fertiliser applied to each production system (FN_{ij}) was determined for each State by first estimating the mass of N-fertiliser applied to irrigated crops, irrigated pasture, cotton, sugar cane and horticulture using the production areas reported by ABS (e.g. ABS 2010) and the average fertiliser application rates for each of these crops. The balance of the fertiliser

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is then distributed to rain-fed crops and modified pastures (derived from Stewart *et al.* 2001) in proportion to their respective areas. The fertiliser application rates assigned to irrigated crops, irrigated pastures, cotton, and horticultural crops and vegetables are respectively 80 kg N/ha, 80 kg N/ha, 246 kg N/ha, and 125 kg N/ha. For sugar cane, a variable application rate is used (see Appendix 5.H.1). Sugar cane fertiliser application rates in QLD have declined significantly over the time series in response to environmental management legislation.

Table 5.23 Symbols used in algorithms for synthetic fertiliser

State (i)	Activity (j)
1 = ACT	1 = Irrigated pasture
2 = Northern Territory	2 = Irrigated crop
3 = NSW	3 = Non-Irrigated pasture
4 = Queensland	4 = Non-Irrigated crop
5 = Tasmania	5 = Sugar cane
6 = South Australia	6 = Cotton
7 = Victoria	7. Horticulture
8 = Western Australia	

Table 5.24 Nitrous oxide emissions factors for synthetic fertiliser

Production System	Emission Factor(a) (Gg N_2O-N/ Gg N)
Irrigated pasture	0.004
Irrigated crop	0.0085
Non-irrigated pasture	0.002
Non-irrigated crop	0.002(b)
Sugar cane	0.0199
Cotton	0.0055(c)
Horticulture	0.0085

(a) Based on Grace and Scherbak (2014).
(b) Weighted EF assuming 80 per cent of non-irrigated crops occur on low rainfall areas. Low rainfall EF=0.0005 and high rainfall EF = 0.0085.
(c) Based on Scherbak *et al.* (2014) and an N application rate of 246 kg/ha.

Limited amounts of fertiliser are also used in Australian forests. Currently there is no data available to allocate fertiliser use specifically to forestry activities. Given the approach taken to allocating fertiliser, it is assumed that any fertiliser applied for forestry activities will fall under the non-irrigated systems and have an EF of 0.2 per cent applied.

The mass of fertiliser applied to soils is calculated as:

$$M_{ij} = TM_{ij} \times FN_{ij} \quad \text{(3DA\_1)}$$

Where M_{ij} =mass of fertiliser applied to production system j (Gg N)

TM_{ij} = total mass of fertiliser (Gg N)

FN_{ij} =fraction of N applied to production system j

Annual nitrous oxide production from the addition of synthetic fertilisers is calculated as:

$$E_{ij} = \Sigma_i \Sigma_j (M_{ij} \times EF_{ij} \times C_g) \quad \text{(3DA\_2)}$$

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Where E_{ij} = annual emissions from fertiliser (Gg N_2O)

M_{ij} = mass of fertiliser applied in production system j (Gg N)

EF_j = emission factor (Gg N_2O-N/Gg N applied) (Table 5.24)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.3 Animal wastes applied to soils (3.D.A.2.a)

Nitrous oxide is emitted from soil through the metabolism of animal manure derived principally from dairies, feedlots, piggeries and poultry houses and applied to crops and pastures as organic fertiliser. The IPCC default EF for the N_2O emissions from animal waste applied soils (1 per cent) is applied. Inputs to this subsector are calculated in section 5.4.

Table 5.25 Symbols used in algorithms for animal wastes

State (i)	Activity (j)
1 = ACT	1 = Dairy cattle
2 = Northern Territory	2 = Beef cattle – Feedlot
3 = NSW	3 = Pigs
4 = Queensland	4 = Poultry
5 = Tasmania	
6 = South Australia	
7 = Victoria	
8 = Western Australia	

The amount of nitrogen applied to soils is the nitrogen excreted adjusted for the nitrogen that has already been lost as N_2O, NH_3 and NO_x during storage in the different manure management systems.

Thus the nitrogen content of animal waste applied to agricultural soils is calculated as:

$$MN\ Soil_{ij} = \Sigma_{MMS} (((AE_{ij\ MMS=1\text{-}13} \times (1 - EF_{MMS=1\text{-}13} - FracGASM_{j\ MMS=1\text{-}13})) - MNLEACH_{ij\ MMS=1\text{-}13}) \quad (3DA\_3)$$

Where AE = mass of nitrogen excreted as calculated in section 5.4. For dairy cattle AE is the sum of faecal (AF) and urinary (AU) nitrogen.

$EF_{MSS=1\text{-}13}$ = direct nitrous oxide EF from the different manure management systems

$FracGASM_{MMS}$ = fraction of animal waste N volatilised from the different manure management systems t

$MNLEACH_{MMS}$ = mass of animal wastes N leached and runoff as calculated in section 5.4

Annual nitrous oxide production is calculated as:

$$E_{ij} = \Sigma_i \Sigma_j (MN\ Soil_{ij} \times EF \times C_g) \quad (3DA\_4)$$

Where E_{ij} = annual emission from animal waste (Gg N_2O)

$MN\ Soil_{ij}$ = mass of nitrogen in manure applied to agricultural soils (Gg N) (as calculated above)

EF = 0.01 (Gg N_2O-N/Gg N deposited)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.4 Sewage sludge applied to land (3.D.A.2.b)

Treated sewage sludge is applied to land in Australia for the purposes of disposal rather than as a fertiliser for agricultural production due to health concerns. A country specific emission factor based on experimental studies where sewage sludge was applied to soils (Bouwman *et al.* 2002) is used to estimate emissions. The experiments gave an average N_2O emissions factor of 0.9 per cent (0.8 to 1.0 per cent).

Table 5.26 Symbols used in algorithms for sewage sludge applied to lands

State (i)
1 = ACT
2 = Northern Territory
3 = NSW
4 = Queensland
5 = Tasmania
6 = South Australia
7 = Victoria
8 = Western Australia

Annual nitrous oxide production is calculated as:

$$E = \Sigma_i (M_i \times EF \times C_g) \quad \text{(3DA\_5)}$$

Where E = annual emissions from treated sewage sludge applied to lands (Gg N_2O)

M_i = Mass of sewage sludge N applied to lands (Gg)

EF = 0.009 (Gg N_2O-N/Gg N).

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.5 Urine and dung deposited during grazing (3.D.A.3)

Nitrous oxide is emitted from soil through the metabolism of urine and faeces deposited directly on pastures. The IPCC default EF for the N_2O emissions from urine and dung deposition during grazing (1 per cent) is the same as for N additions from inorganic fertiliser, animal wastes applied to soil, crop residues and N mineralisation as a result of loss of soil carbon.

Urine experiments conducted on rainfed legume and annual pastures at Book Book, central NSW (Galbally *et al.* 1994), and irrigated pastures in Kyabram, Victoria (Galbally *et al.* 2005) found emission rates of 0.4 per cent. There are still relatively few measurements of EFs from animal faeces deposited directly to soil in the absence of urine but Flessa *et al.* (1996), Yamulki and Jarvis (1997), and Oenema *et al.* (1997) have reported emission rates from dung of 0.3-0.7 per cent.

As such an EF of 0.4 per cent (0.004 Gg N_2O-N/Gg N), is used to estimate N_2O emissions from urinary and faecal N deposition to soil.

Table 5.27 Symbols used in algorithms for animal wastes

State (i)	Activity (j)
1 = ACT	1 = Dairy cattle
2 = Northern Territory	2 = Beef cattle – pasture
3 = NSW	3 = Sheep
4 = Queensland	4 = Poultry
5 = Tasmania	5 = Other livestock
6 = South Australia	
7 = Victoria	
8 = Western Australia	

Annual nitrous oxide production is calculated as:

$$E_{ijk} = \Sigma_i \Sigma_j \Sigma_k ((AF_{ij\ MMS=14} \times EF_j \times C_g) + (AU_{ij\ MMS=14} \times EF_j \times C_g)) \quad (3DA\_6)$$

Where E_{ijk} = annual emission from animal waste (Gg N_2O)

AF and AU = mass of faecal and urinary nitrogen excreted on pasture range and paddock as calculated in section 5.4. For poultry all N excreted is assumed to be faeces.

EF_j = 0.004 (Gg N_2O-N/Gg N deposited)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.6 Crop Residues (3.D.A.4)

The method used to estimate emissions from crop residues returned to the soil is based on the IPCC tier 2 method and emission factor but using country-specific crop information.

Table 5.28 Symbols used in algorithms for crop residues

State (i)	Crops (j)	Pasture (k)	Renewal system (l)
1 = ACT	1 = Wheat	1 = Lucerne	1 = Intensive (1 in 10 years)
2 = NT	2 = Barley	2 = Other Legume Pasture	2 = Other (1 in 30 years)
3 = NSW	3 = Maize	3 = Grass Clover Mixture	
4 = Qld	4 = Oats	4 = Perennial Pasture	
5 = Tas	5 = Rice	5 = Annual Grass	
6 = SA	6 = Sorghum		
7 = Vic	7 = Triticale		
8 = WA	8 = Other Cereals		
	9 = Pulses		
	10 = Tuber and Roots		
	11 = Peanuts		
	12 = Sugar cane		
	13 = Cotton		
	14 = Hops		
	15 = Oilseeds		
	16 = Forage crops		

The mass of N in crop residues returned to soils is calculated as:

$$M_{ijk} = (P_{ij} \times R_{AGj} \times (1 - F_{ij} - FFOD_{ij}) \times DM_j \times NC_{AGj}) + (P_{ij} \times R_{AGj} \times R_{BGj} \times DM_j \times NC_{BGj)} \quad \text{(3DA\_7)}$$

Where M_{ij} = mass of N in crop residues (Gg N)

P_{ij} = annual production of crop (Gg)

R_{AGj} = residue to crop ratio (kg crop residue/kg crop) (Appendix 5.I)

R_{BGj} = below ground-residue to above ground residue ratio (kg /kg) (Appendix 5.I)

DM_j = dry matter content (kg dry weight/kg crop residue) (Appendix 5.I)

NC_{AGj} = nitrogen content of above-ground crop residue (kg N/kg DM) (Appendix 5.I)

NC_{BGj} = nitrogen content of below-ground crop residue (kg N/kg DM) (Appendix 5.I)

F_{ij} = fraction of crop residue that is burnt (Appendix 5.I)

$FFOD_{ij}$ = fraction of the crop residue that is removed (Appendix 5.I)

The mass of N in pasture residues returned to soils is calculated as:

$$M_{ikl} = (A_{ikl} \times Frac_{Renew\ l} \times (Y_k / 1000) \times (1 - FFOD_{ik}) \times NC_{AGk}) + (A_{ikl} \times Frac_{Renew\ l} \times (Y_k / 1000) \times R_{BGk} \times NC_{BGk)} \quad \text{(3DA \_8)}$$

Where M_{ikl} = mass of N in pasture residues (Gg N)

A_{ikl} = Area of pasture (ha)

$Frac_{Renew\ l}$ = Fraction of pasture renewed = 1/ X where X is the average renewal period in years. X is 10 years for intensive systems and 30 years for other systems

Y_k = Average yield (t DM/ha) (Appendix 5.I)

R_{BGk} = below ground-residue to above ground residue ratio (kg /kg) (Appendix 5.I)

NC_{AGk} = nitrogen content of above-ground crop residue (kg N/kg DM) (Appendix 5.I)

NC_{BGk} = nitrogen content of below-ground crop residue (kg N/kg DM) (Appendix 5.I)

$FFOD_{ik}$ = fraction pasture yield that is removed (Appendix 5.I)

Annual nitrous oxide production is calculated as:

$$E_i = \Sigma_i \Sigma_k \Sigma_l (M_{ijkl} \times EF \times C_g) \quad \text{(3DA \_9)}$$

Where E_j = annual emissions from crop residues (Gg N_2O)

M_{ijkl} = mass of N in crop residues (Gg N)

EF = 0.01 (Gg N_2O-N/Gg N) IPCC default emission factor

C_g = 44/28 factor to convert from elemental mass of N_2O to molecular mass

5.6.7 Mineralisation associated with loss of soil organic matter (3.D.A.5)

Where a loss of soil carbon in *cropland remaining cropland* occurs, this loss will be accompanied by a simultaneous mineralisation of N. This mineralised N is considered as an additional source of N available for conversion to N_2O just as mineralised N released through the decomposition of crop residues (IPCC 2006).

The IPCC (2006) method, using country specific parameters and EFs, is used to calculate N_2O emissions from this source. The C:N value used is 10, reflecting the approximate median value extracted from a survey of national estimates (Snowdon *et al.* 2005). The country specific emission factor for fertiliser additions to non-irrigated crops (0.002) is then applied. In years in which *cropland remaining cropland* is a net sink there will be no emissions reported in this category.

Table 5.29 Symbols used in algorithms for mineralisation associated will loss of soil C

State (i)
1 = ACT
2 = Northern Territory
3 = NSW
4 = Queensland
5 = Tasmania
6 = South Australia
7 = Victoria
8 = Western Australia

Annual nitrous oxide production is calculated as:

$E_j = \Sigma_i (M_i \times NC \times EF \times C_g)$ .... (3DA _10)

Where E_j = annual emissions from mineralisation associated with loss of soil C (Gg N_2O)

M_i = loss of soils carbon in croplands remaining croplands (Gg)

NC = nitrogen to carbon ratio for cropland soils

EF = 0.002 (Gg N_2O-N/Gg N).

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.8 Cultivation of histosols (3.D.A.6)

The default IPCC tier 1 methodology is used to estimate emissions from the cultivation of histosols.

The areas of cultivated histosols are very small in Australia occurring only in Queensland where they are mostly used for sugar cane production and small locations of Gippsland and Western Victoria where peatlands were cleared and subsequently grazed or cropped. The individual patches are typically very small, which leads to significant uncertainty when estimating the national area. There is also a significant area of histosols in Tasmania. However, this land is not cultivated, and therfore, not included in Australia's calculation of cultivated histosols.

Table 5.30 Symbols used in algorithms for cultivation of histosols

State (i)
1 = ACT
2 = Northern Territory
3 = NSW
4 = Queensland
5 = Tasmania
6 = South Australia
7 = Victoria
8 = Western Australia

Annual nitrous oxide production is calculated as:

$E_j = \Sigma_i (A_i \times EF \times C_g \times 10^{-6})$ .... (3DA _11)

Where E_j = annual emissions from cultivation of histosols (Gg N_2O)

A_i = area of cultivated histosols (ha)

EF = 8 kg N_2O-N/ha. IPCC (2000) default emissions factor for mid-latitude organic soils

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.9 Atmospheric deposition (3.D.B.1)

A country specific method is used to estimate emissions from the atmospheric deposition. As the highest deposition rates (kg/ha) are found within a few hundred meters of the emission source, the EFs applied for deposition are related to the source of the N.

For N volatilised from inorganic fertilisers or sewage sludge the EFs applied for atmospheric deposition are the same as those applied for direct N_2O emissions. For N derived from manure Source the inorganic fertiliser EF which best represents the production system immediately surrounding the farm is used to estimate atmospheric deposition emissions.

Table 5.31 Symbols used in algorithms for atmospheric deposition

State (i)	Activity (j)
1 = ACT	1=Inorganic fertiliser
2 = Northern Territory	2=Manure
3 = NSW	3= Sewage sludge applied to land
4 = Queensland	
5 = Tasmania	
6 = South Australia	
7 = Victoria	
8 = Western Australia	

The mass of inorganic fertiliser N volatilised is calculated as:

$M_{ij=1} = TM_{ij=1} \times FracGASF_j$ .... (3DB_1)

Where $M_{ij=1}$ =mass of synthetic fertiliser volatilised (Gg N)

TM_{ij} = total mass of fertiliser (Gg N)

$FracGASF_j$ = 0.1 (Gg N/Gg applied) IPCC (2006) default

The mass of animal waste N deposited on or applied to soils that volatilised is calculated as:

$M_{ij=2} = \Sigma (MNsoil_{ij} + UNsoil_{ij} + FNsoil_{ij}) \times FracGASMSOIL_{ij}$ .... (3DB_2)

Where FracGASMSOIL =0.2 (Gg N/Gg applied) IPCC (2006) default

The mass of sewage sludge N volatilised is calculated as:

$M_{ij=3} = TM_{ij=3} \times FracGASS_j$ .... (3DB_3)

Where $M_{ij=3}$ =mass of sewage sludge volatilised (Gg N)

Agriculture

TM_{ij} = total mass of sewage sludge (Gg N)

$FracGASS_j$ = 0.2 (Gg N/Gg applied) IPCC (2006) default

Annual nitrous oxide production from atmospheric deposition is calculated as:

$$E = \Sigma_i \Sigma_j (M_{ij} \times EF_{ij} \times C_g) \quad \text{(3DB\_4)}$$

Where E = annual emissions from atmospheric deposition (Gg N_2O)

M_{ij} = mass of N volatilised from subset k (Gg N)

EF_{ij} = source specific EF (Gg N_2O-N/Gg N)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.10 Leaching and runoff

Australia is the driest continent, with substantially less runoff than all other continents. In Australia, much of the cropping takes place in semi-arid regions, or regions of marginal rainfall. The IPCC (2006) accept that leaching of applied nitrogen into waterways and estuaries is unlikely where evaporation exceeds precipitation.

The areas of Australia which are unlikely to be susceptible to significant leaching can be identified using the ratio of evapotranspiration to annual precipitation (Et/P). Evapotranspiration is a better measure than evaporation as it takes into account climatic factors (rainfall, humidity, temperature, wind speed) as well as the effect of differences in vegetation classes (forest, shrubland, grassland) on the demand for soil water.

Evapotranspiration has been estimated using the biogeochemical model BIOS (Raupach *et al.* 2000) for the National Land and Water Audit. Et/P ranges up to 1 where all rainfall is returned to the atmosphere. In areas such as wetlands and irrigation areas in inland regions, where water supply additional to precipitation is available Et/P can exceed 1.

In this methodology, we consider leaching to occur where Et/P <0.8 or Et/P >1 (Figure 5.4). Regions outside these areas are considered to be 'dryland' and not subject to leaching. The fraction of each crop and animal class occurring outside the dryland areas (Frac WET) were determined by overlaying the dryland area mask onto the spatial map of crops, pastures and animal density from the 1997 Agricultural census.

Figure 5.4 The ratio of mean annual evapotranspiration to annual precipitation (Et/P)

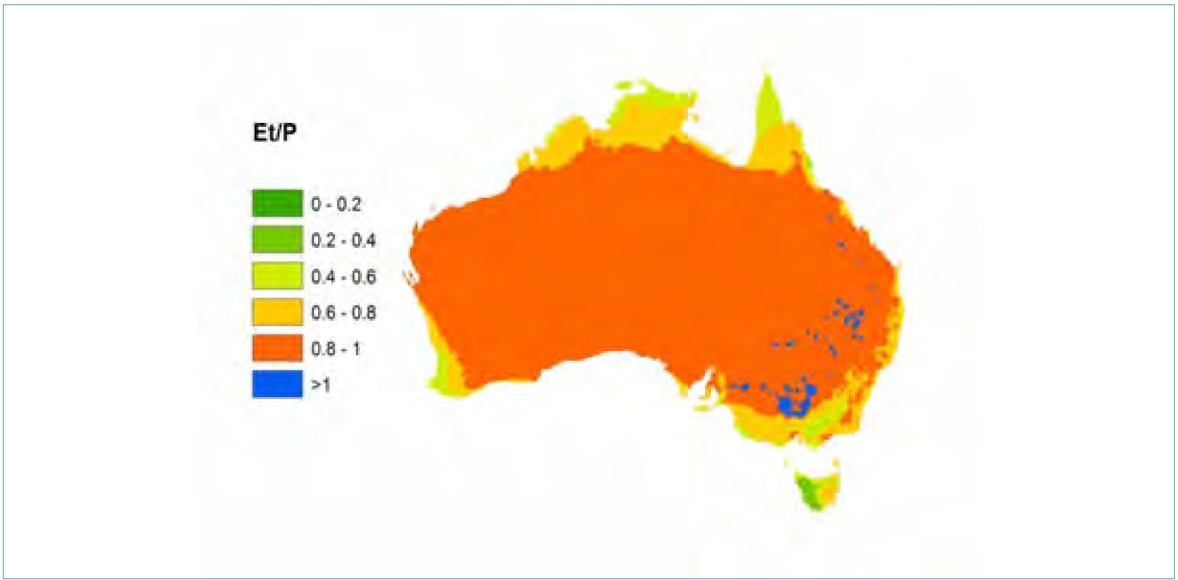

Table 5.32 Symbols used in algorithms for leaching and runoff

State (i)	Activity (j)
1 = ACT	1 = Inorganic fertiliser
2 = Northern Territory	2 = Animal waste
3 = NSW	3 = Sewage sludge
4 = Queensland	4 = Crop Residues
5 = Tasmania	5 = N mineralisation due to loss of soil C
6 = South Australia	
7 = Victoria	
8 = Western Australia	

The mass of inorganic fertiliser N applied to soils that is lost through leaching and runoff is calculated as:

$M_{ij=1} = M_{ij} \times FracWET_{ij} \times FracLEACH$ .... (3DB_5)

Where $M_{ij=1}$ = mass of synthetic fertiliser lost through leaching and runoff (Gg N)

M_{ij} = mass of fertiliser in each production system (Gg N)

$FracWET_{ij}$ = fraction of N available for leaching and runoff (Appendix 5.J.1)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff. .

The mass of animal waste N excreted or applied to soil that is lost through leaching and runoff is calculated as:

$M_{ij=2} = (MNsoil_{ij} + UNsoil_{ij} + FNsoil_{ij}) \times FracWETSOIL_{ij} \times FracLEACH$ .... (3DB_6)

Where $M_{ij=2}$ = mass of animal waste N lost through leaching and runoff (Gg N)

$MNsoil_{ij}$ = mass of manure N applied to soils (Gg N) as calculated in the section 5.6.3

$UNsoil_{ij}$ = mass of urinary N excretion on pasture (Gg N) as calculated in the section 5.4

$FNsoil_{ij}$ = mass of faecal N excretion on pasture (Gg N) as calculated in the section 5.4

$FracWETSOIL_{ij}$ = fraction of N available for leaching and runoff (Appendix 5.J.2)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

The mass of sewage sludge N applied to soils that is lost through leaching and runoff is calculated as:

$M_{ij=3} = M_{ij} \times FracWET_{ij} \times FracLEACH$ .... (3DB_7)

Where $M_{ij=3}$ = mass of sewage sludge lost through leaching and runoff (Gg N)

M_{ij} = mass of sewage sludge N (Gg N)

$FracWET_{ij}$ = fraction of N available for leaching and runoff = 1.0

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff. .

The mass of crop residue that is lost through leaching and runoff is calculated as:

$M_{ij=4} = M_{ij} \times FracWET_{ij} \times FracLEACH$ .... (3DB_8)

Where $M_{ij=4}$ = mass of crop residue lost through leaching and runoff (Gg N)

M_{ij} = mass of crop residue N (Gg N)

$FracWET_{ij}$ = fraction of N available for leaching and runoff (Appendix 5.J.1)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

The mass of N mineralised due to a loss of soil carbon lost through leaching and runoff is calculated as:

$$M_{ij=4} = M_{ij} \times FracWET_{ij} \times FracLEACH \quad (3DB\_9)$$

Where $M_{ij=5}$ = mass of mineralised N lost through leaching and runoff (Gg N)

M_{ij} = mass of N mineralised due to a loss of soil carbon (Gg N)

$FracWET_{ij}$ = fraction of N available for leaching and runoff (Appendix 5.J.I – non-irrigated crops)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff.

Annual nitrous oxide production from leaching and runoff is calculated as:

$$E = \Sigma_i \Sigma_j (M_{ij} \times EF \times C_g) \quad (3DB\_10)$$

Where E = annual emissions from leaching and runoff (Gg N_2O)

M_{ij} = mass of N lost through leaching and runoff (Gg N)

EF = 0.0075 (Gg N_2O-N/Gg N) IPCC (2006) default EF

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.11 Uncertainties and time series consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for agricultural soils were estimated to be in the order of 56 per cent. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full time series recalculations for all refinements to methodology.

5.6.12 Source specific QA/QC

5.6.12.1 Quality control

The Australian Bureau of Statistics (ABS) is the national statistical agency of Australia and is the key provider of activity data for this source category. ABS has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated. Data quality used in the inventory is also kept under review by the DoEE.

This source category is also covered by the general QA/QC procedures detailed in Chapter 1. The QC procedure 'ensuring consistency in data between categories' is of specific importance for this category. The AGEIS ensures that data used across multiple categories is entered only once and that intakes or emissions calculated in one category form the input for other categories.

Fertilizer Australia is the industry association represeting manufacturers, importers and distributors of fertiliser in Australia. The FAO receives their data from the International Fertilizer Association (IFA), which originates from Fertilizer Australia (Fertilizer Australia provides data to IFA, which they share with FAO).

Inorganic N consumption supplied by Fertilizer Australia and used in the inventory are compared with those published by the FAO. The results are very close between the two data sources (typically less than 1 per cent) throughout the time-series.

DoEE fertiliser use data differs slightly to FAO's data throughout the available FAO time-series. There are two main reasons which account for these observed differences:

- The FAO rounds their published data to the nearest '00 tonnes, while Australia uses fertiliser data to the nearest tonne;
- Fertilizer Australia revises their data frequently to ensure accuracy. In a number of years revisions have occurred between the provision of data to IFA and to DoEE. These revisions are not reflected in the FAO data.

5.6.12.2 Quality assurance

As data from additional research studies into the fertiliser EFs are published the results are used to QA the selected CS EFs. Where new studies give values that are significantly different from the CS EFs these EFs are identified for review.

5.6.13 Recalculations since the 2016 Inventory

Recalculations of agricultural soils estimates have occurred due to:

- a revision of the milk production for 2012, 2013, 2014, 2015 and 2016
- a revision of the regional breakdowns of beef cattle pasture for 2012, 2013, 2014, 2015, and 2016
- a revision of 'other livestock' population numbers for 2016
- a revision of sheep population numbers for 2016
- a revision of swine population numbers for 2016
- a revision to urea consumption data for 2015 and 2016
- a revision to fraction of N fertiliser for 2013, 2014, 2015 and 2016
- A revision in N-mineralisation associated with losses of soil carbon in *cropland*

Table 5.33 shows the impact of this recalculation.

Table 5.33 Agricultural Soils (3.D): recalculations of total CO_2-e emissions, 1990-2016

Year	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	11,501	11,722	221	1.9 per cent
2000	12,937	12,900	-37	-0.3 per cent
2005	12,637	12,415	-222	-1.8 per cent
2008	10,648	10,775	126	1.2 per cent
2009	11,250	11,329	79	0.7 per cent
2010	11,291	11,155	-136	-1.2 per cent
2011	12,600	12,288	-312	-2.5 per cent
2012	12,885	12,762	-123	-1.0 per cent
2013	12,850	12,556	-294	-2.3 per cent
2014	13,052	13,128	75	0.6 per cent
2015	12,379	12,544	165	1.3 per cent
2016	12824	12,679	-145	-1.1 per cent

5.6.14 Planned improvements

The inventory improvement plan for the agriculture sector identified areas which require updating or review over the next two years. Areas for improvement plan are identified through the UNFCCC expert reviews, domestic QA/QC process or the expected availability of new data or empirical studies which could improve accuracy of the inventory.

For agricultural soils the following areas have been identified for review and/or change:

1. *N_2O EF for animal waste applied to soils*: Research on emissions from animal wastes applied to soils is currently underway in Australia through the National Agricultural Manure Management Program and is expected to deliver results in mid-2015. Over the next two years the EF will be reviewed and updated as new data becomes available.

5.7 Source Category 3.E Prescribed Burning of Savannas

Non-CO_2 emissions from the prescribed burning of savannas has been reallocated to 4.A.1 Forest land remaining forest land, 4.C.1 Grassland remaining grassland and 4.C.2 Land converted to grassland to align Australia's reporting with the categories specified in the 2006 IPCC Guidelines (which do not mention savanna burning).

Refer to volume 2 of the NIR for further information about the methods used to estimate emissions from prescribed burning of savannas.

This change is a classification of emissions issue only, and does not change the national inventory total.

5.8 Source Category 3.F Field Burning of Agricultural Residues

5.8.1 Source category description

The burning of residual crop material releases CH_4, N_2O, CO, NO_x and NMVOCs into the atmosphere. These gases are formed from carbon and nitrogen in the plant material during the combustion process. As per the IPCC *Guidelines* (IPCC 2006) the CO_2 emissions from burning of agricultural residues are not included in the inventory total since it is assumed that an equivalent amount of CO_2 was removed by the growing crop.

Stubble burning involves firing the standing stalks in either late autumn or spring. Increasingly, as a form of land management, it is being replaced by stubble retention, which reduces erosion and conserves nutrients. In this latter practice the stubble is grazed some weeks after harvest and the next crop is sown by drilling though the remaining vegetation. Firing of sugar cane has also become less common with the rapid introduction of green cane mechanical harvesting. Sugar cane crops are now burnt once every three or four years at the end of the sowing/ratoon cycle.

The amount of crop residue at the time of burning is in most cases, less than that at the time of harvest. This applies particularly to crops where there is a long interval between harvest and burning. Vegetation decay and grazing by animals can, over several months, reduce the amount of residue per unit area by one half (R. Jarvis pers. comm., Mulholland *et al.* 1976). This loss is allowed for in the algorithm.

Table 5.34 Burning of agricultural residues – emission factors

Gas species	Emission factor [a] EF_g (Gg element in species/Gg element in fuel burnt)	Elemental to molecular mass conversion factor (C_g)
CH_4	0.0035	16/12
N_2O	0.0076	44/28
NO_x	0.2100	46/14
CO	0.0780	28/12
NMVOC	0.0091	14/12

Source: Hurst *et al.* (1994 a, b).

Table 5.35 Symbols used in algorithms for burning of agricultural residues

State (i)	Subset (j)
1 = ACT	1 = Wheat
2 = Northern Territory	2 = Barley
3 = NSW	3 = Maize
4 = Queensland	4 = Oats
5 = Tasmania	5 = Rice
6 = South Australia	6 = Sorghum
7 = Victoria	7 = Triticale
8 = Western Australia	8 = Other Cereals
	9 = Pulses
	10 = Tuber and Roots
	11 = Peanuts
	12 = Sugar cane
	13 = Cotton
	14 = Hops
	15 = Oilseeds
	16 = Forage crops

The mass of fuel burnt is calculated as:

$$M_{ij} = P_{ij} \times R_j \times S_j \times DM_j \times Z \times F_{ij} \quad (3F\_1)$$

Where M_{ij} = mass of residue burnt from crop (Gg)

P_{ij} = annual production of crop (Gg)

R_j = residue to crop ratio (kg crop residue/kg crop) (Appendix 5.I.1)

S_j = fraction of crop residue remaining at burning (Appendix 5.I.1)

DM_j = dry matter content (kg dry weight/kg crop residue) (Appendix 5.I.1)

Z = burning efficiency (fuel burnt/fuel load) = 0.96 (Hurst *et al.* 1994 a, b)

F_{ij} = fraction of the annual production of crop that is burnt (ha burnt/ ha harvested) (Appendix 5.I.1 and 3)

The mass of fuel burnt is converted to an emission of CH_4, CO or NMVOC by multiplying by the carbon content of the fuel, and an EF. That is:

$$E_{ij} = M_{ij} \times CC_j \times EF_g \times C_g \quad (3F\_2)$$

Where E_{ij} = annual emission from burning crop residue (Gg)

Agriculture

CC_j = carbon mass fraction in crop residue

EF_g = emission factor (Gg element /Gg burnt) (Table 5.34)

C_g = factor to convert from elemental mass of gas to molecular mass

For N_2O and NO_x an additional term in the algorithm, the nitrogen to carbon ratio (NC_j), is required in order to calculate the fuel nitrogen content. Hence:

$$E_{ijk} = M_{ij} \times NC_j \times EF_g \times C_g \quad (3F\_3)$$

Where E_{ij} = annual emission from burning crop residue (Gg)

NC_j = nitrogen content in above ground residue

EF_g = emission factor (Gg element /Gg burnt) (Table 5.34)

C_g = factor to convert from elemental mass of gas to molecular mass

5.8.2 Uncertainties and time series consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for the burning of agricultural residues were estimated to be in the order of 38 per cent. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full time series recalculations for all refinements to methodology.

5.8.3 Source specific QA/QC

ABS, the principal data supplier, has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated. Data quality used in the inventory is also kept under review by the Department. This source category is also covered by the general QA/QC procedures detailed in Chapter 1.

5.8.4 Recalculations since the 2016 Inventory

Recalculations of agricultural residues estimates have occurred due to an update of soybean production data for 2015. The net effect f this change was a 0.2 Gg CO_2-e increase to the estimate.

Table 5.36 Field Burning of Agricultural Residues (3.F): recalculation of total CO_2-e emissions 1990-2016

Year	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	431	431	-	0.0 per cent
2000	511	511	-	0.0 per cent
2005	338	338	-	0.0 per cent
2008	237	237	-	0.0 per cent
2009	293	293	-	0.0 per cent
2010	255	255	-	0.0 per cent
2011	376	376	-	0.0 per cent
2012	381	381	-	0.0 per cent
2013	359	359	-	0.0 per cent
2014	332	332	-	0.0 per cent
2015	317	317	0.2	0.1 per cent
2016	288	288	-	0.0 per cent

5.8.5 Planned improvements

All data and methodologies are kept under review.

5.9 Source Category 3.G Liming

5.9.1 Source category description

Limestone and dolomite are used in Australia to ameliorate soil acidity, improve soil structure, and improve plant growth in *cropland* and *grassland* and to a very limited degree in *forest land*. Adding carbonates to soils in the form of lime (eg. calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) leads to CO_2 emissions as the carbonate reacts with acids in the soil to produce bicarbonate and eventually leading to the production of CO_2 and water.

5.9.2 Methodology

Table 5.37 Symbols used in algorithms for liming

State (i)	Subset (j)
1 = ACT	1 = Limestone
2 = Northern Territory	2 = Dolomite
3 = NSW	
4 = Queensland	
5 = Tasmania	
6 = South Australia	
7 = Victoria	
8 = Western Australia	

For lime application, the annual emissions of CO_2 are calculated as:

$$E_{ij} = ((M_{ij} \times FracLime_{ij} \times P_{j=1} \times EF_{j=1}) + (M_{ij} \times (1 - FracLime_{ij}) \times P_{j=2} \times EF_{j=2})) \times C_g / 1000 \quad (3G\_1)$$

Where E_{ij} = annual emission of CO_2 from lime application (Gg)

M_{ij} = mass of limestone and dolomite applied to soils (t)

$FracLime_{ij}$ = fraction limestone

$P_{j=1}$ = fractional purity of limestone = 0.9

$P_{j=2}$ = fractional purity of dolomite = 0.95

$EF_{j=1}$ = 0.12 – IPCC (2006) default emission factor for limestone

$EF_{j=2}$ = 0.13 – IPCC (2006) default emission factor for dolomite

C_g = 44/12 factor to convert elemental mass of CO_2 to molecular mass

5.9.3 Uncertainties and time series consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for liming were estimated to be in the order of 54 per cent. Further details on the analysis are provided in Annex 7.

National data on limestone and dolomite applications to agricultural soils are only available from the Australian Bureau of Statistics for eight years (1993, 1994, 1996, 2001, 2002, 2008, 2013 and 2014), with limestone and dolomite reported separately for only eight (1996, 2001, 2002, 2008, 2013, 2015, 2016, 2017) of those years.

Additional data are available for Western Australia (1991, 1995, 1998-2000 and 2004). Interpolation techniques have been used to estimate the mass of limestone and dolomite applied in years for which data are not available. The fraction of the estimated mass applied that is assumed to be limestone, was based on the average of years for which data are available.

5.9.4 Source specific QA/QC

This source category is covered by the general QA/QC procedures detailed in Chapter 1.

5.9.5 Recalculations since the 2016 Inventory

There were no recalculations affecting this subsector in the 2019 submission.

Table 5.38 Liming (3.G): recalculation of total CO_2-e emissions 1990-2016

Year	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	215	215	-	0.0 per cent
2000	738	738	-	0.0 per cent
2005	1,076	1,076	-	0.0 per cent
2008	1,066	1,066	-	0.0 per cent
2009	1,159	1,159	-	0.0 per cent
2010	1,253	1,253	-	0.0 per cent
2011	1,088	1,088	-	0.0 per cent
2012	925	925	-	0.0 per cent
2013	760	760	-	0.0 per cent
2014	1,139	1,139	-	0.0 per cent
2015	1,224	1,224	-	0.0 per cent
2016	1,153	1,153	-	0.0 per cent

5.9.6 Planned improvements

All data and methodologies are kept under review.

5.10 Source Category 3.H Urea Application

5.10.1 Source category description

Adding urea to soils for fertilisation leads to a loss of the CO_2 that was fixed during the manufacturing process. Similar to the reaction following the addition of lime, the bicarbonate that is formed evolves into CO_2 and water.

5.10.2 Methodology

For urea application, the annual emissions of CO_2 are calculated as:

$$E_i = M_i \times EF \times C_g / 1000 \quad \text{(3H\_1)}$$

Where E_i = annual emission of CO_2 from urea application (Gg)

M_i= mass of urea applied to soils (t)

EF = 0.2 – IPCC (2006) default emission factor for urea

C_g = 44/12 factor to convert elemental mass of CO_2 to molecular mass

5.10.3 Uncertainties and time series consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for application of urea were estimated to be in the order of 51 per cent. Further details on the analysis are provided in Annex 7. Time series consistency is ensured by the use the same methods and data Source for the full time series.

5.10.4 Source specific QA/QC

This source category is covered by the general QA/QC procedures detailed in Chapter 1.

5.10.5 Recalculations since the 2016 Inventory

A recalculation has occurred in the 2015 inventory year due to a revision in urea consumption data. Table 5.39 shows the impact of this recalculation. The net effect of this change was a 44 Gg CO_2-e increase to the estimate.

Table 5.39 Urea Application (3.H): recalculation of total CO_2-e emissions 1990-2016

Year	2018 submission	2019 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	367	367	-	0.0 per cent
2000	963	963	-	0.0 per cent
2005	887	887	-	0.0 per cent
2008	765	765	-	0.0 per cent
2009	784	784	-	0.0 per cent
2010	936	936	-	0.0 per cent
2011	1,112	1,112	-	0.0 per cent
2012	1,120	1,120	-	0.0 per cent
2013	1,278	1,278	-	0.0 per cent
2014	1,352	1,352	-	0.0 per cent
2015	1,309	1,352	44	3.3 per cent
2016	1,510	1,510	-	0.0 per cent

5.10.6 Planned improvements

All data and methodologies are kept under review.

Appendix 5.A Dairy cattle

Table 5.A.1 Dairy cattle – liveweight (kg)

Time period	Milking Cows	Heifers >1	Heifers <1 (weaned)	Bulls >1	Bulls <1 (weaned)
1990-1994	520	350	172	600	225
1995-1999	530	360	176	600	225
2000-2004	545	365	178	600	225
2005-2009	550	370	179	600	225
2009-2017	550	370	179	600	225

Table 5.A.2 Dairy cattle – liveweight gain (kg/day)

Time period	Milking Cows	Heifers >1	Heifers <1 (weaned)	Bulls >1	Bulls <1 (weaned)
1990-1994	0.015	0.6	0.53	0.1	0.8
1995-1999	0.016	0.6	0.55	0.1	0.8
2000-2004	0.016	0.6	0.56	0.1	0.8
2005-2009	0.016	0.6	0.57	0.1	0.8
2009-2017	0.016	0.6	0.57	0.1	0.8

Table 5.A.3 Dairy cattle – standard reference weights (kg)

Time period	Milking Cows	Heifers >1	Heifers <1 (weaned)	Bulls >1	Bulls <1 (weaned)
1990-1994	555	555	555	770	770
1995-1999	570	570	570	770	770
2000-2004	580	580	580	770	770
2005-2009	590	590	590	770	770
2009-2017	590	590	590	770	770

Table 5.A.4 Dairy cattle – dry matter digestibility and crude protein content of feed intake (per cent)

State	DMD	CP
All	75	20

Source: Christie *et al.* (2012)

Table 5.A.5 Dairy cattle – data for pre-weaned calves

		CH_4 production	Volatile solids	Faecal N	Urinary N
		(kg/day)			
1990-1994	Heifers<1	0.0187	0.2738	0.0057	0.0087
1995-1999	Heifers<1	0.0185	0.2715	0.0057	0.0086
2000-2004	Heifers<1	0.0184	0.2700	0.0056	0.0085
2005+	Heifers<1	0.01825	0.2685	0.0056	0.0085
All years	Bulls<1	0.02081	0.3003	0.0051	0.0044

Table 5.A.6 Dairy cattle – integrated MCF

	Milking Cows								Other Dairy Cattle
	ACT	NSW	NT	QLD	SA	TAS	VIC	WA	
1990-1994	0.0295	0.0318	0.0653	0.0461	0.0370	0.0382	0.0512	0.0563	0.01
1995-1999	0.0328	0.0345	0.0699	0.0449	0.0428	0.0415	0.0575	0.0578	0.01
2000-2004	0.0440	0.0456	0.0809	0.0511	0.0524	0.0467	0.0683	0.0619	0.01
2005-2009	0.0743	0.0765	0.0990	0.0735	0.0749	0.0561	0.0871	0.0730	0.01
2009-2017	0.0988	0.1016	0.1032	0.0915	0.0902	0.0670	0.0958	0.0894	0.01

Table 5.A.7 Dairy cattle – Methane Conversion Factors (MCF)

MMS	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Pasture[a]	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Anaerobic lagoon[b]	0.73	0.75	0.8	0.77	0.74	0.70	0.74	0.75
Sump and dispersal systems[b]	0.005	0.005	0.01	0.005	0.005	0.001	0.005	0.005
Drains to paddocks[b,c]	0.15	0.18	0.50	0.24	0.17	0.15	0.17	0.18
Solid Storage[d]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

(a) Williams (1993). (b) IPCC (2006). (c) MCF is assumed to be similar to a liquid/slurry system. (d) IPCC (2006) cool region values applied as these more closely align with Australian experimental data (Redding *et al.* (2015), J. Devereux and M. Redding pers. comm., QDAFF June 2014).

Table 5.A.8 Dairy cattle – allocation of waste to manure management systems – Milking Cows

	ACT/ NSW	NT/QLD	SA	TAS	VIC	WA
1990-1994						
Pasture	87.7	87.1	87.8	87.9	87.6	88.0
Anaerobic lagoon	1.4	2.0	3.3	3.5	4.8	4.9
Daily Spread: Sump and dispersal	3.0	0.1	5.7	4.4	2.5	0.3
Daily Spread: Drains to paddocks	6.7	9.0	2.1	3.2	3.7	5.8
Solid Storage	1.2	1.8	1.1	1.0	1.3	0.9
1995-1999						
Pasture	87.7	87.1	87.8	87.9	87.6	88.0
Anaerobic lagoon	2.4	2.9	4.2	4.2	6.0	5.6
Daily Spread: Sump and dispersal	4.6	2.8	5.6	5.0	2.9	1.9
Daily Spread: Drains to paddocks	4.2	5.6	1.3	2.0	2.3	3.6
Solid Storage	1.1	1.7	1.0	1.0	1.2	0.9
2000-2004						
Pasture	87.1	86.3	87.5	87.9	87.4	87.7
Anaerobic lagoon	4.2	4.3	5.6	5.1	7.6	6.5
Daily Spread: Sump and dispersal	4.5	3.6	4.8	4.8	2.2	2.4
Daily Spread: Drains to paddocks	2.8	3.7	0.9	1.3	1.5	2.4
Solid Storage	1.4	2.1	1.1	0.8	1.2	1.0
2005-2009						
Pasture	84.0	83.6	84.5	87.5	85.9	86.1

	ACT/ NSW	NT/QLD	SA	TAS	VIC	WA
Anaerobic lagoon	8.6	7.4	8.7	6.3	11.6	8.2
Daily Spread: Sump and dispersal	3.0	2.8	3.5	3.4	1.1	2.5
Daily Spread: Drains to paddocks	1.5	3.2	0.7	1.9	0.6	1.5
Solid Storage	2.8	3.1	2.6	0.8	2.5	1.6
2010-2017						
Pasture	79.2	79.4	80.7	85.2	84.3	81.9
Anaerobic lagoon	12.0	9.7	10.8	8.0	11.6	10.3
Daily Spread: Sump and dispersal	2.4	2.6	3.5	3.4	1.1	2.5
Daily Spread: Drains to paddocks	1.2	3.3	0.7	1.4	0.6	1.5
Solid Storage	5.1	5.0	4.3	2.0	2.5	3.7

Table 5.A.9 Dairy Cattle – N_2O oxide emission factors and fraction of N volatilised by manure management system

MMS	EF (kg N_2O-N/kg N excreted)	$FracGASM_m$ (kg N_2O-N/kg N excreted)
Void at Pasture	0[(a)]	0
Anaerobic lagoon	0[(a)]	0.35
Daily Spread – Sump and Dispersal	0[(a)]	0.07
Daily Spread – Drains to Paddock	0[(a)]	0.2[(b)]
Solid Storage	0.005	0.3

Source: IPCC (2006); (a) There are no direct emissions from these Source; (b) Considered similar to a liquid slurry systems (0.4), 20 per cent is assumed to be lost by MMS with further 20 per cent loss under Agricultural Soils.

Table 5.A.10 Dairy cattle – Average milk production (kg/head/year)

State	1990	1995	2000	2005	2010	2016	2017
NSW/ACT	3,603	4,519	4,827	4,925	5,329	6,610	6,309
NT	3,123	3,964	4,349	3,735	5,052	4,446	4,731
Queensland	3,123	3,964	4,349	3,735	5,052	4,571	4,731
South Australia	3,934	5,057	6,790	5,862	5,907	7,497	6,521
Tasmania	3,775	3,781	4,381	4,497	4,640	5,981	5,651
Victoria	3,920	4,653	4,989	5,101	5,518	5,638	5,761
Western Australia	4,202	4,609	6,338	5,418	6,641	6,582	6,504

Source: Dairy Australia.

Appendix 5.B Beef cattle

Table 5.B.1 Beef cattle – liveweight (kg)

State	Region	Season	Bulls <1 (kg)	Bulls >1 (kg)	Cows <1 (kg)	Cows 1 to (kg)	Cows >2 (kg)	Steers <1 (kg)	Steers >1 (kg)
ACT/NSW		Spring	80	480	75	300	440	75	380
		Summer	170	520	160	360	470	160	420
		Autumn	240	550	220	390	490	220	450
		Winter	280	560	260	410	500	260	460
South Australia		Spring	250	800	220	400	500	230	420
		Summer	320	800	280	420	500	290	420
		Autumn	80	700	70	300	450	75	400
		Winter	160	700	140	350	450	150	400
Tasmania		Spring	105	700	85	300	490	90	480
		Summer	480	750	150	350	530	160	460
		Autumn	250	725	200	360	500	215	490
		Winter	260	700	210	380	460	230	470
Victoria		Spring	250	820	240	410	560	240	510
		Summer	280	850	260	440	550	270	520
		Autumn	100	700	95	300	450	95	410
		Winter	150	720	140	320	470	140	440
Western Australia	South West	Spring	340	800	260	420	550	300	480
		Summer	380	780	300	450	530	340	470
		Autumn	100	680	80	320	480	100	340
		Winter	190	700	150	330	490	170	360
	Pilbara	Spring	80	450	70	260	340	80	370
		Summer	150	500	140	310	360	150	400
		Autumn	230	550	220	330	380	230	420
		Winter	250	500	240	340	360	250	390
	Kimberley	Spring	220	500	180	300	320	210	340
		Summer	110	550	90	220	380	100	390
		Autumn	170	600	140	270	390	160	430
		Winter	200	550	150	280	350	190	400

State	Region	Season	Bulls <1 (kg)	Bulls >1 (kg)	Cows <1 (kg)	Cows 1 to 2 (kg)	Cows 2-3 (kg)	Cows >3 (kg)	Steers <1 (kg)	Steers 1-2 (kg)	Steers 2-3 (kg)	Steers >3 (kg)
Northern Territory	Alice Springs	Spring	220	706	208	323	415	467	223	371	493	585
		Summer	110	703	112	256	368	465	108	280	421	543
		Autumn	170	721	169	306	392	464	176	339	470	580
		Winter	200	727	211	338	432	492	222	377	498	590
	Barkly	Spring	220	620	227	319	398	452	216	334	NO	NO
		Summer	110	650	108	262	346	430	111	236	NO	NO
		Autumn	170	670	170	266	363	444	169	282	NO	NO
		Winter	200	660	225	307	398	452	214	326	NO	NO
	Northern	Spring	220	620	177	267	365	406	231	249	324	NO
		Summer	110	650	102	203	299	380	102	218	263	NO
		Autumn	170	670	173	250	336	414	175	243	304	NO
		Winter	200	660	202	272	365	390	208	260	337	NO
Queensland	High	Spring	260	705	215	302	416	519	234	455	551	660
		Summer	153	703	118	277	397	483	111	304	521	547
		Autumn	168	718	191	319	440	506	188	326	520	582
		Winter	235	722	207	352	470	514	209	421	512	605
	Moderate/High	Spring	230	674	217	344	357	467	242	370	550	620
		Summer	113	669	113	283	361	477	120	273	545	553
		Autumn	172	685	172	309	376	471	238	329	573	620
		Winter	241	692	208	344	364	484	260	350	567	620
	Moderate/Low	Spring	236	674	178	310	428	466	193	370	519	565
		Summer	120	669	112	250	390	448	115	273	433	556
		Autumn	125	685	140	277	407	455	141	296	445	593
		Winter	180	692	183	316	438	468	189	354	500	553
	Low	Spring	190	617	174	265	371	415	170	272	392	531
		Summer	119	591	140	205	310	405	133	218	315	445
		Autumn	175	610	163	232	351	427	146	242	320	471
		Winter	192	615	162	255	364	420	157	261	342	484

Source: QLD and NT data from Bray *et al.* (2015)

Table 5.B.2 Beef cattle – liveweight gain (kg/head/day)

State	Region	Season	Bulls <1 (kg/day)	Bulls >1 (kg/day)	Cows <1 (kg/day)	Cows 1 to 2 (kg/day)	Cows >2 (kg/day)	Steers <1 (kg/day)	Steers >1 (kg/day)
ACT/NSW		Spring	0.5	0.4	0.2	0.5	0.3	0.4	0.5
		Summer	1.0	0.7	0.4	0.9	0.3	0.4	0.9
		Autumn	0.8	0.3	0.3	0.7	0.2	0.3	0.7
		Winter	0.4	0.2	0.1	0.4	0.1	0.1	0.4
South Australia		Spring	0.99	0.55	1.10	0.88	0.55	0.22	0.88
		Summer	0.77	0.22	0.00	0.66	0.00	0.00	0.66
		Autumn	0.90	0.22	-1.10	0.70	-0.55	-0.22	0.80
		Winter	0.88	0.55	0.00	0.77	0.00	0.00	0.82
Tasmania		Spring	1.0	1.0	0.50	1.0	0.5	0.50	1.0
		Summer	0.82	0.55	0.55	0.71	0.44	0.5	0.77
		Autumn	0.77	0.11	0.50	0.55	-0.33	0.33	0.6
		Winter	0.11	0.22	-0.27	0.11	-0.44	-0.22	0.16
Victoria		Spring	1.10	0.99	1.10	1.10	0.99	0.77	1.10
		Summer	0.33	0.33	0.33	0.22	-0.10	0.11	0.33
		Autumn	0.50	0.44	0.20	0.55	0.20	0.20	0.55
		Winter	0.55	0.22	0.22	0.49	0.22	0.33	0.49
Western Australia	South West	Spring	1.64	1.10	1.21	0.99	0.66	1.42	1.10
		Summer	0.44	-0.22	0.44	0.33	-0.22	0.44	-0.11
		Autumn	0.60	0.00	0.60	0.22	-0.55	0.60	0.00
		Winter	0.99	0.22	0.77	0.11	0.11	0.77	0.44
	Pilbara	Spring	0.70	-0.55	0.70	0.22	-0.22	0.70	-0.22
		Summer	0.77	0.55	0.77	0.66	0.55	0.77	0.33
		Autumn	0.88	0.55	0.88	0.22	0.22	0.88	0.22
		Winter	0.22	-0.55	0.22	0.11	-0.22	0.22	-0.33
	Kimberley	Spring	0.22	-0.55	0.33	0.22	-0.33	0.22	-0.66
		Summer	0.80	0.55	0.70	0.44	0.66	0.80	0.55
		Autumn	0.66	0.55	0.55	0.55	0.11	0.66	0.44
		Winter	0.33	-0.55	0.11	0.11	-0.44	0.33	-0.33

State	Region	Season	Bulls <1 (kg/day)	Bulls >1 (kg/day)	Cows <1 (kg/day)	Cows 1 to 2 (kg/day)	Cows 2-3 (kg/day)	Cows >3 (kg/day)	Steers <1 (kg/day)	Steers 1-2 (kg/day)	Steers 2-3 (kg/day)	Steers >3 (kg/day)
Northern Territory	Alice Springs	Spring	0.22	-0.23	0.25	0.17	0.18	-0.28	0.32	0.24	0.25	-0.05
		Summer	0.66	0.20	0.62	0.54	0.38	0.27	0.75	0.64	0.55	0.48
		Autumn	0.49	0.13	0.54	0.45	0.35	0.15	0.63	0.54	0.42	0.26
		Winter	0.27	-0.80	0.22	0.09	0.12	0.02	0.25	0.18	0.12	0.03
	Barkly	Spring	0.22	-0.44	0.20	0.21	0.18	0.01	0.12	0.09	NO	NO
		Summer	0.66	0.22	0.68	0.22	0.24	0.25	0.64	0.37	NO	NO
		Autumn	0.49	0.05	0.64	0.25	0.29	0.12	0.57	0.49	NO	NO
		Winter	0.27	-0.27	0.31	0.29	0.19	0.04	0.26	0.28	NO	NO
	Northern	Spring	0.22	-0.44	0.00	0.15	0.08	0.17	0.06	0.02	-0.14	NO
		Summer	0.66	0.22	0.79	0.40	0.38	0.27	0.80	0.16	0.30	NO
		Autumn	0.49	0.05	0.55	0.38	0.36	0.06	0.58	0.23	0.40	NO
		Winter	0.27	-0.27	0.02	0.09	0.16	-0.04	0.21	0.03	0.11	NO
Queensland	High	Spring	0.27	-0.23	0.38	0.25	0.07	0.05	0.52	0.55	0.19	NO
		Summer	0.16	0.20	0.80	0.57	0.76	0.49	0.84	0.51	0.36	0.60
		Autumn	0.45	0.13	0.49	0.41	0.40	0.17	0.54	0.64	-0.05	0.17
		Winter	0.51	-0.80	0.13	-0.09	-0.13	0.07	0.25	0.71	0.17	0.32
	Moderate/ High	Spring	-0.12	-0.44	0.41	0.09	0.41	-0.19	0.07	1.07	-0.08	0.43
		Summer	0.65	0.22	0.65	0.51	0.18	0.63	1.30	0.48	1.12	0.00
		Autumn	0.70	0.05	0.52	0.34	0.02	0.04	0.77	0.42	0.12	0.38
		Winter	0.32	-0.27	0.25	0.19	-0.10	-0.02	0.02	0.23	-0.13	0.74
	Moderate/ Low	Spring	0.62	-0.44	0.37	0.41	0.06	-0.02	0.47	0.44	0.30	0.00
		Summer	0.05	0.22	0.31	0.54	0.53	0.15	0.28	0.57	0.42	0.13
		Autumn	0.33	0.05	0.39	0.36	0.26	0.11	0.40	0.44	0.37	0.40
		Winter	0.61	-0.27	0.21	0.18	0.12	0.06	0.29	0.41	0.41	-0.01
	Low	Spring	-0.20	-0.23	0.24	0.30	0.23	-5.00	0.34	0.30	0.57	-0.15
		Summer	0.62	0.20	0.25	0.32	0.47	0.31	0.14	0.40	0.26	0.52
		Autumn	0.40	0.13	0.12	0.27	0.30	0.08	0.13	0.24	0.15	0.43
		Winter	0.08	-0.80	0.06	0.18	0.11	-0.07	0.13	0.16	0.40	0.21

Source: QLD and NT data from Bray *et al.* (2015)

Table 5.B.3 Beef cattle – dry matter digestibility of feed intake (per cent)

State	Region	Season			
		Spring	Summer	Autumn	Winter
ACT/NSW		55	65	60	50
NT		55	61	57	54
QLD		53	57	55	51
SA		70	55	55	75
TAS		75	60	70	75
VIC		80	55	60	76
WA	South West	80	58	50	75
	Pilbara	40	65	55	45
	Kimberley	40	65	55	45

Table 5.B.4 Beef cattle – crude protein content of feed intake (per cent)

State	Region	Season			
		Spring	Summer	Autumn	Winter
ACT/NSW		0.07	0.13	0.1	0.06
NT		0.058	0.092	0.075	0.053
QLD		0.07	0.13	0.1	0.06
SA		0.072	0.099	0.078	0.059
TAS		0.16	0.07	0.09	0.2
VIC		0.2	0.1	0.16	0.2
WA	South West	0.25	0.07	0.1	0.21
	Pilbara	0.2	0.09	0.06	0.2
	Kimberley	0.04	0.12	0.09	0.06

Table 5.B.5 Beef Cattle – feed intake adjustment and milk production and intake

State	Region	Season	Feed adjustment	Milk intake / production (kg/day)
ACT/NSW		Spring	1.3	6
		Summer	1.1	4
		Autumn	0	0
		Winter	0	0
Northern Territory		Spring	0	0
		Summer	1.3	4
		Autumn	1.1	3
		Winter	0	0
Queensland		Spring	0	0
		Summer	1.3	4
		Autumn	1.1	3
		Winter	0	0
South Australia		Spring	0	0
		Summer	0	0
		Autumn	1.3	6
		Winter	1.1	4
Tasmania		Spring	1.3	6
		Summer	1.1	4
		Autumn	0	0
		Winter	0	0
Victoria		Spring	0	0
		Summer	0	0
		Autumn	1.3	6
		Winter	1.1	4
Western Australia	South West	Spring	0	0
		Summer	0	0
		Autumn	1.3	6
		Winter	1.1	4
	Pilbara	Spring	1.3	4
		Summer	1.1	3
		Autumn	0	0
		Winter	0	0
	Kimberley	Spring	0	0
		Summer	1.3	4
		Autumn	1.1	3
			0	0

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Table 5.B.6 Beef cattle – standard reference weights

State	Bulls >1 (kg)	Bulls <1 (kg)	Steers <1 (kg)	Cows 1 to (kg)	Cows >2 (kg)	Cows <1 (kg)	Steers >1 (kg)
ACT/NSW	700	700	600	500	500	500	600
Northern Territory	770	770	660	550	550	550	660
Queensland	770	770	660	550	550	550	660
South Australia	770	770	660	550	550	550	660
Tasmania	770	770	660	550	550	550	660
Victoria	770	770	660	550	550	550	660
Western Australia	770	770	660	550	550	550	660

Based on SCA 1990.

Table 5.B.7 Beef cattle – allocation of animals to climate regions

State	Region	Proportion Warm	Proportion Temperate
ACT		0	1
Northern Territory	Alice Springs	0.1	1
	Barkly	0.5	0.5
	Northern	1	0
NSW		0	1
Queensland	High	0	1
	Moderate/High	0	1
	Moderate/Low	0	1
	Low	0.8	0.2
South Australia		0	1
Tasmania		0	1
Victoria		0	1
Western Australia	South West	0	1
	Pilbara	1	0
	Kimberly	1	0

Appendix 5.C Feedlot cattle

Table 5.C.1 Feedlot cattle – Animal characteristics

		1990-1994[a]	1995-1999[a]	2000-2004[a]	2005-2009[a]	2010-2017[a]
Domestic						
Days on feed		75	75	70	70	70
Average daily gain	kg/d	1.5	1.6	1.7	1.7	1.7
Mean liveweight	kg LW	356	360	381	400	410
N retention[b]	per cent of intake	21.4	22.3	22.2	21.1	20.4
Mid-fed						
Days on feed		140	120	115	115	115
Average daily gain	kg/d	1.5	1.5	1.6	1.7	1.7
Mean liveweight	kg LW	520	529	534	538	538
N retention[b]	per cent of intake	11.8	11.6	12.0	12.5	12.7
Long-fed						
Days on feed		250	250	250	250	250
Average daily gain	kg/d	1.1	1.1	1.1	1.2	1.3
Mean liveweight	kg LW	598	598	598	600	613
N retention[b]	per cent of intake	6.4	6.3	6.1	6.6	7.0

(a) Productivity data for the period 1990-1994 derived from Tucker *et al.* (1991) and Watts and Tucker (1994). Data for subsequent periods checked against know industry performance (Dr Rob, Lawrence Integrated Animal Production 2014).
(b) N retention determined using BeefBal (McGahan *et al.* 2004).

Table 5.C.2 Feedlot cattle – Diet properties

Nutrient analysis	Unit	1990-1994[a]	1995-1999[b]	2000-2004[b]	2005-2009[b]	2010-2017[b]
Domestic and Mid-fed						
Dry matter digestibility	per cent	80	81	81	81	81
Crude protein	per cent	13.2	13.2	13.2	13.3	13.4
Net Energy (NEma)	MJ/kg	8.0	8.0	8.0	8.2	8.4
Soluble residue		0.58	0.61	0.64	0.63	0.62
Hemi-cellulose		0.09	0.09	0.10	0.10	0.10
Cellulose		0.12	0.08	0.05	0.05	0.05
Long-Fed						
Dry matter digestibility	per cent	80	80	80	79	79
Crude protein	per cent	13.2	13.6	14.0	13.6	13.2
Net Energy (NEma)	MJ/kg	8.0	8.0	8.1	8.2	8.3
Soluble residue		0.57	0.57	0.57	0.57	0.58
Hemi-cellulose		0.12	0.12	0.12	0.12	0.12
Cellulose		0.06	0.06	0.06	0.07	0.07

(a) Feedlot diets for the 1990-1994 period derived from Tucker *et al.* (1991) and van Sliedregt *et al.* (2000).
(b) Feedlot diets for subsequent periods reviewed by Integrated Animal Production (Dr Rob Lawrence) in 2014.

Table 5.C.3 Feedlot cattle – Integrated emission factors 1990 – 2017

	1990-1994	1995-1999	2000-2004	2005-2009	2010-2017
iMCF					
NSW	0.03420	0.03420	0.03345	0.03230	0.03230
QLD	0.04213	0.04213	0.04138	0.04023	0.04023
SA	0.03420	0.03420	0.03345	0.03230	0.03230
VIC	0.03420	0.03420	0.03345	0.03230	0.03230
WA	0.03460	0.03460	0.03385	0.03270	0.03270
$iFracGASM_{MSS}$	0.68980	0.68980	0.69790	0.71032	0.71032
iNOF	0.021656	0.021656	0.021926	0.022340	0.022340

Note: The integrated factors are derived from the allocation of waste to different MMS (Table C.4) and the specific MCF (Table C.5), N_2O EF (Table C.6) and $FracGASM_{MMS}$ (Table C.7) of each MMS.

Table 5.C.4 Feedlot cattle – Allocation of waste to MMS 1990 – 2017 (per cent)

MMS	1990-1994	1995-1999	2000-2004	2005-2009	2010-2017
Primary Systems					
Drylot (Feedpad)	100.0	100.0	100.0	100.0	100.0
Secondary Systems[(a)]					
Stockpile (Solid storage)	92.0	92.0	77.0	54.0	54.0
Composting (Passive windrow)	0.0	0.0	15.0	38.0	38.0
Direct Application	8.0	8.0	8.0	8.0	8.0
Tertiary System[(b)]					
Uncovered anaerobic lagoon (Effluent pond)	2	2	2	2	2

(a) 50 per cent of VS is assumed to be lost during storage in the primary system, predominantly as biogenic CO_2 (McGahan *et al.* 2004; Wiedemann *et al.* 2014).
(b) 2 per cent of VS and N from the feed pad is assumed to run-off into effluent ponds (Watts *et al.* 2012, Wiedemann *et al.* 2014).

Table 5.C.5 Feedlot cattle – methane conversion factors (MCFs)

MMS	NSW	QLD	SA	VIC	WA
Dry lot (Feedpad)	0.01[(b)]	0.03[(a)]	0.01[(b)]	0.01[(b)]	0.01[(b)]
Solid Storage (Stockpile)[(b)]	0.02	0.02	0.02	0.02	0.02
Composting (Passive Windrow)[(c)]	0.01	0.01	0.01	0.01	0.01
Uncovered anaerobic lagoon (Effluent pond)	0.75	0.77	0.75	0.75	0.77

Source: (a) Redding *et al.* (2015). (b) IPCC (2006) cool region values applied as these more closely align with Australian experimental data (Redding *et al.* (2015) and J. Devereux and M. Redding pers.comm., QDAFF June 2014). (c) IPCC (2006)

Table 5.C.6 Feedlot cattle – Nitrous oxide emission factors (kg N_2O-N / kg N)

MMS	N_2O	Source
Dry lot (Feedpad)	0.02	IPCC (2006)
Solid Storage (Stockpile)	0.005	IPCC (2006)
Composting (Passive Windrow)	0.01	IPCC (2006)
Uncovered anaerobic lagoon (Effluent pond)	0	IPCC (2006)

Table 5.C.7 Feedlot cattle – Fraction of N volatilised by Manure Management Systems

MMS	FracGASM	Source
Dry lot (Feedpad)	0.6	DEWR (2007) and Watts *et al.* (2012)
Solid Storage (Stockpile)	0.25	DEWR (2007) and Watts *et al.* (2012)
Composting (Passive Windrow)	0.4	Rotz (2004)
Uncovered anaerobic lagoon (Effluent pond)	0.35	IPCC (2006)

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Appendix 5.D Sheep

Table 5.D.1 Sheep – liveweight (kg)

State	Season	Sheep > 1					Sheep < 1
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
ACT/NSW	Spring	75	62	44	54	56	20
	Summer	75	55	42	49	51	27
	Autumn	69	55	43	50	50	32
	Winter	69	55	45	50	51	34
Queensland	Spring	58	50	35	40	45	20
	Summer	61	55	40	45	50	25
	Autumn	63	55	40	45	50	20
	Winter	60	50	35	42	48	25
South Australia	Spring	80	70	52	55	55	40
	Summer	70	65	52	55	55	45
	Autumn	70	60	52	55	55	20
	Winter	70	60	52	55	55	30
Tasmania	Spring	90	55	45	50	50	14
	Summer	90	55	45	50	50	24
	Autumn	75	50	45	50	50	36
	Winter	75	45	50	55	50	42
Victoria	Spring	70	60	50	55	50	22
	Summer	65	55	45	50	50	28
	Autumn	65	52	43	48	50	33
	Winter	60	50	40	45	50	35
Western Australia	Spring	75	60	50	55	55	30
	Summer	65	55	45	50	50	30
	Autumn	65	48	40	45	45	10
	Winter	65	48	45	50	50	20

Table 5.D.2 Sheep – dry matter digestibility of feed intake (per cent)

State	Season	Sheep > 1					Sheep < 1
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(per cent)	(per cent)	(per cent)	(per cent)	(per cent)	(per cent)
ACT/NSW	Spring	75	75	75	75	75	75
	Summer	61	61	61	61	61	61
	Autumn	64	64	64	64	64	64
	Winter	72	72	72	72	72	72
Queensland	Spring	51	51	51	51	51	51
	Summer	55	55	55	55	55	55
	Autumn	59	59	59	59	59	59
	Winter	58	58	58	58	58	58
South Australia	Spring	70	70	70	70	70	70
	Summer	55	55	55	55	55	55
	Autumn	55	55	55	55	55	55
	Winter	75	75	75	75	75	75
Tasmania	Spring	75	75	75	75	75	75
	Summer	55	55	55	55	55	55
	Autumn	67	67	67	67	67	67
	Winter	70	70	70	70	70	70
Victoria	Spring	70	70	70	70	70	70
	Summer	55	55	55	55	55	55
	Autumn	65	65	65	65	65	65
	Winter	60	60	60	60	60	60
Western Australia	Spring	73	73	73	73	73	73
	Summer	55	55	55	55	55	55
	Autumn	50	50	70	70	50	70
	Winter	76	76	76	76	76	76

Table 5.D.3 Sheep – feed availability (t/ha)

State	Season	Sheep > 1					Sheep < 1
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(t/ha)	(t/ha)	(t/ha)	(t/ha)	(t/ha)	(t/ha)
ACT/NSW	Spring	2.90	2.90	2.90	2.90	2.90	2.90
	Summer	2.50	2.50	2.50	2.50	2.50	2.50
	Autumn	1.60	1.60	1.60	1.60	1.60	1.60
	Winter	1.70	1.70	1.70	1.70	1.70	1.70
Queensland	Spring	1.50	1.50	1.50	1.50	1.50	1.50
	Summer	2.00	2.00	2.00	2.00	2.00	2.00
	Autumn	2.20	2.20	2.20	2.20	2.20	2.20
	Winter	1.70	1.70	1.70	1.70	1.70	1.70
South Australia	Spring	4.00	4.00	4.00	4.00	4.00	4.00
	Summer	2.50	2.50	2.50	2.50	2.50	2.50
	Autumn	0.70	0.70	0.70	0.70	0.70	0.70
	Winter	0.90	0.90	0.90	0.90	0.90	0.90
Tasmania	Spring	2.50	2.50	2.50	2.50	2.50	2.50
	Summer	2.50	2.50	2.50	2.50	2.50	2.50
	Autumn	1.30	1.30	1.30	1.30	1.30	1.30
	Winter	0.80	0.80	0.80	0.80	0.80	0.80
Victoria	Spring	3.20	3.20	3.20	3.20	3.20	3.20
	Summer	3.00	3.00	3.00	3.00	3.00	3.00
	Autumn	1.80	1.80	1.80	1.80	1.80	1.80
	Winter	1.00	1.00	1.00	1.00	1.00	1.00
Western Australia	Spring	3.50	3.50	3.50	3.50	3.50	3.50
	Summer	1.50	1.50	1.50	1.50	1.50	1.50
	Autumn	0.70	0.70	0.70	0.70	0.70	0.70
	Winter	1.20	1.20	1.20	1.20	1.20	1.20

Table 5.D.4 Sheep – crude protein content of feed intake (per cent)

State	Season	Sheep > 1					Sheep < 1
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(per cent)	(per cent)	(per cent)	(per cent)	(per cent)	(per cent)
ACT/NSW	Spring	20	20	20	20	20	20
	Summer	10	10	10	10	10	10
	Autumn	12	12	12	12	12	12
	Winter	18	18	18	18	18	18
Queensland	Spring	8	8	8	8	8	8
	Summer	10	10	10	10	10	10
	Autumn	9	9	9	9	9	9
	Winter	7	7	7	7	7	7
South Australia	Spring	16	16	16	16	16	16
	Summer	7	7	7	7	7	7
	Autumn	9	9	9	9	9	9
	Winter	20	20	20	20	20	20
Tasmania	Spring	20	20	20	20	20	20
	Summer	7	7	7	7	7	7
	Autumn	14	14	14	14	14	14
	Winter	16	16	16	16	16	16
Victoria	Spring	16	16	16	16	16	16
	Summer	7	7	7	7	7	7
	Autumn	13	13	13	13	13	13
	Winter	10	10	10	10	10	10
Western Australia	Spring	18	18	18	18	18	18
	Summer	6	6	6	6	6	6
	Autumn	6	6	16	16	6	16
	Winter	21	21	21	21	21	21

Table 5.D.5 Sheep – liveweight gain (kg/day)

State	Season	Sheep > 1					Sheep < 1
		Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
		(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day)	(kg/day)
ACT/NSW	Spring	0.07	0.08	0.07	0.04	0.05	0.16
	Summer	0	-0.08	0.00	-0.05	-0.05	0.08
	Autumn	-0.07	0.00	0.00	0.01	-0.01	0.05
	Winter	0.00	0.00	0.02	0.00	0.01	0.04
Queensland	Spring	-0.02	0.00	0.00	-0.02	-0.03	0.20
	Summer	0.03	0.05	0.05	0.05	0.05	0.05
	Autumn	0.02	0.00	0.00	0.00	0.00	0.20
	Winter	-0.03	-0.05	-0.05	-0.03	-0.02	0.05
South Australia	Spring	0.11	0.11	0.00	0.00	0.00	0.11
	Summer	-0.10	-0.10	0.00	0.00	0.00	0.05
	Autumn	0.00	-0.10	0.00	0.00	0.00	0.16
	Winter	0.00	0.00	0.00	0.00	0.00	0.16
Tasmania	Spring	0.16	0.11	0.03	-0.02	0.00	0.15
	Summer	0.00	0.00	0.00	0.00	0.00	0.11
	Autumn	-0.20	-0.10	0.00	0.00	0.00	0.13
	Winter	0	-0.10	0.5	0.02	0.00	0.07
Victoria	Spring	0.11	0.11	0.16	0.11	0.00	0.15
	Summer	-0.05	-0.05	-0.05	-0.05	0.00	0.07
	Autumn	0.00	-0.03	-0.02	-0.02	0.00	0.05
	Winter	-0.05	-0.02	-0.03	-0.03	0.00	0.02
Western Australia	Spring	0.11	0.13	0.05	0.05	0.05	0.11
	Summer	-0.11	-0.05	-0.05	-0.05	-0.05	0.00
	Autumn	0.00	-0.08	0.11	-0.05	-0.05	0.11
	Winter	0.00	0.00	0.05	0.05	0.05	0.11

Table 5.D.6 Sheep – proportion of lambs receiving milk in each season

State	Spring	Summer	Autumn	Winter
ACT/NSW	0.4	0.1	0.2	0.3
Queensland	0.5	0	0.5	0
South Australia	0.15	0.05	0.3	0.5
Tasmania	0.6	0	0.1	0.3
Victoria	0.3	0.1	0.25	0.35
Western Australia	0.15	0.1	0.15	0.6

Source: Based on breed weighted season of joining (+ 2 seasons) as reported in the MLA 2002 Lamb Survey. Queensland and Tasmania estimates based on information provided by State experts.

Table 5.D.7 Sheep – standard reference weights (kg)

State	Sheep > 1					Sheep< 1
	Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
ACT/NSW	78	62	57	57	57	60
Queensland	70	60	50	50	50	55
South Australia	84	72	60	60	60	66
Tasmania	77	66	55	55	55	60
Victoria	70	60	50	50	50	55
Western Australia	84	72	60	60	60	66

Based on SCA 1990.

Appendix 5.E Pigs

PIGBAL (v4; Skerman *et al.* 2013) is a nutrient balance model for intensive piggeries in Australia. By entering typical animal characteristic, intakes, diet compositions and wastage rates (Tables E.1 and E.2) the model calculates the volatile solids in the animal manure and waste feed and the nitrogen retained by the animals (Table E.3). Pig industry experts provided information on average intakes and other relevant details for a typical herd.

Table 5.E.1 Pigs – Herd characteristics

	Units	1990- 1994	1995-1999	2000-2004	2005-2009	2010-2017
Pig mass and productivity						
Av pig live weight						
Sows	(kg/pig)	188	188	198	198	188
Boars	(kg/pig)	201	204	206	207	206
Gilts	(kg/pig)	115	121	125	127	125
Slaughter pigs	(kg/pig)	34	36	34	38	39
Slaughter pigs at turnoff	(kg/pig)	85	91	95	94	97
Av. slaughter pig age at turnoff	(weeks)	21	21	21	20	21
Breeder mortality	(per cent)	10	10	10	10	10
Slaughter pig mortality	(per cent)	5	5	5	5	5
Pigs slaughtered / sow.yr	(pigs/sow/yr)	19	18	19	19	21
Dressing percentage	(per cent)	76	77	77	78	78
FCR (whole herd)	kg feed fed / kg live weight	3	3	3	3	3
ADG (wean-finish)	g/day/pig	658	690	721	727	730
Feed intake (ingested as-fed)						
Sows	kg/pig/day	2.98	2.92	3.31	2.58	2.62
Boars	kg/pig/day	2.20	2.20	2.20	2.30	2.30
Gilts	kg/pig/day	2.20	2.20	2.80	2.50	2.50
Slaughter pigs (mean LW)	kg/pig/day	1.49	1.47	1.63	1.65	1.71
Feed wastage (per cent)						
Sows	per cent	5.0	5.0	5.0	5.0	5.0
Boars	per cent	5.0	5.0	5.0	5.0	5.0
Gilts	per cent	10.0	10.0	10.0	10.0	10.0
Slaughter pig herd	per cent	11.5	12.1	10.4	12.6	11.0

Table 5.E.2 Pigs – Feed specifications

Diet characteristics		1990- 1994	1995-1999	2000-2004	2005-2009	2010-2017
Breeder herd						
Dry matter	per cent	90.2	90.2	91.2	91.2	88.8
DMD	per cent	82.7	82.5	82.1	82.2	80.3
CP	per cent	2.6	2.5	2.4	2.4	2.3
Slaughter pig herd						
Dry matter	per cent	90.2	90.2	90.2	90.2	88.8
DMD	per cent	86.9	87.0	86.2	85.8	82.5
CP	per cent	3.5	3.5	3.1	3.0	2.6

Table 5.E.3 Pigs – Manure characteristics derived from PigBAL

		1990- 1994	1995-1999	2000-2004	2005-2009	2010-2017
Breeder herd						
Manure ash						
Boars	per cent	26.3	26.3	25.3	25.4	26.7
Sows	per cent	27.0	27.1	26.7	26.0	25.5
Gilts	per cent	31.4	31.7	25.7	25.4	24.7
N retention						
Boars	per cent DMI	24.3	23.2	21.8	23.9	27.6
Sows	per cent DMI	7.9	7.7	7.4	10.1	9.7
Gilts	per cent DMI	24.3	23.2	21.8	23.9	27.6
Volatile solids						
Boars	kg/hd/day	0.37	0.37	0.39	0.40	0.40
Sows	kg/hd/day	0.47	0.47	0.55	0.43	0.46
Gilts	kg/hd/day	0.41	0.41	0.57	0.51	0.55
Nitrogen in waste						
Boars	kg/hd/yr	17.11	17.19	16.47	17.35	16.93
Sows	kg/hd/yr	23.37	23.27	25.91	19.24	17.91
Gilts	kg/hd/yr	21.84	22.12	22.57	19.69	16.70
Slaughter pig herd						
Manure ash	per cent	34.7	34.4	29.5	28.1	21.7
N retention	per cent	32.0	33.9	36.8	37.3	42.1
Volatile solids	kg/hd/day	0.28	0.27	0.32	0.36	0.39
Nitrogen in waste	kg/hd/yr	15.6	15.0	14.0	14.2	11.4

Source: PigBal v4 – Skerman *et al.* (2013).

Table 5.E.4 Pigs – Integrated emission factors 1990 – 2016

	NT	NSW	QLD	SA	TAS	VIC	WA
1990-1994							
iMCF	0.726230	0.682990	0.726230	0.661320	0.617420	0.654825	0.689240
$iFracGASM_{MMS}$	0.53068	0.52283	0.53068	0.51433	0.51433	0.51948	0.51853
iNOF	0.000350	0.001045	0.000350	0.001197	0.001197	0.001159	0.001169
1995-1999							
iMCF	0.702285	0.650375	0.702285	0.625695	0.584345	0.626540	0.627980
$iFracGASM_{MMS}$	0.52280	0.51124	0.5228	0.50154	0.50154	0.50915	0.49734
iNOF	0.000960	0.001778	0.000960	0.002026	0.002026	0.001820	0.002548
2000-2004							
iMCF	0.642980	0.519160	0.642980	0.453330	0.424480	0.475805	0.457080
$iFracGASM_{MMS}$	0.50266	0.46475	0.50266	0.44051	0.44051	0.45409	0.43856
iNOF	0.002269	0.004702	0.002269	0.005927	0.005927	0.005337	0.006304
2005-2009							
iMCF	0.645980	0.528260	0.645980	0.468620	0.438670	0.489010	0.474280
$iFracGASM_{MMS}$	0.50406	0.46832	0.50406	0.44630	0.44630	0.46215	0.44490
iNOF	0.002249	0.004544	0.002249	0.005628	0.005628	0.004892	0.006004
2010-2017							
iMCF	0.645980	0.441743	0.619895	0.560800	0.524300	0.450670	0.528710
$iFracGASM_{MMS}$	0.50406	0.45946	0.50371	0.47860	0.47860	0.45279	0.46465
iNOF	0.002249	0.005167	0.002432	0.003425	0.003425	0.005334	0.004983

Table 5.E.5 Pigs – Allocation of waste to MMS 1990 – 2016 (per cent)

	NSW	NT	QLD	SA	TAS	VIC	WA
1990-1994							
Outdoor (Dry lot)	3.5	0.0	0.0	4.0	4.0	4.0	4.0
Deep litter[(a)]	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Effluent pond[(b)] (Uncovered anaerobic lagoon)	90.8	94.1	94.1	87.8	87.8	87.3	89.2
Anaerobic digester / Covered lagoon	0.0	0.0	0.0	0.0	0.0	2.3	0.0
Short HRT tank storage (< 1 month)	1.1	1.1	1.1	3.7	3.7	1.8	2.3
Solid Separation	3.6	3.7	3.7	3.6	3.6	3.6	3.6
1995-1999							
Outdoor (Dry lot)	4.0	2.0	2.0	5.0	5.0	4.5	6.0
Deep litter[(a)]	5.5	2.5	2.5	5.5	5.5	5.0	8.0
Effluent pond[(b)] (Uncovered anaerobic lagoon)	86.1	90.8	90.8	82.7	82.7	83.2	80.7
Anaerobic digester / Covered lagoon	0.0	0.0	0.0	0.0	0.0	2.2	0.0
Short HRT tank storage (< 1 month)	1.0	1.1	1.1	3.4	3.4	1.7	2.1
Solid Separation	3.4	3.6	3.6	3.4	3.4	3.4	3.2
2000-2004							
Outdoor (Dry lot)	5.0	2.0	2.0	6.0	6.0	6.0	8.0
Deep litter[(a)]	25.0	12.0	12.0	32.0	32.0	28.0	32.0
Effluent pond[(b)] (Uncovered anaerobic lagoon)	67.1	82.4	82.4	57.7	57.7	61.3	56.7

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	NSW	NT	QLD	SA	TAS	VIC	WA
Anaerobic digester / Covered lagoon	0.0	0.0	0.0	0.0	0.0	1.5	0.0
Short HRT tank storage (< 1 month)	0.8	1.0	1.0	2.4	2.4	1.3	1.5
Solid Separation	2.1	2.6	2.6	1.9	1.9	2.0	1.8
2005-2009							
Outdoor (Dry lot)	5.0	2.0	2.0	6.0	6.0	6.0	8.0
Deep litter[(a)]	24.0	12.0	12.0	30.0	30.0	25.0	30.0
Effluent pond[(b)] (Uncovered anaerobic lagoon)	68.4	82.8	82.8	59.9	59.9	62.6	59.1
Anaerobic digester / Covered lagoon	0.0	0.0	0.0	0.0	0.0	3.4	0.0
Short HRT tank storage (< 1 month)	0.8	1.0	1.0	2.5	2.5	1.3	1.3
Solid Separation	1.8	2.2	2.2	1.6	1.6	1.7	1.6
2010-2017							
Outdoor (Dry lot)	6.0	2.0	3.0	2.0	2.0	6.0	10.0
Deep litter[(a)]	27.0	12.0	12.0	20.0	20.0	28.0	20.0
Effluent pond[(b)] (Uncovered anaerobic lagoon)	51.6	82.8	77.5	73.0	73.0	56.0	66.9
Anaerobic digester / Covered lagoon	13.1	0.0	5.0	0.0	0.0	6.4	0.0
Short HRT tank storage (< 1 month)	0.7	1.0	0.4	3.0	3.0	1.9	1.4
Solid Separation	1.7	2.2	2.1	2.0	2.0	1.7	1.8

(a) Secondary MMS for waste from deep litter is Solid Storage. 5 per cent of VS is assumed to be lost in the primary system (Wiedemann *et al.* 2014).

(b) Secondary MMS for waste from covered pond/digester is an uncovered lagoon. 75 per cent of VS is assumed to be lost in the primary system (Wiedemann *et al.* 2014). (c) Separated solids pass directly to the secondary MMS – Solid Storage.

Table 5.E.6 Pigs – Methane conversion factors (MCFs)

MMS	NSW	QLD/NT	SA	TAS	VIC	WA
Outdoor (Dry lot)	0.01[(b)]	0.03[(a)]	0.01[(b)]	0.01[(b)]	0.01[(b)]	0.01[(b)]
Deep litter [(c)]	0.04	0.04	0.04	0.04	0.04	0.04
Stockpile (Solid storage) [(b)]	0.02	0.02	0.02	0.02	0.02	0.02
Effluent pond (Uncovered anaerobic lagoon)[(d)]	0.75	0.77	0.75	0.70	0.74	0.77
Anaerobic digester / Covered lagoon[(e)]	0.1	0.1	0.1	0.1	0.1	0.1
Short HRT tank storage (< 1 month) [(d)]	0.03	0.03	0.03	0.03	0.03	0.03

(a) Redding *et al.* (2015). (b) IPCC (2006) cool region values applied as these more closely align with Australian experimental data (Redding *et al.* (2015) and J. Devereux and M. Redding pers.comm., QDAFF June 2014). (c) Based on average of international literature (Wiedemann *et al.* 2014, Cabaraux *et al.* 2009; Nicks 2003, 2004; Philippe *et al.* 2007, 2010, 2011, 2012). (d) IPCC (2006); (e) IPCC (1997).

Table 5.E.7 Pigs – Nitrous oxide emission factors by Manure Management System

MMS	N_2O	Source
Outdoor(Dry lot)	0.02	IPCC (2006)
Deep litter	0.01	IPCC (2006)
Stockpile (Solid storage)	0.005	IPCC (2006)
Effluent pond (Uncovered anaerobic lagoon)	0	IPCC (2006)
Anaerobic digestor / Covered lagoon	0	IPCC (2006)
Short HRT tank storage (< 1 month)	0.002	IPCC (2006)

Table 5.E.8 Pigs – Fraction of N volatilised by Manure Management System

MMS	FracGASM	Source
Outdoor (Dry lot)	0.3	IPCC (2006) (Other Cattle)
Deep litter	0.125	Wiedemann *et al.* (2014)
Stockpile (Solid storage)	0.2	FSA Consulting (2007)
Effluent pond (Uncovered anaerobic lagoon)	0.55	Tucker *et al.* (2010), Wiedemann *et al.* (2012)
Anaerobic digester / Covered lagoon	0	IPCC (2006)
Short HRT tank storage (< 1 month)	0.25	IPCC (2006)

Appendix 5.F Poultry

Table 5.F.1 Poultry – Diet properties

Nutrient Analysis	Layers[(a)]	Meat Chicken Growers	Meat Chicken Breeder	Meat Other
Dry matter intake (kg/hd/day)	0.086	0.093	0.103	0.093
Dry matter digestibility	0.80	0.80	0.80	0.80
Crude protein[(b)]	0.19	0.23	0.19	0.23
Nitrogen retention rate	0.35	0.47	0.32	0.47
Manure ash	0.18	0.15	0.18	0.15

(a) Values for layer hens represent the average for hens and pullets over a complete growing cycle. (b) Crude protein is based on whole diet weighted average, converted to DM basis (K. Bruerton, Protea Park Nutrition Services, pers. comm., 2014.).

Table 5.F.2 Poultry – Meat and Layer Chicken integrated emission factors

	1990-1994	1995-1999	2000-2004	2005-2009	2010-2017
iMCF					
Meat Chickens					
ACT/NSW	0.024830	0.024830	0.024771	0.024711	0.024414
NT/QLD	0.024870	0.024870	0.024891	0.024911	0.025014
SA	0.024830	0.024830	0.024771	0.024711	0.024414
TAS	0.023812	0.023812	0.023757	0.023702	0.023425
VIC	0.024830	0.024830	0.024771	0.024711	0.024414
WA	0.024830	0.024830	0.024771	0.024711	0.024414
Layer Chickens					
ACT/NSW	0.029841	0.029887	0.030655	0.031527	0.031702
NT/QLD	0.029869	0.029927	0.030743	0.031687	0.031930
SA	0.029841	0.029887	0.030655	0.031527	0.031702
TAS	0.029229	0.029273	0.030009	0.030845	0.031011
VIC	0.029841	0.029887	0.030655	0.031527	0.031702
WA	0.029841	0.029887	0.030655	0.031527	0.031702
$iFracGASM_{MSS}$					
Meat Chickens	0.397064	0.397064	0.395473	0.393881	0.385924
Layer Chickens	0.483880	0.478978	0.413370	0.336948	0.315956
iNOF					
Meat Chickens	0.004277	0.004277	0.004260	0.004242	0.004157
Layer Chickens	0.004327	0.004261	0.004454	0.004675	0.004728

Table 5.F.3 Poultry – Meat Chickens allocation of waste to Manure Management Systems (per cent)

MSS	1990-1994	1995-1999	2000-2004	2005-2009	2010-2017
Primary System					
Poultry manure with litter (housing)	99.8	99.8	99.4	99.0	97.0
Pasture range and paddock (free range)	0.2	0.2	0.6	1.0	3.0
Secondary System[(a)]					
Solid storage (Stockpile)	46.0	46.0	46.0	46.0	46.0
Composting (Passive windrow)	24.0	24.0	24.0	24.0	24.0
Direct Application to Soil	30.0	30.0	30.0	30.0	30.0

Source: Wiedemann *et al.* (2014). (a) only housing waste is transferred to the secondary systems. 15 per cent of VS is assumed to be lost in the primary system

Table 5.F.4 Poultry – Layer Hens allocation of waste to Manure Management Systems (per cent)

MSS	1990-1994	1995-1999	2000-2004	2005-2009	2010-2017
Primary System					
Poultry Manure without litter (housing)	98	97.2	93.8	89.0	85.4
Belt manure removal	8	9.4	31	55.8	61.6
Manure stored in house under cages or slat	90	87.8	62.8	33.2	23.8
Poultry Manure with litter (housing)	1.86	2.6	5.76	10.2	13.46
Pasture range and paddock (Free range)	0.14	0.2	0.44	0.8	1.14
Secondary System [(a)]					
Solid storage (Stockpile)	76.0	76.0	76.0	76.0	76.0
Composting (Passive windrow)	15.0	15.0	15.0	15.0	15.0
Direct application to soils	5.0	5.0	5.0	5.0	5.0
Direct processing	2.5	2.5	2.5	2.5	2.5
Anaerobic digester / Covered pond	1.5	1.5	1.5	1.5	1.5

Source: AECL (2012), G. Runge, Australian Egg Corporation – AECL and E. McGahan, FSA Consulting, pers. comm. 2014).
(a) Only housing waste is transferred to the secondary systems. VS lost in primary system is assumed to be 20 per cent for manure stored in house and 0 per cent for belt removal systems.

Table 5.F.5 Poultry – Methane conversion factors (MCFs)

MMS	All States	NSW	QLD/NT	VIC	SA	WA	TAS
Poultry manure with litter	0.015						
Poultry manure without litter	0.015						
Pasture range and paddock [(a)]		0.01	0.03	0.01	0.01	0.01	0.01
Solid storage	0.02						
Composting (Passive windrow)		0.01	0.01	0.01	0.01	0.01	0.005
Anaerobic digester / Covered pond	0.1						
Direct processing	0						

Source: IPCC (2006).

(a) MCF assumed to be similar to a drylot. QLD/NT based on Redding *et al.* (2015) and other States based on IPCC (2006) cool region values as these more closely align with Australian experimental data (Redding *et al.* (2015) and J. Devereux and M. Redding pers. comm., QDAFF June 2014);

Table 5.F.6 Poultry – Nitrous oxide emission factors by Manure Management System

MMS	N_2O	Source
Poultry manure with litter (housing)	0.001	IPCC (2006)
Poultry manure without litter (housing)	0.001	IPCC (2006)
Pasture range and paddock (free range)	0.02	IPCC (2006)
Solid storage (Stockpile)	0.005	IPCC (2006)
Composting (Passive windrow)	0.01	IPCC (2006)
Direct processing	0	Wiedemann *et al.* (2014)
Anaerobic digester / Covered pond	0	IPCC (2006)

Table 5.F.7 Poultry – Fraction of N volatilised by Manure Management System

MMS	FracGASM	Source
Poultry manure with litter (housing)	0.3	DSEWPC (2013)
Poultry manure without litter (housing)		
Belt manure removal	0.05	DSEWPC (2013)
Manure stored in house under cages or slat	0.4	DSEWPC (2013)
Solid storage (Stockpile)	0.2	DSEWPC (2013)
Composting (Passive windrow)	0.2	DSEWPC (2013)
Direct processing	0	Wiedemann *et al.* (2014)
Anaerobic digester / Covered pond	0	Wiedemann *et al.* (2014)

Appendix 5.G Other livestock

Table 5.F.1 'Other livestock' – manure production (kg DM/head/year)

Livestock Type	Manure Production (kg DM/head/year)	Assumption
Goats, alpacas, emus and ostriches	114	Equivalent to a sheep
Deer, donkeys and mules	319	One-third of beef cattle – pasture
Horses, buffalo and camels	957	Equivalent to beef cattle – pasture

Table 5.G.2 'Other livestock' – nitrogen excretion factors (kg N/head/year)

Livestock Type	Manure Production (kg DM/head/year)	Assumption
Goats, alpacas, emus and ostriches	7.0	Equivalent to a sheep
Deer, donkeys and mules	13.2	One-third of beef cattle – pasture
Horses, buffalo and camels	39.5	Equivalent to beef cattle – pasture

Table 5.G.2 'Other livestock' – Allocation of animals to climate regions

State	Proportion Warm	Proportion Temperate
ACT	0	1
NT	1	0
NSW	0	1
QLD	0	1
SA	0	1
TASMANIA	0	1
VIC	0	1
WA	0	1

Appendix 5.H Synthetic fertilisers

Table 5.H.1 Sugar cane N fertiliser application rates

Year	NSW	QLD
1990-2000[a]	165	205
2001	155	185
2002	150	181
2003	148	175
2004	155	178
2005	148	173
2006	158	177
2007	161	172
2008	97	150
2009	154	180
2010	141	143
2011	176	164
2012	177	161
2013	175	162
2014	183	159
2015	176	160
2016	181	157
2017	181	157

Source: Incitec Pivot.
(a) 1990 – 2000 rates based on the average of 1996-2000;

Appendix 5.I Crop and pasture attributes

Table 5.I.1 Crop attributes[a]

Crop type	Residue: Crop ratio	Below-ground : above-ground residue ratio	Dry matter content	Carbon fraction in dry matter	N content		Fraction of residue remaining at time of burning[b]	Fraction burnt	Fraction Removed
					Above-ground	Below-ground			
k	R_{AGk}	R_{BGk}	DMk	CCk	NC_{AGk}	NC_{BGk}	S_k	F^{ik}	$FFOD^{ik}$
Wheat	1.50	0.29	0.88	0.40	0.006	0.010	0.5	Table 5.I.3	Table 5.I.3
Barley	1.24	0.32	0.88	0.40	0.007	0.010	0.5	Table 5.I.3	Table 5.I.3
Maize	0.81	0.39	0.85	0.42	0.005	0.007	1.0	Table 5.I.3	Table 5.I.3
Oats	1.42	0.43	0.88	0.40	0.006	0.010	0.5	Table 5.I.3	Table 5.I.3
Rice [c]	1.31	0.16	0.80	0.42	0.007	0.010	1.0	0.815	0.06
Sorghum	1.50	0.22	0.80	0.40	0.008	0.007	0.5	Table 5.I.3	Table 5.I.3
Triticale	1.50	0.42	0.88	0.40	0.006	0.010	0.5	Table 5.I.3	Table 5.I.3
Other Cereals	1.50	0.36	0.88	0.40	0.006	0.010	0.5	Table 5.I.3	Table 5.I.3
Pulses	1.37	0.51	0.87	0.40	0.009	0.010	0.5	Table 5.I.3	Table 5.I.3
Tuber and Roots	0.34	0.43	0.25	0.40	0.020	0.010	NA	0	1
Peanuts [d]	1.07	0.20	0.80	0.42	0.016	0.014	0.5	Table 5.I.3	Table 5.I.3
Sugar cane[e]	0.25	0.45	0.20	0.40	0.005	0.007	1.0	Table 5.I.4	(f)
Cotton [g]	1.90	0.30	0.90	0.40	0.01	0.01	NA	0	0
Hops	1.50	0.29	0.88	0.40	0.006	NA	NA	0	0
Oilseeds	2.10	0.33	0.96	0.40	0.009	0.010	0.5	Table 5.I.3	Table 5.I.3
Forage crops	1.34	0.37	0.88	0.40	0.006	0.010	NA	0	0.8

(a) Sourced from Janzen *et al.* (2003) unless otherwise specified; (b) Mulholland *et al.* (1976) and R Jarvis pers. comm, (c) Robinson and Kirby 2002; (d) IPCC (2006); (e) root:shoot from Morris and Tai (2004), N content from Fortes *et al.* (2013); (f) 0.03 for QLD and zero for WA and NSW. (g) Rochester pers. comm. (2014) above ground values only; .

Table 5.I.2 Pasture attributes

Pasture type	Fraction Renewed		Average Yield (a)	Below-ground : above-ground residue ratio (b)	N content (b)		Fraction above ground residue removed
	Intensive	Other	(t DM ha)		Above-ground	Below-ground	
	$Frac_{Renew}$		Y	R_{BG}	NC_{AG}	NC_{BG}	FFOD
Annual Grass	0.1	0.03	4.4	0.4	0.015	0.012	0.8
Grass Clover Mixture	0.1	0.03	8.3	0.8	0.025	0.016	0.8
Lucerne	0.1	0.03	8.6	0.4	0.027	0.019	0.8
Other Legume Pasture	0.1	0.03	5.6	0.4	0.027	0.022	0.8
Perennial Pasture	0.1	0.03	8.4	0.8	0.015	0.012	0.8

(a) Average yields as estimated by FullCAM (b) IPCC (2006).

Table 5.I.3 Crop Residues – proportion burnt or removed

Year (time-step)	State	Proportion burnt	Proportion removed
1990 – 1994	NSW	0.37	0.12
	VIC	0.38	0.16
	QLD	0.22	0.12
	SA	0.31	0.19
	WA	0.32	0.24
	TAS	0.16	0.19
	NT	0.30	0.05
	ACT	0.12	0.06
1995 – 1999	NSW	0.33	0.10
	VIC	0.36	0.15
	QLD	0.17	0.09
	SA	0.29	0.18
	WA	0.23	0.19
	TAS	0.14	0.19
	NT	0.28	0.04
	ACT	0.09	0.05
2000 – 2004	NSW	0.30	0.09
	VIC	0.32	0.13
	QLD	0.12	0.07
	SA	0.23	0.15
	WA	0.14	0.15
	TAS	0.13	0.18
	NT	0.26	0.03
	ACT	0.06	0.03
2005 – 2009	NSW	0.25	0.06
	VIC	0.26	0.10
	QLD	0.06	0.04
	SA	0.17	0.12
	WA	0.08	0.12
	TAS	0.11	0.17
	NT	0.24	0.02
	ACT	0.02	0.01
2010 – 2017	NSW	0.22	0.05
	VIC	0.21	0.07
	QLD	0.06	0.04
	SA	0.12	0.09
	WA	0.06	0.11
	TAS	0.09	0.16
	NT	0.23	0.01
	ACT	0.00	0.00

Table 5.I.4 Fraction of sugar cane burnt in each State

Year	NSW	QLD	WA
1989	1.000	0.735	NO
1990	0.978	0.686	NO
1991	0.987	0.664	NO
1992	0.987	0.639	NO
1993	0.987	0.641	NO
1994	0.965	0.596	NO
1995	0.949	0.585	NO
1996	0.975	0.505	1.000
1997	0.976	0.430	1.000
1998	0.951	0.404	1.000
1999	0.951	0.307	1.000
2000	0.928	0.346	1.000
2001	0.920	0.390	1.000
2002	0.897	0.357	1.000
2003	0.884	0.331	1.000
2004	0.915	0.329	1.000
2005	0.963	0.306	1.000
2006	0.975	0.282	1.000
2007	0.947	0.434	1.000
2008	0.947	0.271	1.000
2009	0.733	0.263	NO
2010	0.797	0.287	NO
2011	0.874	0.359	1.000
2012	0.958	0.374	1.000
2013	0.896	0.265	NO
2014	0.896	0.265	1.000
2015	0.919	0.250	1.000
2016	0.934	0.280	1.000
2017	0.959	0.359	1.000

Source: QLD Cane Growers Association and NSW Sugar Milling Cooperative Ltd.

Appendix 5.J Nitrogen leaching and runoff

Table 5.J.1 Fraction of fertiliser N available for leaching and runoff (FracWET)

Production System	ACT/NSW	NT	Qld	SA	Tas	Vic	WA
Irrigated Pasture	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Irrigated crops	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Non-irrigated pasture	0.334	0.811	0.128	0.708	0.991	0.855	0.508
Non-irrigated crops	0.192	0.777	0.043	0.279	0.985	0.438	0.223
Sugar	0.990		0.656				0.759
Cotton[(a)]	0.932		0.713				1.000
Horticultural crops	0.599	0.857	0.293	0.667	0.996	0.702	0.911

(a) Weighted average of FracWET for irrigated (1) and non-irrigated (NSW = 0.246, QLD=0.075 and WA=0.759) cotton.

Table 5.J.2 Fraction of animal waste available for leaching and runoff (FracWET)

State	Region	Dairy Cattle	Beef Cattle		Sheep	Pigs	Poultry		Other categories
			Pasture	Feedlot			Meat	Layer	
ACT		1	0.785	0	0.812	0.500	0.442	0.396	0.665
NSW		1	0.365	0.192	0.269	0.500	0.442	0.396	0.335
NT		1		0	0	0	0	0	0.773
	Alice Springs								
	Barkly								
	Northern		0.582						
QLD		1		0.043	0.018	0.250	0.578	0.131	0.107
	High		0.07						
	Moderate/High								
	Moderate/Low		0.01						
	Low		0.66						
SA		1	0.691	0.279	0.516	0.750	0.147	0.443	0.415
TASMANIA		1	0.997	0	0.987	1.000	1.000	1.000	0.995
VIC		1	0.914	0.438	0.873	0.500	0.901	0.858	0.768
WA		1		0.223	0.51	0.400	0.891	0.869	0.668
	South West		0.826						
	Pilbara								
	Kimberley		0.392						

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6 Land Use, Land Use Change and Forestry

6.1 Emission trends

The net emissions from the *land use, land use change and forestry* (*LULUCF*) sector were -19.4 Mt CO_2-e in 2017, and -19.7 Mt CO_2-e in 2018.

Table 6.1 Land Use, Land Use Change and Forestry net CO_2-e emissions, 2017

Greenhouse gas source and sink categories	CO_2-e emission (Gg)			
	CO_2	CH_4	N_2O	Total
4 Land use, land use change and forestry	-35,286.9	11,930.3	3,925.4	-19,431.1
A. Forest land	-68,330.8	5,854.4	1,459.8	-61,016.6
A.1 Forest land remaining forest land	-19,768.3	5,781.6	1,135.1	-12,851.6
A.2 Land converted to forest land	-48,562.4	72.8	324.7	-48,164.9
B. Cropland	-1,506.2	42.4	22.3	-1,441.4
B.1 Cropland remaining cropland	-3,080.4	-	-	-3,080.4
B.2 Land converted to cropland	1,574.3	42.4	22.3	1,639.0
C. Grassland	38,579.7	5,780.3	2,343.5	46,703.5
C.1 Grassland remaining grassland	-5,062.2	4,539.1	1,874.7	1,351.6
C.2 Land converted to grassland	43,641.9	1,241.1	468.9	45,351.9
D. Wetlands	42.1	233.8	91.5	367.4
D.1 Wetlands remaining wetlands	42.5	233.8	91.5	367.8
D.2 Land converted to wetlands	-0.4	-	-	-0.4
E. Settlements	577.7	19.5	8.2	605.4
E.1 Settlements remaining settlements	-24.3	-	-	-24.3
E.2 Land converted to settlements	602.1	19.5	8.2	629.7
F. Other land	NO,NA	NO,NA	NO,NA	NO,NA
G. Harvested wood products	-4,649.4	-	-	-4,649.4

Notes: NA = not applicable, NO = not occurring.

Forest land (4A) comprises emissions and removals from *forest land remaining forest land* and *land converted to forest land*. *Forest land remaining forest land* includes historic plantations, harvested native forests and other native forests. Emissions from *fuelwood consumption* and biomass burning in forests (*controlled burning* and *wildfire*) are also included as are the removals associated with post-fire recovery. *Land converted to forest land* includes grassland, croplands, settlements and wetlands (tidal marsh) on which forest is identified to emerge, including for new plantations. The *forest land* category is estimated to have constituted a net sink of -61.0 Mt CO_2-e in 2017.

Cropland (4B) comprises emissions and removals from *cropland remaining* cropland, *forest land converted to cropland* and *wetlands converted to cropland*. The *cropland* category is estimated to have constituted a net sink of -1.4 Mt CO_2-e in 2017.

Grassland (4C) comprises emissions and removals from *grassland remaining grassland, forest land* and *wetlands converted to grassland*. The *grassland* category is estimated to have constituted a net source of 46.7 Mt CO_2-e in 2017.

Wetlands (4D) comprises emissions and removals from *wetlands remaining wetlands* and *forest land converted to wetlands*. *Wetlands remaining wetlands* estimates include N_2O emissions from aquaculture use in tidal wetlands and net CO_2 emissions from removal of seagrass due to capital dredging in addition to other vegetation-related sources of emissions and removals. The *wetlands* category is estimated to have constituted a net source of 0.4 Mt CO_2-e in 2017.

Settlements (4E) comprises emissions and removals from *settlements remaining settlements*, *forest land converted to settlements* and *wetlands converted to settlements*. The *settlements* category is estimated to have constituted a net source of 0.6 Mt CO_2-e, in 2017.

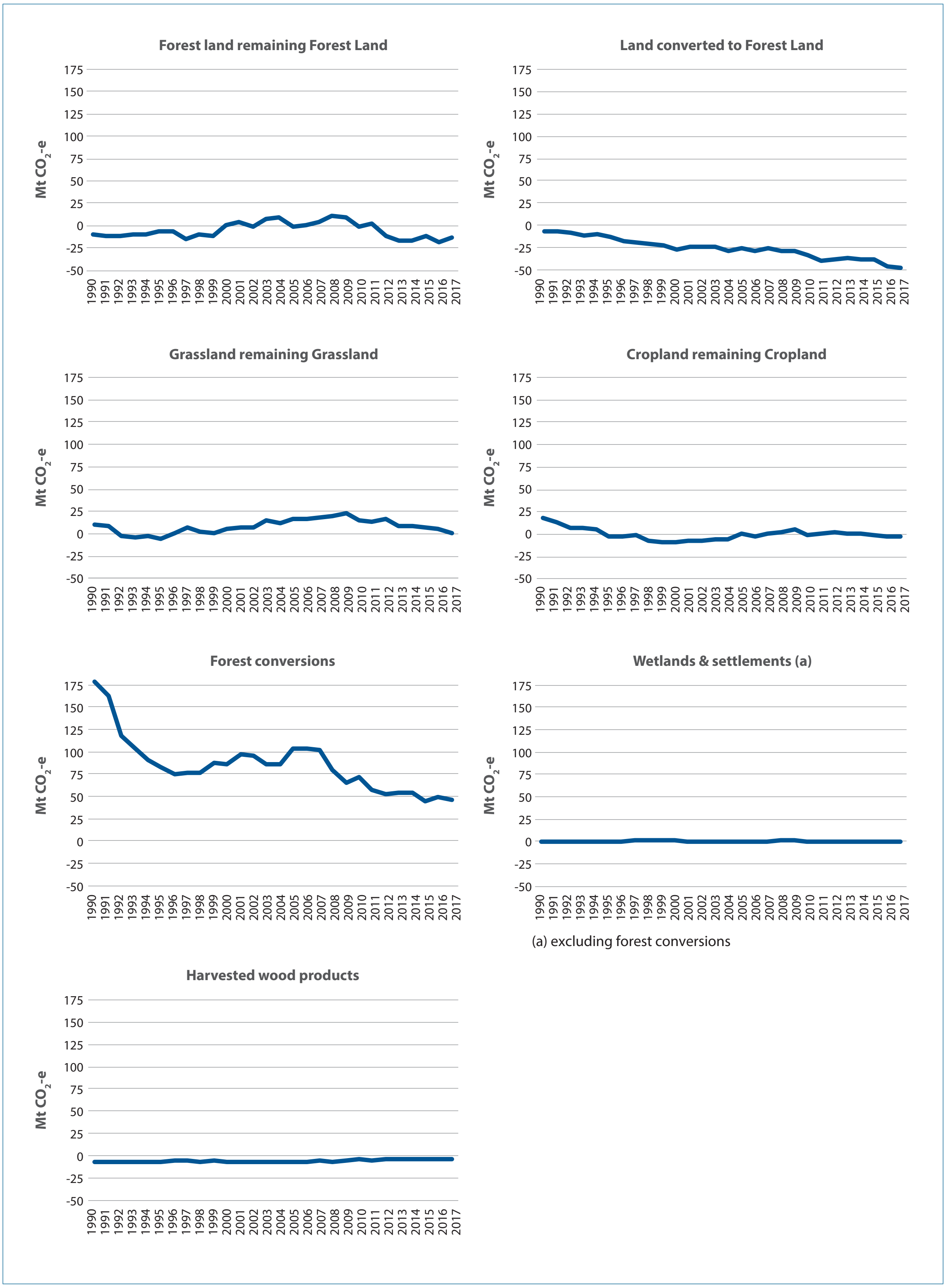
Forest land converted to cropland, *to grassland, to wetlands* and *to settlements* together constituted a net source of 46.5 Mt CO_2-e in 2017. These estimates account for the direct emissions associated with the land conversion operation in the year being reported, along with the ongoing emissions and removals on land converted in previous years, but excluding the removals associated with forest regrowth on previously converted land. These removals are reported as part of *land converted to forest land*.

The net accumulation of carbon in the *harvested wood products* pool equated to a sink of -4.6 Mt CO_2-e in 2017, including net accumulations in solid waste disposal sites.

Net *LULUCF* emissions decreased from 184.6 Mt CO_2-e in 1990 to -19.4 Mt CO_2-e in 2017. The preliminary estimate for 2018 is -19.7 Mt CO_2-e, a change of around two per cent compared to 2017 levels (Table 6.1).

The underlying trend of declining emissions from *LULUCF* since 1990 has been mainly driven by the decline in emissions from *forest land converted to cropland and grassland* and the increase in removals through forest regrowth on previously cleared land (Figure 6.1) as well as, in recent years, declining net emissions from the harvest of native forests.

Figure 6.1 Net CO_2-e emissions from land use, land use change and forestry, by sub-category, 1990–2017



(a) excluding forest conversions

The principal drivers of change in carbon fluxes across the Australian landscape relate to losses and gains of woody vegetation. The loss of woody vegetation is mainly reported under three classifications – *forest conversion to other land uses*, *forest land remaining forest land*, and *grassland remaining grassland*.

Permanent losses of woody vegetation that has been classed as *forest land* are reported under forest conversion to other land use classifications. In 2017, the additional area reported under forest conversion to other land uses was 111 kha.

Temporary losses of woody vegetation on *forest land* are reported under the *forest land remaining forest land* classification. In 2017, the area of temporary loss of vegetation - or area of harvest from native forests – was 61 kha (Figure 6.2). All forests subject to harvest events are monitored over time to ensure that the forest regenerates – if this does not happen, these areas are reported under forest conversion.

Losses of woody vegetation that is not classed as *forest land* (called 'sparse' woody vegetation) – both permanent and temporary – are reported under *grassland remaining grassland*, *wetlands remaining wetlands* and *settlements remaining settlements*. In 2017, the area of sparse woody vegetation lost was 1,467 kha (Figure 6.4).

Increases in woody vegetation cover classed as *forest land* are reported under *land converted to forest land*. These changes include new plantations and forest regrowth on land previously cleared for other uses, environmental plantings and the regeneration of forest from natural seed sources). In 2017, the additional area reported under *land converted to forest land* was 745 kha.

A regeneration of forest following a harvest event is reported under *forest land remaining forest land* as no change in land use has occurred.

Increases in the area of sparse woody vegetation not classed as *forest land* are reported under *grassland remaining grassland*, *wetlands remaining wetlands* and *settlements remaining settlements*. In 2017, the area of gains in sparse woody vegetation was 2,060 kha. (Figure 6.4)

Forest land

Net emissions from *forest land* (4A) were -61.0 Mt CO_2-e in 2017 compared with -16.4 Mt CO_2-e in 1990, a difference of -44.6 Mt CO_2-e. Within *forest land*, *forest land remaining forest land* net emissions were -12.9 Mt CO_2-e in 2017 compared with -10.0 Mt CO_2-e in 1990, while the net emissions from *land converted to forest land* were -48.2 Mt CO_2-e in 2017 compared with -6.4 Mt CO_2-e in 1990.

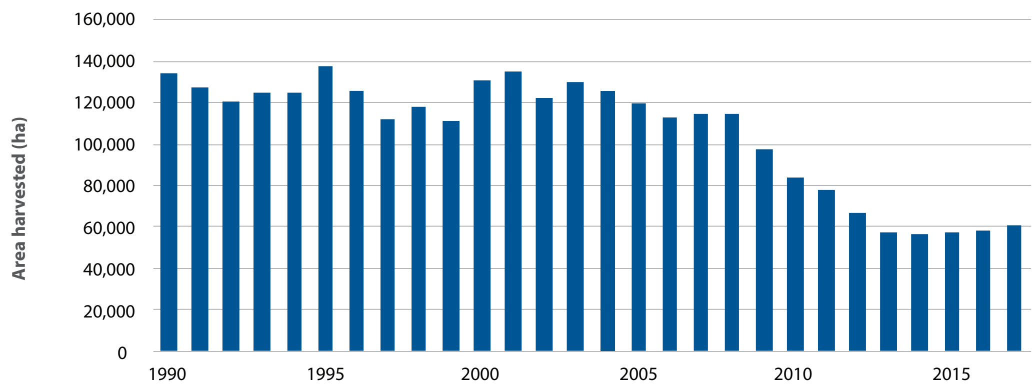
On average, since 1990, *forest land* has been accumulating carbon stocks of approximately 8.4 Mt of carbon each year (equivalent to a sink of approximately 30.9 Mt CO_2 per year, see Figure 6.1).

The key drivers of variation in *forest land* outcomes are annual harvest areas, the areas of new forest, from regeneration of natural seed sources and from plantations, prescribed burning, climate and wildfires.

Harvesting in Australia's native forests, including multiple use forests and private native forests, is the key driver of human induced emissions and removals in these forests. Over recent years, harvesting in the native forest sector has reached historically low levels (Figure 6.2).

The areas of new plantations from 1990 to 2017 are shown in Figure 6.3a and cumulative area of new softwood and hardwood plantings from 1990 to 2016 compared with the ABARES Australian Plantation Statistics 2018 update, is shown in Figure 6.3b.

Figure 6.2 Area harvested in native forests 1990–2017



Wildfires are the largest cause of variability in emissions from *forest land remaining forest land*. Wildfires occur annually across Australia's 138 million hectares of forests with the area burnt varying considerably from year to year. In addition, *forest land remaining forest land* is subject to significant non-anthropogenic natural disturbances including wildfires that are beyond control despite extensive efforts of emergency management organisations.

All anthropogenic fires are included in reporting. Approaches have been developed to identify non-anthropogenic natural disturbances on *forest land remaining forest land*, and carbon stock loss and subsequent recovery from non-anthropogenic natural disturbances are modelled to average out over time, leaving greenhouse gas emissions and removals from anthropogenic fires as the dominant result. Prescribed fires are all considered to be anthropogenic in nature. Disturbance areas are monitored for permanent changes in land use, in which case emissions are reported in the appropriate land conversion category, and salvage logging emissions are reported.

Net emissions due to wildfire in forests in 2017 were 6.1 Mt CO_2-e.

Figure 6.3a Area of new plantings 1990 to 2017

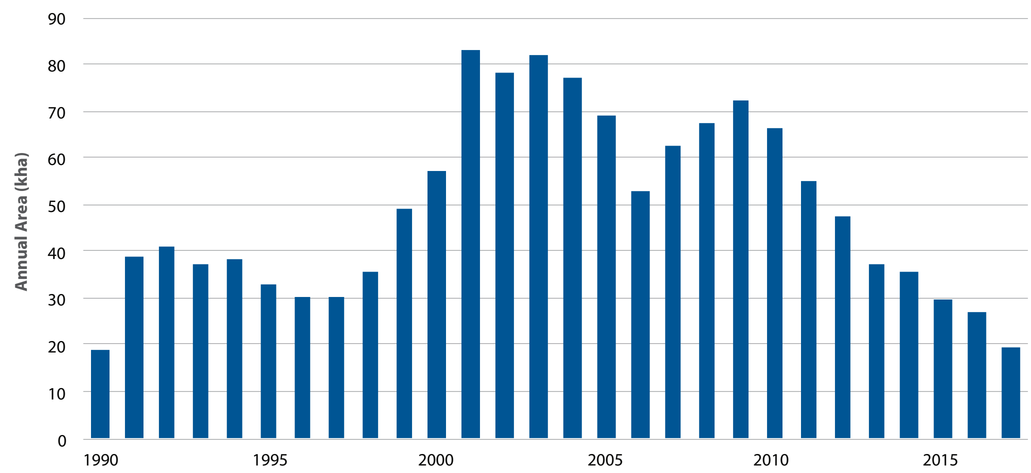
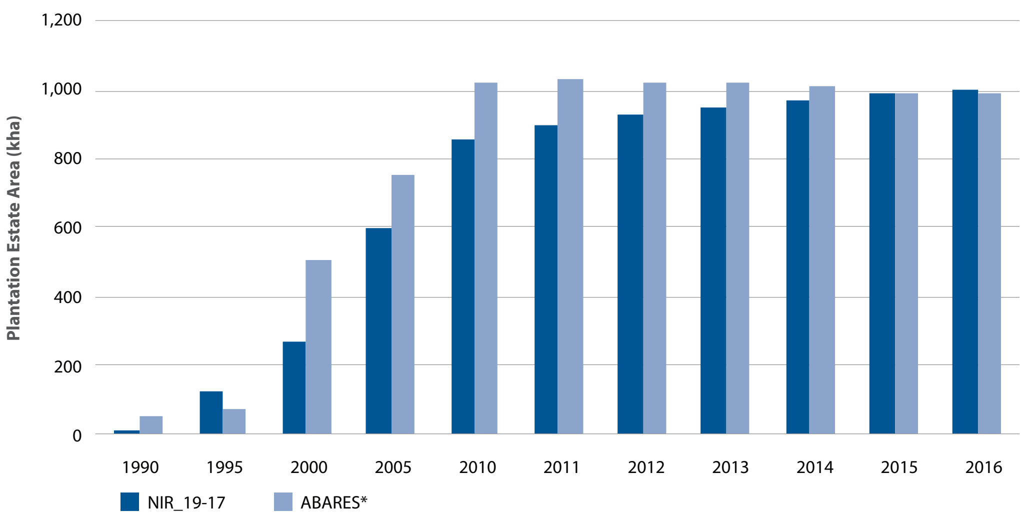


Figure 6.3b Cumulative area of post-89 Softwood and Hardwood plantations 1990–2016



Note: *Australia Plantation Statistics 2018 update, May 2018

Cropland

Net emissions from *cropland* (4.B) were an estimated -1.4 Mt CO_2-e in 2017. Within the *cropland* category, *cropland remaining cropland* net emissions were -3.1 Mt CO_2-e in 2016 compared with 17.9 Mt CO_2-e in 1990. The uptake of reduced, minimum and no-till management techniques through the 1980's and 90's is reflected in decreasing emissions during this period as a new soil C state of equilibrium is reached. Further management changes in recent years and their impact on the soil C steady state can be detected in shifts later in the emissions trend.

The net emissions from *land converted to cropland* were 1.6 Mt CO_2-e in 2017 compared with 19.3 Mt CO_2-e in 1990. This sub-category includes *forest land converted to cropland* and *wetlands converted to cropland.*

Grassland

Net emissions from *grassland* (4.C) were an estimated 46.7 Mt CO_2-e in 2017. Within *grassland*, *grassland remaining grassland* net emissions were 1.4 Mt CO_2-e in 2017 compared with 10.6 Mt CO_2-e in 1990.

Grassland remaining grassland

Changes in carbon stocks in *grassland remaining grassland* are largely driven by changes in land management practices and climate. These factors determine the amount of live biomass and dead organic matter (DOM) as well as the amount of residues, root and manure inputs to soil carbon. The results are reported in three components to reflect the three elements of the emission estimation:

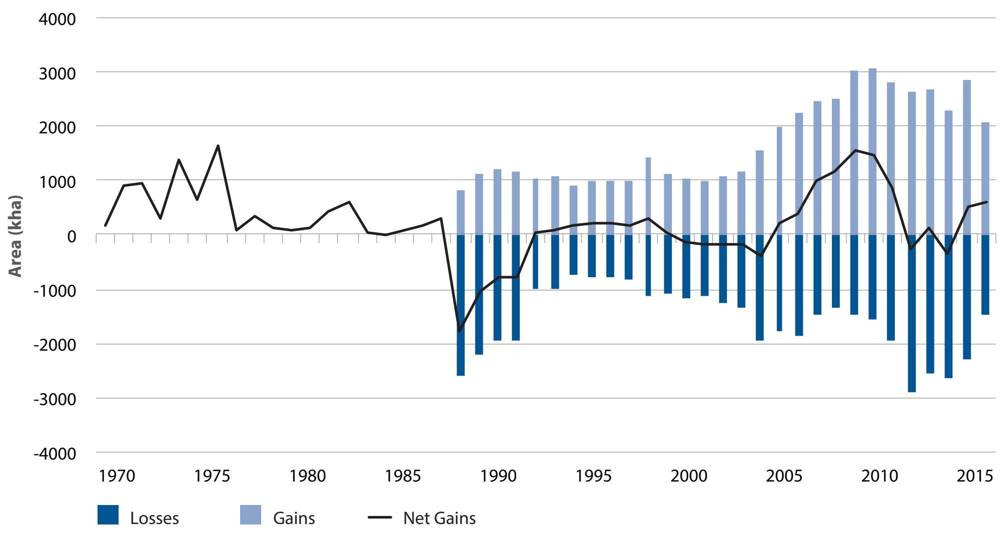
- herbaceous grassland (soil carbon and N mineralization, leaching and runoff);
- changes in sparse woody or shrubland extent; and
- fire.

In the reported estimates for herbaceous grasslands, management and climatic changes can be detected as the emissions trend moves to new equilibrium levels through time. In the arid and semi-arid rangelands of central Australia, soil carbon stocks under natural grass species are assumed to have reached a steady state.

Woody shrubs are a key component of grassland ecosystems in semi-arid and arid regions of central Australia.

Emissions and removals on these shrublands are driven by land management and transitions between shrubs and grasses. These processes are driven by anthropogenic activities such as clearing of vegetation as well as climatic factors. Annual area gains and losses of sparse woody vegetation are shown in Figure 6.4 below.

Figure 6.4 Area of sparse woody vegetation gains and losses, kha, 1970–2017



Net changes in shrub or sparse woody vegetation appear to be strongly correlated with the El Niño Southern Oscillation Index (Bureau of Meteorology), but also reflect the incidence of fire (55 per cent of all lost sparse vegetation in the Northern Territory coincides with a fire event) and mechanical clearing activity by land managers.

According to the Queensland Government Department of Science, Information Technology and Innovation (DSITI, 2015), over 50 per cent of all clearing permits issued in 2013-14 were for the purpose of providing fodder for animals. In drought conditions woody vegetation, for example in the Mulga lands, is an important source of feed for sheep and cattle. The Department of the Environment and Energy's analysis of the Queensland DSITI data shows that, in 2014, the clearing of non-forest vegetation for fodder and other purposes across the *grasslands remaining grasslands* category amounted to around 150,000 hectares with the remainder of vegetation losses reported in the inventory due to non-mechanical causes.

Fire is also an important management action as well as natural disturbance to Australia's grasslands. Net emissions associated with these management fires include carbon dioxide and non-carbon dioxide gases and are reported in section 6.8.

Land converted to grassland

The net emissions from *land converted to grassland* were 45.4 Mt CO_2-e in 2017 compared with 156.4 Mt CO_2-e in 1990. This subcategory includes *forest land converted to grassland* and *wetlands converted to grassland*. Forest conversion to grassland is the dominant contributor to both the level and trend in net emissions in this subcategory.

Forest land converted to cropland and grassland

In 2017, total emissions from *forest land converted to cropland* and *forest land converted to grassland* were around 74 per cent (128.7 Mt CO_2-e) lower than in 1990. The total emissions associated with the transition from forest to non-forest land use include the immediate loss of carbon as trees are cleared and burnt, as well as an ongoing loss of soil carbon as it decays to a new equilibrium stock level and other ongoing emissions and removals associated with the new land use. CO_2 removals associated with forest regrowth emerging on previously cleared land are accounted for separately as part of *land converted to forest land*. See also the sub-section "Forest Conversions" below.

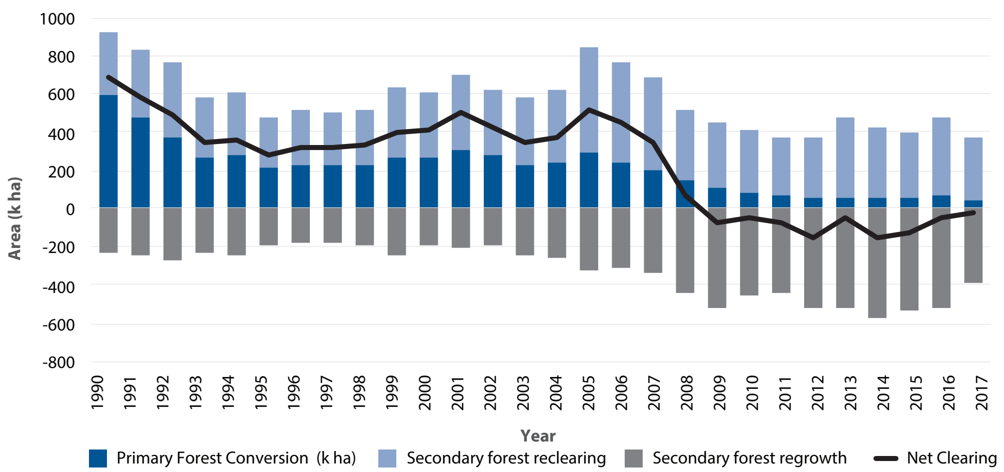
The management of native vegetation and the majority of forest conversion processes in Australia is governed by the *Native Vegetation Framework,* which is an intergovernmental agreement among all levels of Australian government under the Council of Australian Governments (COAG).

Individual jurisdictions implement the national *Native Vegetation Framework* commitments in accordance with their own individual circumstances and land management practices and legislative frameworks.

Examples of administrative processes include compliance with regional ecosystem plans established under legislation, individually negotiated property management plans or additional approval processes / permit processes for clearing. Permits for conversion of all forests to grasslands for agriculture are required in the Northern Territory, Western Australia, Victoria, South Australia and Tasmania, with minor exceptions. In Queensland and in New South Wales, the processes are more complex.

Figure 6.5 illustrates the trend in forest land conversion to cropland and grassland in Australia between 1990 and 2017 and shows the contribution of conversion of mature primary forest and re-clearing of secondary forest cover that has re-grown on previously cleared land. The relative stability of the rate of re-clearing, including of juvenile forest already converted to grassland and cropland, indicates an ongoing and cyclical need of land managers to re-clear certain areas on the fringe of agricultural regions where seed from adjacent forests has supported forest regeneration. Figure 6.5 also shows, for each year, the area on which forest has been observed to re-emerge on previously cleared land.

Figure 6.5 Area of primary and secondary forest conversion and regrowth, Australia, 1990–2017



Note: Losses of woody vegetation that falls below the threshold for a forest are shown in Figure 6.4.

Within this national *Native Vegetation Framework*, economic considerations remain important drivers of the demand for forest conversion to alternative uses.

Most forest land converted in Australia is used for cattle grazing but also for crop production, settlements and mining. For graziers and other landowners, economic considerations are an important driver of forest land conversion. When the prices of agricultural products, for example beef, are high, landowners have a strong incentive to clear land and expand production.

Although economic conditions are also a factor, the effects of the more restrictive policy changes implemented in 2007 may be seen in the drop in first-time conversion from 2007 onwards (Figure 6.5). In addition, the sharpness of the decline may also reflect land managers bringing forward decisions to clear land to the period 2004 and 2006 – the period between the announcement of new policies and when they came into force.

The shift in the balance between first-time conversion and re-clearing evident in Figure 6.5 also contributes to the trend in emissions from *forest land converted to cropland* and *grassland*. Where land is re-cleared the biomass stock at clearing will be significantly less than the initial biomass of first time conversion. To illustrate the importance of this effect, for the purpose of the Tier 2 forest conversion model (see Appendix 6.H) it is assumed that the biomass of re-cleared forests is 32 per cent of the mature forest biomass.

Note that net emissions from the temporary loss of vegetation that meets the criteria for a forest but which was harvested for timber or which was subject to a fire event are classified under *forest land remaining forest land*. Net emissions from the conversion of an orchard to another crop type are classified under *croplands remaining croplands*. Net emissions from the loss of woody vegetation which does not meet the criteria for a forest are classified under *grasslands remaining grasslands*, *wetlands remaining wetlands* or *settlements remaining settlements*.

Wetlands

Net emissions from *wetlands* (4.D) are estimated to be 0.37 Mt CO_2-e in 2017. Within wetlands, *wetlands remaining wetlands* net emissions were 0.37 Mt CO_2-e in 2017 compared with 0.4 Mt CO_2-e in 1990 (See section 6.10.2). The estimate included net changes in sparse vegetation, loss of seagrass beds due to capital dredging and N_2O emissions from aquaculture operations (Tables 6.55 to 6.57). Changes in sparse vegetation exerted the dominant influence on both the level and trend in emissions reported over the time period.

The net emissions from *land converted to wetlands* were less than -0.001 Mt CO_2-e in 2017 compared with 0.71 Mt CO_2-e in 1990. This sub-category comprises *forest land converted to flooded lands* (e.g. reservoirs) (Table 6.59 in section 6.11.2).

Settlements

Net emissions from *settlements* (4.E), are estimated to be 0.6 Mt CO_2-e in 2017. Within the *settlements* category, *settlements remaining settlements* net emissions were -0.024 Mt CO_2-e in 2017 compared with -0.020 Mt CO_2-e in 1990 (See section 6.12.2). The estimate comprises net changes in sparse vegetation (Table 6.61).

The net emissions from *land converted to settlements* were 0.6 Mt CO_2-e in 2017 compared with 3.1 Mt CO_2-e in 1990 (table 6.64). This sub-category comprises mangrove and other *forest land converted to settlements* and *wetlands* (tidal marsh) *converted to settlements*. Conversion of tidal marsh is assumed to occur along with any clearing of mangroves for settlements – as such the trends are identical. The key drivers of variation over the time period have been urbanisation and population growth.

Forest Conversions

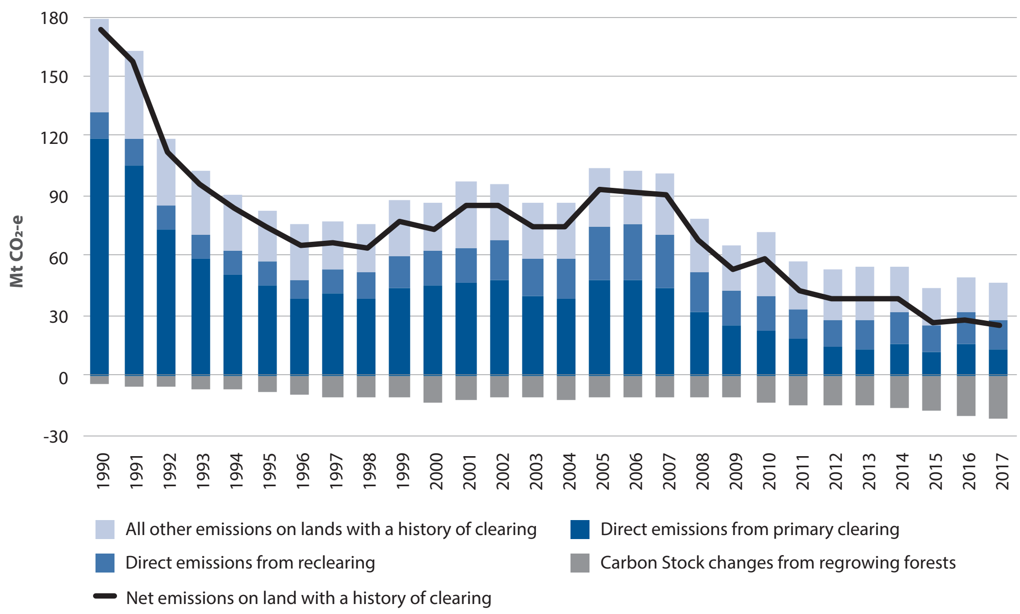
In last year's NIR, for the first time we reported separately the main components of emissions and removals associated with the clearance of forest for other land uses (cropland, grassland, wetlands (flooded land) and settlements). This disaggregation has been undertaken in response to ERT recommendation L6 that for subsequent land-use changes within a period shorter than 50 years, the allocation of AD and estimates in each reporting year be based on the end-use category of the land in that year (Volume III, Annex 6.3 - Summary of responses to UNFCCC ERT Recommendations and Comments).

Figure 6.6 shows national net forest conversions emissions disaggregated as follows:

- Direct emissions from the forest clearing activity, including:
  - the emissions from the primary conversion of land that was forested in 1972; and
  - the emissions associated with secondary clearing (reclearing) of forest which has regrown on cleared land.
- Indirect emissions from the converted land under the changed land use – subcomponents include the gradual loss of soil carbon and other emissions and removals associated with the new land use.
- Removals of CO_2 from the atmosphere on previously converted land on which forest has re-emerged.

While all four components are shown in figure 6.6, the removals associated with re-growing forests are now reported under the *land converted to forest* category rather than the forest conversions categories.

Figure 6.6 Disaggregated emissions and removals associated with forest conversions



Carbon-stock accounting

Our last NIR introduced a new perspective on the data underpinning land sector calculations in the form of carbon-stock accounts compiled under the System of Environmental-Economic Accounting (UN, 2014a).

These carbon stocks can be spatially mapped using the FullCAM architecture underpinning the estimates. Figure 6.7 shows carbon density on the whole of the Australian landscape, and Figure 6.8 shows the changes in forest-related carbon stocks with a focus on South-Western Australia. These maps show the higher density of carbon in Australia's native forests and highlight the mixed stories of land clearing and regeneration over the recent decades.

Figure 6.7 Carbon stocks on the Australian continent, 2016, t/ha

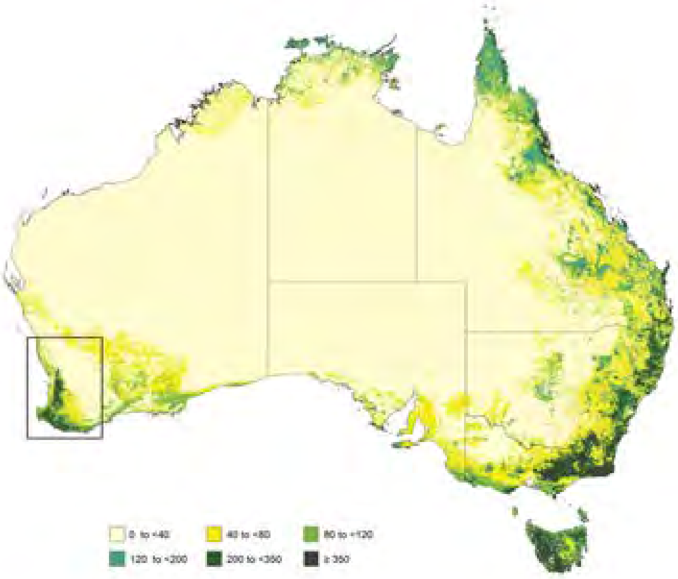


Figure 6.8 Carbon stock changes in South-Western Australia due to forest gains and losses, 1990-2016, t/ha

6.2 Source category description and methodology

6.2.1 National circumstances

Australia has a land area of 769 million hectares containing unique land, water, vegetation and biodiversity resources. Australia is a dry continent where rainfall is highly variable and floods and droughts are a common feature. There are a number of distinct climatic zones, with summer dominant rainfall in the tropics/subtropics in the north, Mediterranean climates in the south, arid and semi-arid regions in the centre, and areas of high rainfall on the coastal fringes and in the ranges of the east (Figure 6.9a and Figure 6.9b).

Australia has a diversity of soil types ranging from old, highly weathered and infertile, to younger, more fertile soils derived from volcanic rocks and alluvium. Approximately 50 per cent are dominated by sandy surface soil horizons, 37 per cent are dominated by loam and sandy clay loams in the surface horizon and 13 per cent are dominated by light to medium clay textured soil in the surface horizon. Most of these soils have low levels of nitrogen, phosphorus and other nutrients.

The areas of the continent under different land uses are shown in Figure 6.10. Significant agricultural activities include wool, beef, wheat, cotton and sugar production. Australia is also an exporter of dairy produce, fruit, rice and flowers. Australia's forest resources consist of native forests (primarily dominated by *Eucalyptus* species), which are used for wood production, recreation and conservation, and plantations of native (primarily *Eucalyptus* species) and exotic species (primarily *Pinus* species).

Cropland is generally located along a broad inland fringe across the southern and eastern areas of Australia, with the highest yields commonly obtained in the south west and eastern regions. In the southern regions, *cropland* is dominated by wheat production, with barley, oats, lupins and canola being the other dominant crops. In the north; wheat, sugarcane, sorghum and cotton production dominate.

The majority of *grassland* areas occur in inland Australia and are used for extensive grazing of both sheep and cattle. In Australia, grazing occurs across very diverse climate, ecosystem and management systems. The pasture types and associated management intensities range from highly improved to extensive rangeland systems in the semi-arid and arid regions of Australia. Native or naturalised pastures are the major pasture type, occupying approximately 17 per cent of Australia's land area with sown and fertilised pastures occupying only 4 per cent of the land area. Sown pastures are represented by mixed annual grasses and legumes as well as mixed perennial grasses and legume species depending upon rainfall and regional location. Irrigated pastures represent about 1 per cent of all pastures and are generally confined to the dairy and feedlot industries.

Australia's coastal wetlands

The three floristically diverse tidal wetland communities covered in the 2013 IPCC Wetlands Supplement, namely mangrove forests, tidal marshes and seagrasses are present in Australia. Together they cover 8 to 12 million hectares of coastal wetlands around Australia's 60,000 kilometre coastline (mainland plus islands) and store an estimated 3 billion tonnes of carbon, mostly in the soil (mean value, range = 1.4 to 6 billion tonnes – Lawrence *et al.*, 2012).

Australia's continental expanse incorporates a wide range of climate zones and coastal features that together determine the character of its coastal wetlands, including their carbon emissions and removal capacity.

Mangrove forests are one of eight native forest types under Australian national reporting (Commonwealth of Australia, 2014). They are found in the intertidal zones of tropical, subtropical and sheltered temperate coastal rivers, estuaries and bays. They grow in fine sediments deposited by rivers and tides, where they are regularly exposed to tidal inundation and lack of oxygen in the soil. They occupy an estimated 913,000 hectares around the Australian coastline (Bridgewater and Cresswell, 2014; Commonwealth of Australia, 2014). Mangroves meet Australia's definition of forests, and estimates of emissions and removals are reported under the appropriate forest land sub-categories (See sections 6.5.1.2 and 6.11).

Tidal marshes comprise salt tolerant succulent herbs, sedges and grasses covering an estimated area of 1.4 million hectares in Australia. They are situated high in the intertidal zone, with the highest areas of tidal marsh only inundated at the highest spring tides. They are often subject to hypersaline conditions. Tidal marsh species diversity increases with increasing latitude in Australia, an association that appears strongly linked to mean minimum daily temperature (Saintilan and Rogers, 2013).

Seagrasses are a diverse group of marine flowering plants adapted to a submerged life. Seagrasses are found along both tropical and temperate Australian coasts, where they may occupy intertidal flats, as well as the sub-tidal near-shore and deeper offshore locations. They cover an estimated area of 5 to 9 million hectares in Australia. Species diversity is greatest in tropical waters, but biomass per unit area increases with increasing latitude in Australia (Butler and Jernakoff, 1999).

Tidal marshes and seagrass meadows are distinct plant communities and are reported as subdivisions under *wetlands remaining wetlands*. Emissions and removals associated with anthropogenic changes in tidal marsh extent were reported for the first time in the 2015 Inventory and anthropogenic emissions associated with seagrass removal were included for the first time in the 2016 Inventory.

Aquaculture (use) is also reported in the wetlands inventory. This sub-category accounts for N_2O emissions from the production of finfish and crustaceans in aquaculture systems located in coastal wetland habitats.

Figure 6.9a Long-term average annual rainfall

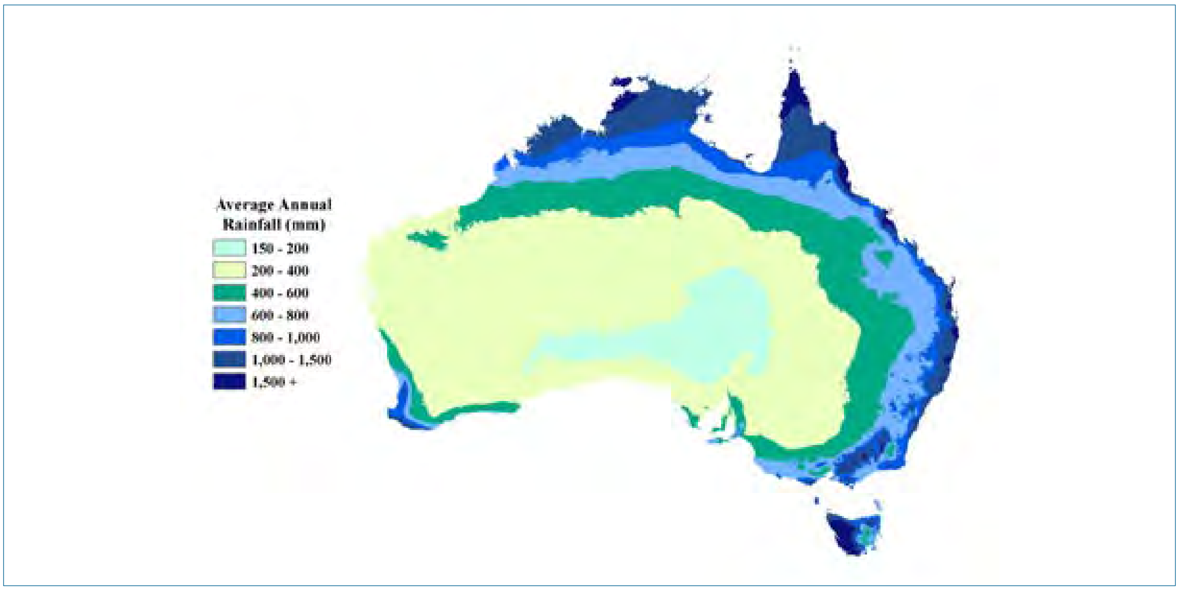


Figure 6.9b Long-term average annual temperature

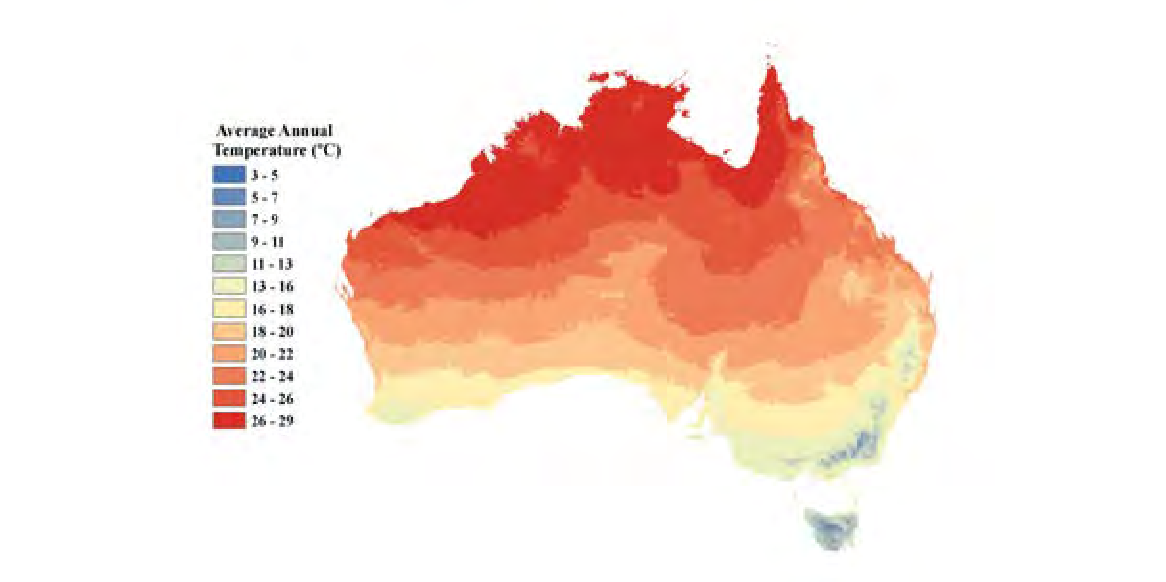
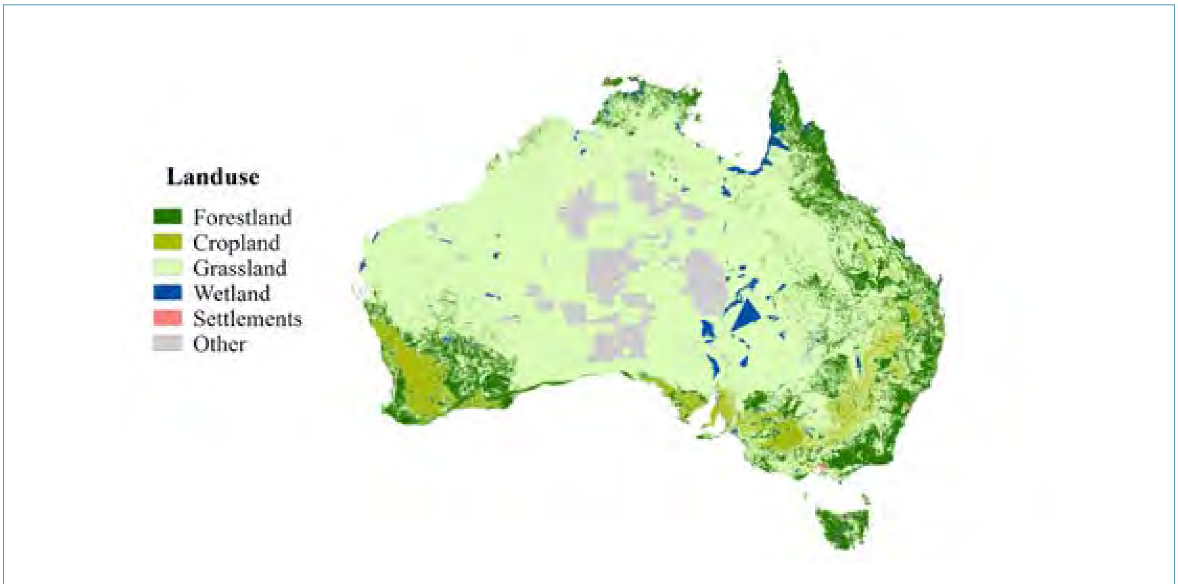


Figure 6.10 Map of land use in Australia



6.2.2 Methodology

Land use and management activities influence a variety of vegetation and carbon system processes that affect greenhouse gas fluxes. The focus of reporting for the *LULUCF* sector is the estimation of emissions and removals of carbon dioxide (CO_2) from these activities. Carbon dioxide fluxes between the atmosphere and managed land systems are primarily controlled by uptake via plant photosynthesis and releases from respiration, decomposition and oxidation of organic material. Nitrous oxide (N_2O) may be emitted from the system as a by-product of nitrification and denitrification and the burning of organic matter. Other gases released during biomass burning include methane (CH_4), carbon monoxide (CO), other oxides of nitrogen (NO_x) and non-methane volatile organic compounds (NMVOC).

Predominantly country specific methodologies and Tier 3 models (Table 6.2) are used for *LULUCF*. The methods used in the estimation of the *LULUCF* categories of the inventory are described in detail in Appendices 6.A to 6.K.

Table 6.2 Summary of methodologies and emission factors – *LULUCF* sector

Greenhouse Gas Source And Sink	CO_2		CH_4		N_2O		NO_x, CO and NMVOC	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
4. Land Use, Land Use Change and Forestry								
A. Forest Land								
1. Forest land remaining Forest land								
Harvested native forests	T2	M						
Other native forests	T2	CS						
Pre-1990 Plantations	T3	M						
Fuelwood consumed	T2	CS						
2. Land converted to Forest land								
Cropland converted to forest land	T3	M						
Grassland converted to forest land	T3	M						
Settlements converted to forest land	T3	M						
Wetlands converted to forest land	T2	CS						
B. Cropland								
1. Cropland remaining Cropland	T3	M						
2. Land converted to Cropland								
Forest converted to cropland	T3	M						
Wetlands converted to cropland	T1	D						
C. Grassland								
1. Grassland remaining Grassland	T3, T2	M, CS						
2. Land converted to Grassland								
Forest converted to grassland	T3	M						
Wetlands converted to grassland	T1	D						
D. Wetlands								
1. Wetlands remaining Wetlands	T2	CS			T1/2	D		
2. Land converted to Wetlands	T3	M						
E. Settlements								
1. Settlements remaining Settlements	T2	CS						
2. Land converted to Settlements								
Forest converted to settlements	T2, T3	CS, M						
Wetlands converted to settlements	T2	CS						
F. Other Lands								
1. Other Lands remaining Other Lands	NA	NA						
2. Land converted to Other Lands	NO	NO						
G. Harvested wood products								
Harvested Wood Products	T3	M						
4(I) Direct nitrous oxide (N2O) emissions from nitrogen (N) inputs to managed soils (a)					IE	IE		
4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils (b)	NE	NE	NE	NE	NE	NE	NE	NE

Greenhouse Gas Source And Sink	CO_2		CH_4		N_2O		NO_x, CO and NMVOC	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
4(III) Direct nitrous oxide (N2O) emissions from nitrogen (N) mineralization/ immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils (c)					T2	CS		
4(IV) Indirect nitrous oxide (N2O) emissions from managed soils (c)					T2, CS	D		
4(V) Biomass burning (c)	IE	IE	T2	CS	T2	CS	T2	CS
H. Other (d)	NA	NA	NA	NA	IE	IE	NA	NA

(a) In accordance with footnote 5 of CRF Table 4(I), Australia reports all N_2O emissions from N inputs to managed soils in the Agriculture sector
(b) Australia does not estimate emissions for this voluntary reporting category
(c) Emissions from this source include emissions from land classifications 4.A to 4.E
(d) Emissions from aquaculture are reported under *wetlands remaining wetlands*
EF = emission factor, CS = country specific, D = IPCC default, M = Model, NA = not applicable, NE= not estimated, NO = not occurring, IE=included elsewhere, T1 = Tier 1, T2 = Tier 2 and T3 = Tier 3,

Australia's land sector inventory system integrates spatially referenced data with an empirically constrained, mass balance, carbon cycling ecosystem model (*FullCAM*) to estimate carbon stock changes and greenhouse gas emissions (including all carbon pools, gases, lands and land use activities). The system supports Tier 3, Approach 3 spatial enumeration of emissions and removals calculations for the following sub-categories:

- *Forest land converted to cropland, wetlands (Flooded Land), grassland, and settlements*
- *Grassland, cropland and settlements converted to forest land*; and
- The agricultural/grazing system components of *cropland remaining cropland* and *grassland remaining grassland*.

Spatial enumeration is achieved through the use of a time-series (since 1972) of Landsat satellite data which is used to determine change in forest and sparse woody vegetation extent at a fine spatial disaggregation. The forest cover change information is coupled together with spatially referenced databases of climate and land management practices which allows a comprehensive quantification of emissions (see Appendices 6.A and 6.B).

FullCAM can also be configured to operate in a Tier 3, Approach 2 mode where spatially explicit data are unavailable. In this configuration, known as the 'Estate' module, *FullCAM* uses age-based growth data to estimate living biomass and dead organic matter (DOM) from both turnover and harvest residue. The 'Estate' module of *FullCAM* is used to scale regional models of carbon stock change by the areas of each forest type (see Richards and Evans (2000a)).

The other principal reporting elements, *wetlands converted to forest land, forest land* (mangrove*) converted to settlements, wetlands (*tidal marsh*) converted to settlements, forest land remaining forest land, cropland remaining cropland, grassland remaining grassland*, *wetlands remaining wetlands* and *settlements remaining settlements* are reported using Tier 2 and Tier 3 methods.

6.3 Representation of lands

Land representation must be consistent over time and land units must be represented in only one category in order to meet the criteria for good practice established in the IPCC (2006).

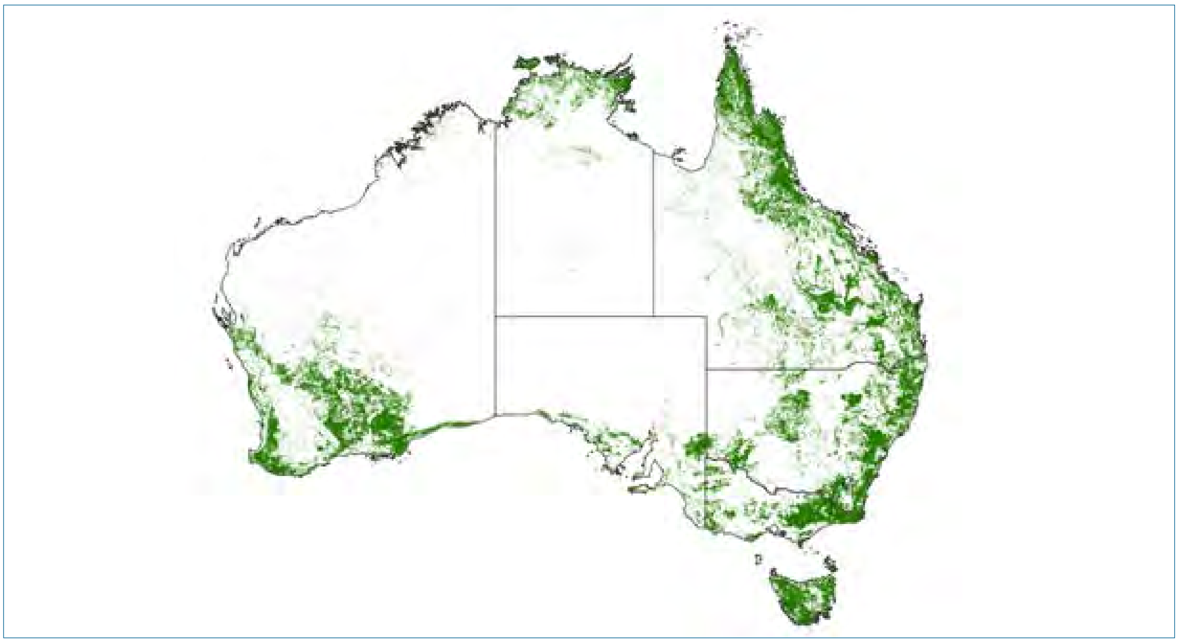
6.3.1 Land classifications

Forest land includes all lands with a tree height of at least 2 metres and crown canopy cover of 20 per cent or more (Figure 6.11) and lands with systems with a woody biomass vegetation structure that currently fall below but which, *in situ,* could potentially[1] reach the threshold values of the definition of *forest land*. Young natural stands and all plantations and environmental plantings which have yet to reach a crown density of 20 per cent or tree height of 2 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of either human intervention, such as harvesting, or natural causes, but which are expected to revert to forest.

Forest land does not include woody horticulture which meets the forest threshold parameters; this land is classified as croplands.

The forest cover definition is consistent with the definition used in Australia's National Forest Inventory that has been used for reporting to the Food and Agriculture Organisation and Montreal Process. Australia has adopted a minimum forest area of 0.2 ha.

Figure 6.11 Forest extent in Australia

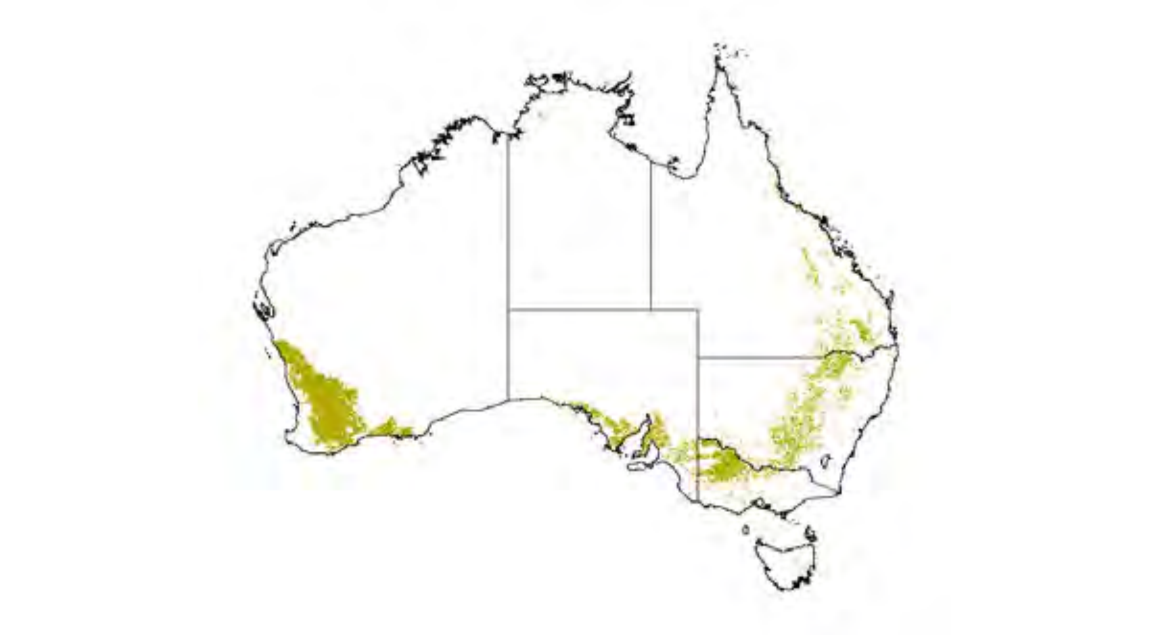


Cropland includes all land that is used for continuous cropping and those lands managed as crop-pasture (grassland) rotations (Figure 6. 12) (ABARES, 2017).

Non-CO_2 emissions from *cropland remaining cropland* are reported in the Chapter 5 *Agriculture* sector.

1 This potential is evidenced from the Landsat series that the land had previously supported forest.

Figure 6.12 *Cropland remaining cropland* distribution in Australia



The *grassland* category represents a diverse range of climate, management and vegetation cover (Figure 6.13) (ABARES, 2014). The *grassland* category also includes sub-forest forms of woody vegetation (shrubs).

Figure 6.13 *Grassland remaining grassland* distribution in Australia

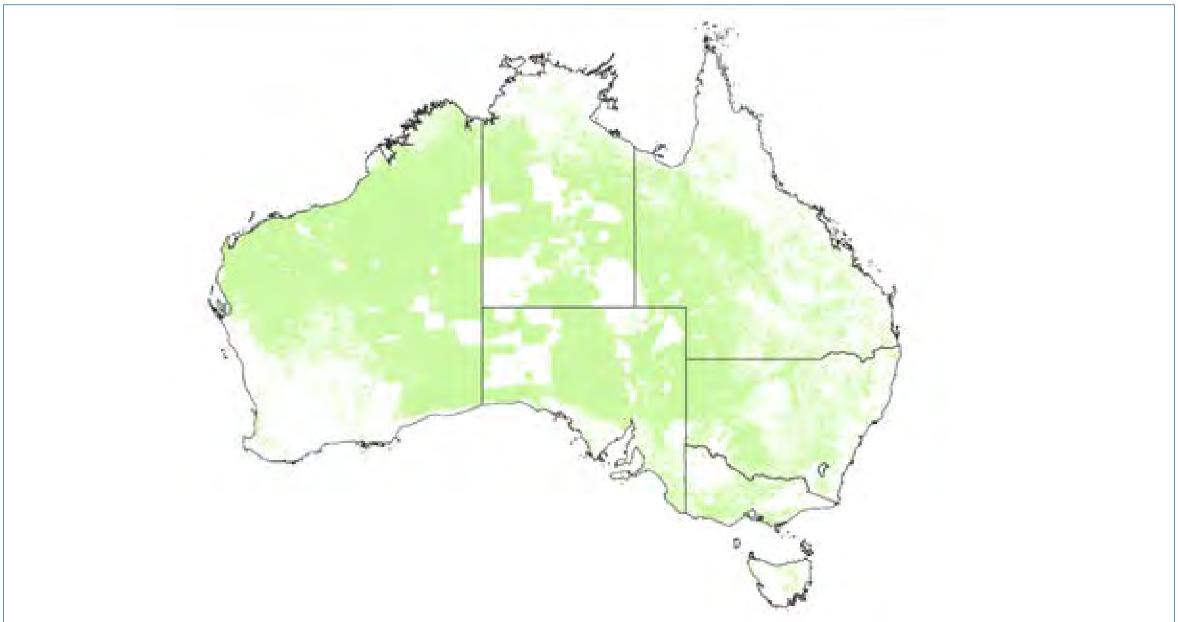


Figure 6.14 Examples of forest types and clearing activity

Closed Forest (>80%) Barron River, Qld

Open Forest (50-80%) Wombeyan, NSW

Woodland Forest (20-50%) – Undara NP, Qld

Sparse Woody Vegetation (5-20%) NT

Permanent forest conversion

Clearing for fodder

Source: (top and centre row) MIG/NFISC (2013), (bottom left) ABC 2016, (bottom right) DNRM 2013)

Settlements include areas of residential and industrial infrastructure, including cities and towns, and transport networks. The area of the *settlements* land use classification is based on the latest information sourced from the 2014 ABARES catchments scale land use data (ABARES, 2014), and includes additional land use classes such as manufacturing and industry, commercial services, transport and communications including airports etc.

Land areas that meet the definition of forest land are reported under the *forest land* category.

Wetlands include areas of perennial lakes, reservoirs, swamps and major water course areas derived from the Australian Hydrological Geospatial Fabric (AHGF) data published by the Australian Bureau of Meteorology, and all existing wetlands as defined in the Directory of Important Wetlands in Australia (DIWA) dataset published by the Department of the Environment and Energy. Land areas that meet the definition of *forest land*, such as mangroves, are reported under the *forest land* category.

The *other land* category includes bare soil, rock and other land areas that do not fall into any of the other five categories according to ABARES' catchment scale land use map of Australia (2014).

The allocation of a particular forest conversion area to either *wetland (flooded land), settlement, cropland* or *grassland* is determined using the same criteria as outlined above for the location in which the conversion occurred. Where the regrowth of forest is observed on these lands, the land is re-assigned to the inverse category for conversion to forest.

Where there has been direct human-induced conversion from grass to forest, these lands are classified and reported as *land converted to forest*. The generation of woody vegetation on *grassland* from natural seed sources is classified as *land converted to forest land* or *grassland remaining grassland*, depending on whether the vegetation meets the criteria for *forest land*.

6.3.2 Land monitoring systems

Australia uses Approaches 1 and 3 as described in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* to monitor land use, land use change and forestry.

The principal monitoring system is a remote sensing programme used to identify *forest lands* and changes in forest cover. Significant improvements to the remote sensing programme were made in 2016 (see Appendix 6.A for details).

The remote sensing programme is implemented by the Department of the Environment and Energy. The system monitors national forest cover on an annual basis using Landsat satellite data (collected by MSS, TM, ETM+ and OLI sensors). The time series of national maps of forest cover extends across 25 time epochs from 1972 to 2016 and has been assembled on an annual basis since 2004. These maps are able to detect fine scale changes in forest cover at a 25 m by 25 m resolution.

Within *forest land remaining forest land*, data on areas of forest management are drawn from Australia's National Forest and Wood Products Statistics (ABARES 2016a), Australia's State of the Forests Report (ABARES 2013) and Lucas *et al.* (1997).

Supplementary spatial information from the Land Use Mapping programme of Australia's Bureau of Agricultural Resource Economics and Sciences (ABARES, 2014) is used to identify land areas in the *grassland, wetlands, settlements*, and *other land* categories. Cropland has been updated to the September 2017 revision of these areas (ABARES, 2017) and the other land categories are expected to be updated for the next report. This information supports an Approach 1 representation of land, where only total areas are known for the areas under these land categories, not the prior land-use. In accordance with the *2006 IPCC Guidelines* where the prior land-use is not known, emissions and removals associated with conversions to these land uses are estimated using the methods for land remaining in a land category. Further information on reporting of conversions between different land uses is included in Annex 5 (Completeness).

Identified changes in forest area from the remote sensing programme are assessed through a series of automated analytical tools and are quality controlled through inspection by trained operators to determine if these changes are due to human activity and are followed by land use change (e.g. forest clearing for agriculture, mining or urban development). The full details of the remote sensing and attribution analysis are provided in Appendix 6.A.

Loss of forest cover

In cases where there is a temporary loss of forest cover, due to a forest harvest or fire, the land remains in the *forest land* category unless a subsequent land use change is identified.

The permanent conversion of forest land to other land uses is distinguished from a temporary removal or loss of forest cover. Losses in forest cover due to natural events (e.g. fire, drought) or changes that occur within land tenures where it is expected that the land will revert to forest (e.g. harvested forest, national park) are monitored for a period of time, depending upon the type of forest land use (2.6.2.1 of IPCC 2014). In the absence of land use change, most of the areas without forest cover that have entered the monitoring system continue to be classified as "forest" provided that the time since forest cover loss is shorter than the number of years within which tree establishment is expected. After that time period, lands that have lost forest cover due to direct human-induced actions, have undergone land use change, and failed to regenerate are classified as converted to the appropriate non-forest land use classification. As an interim estimate for reporting purposes, a small proportion of the area being monitored is assumed to have undergone a land use change. This proportion is based on historical observations.

In Australia, land remains in the "conversion" sub-category for 50 years. This period is longer than the IPCC default, and reflects the long term impacts of conversion on carbon dynamics in Australian systems.

Once classified as a forest conversion event, the land continues to be monitored for subsequent forest cover changes associated with regrowth and re-clearing. Where subsequent forest-cover changes occur within a period shorter than 50 years, the land is reported in each reporting year based on the end-use category of the land in that year (either l*and converted to forest land* following regrowth, or to the relevant "*forest land converted to…*" subcategory following re-clearing).

Gain in forest cover

In cases where new forest cover is detected on land previously under another land use (cropland, grassland, wetland or settlement), the land enters the *land converted to forest land* subcategory. Land monitored for this cover gain includes:

- Establishment of new commercial plantations
- Environmental plantings
- Forest emerging through natural regeneration (from seed or rootstock) on unforested, protected lands (i.e. land which is not public or private tenured land and on which a permit is required for clearance of the land)
- Forest remerging on land that has previously been converted from forest to a non-forest land use.

Movement between sub-categories - greater than 50 years

After 50 years without further forest cover changes, the lands will be moved into the "*land remaining…*" sub-categories. Archives of satellite data currently support only 45 years of conversion monitoring so that additional methods and data sources are used to identify amounts of land subject to conversion prior to 1972 (see Appendix 6.A).

Planned improvements are underway to develop a fully spatially explicit time series of land-use maps to apply Approach 3 land representation to all land-uses, to enable reporting of separate activity data and emissions estimates for all conversion categories.

6.3.3 Land representation matrix

Areas of forest cover change are supported by spatially referenced databases of land management information held by the Department of the Environment and Energy. Reconciliations are performed on a land unit by land unit basis to ensure that there are no gaps or overlaps which would lead to omission or double counting of areas of land.

Improvements to land-use and land-cover reporting

The Department of the Environment and Energy's comprehensive remote sensing program allows tracking of the land use history for any point across Australia. In response to UNFCCC Expert Review Team (ERT) recommendations, reporting has been improved for lands with a complex land-use history that includes multiple forest cover transitions.

In cases where successive forest cover changes occur within a period shorter than 50 years, the allocation of activity data and emissions is now based on the end-use for the reporting year in areas where direct, human induced clearing has been observed. This change improves transparency regarding the emissions from clearing of forests, emissions from the subsequent land use, and removals from re-emerging forests on previously cleared lands, as shown in Figure 6.6 in section 6.1 above. Consistent with ERT recommendations L.5 and L.6 in the 2017 Annual Review Report, commencing in the 2016 National Inventory Report (published in 2018) the area of re-emerging forests and associated carbon stock changes are now reported as part of *land converted to forest lands*, whereas in earlier submissions such lands remained within the forest converted to other land categories.

Changes in forest and woody vegetation cover may not represent a land-use change. For example, on industrial timber plantations, loss of forest cover due to harvesting is not reported as a land-use change, unless no forest regeneration is observed. Likewise, temporary dieback of natural regeneration on protected areas is not considered a land-use change.

However, consistent with the planned improvements following the last in-country review (recommendation L.5 in the 2017 ARR), all successive forest cover changes which are used in carbon modelling are separately identified and tracked in the CRF tables, even those which are not considered a change in land-use.

Areas under each land-use as defined by the IPCC 2006 Guidelines are reported in Table 6.3 below. By contrast, the land representation matrix (Table 6.4 below & CRF Table 4.1) portrays the impacts of all forest cover changes used for calculating emissions and removals, irrespective of their land-use classification. Most notably, an area of land classified and reported as l*and converted to forest* will be represented as grassland in the reporting year if it has exhibited dieback or another form of temporary forest cover loss. Emissions and removals are calculated to account for this temporary loss of cover, even though the land still meets the definition of a forest as defined above in section 6.3.1.

In the CRF tables 4.A.2, 4.B.2, 4.C.2 and 4.D.2, emissions and activity data continue to show the quantities relevant to their accounting category, as shown in Table 6.4

Modelling of emissions and removals on land takes account of all forest cover changes shown in the land matrix, regardless of whether this forest loss or gain is considered to be a change in land-use.

Table 6.3 Area under land use and land use change and forestry classifications, 1990-2017 (kha)

Year	Forest remaining Forest	Land converted to Forest	Cropland remaining Cropland	Land converted to Cropland	Grassland remaining Grassland	Land converted to Grassland	Wetlands remaining Wetlands	Land converted to Wetlands	Settlements remaining Settlements	Land converted to Settlements	Other land
1990	135,697	2,965	37,191	1,931	504,981	7,047	17,424	26	972	72	60,694
1991	134,842	3,583	37,190	1,987	504,628	7,576	17,421	28	972	80	60,694
1992	134,051	4,092	37,191	2,017	504,400	8,047	17,417	29	971	91	60,694
1993	133,390	4,498	37,194	2,033	504,340	8,337	17,414	31	972	97	60,694
1994	132,765	4,857	37,195	2,053	504,230	8,690	17,411	32	971	103	60,694
1995	132,208	5,223	37,200	2,069	504,195	8,892	17,407	32	973	108	60,694
1996	131,710	5,497	37,202	2,094	504,094	9,184	17,404	33	973	115	60,694
1997	131,213	5,778	37,203	2,119	503,996	9,467	17,401	34	973	122	60,694
1998	130,714	6,033	37,202	2,141	503,902	9,781	17,398	35	973	128	60,694
1999	130,159	6,285	37,199	2,162	503,766	10,199	17,395	35	971	136	60,694
2000	129,486	6,576	37,202	2,175	503,778	10,550	17,391	35	971	140	60,694
2001	128,751	6,800	37,202	2,193	503,781	11,042	17,388	36	970	143	60,694
2002	128,065	7,036	37,204	2,209	503,804	11,452	17,385	36	971	144	60,694
2003	127,448	7,251	37,204	2,224	503,813	11,826	17,382	37	972	150	60,694
2004	126,819	7,505	37,204	2,237	503,802	12,194	17,378	37	972	157	60,694
2005	126,138	7,692	37,202	2,256	503,701	12,764	17,375	37	971	170	60,694
2006	125,475	7,924	37,203	2,269	503,682	13,194	17,372	38	970	179	60,694
2007	124,906	8,125	37,203	2,281	503,669	13,559	17,369	38	971	186	60,694
2008	124,579	8,386	37,202	2,287	503,551	13,736	17,365	38	973	189	60,694
2009	124,346	8,795	37,199	2,290	503,377	13,736	17,362	38	972	191	60,694
2010	124,091	9,312	37,199	2,289	503,224	13,631	17,359	40	971	191	60,694
2011	124,050	9,830	37,201	2,289	502,828	13,551	17,356	42	969	190	60,694
2012	124,123	10,336	37,200	2,290	502,308	13,499	17,352	42	969	186	60,694
2013	124,096	10,888	37,200	2,292	501,825	13,460	17,349	42	970	184	60,694
2014	124,226	11,510	37,197	2,292	501,159	13,384	17,346	42	968	182	60,694
2015	124,273	12,208	37,202	2,288	500,569	13,235	17,342	42	970	177	60,694
2016	124,383	12,897	37,201	2,288	499,812	13,199	17,339	42	970	176	60,694
2017	124,410	13,642	37,199	2,280	499,183	13,070	17,336	42	972	173	60,694

Table 6.4 All land cover representations reported in the land matrix (CRF4.1), 1989-2017 (kha)

Year ending June	Forest land	Cropland	Grassland	Wetland	Settlements	Other land
1989	139,079	39,047	511,692	17,451	1,036	60,694
1990	138,663	39,122	512,028	17,450	1,044	60,694
1991	138,424	39,177	512,204	17,449	1,052	60,694
1992	138,143	39,208	512,447	17,447	1,062	60,694
1993	137,888	39,227	512,677	17,445	1,069	60,694
1994	137,622	39,248	512,920	17,442	1,075	60,694
1995	137,431	39,269	513,086	17,440	1,080	60,694
1996	137,207	39,296	513,278	17,437	1,088	60,694
1997	136,990	39,322	513,464	17,435	1,095	60,694
1998	136,747	39,343	513,683	17,432	1,101	60,694
1999	136,444	39,361	513,964	17,430	1,108	60,694
2000	136,063	39,377	514,328	17,427	1,112	60,694
2001	135,551	39,396	514,823	17,424	1,113	60,694
2002	135,101	39,412	515,257	17,421	1,115	60,694
2003	134,699	39,427	515,639	17,418	1,122	60,694
2004	134,324	39,442	515,996	17,415	1,129	60,694
2005	133,830	39,458	516,466	17,412	1,140	60,694
2006	133,399	39,473	516,876	17,409	1,150	60,694
2007	133,032	39,484	517,228	17,406	1,156	60,694
2008	132,965	39,489	517,287	17,403	1,162	60,694
2009	133,141	39,489	517,113	17,400	1,163	60,694
2010	133,403	39,488	516,854	17,399	1,162	60,694
2011	133,879	39,491	516,380	17,398	1,158	60,694
2012	134,459	39,490	515,808	17,395	1,155	60,694
2013	134,985	39,491	515,285	17,391	1,154	60,694
2014	135,736	39,489	514,543	17,388	1,150	60,694
2015	136,481	39,489	513,803	17,385	1,147	60,694
2016	137,280	39,489	513,011	17,381	1,146	60,694
2017	138,052	39,478	512,253	17,378	1,145	60,694

6.4 Forest Land Remaining Forest Land (Source Category 4.A.1)

There are four broad sub-divisions to *forest land remaining forest land*: harvested native forests, plantations, other native forests and fuelwood.

Harvested native forests are those forests comprised of endemic species arising from natural regrowth. Various silvicultural techniques may be applied to initiate and promote particular growth characteristics. The areas included in this sub-division include multiple-use public forests as at 2008 (MPIG, 2008) and private native forests subject to harvest, or regrowing from prior harvest.

Plantations included within *forest land remaining forest land* are commercial plantations (hardwood and softwood) established in Australia up to the end of 1989. Softwood plantations make up the vast majority of these pre-1990 plantations with hardwood plantations (primarily eucalypt species) making up only a minor part of the plantation estate. Until the mid-1960s, most new areas of softwood plantation were derived from clearing of native forest or scrublands. In later years, some of the hardwood plantations were also established after clearing native forest (Snowdon and James, 2008). By the mid-1980s, clearing of native forests for the establishment of plantations had ceased in most states, and most new plantations were established on farmland.

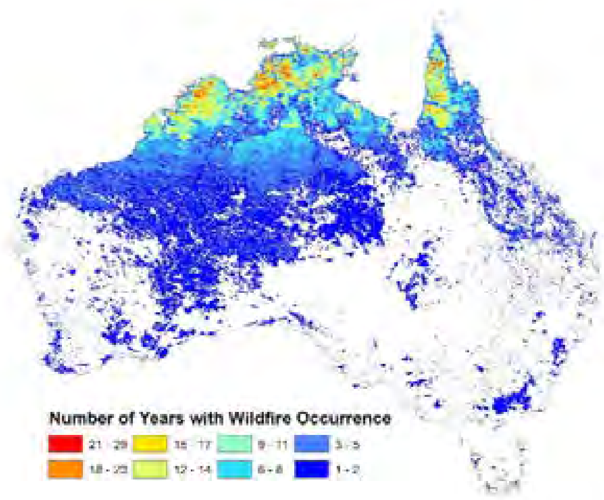
Other native forests include those forests that are comprised of endemic species, which are not harvested native forests or plantations. The *other native forests* sub-division includes protected areas (such as Wilderness areas and National Parks) not previously subject to harvesting and areas of extensive forests including woodlands.

The main processes affecting emissions and removals from these forests include fire management practices and wildfires. Accordingly net emissions are estimated for the following activities:

- prescribed burning of temperate forests;
- wildfire in temperate forests; and
- prescribed burning and wildfire in tropical, sub-tropical and semi-arid forests.

Most Australian forests are adapted to fire, and fires, whether wildfires or prescribed fires, are generally not stand replacing. Many eucalypt species continue growing, with burned leaves and twigs quickly regrowing from epicormic shoots with no effect on stand age-class. In most eucalypt forests, fires do not cause significant changes in the rate of turnover of living biomass to dead biomass, particularly following lower intensity fires which primarily burn only litter and deadwood (Raison and Squire *et al.* 2008, Bradstock *et al.* 2012, Fairman *et al.* 2015). Fire regimes differ widely in regards to fire frequency and intensity across Australia as shown in Figure 6.15, with implications for the estimation of carbon stocks.

Figure 6.15 AVHRR burned area frequency and extent (1988–2018)



In the northern and central Australian wet/dry tropical, subtropical and semi-arid forest ecosystems, burning occurs for a variety of reasons including pasture management, fuel reduction, prevention of uncontrollable wildfires and traditional indigenous burning.

In temperate forests, prescribed burning includes managed fires that aim to mitigate the risk and severity of wildfires by reducing debris loads in forest biomass burning. Prescribed burning is typically low intensity, consuming only a proportion of the dead organic matter present in the forest.

Wildfires can range from moderate intensity burns through to high intensity wildfire, which can remove most debris as well as under-storey vegetation, foliage, and small branches.

Some wildfires constitute non-anthropogenic natural disturbances as they are beyond the control of, and not materially influenced by, Australian authorities and occur despite costly and on-going efforts across regional and national government agencies and emergency services organisations to prevent, manage and control the fires.

In this inventory, anthropogenic fires include prescribed fires and wildfires. Non-anthropogenic natural disturbances are modelled to average out over time, leaving anthropogenic emissions and removals as the dominant result.

Harvested wood products are not reported in this category and carbon stocks in wood products are transferred to category *4.G Other – harvested wood products*.

As for all forests, the *harvested native forests* sub-category is monitored for forest conversions. Areas that are identified as direct human induced forest conversions are excluded from *forest land remaining forest land*, and any harvesting associated with the conversion event is also excluded to avoid double-counting.

6.4.1 Methodology

6.4.1.1 Harvested native forests

The emissions and removals from *harvested native forests* are estimated using the non-spatially explicit Estate modelling capability of *FullCAM*.

Estimating changes in living biomass

The annual change in living biomass in *harvested native forests* is the net result of uptake due to forest growth (above and below ground as determined from the growth models) and losses due to forest harvesting. Losses occur with the removal of forest products (transferred to *4.G Other – harvested wood products*) and movement of residue material (including belowground biomass) to dead organic matter (DOM) and soils.

Harvested native forests are modelled based on forest types which are consistent with reporting used under the Montreal Process National Forest Inventory (MPIG, 2013) and National Vegetation Information System Major Vegetation Groups (NVIS, see NLWRA, 2001). A comparison table with the inventory forest classes is shown in Table 6.5 (Waterworth *et al.* 2015). Age classes and growth rates (t C ha^{-1} yr^{-1}) for each forest type in multiple-use public forests were reported by Lucas *et al.* (1997) (Table 6.6, 6.7).

The changes in carbon stock are estimated using *FullCAM,* which is configured using the area of each forest type and age class in Table 6.7 and using biomass increments based on the growth rates reported in Table 6.8. Forests of unknown age, or those which contain two or more age classes, were assumed to be equivalent to the 'Mature' age class (Table 6.7).

Post-harvest growth is modelled according to the type of harvest that took place. Areas subject to clearfell harvest regrow from age zero. Areas subject to partial harvest continue to grow at the same rate as they were growing prior to the harvest (i.e. there is no thinning effect at the stand level, either positive or negative, on the rate of biomass accumulation despite the reduction in stem numbers).

Table 6.5 Forest classification comparison table

Inventory forest class (Lucas et al. **1997)**	**NVIS Major Vegetation Groups**	**National Forest Inventory (SOFR 2013)**
Rainforest	Rainforest and vine thickets	Rainforest
Tall dense eucalypt forest	Eucalyptus tall open forest	Eucalypt tall closed
		Eucalypt tall open
Medium dense eucalypt forest	Eucalyptus open forest	Eucalypt medium closed
		Eucalypt medium open
Low dense eucalypt forest	Low Closed Forests and Tall Closed Shrublands	Eucalypt low closed
		Eucalypt low open
Tall sparse eucalypt forest	Eucalypt Open Forests	Eucalypt tall woodland
Medium sparse eucalypt forest		Eucalypt medium woodland
Low sparse eucalypt forest	Eucalyptus woodland	Eucalypt low woodland
	Eucalyptus open woodland	
	Other Open Woodlands	
	Tropical woodlands and grasslands	
	Eucalypt Low Open Forests	
Eucalypt Mallee	Mallee Woodlands and Shrublands	Eucalypt Mallee open
	Mallee Open Woodlands and Sparse Mallee Shrublands	Eucalypt Mallee woodland
Callitris forests	Callitris Forest and Woodlands	Callitris
Acacia forests	Acacia forest and woodlands	Acacia
Other forests	Casuarina Forests and Woodlands	Casuarina
	Melaleuca Forests and Woodlands	Melaleuca
	Mangrove	Mangrove
	Acacia Open Woodlands	
	Eucalypt Woodlands	

(Waterworth *et al.* 2015)

Table 6.6 Areas by forest type and age classes in 1990 in multiple-use public forests (ha).

Forest Type	Establishment 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 100–200 yrs	Senescent > 200 yrs	Forests of unknown age (a)	Two Aged	Three or More Aged	Total
Rainforests				842,580					842,580
Tall Dense Eucalypt Forests	46,728	95,470	234,898	292,095	230,102	641,646	115,683	388,188	2,044,810
Medium Dense Eucalypt Forests	14,576	97,742	173,424	829,088	168,152	1,659,839	273,720	1,022,136	4,238,677
Medium Sparse Eucalypt Forests					345,153	274,270		663,366	1,282,789
Cypress pine Forests						42,258		144,182	186,440
Other Forests						673,019		141,686	814,705
Totals	61,304	193,212	408,321	1,963,763	743,407	3,291,031	389,404	2,359,558	9,410,000

(a) The unknown and mixed age classes were represented in the model consistent with the 'Mature' age class.

Table 6.7 Aboveground growth rates by forest type and age class (t C ha^{-1} yr^{-1})

Forest Type	Establishment 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 100–200 yrs	Senescent > 200 yrs
Rainforests	-	-	-	0.58	0
Tall Dense Eucalypt Forests	6.44	4.41	2.23	0.74	0
Medium Dense Eucalypt Forests	4.24	2.80	0.99	0.18	0
Medium Sparse Eucalypt Forests	0.24	0.24	0.24	0.24	0
Cypress pine Forests	0.25	0.25	0.25	0.25	0
Other Forests	0.23	0.23	0.23	0.23	0

Partitioning of biomass to tree components

The ratios used to partition biomass to the different tree components (Table 6.8) are drawn from a synthesis of available data compiled by Snowdon *et al.* (2000) and the results of Ximenes and Gardner (2005) and Ximenes *et al.* (2005).

Table 6.8 Partitioning of biomass to each of the tree components

Forest Type	Fraction of biomass allocated to:					
	Stems	Branches	Bark	Leaves	Coarse roots	Fine roots
Rainforest	0.60	0.08	0.09	0.03	0.17	0.03
Tall Dense Eucalypt Forest	0.55	0.12	0.10	0.03	0.17	0.03
Medium Dense Eucalypt Forest	0.50	0.15	0.12	0.03	0.17	0.03
Medium Sparse Eucalypt Forest	0.47	0.15	0.12	0.03	0.20	0.03
Cypress pine Forest	0.47	0.15	0.12	0.03	0.20	0.03
Other forest	0.47	0.15	0.12	0.03	0.20	0.03

Carbon fraction of biomass

The carbon fractions of the tree components (Table 6.9) are based on studies of Australian vegetation (Gifford, 2000a and 2000b).

Table 6.9 Carbon Fraction of biomass for each tree component based on Gifford (2000a and 2000b)

Tree component	% Carbon
Stems	52
Branches	47
Bark	49
Leaves	52
Coarse roots	49
Fine roots	46

Forest harvest

The amount of carbon removed as products in a harvest is dependent upon age class, forest type and the type of harvest.

The area of *harvested native forests* harvested in each broad forest type and age class was derived from roundwood log volumes removals for each state (ABARES, 2017a) using a historical relationship between roundwood removals and harvest area data collated by state agencies (Table 6.10).

Table 6.10 Estimated total area of native forest harvested

Year	Area harvested (ha)
1990	133,871
1995	137,963
2000	130,704
2005	119,959
2006	112,710
2007	114,515
2008	114,832
2009	97,285
2010	84,185
2011	77,725
2012	66,950
2013	56,964
2014	56,875
2015	57,042
2016	57,944
2017	61,210

Source: Derived from ABARES 2017a.

The broad silvicultural systems applicable to each state are reported in Table 6.11. Information on the forest type and silviculture method applied also varied in the level of detail available. Where the information was not explicitly reported, it was inferred from the best available information, including information within the state agency reporting, publications from state agencies (e.g., Forestry Tasmania, 2008; FPA, 2007; Forests NSW, 2008; Vic Forests, 2008) and from Raison and Squire (2008). It was assumed that no harvesting occurred in the Establishment (1-10 years) and Juvenile (11-30 years) phases as these are generally too young to produce forest products in Australia's native forests.

Most states began phasing out logging of rainforests in the 1980s, and for the most part, logging was entirely phased out prior to 1990 (Raison and Squire, 2008). It was not possible to separate cold temperate rainforest logging from logging in wet temperate eucalypt forests in Tasmania. The harvested area for rainforests in Tasmania was therefore modelled as tall and medium dense eucalypt forests, which are closest to cold temperate rainforests spatially and in successional sequence (Hickey, 1994).

Table 6.11 Broad silvicultural systems used in the *harvested native forests* model

Forest type	Silviculture	% of trees harvested	Post harvest management
Tall dense eucalypt forest	Clearfell with pulpwood	100%	Regeneration burn
	Clearfell without pulpwood	100%	Regeneration burn
	Partial harvest with pulpwood	35-50%	Slash left on-site
	Partial harvest without pulpwood	25%	Slash left on-site
Medium dense eucalypt forest	Clearfell with pulpwood	100%	Regeneration burn
	Clearfell without pulpwood	100%	Regeneration burn
	Partial harvest with pulpwood	35-75%	Slash left on-site
	Partial harvest without pulpwood	40%	Slash left on-site
Medium sparse eucalypt forest	Partial harvest without pulpwood	30%	Slash left on-site
Callitris forest	Partial harvest without pulpwood	40%	Slash left on-site

Once harvested, in the model, the removal of products at harvest is assumed to result in a transfer of carbon to the *harvested wood products* modelling (see section 6.12) (based on production statistics).

Estimating changes in debris

The annual change in DOM in *harvested native forests* is the net result of additions from turnover and losses due to decay and turnover into soils. Losses are caused by decomposition of both natural accumulation and harvest residue, and burning of residues as part of some silvicultural systems.

The initial amount of forest debris for each forest type and age class combination is based upon model simulations, cross checked with published estimates of debris in Australian forests. For each forest type, a clearfell event was simulated using initial debris levels. This simulation was then run to equilibrium over 200 years. The final debris pools from this simulation were then used as the initial conditions for a final simulation. The results of the final simulation were used to define the initial debris for each age class for each respective forest type. This method produced debris quantities that are comparable with published estimates of debris in Australian forests (e.g., Woldendorp and Keenan, 2005, Hingston *et al.* 1981).

The turnover rates applied for each plant component in the model are shown in Table 6.12. There is limited information on decomposition rates in the *harvested native forests* of Australia. The decomposition rates for the different debris pools were drawn from the best available information including Mackensen *et al.* (2003), Mackensen and Bauhaus (1999), O'Connell (1997) and Paul and Polglase (2004a). The rates used are shown in Table 6.13.

Table 6.12 Turnover for tree components

Tree component	Turnover $year^{-1}$
Branches	0.05
Bark	0.07
Leaves	0.50
Coarse Roots	0.10
Fine Roots	0.85

Table 6.13 Decomposition rates for debris pools used in the *harvested native forests* model.

Debris component	Breakdown yr^{-1}	
	Decomposable	Resistant
Deadwood	0.05	0.05
Bark litter	0.50	0.50
Leaf litter	0.80	0.80
Coarse dead roots	0.40	0.10
Fine dead roots	1.00	1.00

The amount of residue produced by a harvest is also dependent upon the harvest type, forest age and forest type. Information on the production of harvest residue by broad forest type, harvest type and forest age was sourced from Raison and Squire, 2008 and studies of residue production (Ximenes and Gardner, 2005; Ximenes *et al.* 2005).

Estimating changes in soil organic carbon

Soil carbon is estimated using *FullCAM* operating in estate mode with a national soil carbon map (Viscarra-Rossell *et al.* 2015) (Appendix 6.E) as the base input data. *FullCAM* simulates changes in soil carbon using the Roth-C soil carbon model. The Roth-C model computes turnover of organic carbon in soils, taking into account clay content, temperature, moisture content, plant material inputs and plant cover.

Harvested native forests – biomass burning

Wildfires and prescribed fires on *Harvested native forests* are modelled as temperate forest fires consistent with *Other native forests* – see section 6.4.2.3.

The CO_2 emissions associated with slash burning in *harvested native forests* are estimated by *FullCAM*. The mass of carbon burnt annually (FC_{jk}) is taken directly from *FullCAM* and is used to estimate the CO_2 and non-CO_2 gas emissions associated with slash burning.

There are no direct measurements of trace gas emissions from slash burning in Australia; however it is considered that these fires will have similar characteristics to hot prescribed fires and wildfires (Hurst *et al.* 1996).

The algorithms for total annual emissions of CH_4, CO and NMVOCs are:

$$E_{ijk} = FC_{jk} * EF_{ijk} * C_i \quad (4.A.1\_1))$$

and for total annual emissions for NO_x and N_2O are:

$$E_{ijk} = FC_{jk} * NC_{jk} * EF_{ijk} * C_i \quad (4.A.1\_2))$$

Where FC_{jk} = annual carbon burnt in slash burning (obtained from *FullCAM*) (Gg),

EF_{ijk} = emission factor for gas *i* from vegetation (Table 6.K.10-6.K.12),

NC_{jk} = nitrogen to carbon ratio in biomass (Appendix 6.K.8)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Appendix 6.K.9).

6.4.1.2 Pre-1990 Plantations

Plantations included within *forest land remaining forest land* are commercial plantations (predominantly softwood) established in Australia up to the end of 1989.

Until last year, the pre-90 plantations were simulated using FullCAM in a non-spatial "Estate" mode consisting of 36 plots, representative of each NPI region.

This year for the first time, the pre-1990 plantations are simulated using a fully spatial FullCAM simulation. We have built new spatial layers based on information obtained from ABARES. These spatial layers provide more accurate spatial, temporal and species information on plantings during 1940 to 1989.

The carbon pools considered for *plantations* include above and below ground biomass, DOM and soil.

Harvested wood products are not reported in this category. Carbon stocks removed as products are reported under 4.G *Harvested wood products*.

Estimating changes in living biomass

For the *plantations* category, tree growth is modelled using the tree yield formula embedded into the *FullCAM* code (see Appendix 6.A and 6.D and also Waterworth *et al.,* 2007; Waterworth and Richards, 2008).

The plantation management database incorporated in the *FullCAM* modelling system contains information on tree species characteristics including forest growth model parameters, carbon allocation to tree components over time, biomass carbon percentages, basic wood density, turnover rates for each tree component, decay and product use data. These data allow *FullCAM* to model forest growth for any point based on the site and climate data.

FullCAM is parameterised to allocate biomass to different plant parts, depending upon species and age of the forest. *FullCAM* calculates the partitioning using an empirical approach derived from expansion factors reported in Snowdon *et al.* (2000) and Mokany *et al.* (2006). This method allows allocation to vary between sites and species within set ranges based on age, site productivity and level of stand development.

The ratio of stem (merchantable) quantities to non-merchantable components is particularly important for the calculation of the amounts of forest slash generated by thinning and harvesting activity. The potential accumulation of slash can make a considerable contribution to increased carbon stock, particularly on former pasture sites.

Studies of the carbon fractions of above and below ground biomass components for Australian vegetation were used to provide the parameters for the carbon fractions of tree components in the model (Gifford, 2000a and 2000b). Carbon fractions were examined for a range of species and growing conditions, which provided a range for the carbon fractions with a recommended estimate. There was little variability in the results, and more importantly, no cause to suspect bias in any set of environmental conditions or plant groups. These results could be considered as robust and reliable estimates, providing little source of uncertainty in the carbon models. The carbon contents are listed in Table 6.16.

Estimating changes in debris

The amount of carbon moved from living biomass to the DOM pools due to forest harvesting is determined in the model by the age, type of harvest and species characteristics. The above ground harvest residues were assumed to be standing dead material, which slowly breaks down (Table 6.30a) to produce CO_2 and debris at an assume ratio of 9:1 (Paul and Roxburgh 2019b). The turnover rate of leaves and fine roots affects both the amount of fine litter on the forest floor, and subsequently, most of the contribution to soil carbon. The tree component turnover rates applied in the model were guided by work by Paul *et al.* (2004b and 2017). The tree component turnover rates are shown in Table 6.14.

Decomposition rates determine the rates of loss of carbon back to the atmosphere as the debris breaks down. The rates of decomposition applied in the model have been guided by the work of Mackensen and Bauhus (1999) and Paul *et al.* (2017). Table 6.15 shows the decomposition rates applied. The balance of these two factors determines the amount of debris on site, excluding the effects of management.

Fires on *Plantations* are modelled as temperate forest fires consistent with *Other native forests* – see section 6.4.1.3.

Table 6.14 Tree component annual turnover rates

Tree Component	Softwood Turnover % $month^{-1}$	Hardwood Turnover % $month^{-1}$
Branches	0.74	0.74
Bark	0.41	0.41
Leaves	3.07	4.22
Coarse Roots	0.87	0.87
Fine Roots	12.55	12.55

Note: FullCAM calculations of turnover were simplified since the previous report (redundant exponential function removed), thereby requiring an update in the units for reporting turnover. These changes resulted in no recalculations as values provided here for application in the revised version of FullCAM provide the same predictions of turnover as obtained when defaults previously reported were entered into the previous version of FullCAM.

Table 6.15 Debris decomposition rates

Debris Component	Softwood Turnover % $month^{-1}$	Hardwood Turnover % $month^{-1}$
Deadwood	1.25	1.25
Bark Litter	1.44	1.44
Foliage litter, decomposable	100	100
Foliage litter, resistant	1.84	2.70
Coarse Dead Roots	2.93	2.93
Fine Dead Roots	100	100

Note: FullCAM calculations of turnover were simplified since the previous report (redundant exponential function removed), thereby requiring an update in the units for reporting turnover. These changes resulted in no recalculations as values provided here for application in the revised version of FullCAM provide the same predictions of turnover as obtained when defaults previously reported were entered into the previous version of FullCAM.

Table 6.16 Plantation types, wood densities, carbon contents and management regimes

Region(s)	Species	Density	CC% Leaf	CC% Branch	CC% Wood	CC% Bark	CC% Fine Roots	CC% Coarse Roots	Regime Description [(a)]
Green Triangle	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
Green Triangle	Pinus (other than radiata)	440	52	51	52	53	46	49	Average Sites – 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
NSW Northern Tableland	Southern Pine (P. elliotti, P. taeda, Araucaria cunninghamii)	440	52	51	52	53	46	49	Average Sites – 27% thinning @ 14 years, 47% @ 20, CF @ 30
NSW	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – 67% @ 20 years, 47% @ 35, CF @ 45
NSW	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
Qld	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – 67% @ 20 years, 47% @ 35, CF @ 45
Qld	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
Qld	Southern Pine (P. elliotti, P. taeda, Araucaria cunninghamii)	440	52	51	52	53	46	49	All Sites – 35% @ 18 years, CF @ 35
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 15
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 25
South Australia	Pinus (other than radiata)	440	52	51	52	53	46	49	Average Sites – 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
Tasmania	Eucalyptus nitens	550	52	47	52	49	46	49	All Sites – CF @ 30
Tasmania	Eucalyptus nitens	550	52	47	52	49	46	49	All Sites – CF @ 15
Tasmania	Eucalyptus nitens	550	52	47	52	49	46	49	All Sites – CF @ 25
Tasmania	Pinus radiata	440	52	51	52	53	46	49	Average Sites – CF @ 35
Tasmania	Pinus (other than radiata)	440	52	51	52	53	46	49	All Sites – CF @ 35
Victoria (Central)	Pinus radiata	440	52	51	52	53	46	49	Average Sites -34% thinning @ 15 years, 18% @ 22, 24% @ 28, CF @ 35
Victoria (Central)	Pinus radiata	440	52	51	52	53	46	49	Average Sites – CF @ 30
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 25
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20

Region(s)	Species	Density	CC% Leaf	CC% Branch	CC% Wood	CC% Bark	CC% Fine Roots	CC% Coarse Roots	Regime Description [(a)]
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 30
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 35
Victoria (Central Gippsland)	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 33% thinning @ 15 years, 37% @ 20, CF @ 30
Murray Valley	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 47% thinning @ 14 years, 35% @ 22, 29% @ 29, CF @ 30
Murray Valley	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 47% thinning @ 14 years, 35% @ 22, CF @ 30
Murray Valley	Pinus radiata	440	52	51	52	53	46	49	Very Good Sites – 44% thinning @ 14 years, 31% @ 18, 27% @ 23, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites – CF @ 30 years
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 65% thinning @ 16 years, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 65% thinning @ 16 years, 57% @ 24, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Poor Sites – 26% thinning @ 18 years, 32% @ 24, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Poor Sites – CF @ 30 years
Western Australia	Eucalyptus globulus	550	52	47	52	49	46	49	Clear fall @ 10
Western Australia	Pinus pinaster	470	52	51	52	53	46	49	Average Sites – 65% thinning @ 18 years, 37% @ 25, CF @ 40
Western Australia	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 51% thinning @ 12 years, 39% @ 18, 32% @ 24, CF @ 35

(a) The default timing of Clear Fell (CF) elements in a regime are not used for post-1990 plantations where spatial imagery demonstrates a more accurate time of harvest for individual plantations. Planned improvement projects will extend this application to pre-1990 plantations in the future.

Estimating changes in soil carbon

Soil carbon is estimated using *FullCAM* with a national soil carbon map (Viscarra-Rossel *et al.* 2014) (Appendix 6.E) as the base input data. *FullCAM* simulates changes in soil carbon using Roth-C soil carbon model. Roth-C model computes turnover of organic carbon in soils, taking into account clay content, temperature, moisture content, plant material inputs and plant cover.

Activity data

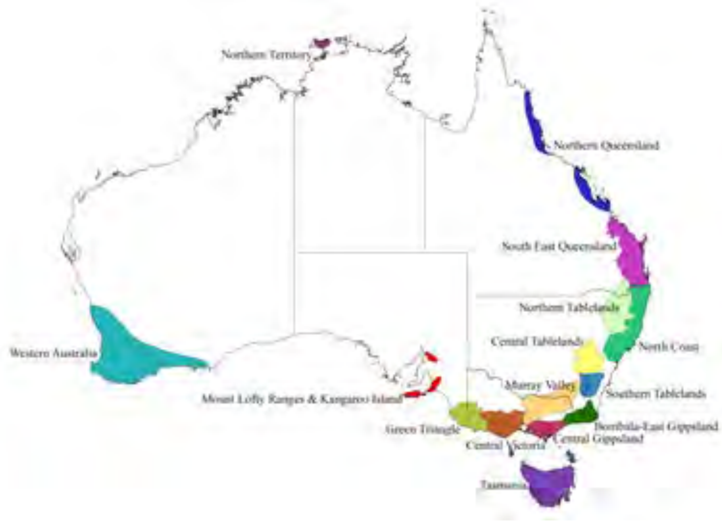
Activity data for *plantations* is sourced from the National Plantation Inventory (NPI) (ABARES, 2016c), which provides spatial information on area planted during 1940 to 1989, year of planting and plant type/species. The plantation area is spread over the 15 NPI regions (Figure 6.16) in three broad classes defined as – Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW). Table 6.17 shows the plantation establishment activity data.

Timing of harvesting and thinning is also based on region and species specific management practices.

Table 6.17 Cumulative area of land converted to plantation from 1940-1989

Year	Area (ha)	Year	Area (ha)
1940	818	1965	88,604
1941	1,476	1966	101,756
1942	2,445	1967	117,873
1943	2,981	1968	133,301
1944	4,131	1969	153,668
1945	5,947	1970	175,120
1946	7,754	1971	198,206
1947	9,950	1972	222,606
1948	11,889	1973	247,308
1949	14,613	1974	272,860
1950	17,205	1975	298,229
1951	19,885	1976	325,047
1952	22,530	1977	351,034
1953	25,291	1978	377,747
1954	28,068	1979	404,411
1955	30,849	1980	428,865
1956	33,793	1981	455,193
1957	36,706	1982	478,510
1958	39,812	1983	505,584
1959	44,449	1984	533,585
1960	50,120	1985	561,296
1961	55,885	1986	590,648
1962	61,750	1987	621,613
1963	69,064	1988	653,011
1964	78,245	1989	684,508

Figure 6.16 The National Plantation Inventory regions



6.4.1.3 Other native forests

Wildfire emissions and removals in temperate and tropical zone forests are estimated using a Tier 3, Approach 3 spatial simulation using FullCAM.

The same methods, factors and data are used to estimate emissions and removals from fire in sparse woody vegetation in *grassland remaining grassland*, *forest converted to grassland* and *wetland remaining wetland* to ensure consistent estimation of emissions and removals across land classifications.

Tier 2 models are used for prescribed burning of temperate forests, and fire in the arid and semi-arid central Australian forests and grasslands (see below).

Stratification of forests

Other native forests are stratified into three geographic / climatic zones where fires demonstrate significantly different behaviour.

a) Tropical zone forests – the northern part of the Northern Territory (NT), Western Australia (WA) and Queensland (Qld), is characterised by wet/dry tropical woodland and higher rainfall than the arid centre and is known as the 'Top End'. The Top End corresponds to the Interim Biogeographic Regionalisation for Australia (IBRA)[2] version 4.1 zones AEZ 1, AEZ 2 and AEZ 3 which are predominantly woodland with smaller areas of open forest and grassland;

b) The open woodlands and grasslands of the arid interior of central Australia ('the Centre') comprise AEZ 5, AEZ 6 and AEZ 11 of the NT, WA, Qld, South Australia (SA) and New South Wales (NSW) and these zones are used as the inventory definition of subtropical and semi-arid zone forests; and

c) Temperate forests – comprising forests in zones AEZ4 and AEZ zones 7-10.

2 IBRA is a framework used for sustainable resource management and conservation planning. The 80 IBRA regions in IBRA version 4.1 represent a landscape-based approach to classifying the land surface from a range of continental data on environmental attributes such as vegetation, geology, soils and climate. Background information and a map of the IBRA regions is available at www.environment.gov.au/parks/nrs/science/bioregion-framework/ibra/index.html

Tropical zone forests are further disaggregated into ten vegetation classes (Table 6.18). These classes are derived using a combination of validated vegetation, land use and geological data sets (Lynch *et al.* 2015; Meyer and Cook, 2015).

Table 6.18 Symbols used in algorithms for biomass burning of forest land

State (i)	Vegetation Class (j)	Rainfall Zone (k)	Fire Variant (l)	DOM size class (m)
1 = ACT	1 = Wet/dry tropical zone		1 = Early Dry Season (EDS)	1 = Fine
2 = NSW	1.1 = Woodland hummock	1 = High	2 = Late Dry Season (LDS)	2 = Coarse
3 = NT	1.2 = Shrubland hummock	1 = High	3 = Other fire	3 = Heavy
4 = SA	1.3 = Woodland mixed	1 = High	4 = Temperate Wildfire	4 = Shrub
5 = Tas	1.4 = Open forest mixed	1 = High	5 = Temperate Controlled burning	5 = Aggregated
6 = Qld	1.5 = Melaleuca woodland	1 = High		
7 = Vic	1.6 = Shrubland (heath) with hummock grass	2 = Low		
8 = WA	1.7 = Woodland with mixed grass	2 = Low		
	1.8 = Open woodland with mixed grass	2 = Low		
	1.9 = Woodland with tussock grass	2 = Low		
	1.10 = Woodland with hummock grass	2 = Low		
	2 = Subtropical and semi-arid zone	3 = NA		
	3 = Temperate zone	3 = NA		

Carbon stock changes

The *other native forests* component excludes areas subject to observed harvesting and deforestation, therefore are assumed to represent mature stands in equilibrium conditions, with annual increments in living biomass and soil carbon stocks balanced by annual losses. The main processes leading to emissions and removals in these forests are related to fire management practices.

A time-series of monthly satellite data is used to identify the time and location of fires, which are simulated at the 25m x 25m plot size. The AVHRR burnt area product produced by the Western Australian Land Authority (Landgate), is tailored to Australian conditions and based on the visual interpretation of fire areas by experienced operators. The data was assessed by the Royal Melbourne Institute of Technology (RMIT, 2014) and compared with a range of alternative datasets, and was found to be the most suitable and highest quality time series data available.

When fires are detected, they are assumed to affect the DOM pool (including standing dead stem, branches bark and coarse woody debris and bark debris).

Accordingly, changes in carbon stocks in *other native forests* are calculated in accordance with the gain-loss method in Equation 2.18 of the IPCC 2006 Guidelines (Volume 4) for estimating annual change in carbon stocks in dead wood or litter for areas remaining in a land-use category:

$$\Delta C_{DOM} = \Sigma_{ijklm} (A \times (DOM_{in} - DOM_{out}) \times CF) \qquad (4.A.1\_3))$$

Where Subscripts $_{ijklm}$ are the dimensions over which DOM is stratified for the purposes of this estimate (see table 6.18)

ΔC_{DOM} = annual change in carbon stocks in the DOM pools;

A = area of land remaining in land-use category

DOM_{in} = average annual transfer of biomass into the dead wood / litter pool due to annual processes and disturbances;

DOM_{out} = average annual carbon loss out of dead wood or litter pool

CF = carbon content (Appendix 6.K.7);

DOM stocks are modelled using the spatially explicit (Approach 3) capabilities of the Tier 3 *FullCAM* modelling system. These were parameterised for typical fires, and not assumed to be highly intense stand-replacing fires which are unusual in most Australian eucalypt and dominated forests. Hence, for both woody and grass live biomass components, it was assumed that fire did not burn roots, with live root biomass assumed to continue at equilibrium conditions of growth and turnover regardless of the fire simulation. A full description of the modelling system is provided in Appendix 6.B and 6.D, Waterworth *et al*., 2007; Waterworth and Richards, 2008; and Paul and Roxburgh, 2019.

Table 6.19 Comparison of carbon pools modelled under the previous T2 model and the current T3 FullCAM implementation

Pool type	Fuel pools calculated using previous T2 method	Fuel pools simulated using FullCAM
Live biomass	Shrub	Live Above-Ground Biomass impacted by fire, but which recovers quickly
Fine DOM	Fine-grass	Decomposable grass litter + Resistant grass litter + above-ground biomass of grass
Fine DOM	Fine-woody	Standing Dead foliage + Decomposable foliage litter + Resistant foliage litter
Coarse DOM	Coarse-light	Standing dead bark + Decomposable bark litter + Resistant bark litter
Coarse DOM	Coarse-heavy	Standing Dead stem + Standing Dead branch + Decomposable deadwood + Resistant deadwood

The FullCAM model simulates turnover and decay processes for each pool based on site conditions (productivity and vegetation type) and monthly climate data, until a fire event is identified based on the AVHRR satellite data. Figure 6.19 compares the pools modelled under the previous tier 2 model with pools modelled using tier 3 FullCAM. Fire events were individually parameterized for each State (i), Vegetation Class (j), Rainfall Zone (k), Fire Variant / seasonality (l), and DOM size class (m) (Meyer *et al.* 2015; Roxburgh *et al.* 2015), with the resulting fuel dynamics being replicated by FullCAM as described by Paul and Roxburgh (2019).

For some stocks (i.e. fine fuels as well as live biomass of both grasses and woody biomass) the carbon lost during the fire is assumed to recover within a few months to a few years, so there is no net change in carbon stocks. Non-CO_2 emissions are estimated and reported for all DOM classes as these fluxes are not recovered in subsequent re-growth.

Where supported by empirical data, the default IPCC DOM classes of litter and dead wood are further disaggregated into fine (grass live biomass, grass litter, foliage on standing dead material, and foliage litter), coarse-light (standing dead bark, and bark litter), coarse-heavy (standing dead stem and branches, and coarse woody debris) and live woody biomass (Appendix 6.K.4).

In order to initialise the model ahead of the reporting period, fires prior to 1988 are simulated based on available estimates of typical fire return intervals, time of year fires occur, area of the fire scar, and the proportion of EDS to LDS burns in tropical savanna fire zones, where available from previous studies and expert opinion (Meyer *et al.* 2009; Murphy *et al.* 2013). To introduce variation in the simulated fire events, uniform probability distribution functions were applied to vary these assumptions between what was deemed to be their upper and lower bounds.

Live woody biomass is simulated as mature stands at equilibrium conditions. The model inputs of initial above-ground biomass of living woody vegetation were derived from the maximum site carrying capacity; the value of the *M* parameter in FullCAM's TYF (Roxburgh *et al.* 2019). Simulations include short-term fire-induced impacts on the predicted relative allocation of woody biomass due to: (i) fires resulting in only partial burning of live woody biomass components, with the extent of impact varying between components, and; (ii) rates of post-fire re-sprouting or regeneration differing between components, e.g. relatively fast for foliage and relatively slow for stem wood.

It was also assumed that grasses were a component of the total live biomass within each fire zone. FullCAM has existing default inputs (e.g. yields, allocation of biomass, die-off, decomposition, etc.) for simulation of different perennial grass species (Appendix 6.K).

Burning efficiencies and Patchiness

The amount of DOM loss during a disturbance depends on the fraction exposed to flame that is volatilised (completeness of combustion or burning efficiency (BEF)), and the fraction of overall fire-affected area that is actually burnt, i.e. the fire patchiness (P).

Fires do not uniformly affect the landscape, and will leave unburned patches at a finer scale than the resolution of the satellite data. In FullCAM fire events are only applied to a proportion of cells randomly selected within the fire scar in accordance with the assumed Patchiness values *(P)*. Patchiness depends on fire intensity, and varies based on State, Vegetation Type and Fire Variant (e.g. seasonality). Figure 6.17 shows fire patches (various colours indicate different year in which the fire occurred) in north-west Australia. As indicated in the panel to the right, within each fire scar detected, the patchiness assumption is applied such that a burning event is simulated within only a randomly selected proportion of pixels within each fire scar.

Figure 6.17 Diagrammatic example indicating how spatial fire is implemented within FullCAM

In the wet/dry tropical zone, fires are classified by the season of burning as either early dry season (EDS) or late dry season (LDS). EDS fires are characterised by low intensity or severity, a high degree of patchiness, a greater propensity to extinguish spontaneously and reduced total DOM consumption. LDS fires are characterised by high intensity, low levels of patchiness, a greater propensity to spread and high total DOM consumption. For the vegetation classes burning efficiency is a function of seasonality, severity of fire and DOM stock size class.

The average date of transition from EDS to LDS is the last day of July. This date is based on indigenous fire management practices and observations of the seasonal patterns of fire behaviour (C. Meyer, J. Russell-Smith pers. comm.). On average, changes in ambient humidity and wind speed at this time are sufficient to support fire propagation through the night; which allows fires to spread for several days and to reach high intensities (Haynes 1985; Russell-Smith *et al.* 1997).

For subtropical and semi-arid forests, burning efficiencies are assumed to be constant from year to year and throughout the year. In temperate forests, while different burning efficiencies are applied for prescribed fires and wildfires, these are not further disaggregated based on seasonality.

Emissions factors

FullCAM calculates area burned, the DOM stocks at time t, and the losses due to fire based on the burning efficiency, providing an output in terms of carbon flow to atmosphere due to fire for each State (i), Vegetation Class (j), Rainfall Zone (k), Fire Variant (l), and DOM size class (m). Using these calculations, emission factors derived from direct field measurements from fires across Australia (Meyer and Cook 2015; Roxburgh *et al.* 2015; Meyer *et al.* 2012; Hurst *et al.*1994a, b) were then applied to calculated non-CO_2 emissions Table 6.K.9 to Table 6.K.11.

Non-CO_2 emissions

For CH_4, CO, and NMVOCs calculate emissions as:

$$E = \Sigma_{ijklm\ YSLB} (A \times DOM_{out\ ijklmYSLB} \times CC_{jkm} \times EF_{g,jkm} \times C_g) \quad (4A.1\_9)$$

and for NO_X, N_2O:

$$E = \Sigma_{ijklm\ YSLB} (A \times DOM_{out\ ijklmYSLB} \times CC_{jkm} \times NC_{jkm} \times EF_{g,jkm} \times C_g) \quad (4A.1\_10)$$

Where E = emissions from fires (Gg);

A = Area of land remaining in land-use category

$DOM_{out\ ijklm}$ = average DOM losses in fire (Gg);

CC_{jkm} = carbon content (Appendix 6.K.5);

NC_{jkm} = nitrogen:carbon ratio (Appendix 6.K.7);

$EF_{g,jkm}$ = emission factor (g N or C emitted as trace species / g DOM N or C emitted) (Tables 6.K9 - 6.K.11);

C_g = elemental to molecular mass conversion factor (Appendix 6.K.8); and

$_{YSLB}$ = age class of DOM stocks based on the number of years since last burned.

1. Definition of natural disturbances and types of disturbances identified in the inventory

The fire-adapted ecology of Australian eucalypt-dominated temperate forests leads to infrequent, extreme wildfires. Natural 'background' emissions and removals caused by natural disturbance fires are considered to be caused by non-anthropogenic events and circumstances beyond the control of, and not materially influenced by, Australian authorities and occur despite costly and on-going efforts across regional and national government agencies and emergency services organisations to prevent, manage and control natural disturbances to the extent practicable. These fires are considered to be part of the 'natural background' of non-anthropogenic emissions and removals, which under the Managed Land Proxy (MLP) are understood to average out over time and space.[3]

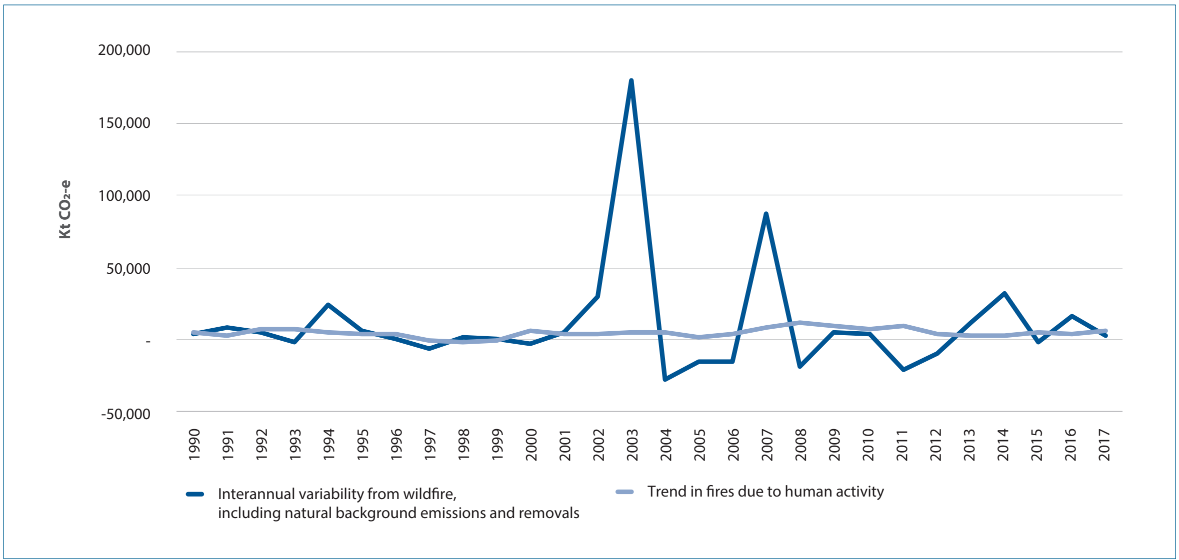
This national definition of natural disturbances applies to wildfires on temperate forests, and does not apply to fires reported as controlled burning (e.g. in temperate forests or in wet-dry tropical forests and woodlands). All fires on *land converted to forest land* are treated as anthropogenic.

The impacts of human activities (e.g. salvage logging, prescribed burning, deforestation) are excluded from the identification of natural disturbances through the application of an Approach 3 representation of lands which is used to track lands subject to natural disturbances and separately identify and exclude land subject to human activities, as explained on pages 46-47 [refer to subheading 4 and 6].

2. Quantification of inter-annual variability due to all wildfire and natural disturbances (total Managed Land Proxy (MLP) flux)

In Australia, all lands are considered managed lands. All carbon stock changes on managed land from anthropogenic and natural 'background' emissions and removals are reported, consistent with the MLP, including from wildfires. Inter-annual variability in natural 'background' of emissions and removals is also modelled as shown in figure 6.18 below.

Figure 6.18 Interannual variability from wildfire, including natural 'background' emissions and removals (total MLP flux)



3. Methods used for quantification and disaggregation of emissions and removals due to natural disturbances

The quantification of emissions and subsequent removals from natural disturbances is done by identifying fires which meet the definition of natural disturbances both at the total (landscape-level) emissions and regional levels, and tracking disturbed areas at fine spatial scales within the Tier 3, Approach 3 FullCAM modelling system.

3 IPCC 2006 Guidelines, Volume 4, Chapter 1 (p 1.5) states that, "*…while local and short-term variability in emissions and removals due to natural causes can be substantial (e.g. emissions from fire, see footnote 1), the natural 'background' of greenhouse gas emissions and removals by sinks tends to average out over time and space.*"

In order to disaggregate emissions and removals due to natural disturbances under the Tier 3 method applied in this inventory, natural disturbances are explicitly identified in the activity data. Both initial carbon losses and subsequent recoveries in carbon stocks are modelled as part of the disturbance event, and carbon stocks are spatially tracked until pre-disturbance levels are reached to ensure completeness and balance in reporting. A modelling approach is then applied to ensure that emissions and subsequent removals from non-anthropogenic natural disturbances average out over time, leaving greenhouse gas emissions and removals of anthropogenic fires as the dominant result in the national inventory (IPCC 2006 Volume 4 1.5), consistent with the Managed Land Proxy (see footnote 3). The approach ensures that Australia's modelled implementation of the MLP is comparable with estimates generated using other methods, such as Tier 3 stock-difference approaches, that tend to average out interannual variability due to natural causes over space (scaling from plots to region) and time (averaging between periodic re-measurements). Natural disturbances evident in the activity data are identified in two steps, summarised in Table 6.21.

1. First, at the national level, emissions from the area burned are assessed on a year by year basis for extreme fire events where outcomes at the national level were beyond the control of authorities to manage. This is done by comparing each year's data with a threshold level or 'margin' based on two standard deviations above the mean of gross annual emissions from all fires and after iteratively excluding outliers. The national natural disturbance threshold is calculated for the calibration period of 2000–2012.

2. Second, once natural disturbance years are identified at a national level, natural disturbances are spatially identified and the area burnt tracked at the sub-national level. Natural disturbances at the State and Territory level were identified where the area burned during their local fire season exceeded a State or Territory natural disturbance threshold equal to the average area of the calibration period plus one standard deviation of the non-natural disturbance years.

Natural disturbance areas are identified at the level of each State or Territory for a year in which both the area burned exceeds the State or Territory natural disturbance threshold and the national emissions from total area burned exceeds the national natural disturbance threshold. Anthropogenic emissions and removals are estimated using the time series of area burned in anthropogenic fire in each State or Territory.

The methodology for identifying natural disturbance events does not preclude long-term changes in fire management practices (such as prescribed burning) affecting trends in anthropogenic emissions and removals.

Wildfires that constitute natural disturbances are reported in Table 6.20.

Table 6.20 Temperate Forest wildfire and natural disturbance areas, Australia, ha, 1990–2017

Year	Natural disturbances	Temperate wildfire	Tropical & semi-arid forest fire
1990	0	243,492	27,399,953
1991	0	222,014	21,815,229
1992	0	362,435	23,966,798
1993	0	378,462	18,936,782
1994	0	304,490	22,165,277
1995	0	272,921	35,408,511
1996	0	310,162	36,383,993
1997	0	184,842	36,813,888
1998	0	151,237	47,773,450
1999	0	221,233	41,928,572
2000	0	354,059	51,954,772

Year	Natural disturbances	Temperate wildfire	Tropical & semi-arid forest fire
2001	0	306,918	55,119,933
2002	0	297,271	62,204,035
2003	2,608,454	340,871	37,413,215
2004	0	289,818	32,076,380
2005	0	233,034	56,759,568
2006	0	297,625	22,024,087
2007	1,313,646	376,757	47,737,290
2008	0	495,828	52,933,921
2009	0	476,972	43,123,061
2010	0	489,988	51,852,058
2011	0	561,820	36,823,726
2012	0	514,682	58,461,675
2013	0	448,690	63,396,320
2014	875,585	439,413	39,675,174
2015	0	463,729	47,433,135
2016	805,877	432,919	33,137,302
2017	0	488,780	40,099,542

Table 6.21 Calculations for the natural disturbance test in States and Territories, 1990–2017

	Calibration period	Calculation details	Threshold	Number of natural disturbance years 1990-2017
Step 1: National Level Test	2000-2012	Applied to: gross emissions (not including removals). Threshold calculation: mean plus two standard deviations of calibration period.	45,024 Kt CO_2-e	4
Step 2: Regional test	2000-2012	Only applies in national outlier years (following Step 1 test). Applied to: annual area burned. Threshold calculation: mean area burned plus one standard deviation of background (non-outlier) years.		
ACT			0.02 kha	2
NSW			231.18 kha	2
Qld			192.52 kha	2
SA			44.31 kha	2
Tas			19.3 kha	2
VIC			132.36 kha	3
WA			371.29 kha	2

All fire areas are monitored for any permanent change in land use, which would trigger reporting of emissions in the appropriate land conversion category. Emissions from salvage logging are reported as part of *harvested native forests*.

To ensure the transparency and demonstrate complete reporting of anthropogenic and natural disturbance emissions and removals, the following additional information has been included:

- Identification of lands subject to natural disturbances and monitoring for forest recovery
- Monitoring for land-use changes to ensure that no land-use change has occurred on lands subject to natural disturbances
- Demonstrating practicable efforts to prevent, manage and control wildfires in Australia
- Inclusion of salvage logging emissions.

4. Identification of lands subject to natural disturbances and monitoring for forest recovery (expectation of balance between emissions and subsequent removals)

The Tier 3, Approach 3, modelling system using FullCAM has been designed to comply with the following safeguard mechanisms:

- the use of geolocated time series wildfire activity data,
- coverage of all forest lands,
- the ability to monitor if there is a permanent land use change on those lands following a wildfire event during the commitment period,
- the inclusion of emissions associated with salvage logging in the accounting, and
- identification of lands where the natural disturbance is followed by another disturbance event, in order to avoid double counting.

FullCAM uses two remote sensing data sources. The Advanced Very High Resolution Radiometer (AVHRR) is used identify and map natural disturbance impacts due to wildfire on forest lands, whereas Landsat data is used to map forest cover changes and identify permanent land-use changes across all forest lands.

FullCAM spatially tracks areas and carbon stocks at the 25m x 25m pixel-level on lands identified as experiencing natural disturbances in a particular year, until another anthropogenic activity occurs (e.g. non-natural disturbance fire, salvage logging or land-use change).

Further information to demonstrate the disaggregation and monitoring of recovery of carbon stocks lost during disturbances is included in section 6.4.4.3 (Source specific QAQC - Other native forests).

5. Monitoring for land-use changes to ensure that no land-use change has occurred on lands subject to natural disturbances

All forest land is monitored for harvesting and land-use change events. Where forest cover loss events are identified, these areas visually attributed by experienced operators to either direct, human-induced land-use change, or a temporary forest loss which does not constitute land-use change such as harvesting, fire and other non-anthropogenic disturbance.

6. Demonstrating practicable efforts to prevent, manage and control wildfires in Australia (how the requirements of natural definition of disturbances have been met)

In Australia, wildfires threaten life and property, and are addressed in disaster response plans and management arrangements in each state and territory. Common frameworks for national, state and territory fire management policies include: reducing the likelihood of fires occurring, for example through fuel reduction burning and fire bans; managing or controlling the fire during its occurrence; monitoring programs and early warning systems; and firefighting operations. In addition to such disaster management policies, there is also a significant research effort into understanding and better managing wildfires, and following many significant fire events, inquests or enquiries are held to assess the disaster response and potential for improvement.

There are fire management policies and plans in place at the national and the state and territory level to control for the risks, events and consequence of wildfire to the extent that this is possible. These documents set out frameworks for:

- Reducing the likelihood of a wildfire occurring, for example, through the use of prescribed burning;
- Managing or controlling the disturbance during its occurrence;
- Monitoring programs and early warning systems; and
- Firefighting operations.

The implementation of plans and strategies to avoid and minimise risks to life and property from wildfires is documented in the following section.

National level

The National Bushfire Management Policy Statement for Forests and Rangelands (FFMG 2014)[4] outlines Australian, state and territory government objectives and policies for the management of landscape-level fire in Australia's forests and rangelands. The statement was developed by the Forest Fire Management Group, a national body within the Council of Australian Governments, with the role of providing information to governments on major forest fire-related issues, policies and practices affecting land management. The Australasian Fire and Emergencies Authorities Council is the national peak organisation that provides advice on a range of polices and standards. Research on bushfires is performed by a number of organisations, including:

- the Bushfire Cooperative Research Centre, which brings together experts from universities;
- the Commonwealth Scientific and Industrial Research Organisation (CSIRO);
- other Australian, state and territory government organisations; and
- the private sector for long-term programs of collaborative research.

The national Bureau of Meteorology publishes fire weather warnings and has a role in the declaration of fire bans when weather conditions are conducive to the spread of dangerous bushfires. Warnings are generally issued within 24 hours of the potential onset of hazardous conditions. Warnings are also broadcast on radio and television.

Fire agencies determine Fire Danger Ratings. In most States and Territories, fire agencies declare fire bans based on a range of criteria including forecast weather provided by the Bureau.

The Bureau also incorporates Total Fire Ban Advices into warnings, if one is being enforced at the time of issue, and an action statement from local fire authorities detailing areas where the ban is in effect.

Fire Weather Warnings are distributed through the media, fire agencies and other key emergency service organisations. Warnings are normally issued in the afternoon for the following day so to be available for evening television and radio news broadcasts. Warnings are renewed at regular intervals and generally at the same time major forecasts are issued. However, warnings may be issued or amended and reissued at any time if a need is identified. If there is a Fire Weather Warning current, the Bureau will mention this in State, Territory and District weather forecasts for that area.

In each State the issue of a Fire Weather Warning has different impacts on restrictions for lighting fires.

The Bureau of Meteorology does not have the power to declare a Total Fire Ban. This responsibility resides with designated fire agencies in each State and Territory. However, in South Australia, Northern Territory, Victoria, New South Wales and Tasmania, the Bureau does issue Total Fire Ban Advices to assist publicising and distributing the message. The Bureau also includes information about the existence of current fire bans in weather forecasts and warnings.

4 https://www.semc.wa.gov.au/riskmanagement/Documents/NationalBushfireManagementPolicy_2014.pdf

The areas covered by fire bans do not align with Bureau forecast districts in New South Wales, Tasmania and Northern Territory.

State and territory level

Each state and territory has published a document which sets the framework for the management of bushfires. These plans include information on the use of public information campaigns and requirements around the declaration and publication of fire bans and fire danger ratings during fire seasons. In Queensland the documents are published for a number of regions within the state, rather than at the state level.

New South Wales

The aim of the State Bush Fire plan is to set out the arrangements for preparedness, prevention, mitigation, response to and recovery from bush fire events by combat, participating and support agencies in NSW, including Lord Howe Island.

This plan describes the arrangements for the control and coordination by the New South Wales Rural Fire Service (NSW RFS) Commissioner for the response to Class 2 & 3 bush and grass fires, including those managed under the provisions of section 44 of the Rural Fires Act 1997, and the provisions for emergency warnings at all classes of fires.

These arrangements ensure that the two combat agencies, NSW RFS and Fire & Rescue NSW, are able to manage small scale bush and grass fires, utilising assistance from the other fire fighting authorities being the National Park & Wildlife Service and Forestry Corporation NSW.

The current NSW State Bush Fire plan is available at www.emergency.nsw.gov.au

Victoria

Victoria's State Bushfire Plan provides an overarching view of responsibilities of agencies, government and communities in bushfire management.

The first version of the State Bushfire Plan was developed in 2012 in conjunction with the Country Fire Authority, the Metropolitan Fire Brigade, the Department of Environment and Primary Industries and the Fire Services Commissioner.

The second version of the State Bushfire Plan was produced in 2014, with updates to reflect the changes in Victorian emergency management legislation and the emergency management sector.

The plan reflects an integrated approach and shared responsibility for bushfire management between government, agencies, business, communities and individuals.

Although intended as a reference document for fire and emergency management agencies, the State Bushfire Plan will be of equal interest to anyone who works or volunteers in bushfire management.

The State Bushfire Plan is a sub-plan of the State Emergency Response Plan, found in the Emergency Management Manual of Victoria, the principal document for guiding the State's emergency management arrangements.

Victoria's State Bushfire Plan is available at www.emv.vic.gov.au

Queensland

In Queensland, fire management policies and plans are developed at regional rather than at the state level. The Queensland government provides an overview of the approach to disaster management in Queensland at www.disaster.qld.gov.au/

Western Australia

Western Australia has developed a series of State Hazard Plans (Westplans) through its State Emergency Management Committee. These include a hazard plan for fire. These plans are available at semc.wa.gov.au

South Australia

In South Australia, State Emergency Management Arrangements are organized through the South Australian Fire and Emergency Services Commission, including the establishment and maintenance of the State Emergency Management Plan which include plans for fire management and response.

The South Australian State Emergency Management Plan is available at www.safecom.sa.gov.au

Tasmania

Tasmania's State Fire Management Council (SFMC) is established under Section 14 of the Fire Service Act 1979 (Tasmania). It is an independent body that has the responsibility of providing advice to the Minister and the State Fire Commission about the management of vegetation fire across Tasmania, particularly in the areas of prevention and mitigation of fires. It also formulates and promulgates policy in relation to vegetation fire management within Tasmania in relation to bushfire fuels and mitigation. The primary function of the SFMC is to develop a State Vegetation Fire Management Policy that is used as the basis for all fire management planning.

Fire protection plans for the various regions of Tasmania are maintained on the SFMC website at www.sfmc.tas.gov.au

Northern Territory

In the Northern Territory, fire management in urban areas is the responsibility of the NT Fire and Rescue Service, and in rural areas is the responsibility of Bushfires NT.

The Territory Emergency Plan and further information is available at www.pfes.nt.gov.au

Australian Capital Territory

The ACT Government Emergency Services Agency's Strategic Bushfire Management Plan is available at esa.act.gov.au

7. Inclusion of salvage logging emissions.

Emissions from salvage logging are included in estimates for *harvested native forests* and *pre-1990 plantations*. Estimates of forest harvesting are based on log production information that includes the products of salvage logging. These production statistics do not differentiate between material sourced from conventional clear felling and salvaging activities following wildfire or other natural disturbances.

A review of salvage harvesting by ABARES (Finn *et al.*, 2015) identified that this is a very minor activity compared to either total harvesting activity or total areas burned. Salvage harvesting is generally opportunistic, determined as much by commercial factors as biophysical factors.

6.4.1.4 Fuelwood

Emissions of CO_2 from the consumption of *fuelwood* are estimated using data on the residential consumption of wood and wood-waste obtained from the Australian Energy Statistics. Carbon stocks lost through emissions from consumption of fuelwood from the residential sector are assumed to be collected from DOM in forests. To ensure no double counting with modeled decay or fires affecting the DOM pool, these instant losses through fuelwood consumption are offset against an Olson fuel accumulation curve ($T_{95\text{ per cent}}$ = 11 years).

There is no double counting of *Fuelwood* between the *LULUCF* and Energy sectors as emissions from biomass consumption are provided as an information item but are not reported as emissions in the Energy sector.

6.4.2 Emission estimates

Anthropogenic emissions and removals from *forest land remaining forest land* are shown in Table 6.22.

Table 6.22 Emissions and removals from forest land remaining forest land (1990-2017) (Gg CO_2-e)

Year	Harvested native forests	Plantations	Fuelwood consumed	Wildfires	Prescribed burning of temperate forests	Non-temperate forest fires	Total
1990	-4,952	-12,418	446	4,445	441	2,047	-9,991
1995	-1,443	-14,228	501	3,342	3,205	1,599	-7,025
2000	-1,178	-5,883	244	5,579	-2,719	4,163	206
2005	-2,939	-1,454	-419	1,425	-230	2,377	-1,239
2006	-7,666	1,912	-491	3,912	-218	3,074	524
2007	-7,486	935	-555	8,649	-158	3,151	4,535
2008	-6,179	2,629	-612	11,113	409	4,347	11,708
2009	-10,289	5,504	-664	9,234	1,030	4,321	9,136
2010	-15,423	2,312	-712	6,854	1,408	4,171	-1,391
2011	-16,955	3,628	-756	9,552	1,811	4,579	1,859
2012	-24,432	4,644	-576	3,777	671	3,830	-12,085
2013	-28,035	5,019	-439	2,463	298	3,507	-17,187
2014	-28,482	4,168	-414	2,326	1,307	4,191	-16,905
2015	-29,313	7,429	-465	5,294	1,847	3,473	-11,734
2016	-29,554	4,792	-403	3,160	1,630	2,181	-18,194
2017	-29,357	5,632	-342	5,970	3,057	2,188	-12,852

6.4.3 Uncertainties and time series consistency

Uncertainties for the *forest land remaining forest land* sub-category are estimated to be ±33.5 per cent for CO_2. The majority of this uncertainty is due to the *other native forest* sub-division. Uncertainty in the *plantations* is expected to be less than 10 per cent. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

6.4.4 Source Specific QA/QC

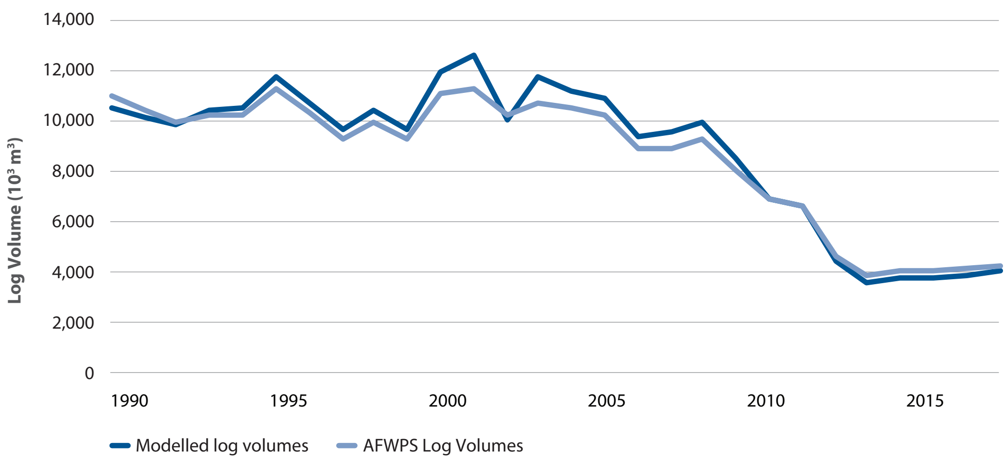
6.4.4.1 Harvested native forests

Data on native forest harvesting is derived from roundwood log volumes for each state (ABARES, 2017a) using a historical relationship between roundwood removals and harvest area data collated by state agencies. Roundwood log volumes are published in the biannual Australian Forest and Wood Products Statistics report (ABARES, 2017a), a comprehensive dataset relating to Australia's forestry sector, including time series data on forest and wood products resources, production, consumption, trade and employment. Historical harvest area data was obtained from a combination of annual reports of Australian State agencies, financial statements, and spatial harvest area data. These data sets have been subject to review processes and financial auditing.

Data on stem to whole tree conversions, carbon contents and wood densities are within the ranges published in Gifford, 2000a; Gifford, 2000b; Ilic *et al.* 2000; and Snowdon *et al.* 2000. The estimated slash produced by forest harvesting is in line with independent studies of slash production from forest harvesting for major Australian harvested forests (Snowdon *et al.* 2000; Ximenes *et al.* 2008a).

The *harvested native forests* model was verified by comparing the log volume, calculated using the harvested native forest model used for emissions estimation with national statistics of round wood production in native forest, (ABARES, 2017a) (Figure 6.19). The log volume from the *harvested native forest* model was estimated by converting the carbon removed from forests as forest products to stem volume, assuming a stemwood carbon percentage of 50 per cent and average wood basic density of 800 kg m-3. The modelled log volumes closely track the published statistics over time.

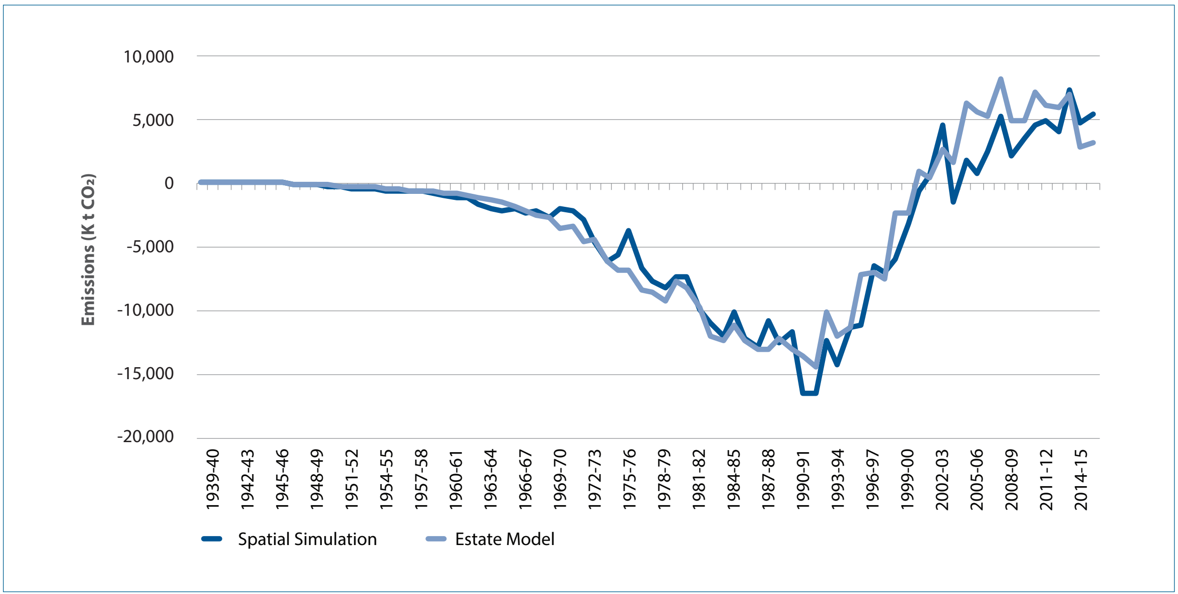
Figure 6.19 Estimated removals in Harvested Native Forests, *FullCAM* model outputs compared to national harvesting statistics (ABARES, 2017a)



6.4.4.2 Pre-90 Plantations

The Pre-90 plantations emissions obtained from spatial simulations follow a trend similar to emissions from the old "Estate" simulation using FullCAM (Figure 6.20). Small differences in emissions are due to differences in the area of the plantation estate and the fact that the spatial simulations capture spatial variability (Rainfall, temperature, productivity and soils).

Figure 6.20 Comparison of Pre-90 Plantation emissions from old FullCAM Estate model and new spatial simulation



The calibration and validation of the *FullCAM* model, along with the associated quality assurance and quality control program are described in Appendix 6.B. An independent review of the models used to estimate emissions and removals in the *plantations* category was undertaken by CSIRO in 2001.

6.4.4.3 Other native forests

The reporting of net emissions from other native forests, and the identification and disaggregation of non-anthropogenic natural disturbances in temperate forests, results in both carbon dioxide emissions and removals from natural disturbances averaging out over time without impacting anthropogenic net emissions. This methodology and outcomes have been subjected to independent review (Federici, 2016a).

Demonstrating balance of emission and subsequent removals associated with natural 'background' fires

Over time, average net emissions of CO_2 from non-anthropogenic emissions and subsequent removals will approach zero. Therefore the disaggregation of natural disturbance emissions will neither over- nor under-estimates net emissions in the long term. This can be further demonstrated when simulating a fire event at the plot level – over the long-term the average net carbon dioxide emissions from natural disturbances is zero.

This is shown in Figure 6.21c in the commentary on recalculations since the 2016 Inventory in section 6.4.5.

Natural disturbance emissions and removals are not in exact balance over the 1990-2017 period due to a number of recent disturbances from 2007 to 2014, recovery from which is ongoing. Given the recovery rates for a typical disturbance event, it is projected to take an extended period without further disturbance for average net emissions to equal zero. For this reason, a modelling approach is used to ensure that these natural disturbances net emissions and removals average out within the reporting timeframes.

Net emissions and removals from wildfires prior to 1990 are included in reporting. However no natural disturbances have been identified which affect net emissions and removals during the reporting period.

Table 6.23 Balancing of natural disturbance CO_2 emissions and removals

Year	Natural disturbance CO_2 emissions	Natural disturbance CO_2 removals
	Mt CO_2	
1990	0.00	0.00
1991	0.00	0.00
1992	0.00	0.00
1993	0.00	0.00
1994	0.00	0.00
1995	0.00	0.00
1996	0.00	0.00
1997	0.00	0.00
1998	0.00	0.00
1999	0.00	0.00
2000	0.00	0.00
2001	0.00	0.00
2002	0.00	0.00
2003	156.07	0.00
2004	0.00	-26.76
2005	0.00	-21.39
2006	0.00	-17.52
2007	72.02	-13.50
2008	0.00	-24.21
2009	0.00	-19.81
2010	0.00	-16.05
2011	0.00	-13.50
2012	0.00	-11.13
2013	0.00	-9.34
2014	37.39	-7.54
2015	0.00	-13.52
2016	29.84	-11.26
2017	0.00	-14.60
2018	0.00	-12.34
Total (1990 - 2018)	295.32	-232.48
1990-2017 net average	**2.69**	
1990-2017 net standard deviation	**34.6**	

All fire areas are monitored for any permanent change in land use or salvage logging (which, if identified, would trigger reporting of emissions in forest conversions or harvested native forests, respectively).

No systematic bias is introduced into the inventory by the disaggregation of natural disturbances from anthropogenic fires. The approach does not introduce any artificial trend in reported emissions and removals (that is, it avoids the expectation of credits or debits).

The approach also improves the quality, accuracy and time series consistency of annual estimates by reducing the high levels of inter-annual variability in the time series.

6.4.5 Recalculations since the 2016 Inventory

The recalculations reported in the current submission are shown in Table 6.24 and include:

A. Other native forests – spatial fire simulation

Methodological change: moving to Tier 3, Approach 3 spatial simulation of fires using FullCAM in tropical forests and for temperate wildfires.

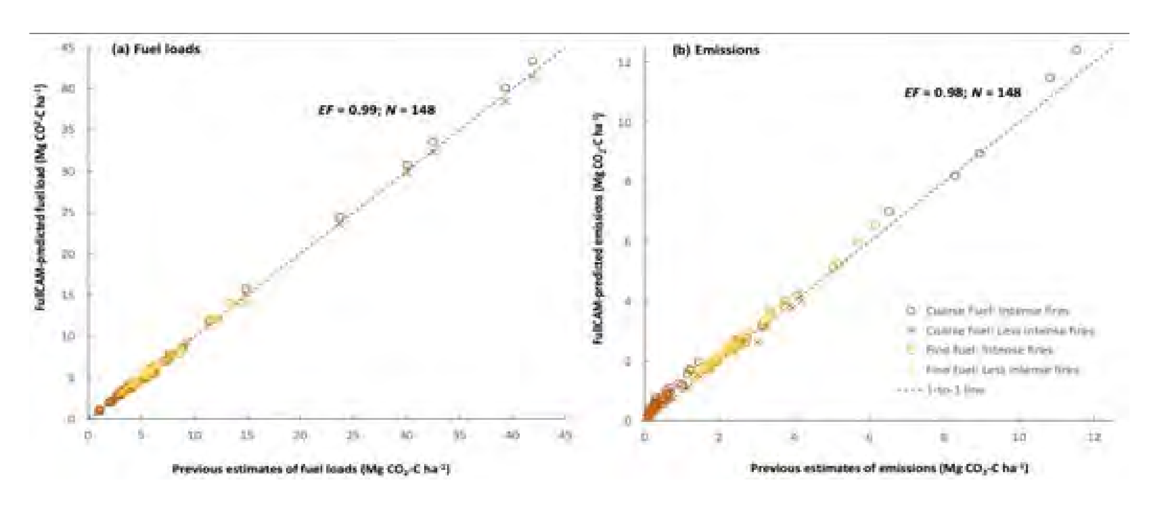
The methodological change for *other native forests* was included as a planned improvement in previous submissions. This change replaces the previous gain-loss models for forest fires, with the fully spatially-explicit, Tier 3, Approach 3 FullCAM model, through the development of new modelling capability and model calibration (see Paul and Roxburgh, 2019).

The new FullCAM method retains the same activity data and stratification of forest lands and fire types. In addition, the calibration of FullCAM under typical fire conditions and average site productivity (before considering spatio-temporal and climate variability) replicates the previous model for emissions and subsequent recovery, as shown in Figure 6.21a (from Paul and Roxburgh, 2019).

However, the following three main factors have affected the trend in reported emissions compared to the previous submission:

- **Inclusion of standing dead pools** to more accurately simulate not just the carbon dynamics of fuel in response to wildfires, but also dynamics of inputs of C into the soil pools, and hence, stocks of soil carbon. This has resulted in slightly more fuel post-fire, compared with simplifying assumptions in previous models, particularly in temperate fire zones.
- **Spatio-temporal variability in fire activity and carbon dynamics is reflected in Tier 3 modelling of fire emissions and recoveries.** Although the FullCAM calibration simulations under scenarios of typical site productivities and fire return intervals replicate previous Tier 2 estimates of fuel loads and emissions, the Tier 3 spatial-temporal application of the model under conditions of varying site productivity and fire return intervals has, as expected, increased variability in estimates (Figure 6.21d).
- **The identification of natural disturbances in temperate forests** still applies the same outlier tests, consistent with the previous NIR submission. However due to recalculations in the historical time-series (affecting levels and inter-annual variability in emissions), fewer natural disturbance events are identified, resulting in higher anthropogenic emissions particularly since 2009 (see Table 6.21).

Figure 6.21a Comparison between FullCAM-predicted: (a) fuel loads, and (b) emissions of CO_2-C and that expected based on previous NIR-based estimates for coarse and fine fuels for the different fire zones and under both intense fires (wildfires in southern fire zones; LDS burns in savanna fire zones) and less intense fires (prescribed burns in southern fire zones, or EDS burns in savanna fire zones).



As the examples shown in Figure 6.21b and Figure 6.21c demonstrate, FullCAM was also able to replicate the rates of fuel recovery post-fire (Paul and Roxburgh, 2019).

Figure 6.21b Example of FullCAM replication of expected (or previous NIR estimates) emissions and fuel dynamics within patches of burnt land within fire scars for late dry season fires in NT high-rainfall woodlands with hummock grass (wet-dry tropical zone) of assumed fire return intervals of 3 years.

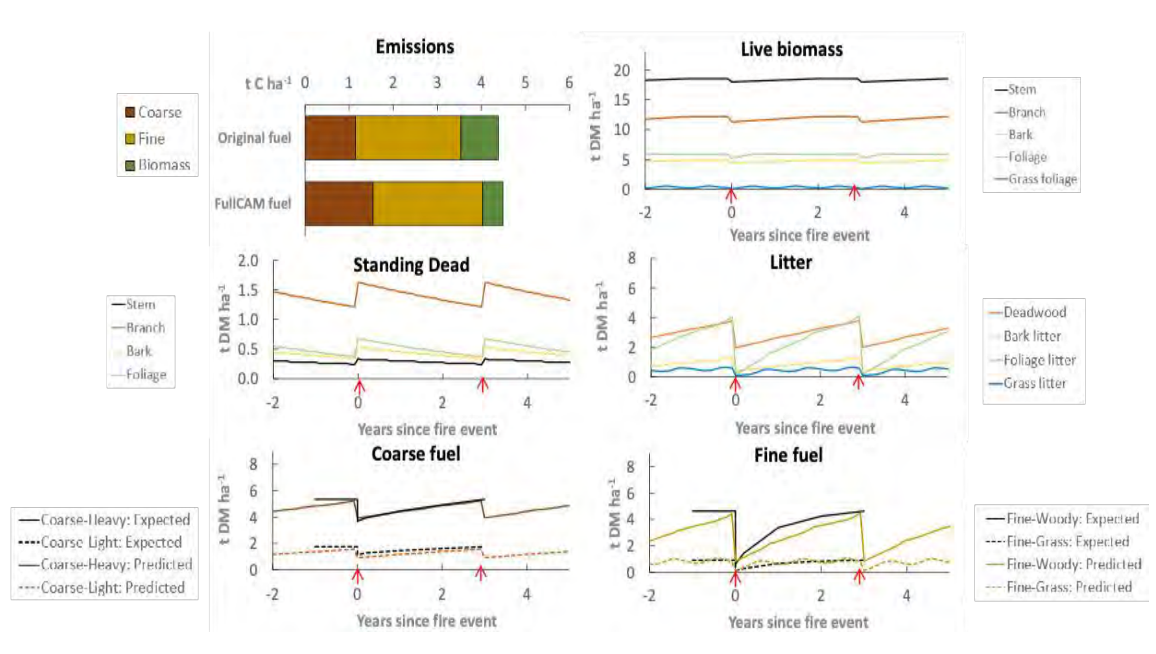


Figure 6.21c Example of FullCAM replication of expected (or previous NIR estimates) emissions and fuel dynamics within patches of burnt land within fire scars for Victorian wildfires of assumed fire return intervals of 78 years.

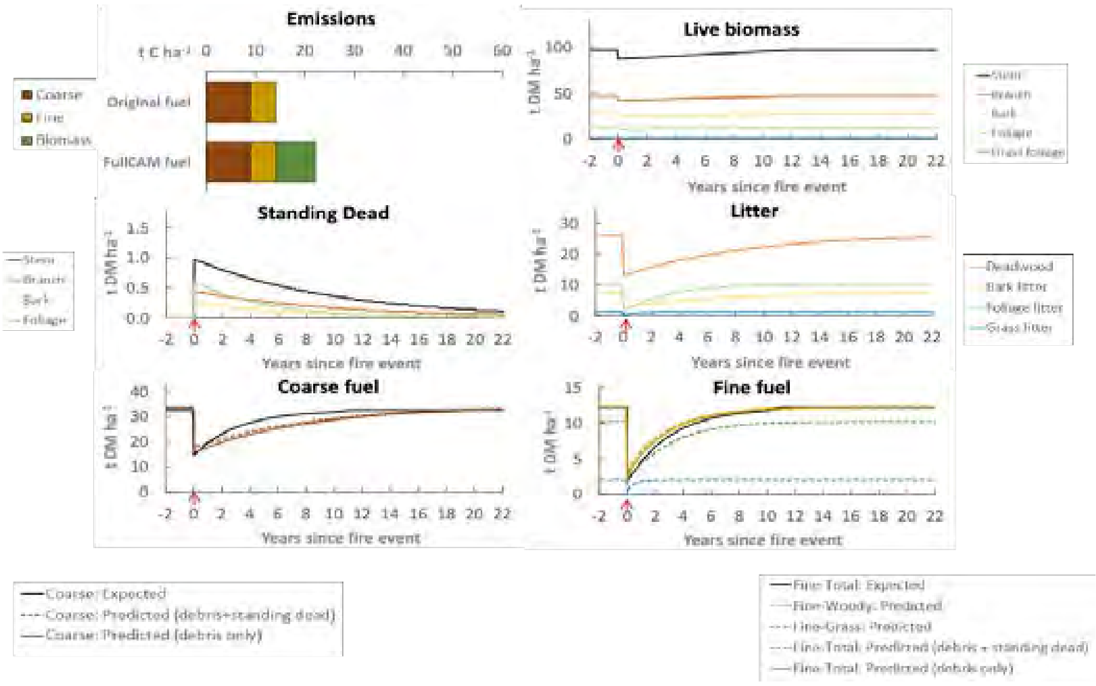
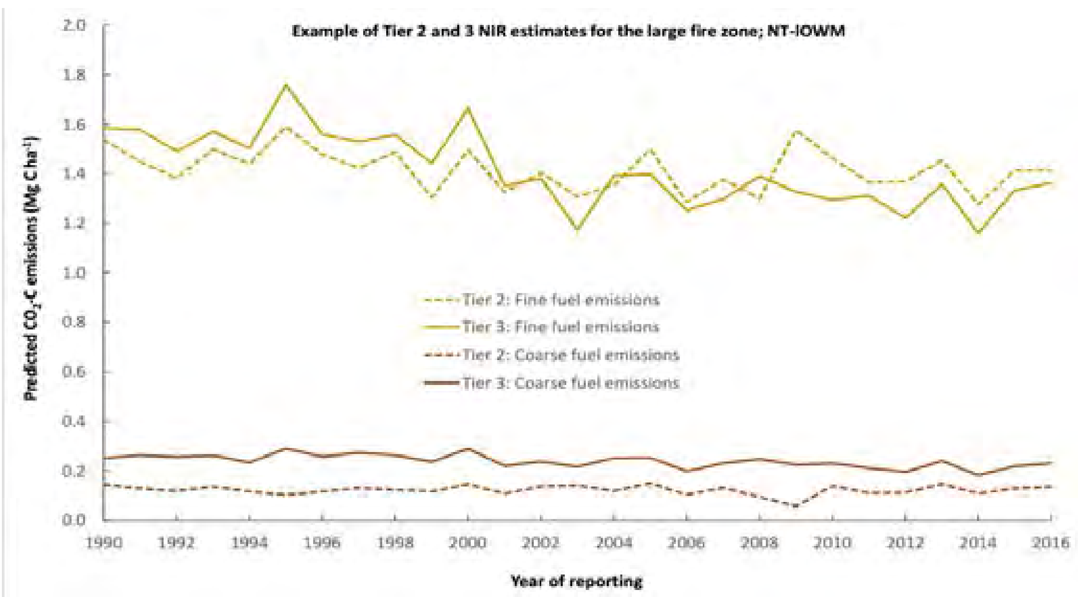


Figure 6.21d Tier 2 (original approach) and Tier 3 (spatial-temporal application of FullCAM) based estimates of CO_2-C emissions over the 1990-2016 NIR reporting period from fires in an example fire zone; NT-IOWM, which is the tropical savanna fire zone with the largest area burnt over the 1990-2016 period.



B. Pre-90 Plantations

Methodological change: moving to Tier 3, Approach 3 spatial simulation of pre-1990 plantations using FullCAM.

This improvement, outlined earlier (section 6.4.1.2) has resulted in a more accurate identification of the area of the pre-90 plantation estate and its growth over time. In addition, the method better captures the spatial variability in the factors (rainfall, temperature, productivity and soil) affecting the growth rate and total biomass at harvest of the plantation trees.

C. Harvested native forests – data updates

The age structure of the managed forest estate has been updated over the full time series to reflect data on forests harvested in 2017, and corrections to harvesting activity data in 1990 (including forest type, age structure of forests at the time of harvesting).

Table 6.24 Forest land remaining forest land: recalculation of total CO_2-e emissions (Gg), 1990–2016

Year	2018 submission	2019 submission	Change		Changes included in 2018 recalculation		
	(Gg CO_2)		(Gg CO_2)	%	A. Spatial Fire	B. Pre-1990 Plantations	C. Data updates relating to native forest harvesting
1990	-12,713	-9,991	2,722	21%	2,965	-298	54
1995	-11,730	-7,025	4,706	40%	6,930	-2,293	68
2000	101	206	105	104%	3,710	-3,722	117
2005	2,518	-1,239	-3,757	-149%	-636	-3,192	71
2006	4,532	524	-4,008	-88%	290	-4,398	100
2007	6,690	4,535	-2,154	-32%	2,397	-4,690	139
2008	5,692	11,708	6,015	106%	8,554	-2,708	170
2009	3,489	9,136	5,647	162%	8,231	-2,778	193
2010	-4,328	-1,391	2,937	68%	5,600	-2,766	103
2011	-6,693	1,859	8,552	128%	9,823	-1,382	111
2012	-17,296	-12,085	5,211	30%	7,738	-2,675	148
2013	-19,827	-17,187	2,640	13%	3,643	-1,174	171
2014	-18,585	-16,905	1,680	9%	3,402	-1,838	115
2015	-21,901	-11,734	10,167	46%	9,626	374	167
2016	-24,346	-18,194	6,151	25%	4,254	1,740	157

6.4.6 Source specific planned improvements

Harvested native forests and pre-90 plantations

Building on the improvements to activity data outlined in section 6.4.1.2 for pre-90 plantations, the Department of the Environment and Energy is continuing to fine tune use of Tier 3, Approach 3 modelling in the future for the pre-90 *plantations*.

We plan to develop similar capacity to have comprehensive Tier 3, Approach 3 (satellite-imagery-based) modelling of the *harvested native forests* sub-category. This will enable the ongoing incorporation of the most recent empirical research into aboveground biomass, allometrics, turnover and decay factors into the *pre-90 plantations* and *harvested native forests* sub-categories.

Other native forests

The Department is investigating sources of spatial data on prescribed burning activity in high-biomass temperate forests (below-canopy fires are not reliably detected using current remote-sensing data) in order to utilize FullCAM Tier 3 modelling for this activity.

The Department also plans to review and update calibrations using additional field studies, particularly focusing on live-biomass and standing-dead pool dynamics post-fire.

6.5 Land Converted to Forest Land (Source Category 4.A.2)

Land converted to forest land includes the sub-categories *grassland converted to forest land, cropland converted to forest land, settlements converted to forest land* and *wetlands converted to forest land*.

Grassland converted to forest land contains forest established on land that was previously non-forest. These conversions include commercial plantations and environmental plantings, forest that has regrown on land that was previously converted from a forest to grassland, and regeneration from natural seed sources on land protected as forest by State or Territory vegetation management policies.

Cropland converted to forest land and *settlements converted to forest land* contains forest that has regrown on land that was previously converted from forest land to the land use identified.

Wetlands converted to forest land comprises land on which mangrove forest has been detected to emerge on tidal marsh.

6.5.1 Methodology

6.5.1.1 Grassland converted to forest land

The emissions and removals from *grassland converted to forest land* are estimated using the spatially explicit (Approach 3) capabilities of the Tier 3 *FullCAM* modelling system. A full description of the modelling system is provided in Appendix 6.B and 6.D, and Waterworth *et al.*, 2007; Waterworth and Richards, 2008.

Reporting includes carbon in living biomass, dead organic matter (DOM) and soil pools.

The areas of *grassland converted to forest land*, including regrowth forest on land previously converted from forest to grassland and initially reported under section 6.9, and areas of forest regenerated from natural seed sources, are drawn from remotely sensed data as per the methods described in Appendix 6.A. The time-series of Landsat satellite data (25 m) is analysed to provide the previous vegetation cover, area, time of establishment, time of harvesting and, if applicable, type of plantation (Caccetta and Chia, 2004).

Each individual 25 m × 25 m pixel identified as being a *plantation* is modelled through time from the time of establishment. Each 25 m × 25 m model takes into account the age, plantation type, management (including time of harvesting as detected from satellite imagery) and site conditions to estimate emissions and removals.

Estimating changes in living biomass

Forest growth

As described in detail by Waterworth *et al.* (2007), to estimate growth of above-ground biomass in Australian plantations, the generic forest regrowth model in FullCAM (Appendix 6.B and 6.D) is supplemented to include functions that represent Type 1 and Type 2 growth responses (Snowdon and Waring, 1984) and the impact of using non-endemic species (Appendix 6.F). Type 1 management practices advance or retard stand development (effectively age) but do not increase underlying site productivity over the life of the rotation (e.g. weed control at establishment). Type 2 treatments increase (or decrease) a site's carrying capacity in the longer term (e.g. phosphorus application).

The net emissions from land converted to forest through regeneration from natural seed sources are estimated using *FullCAM* operated in Approach 3 mode (Appendix 6.B and 6.D). The model is parameterised to model the growth of native forest vegetation from seed (Richards and Brack, 2004a, Fig. 2).

The greenhouse gas removals associated with the regrowing forest detected by the remote sensing system on previously converted land is modelled via the generic forest regrowth model in FullCAM (Appendix 6.B and 6.D).

Partitioning of biomass and growth of below-ground biomass

FullCAM calculates below-ground biomass (coarse and fine roots) and the partitioning of above-ground biomass (stems, branches, bark and leaves), using an empirical approach as outlined by Paul *et al.* (2017). This method allows allocation to vary between tree species based on stand age (Table 6.25).

Table 6.25 Example of the different partitioning of biomass to each of the tree components under different types of plantation species. Estimates are provided for a stand age of 10 years

Forest Type	Fraction of biomass allocated to:					
	Stems	Branches	Bark	Leaves	Coarse roots	Fine roots
E. globulus; short rotation	0.41	0.20	0.07	0.09	0.19	0.04
E. nitens; long rotation	0.43	0.20	0.07	0.08	0.19	0.04
P. pinaster	0.37	0.11	0.05	0.06	0.32	0.08
P. radiata	0.51	0.15	0.07	0.07	0.16	0.03

Carbon contents

The carbon fractions of above and below ground biomass components for Australian vegetation are reported in Table 6.26 and taken from Gifford, 2000a and 2000b.

Table 6.26 Percent carbon of tree components – *land converted to forest land*

Tree Component	Hardwood carbon content %	Softwood carbon content %	Other (environmental plantings) carbon content %
Stems	50.0	51.0	50.0
Branches	46.8	51.4	46.8
Bark	48.7	53.3	48.7
Leaves	52.9	51.1	52.9
Coarse roots	49.2	50.4	49.2
Fine roots	46.1	48.4	46.1

Forest management practices

The Tier 3, Approach 3 modelling system is supported by a comprehensive database of the plantation management practices used in Australia since 1970 (Waterworth and Richards, 2008). The plantation management database contains information on management practices for each tree species within each region. The range of possible management actions is shown in Table 6.27. The management regimes are assigned frequencies within each region to enable time series management regimes to be developed for each plantation pixel through time (Table 6.28) (Waterworth and Richards, 2008).

Table 6.27 Management actions, the *FullCAM* events used to represent them and the choices available through parameterisation of the *FullCAM* event

Management action	FullCAM event type	Effect in model	Standard event options
Mechanical weed control	Plough (agriculture)	Moves herbaceous species carbon to debris, mulch and soil	Spot Strip Broadcast
Chemical weed control	Herbicide event (agriculture)	Kills herbaceous species cover, moving it to debris	Spot application Strip application Broadcast application
Chopper roll	Chopper roll (forest)	Transfers woody debris to faster decaying 'chopped wood' pool	Chopper roll
Management fires	Forest fire (forest)	Transfers carbon from trees to debris and atmosphere, and debris to the atmosphere or soil pools.	Prescribed burn Broadcast burn Windrow and burn
Wildfire[1]	Forest fire (forest)	Transfers carbon from trees to debris and atmosphere, and debris to the atmosphere or soil pools.	Trees killed Trees not killed
Grazing	Graze (agriculture)	Removes aboveground herbaceous species mass and varies root slough	Normal Heavy
Plant trees	Plant trees (forest)	Establishes trees on a site	Different initial masses depending on stocking
Cultivation	Plough (agricultural)	Moves herbaceous species carbon to debris, mulch and soil	Spot cultivation Strip cultivation Broadcast cultivation
Forest thin and harvest and pruning	Forest thin (forest)	Moves tree components to products or debris, debris to bioenergy	Varies by time, species and region.

Management action	FullCAM event type	Effect in model	Standard event options
Fertiliser application[2]	Type 1 or 2 event (forest)	Varies tree growth based on the type and intensity of fertilisation (see Snowdon, 2002).	Normal N fertilisation Applied to any treatment that affects tree growth
Fertiliser application[3]	Fertiliser application (forest and agriculture)	Adds N to the mineral N pool	Different levels of N addition (kg ha-[1])

Source: Waterworth and Richards (2008)
1 Although not a management practice, wildfire events allow for the future spatial modelling of their effect on carbon stocks. See the discussion for more details.
2 *FullCAM* only requires kg N ha^{-1} when using the nitrogen cycling model capacity.
3 Applies only when using the nitrogen cycling model capacity.

Table 6.28 Plantation management database – Time series management regime

Year	Day	Species	Management action	FullCAM event
0	152	Agricultural species	Cultivation: Strip plow	Plow
0	166	Agricultural species	Weed control initial: Blanket herbicide	Herbicide
0	196	Pinus radiata	Plant trees: seedlings normal stocking	Plant trees
0	196	NA	Forest percentage -> determined by tree yield formula	Forest percentage Change
0	196	Pinus radiata	Weed control – Standard (All 1980-present)	Type 1 Forest Treatment
0	196	Pinus radiata	Starter fertiliser – normal	Type 1 Forest Treatment
1	196	Agricultural species	Weed control post planting: Strip herbicide	Herbicide
10	196	Pinus radiata	Thin 1 (SthnTbl ACT 1978-1996)	Forest Thin
10	196	Pinus radiata	Fertilisation: Mid-rotation (Medium)	Type 1 Forest Treatment
10	197	Pinus radiata	Prune (Selective 33%)	Forest Thin
20	196	Pinus radiata	Thin 2 (SthnTbl ACT 1978-1996)	Forest Thin
20	196	Pinus radiata	Fertilisation: Mid-rotation (Medium)	Type 1 Forest Treatment
30	196	Pinus radiata	Thin 3 (SthnTbl ACT 1987-1996)	Forest Thin
See note	196	Pinus radiata	Thin clearing Pa (SthnTbl ACT 1987-1996)	Forest Thin

Note: The year of plantation harvesting is determined using satellite imagery.

The species table in *FullCAM* contains information on tree species characteristics including forest growth model parameters, carbon allocation to tree components over time, biomass carbon percentages, basic wood density, turnover rates for each tree component, decay and product use data. These data allow *FullCAM* to model forest growth for any point based on the site and climate data using the methods described previously.

Estimating changes in debris

Turnover and decomposition rates

The above ground harvest residues were assumed to be standing dead material, which slowly breaks down (Table 6.30a) to produce CO_2 and debris at an assume ratio of 9:1 (Paul and Roxburgh 2019b).

The turnover rate of leaves and fine roots (Table 6.29) affects both the amount of fine litter on the forest floor and subsequently most of the contribution to soil carbon. The tree component turnover rates applied in the model are based on datasets reviewed by Paul *et al.* (2017). Decomposition rates determine the rates of loss of carbon back to the atmosphere as the debris breaks down.

The balance of these two factors determines the amount of debris on site, excluding the effects of management. The amount of carbon moved from living biomass to the DOM pools due to forest harvesting, and is determined in the model by the age, type of harvest and species characteristics.

Table 6.29 Tree component annual turnover rates

Tree Component	Turnover % mth^{-1}
Branches	0.74
Bark	0.41
Leaves; Softwood	3.07
Leaves; Hardwood	4.22
Leaves; Other Environmental Plantings	1.41
Coarse Roots	0.87
Fine Roots	12.55

Note: FullCAM calculations of turnover were simplified since the previous report (redundant exponential function removed), thereby requiring an update in the units for reporting turnover. These changes resulted in no recalculations as values provided here for application in the revised version of FullCAM provide the same predictions of turnover as obtained when defaults previously reported were entered into the previous version of FullCAM.

The rates of decomposition (Tables 6.30a and b) are based on datasets reviewed by Paul *et al.* (2017) and Paul and Roxburgh (2019b).

Table 6.30a Decomposition rates of standing dead pools.

Standing Dead Component	Breakdown Rate % mth^{-1}
Stem	0.83
Branch	0.83
Bark	1.25
Foliage	1.67

Table 6.30b Debris decomposition rates

Debris Component	Breakdown Rate % mth^{-1}
Deadwood	1.25
Bark litter	1.44
Foliage litter, decomposable*	100
Foliage litter, resistant* - Softwoods	1.84
Foliage litter, resistant* - Hardwoods	2.70
Coarse dead roots	2.93
Fine dead roots	100

* The fraction of leaf litter that was resistant was 77 per cent and 85 per cent for hardwood and softwood plantings, respectively.

Note that FullCAM calculations of debris breakdown rates were simplified since the previous report (redundant exponential function removed), thereby requiring an update in the units for reporting breakdown. These changes resulted in no recalculations as values provided here for application in the revised version of FullCAM provide the same predictions of decomposition of debris as obtained when defaults previously reported were entered into the previous version of FullCAM.

Estimating changes in Soil Carbon

Soil carbon is estimated using the fully spatially explicit approach described in Appendix 6.B and Appendix 6.E, with a recent soil carbon map as the base input data for modelling *post-1990 plantations.*

Parameters governing the input of carbon to the soil following the decomposition of DOM are the fractions of decomposed DOM that is lost to the atmosphere as CO_2-C. The remaining decomposed DOM that is not lost as CO_2-C is predicted to enter the pools of soil C. Values for these parameters were calibrated using forest soil carbon studies as described by Paul *et al.* (2017).

Activity data

The activity data for the grass*land converted to forest land* classification is drawn from the remote sensing program(see Appendix 6.A) (Table 6.31).

Commencing last year, activity data for this classification includes pre-1990 transitions, and areas of regrowing forest on land that had previously been converted from forest to grassland.

Table 6.31 Cumulative area of *grassland converted to forest land* 1990–2016

Year	Area (ha)
1990	2,921,867
1995	5,138,025
2000	6,486,162
2005	7,605,659
2010	9,218,485
2011	9,728,710
2012	10,226,638
2013	10,770,958
2014	11,384,838
2015	12,069,471
2016	12,750,391
2017	13,480,690

6.5.1.2 Cropland converted to forest land and settlements converted to forest land

Cropland converted to forest land and *settlements converted to forest land* contain forest that has regrown on land that was previously converted from forest land to the land use in question. These conversions do not always mean that the land has ceased being used for its converted purpose, but that a canopy of trees has been detected as re-emerging above the identified land use. For example, a canopy may emerge due to the urban landscaping of parks and gardens, or the restoration of riparian vegetation along waterways in cropping regions. The re-emergence of sufficient trees as would meet the definition of a forest gives cause for these lands to be recognised as converted to forest for the purposes of the national inventory. The activity data and emissions methods are the same as those described for *grassland converted to forest land* (6.5.1.1) with respect to the regrowth of forest on previously cleared lands.

Table 6.32 Cumulative area of croplands and settlements converted to forest land 1990–2017

Year	Area of cropland re-converted (ha)	Area of settlement re-converted (ha)
1990	34,523	6,247
1995	64,086	17,057
2000	64,208	21,903
2005	56,724	24,924
2010	63,254	25,050

Year	Area of cropland re-converted (ha)	Area of settlement re-converted (ha)
2011	68,482	27,373
2012	72,500	32,052
2013	76,469	35,350
2014	81,420	38,234
2015	90,013	43,339
2016	94,086	46,544
2017	104,986	50,353

6.5.1.3 Wetlands converted to forest land

The emergence of mangrove forest is identified using satellite imagery, as for the *grassland converted to forest* sub-category. Given mangrove forests are generally bordered by water on the lower side and salt marsh on the higher side, it is reasonable to assume that any emerging coastal mangrove forest does so on land which was previously tidal marsh.

Carbon dioxide emissions and removals are modelled using mangrove-specific parameter values in a Tier 2 Excel[TM]-based growth model. The changes in above- and below-ground biomass, soil carbon, and dead organic matter (as woody and non-woody litter) are captured using a sigmoidal equation. The equation, based on equation 8 in Yin *et al.* (2003) was modified to employ non-zero minimum values, according to the procedure of Shi *et al.* (2016):

$$W_t = [W_0 + (W_{max} - W_0) \times (1 + (t_{max} - t_t)/(t_{max} - t_{mg})) \times (t_t/t_{mg})^{tmax/(tmax-tmg)}] \times \text{Area converted,}$$

where W_t = total mass at time t for AGB, BGB, Woody litter, non-Woody litter, or Soil organic carbon (SOC)

W_0 = initial mass per hectare

W_{max} = maximum mass per hectare

t_t = time t, years

t_{max} = time when maximum mass is reached, 30 years

t_{mg} = time when maximum growth rate is reached, 23 years

The minimum and maximum values for each parameter (Table 6.J.1) are established from the scientific literature. However times to maximum growth rate, and to maximum biomass, are established through interpretation of a single study that described mangrove development over time (Semeniuk, 1980). The developmental milestones were plotted against time and the transitions smoothed by generating a six order polynomial trend line in MS Excel™. Time to maximum growth rate (23 years) and time to maximum biomass (30 years) were then estimated against the trend line.

This equation was developed by the above authors to model biomass growth in individual plants. It is used in this model to estimate the annual change in mass of individual carbon pools associated with growing a mangrove stand from establishment to maturity. It is assumed that the value of each carbon pool is directly proportional to the mass of an even-aged and sized mangrove stand in which the trees continue to grow synchronously and without self-thinning.

Activity data

The activity data for the *wetlands converted to forest land* classification is drawn from the remote sensing program (see Appendix 6.A) (Table 6.33). Whereas the dataset reported in 2017 presented area data from 1990 to 2015, the dataset reported last year was the first to provide area data from 1972 onwards. The cumulative areas reported last year reflected this additional data. Expanded analysis of satellite imagery covering coastal areas in NW Western Australia has provided additional areas of wetland conversion to mangrove over the period 1973 to 2017, which are reported in the NIR this year for the first time

Table 6.33 Cumulative area of *wetland converted to forest land* 1990–2017

Year	Area (ha)
1990	2,813
1995	3,657
2000	4,067
2005	4,458
2010	4,924
2011	5,058
2012	5,178
2013	5,306
2014	5,436
2015	5,535
2016	5,616
2017	5,857

6.5.2 Emission estimates

The annual net emissions for the *land converted to forest land* category for the period 1990 to 2017 are in Table 6.34 below.

Table 6.34 Annual net emissions for *land converted to forest land,* 1990–2017 (Gg CO_2-e)

Year	Cropland converted to forest land	Grassland converted to forest land	Settlements converted to forest land	Wetlands converted to forest land	Total
1990	-191	-6,057	-49	-125	-6,421
1995	-338	-12,529	-135	-203	-13,204
2000	-466	-25,808	-198	-301	-26,773
2005	-343	-25,093	-214	-309	-25,960
2006	-339	-27,251	-207	-317	-28,113
2007	-336	-25,454	-204	-325	-26,319
2008	-345	-28,430	-187	-328	-29,291
2009	-330	-28,227	-174	-331	-29,061
2010	-352	-32,347	-185	-330	-33,213
2011	-404	-39,354	-186	-327	-40,270
2012	-438	-37,014	-209	-316	-37,976
2013	-426	-35,531	-248	-308	-36,512
2014	-458	-36,715	-279	-299	-37,750
2015	-514	-37,223	-301	-291	-38,329
2016	-577	-44,742	-387	-283	-45,990
2017	-658	-46,828	-386	-293	-48,165

6.5.3 Uncertainties and time series consistency

Uncertainty in the *land converted to forest land* sub-category is expected to be 17.3 per cent. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

Under *wetland converted to forest land* the confidence intervals associated with 2013 IPCC guidance values for parameters associated with land use, land use change involving coastal wetlands range from 24 per cent to over 200 per cent. This inventory applies available country-specific values, sourced from the scientific literature, to reduce that level of uncertainty. Although a formal uncertainty analysis is not yet available, the level of uncertainty is anticipated to be towards the lower end of the guidance values, and is considered to be within the medium range.

While there is a higher uncertainty in *wetlands converted to forest land* than in *grassland converted to forest land estimates,* the former category makes only a small contribution to the overall uncertainty of *land converted to forest land* due to its lower emissions.

6.5.4 Source Specific QA/QC

The calibration and validation of the *FullCAM* model, along with the associated quality assurance and quality control program are fully described in Appendices 6.B and 6.F.

Up until the 2014 Inventory, to conduct quality control of the Tier 3, Approach 3 model, a series of Tier 2 models based on 48 plot files drawn from within the *FullCAM* modelling framework were selected. The Tier 2 models were parameterised with site average climate (rainfall, temperature and open pan evaporation) and forest productivity data. The selected plot files are representative of the most common species and management regimes within each state and National Plantation Inventory (NPI) region (Figure 6.16).

The area of each type of forest (hardwood, softwood and native planting) in each region was determined from the land sector remote sensing program. As *FullCAM* is used for both the Tier 2 and Tier 3 models, the model inter-comparison primarily represents a test of the Approach 3 component of Australia's inventory method for *grassland converted to forest land*; and use of annually updated, spatially explicit climate and forest productivity data (Tier 3) as compared to site average data (Tier 2).

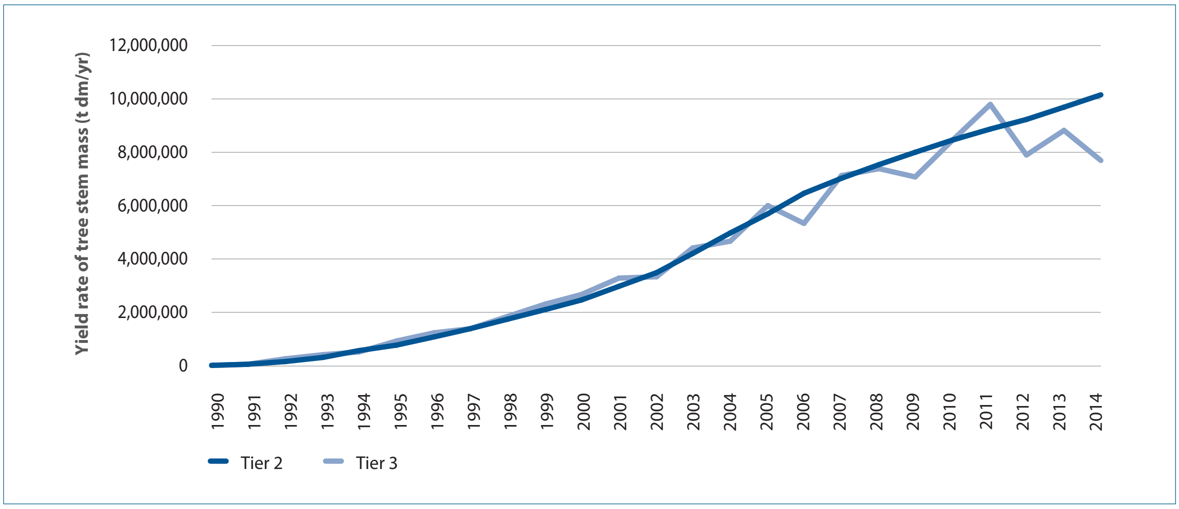
A comparison of the yield rate of tree stem mass (Figure 6.22) showed a close agreement between the two models. The Tier 3 model results are more variable, reflecting the ability of the Tier 3 model to represent the effects of spatial and temporal variability in climatic variables on plant growth.

Over the period 2010–2015, the Tier 3 yield rate of stem mass increased and decreased relative to the Tier 2 models (Figure 6.22). These variations were due to conditions for plant growth being close to optimal in 2011 and then becoming less optimal during 2012 to 2015. In 2014 conditions for plant growth within the post 1990 plantation estate were worse than average. The variability in plant growth in the Tier 3 model is driven by the spatially and temporally explicit Forest Productivity Index (Appendix 6.C), which is a parameter of the Tree Yield Formula (Appendix 6.B) within the *FullCAM* model framework.

The results of the Tier 3 soil carbon model (Figure 6.23) were also compared to the results of the Tier 2 model based on the same 48 plot files described earlier in this section. The comparison shows that the trend is similar but that emissions estimated from the Tier 3 model are more variable due to the effects of spatial variability in soil and climatic conditions and better representation of the effects of previous land use on initial soil carbon stocks.

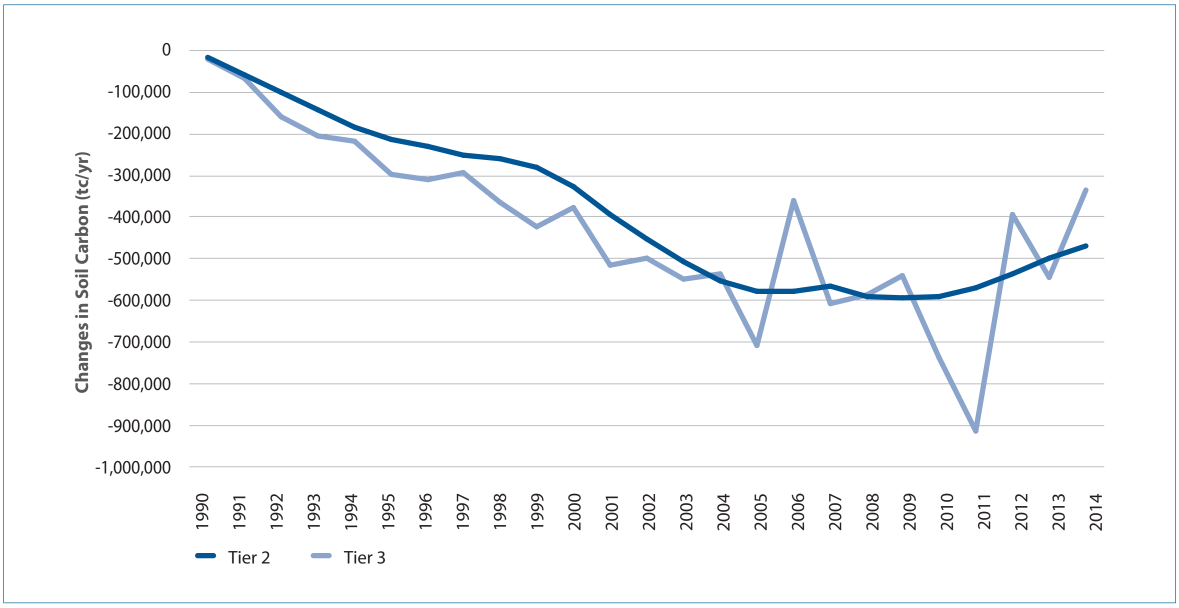
Due to the significant updates and improvements to activity data collection and estimation methods (see section 6.5.5 below), particularly satellite imagery-based spatio-temporal modelling of harvesting in post-1990 plantations, comparison with the Tier 2 model as described above is no longer strictly valid. However, historical use of the model as described above remains valid, and the factors driving the changes between the 2014 and 2016 Inventories are well understood and explained, along with their impacts, in section 6.5.5 below. As per the improvement plan, Australia will review and update the current Tier 2 model to ensure it remains a valid QA check for future inventories.

Figure 6.22 Yield rate of tree stem mass (dm t/yr) output from Tier 2 and Tier 3 methodology, 1990–2014



Quality control of the Excel™-based Tier 2 coastal wetland models is based on the comparison of model outcomes against expected outcomes from test data sets used as model inputs. In addition, the area of mangrove forest is determined from the land sector remote sensing program and is subject to the associated quality control and quality assurance protocols described in Appendix 6A. Initial quality assurance of the coastal wetland models is based on in-house reviews of the models, underlying assumptions, and parameter and emission factor values, and is informed by the latest scientific literature published by members of the wetland advisory group, an external and independent advisory panel to the Department of the Environment and Energy.

Figure 6.23 Soil carbon (t C/yr) output from Tier 2 and Tier 3 methodology, 1990–2014



6.5.5 Recalculations since the 2016 Inventory

Improvements and updates made to FullCAM relating to simulation of the *grassland and cropland land converted to forest land* sub-categories that have contributed to the recalculations include:

A. Improvement to the key site productivity parameter in FullCAM's growth model:

   As explained in section 6.9.5.1, the tree yield formula (TYF), which underpins plant growth (productivity) in FullCAM forest systems, functions by taking climate-related fluctuations in conditions and applying them as variations to a long-term average forest productivity index (FPI). This formula functions best when the long-term average mirrors the period being simulated (Roxburgh and Paul 2019). This revision revises that long-term average to be based on a 1972-2016 series rather than an earlier series. As outlined by Roxburgh and Paul (2019), given the revised long-term average FPI is generally slightly higher than that previously applied, the effect here is that growth rates in forest systems reach the long-term expected maximum (M) under average climatic conditions, which in turn results in an increase in sequestration in all the carbon pools (plant, debris and soil).

B. Inclusion of 'Standing Dead' debris pool:

   Previously, in FullCAM simulations, thinning and other stand-related disturbances such as dieback created only ground-based debris and no standing dead. As outlined by Paul and Roxburgh (2019b), FullCAM has been modified to produce a standing dead pool following such disturbances (Appendix 6.B) to more accurately simulate not just the carbon dynamics post-disturbance, but also dynamics of inputs of C into the soil pools, and hence, stocks of soil carbon. Since the standing dead pool breaks down more slowly than debris which is in contact with the soil, post-thinning and dieback emissions are lower, particularly in the shorter term.

C. Improvements in FullCAM simulation and updates to spatial input datasets:

   A key factor in annual recalculations for this sub-category is revisions to the area of forest change identified using satellite imagery. These revisions are due to expansion of the forest area monitored and improvements in the analysis of satellite imagery. Such improvements include increased resolution of transitions between non-woody, sparse (sub-forest) woody vegetation and forest states, which impact the transition dates and area distribution between inventory years, and also affect cumulative area and emissions. These revisions also include annual updates to climate (weather) data.

   Refinements were also made to aspects of the model calculation of the FPI and Maximum Biomass layer to better reflect observed forest behaviour

D. Additional Refinements to FullCAM

   In addition to the factors described above: A number of further refinements to the FullCAM model were made to reduce model uncertainty and address minor issues encountered during the year.

   A refinement in the analysis of coastal wetland spatial data has led to a small recalculation in emissions from *wetlands converted to forest land.*

Table 6.35 *Land converted to forest land*: recalculation of total CO_2-e emissions (Gg), 1990–2016

Year	2018 submission	2019 submission	Change		Reasons for Recalculation			
					A. FullCAM improvement - update of key growth parameter productivity in TYF	B. FullCAM improvements - Inclusion of 'Standing Dead' debris pool	C. Improvements in simulation and updates to input datasets	D. Additional refinementss to FullCAM
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	(% change)				
1990	-4,207	-6,421	-2,214	52.6%	-2,638	-1,796	1,614	606
1995	-11,007	-13,204	-2,197	20.0%	-4,404	-690	2,465	432
2000	-23,557	-26,773	-3,216	13.7%	-6,402	-1,098	4,146	138
2005	-21,991	-25,960	-3,968	18.0%	-4,669	-4,102	4,302	501
2006	-21,572	-28,113	-6,541	30.3%	-4,304	-4,607	3,069	-699
2007	-21,951	-26,319	-4,368	19.9%	-4,305	-3,947	3,633	251
2008	-25,901	-29,291	-3,390	13.1%	-5,029	-2,094	3,940	-207
2009	-26,469	-29,061	-2,592	9.8%	-5,131	-296	2,643	193
2010	-29,715	-33,213	-3,498	11.8%	-5,673	-19	1,557	637
2011	-35,819	-40,270	-4,452	12.4%	-7,407	1,386	1,457	113
2012	-36,890	-37,976	-1,086	2.9%	-7,472	2,263	2,639	1,484
2013	-37,181	-36,512	668	-1.8%	-7,810	3,009	3,843	1,626
2014	-37,483	-37,750	-266	0.7%	-8,500	3,191	3,973	1,069
2015	-37,506	-38,329	-823	2.2%	-9,310	3,878	3,607	1,002
2016	-39,382	-45,990	-6,608	16.8%	-9,902	3,999	-1,882	1,178

*includes 3-class identification, spatial harvesting and revisions of parameters

6.5.6 Source specific planned improvements

Ongoing refinements to the Tier 3 *FullCAM* modelling parameters for forest/plantation growth and regeneration (including for pre-1990) are to be informed by empirical research.

More specifically:

Revised FullCAM TYF calibrations. Work is currently underway to revise the tree yield forumla (TYF) calibrations. This was required given: (i) additional measurements of stand AGB have become available since initial calibrations were undertaken by Waterworth *et al.* (2007) and Paul *et al.* (2015a,b); (ii) the key TYF input of site productivity potential (M) was recently revised, resulting in significant improvements in spatial variation in productivity potential, particularly across temperate regions of Australia (Roxburgh *et al.* 2019); (iii) it was timely to up-date TYF predictions for natural regeneration of woody vegetation, particularly in land managed for grazing, and; (iv) it was timely to explore options to include TYF predictions for woody vegetation being established along riparian or floodplain zones. This TYF recalibration work is already well-advanced for land restoration activities such as environmental plantings and natural regeneration (see Paul and Roxburgh 2019c).

Given the revised "M" input layer, the TYF also requires recalibration for each plantation species-by-management regime-by NPI region. As per the initial TYF calibrations, revised TYF calibrations are being informed by the latest (2016) ABARES estimates of wood volumes harvested for different plantation species-by-management regime-by NPI region. This recalibration of the TYF for hardwood and softwood species is currently in progress. As part of this work, it is planned to expand plantation TYF calibrations available to other species of interest, e.g. sandalwood.

Full implementation of updates to FullCAM parameters specifying allocation of tree biomass. Paul & Roxburgh (2017) outlined new empirical models that provide, as an output, the input for *FullCAMs* time-series tables for allocation of biomass for each tree species. Allocation varied with productivity of aboveground biomass (AGB). For many plantation species, productivity (i.e. TYF parameters) varies between regions, while for environmental and Mallee plantings, productivity varies between regimes (i.e. stand density, configuration, species or species mix). Therefore, additional separate revised allocation input tables were generated for each region of each plantation species, and for each of the various regimes of environmental and Mallee plantings. However, additional *FullCAM* programing would be required to enable allocation inputs to vary with region or regime. Given time limitations, the original *FullCAM* configuration of allowing for only one allocation input table for each forest type was used for the submission in 2016 and 2017 Inventories. This required the revised allocation tables from a single region for a given plantation species to be applied to all other regions within which that species grows. Similarly, a single regime for temperate environmental (or Mallee) plantings was applied to all other regimes. It is planned to complete implementation of the revised allocation inputs for the 2018 Inventory submission in 2020.

Improved simulation of plantations. Further improvements are planned to utilise remotely sensed forest transitions in spatial simulation of pre-1990 plantations. It is planned to implement standing dead in simulation of both pre-1990 and post-1989 plantations.

Improved simulation of decomposition of debris. Further improvements are planned to the accuracy of dynamics in stocks of debris (and hence soil). The proposed improvements include:

Allowing dead fine roots to directly enter the soil pool. This was suggested by Farquharson *et al.* (2013). It makes practical sense given fine roots are defined as roots with diameters of <2 mm. When sampling SOC, the soil is also defined as < 2mm. Hence, dead fine roots would be sampled as part of the SOC. If measured as SOC, dead fine roots should also be modelled as SOC.

Allowing for greater flexibility in management of debris. With the proposed revisions, management options would be available for harvesting of standing dead debris (harvest residues or crop stubble) for biomass or bioenergy, and addition of soil amendments, e.g. biochar etc.

Improvements to mangrove modelling. Ongoing refinement to the wetlands (salt marsh) to forest (mangrove) modelling parameters informed by empirical research. This will provide enhancement to the Tier 2 spreadsheet-based model, and facilitate later integration into the FullCAM system as a Tier 3 model.

Extension of the remote sensing program is planned to improve spatial and temporal identification and attribution of transitions from tidal marsh and salt pan to mangrove forest.

6.6 Cropland Remaining Cropland (Source Category 4.B.1)

The *cropland remaining cropland* sub-category includes continuous cropping lands and lands that are cropped in rotation with pastures. Croplands are considered to be of high land value with a high return on production and of moderate to high soil nutrient status and are therefore not generally converted to *forest land* or *grassland* but remain as *cropland*.

Anthropogenic emissions and removals on croplands occur as a result of changes in management practices on cropping lands, from changes in crop type and from changes in land use. Permanent changes in management practices generate changes in the levels of soil carbon or woody biomass stocks over the longer term. Changes in carbon stock levels during the transition period to a new stock equilibrium are recorded under croplands.

Emissions and removals from *grassland converted to cropland* are reported under *cropland remaining cropland* because annual variations in area under cropping in Australian agricultural systems do not constitute a permanent land-use change. Activity data for crop-pasture rotations based on Australian national statistical information includes permanent conversions to croplands. This is appropriate for national circumstances and Australian agricultural systems which apply predominantly rain-fed cropping practices and respond to market fluctuations, resulting in seasonal variations in the lands under cropping rather than permanent land-use changes. The IPCC 2006 guidelines permit such an approach where appropriate based on the activity data (for example where prior-land use is not known, see *IPCC 2006 Guidelines*, Vol 4, Ch 5.3.3).

Anthropogenic emissions and removals from croplands are estimated from changes in specified management practices on croplands including:

- Total cropping area;
- Crop type and rotation (including pasture leys);
- Stubble management, including burning practices;
- Tillage techniques;
- Fertiliser application and irrigation;
- Application of green manures (particularly legume crops); and
- Soil ameliorants (application of manure, compost or biochar).

Conversion of pasture to cropping activities is included within the *cropland remaining cropland* estimates.

Carbon dioxide emissions from the application of lime are reported under *Agriculture*. Nitrous oxide emissions from the application of fertiliser are also reported under *Agriculture*.

6.6.1 Methodology

Emissions and removals from crop land activities are estimated using methods consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), in conjunction with techniques described in the *2013 Revised Supplementary Methods and Good Practice Guidance for LULUCF Arising from the Kyoto Protocol* (IPCC, 2014)[5].

Carbon dioxide emissions and removals from the *cropland remaining cropland* soils component are estimated using *FullCAM* (Appendix 6.B). The CO_2 emissions and removals associated with changes in the area of perennial woody crops are estimated using the Tier 2 approach outlined below.

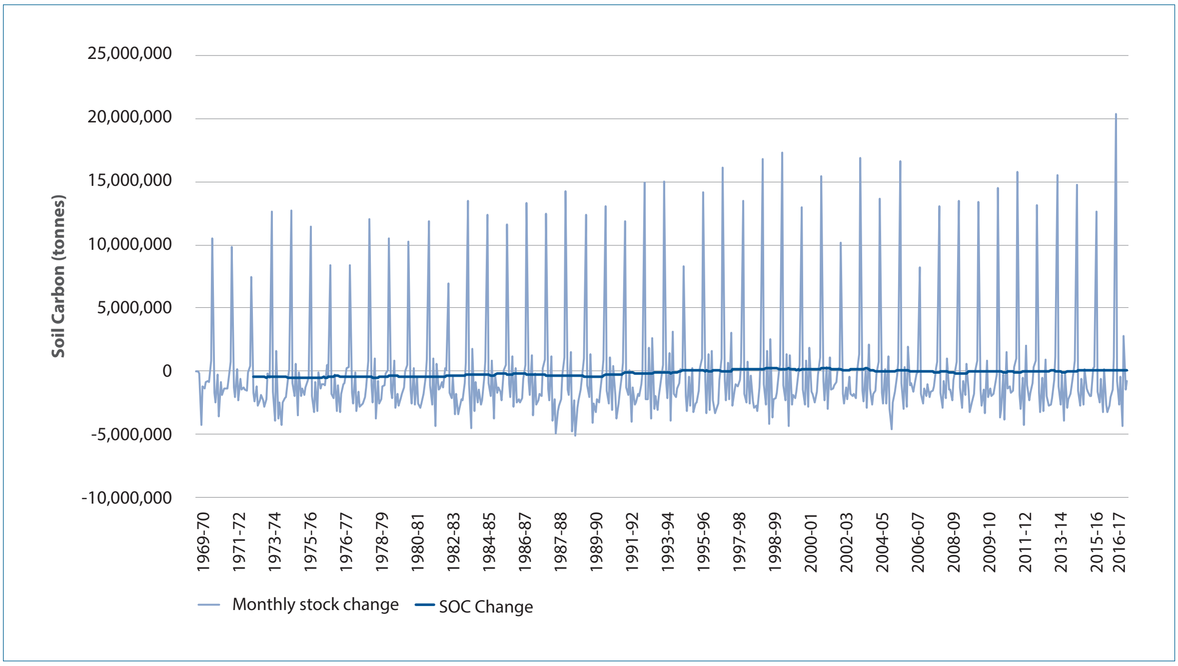
The areas of *cropland remaining cropland* is estimated using ABARES Catchment Scale Land Use of Australia 2017 provided by the Department of Agriculture and Water Resources at the mapping scale of 1:5000 to 1:250 000.

Herbaceous crops

FullCAM is simulated in monthly time steps commencing at the time of first planting in 1970 (Figure 6.24). When configured for cropland remaining cropland, *FullCAM* uses the same climate, site and management datasets as those used in the f*orest land converted to cropland* estimates as described in Appendix 6.B and 6.E.

All on-site carbon pools (living biomass, dead organic matter (DOM) and soil) are estimated. For non-woody crops in *cropland remaining cropland* the changes in the soil carbon pool are reported. Carbon stock changes from living biomass and DOM of non-woody annual crops are reported to be zero, consistent with the guidance in *2006 IPCC Guidelines for National Greenhouse Gas Inventories* that indicates that the increase in biomass stocks in a single crop year may be assumed equal to biomass losses from harvest and mortality in that year – thus there is no net accumulation of biomass carbon stocks (IPCC 2006, p5.7). In general, croplands will have little or no dead wood, crop residues or litter (IPCC 2006, p5.12). Consistent with the method outlined in the *IPCC 2006 Vol 4, 2.3.3.1*, a mean incremental value for the transitions between SOC near steady states is derived, in this case from the simulated monthly data, as shown in Figure 6.24.

Figure 6.24 Carbon stock change from cropland remaining cropland, 1970-2017



5 According to the IPCC (2014), in all cases, the aim of the estimation processes is to identify and report trends and systematic changes in the carbon stocks resulting from changes in management practices over time. More explicitly, (IPCC 2013, p2.135) countries are encouraged to use higher tier methods (Tier 2 or Tier 3) to develop emissions coefficients or models to represent the effects of management practices rather than those of inter-annual variability and natural disturbances on carbon stocks.

Initial soil carbon values come from a baseline map of soil organic carbon (Viscarra-Rossel *et al.*, 2014) (Appendix 6.E).

Management practice change has been monitored in the ABS Land Management and Farming 4627.0 which provides information on management practices being adopted and utilised by Australian agricultural business. Further details on changes in management practices are provided in Appendix 6.E.

Perennial woody crops

The carbon dioxide emissions and removals from changes in the area of perennial woody crops are estimated using a country-specific Tier 2 approach. The Tier 2 method retains the basic Tier 1 approach from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, but with the differences to the period over which biomass accumulates (harvest/maturity cycle) and use of more accurate crop-specific coefficients.

Crop-specific coefficients were sourced from the literature to calculate CO_2 emissions and removals. The coefficients required are: total biomass carbon stock at harvest (tonnes C ha^{-1}), harvest cycle (yr), biomass accumulation rate (tonnes C ha^{-1} yr^{-1}) and plot density (trees ha^{-1}). The mathematical relationships between these coefficients are displayed in Table 6.36. Additionally, root to shoot ratios were sourced from the literature and biomass accumulations associated with fruit production were excluded from all calculations.

Table 6.36 Calculations used to develop tier 2 coefficients for perennial woody crops

	total biomass carbon stock at harvest (t C ha^{-1})	harvest cycle (yr)	biomass accumulation rate (t C ha^{-1} yr^{-1})
calculations	(X ÷ 2) × y	X	y
e.g. (oranges)	7.5	30	0.5

Note that x and y are sourced from literature and crop maturity is half of harvest cycle.

In total, 27 perennial woody crop types are grouped by major crop-type. The coefficients applied to each group were based on the dominant crop type (Table 6.37). The four main crop-types and dominant crops are: 1) citrus, with crop coefficients represented by orange data, 2) Nuts, with crop coefficients represented by macadamia data, 3) pomes, with crop coefficients represented by apple data and 4) stone fruit, with crop coefficients represented by peach data. Other smaller crops modelled included: olives, grapes, kiwifruit, avocados and mangoes. Grape crop coefficients were used to model kiwifruit, and avocado coefficients were used to model mangoes. Regarding nuts, while macadamias were used as the representative crop, almonds were estimated separately as almond-specific coefficients were available.

Estimates of changes in area of perennial woody crops are taken from the *ABS agricultural commodities statistics (ABS, 2016)*. Most crop data are provided as tree number values and subsequently were converted to area statistics using crop-specific plot density coefficients (Table 6.37).

Table 6.37 Perennial woody crop Tier 2 coefficients

Crop type	total biomass carbon stock at harvest (t C ha^{-1})	harvest cycle (yr)	biomass accumulation rate (t C ha^{-1} yr^{-1})	plot density (trees ha^{-1})	root: shoot
Citrus					
Oranges	7.5	30 a	0.5 a	556 b	0.17 c
Nuts					
Macadamias	45	30 d	3 e	355 e	0.25 e

Crop type	total biomass carbon stock at harvest (t C ha^{-1})	harvest cycle (yr)	biomass accumulation rate (t C ha^{-1} yr^{-1})	plot density (trees ha^{-1})	root: shoot
Almonds	15	25 a	1.2 a	222 f	
Pomes					
Apples	10.2 g	28 g	0.7	500 g	0.17 c
Stone fruit					
Peaches	9.8	15 a	1.3 a	740 h	0.17 c
Grapes	3.8	25 a	0.3 a	N/A	0.5 c
Kiwifruits	3.8	25 a	0.3 a	N/A	0.5 c
Olives	6.67	20 i	0.67 j	250 k	0.145 c
Avocados	7.2 l	25 a	0.6	100 l	0.125 l
Mangoes	16 l	25 a	1.3	222 m	0.125 l
IPCC default	63	30	2.1		

Source and location of study is: *a* = Kroodsma & Field (2006) USA California, *b* = Morgan *et al.* (2006) USA Florida, *c* = German and/or Spanish National Inventory Reports (2013), *d* = Australian Macadamia Society website, *e* = Murphy *et al.* (2013) Australia, *f* = Fernandez-Puriatch *et al.* (2013) Spain, *g* = Haynes and Goh (1980) New Zealand, *h* = Marini & Sowers (2000) USA, *i* = Sanfelipe Olives website (2013) USA California, *j* = Villalobos *et al.* (2006) Spain, *k* = Olives Australia website (2013), *l* = Lovatt (1996) USA California and *m* = Western Australian Government Agricultural website (2013). Note that plot density is represented by N/A for Grapes and Kiwifruit as reported in hectares by ABS. All figures not referenced were determined using calculations in Table 6.36.

6.6.2 Emission estimates

Net annual emissions estimates for *cropland remaining cropland* for the period 1990 to 2017 are shown graphically in Figure 6.25, and a breakdown by sub-category is shown in Table 6.38. While climate has important cyclical effects, the uptake of reduced, minimum and no-till management techniques through the 1980's and 90's is reflected in the tendency towards decreasing emissions during this period as a new soil C state of equilibrium is reached. Further management changes in recent years and their impact on the soil C steady state can be detected in shifts later in the emissions time series.

Figure 6.25 Net CO_2-e emissions from soils in *cropland remaining cropland*, 1990–2017

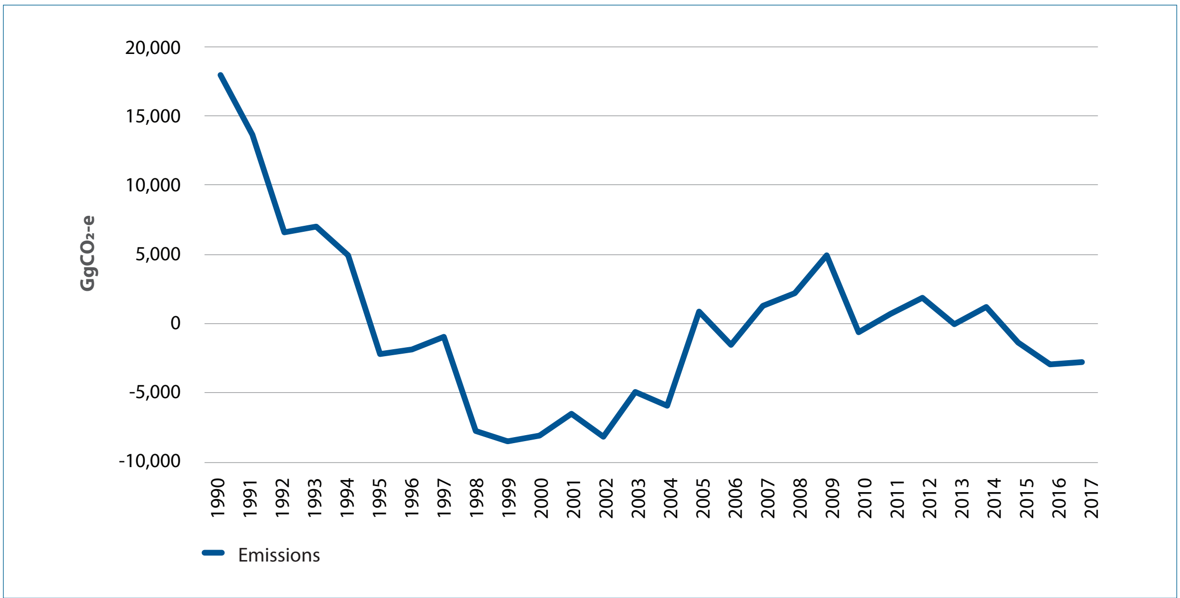


Table 6.38 Net emissions and removals from *cropland remaining cropland* sub-categories, 1990–2017 (Gg CO_2-e)

Year	Soil carbon	Perennial woody crops (biomass)	Total
1990	17,963	-69	17,894
1995	-2,165	-100	-2,265
2000	-8,126	-50	-8,176
2005	893	-162	732
2006	-1,499	-175	-1,674
2007	1,251	36	1,287
2008	2,218	-122	2,096
2009	4,910	-152	4,757
2010	-621	-282	-903
2011	703	-363	340
2012	1,841	-109	1,732
2013	-26	94	68
2014	1,226	36	1,262
2015	-1,410	-83	-1,493
2016	-2,982	-225	-3,207
2017	-2,811	-269	-3,080

6.6.3 Uncertainties and time series consistency

Based on a qualitative assessment the uncertainties for *cropland remaining cropland* were estimated to be medium. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

There are a number of gaps in the time series of *ABS commodities statistics* (ABS, 2016) for perennial woody crops. All data-gaps were filled using extrapolation and interpolation techniques consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

6.6.4 Source specific QA/QC

The calibration, validation and verification of the *FullCAM* model, along with the associated quality assurance and quality control programme are fully described in Appendix 6.B.

Additional category specific QA/QC activities are undertaken on the crop yield database and *cropland remaining cropland* emissions and removal estimates. In relation to crop yields, CSIRO Agriculture and Food has tested the performance of the crop growth model against a database of crop yields (see Appendix 6.E).

The Department of the Environment and Energy also undertakes quality control processes in accordance with the Quality Assurance-Quality Control plan.

6.6.5 Recalculations since the 2016 Inventory

The recalculation of the *cropland remaining cropland* time series is presented in Table 6.39, and an explanation of the key influences on the change in estimates follows:

The method for reporting emissions from soil carbon from *cropland remaining cropland* has been altered. The new approach applies the Managed Land Proxy and is consistent with the other LULUCF sectors. The previous approach calculated the difference between a scenario with human management and a scenario without human management where management activities were held constant at 1990 levels. This difference was used to derive a time series of emissions due to impacts of human management.

A revised time series of climate data at a fine spatial disaggregation has been introduced for *cropland remaining cropland*. This data is prepared by the Australian National University and is due to improved algorithms and increased automation of the quality control tools used to process the raw climate information which generates the final time series data sets.

A revision of land areas across the LULUCF sectors has resulted in a recalculation for the cropland time series reflecting this land-use allocation change.

Crop and pasture activity data for 2015 onwards has been updated to reflect the release by the ABS of the Land Management and Farming 4627.0 2016-17. This publication contains land survey census data including tillage and stubble management for areas under cultivation. Adjustments were also made to existing data to ensure time series consistency due to changes made by the ABS in the categories reported since the previous release.

The fire event within FullCAM has been re-parameterised to more accurately reflect the impact fire has on living biomass and the above- and below-ground debris pools for fire events on crop residues.

The resistant debris pool calculation by FullCAM has been recalibrated to compensate for excessive losses which were previously modelled as occurring in agricultural systems. Debris breakdown rates for both the resistant and decomposable pools have been updated to provide more accurate levels in the resistant debris pools.

The resistant fraction of crops and pastures within FullCAM have been adjusted to match the Roth-C default values. The values used are a ratio of 1.44 for DPM/RPM for agricultural crops and improved grassland, and a ratio of 0.67 for unimproved grassland.

A revision of root:shoot ratios for crops and pasture within FullCAM was undertaken from published literature. Literature reviewed includes Alvery *et al.* (2001), Bolinder *et al.* (2007), Bray (1963), Davidson (1969), Eastam and Rose (1990), Gregory *et al.* (1978), Gregory *et al*, (1997), Hill *et al.* (2006), Hirte *et al.* (2018), Jackson (1996), Johnson *et al.* (2006), Lyu *et al.* (2016), Ma *et al.* (2010), Manschadi *et al.* (2008), Moore and Lawrence (2013), Nahar (2017), Olupot *et al.* (2010), Poepau and Katterer (2017), Rogers *et al.* (1996), Sainju *et al.* (2017), Schlapfer *et al.* (1996), Siddique *et al.* (1990), Smith *et al.* (2005), Steingrobe *et al.* (2001), Wakeel *et al.* (2005), Ward *et al.* (2011), Williams *et al.* (2013).

Table 6.39 *Cropland remaining cropland:* Recalculation of CO_2-e emissions 1990–2016

Year	2018 submission	2019 submission	Change	Reasons for recalculation: A. Revised activity data, FullCAM enhancements and parameter updates	Reasons for recalculation: C. Introduction of the Managed Land Proxy
	(Gg CO_2)	(Gg CO_2-e)	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)
1990	-69	17,894	17,963	0	17,963
1991	-3,189	13,628	16,817	741	16,076
1992	-875	6,498	7,374	-6,336	13,709
1993	21	6,929	6,908	-7,469	14,377
1994	2,165	4,811	2,646	-6,820	9,466
1995	539	-2,265	-2,804	-4,066	1,263
1996	47	-1,998	-2,045	-5,815	3,770
1997	-355	-1,094	-738	-7,948	7,210
1998	1,288	-7,867	-9,155	-6,517	-2,638
1999	-636	-8,513	-7,877	-7,631	-246
2000	368	-8,176	-8,544	-8,837	293
2001	-1,407	-6,656	-5,248	-5,745	496
2002	-2,992	-7,941	-4,949	-6,672	1,723
2003	-2,379	-5,203	-2,824	-6,723	3,899
2004	-1,489	-5,712	-4,223	-5,796	1,573
2005	-4,052	732	4,783	-5,109	9,892
2006	-4,706	-1,674	3,032	-6,995	10,027
2007	-5,029	1,287	6,316	-5,948	12,264
2008	-5,658	2,096	7,754	-4,433	12,187
2009	-6,045	4,757	10,803	-5,045	15,848
2010	-7,037	-903	6,134	-6,321	12,455
2011	-4,732	340	5,072	-4,162	9,233
2012	-4,816	1,732	6,548	-2,969	9,518
2013	-5,530	68	5,598	-3,101	8,699
2014	-5,743	1,262	7,005	-2,920	9,926
2015	-4,969	-1,493	3,476	-3,625	7,102
2016	-4,849	-3,207	1,641	-3,659	5,301

6.6.6 Source specific planned improvements

The handling of the below-ground debris pool within the FullCAM model requires investigation to determine the correct behaviour of the relationship of the Roth-C implementation within FullCAM and changing management practices. Further investigation is planned into the initialisation of the FullCAM model and refinement of the processes to more accurately reflect the measureable carbon soil fractions at any given period in time.

Tillage activities within the FullCAM modelling framework require examination to calibrate the impact that varying tillage practices, such as minimum and no till, have on soil decay functions. Additionally, research will be conducted into options for enabling more accurate modelling of the impacts of management strategies on the entry of crop residues into the soil.

The application of a tier 2 soil carbon model to verify FullCAM outputs for croplands is currently underway with completion intended for the next inventory cycle. Results from the tier 2 model will help drive further work such as the calibration and verification of the carbon flows within the FullCAM framework. Potential areas for research include plant turnover and debris decomposition rates and their rates at the regional level across crop, improved pasture, and native perennial grass lands. Measured sites from the Soil Carbon Research Program (SCaRP) along with additional pasture sites would be used to optimize and run sensitivity analysis to update the FullCAM parameters to better reflect the varying Australian agricultural zones.

6.7 Land converted to cropland (Source Category 4.B.2)

The *land converted to cropland* subcategory includes *forest land converted to cropland* and *wetlands converted to cropland* subcategories.

Net emissions from conversions between croplands and grasslands are included in *croplands remaining croplands* as it is common for cropping systems to include pasture/grazing rotations.

6.7.1 Methodology

6.7.1.1 Forest land converted to cropland

The methodology for the subcategory *forest land converted to cropland* is covered in detail under *forest land converted to grassland* (Section 6.9 below).

6.7.1.2 Wetlands converted to cropland

Areas of *wetlands converted to cropland* were estimated using IPCC Approach 2 using activity data acquired from the 1996 and 2010 Land use of Australia surveys (ABARES *National scale land use data*. Accessed 15 February 2017). Spatial information on final land uses, including grazing on native, improved and irrigated pastures, and cropping, irrigated cropping and perennial horticulture, was used in conjunction with available wetlands spatial data to estimate conversions to cropland.

Following IPCC guidance (Volume 1, Chapter 2.2.3), extrapolation and interpolation methods were used to calculate an average annual rate of conversion of wetlands to cropland over the required time period. The default IPCC time period of 20 years was used for land remaining in transitional categories so that converted lands remain in a transitional category for this period during which time emissions from organic soils continue to be estimated.

With respect to biomass and dead organic matter, only non-woody biomass is assumed to be present in the wetlands prior to conversion - noting that conversions of forested wetlands are already accounted for in the inventory. Therefore the IPCC tier 1 assumption, that no net change in biomass or dead organic matter stocks from conversion of wetlands to cropland occurs, was applied in this model. Consequently only emissions from the drainage of organic soils are estimated. For each state, Equation 2.26 from IPCC 2006 Guidelines Vol 4 was used to estimate those emissions and then aggregated to give the national total:

$$L_{organic} = A \times EF, \text{ where}$$

- $L_{organic}$ = emissions from draining organic soils
- A = area converted
- EF = emission factor

IPCC default emissions factor for cool temperate zones was applied (5 t C / ha / yr - Table 5.6 IPCC 2006 GL, Vol 4), based on expert understanding of wetland ecosystems in areas where such conversions occur.

The activity data for the *forest land converted to cropland* classification is drawn from the remote sensing program (see Appendix 6.A).

Table 6.40 below shows the cumulative areas of *forest land* and *wetlands* that were *converted to croplands* over the period 1990 to 2017.

Table 6.40 Cumulative area of *land converted to cropland* 1990–2017 (ha)

Year	Forest land converted to cropland	Wetlands converted to cropland	Total
1990	1,918,361	12,661	1,931,022
1995	2,056,602	12,661	2,069,263
2000	2,162,194	12,661	2,174,855
2005	2,243,297	12,661	2,255,958
2010	2,276,793	12,661	2,289,454
2011	2,276,808	12,661	2,289,469
2012	2,277,389	12,661	2,290,050
2013	2,278,959	12,661	2,291,619
2014	2,279,309	12,661	2,291,970
2015	2,275,296	12,661	2,287,957
2016	2,275,685	12,661	2,288,346
2017	2,266,956	12,661	2,279,617

6.7.2 Emission estimates

As Table 6.41 below indicates, *forest land converted to cropland* is the dominant contributor to both the level and trend in net emissions in this sub-category.

Table 6.41 Net emissions from *land converted to cropland* by sub-category, 1990–2017 (Gg CO_2-e)

Year	Forest land converted to cropland	Wetlands converted to cropland	Total
1990	19,052	232	19,284
1995	6,289	232	6,521
2000	5,131	232	5,363
2005	4,355	232	4,587
2006	4,919	232	5,152
2007	3,985	232	4,217
2008	3,767	232	3,999
2009	3,527	232	3,759
2010	3,579	232	3,811
2011	2,798	232	3,030
2012	1,558	232	1,790
2013	3,745	232	3,977
2014	3,953	232	4,185
2015	2,311	232	2,543
2016	2,284	232	2,517
2017	1,407	232	1,639

6.7.3 Uncertainties and time series consistency

Uncertainties for *forest land converted to cropland* at the national scale were estimated to be ±27.3 per cent for CO_2. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

Emissions estimated against *wetlands converted to cropland* are reported for the period 1990 to 2016. The current Tier 1 method relies on interpolation and extrapolation with respect to two observational years. ABARES does not report on uncertainty about the land use estimates. However these are likely fall in the medium to high range.

While there is a higher uncertainty *wetlands converted to cropland* than in *forest land converted to cropland,* the former category makes only a small contribution to the overall uncertainty of *land converted to cropland due to its lower emissions.*

6.7.4 Source specific QA/QC

The source specific QA/QC for the subcategory *forest land converted to cropland* is covered in detail under *forest land converted to grassland* (Section 6.9 below).

Quality assurance/quality control measures for *wetlands converted to cropland* involve internal reviews of data entry and model outputs, including a check on the consistency of land use statistics across Australian jurisdictions.

6.7.5 Recalculations

Recalculations for the two sub-categories are presented separately here.

6.7.5.1 Forest land converted to cropland

Table 6.42 provides the recalculation results, including reasons and quantified impacts.

See section 6.9.5 (‘*forest land converted to grassland*’) for descriptions of the updates and improvements to activity data collection and estimation methods/models that underpinned these recalculations.

Table 6.42 *Forest land converted to cropland:* Recalculation of CO_2-e emissions 1990–2016

	Forest land converted to cropland				Reasons for Recalculations			
	2018 submission	2019 submission	Change		A. FullCAM Tree Growth	B. New Geospatial Data	C. Management of Spatial Information	D. Standing Dead
	(Gg CO2 -e)	(Gg CO_2 -e)	(Gg CO_2 -e)	%				
1990	18,603	19,052	449	2.4%	523	-1,159	1,529	-445
1995	6,989	6,289	-700	-10.0%	250	-692	-553	294
2000	12,340	5,131	-7,209	-58.4%	667	41	-8,136	220
2005	12,620	4,355	-8,266	-65.5%	1,190	-833	-8,656	33
2006	11,447	4,919	-6,528	-57.0%	517	-973	-6,108	37
2007	10,509	3,985	-6,524	-62.1%	1,042	-1,342	-6,264	40
2008	8,316	3,767	-4,549	-54.7%	-105	-912	-3,629	97
2009	6,954	3,527	-3,426	-49.3%	305	-963	-2,857	89
2010	7,063	3,579	-3,484	-49.3%	752	-1,452	-2,838	54
2011	6,630	2,798	-3,832	-57.8%	-413	-895	-2,597	72
2012	6,178	1,558	-4,621	-74.8%	1,363	-595	-5,478	89
2013	6,909	3,745	-3,165	-45.8%	74	-454	-2,858	73
2014	6,773	3,953	-2,820	-41.6%	23	-497	-2,373	27
2015	5,499	2,311	-3,189	-58.0%	122	-411	-2,938	38
2016	6,017	2,284	-3,732	-62.0%	495	-1,237	-2,965	-25

6.7.5.2 Wetlands converted to cropland

There is no recalculation for *wetlands converted to cropland* over the period 1990 to 2016. Table 6.43 is a comparison of the 2019 and 2018 submissions.

Table 6.43 *Wetlands converted to cropland:* Comparison of the 2019 submission to the 2018 submission for CO_2-e emissions 1990–2016

Year	2018 submission	2019 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)
1990	232.1	232.1	0.0	0.0%
1995	232.1	232.1	0.0	0.0%
2000	232.1	232.1	0.0	0.0%
2005	232.1	232.1	0.0	0.0%
2006	232.1	232.1	0.0	0.0%
2007	232.1	232.1	0.0	0.0%
2008	232.1	232.1	0.0	0.0%
2009	232.1	232.1	0.0	0.0%
2010	232.1	232.1	0.0	0.0%
2011	232.1	232.1	0.0	0.0%
2012	232.1	232.1	0.0	0.0%
2013	232.1	232.1	0.0	0.0%
2014	232.1	232.1	0.0	0.0%
2015	232.1	232.1	0.0	0.0%
2016	232.1	232.1	0.0	0.0%

6.7.6 Source specific planned improvements

The source specific planned improvements for the subcategory *forest land converted to cropland* is covered in detail under *forest land converted to grassland* (Section 6.9 below).

Planned improvements are underway to develop a fully spatially explicit timeseries of land-use maps that will improve reporting of activity data and emissions for *wetlands converted to cropland*.

6.8 Grassland Remaining Grassland (Source Category 4.C.1)

The *grassland remaining grassland* category includes all areas of *grassland* that are not reported under *land converted to grassland*. Areas that are in rotational use between *grassland* and *cropland* are reported under either *forest land converted to cropland* or *cropland remaining cropland*.

There are three components of the *grassland remaining grassland* emission estimates – the grasslands component, the shrubland transitions component and the carbon dioxide emissions and post fire removals associated with burning of northern, central Australian and temperate grasslands. Shrublands are areas of woody vegetation that are not, by definition, 'forest'. Shrublands are typically sparse tree and shrub formations and are not separable into areas made up of uniquely tree or shrub plant types.

Anthropogenic emissions and removals on grasslands result from changes in management practices on grasslands, particularly from changes in pasture, grazing and fire management; changes in woody biomass elements and from changes in land use.

Permanent changes in management practices generate changes in the levels of soil carbon or woody biomass stocks over the longer term. The national inventory does not record the new carbon stock levels directly, but it is affected during the transition from one carbon stock level to another from changes in the flow of carbon to and from the land. These effects on the national inventory are transitory and are not permanent and, after a time (25 years), the rate of net emissions or removals associated with the changed management practice will approach zero.

The distribution of land areas in the *grassland remaining grassland* sub-category is estimated using the ABARES Catchment Scale Land Use of Australia 2017 at the mapping scale of 1:5000 to 1:250 000. The subset of areas of *grassland remaining grassland* that were shrub vegetation was established by the methods described below. The area that was only grasses was established by removing the areas of shrubland from the total *grassland remaining grassland* area.

6.8.1 Methodology

Carbon dioxide emissions from the *grassland remaining grassland* category are estimated using a mix of methods. The grasslands (grass only) component is estimated using *FullCAM* (Appendix 6.B), while the shrubland transition component and CO_2 emissions and removals associated with grassland fires are estimated using the Tier 2 methods outlined below.

6.8.1.1 Pasture

Emissions and removals for the pasture (grasslands) component are estimated using Tier 3, Approach 3 in *FullCAM*.

Anthropogenic emissions and removals from grasslands are estimated from changes in specified management practices including:

- the area under grasslands;
- pasture management from fertilisers, irrigation and other inputs and seed selection;
- the area under grazing and changes in grazing intensity;
- woody biomass management; and
- fire management.

FullCAM estimates emissions from all on-site carbon pools (living biomass, dead organic matter (DOM) and soil). For the herbaceous grass component only the changes in the soil pool are reported. Carbon stock changes from living biomass and DOM of non-woody annual crops are reported to be zero, consistent with the guidance in *2006 IPCC Guidelines for National Greenhouse Gas Inventories* that indicates that the increase in biomass stocks in a single crop year may be assumed equal to biomass losses from harvest and mortality in that year – thus there is no net accumulation of biomass carbon stocks for non-woody biomass.

Stratification of grasslands

There are two main agro-ecological categories in grasslands:

- native arid grasslands which comprise sparse woody vegetation and woodlands, and remain as primarily native grasses; and
- high rainfall improved pastures.

The key management practices relevant to estimating changes in carbon stocks in the high rainfall pastures include: grazing intensity; pasture composition; fertiliser and organic amendments; and irrigation. For the native arid and semi-arid grasslands, the key drivers include grazing intensity, fire management and the presence of woody vegetation.

Stratification of grasslands is undertaken based on climate and vegetation type. For the high rainfall pastoral regions, where cropping also occurs, the impacts of pasture composition and fertiliser and irrigation have been modelled (Appendix 6.E). In the arid rangelands areas it is assumed that these lands have remained native pastures and as such no stock changes are identified on these lands.

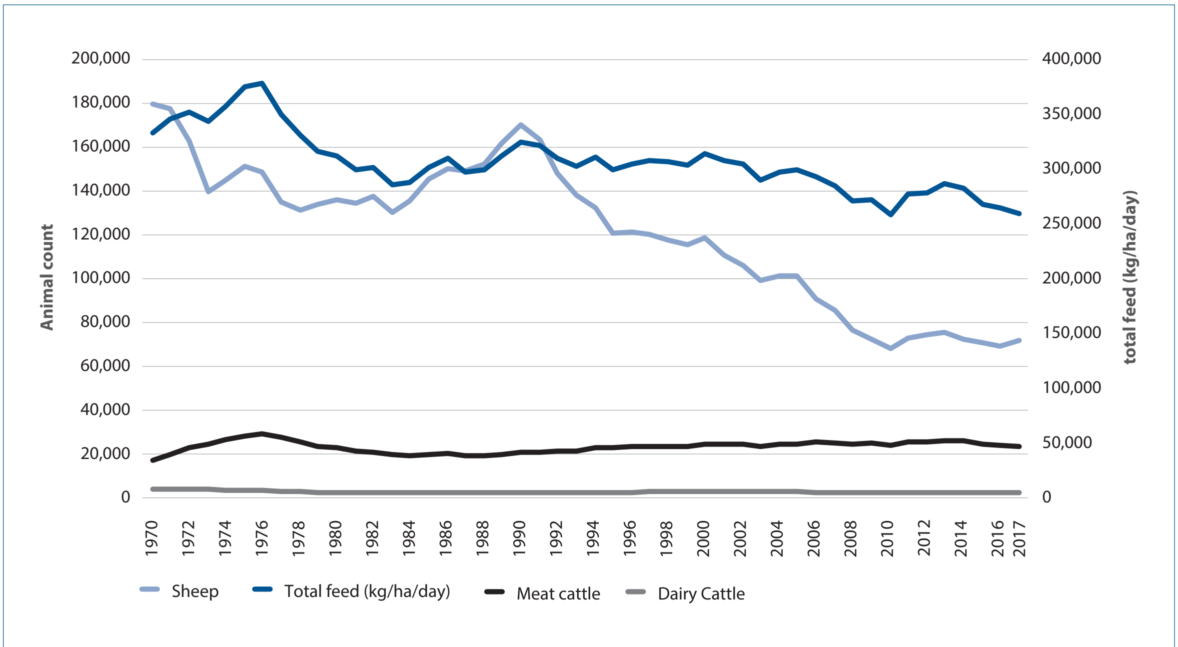
Data

Initial soil carbon values are taken from the baseline map of soil organic carbon (Viscarra-Rossel *et al.*, 2015) – see Appendix 6.E.

Management practice change has been monitored in the ABS Land Management and Farming 4627.0 which provides information on management practices being adopted and utilised by Australian agricultural business. Further details on changes in management practices are provided in Appendix 6.E.

Grazing pressure for each ABS Statistical Area 2 region across Australia has derived from the ABS Commodity Statistics (Figure 6.26a).

Figure 6.26a Grazing pressure by animal type Australia, 1970-2017

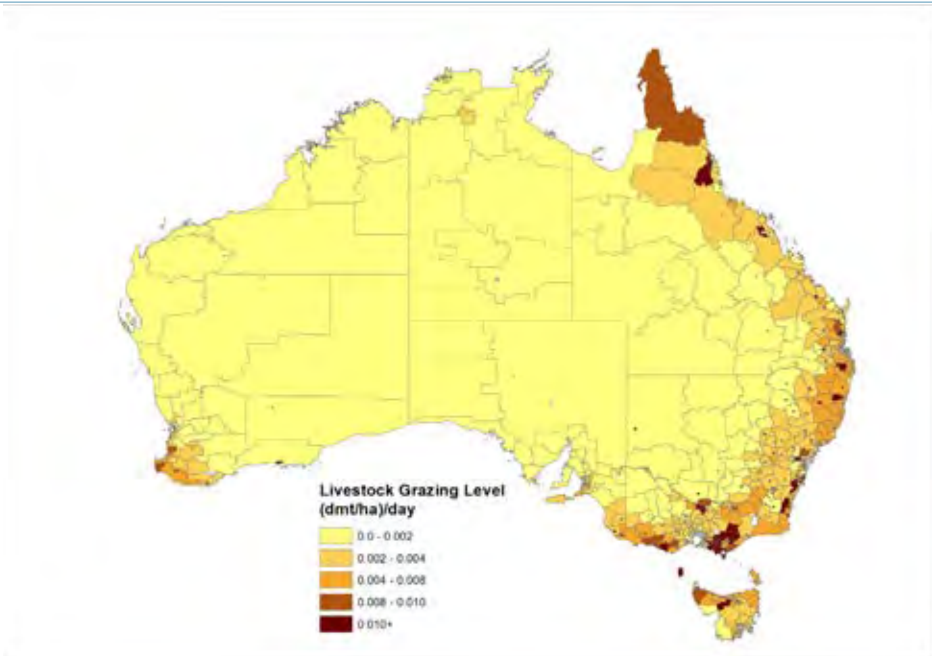


Published beef cattle, dairy cattle, and sheep population and age data from the Australian Bureau of Statistics Agriculture Commodities (ABS 2017) were used to derive average feed amounts for these livestock types. This data is combined to calculate the grazing pressure for each Statistical area 2 (SA2) which is then inserted into the *FullCAM* model as tonnes per hectare of standing dry matter eaten per day.

With respect to unmanaged grazing by native and feral animals such as kangaroos, published data from the Department of the Environment and Energy (DoEE 2011) is used to determine the grazing pressure for each State of Australia.

The combination of both managed and non-managed grazing values are applied to grasslands. For croplands the managed grazing method is applied to pasture lands in a crop rotation. Figure 6.26b shows the spatial distribution and levels of biomass eaten in 2010.

Figure 6.26b Livestock grazing pressure levels for Australia (2010) at the SA2 level: tonnes dry matter per hectare of pasture per day

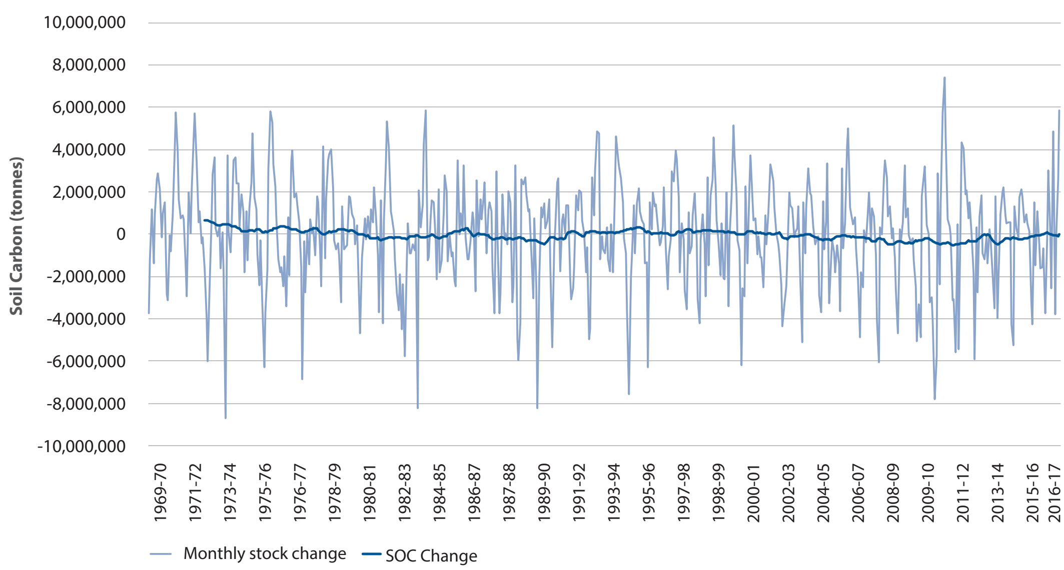


Additional details on data sources for changes in management practices are provided in Appendix 6.E.

Methods

The estimation of emissions from soil carbon from *grassland remaining grassland* is modelled in the same way as for *cropland remaining cropland*. See the discussion on the methodology for herbaceous crops in section 6.6.1.

Figure 6.26c Carbon stock change from *grassland remaining grassland*, 1970-2017



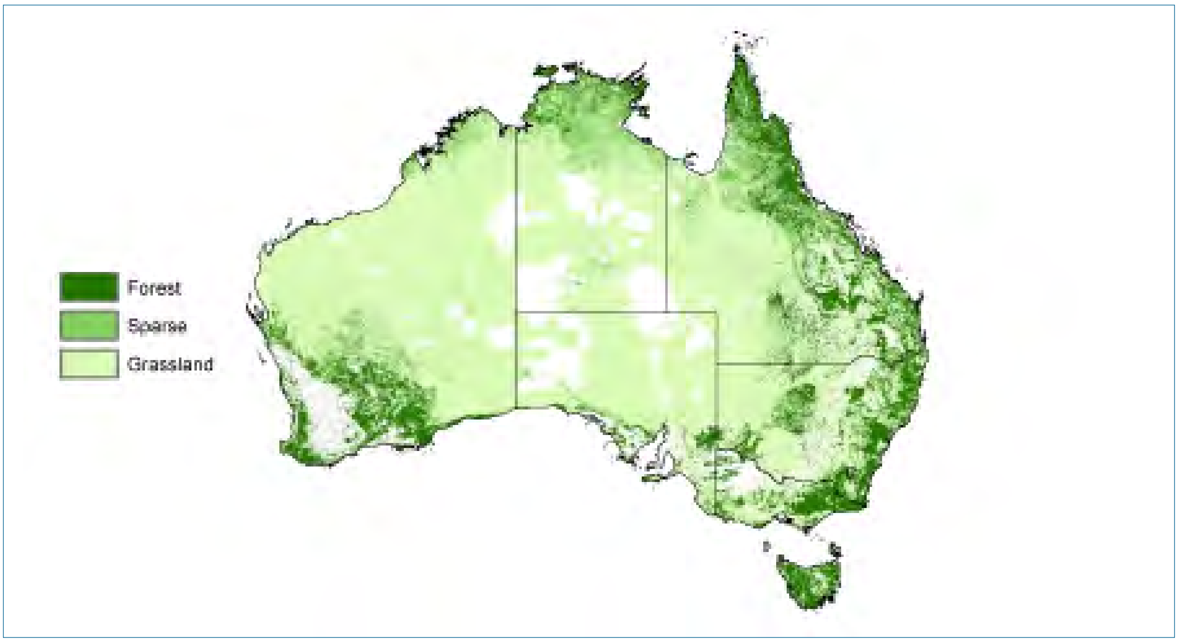
6.8.1.2 Grass and shrub transitions

To supplement the forest extent mapping, a national mapping programme has been completed to assess both the extent, and changes in extent, of sub-forest forms of woody vegetation using the Landsat TM, ETM+ and OLI data for the years from 1988 to 2018 (Caccetta and Furby, 2004). This method builds on the 2-class (forest and non-forest) time series CPN classification technique, by incorporating an additional spatial texture measure to distinguish between the sparse woody vegetation cover (5-7 per cent to <20 per cent canopy cover) and the forest cover (> 20 per cent canopy cover). Figure 6.27 shows the extent of sparse vegetation in Australia.

Data on sparse woody vegetation extends for the period from 1988 to 2016, except for two interior rangeland tiles, for which current sparse woody coverage is limited to 2006. For the period 1970-1985, the net gain in area of sparse woody vegetation has been backcast using the El Niño Southern Oscillation index (Bureau of Meteorology) as a proxy variable.

To estimate the change in shrub biomass due to the change in shrub area, the net annual change in area was placed in a Tier 2 model. The model uses an average woody biomass of 10 t DM ha^{-1} (Raison *et al.,* 2003) and presumes a linear loss of that amount over a period of twenty years. At the time of disturbance, lands have been subject to a mix of regular cyclic clearing, on around a 15 year cycle (Fensham *et al.,* 2012), grazing management practices (Department of Agriculture and Fisheries, Queensland Government 2012) and natural disturbances such as drought and pests. Where the area of sparse vegetation increases it is assumed that these will regrow to 10 t DM ha^{-1} over twenty years (i.e. a growth rate of 0.5 t DM ha^{-1} yr^{-1}) (Fensham *et al.*, 2012 and Witt *et al.*, 2011).

Figure 6.27 Extent of sparse woody vegetation



6.8.1.3 Carbon stock changes in dead organic matter

Emissions and removals from the DOM pool (associated with the burning and subsequent regrowth) are modeled using the same methods, factors and data as described for *other native forests* reported in *forest land remaining forest land* (section 6.4.1.3).

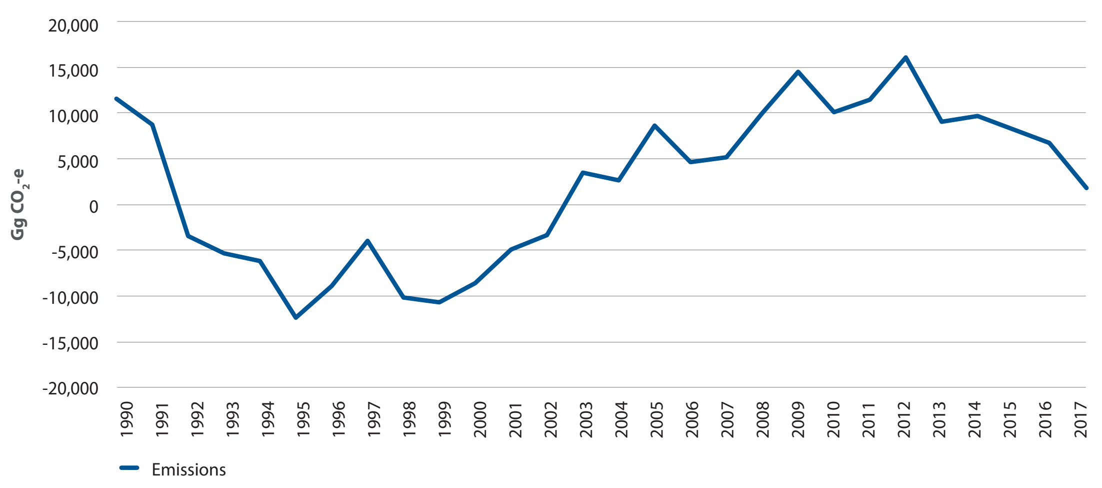
6.8.2 Emission estimates

Emission estimates for the components of *grassland remaining grassland* are reported in Table 6.44.

Table 6.44 Emissions and removals from *grassland remaining grassland*, by sub-category 1990–2017 (Gg CO_2-e)

Year	Herbaceous grasslands	Perennial woody biomass		All
	Soil Carbon and Nitrogen mineralisation and run-off	Live biomass (Sparse Transitions)	Dead organic matter (non-temperate fire)	
1990	12,040	-5,035	3,635	10,640
1995	-12,088	-179	5,9894	-6,277
2000	-8,484	1,119	12,310	4,945
2005	9,061	3,282	4,988	17,331
2006	5,038	3,076	8,474	16,588
2007	5,520	2,819	9,451	17,790
2008	10,405	2,178	7,172	19,755
2009	15,130	-459	8,403	23,074
2010	10,635	-2,838	7,460	15,257
2011	11,937	-4,871	6,109	13,174
2012	16,828	-6,187	5,363	16,005
2013	9,514	-5,881	5,852	9,486
2014	10,075	-5,930	4,961	9,106
2015	8,496	-5,447	3,797	6,845
2016	7,054	-5,690	3,877	5,241
2017	1,998	-6,049	5,403	1,352

Figure 6.28 Net CO_2-e emissions from soils in *grassland remaining grassland*, 1990–2017



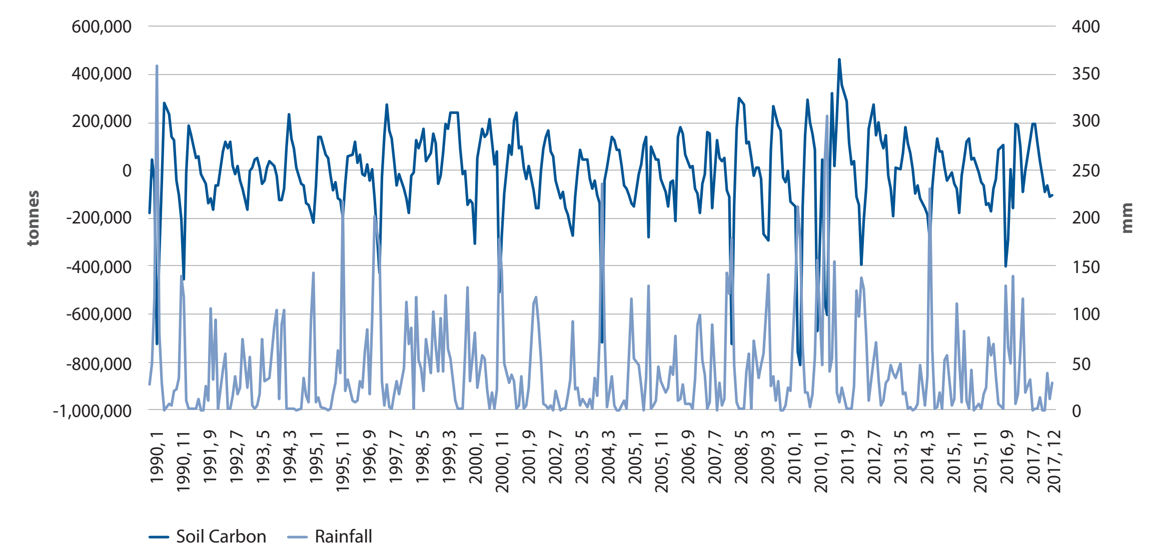
6.8.3 Uncertainties and time series consistency

Based on a qualitative assessment the uncertainties for *grassland remaining grassland* were estimated to be medium. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

6.8.4 Source specific QA/QC

The impact of climate data on soil carbon change in pasture lands as simulated in FullCAM has been analysed to assure consistency with modelling expectations. The climate inputs (temperature, rainfall and open-pan evaporation) for selected regions and states have been verified against model outputs as seen below in Figure 6.29.

Figure 6.29 Barcaldine SA2 region, soil carbon stock change charted against rainfall inputs in FullCAM



The QA/QC of the activity data for detecting gains and losses of woody vegetation is described in Appendix 6.A.4.

The fire affected area data for the shrubland component is collated and quality assured by Western Australian Land Authority (Landgate) before being received by the Department of the Environment and Energy.

6.8.5 Recalculations since the 2016 Inventory

Table 6.45a and 6.45b below provide the recalculation results, including reasons and quantified impacts.

A. Changes in pasture management

The method for reporting emissions from soil carbon from *grassland remaining grassland* has been altered. The new approach estimates emissions from carbon stock gains or losses using the Managed Land Proxy and is consistent with the approach for other LULUCF sectors and IPCC guidelines. The previous approach calculated the difference between a scenario with human management and a scenario without human management where management activities were held constant at 1990 levels. This difference was used to derive a time series of emissions due to impacts of human management alone.

A revised time series of climate data at a fine spatial disaggregation prepared by the Australian National University has been introduced for *grassland remaining grassland*. This is due to improved algorithms and increased automation of the quality control tools used to process the raw climate information which generates the final time series data sets.

A revision of land areas across the LULUCF sectors has resulted in a recalculation for the *grassland remaining grassland* time series reflecting this land use allocation change.

To ensure time series consistency the existing pasture species activity data has been linearly interpolated between known data points (Appendix 6.E.3).

Regional specific carbon use efficiency has been incorporated for the first time for *grassland remaining grassland* (Appendix 6.B.5.2). These efficiency values are derived from the calibration of the FullCAM model for grasslands (Appendix 6.B.6.1).

The fire event within FullCAM has been re-parameterised to more accurately reflect the impact fire has on living biomass and the above and belowground debris pools for fire events within pasture lands.

The resistant debris pool calculation by FullCAM has been recalibrated to compensate for excessive losses which were previously occurring in agricultural systems. Debris breakdown rates for both the resistant and decomposable pools have been updated to provide more accurate levels in the resistant debris pools.

The resistant fraction pools for crops and pastures within FullCAM have been adjusted to match the Roth-C default values. The values used are a ratio of 1.44 for DPM/RPM for agricultural crops and improved grassland, and a ratio of 0.67 for unimproved grassland.

A revision of root-shoot ratios for crops and pasture was undertaken from published literature. Literature reviewed includes Alvery *et al.* (2001), Bolinder *et al.* (2007), Bray (1963), Davidson (1969), Eastam and Rose (1990), Gregory *et al.* (1978), Gregory *et al*, (1997), Hill *et al.* (2006), Hirte *et al.* (2018), Jackson (1996), Johnson *et al.* (2006), Lyu *et al.* (2016), Ma *et al.* (2010), Manschadi *et al.* (2008), Moore and Lawrence (2013), Nahar (2017), Olupot *et al.* (2010), Poepau and Katterer (2017), Rogers *et al.* (1996), Sainju *et al.* (2017), Schlapfer *et al.* (1996), Siddique *et al.* (1990), Smith *et al.* (2005), Steingrobe *et al.* (2001), Wakeel *et al.* (2005), Ward *et al.* (2011), Williams *et al.* (2013).

B. Change in live biomass

Activity data for grass and shrub transitions has been revised due to annual updates in image analysis and expanded national coverage. The FullCAM simulation software is now being utilised to ensure that the derived dates of transition between satellite imagery passes are more consistent with those derived for forest conversions.

Table 6.45a *Grassland remaining grassland*, soil carbon from pasture lands: Recalculation of CO_2-e emissions 1990–2016

	2018 submission	2019 submission	Change	Reasons for recalculation: A. Revised activity data, FullCAM enhancements and parameter updates	Reasons for recalculation: C. Introduction of the Managed Land Proxy
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)
1990	0	11,547	11,547	0	11,547
2000	-7,960	-8,606	-645	-4,846	4,201
2005	1,303	8,594	7,292	-5,239	12,530
2006	768	4,687	3,919	-16,259	20,178

	2018 submission	2019 submission	Change	Reasons for recalculation: A. Revised activity data, FullCAM enhancements and parameter updates	Reasons for recalculation: C. Introduction of the Managed Land Proxy
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)
2007	-35	5,189	5,224	-2,059	7,283
2008	675	9,963	9,288	-5,519	14,808
2009	-4	14,563	14,567	-8,716	23,283
2010	-4,262	10,153	14,416	3,239	11,177
2011	843	11,431	10,588	-3,602	14,189
2012	-3,773	16,141	19,914	1,570	18,344
2013	-4,203	9,102	13,305	455	12,850
2014	41	9,708	9,667	775	8,892
2015	1,895	8,196	6,300	-14,822	21,122
2016	-120	6,749	6,869	-1,448	8,317

Table 6.45b *Grassland remaining grassland*: Recalculation of CO_2-e emissions 1990–2016

	2018 submission	2019 submission	Total Change	Reasons for recalculation: A. Soil Carbon and Nitrogen mineralisation and run-off*	Reasons for recalculation: B. Live biomass (Sparse Woody Transitions)	Reasons for recalculation: C. Dead organic matter (non-temperate fire management)
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)
1990	2,001	10,640	8,639	9,039	-1,348	948
2000	5,890	4,945	-945	-3,003	-673	2,731
2005	12,999	17,331	4,332	5,818	-826	-660
2006	16,152	16,588	436	1,490	-871	-184
2007	14,551	17,790	3,240	3,474	-619	385
2008	10,864	19,755	8,891	7,426	798	667
2009	8,133	23,074	14,940	12,823	551	1,566
2010	1,694	15,257	13,563	11,596	181	1,786
2011	5,105	13,174	8,069	6,357	-58	1,771
2012	-4,766	16,005	20,771	19,141	-250	1,879
2013	-4,200	9,486	13,687	12,337	-392	1,742
2014	3,908	9,106	5,198	6,632	-558	-875
2015	2,892	6,845	3,953	4,521	-515	-53
2016	1,684	5,241	3,557	5,523	-385	-1,581

* Note: Includes soil carbon emissios data in Table 6.45a

6.8.6 Source specific planned improvements

Further refinement is planned to the spatial grazing model with the goal of modelling more diverse animal species such as feral camels and wild horses, and the improved calibration of grazing management data in the ABS Agricultural Commodities against the CSIRO pasture yield model

The incorporation of MODIS fractional cover is planned to be included as a temporal series into FullCAM to inform total biomass cover. It is proposed to utilise this vegetation area data as a means to remove area always deemed bare (bare ground, rock, disturbed).

The handling of the belowground debris pool within the FullCAM model requires investigation to determine the correct behaviour of the relationship of the Roth-C implementation within FullCAM and changing management practices. Further investigation is planned into the initialisation of the FullCAM model and refinement of the processes to more accurately reflect the measureable carbon soil fractions at any given period in time.

Refine and improve the methodology for modelling grazed cereals. Grazed cereals are currently treated as a pasture species within the *grassland remaining grassland* simulation model. Work will be conducted to carry over the parameters from within *cropland remaining cropland* which will more accurately model the biomass levels available for the cereals species.

The integration of spatially explicit data for grasslands for Northern Australia pasture lands. A digitised map of these grassland regions (Tothill and Gillies (1992)) will be used as an input into FullCAM to provide spatial information on where species grow. See Figure 6.E.9.

Further development of the sparse transitions model is planned. For changes in live biomass, the FullCAM modelling system is to be further developed to utilize the spatial information on transitions in sparse woody vegetation and to better calculate carbon stock changes. Growth and decay models will be further developed, exploring options of non-linear transitions and region-specific biomass volumes. This will advance this subcategory to a tier 3 model by taking advantage of information about the distribution of tree species currently used for simulating forests.

6.9 Land converted to grassland (Source Category 4.C.2)

The *land converted to grassland* category includes *forest land converted to grassland* and *wetlands converted to grassland* subcategories.

There are two types of land use changes accounted for in *forest land converted to grassland*.

The first is where forest is cleared and then maintained as *grassland*. When the land use subsequent to a forest conversion is *grassland* only (i.e., no crops), associated emissions are reported under *forest land converted to grassland*. Lands which are managed under a crop-pasture rotation, or just cropping activity, are reported under *forest land converted to cropland*.

The second type of land use change is where forest is cleared, but then there is regrowth, which may or may not be followed by re-clearing of woody regrowth. Prior to the 2016 Inventory Report, the net emissions on this land had been reported under *forest land converted to grassland*. However since the 2016 Inventory report, in accordance with an ERT recommendation, the carbon removals associated with regrowth are reported in the *grassland converted to forest land* category (section 6.5).

For example, the historical emissions and removals from land which has been monitored as being forest in 1972, cleared and converted to grassland in 1984, and on which vegetation subsequently re-grew to become forest after 1994 and remains forested in 2016 are reported as follows:

- Direct emissions associated with the forest clearance and conversion, and ongoing net emissions associated with the land conversion until 1994, are reported under *forest land converted to grassland*.
- Removals associated with the post-1994 regrowth are reported separately under *land converted to forest*.

The net emissions associated with harvesting of forest for timber are reported under *forest land remaining forest land* (as harvesting does not constitute a permanent land use change), unless a subsequent land use change occurs.

The net emissions associated with fires are reported under *forest land remaining forest land* (as fire does not constitute a permanent land use change), unless a subsequent land use change occurs.

The net emissions associated with the clearing of orchards are reported under *cropland* (as orchards are not defined as forests in the Australian inventory).

The net emissions from the clearing of sparse woody vegetation are reported under *grassland* (as sparse woody vegetation does not meet the definition of a forest in the Australian inventory).

6.9.1 Methodology

6.9.1.1 Forest land converted to grassland

The areas of forest conversion are identified and allocated to the *grassland* sub-category as described in section 6.3. Emissions and removals from *forest land converted to grassland* (and *other land uses*) are estimated using the Approach 3, Tier 3 *FullCAM* as described in Appendix 6.B. The reporting includes all carbon pools (living biomass, dead organic matter (DOM) and soil) other than the agricultural debris of perennial grasses. The model runs in a mixed configuration (i.e., both forest and agricultural systems) using the *CAMFor, CAMAg* and *Roth-C* sub-models. (Table 6.46 below shows the *FullCAM* configuration for modelling emissions and removals for this sub-category).

N_2O emissions from disturbance associated with land-use conversion to cropland and *grassland* are estimated using the methods described in section 6.18.2. Other non-CO_2 emissions that are not related to biomass burning from these lands are reported in the *Agriculture* sector.

Table 6.46 *FullCAM* configuration used for the *forest land converted to cropland* and *grassland* sub-categories

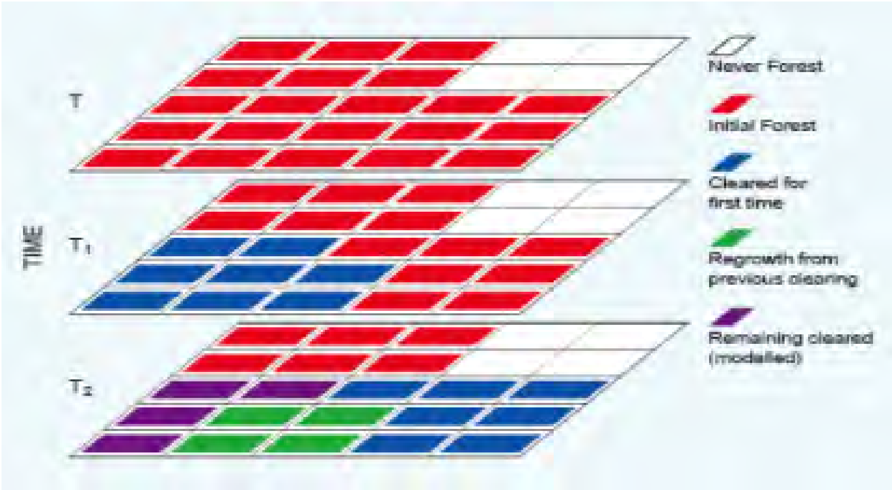
Component	Forest	Agriculture
Living biomass	CAMFor – Forest Productivity Index and Tree Yield Formula	CAMAg – Crop and pasture growth sub-models
Dead organic matter	CAMFor	CAMAg
Soil carbon	Roth-C	Roth-C
Offsite products	NA	NA

Entry of lands into forest land converted to grassland, cropland and settlements sub-categories

The fundamental analytic unit of Tier 3, Approach 3 land sector reporting in Australia is the land cover change pixel (25 m × 25 m) derived from the satellite remote sensing programme. Beginning in 1972, land clearing events are detected through the remote sensing programme. The first time a land clearing event is detected for a pixel, the pixel becomes 'active'. For each year after 1972, an extra set of active pixels which represent new land clearing events, are added to the previously accumulated set of active pixels. Therefore, in any given year, there will be three classes of forest pixels represented as shown in Figure 6.30.

The first class of forest pixel is 'inactive' (red). This means that the forest cover has not been subject to a land clearing event since 1972 and is not in the model. The second class of forest pixel is 'active for the first time'. This means that the forest on that pixel has undergone a land clearing event in the current year (T_1, blue). The pixel now triggers the initiation of *FullCAM* for the quantification of emissions. *FullCAM* calculates the emissions and removals on that pixel from the moment that the pixel becomes active and the tracking continues each year into the future (T_2, purple and green). These active pixels may remain cleared (purple) or may temporarily regrow some forest cover as part of a cyclic clearing/re-clearing management system (green).

Figure 6.30 Diagram representing the spatially explicit approach for estimating forest land conversion sub-categories



Modelling emissions and removals

Once lands enter the conversion category through a land clearing event, based on activity data, *FullCAM:*

- Randomly allocates date of clearing between the two dates of satellite images
- Obtains site, climate, management and initial assumed biomass (see Appendices 6.B to 6.E) data for that pixel from a series of spatial grids and databases
- Begins to model changes in living biomass, debris and soil carbon pools associated with the change in forest cover; and
- Sums the estimates for each pixel each year to estimate the emission/removals.

Where the forest has regrown after clearing (as identified from the remote sensing, other than on flooded lands), FullCAM begins to regrow the forest. The removals associated with this regrowth are reported under land converted to forest (section 6.5). Where this regrowth is subsequently re-cleared, the biomass at re-clearing is based on actual age (through identification of time since regrowth). The emissions associated with the re-clearing along with the subsequent emissions and removals on the converted land are reported under the relevant forest converted to *cropland, grassland or settlements* sub-category.

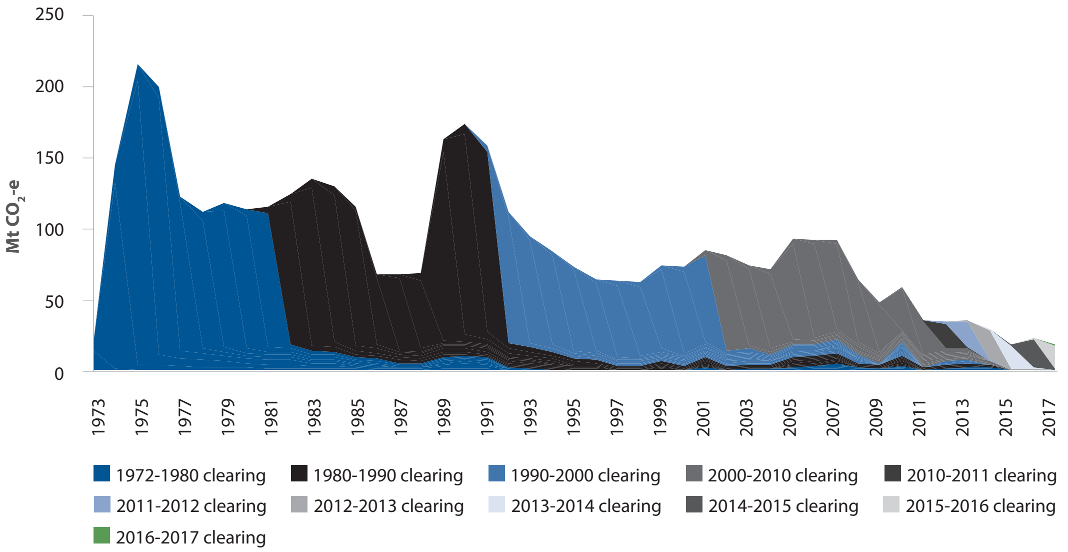
Estimating lagged emissions

Lagged emissions are emissions in any given year that result from a land clearing event in previous years. These lagged emissions are associated with the decay of DOM and soil carbon. As land remains in the conversion category for 50 years from the time of the initial clearing event, any lagged emissions are reported in the years subsequent to the clearing event.

The lagged emissions profile in Figure 6.31 shows that the greatest impact of lagged emissions on overall emissions estimates occurs within the first two years following a land clearing event (n.b. 2012 to 2014).

After 50 years, these forest conversion lands and their associated emissions/removals will be reallocated to the land remaining sub-categories.

Figure 6.31 Tier 3 FullCAM outputs for *forest land converted to cropland and grassland* showing emissions due to past clearing



Estimating changes in biomass

The initial forest biomass and subsequent forest re-growth is estimated using the approaches outlined in Appendices 6.B to 6.D and the parameters described below. The parameters needed to model the subsequent crop and pasture are detailed in Appendix 6.B.

Tree partitioning

The ratios used to partition biomass to the different tree components (Table 6.47) are drawn from a synthesis of available data compiled by Paul *et al.* (2017), with this partitioning varying as the stand matures, and being different for different forest types based on their typical productivity.

Table 6.47 Example of the different partitioning of biomass between the tree components under different types of major vegetation group (MVG). Estimates are for mature stands of assumed stand age 100 years.

Forest Type	Fraction of biomass allocated to:					
	Stems	Branches	Bark	Leaves	Coarse roots	Fine roots
Rainforest	0.43	0.21	0.12	0.05	0.16	0.02
Eucalyptus open forests	0.41	0.20	0.11	0.06	0.19	0.03
Eucalypt open woodlands	0.29	0.20	0.07	0.12	0.27	0.08
Acacia forest and woodland	0.28	0.20	0.07	0.12	0.25	0.09

The carbon content of various tree components (Table 6.48) are drawn from an analysis of a range of species across a range of environments by Gifford (2000a, 2000b).

Table 6.48 Carbon content of tree components – *forest conversion categories*

Tree Component	Carbon Content (fraction of dry matter)
Stems	0.50
Branches	0.47
Bark	0.49
Leaves and Twigs	0.52
Coarse Roots	0.50
Fine Roots	0.48

Estimating changes in debris (dead organic matter or DOM)

Turnover rates impact predictions of inputs to DOM under regenerating forests. But under simulations of both permanently cleared and regenerated forests, decomposition of DOM will be important. The rates of turnover and decomposition (Tables 6.49 and 6.50a and 6.50b) were based on a recent review by Paul *et al.* (2017).

Table 6.49 Tree component turnover rates

Tree component	Turnover % month^{-1}
Branches	0.74
Bark	0.41
Leaves of forests (and woodlands or shrublands)	2.96 (and 1.28)
Coarse Roots	0.87
Fine Roots	12.55

Note that FullCAM calculations of turnover were simplified since the previous report (redundant exponential function removed), thereby requiring an update in the units for reporting turnover. These changes resulted in no recalculations as values provided here for application in the revised version of FullCAM provide the same predictions of turnover as obtained when defaults previously reported were entered into the previous version of FullCAM.

Table 6.50a Decomposition rates for debris pools used in the forests model

Standing Dead component	Breakdown % month^{-1}
Stem	0.83
Branch	0.83
Bark	1.25
Foliage	1.67

Table 6.50b Decomposition rates for debris pools used in the forests model

Debris component	Breakdown (% month $^{-1}$)
Deadwood	1.25
Bark litter	1.44
Leaf litter, decomposable*	100
Leaf litter, resistant*	2.70
Coarse dead roots	2.93
Fine dead roots	100

*The fraction of leaf litter that was resistant was 77 per cent.

Note that FullCAM calculations of debris breakdown rates were simplified since the previous report (redundant exponential function removed), thereby requiring an update in the units for reporting breakdown. These changes resulted in no recalculations as values provided here for application in the revised version of FullCAM provide the same predictions of decomposition of debris as obtained when defaults previously reported were entered into the previous version of FullCAM.

Forest residue management

For each MVG, initial pools of debris just prior to clearing were based on equilibrium simulations of mature forests, with these simulations being undertaking in regions which typify their productivity. Post-clearing, the pools of live biomass are transferred to the DOM pools.

The principal methods of forest conversion involve the extraction of root material (e.g., tree pulling) to allow for subsequent cultivation for pasture and cropping.

Tree pulling usually involves forming 'wind rows' for subsequent burning. Burning of wind rows follows a period of curing (drying), but combustion is still not always complete. FullCAM has been developed to accommodate these processes by implementing a delayed burning, with subsequent decomposition of residual material remaining post-burn. The residual decomposing pool is 'standing dead' of relatively slow decomposition rates (Paul and Roxburgh, 2018b). The standing dead residues burnt is set at 98 per cent, leaving 2 per cent to subsequently decompose on-site. The predictions of post-clearing residues draws upon work by Murphy et al. 2002; Griffin *et al.* 2002; Harms and Dalal, 2003; Harms *et al.* 2005 and Mackensen and Bauhus, 1999. Of residues burnt post-clearing, combustion efficiencies were set at 90% for deadwood, 95 per cent for bark, 95 per cent for leaf litter, 80 per cent for coarse dead roots, and 70% for fine roots (Paul and Roxburgh 2018b).

Estimating changes in soil carbon

A full description of the soil carbon model (*Roth-C*) and the parameterisation of the model are provided in Appendix 6.B.

Parameters governing the input of carbon to the soil following the decomposition of DOM are the fractions of decomposed DOM that is lost as CO_2 to the atmosphere (CO_2-C). The remaining decomposed DOM that is not lost as CO_2-C is predicted to enter the pools of soil C. Values for these parameters calibrated using forest soil carbon studies as described by Paul *et al.* (2017).

Fires

Carbon dioxide emissions from on-site burning associated with land conversion are estimated using *FullCAM* and are reported under sub-categories 4.B.2, 4.C.2, 4.D.2 and 4.E.2. The mass of carbon burnt annually (FC_{jk}) is a *FullCAM* output and is used to estimate the non-CO_2 gases associated with burning (4V).

There are no direct measurements of trace gas emissions from the burning of cleared vegetation in Australia. However, it is considered that these fires will have similar characteristics to hot prescribed fires and wildfires (Hurst and Cook 1996).

The algorithms for total annual emissions of CH_4, CO and NMVOCs are:

$$E_{ijk} = FC_{jk} * EF_{ijk} * C_i \quad (4.C.2\_1)$$

and for total annual emissions for NO_x and N_2O are:

$$E_{ijk} = FC_{jk} * NC_{jk} * EFi_{jk} * C_i \quad (4.C.2\_2)$$

Where FC_{jk} = annual fuel carbon burnt in land conversion (Gg),

EF_{ijk} = emission factor for gas *i* from vegetation (Table 6.K.10-6.K.12),

NC_{jk} = nitrogen to carbon ratio in biomass (Appendix 6.K.9)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Appendix 6.K.9).

Carbon dioxide emissions and removals associated with the burning and subsequent regrowth of northern, central Australian grasslands which occur on *land converted to grassland* are reported under sub-category 4.C.2. The method applied is the same as that for *grassland remaining grassland* fires (section 6.8.1.3).

6.9.1.2 Wetlands converted to grassland

The methodology for activity data collection and modelling of emissions and removals is similar to that underpinning estimates for *wetlands converted to croplands*. As such, this methodology is covered in detail in section 6.7.1.

The activity data for the *forest land converted to grassland* classification is drawn from the remote sensing program (see Appendix 6.A), and that for the *wetlands converted to grassland* classification comes from the 1996 and 2010 Land use of Australia surveys, to which extrapolation and interpolation methods were applied to calculate an average annual rate of conversion (see Section 6.7.1). Table 6.51 shows cumulative areas for *land converted to grassland* over the period 1990-2015.

Table 6.51 Cumulative area of *land converted to grassland* 1990–2017 (ha)

Year	Forest land converted to grassland	Wetlands converted to grassland	Total
1990	6,983,769	48,877	7,032,646
1995	8,827,573	48,877	8,876,450
2000	10,468,953	48,877	10,517,831
2005	12,655,402	48,877	12,704,280
2006	13,077,223	48,877	13,126,100
2007	13,435,014	48,877	13,483,892
2008	13,604,519	48,877	13,653,397
2009	13,596,408	48,877	13,645,285
2010	13,482,721	48,877	13,531,599
2011	13,393,247	48,877	13,442,124
2012	13,328,812	48,877	13,377,689
2013	13,278,270	48,877	13,327,148
2014	13,188,858	48,877	13,237,735
2015	13,022,252	48,877	13,071,129
2016	12,969,969	48,877	13,018,847
2017	12,819,932	48,877	12,868,810

6.9.2 Emission estimates

Emission estimates for the components of *land converted to grassland* are reported in Table 6.52.

Table 6.52 Net emissions and removals from *land converted to grassland* sub-categories 1990–2017 (Gg CO_2-e)

Year	Forest land converted to grassland	Wetlands converted to grassland	All
1990	155,471	896	156,367
1995	74,191	896	75,087
2000	79,668	896	80,564
2005	97,804	896	98,700
2006	95,838	896	96,734
2007	95,496	896	96,392
2008	73,548	896	74,445
2009	60,408	896	61,304
2010	66,819	896	67,715
2011	52,961	896	53,857
2012	50,799	896	51,695
2013	49,353	896	50,249
2014	50,003	896	50,899
2015	41,140	896	42,036
2016	45,762	896	46,658
2017	44,456	896	45,352

6.9.3 Uncertainties and time series consistency

Uncertainties for *forest land converted to grassland* at the national scale were estimated to be ±27.9 per cent for CO_2. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

Emissions estimated against *wetlands converted to grassland* are reported for the period 1990 to 2015. The current Tier 1 method relies on interpolation and extrapolation with respect to two observational years. ABARES does not report on uncertainty about the land use estimates. However, these are likely fall in the medium to high range.

While there is a higher uncertainty in *wetlands converted to grassland* than in *forest land converted to grassland,* the former category makes only a small contribution to the overall uncertainty of *land converted to grassland* due to its lower emissions.

6.9.4 Source specific QA/QC

Verification of area of forest clearing estimates

The Department has undertaken a detailed quality control verification exercise, in consultation with the Queensland Department of Science, Information Technology and Innovation (Queensland DSITI), to address recommendations contained in Federici (2016b) designed to test the quality of the estimates of areas of forest conversion used for the national inventory.

The analysis showed a high level of agreement between the monitoring systems implemented by the Department of the Environment and Energy for the national inventory system and the Queensland DSITI system implemented for the *Vegetation Management Act 1999* for the state of Queensland.

Over the available time series (1988-2014), the Department of the Environment and Energy estimates of the area of the conversion of forest lands were within ±10 per cent of Queensland DSITI datasets (see section 6.A.7) providing assurance that national inventory estimates of forest conversion are complete and unbiased.

One area of difference between the two systems related to the identification of the area of *forest lands.* Some clearing of woody vegetation identified in both systems is reported in the national inventory in the *grasslands remaining grasslands* classification (and is treated as loss of shrub or sparse woody vegetation).

An additional 16,839,196 hectares of shrub or sparse woody vegetation not classified as *forest lands* was also identified in the national inventory system as having been lost since 1988, ensuring that the national inventory is complete in estimated losses of sparse woody vegetation (note that a similar amount of sparse woody vegetation was gained during this period).

In around 6 per cent of cases, the Queensland DSITI identified clearing activity by landowners on national inventory grasslands predominantly consisting of native or improved pastures - which may be interpreted in large part as actions by landowners to prevent the emergence of woody species or to remove isolated woody vegetation in pasture which, while having significant long term implications for the nature of the landscape, does not generate material net emissions at the time of the event and is not recorded in the national inventory.

Validation/fine tuning of biomass estimates using empirical data

Following on from a verification study undertaken in 2016 (Roxburgh et el., 2016), CSIRO scientists have utilised a recent collation of approximately 6,000 new empirical biomass datapoints to update *FullCAM*'s *M* layer to fine tune the accuracy of predicting biomass, particularly in tall temperate forests (Roxburgh *et al.* 2017). The simulation of above-ground forest biomass in FullCAM is based on an empirical relationship between model-predicted forest growth (the Forest Productivity Index or FPI) and observations of biomass collected from minimally disturbed stands. This relationship is used to predict '*M*' - the maximum attainable site above-ground biomass. In the update by Roxburgh *et al.* (2014), the original calibration database was augmented with forest biomass observations from the TERN/AusCover National Biomass Library (See Appendix 6.D for details the latest validation and fine-tuning of the *FullCAM* model).

Further information on the *FullCAM* model, along with the associated quality assurance and quality control program, are in Appendices 6.B, 6.C, 6.D and 6.F.

Verification using Tier 2 model

Up until the 2014 Inventory, verification of the Tier 3 based emission estimates from this sub-category was performed through comparison with a Tier 2, Approach 2 method (described in Appendix 6.H). The Tier 2 method is a spreadsheet model based on country specific biomass data for three broad ecosystem types and uses the areas from the remote sensing analysis, applied using an Approach 2 method (i.e., not fully spatially explicit). The model includes all carbon pools (living biomass, DOM and soil) and emissions from fire.

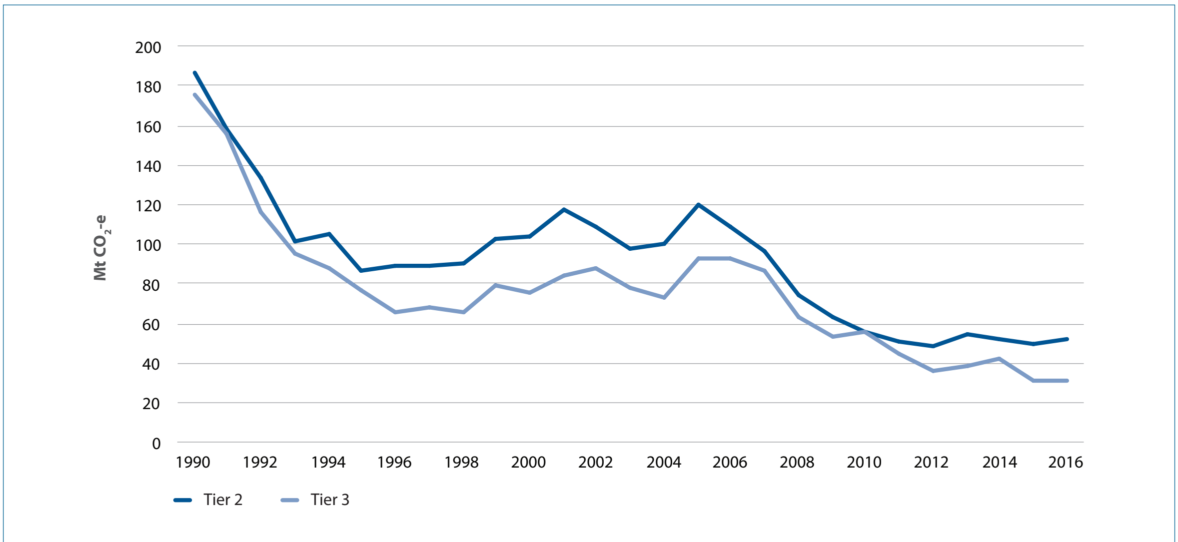
The results from the two models have been largely consistent and have followed a similar trend since 1990 (Figure 6.32). By and large, the emissions output has not varied substantially between the Tier 2 and Tier 3 models; however, the discrepancies between the two model approaches can be explained further.

The Tier 2 method uses country-specific coefficients for three regions differentiated by vegetation class to estimate emissions and removals from deforestation (land use change). It standardises the biophysical (soil, climate, etc.)

environment, and hence forest productivity, across Australia. That is, the Tier 2 model does not encompass the finely disaggregated spatial variability relating to soil types (and their characteristics) and climate variability (particularly rainfall) which would have an effect on emission levels. As such, CO_2 emissions and removals could be overestimated or underestimated. The Tier 3, Approach 3 method is spatially explicit, operates at a fine scale (25 m) and incorporates the variability of the biophysical environment (climate and soil) across Australia. This therefore includes the effects of climate, better represents regrowth and reclearing cycles and varies emissions based on the site characteristics of the land subject to clearing.

Due to the significant updates and improvements to activity data collection and estimation methods in the 2015 Inventory, comparison with the Tier 2 model as described above is no longer strictly valid. However, historical use of the model as described above remains valid, and the factors driving the changes between the 2014 and 2016 Inventories are well understood and explained, along with their impacts, in section 6.5.5 below. As part of our improvement plan, we will review and update the current Tier 2 model to ensure it remains a valid QA check for future inventories.

Figure 6.32 Emissions from *forest land converted to cropland* and *grassland* output from Tier 2 and Tier 3 methodology from 1990–2014

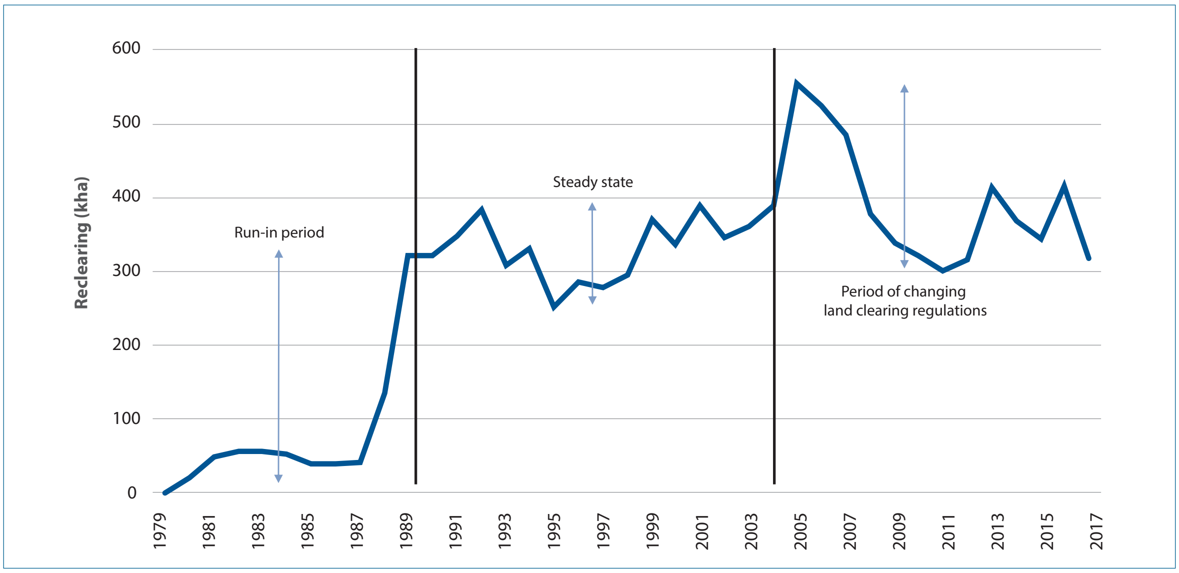


Testing sensitivity of emissions in 1990 to re-clearing prior to 1990

The Tier 2 forest conversion model described in Appendix 6.H has been further used to test the sensitivity of the 1990 estimate of emissions from *forest land converted to other land uses* to the amount of re-clearing prior to 1990.

Re-clearing is the observation of forest clearing on land which has been observed to be cleared previously. Observations of re-clearing are constrained by the availability of Landsat data from 1972 (see Appendix 6.A). Despite this constraint, by 1990, observed re-clearing reaches a level that is consistent with the amount of re-clearing observed subsequently – a steady-state of re-clearing of observed (Figure 6.33). From 2004 re-clearing rates deviate from the steady-state in an apparent response to changes in land clearing regulations.

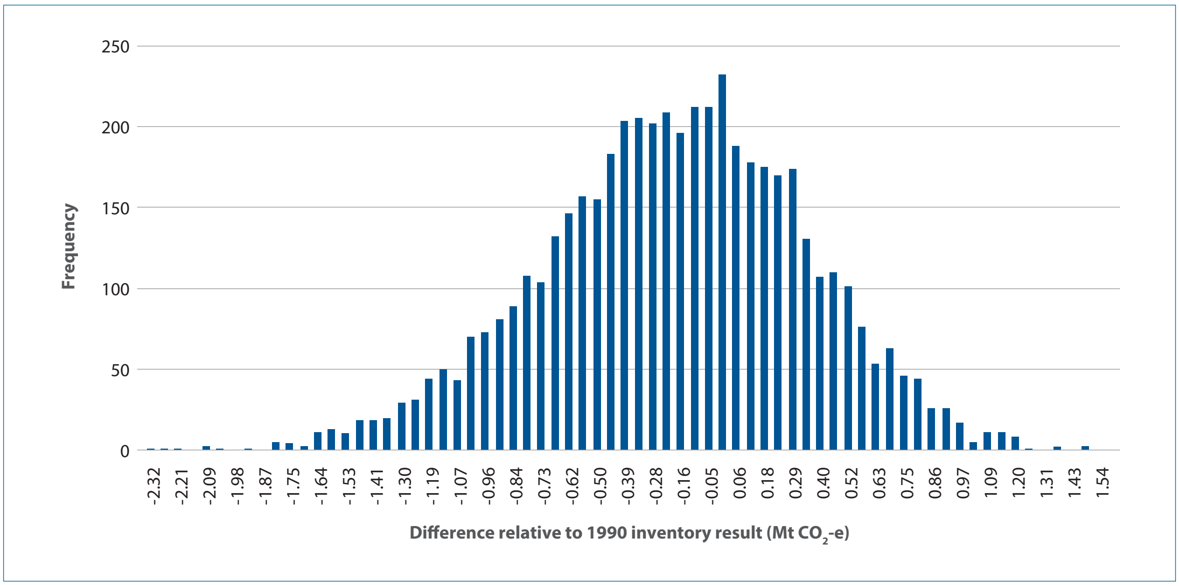
Figure 6.33 Observed re-clearing 1975–2017



While by 1990 re-clearing had reached a steady state, the observed re-clearing during the run-in period 1972-1989 (Figure 6.33) is less certain. To test the potential impact of varying levels of re-clearing prior to 1990 on estimated emissions in 1990 a simulation with 5,000 iterations was undertaken using the tier 2 forest conversion model (see Appendix 6.H for a description of this model).

The impact of varying re-clearing prior to 1990 on emissions in 1990 was tested using a Monte Carlo simulation through 5,000 iterations. The simulations were set to randomly select an amount of re-clearing within the range of approximately 0-500,000 hectares per year in the period 1972-1989. The results of this analysis are presented in Figure 6.34.

Figure 6.34 Sensitivity of 1990 emissions estimate (*Forest land converted to other land uses*) to Monte Carlo simulations of re-clearing scenarios prior to 1990



The results of this sensitivity analysis show that the estimate of emissions in 1990 is relatively insensitive to re-clearing prior to 1990 (Figure 6.34). The results of the 5,000 iterations of the model fell within the range of approximately -2.5 Mt CO_2-e to 1.5 Mt CO_2-e relative to the inventory estimate. To simulate re-clearing rates higher than those observed (Figure 6.33), it was necessary to simulate a corresponding first time clearing event further in the past[6]. When the re-clearing simulated was higher than the observed rate of re-clearing, emissions are estimated to be lower in 1990 under these scenarios because of the additional time available for the decay of soil carbon and forest debris prior to 1990.

The estimates of *forest conversion* for 1990 are based on a limited dataset on estimated land use change extending only from 1973-1990. Extending the observed dataset on land use change to include estimates for the missing data on land use change for the period 1940-1972 could be implemented using a range of techniques identified in IPCC 2006.

The implementation of an extended dataset on land use change to 1940 would lead to higher emissions estimates for *forest conversion* for the entire time series, with larger impacts at the start of the time series, 1990, than for later periods of the time series. It is assessed that the estimate for net emissions for *forest conversion* categories would be 13 Mt CO_2-e higher in 1990 if the land clearing trend is back cast with an assumed clearing peak in 1974 and is applied in the *FullCAM* Tier 2 model (see Appendix 6.A). This step has not yet been implemented. A related question, that of the appropriate length of the transition process, remains open. While the Department of the Environment and Energy assumes a 50-year period for the reporting of land in a land use change category, the IPCC assumes a default length of transition to a new carbon stock level of 20 years.

Quality assurance/quality control measures for *wetlands converted to grassland* involve internal reviews of data entry and model outputs, including a check on the consistency of land use statistics across Australian jurisdictions.

6.9.5 Recalculations since the 2015 Inventory

6.9.5.1 Forest land converted to grassland

Table 6.53 shows the overall size of the recalculations applicable to *forest land converted to grassland* each year since 1990, and includes a break-down of the contributions by the main factors influencing these changes.

The key factors are: improvements to the characterisation of tree growth under the FullCAM tree yield formula; the addition of new and revised geospatial source information; updates to the management of spatial information; and the implementation of Standing Dead behaviour in tree systems.

A. FullCAM Tree Growth

The tree yield formula, which underpins plant growth (productivity) in FullCAM forest systems, functions by taking climate-related fluctuations in conditions and applying them as variations to a long-term average forest productivity index. This formula functions best when the long-term average mirrors the period being simulated (Paul 2019). This revision revises that long-term average to be based on a 1972-2016 series rather than an earlier series. The effect is that growth rates in forest systems and by extension their maximum achievable biomass are increased, which in turn increases the amount of carbon lost to oxidation during a clearing event. As such, this improvement has resulted in higher emissions being reported throughout the time series.

6 Where regrowth (prior re-clearing) was simulated to occur between 5-10 years after first time clearing, which in-turn was simulated to occur between 10-15 year prior to regrowth. As a result the simulation included scenarios where first-time clearing was modelled to occurs as far in the past as 1947 (1972 minus (10+15).

B. New Geospatial Data

A key factor in annual recalculations for the forest conversions sub-categories is revisions to the area of forest conversions identified using satellite imagery. These revisions are due to expansion of the forest area monitored and improvements in the analysis of satellite imagery. Satellite imagery used in earlier inventories is re-analysed each year to take account of independent datasets for vegetation clearing, including vegetation monitoring data prepared by the Queensland Department of Science, Information Technology and Innovation (DSITI) and NSW OEH (See Appendix 6.A for further details). These revisions also include annual updates to climate (weather) data. This improvement has generally increased reported emissions, particularly pre-2010.

C. Management of Spatial Information

This revision covers a range of updates which are quality-improvements to spatial simulation functionality with regards to agricultural species. The improvements are as described for *grassland remaining grasslan*d and *cropland remaining cropland* and include additional improvements as follows:

- The timing for grass-growing behaviour between the identified removal and establishment of forests has been improved, so as to help prevent periods of 'barren' soil.
- The spatial allocation of crop and pasture species following forest removal has been enhanced through the improved use of spatial information on where agricultural practices favour the planting of crops.
- The exclusion of fluctuations in the agricultural debris carbon pool from emission calculations. Consistent with lower-tier methods, the FullCAM model assumes that all agricultural debris will either oxidise or turnover into soil within the space of a year. The trend in long-term carbon pools can therefore be inferred from changes in living biomass and soil carbon. This ensures that the annual movements in sectoral emissions reflect the trends in vegetation rather than the volatility of annual variations in rainfall-driven grass turnover.

This improvement has generally increased reported emissions, with significant variability across the time series reflecting the trade-off between increased spatial variability

D. Implementation of Standing Dead pool

Consistent with improvements to *forest land remaining forest land* arising from Paul and Roxburgh (2018b), improvements governing the behaviour of standing dead vegetation in the FullCAM model have also been applied here. This allows a better interpretation of how strip-cleared debris decays or combusts in a conversion burn as distinct from other forms of forest debris created by litterfall.

Table 6.53 *Forest land converted to grassland*: recalculation of total CO_2-e emissions, 1990–2015

Year	Forest land converted to grassland				Reasons for Recalculations			
	2018 submission	2019 submission	Change		A. FullCAM Tree Growth	B. New Geospatial Data	C. Management of Spatial Information	D. Standing Dead
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	%				
1990	155,263	155,471	208	0.1%	2,042	6,971	-1,942	-6,864
1995	72,666	74,191	1,525	2.1%	1,758	3,313	-2,677	-869
2000	70,508	79,668	9,160	13.0%	2,291	2,818	5,897	-1,846
2005	85,193	97,804	12,611	14.8%	3,652	4,806	7,087	-2,933
2006	85,912	95,838	9,926	11.6%	4,454	5,941	1,969	-2,438
2007	81,354	95,496	14,142	17.4%	4,683	5,024	6,352	-1,917
2008	61,112	73,548	12,437	20.4%	3,884	3,272	5,912	-631
2009	52,917	60,408	7,491	14.2%	3,346	2,527	1,772	-153
2010	57,089	66,819	9,730	17.0%	3,381	2,592	3,894	-137
2011	46,585	52,961	6,375	13.7%	3,530	1,628	1,052	165
2012	40,244	50,799	10,555	26.2%	1,249	998	8,021	288
2013	42,086	49,353	7,266	17.3%	2,625	557	3,976	108
2014	45,535	50,003	4,468	9.8%	3,181	623	844	-180
2015	37,109	41,140	4,031	10.9%	2,099	-66	2,061	-63
2016	38,265	45,762	7,498	19.6%	2,696	1,057	4,172	-428

6.9.5.2 Wetlands converted to grassland

There is no recalculation for wetlands converted to grassland over the period 1990 to 2016. Table 6.54 is a comparison of the 2019 and 2018 submissions.

Table 6.54 *Wetlands converted to grassland:* Comparison of the 2019 submission to the 2018 submission for CO_2-e emissions 1990–2016

Year	2018 submission ($Gg\ CO_2$-e)	2019 submission ($Gg\ CO_2$-e)	Change ($Gg\ CO_2$-e)	Change (%)
1990	896.1	896.1	0.0	0.0%
2000	896.1	896.1	0.0	0.0%
2005	896.1	896.1	0.0	0.0%
2006	896.1	896.1	0.0	0.0%
2007	896.1	896.1	0.0	0.0%
2008	896.1	896.1	0.0	0.0%
2009	896.1	896.1	0.0	0.0%
2010	896.1	896.1	0.0	0.0%
2011	896.1	896.1	0.0	0.0%
2012	896.1	896.1	0.0	0.0%
2013	896.1	896.1	0.0	0.0%
2014	896.1	896.1	0.0	0.0%
2015	896.1	896.1	0.0	0.0%
2016	896.1	896.1	0.0	0.0%

6.9.6 Source specific planned improvements

Systems for the estimation of areas of forest, forest conversion and related assessments of the gains and losses of sparse woody vegetation will continue to be updated to enable routine integration of information contained in datasets obtained from Queensland DSITI and similar products as they develop. The new systems will continue to build on experiences gained in the use of these datasets during the finalisation of the area estimates for this inventory.

Specifically, the remote sensing programme is further advancing the methods to identify:

- Ongoing improvements and development of rule based methods for change detection and attribution;
- Annual updating of Landsat time series data prior to 2004 subject to availability of data;
- Review of land use datasets for improved reporting of time series land conversions;
- Processing of remaining areas of sparse woody vegetation for parts of central Australia to complete the national coverage.

The planned improvements associated with the modelling of crops and grasslands will have impacts on forest conversion estimates. They are detailed in the *cropland remaining cropland* and *grassland remaining grassland* sections of this chapter.

Improvements are also planned in relation to activity data collection and modelling of emissions and removals associated with conversions of conventional forest to wetlands (flooded lands) and of mangrove forest to settlements.

With respect to mangrove forest conversions and accounting more broadly for emissions and removals associated with wetlands, the Department of the Environment and Energy has established an informal expert advisory group of academic and government wetland specialists to provide advice on the development of methods and datasets for the coastal wetlands subsector.

Estimating changes in carbon pools and fluxes depends on data and model availability. Australian empirical data will continue to be developed to support future Tier 2 and Tier 3 models.

6.10 Wetlands Remaining Wetlands (Source Category 4.D.1)

Estimates are guided by the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement) (IPCC 2014b). The wetlands inventory focuses initially on coastal wetlands and will be extended in future inventory reports to include inland wetlands.

Net emissions for three subdivisions of *wetlands remaining wetlands* are reported in this submission:

- Gains and losses of sparse woody vegetation on wetlands (both coastal and inland);
- Emissions from aquacultural production in Australia; and
- Commencing in this NIR, emissions from seagrass removal due to capital dredging projects.

6.10.1 Methodology

Sparse woody vegetation gains/losses

Carbon stock-changes from gains and losses in sub-forest sparse woody vegetation on wetlands have been identified using the same monitoring systems used to identify areas of sparse woody vegetation for grassland systems (see Section 6.9.1.2).

Aquacultural production

The aquaculture (use) subdivision utilises the Australian production figures published annually by the Australian Bureau of Agriculture and Resource Economics (ABARES) in the Australian Fisheries and Aquaculture Statistics report. These statistics are available to the level of state or territory jurisdiction.

ABARES aquaculture production data are reported for various broad groups of animals, and the subgroups within those. The two groups of interest are “Fish” and “Crustaceans”, both of which contain sub-groups that represent marine and/or freshwater species. Only production figures involving sub-groups that are mostly cultured in coastal wetland based facilities are included in this analysis. Therefore fish production data for salmonids, tuna and barramundi are included from “Fish”, while prawns is the only sub-group reported from the “Crustacean” group. There are no other groups from the ABARES dataset reported here. Emissions are reported in Table H of the CRF tables.

A Tier 1 method was developed for reporting N_2O emissions. Direct N_2O emissions were estimated using Equation 4.10 in the 2013 Wetlands Supplement. Note that quantities are expressed here in tonnes rather than kg, so that:

$$N_2O\text{-}N_{AQ} = F_F \bullet EF_F,$$

- $N_2O\text{-}N_{AQ}$ = annual direct N_2O-N emissions from aquaculture use; tonne N_2O-N yr^{-1}
- F_F = annual fish production; tonne fish yr^{-1}
- EF_F = emission factor for N_2O emissions from fish produced; 0.00169 tonne N_2O-N (tonne fish produced)$^{-1}$

Seagrass removal

A report (Kettle 2017) was commissioned by the Department of the Environment and Energy to capture the timing and extent of current and historical capital dredging activity in Australia that informs the seagrass excavation model. (Appendix 6.J).

The seagrass excavation model has a tier 1 model structure to which country-specific parameter values are applied, elevating it to a tier 2 model (IPCC 2014). Parameter values were estimated from pooled data collected from the scientific literature. Where possible these are based on species-specific values within a regional context (Appendix 6.J.2). The coastal regions applied to the seagrass model are the same as those developed for the mangrove and tidal marsh models (Figure 6.J.1). Species presence and abundance within each coastal region was estimated from available survey data (Table 6.J.6 and Table 6.J.7).

The timing and extent of capital dredging activity in Australian waters was reported for the period 1989 to 2016 (Kettle 2017), noting there was no recorded capital dredging activity for 1990-1995, 2011 and 2016.

The model is populated with area estimates for excavated seagrass meadow obtained by spatial modelling. Kettle (2017) provided dredge-related shapefiles (listed in Table 6.J.10) that are overlaid on seagrass habitat shapefiles to determine the areas of seagrass and underlying sediment removed by dredging activity. Seagrass habitat shapefiles are sourced from State and Territory jurisdictions and the University of Tasmania. (Table 6.J.11).

It is reported in the literature that seagrass habitat takes time to recover after removal or burial, depending on the species involved (Preen, Lee Long, and Coles 1995) (Campbell and McKenzie 2004) (Smith *et al.* 2016) (Vanderklift *et al.* 2017). Some seagrass habitat, including that dominated by temperate, high biomass species, may not re-establish when disturbance is regular, periodic, or catastrophic (Meehan and West 2002) (Erftemeijer and Robin Lewis 2006) (Wu *et al.* 2015). As navigational channels also undergo scheduled periodic maintenance dredging it is assumed that seagrass habitat is removed permanently when establishing a channel. Also, in keeping with tier 1 assumptions, all excavated plant and soil based organic carbon is mineralised in the year of removal. Finally, an estimation of the soil organic carbon removed by dredging is based on an excavated depth of one meter only.

6.10.2 Emission estimates

Sparse woody vegetation gains/losses

The key input data and estimated net emissions from changes in sparse woody vegetation on wetlands are presented in Table 6.55 below:

Table 6.55 Area and net emissions of sparse woody vegetation, UNFCCC Wetlands remaining wetlands

Year	Area gains	Area losses	Net emissions
	kha	kha	Gg CO_2
1990	49.8	72.1	296.8
1995	18.1	26.2	365.9
2000	40.2	26.7	254.8
2005	76.4	41.6	141.2
2006	34.8	129.1	225.9
2007	31.7	78.8	265.5
2008	29.7	58.6	284.7
2009	27.2	54.0	242.5

Year	Area gains	Area losses	Net emissions
	kha	kha	Gg CO_2
2010	41.6	66.1	244.5
2011	38.1	42.6	224.8
2012	78.9	30.4	73.4
2013	65.5	54.5	43.5
2014	38.5	70.2	52.5
2015	41.9	63.3	64.5
2016	101.3	48.2	20.2
2017	32.7	43.3	34.3

Aquacultural production

Annual emissions for aquaculture over the reporting period 1990–2017 are shown in Table 6.56 below.

Table 6.56 Annual emissions calculated for aquaculture (use) within the *wetlands remaining wetlands* category

Year	Emissions (Gg CO_2-e)
1990	2.4
1995	6.5
2000	12.2
2005	14.9
2006	17.9
2007	19.6
2008	21.0
2009	23.1
2010	24.3
2011	25.7
2012	30.1
2013	29.1
2014	28.5
2015	33.3
2016	37.0
2017	35.1

Seagrass removal

Nationally, capital dredging removed 416 ha of seagrass meadow, which represents 4 per cent of the aggregated capital dredging area (11,843 ha), during the period 1989/90 to 2014/15. This resulted in total emissions of 129 Gg CO_2-e generated by the removal and aerobic disposal of plant biomass and soil organic carbon. There were no capital dredging projects identified that removed seagrass habitat in 2015/16 or 2016/17.

Annual emissions for seagrass removal over the reporting period 1990–2017 are shown in Table 6.57 below.

Table 6.57 Annual area and emissions for seagrass removal within the *wetlands remaining wetlands* category

Year	Emissions (Gg CO_2-e)	Area removed (ha)
1990	0.0	0.0
1995	0.0	0.0
2000	0.5	1.1
2005	10.8	25.9
2006	10.2	22.0
2007	0.7	2.8
2008	54.5	234.7
2009	0.4	1.1
2010	0.4	1.1
2011	0.0	0.0
2012	1.5	6.3
2013	1.7	7.4
2014	33.8	75.9
2015	1.5	2.6
2016	0.0	0.0
2017	0.0	0.0

The key drivers of variation over the time period are increased sparse transitions in wetlands due to climatic impacts that alter wetland hydrology and increased aquaculture production in tidal wetland areas.

6.10.3 Uncertainties and time series consistency

Based on a qualitative assessment, the uncertainties for sparse woody vegetation transitions on *wetlands remaining wetlands* is estimated to be medium. Further information is provided in Annex 2. Time series consistency is ensured by the use of consistent methods across the time series.

For the subdivision, N_2O from Aquaculture Use, ABARES aquaculture production data is available for the period 1991 to 2017 (ABARES: *Australian fisheries and aquaculture production publications*). These data are reported nationally and by state/territory, and represent live-weight quantity of aquaculture product that is produced and marketed. The data generally excludes hatchery production. ABARES does not specify a level of uncertainty with its aquaculture and fisheries production figures. Uncertainty regarding annual finfish and crustacean production in coastal facilities is likely to be within the low to medium range.

Under *wetland remaining wetland* the confidence intervals associated with 2013 IPCC guidance values for parameters associated with land use, land use change involving coastal wetlands range from 24 per cent to over 200 per cent. For seagrass removal this inventory applies available country-specific values, sourced from the scientific literature, to reduce that level of uncertainty. Although a formal uncertainty analysis is not yet available, the level of uncertainty is anticipated to be towards the lower end of the guidance values, and is considered to be within the medium range.

6.10.4 Source specific QA/QC

The QA / QC of the activity data for detecting gains and losses of woody vegetation is described in Appendix 6.A.4.

Quality assurance/quality control measures for *wetlands remaining wetlands* (*aquaculture and seagrass removal*) involve internal reviews of data entry and model outputs, including a check on the consistency of aquaculture production statistics across Australian jurisdictions.

6.10.5 Recalculations

Recalculations for *wetlands remaining wetlands* for 1990 to 2016 are shown in Table 6.58 below. As with *grassland remaining grassland* (section 6.8.5), activity data for grass and shrub transitions (to and from sparse woody vegetation) has been revised due to annual updates in image analysis and expanded national coverage. The FullCAM simulation software is now being utilized to ensure that the derived dates of transition between satellite imagery passes are more consistent with those derived for forest conversions.

Under the revisions for non-temperate fire management described under forests remaining forests, reporting of these emissions from fire has been extended to *wetlands remaining wetlands* where they are observed to occur on wetlands.

A minor revision was also made to the 2016 emission estimate for aquaculture (use) based on the fish production value for 2016 reported in the 2017 Australian fisheries and aquaculture statistics (ABARES, 2018). The value reported in the 2018 submission was a projected figure as publication of the ABARES report was still pending at time of NIR publication.

Table 6.58 *Wetlands remaining wetlands*: recalculation of total CO_2-e emissions, 1990–2016

Year	Wetlands remaining wetlands				Reason for recalculation		
	2018 submission	2019 submission	Change		Sparse Woody Vegetation	Introduction of biomass burning	Aquaculture
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	%	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)
1990	272.4	399.1	126.7	46.5%	26.8	99.9	0.0
1995	347.8	347.0	-0.8	-0.2%	24.5	-25.3	0.0
2000	240.9	923.9	683.0	283.6%	26.7	656.3	0.0
2005	121.4	392.1	270.7	223.0%	45.5	225.2	0.0
2006	210.1	616.1	406.0	193.2%	44.0	362.0	0.0
2007	233.0	644.6	411.5	176.6%	52.7	358.8	0.0
2008	282.5	780.8	498.3	176.4%	77.8	420.5	0.0
2009	158.4	769.9	611.5	386.0%	107.6	503.9	0.0
2010	167.9	652.8	484.9	288.8%	101.3	383.6	0.0
2011	171.1	602.1	431.1	252.0%	79.4	351.7	0.0
2012	-8.6	380.2	388.8	4505.0%	113.6	275.2	0.0
2013	-27.1	399.2	426.2	1573.9%	101.4	324.9	0.0
2014	24.4	400.0	375.7	1542.4%	90.4	285.3	0.0
2015	20.4	430.6	410.2	2006.2%	78.9	331.3	0.0
2016	-5.6	322.9	328.5	5911.6%	63.2	265.8	-0.5

6.10.6 Source specific planned improvements

Further development of the sparse transitions model is planned as described for *grassland remaining grassland* (section 6.8.6).

Ongoing improvements include extension of reporting to cover seagrass; specifically accounting for the impacts of capital dredging in Australian coastal waters and estuaries.

In terms of seagrass removal activity data, the capital dredging report (Kettle, 2017) has catalogued the capital dredging activity associated with port and related infrastructure projects for the current reporting period 1990 to 2016. Acquisition of data on new and on-going capital dredging activity from 2016 will now be based on surveys of reports of dredging captured in the Notices to Mariners (Australian Hydrological Office), with follow-ups for identified capital dredging projects to determine both their spatial extent and timing.

A process of continuous improvement regarding regionally based seagrass removal parameter values to underpin the emissions model has been established to incorporate updated values acquired in regular surveys of the scientific literature.

6.11 Land converted to wetlands (Source category 4.D.2)

This category comprises the subcategory *forest land converted to wetlands* (flooded land). Forest conversion occurs where forests are cleared as part of the construction of reservoirs and other land categorized in the IPCC 2006 Guidelines as 'flooded lands' under *forest land converted to wetlands*, within the broader *land converted to wetlands source category* (4.D.2).

Where mangrove forests are cleared for commercial developments such as marinas, these conversions are categorised as *forest land converted to settlements* within the broader *land converted to settlements* source category (4.E.2 – see section 6.12 below).

6.11.1 Methodology

Like for areas of forest conversions for cropping and grazing, areas of forest converted to wetland are identified at fine spatial resolution via Australia's Approach 3 remote sensing programme. In this case, the satellite imagery is analysed to identify where forest is cleared for construction of perennial water bodies such as reservoirs.

The method for estimating net emissions is taken from the 2006 IPCC Guidelines, Volume 4.1, Chapter 7, page 7.20, since the conversion to wetlands is a conversion of land to flooded land. Only carbon dioxide is estimated and it is assumed that emissions from the lost biomass occur in the year of conversion. This model is implemented in FullCAM in fully spatial tier 3 mode considering only fluxes in living biomass.

The methodology for activity data collection and modelling of emissions and removals for forest land converted to wetlands has been detailed as part of the earlier section 6.8.1 which covers forest conversion to grassland and cropland subcategories.

6.11.2 Emission estimates

The annual area identified, and associated net emissions are in Table 6.59 below.

Table 6.59 Cumulative areas of *forest land converted to wetlands* (flooded land), and associated net annual emissions 1990–2017

Year	Cumulative National Area (kha)	Net Annual Emissions (Gg CO_2-e)
1990	26	711
1995	32	215
2000	35	21
2005	37	40
2006	38	70
2007	38	25
2008	38	28
2009	38	-12
2010	40	339
2011	42	742
2012	42	11
2013	42	20
2014	42	7
2015	42	2
2016	42	-6
2017	42	-0

6.11.3 Uncertainties and time series consistency

Uncertainties for *land converted to wetland* at the national scale were estimated to be ±27.3 per cent for CO_2. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

6.11.4 Source specific QA/QC

The source specific QA/QC for the subcategory *forest land converted to wetland* is covered in detail under *forest land converted to grassland* (Section 6.9).

6.11.5 Recalculations

Recalculations for *land converted to wetlands* for 1990 to 2016 are shown in Table 6.60 below.

The recalculations are due to improvements in remote sensing of forest cover change and in FullCAM modelling of maximum above-ground biomass.

Table 6.60 Recalculation of total CO_2-e emissions, 1990–2016

Year	Forest land converted to flooded land			
	2018 submission	2019 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	%
1990	691	711	20	2.9%
1995	215	215	1	0.3%
2000	32	21	-11	-35.4%
2005	29	40	11	37.3%
2006	80	70	-10	-12.9%
2007	16	25	9	57.8%
2008	27	28	1	3.1%
2009	6	-12	-18	-315.7%
2010	302	339	37	12.2%
2011	733	742	9	1.2%
2012	4	11	7	186.2%
2013	13	20	7	56.1%
2014	13	7	-5	-42.8%
2015	1	2	1	161.0%
2017	-1	-6	-5	-524.4%

6.11.6 Source specific planned improvements

The source specific planned improvements for the subcategory *forest land converted to wetland* are covered in detail under *forest land converted to grassland* (Section 6.9).

6.12 Settlements Remaining Settlements (Source Category 4.E.1)

The *settlements remaining settlements* subcategory does not include areas of woody vegetation that constitute a forest. This subcategory includes only estimates of net emissions from changes in sparse woody vegetation.

6.12.1 Methodology

Carbon stock-changes from gains and losses in sub-forest sparse woody vegetation on settlements have been identified using the same monitoring and modelling systems used to identify areas of sparse woody vegetation for *grassland remaining grassland* and estimate the associated emissions and removals (see Section 6.8.1).

6.12.2 Emission estimates

The key input data and estimated net emissions are presented in Table 6.61.

Table 6.61 Area and net emissions of sparse woody vegetation, *settlements remaining settlements*

Year	Area gains	Area losses	Net emissions
	kha	kha	kt CO_2
1990	4.4	7.3	-19.8
1995	2.7	3.7	2.6
2000	3.0	3.3	17.4
2005	5.0	7.7	23.7
2006	6.0	6.6	24.5
2007	5.7	6.7	25.7
2008	5.0	7.7	28.7
2009	7.6	7.8	23.1
2010	7.9	6.8	19.6
2011	13.4	4.4	9.1
2012	15.9	4.0	-4.8
2013	11.1	6.7	-9.4
2014	11.6	7.6	-12.4
2015	8.5	7.3	-14.5
2016	8.7	7.6	-17.7
2017	9.9	5.0	-24.3

6.12.3 Uncertainties and time series consistency

Based on a qualitative assessment, the uncertainty for *settlements remaining settlements* is estimated to be medium. Further information is provided in Annex 2. Time series consistency is ensured by the use of consistent methods across the time series.

6.12.4 Source specific QA/QC

The QA / QC of the activity data for detecting gains and losses of woody vegetation is described in Annex 6.A.4.

6.12.5 Recalculations

Recalculations for *settlements remaining settlements* for 1990 to 2015 are shown in Table 6.62. Like for *grassland remaining grassland* (section 6.8.5), activity data for grass and shrub transitions has been revised due to annual updates in image analysis and expanded national coverage. The FullCAM simulation software is now being utilized to ensure that the derived dates of transition between satellite imagery passes are more consistent with those derived for forest conversions.

Table 6.62 Settlements remaining settlements: recalculation of total CO_2-e emissions, 1990–2016

Year	Settlements remaining settlements			
	2017 submission	2018 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	%
1990	-71	-20	51	72.1%
1995	-27	3	30	109.4%
2000	-2	17	19	974.8%
2005	6	24	18	291.8%
2006	3	25	21	633.2%
2007	4	26	21	475.0%
2008	-9	29	38	422.7%
2009	-15	23	38	252.5%
2010	-21	20	41	192.7%
2011	-49	9	58	118.5%
2012	-59	-5	54	91.8%
2013	-59	-9	50	84.1%
2014	-61	-12	48	79.5%
2015	-59	-15	44	75.3%
2016	-59	-18	41	70.1%

6.12.6 Source specific planned improvements

Further development of the sparse transitions model is planned as described for *grassland remaining grassland* (section 6.8.6).

6.13 Land Converted to Settlements (Source category 4.E.2)

The land converted to settlements category includes forest land converted to settlements and wetlands converted to settlements sub-categories.

In reporting net emissions from conversion of forest land to settlements, the emissions and removals from the clearance of terrestrial forests estimated separately from mangrove forests.

6.13.1 Methodology

6.13.1.1 Forest land converted to settlements

While activity data is collected via satellite imagery for both types of clearance, the modelling methods differ, reflecting the significant differences between mangrove and terrestrial forests in terms of their allometrics and carbon fluxes.

Clearance of terrestrial forests for settlement development is modelled using the Tier 3 FullCAM model, considering fluxes between all five carbon pools in the same way that conversions from forest land to grassland are modelled. See section 6.9.1 above.

It is assumed that Australian mangrove forest is cleared for the purpose of development only. As such, emissions from mangrove forest loss are reported under *forest land converted to settlements*. The Tier 2 method employed assumes that the biomass, dead organic matter and soil (to a depth of one meter) are all removed under aerobic conditions, and that all carbon from these pools is emitted as CO_2 during the year of extraction with no subsequent changes (Hiraishi, *et al.*, 2013).

The Tier 1 IPCC default values for above ground biomass (AGB), below ground biomass (BGB), dead organic matter (as woody and non-woody litter), and soil organic carbon (SOC), were replaced with values relevant to Australia's varied coastal regions (See Appendix J, Table 6.J.1). This followed a review of the available empirical data reported in the national and international scientific literature with the Australian-based estimates then distributed across an Australian coastline divided into seven broad regions (See Appendix J, Figure 6.J.1).

Values are weighted averages of values reported for common regional species, with the weighting based on estimates of the relative abundance of each species within each region. See discussion below and Tables 6.J.2 and 6.J.3 in Appendix J for more information on which species were included and their relative abundance within the coastal regions.

Activity data (forest cleared) was acquired by overlaying the mangrove major vegetation group (MVG) spatial layer (DoEE. *NVIS data products*. 2017) over Landsat imagery analysed for deforestation activity, as described in section 6.9.1 above and accounting for those areas of deforestation that overlap into the mangrove MVG layer.

The seven coastal regions defined are constructs that correspond approximately to combinations of mangrove biogeographical regions defined in Cresswell (2012), and also fully incorporate sets of spatial tiles that return areas of vegetation clearance and revegetation (Appendix 6J). Mangrove species common to and across several coastal regions were identified and their relative abundances within each coastal region estimated from surveys undertaken in Australian states and territories (Appendix 6J). Only one species of mangrove (*Avicennia marina*) exists in Victoria and South Australia so that this species had a relative abundance score of 1 in these states.

Differences in regional coastal biogeomorphology are captured by employing species in this analysis that represent a range of intertidal habitats. Therefore the choice of species used in the analysis of regional mangrove mangal characteristics is based on a combination of their relative abundance within and across regions, as well as their place within the intertidal zone. The latter is determined by each species adaption to a combination of factors, particularly frequency and period of tidal inundation, soil pore water salinity and access to freshwater.

6.13.1.2 Wetlands converted to settlements

The *wetlands converted to settlements* sub-category comprises areas of tidal marsh that have been cleared and converted to some form of commercial or residential use. Tidal marsh incorporates all the vegetated, non-forested intertidal habitats that comprise combinations of sparse vegetation (salt marsh mixed with individual mangrove plants), herbs, saline grasses, sedges and rushes. Because tidal marshes form neighbouring and ecotone communities with mangroves any conversion of mangroves to settlement will also result in the clearance of tidal marsh. An estimate of emissions due to this associated clearance of tidal marsh is provided in this inventory.

Whereas mangrove clearance can be detected in Landsat imagery, the same images cannot distinguish between vegetated tidal marsh and un-vegetated saltpan and tidal flat. Therefore the normal spatial analysis framework employed in the Land Sector cannot be used to evaluate the areas of tidal marsh cleared. However the surveys listed in Appendix.J quantify the areas of tidal marsh present, as well as that of mangroves. Therefore the area of tidal marsh cleared is based on their proportional representation (by area) with respect to mangroves within each coastal region (Table 6.J.2).

The methodology for estimating net emissions from conversion of tidal marsh involves a similar tier 1 model to that used for mangrove forest to settlements, using carbon pool parameters relevant to Australia's coastal region. The parameters were derived through a review of the available empirical data reported in the national and international scientific literature with the Australian-based estimates then distributed across an Australian coastline divided into the same seven broad regions used for mangrove forest conversions. Details of the model and parameters are in section 6.13.1.1 and Appendix 6.J

Table 6.63 Cumulative area of *land converted to settlements* 1990–2017 (ha)

Year	Terrestrial forest converted to settlements	Mangrove forest converted to settlements	Wetlands converted to settlements	Total
1990	68,941	1,352	1,565	71,857
1995	103,645	1,832	2,161	3,993
2000	135,631	2,131	2,537	4,667
2005	164,386	2,467	2,969	5,435
2006	173,790	2,569	3,079	5,648
2007	179,807	2,649	3,184	5,833
2008	183,360	2,721	3,319	6,040
2009	184,666	2,767	3,420	6,188
2010	184,848	2,829	3,507	6,335
2011	183,381	2,884	3,578	6,461
2012	179,267	2,939	3,651	6,590
2013	176,776	3,010	3,745	6,755
2014	174,763	3,108	3,834	181,705
2015	170,441	3,151	3,882	177,474
2016	168,044	3,308	4,264	175,616
2017	164,887	3,350	4,305	172,542

6.13.2 Emission estimates

Annual areas identified and associated emissions are in Table 6.64 below.

Table 6.64 Net emissions from *land converted to settlements* 1990–2017 (Gg CO_2-e)

Year	Land converted to settlements			
	Mangrove forest	Terrestrial forest	Wetlands (tidal marsh)	All
1990	206	2,853	83	3,142
1995	101	1,656	54	1,811
2000	91	1,527	56	1,675
2005	159	1,659	59	1,877
2006	174	1,720	71	1,964
2007	120	1,436	64	1,621
2008	100	1,387	86	1,573
2009	60	874	66	1,000
2010	94	951	52	1,098
2011	98	875	44	1,018

Year	Land converted to settlements			
	Mangrove forest	Terrestrial forest	Wetlands (tidal marsh)	All
2012	93	733	54	881
2013	132	659	101	892
2014	158	686	67	911
2015	75	563	32	669
2016	92	796	41	929
2017	80	525	25	630

6.13.3 Uncertainties and time series consistency

Uncertainties for *forest land converted to settlements* at the national scale were estimated to be ±28.4 per cent for CO_2. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

Under *mangrove forests converted to settlements* and *wetlands converted to settlements* the confidence intervals associated with 2013 IPCC guidance values for parameters associated with land use, land use change involving coastal wetlands range from 24 per cent to over 200 per cent. This inventory applies available country-specific values, sourced from the scientific literature, to reduce that level of uncertainty. Although a formal uncertainty analysis is not yet available, the level of uncertainty is anticipated to be towards the lower end of the guidance values, and is considered to be within the medium range.

6.13.4 Source specific QA/QC

The source specific QA/QC for the subcategory *forest land converted to settlements* is covered in detail under *forest land converted to grassland* (Section 6.9).

Quality control of the Excel-based Tier 2 coastal wetland models is based on the comparison of model outcomes against expected outcomes from test data sets used as model inputs. In addition, the area of mangrove forest is determined from the land sector remote sensing program and is subject to the associated quality control and quality assurance protocols described in Appendix 6A. Initial quality assurance of the coastal wetland models is based on in-house reviews of the models, underlying assumptions, and parameter and emission factor values, and is informed by the latest scientific literature published by members of the wetland advisory group, an external and independent advisory panel to the department.

6.13.5 Recalculations

Recalculations for *land converted to settlements* are reported in Table 6.65 below.

These include:

A. Refinements to FullCAM modelling of terrestrial forests – as detailed in section 6.9.5.1, recalculation of *forest land converted to grassland*.

B. Refinements in geospatial identification of mangrove converted to settlements areas.

C. Refinements to activity area for tidal marsh converted to settlements flowing from refinements in identification of mangrove transitions explained above. This reflects that the tidal marsh to settlements model uses as its tidal marsh transitions areas a proportion of tidal marsh transitions from the mangrove transitions spatial data.

Table 6.65 Land converted to settlements: recalculation of total CO_2-e emissions, 1990–2016

Year	Land converted to settlements						
	2018 submission	2019 submission	Change		Reasons for change		
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	%	A. Refinements to terrestrial forest modelling methodology	B. Additional spatial area analysed of mangrove converted to settlements	C. Additional spatial area analysed of wetlands converted to settlements
1990	3,104	3,142	38	1%	38	0	0
1995	1,726	1,811	86	5%	82	0	4
2000	1,654	1,675	20	1%	15	1	5
2005	1,779	1,877	98	5%	98	0	0
2006	1,837	1,964	127	7%	127	0	0
2007	1,422	1,621	199	14%	199	0	0
2008	1,073	1,573	500	47%	500	0	0
2009	909	1,000	91	10%	91	0	0
2010	1,015	1,098	83	8%	83	0	0
2011	971	1,018	47	5%	47	0	0
2012	864	881	17	2%	17	0	0
2013	885	892	7	1%	7	0	0
2014	864	911	47	5%	47	0	0
2015	637	669	33	5%	33	0	0
2016	582	929	347	60%	347	0	0

6.13.6 Source specific planned improvements

Grassland and *cropland converted to settlements* are included within *settlements remaining settlements*, based on land representation Approach 1 (IPCC 2006 Guidelines, Volume 4, page 3.10). Work is underway to accommodate the reporting of all conversions to settlements using land representation Approach 3 (spatially explicit land-use conversion data) in future inventory submissions.

The source specific planned improvements for the subcategory of terrestrial *forest land converted to settlements* is covered in detail under *forest land converted to grassland* (Section 6.9)

The following improvements are planned for the mangrove forest and tidal marsh wetlands conversions methodologies:

- Continuous improvement of parameter values within the seven coastal regions.
- Further assessment of the seven coastal regions regarding their adequacy in representing regional differences in tidal wetland characteristics around Australia.
- Assessing model outcomes against outcomes reported in the scientific literature on natural or anthropogenic disturbances in Australian tidal wetlands.
- A full uncertainty analysis of model parameter values, and model outputs.

6.14 Other Lands (Source Category 4.F)

All *other lands* are considered unmanaged, and as such, Australia does not report emissions and removals from this voluntary reporting category. *Other lands* typically occur in unmanaged regions of central Australia, e.g., deserts.

Other land, by definition, cannot include any land on which a forest has been observed in the Landsat time series since 1972. As a consequence of this definition *land converted to other land* is not observed.

6.15 Harvested Wood Products (Source Category 4.G)

For *harvested wood products*, the carbon pool considered is defined as the wood products in service life within Australia- that is, products consumed in Australia and not yet disposed to a waste stream, plus those that remain in solid waste disposal sites (SWDS). The stock of HWP in service is estimated as the national production (including transfers from *forest land* after harvest that are recorded as a carbon stock reduction in *forest land remaining forest land* and *grassland converted to forest land*) plus the imported material, minus exported material and product disposed to the waste system.

Transfer of carbon from in service HWP to landfill is recorded as a loss of carbon stock from the in-use HWP pools and as a gain in the HWP in SWDS pool. As material in SWDS decays, one half of the losses are recorded as an emission of CO_2 from HWP in SWDS and, reflecting the assumption that landfill gas is 50:50 carbon dioxide and methane, one half of the decaying carbon is emitted as methane.

6.15.1 Methodology

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since the 1940s. It is currently maintained as the Australian forest and wood products statistics by the Australian Bureau of Agricultural and Resource Economics and Sciences within the Department of Agriculture and Water Resources (ABARES, 2017a). This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model.

Model components

Information has been obtained and examined under the following components of the model:

- log flow from the forest: current annual production data were obtained by species groupings, and product classes, e.g., sawlogs, veneer logs, pulp logs, roundwood and other, e.g., sleepers;
- fibre flow from processing: data on the intake of raw materials to the various processing options and the output of products and by-products have been used in the model to estimate the total tonnes of carbon produced each year under various end product classes;
- import and export quantities of wood products;
- recycling;
- entry and decomposition in landfill;
- use for bioenergy; and
- other losses to atmosphere.

Wood flow

The model develops wood flows separately for each pool of wood products within the overall HWP pool and these are integrated to account for cross-linkages. This is particularly important in the accounting for waste or by-products, which are themselves used as resources in production for other wood product pools. In conjunction with the opening carbon stock and life cycle of timber products, this model enables the total and projected carbon stocks in HWP to be estimated.

In broad terms, the components of the models developed for each pool of HWP are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., "x" percentage sawdust, shavings or sander dust for on-site energy generation or compost, "y" percentage woodchips for other manufacturing processes, "z" of sawn timber products, panel products and paper;
- an estimate of the proportion of products by product categories, depending on whether their expected end use is long-term or short-term; e.g., framing timber, dry dressed boards, cases and pallet stock, panel products for use in house construction, panel boards for use in furniture and cabinets, newsprint paper, and writing and printing paper;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon; and
- import and export data obtained via the ABARES (2017a) source data by end use categories.

Details of the flows are shown in Appendix 6.I.

Treatment of bark

There has been no accounting for bark. All bark is regarded as being a component of logging slash (harvesting residue) and accounted for under in-forest logging operations.

Basic density and carbon content

Basic wood density and carbon content estimates (Table 6.66) are relevant to all processing options, and the choice of values adopted has a significant bearing on the final outcome. In the case of all sawn timber, and treated softwood and hardwood poles, weighted basic densities for the species involved have been applied across each category and the values adopted based on Ilic *et al.* (2000). For board products and paper, which have been subjected to varying amounts of compression during manufacture, their basic densities have been adjusted to that of the finished products.

Carbon content is defined variably throughout the literature, with values ranging from 0.4 to 0.53 of the oven dry (bone dry) weight. A figure of 0.5 has been adopted for use in the model as a median value extracted from Gifford (2000a).

Apart from the assumptions concerning basic density and carbon content, the other manufacturing assumptions were developed from interviews with representatives from the various industry associations and individual sawmilling companies.

Table 6.66 Basic densities, moisture and carbon contents

Carbon Fractions	
Description	**Value**
Fraction of softwood sawmilling dry matter that is carbon, by weight	0.50
Fraction of particleboard dry matter that is carbon, by weight	0.40
Fraction of MDF dry matter that is carbon, by weight	0.40
Basic Densities [(a)]	
Description	**Value kg m-3**
Density of softwood sawmilling	460
Density of hardwood sawmilling	630
Density of cypress sawmilling	600
Density of plywood (softwood and hardwood) and veneer	540
Density of particleboard	520
Density of MDF	600
Density of hardboard	930
Density of softboard	230
Density of pulp and paper: Paper	1,000
Density of pulp and paper: Softwood	430
Density of pulp and paper: Hardwood	500
Density of pulp and paper: Waste paper	1,000
Density of pulp and paper: Pulp	1,000
Density of paper and paperboard imports and exports, on average	1,000
Density of chips and logs for export: Softwood logs	415
Density of chips and logs for export: Hardwood logs	630
Density of hardwood poles, sleepers and miscellaneous	790
Moisture Content of Green Wood	
Description	**Value**
Ratio of weight of water to weight of wood substance in softwood chips	1.10
Ratio of weight of water to weight of wood substance in hardwood chips	0.90

(a) Basic density = (mass of oven dry wood in kg) / (volume of green wood in m^3)

Wood flows from processing

Wood flows in the various wood products produced in Australia have been developed under the following species/ industry headings:

- Softwood sawmilling;
- Hardwood sawmilling;
- Cypress sawmilling;
- Plywood;
- Particleboard and medium density fibreboard (MDF);
- Pulp and paper;
- Preservative treated softwood;
- Hardboard and Softboard;
- Hardwood poles, sleepers and miscellaneous; and
- Export of woodchips and logs.

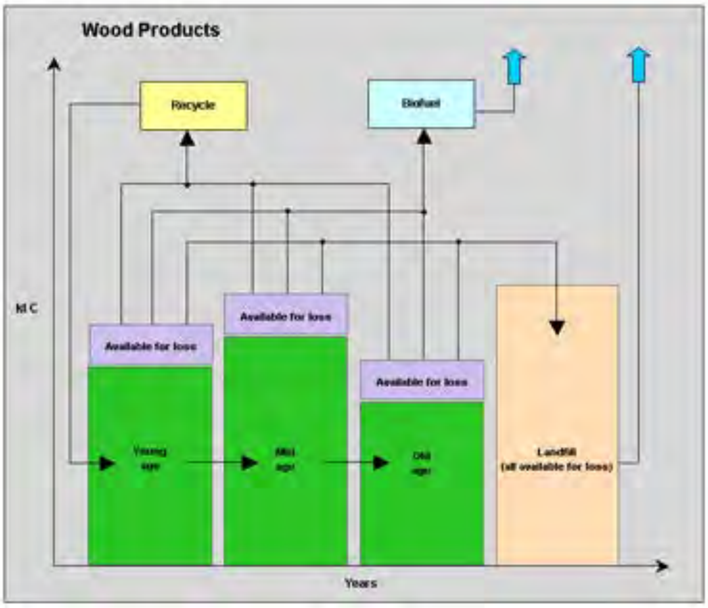
Life span of timber products (recycling and landfill)

The life span of wood products must be taken into account when ascertaining the quantity of carbon stored in timber products. Considerable attention has been given to subdividing the various timber products pools into different classes based on product and decay rates. The decay rates used assume that losses of material from service life will increase with product age. Therefore, the entry and exit of material from production to loss from each product pool is tracked and aged according to three age classes; young, medium and old. The proportion of material lost from each pool may vary (e.g., there may be little loss from young pools (excluding those to the medium age class)). Material is lost at a constant rate and may be placed in landfill, recycled, used for bioenergy or lost to the atmosphere (e.g., burnt with no energy capture) (Figure 6.35). The destination of material lost from service life is shown in Table 6.67.

Table 6.67 Destination of material lost from service life (kt C)

Year	Disposed to Landfill	Recycling and recovery of residues	Fuelwood consumed	Emissions from other processes (e.g. Aerobic decay)
1990	1,241	1,908	461	539
1995	1,265	2,336	531	333
2000	1,276	2,682	550	296
2005	1,294	2,897	544	434
2006	1,145	2,959	536	544
2007	1,056	2,982	546	709
2008	991	3,023	570	847
2009	940	2,998	438	927
2010	734	3,060	413	1,141
2011	762	3,024	392	1,139
2012	657	3,015	420	1,066
2013	611	2,963	311	1,192
2014	564	3,018	346	1,120
2015	573	3,074	355	1,054
2016	572	3,102	350	1,080
2017	520	3,173	350	1213

Figure 6.35 Structure of the Wood Products Model



For shorter-term products, the impact of the size of previous stocks is fairly slight, as the recent additions to the pools have the major impact. For long-term products, an estimate of the size of the initial pool is essential, but difficult. The size of the longest-lived pool representing housing products uses housing starts data.

Life span pools assumed for the Carbon Model

Very short-term products – Pool 1

- Paper and paper products.
- Woodchips and pulplogs for export.
- Age: young = 1; medium = 2; old = 3

Short-term products – Pool 2

- Hardwood – pallets and palings.
- Particleboard and MDF – shop fitting, DIY, miscellaneous.
- Plywood – form board.
- Hardboard – packaging.
- Age: young = 2; medium = 6; old = 10

Medium-term products – Pool 3

- Softwood – pallets and cases
- Plywood – other (noise barriers).
- Particleboard and MDF – kitchen and bathroom cabinets, furniture.
- Preservative treated softwood – decking and palings.
- Age: young = 10; medium = 20; old = 30

Long-term products – Pool 4

- Preservative treated softwood – poles and roundwood.
- Softwood – furniture.
- Roundwood logs for export.
- Age: young = 20; medium = 30; old = 50

Very long-term products – Pool 5

- Softwood – framing, dressed products (flooring, lining, mouldings).
- Cypress – green framing, dressed products (flooring, lining).
- Hardwood – green framing, dried framing, flooring and boards, furniture timber, poles, piles, girders, sleepers and other miscellaneous products.
- Plywood – structural, LVL, flooring, bracing, lining.
- Particleboard and MDF – flooring and lining.
- Softboard and Hardboard – weathertex, lining, bracing, underlay.
- Preservative treated softwood – sawn structural timber.
- Age: young = 30; medium = 50; old =90

A specified proportion of material is lost annually (an exponential loss) from each age class of each in-use product pool. The amount lost from each age class for each product pool can be capped and different proportions can be lost according to age. This feature of the model provides for 'steps' in product loss rather than functioning on either a simple linear or exponential loss applied to a whole product pool, irrespective of the average age of the pool. If inputs vary over time, the average age of products will vary, and this is represented by the amounts of material in each age class of each product pool.

Initial stock assumptions

Input data is available for the model since 1940. This has the benefit of allowing the model to establish new equilibrium pools, as the input material may be 'turned-over' several times prior to an equilibrium stock being reached for recent years. Initial stock estimation (for 1940) is more important for Pool 5 as this material may remain in use in housing assets.

Model calibration

Once the data on production inputs, processing flows and initial stocks is determined, other model calibration requirements include:

- the age at which material moves from young to medium and medium to old pools;
- the amount of each age class for each product pool exposed to loss;
- the rate of loss from each age class in each product pool; and
- the fraction of losses from each age class in each product pool to each of landfill, recycling, bioenergy and otherwise to the atmosphere.

The model estimates used are presented in Tables 6.68 and 7.5 (in Chapter 7).

Table 6.68 Decomposition rates and maximum possible loss

Pool	YOUNG		MEDIUM		OLD	
	Loss Yr^{-1}	Proportion of in use Pool exposed to decay	Loss Yr^{-1}	Proportion of in use Pool exposed to decay	Loss Yr^{-1}	Proportion of in use Pool exposed to decay
1	1.0	0.60	1.0	0.65	1.0	0.90
2	0.50	0.30	0.25	0.50	0.25	0.90
3	0.10	0.15	0.1	0.65	0.1	0.45
4	0.05	0.25	0.1	0.65	0.05	0.80
5	0.033	0.20	0.05	0.55	0.025	0.95

Model results

By integrating the carbon pools and life cycles of wood products, the model enables the total carbon pools and emissions to be estimated (Table 6.69).

Table 6.69 Carbon stock and emissions outcomes (kt C)

Year	Domestic Production of Wood Products	Imports of Wood Products	Exports of Wood Products	Increase Due to Wood Products	Carbon Pool (excl. landfill)
	kt C	kt C	kt C	kt C	kt C
1990	2,905	854	786	2,972	64,063
1995	3,503	997	1,194	3,307	69,846
2000	4,401	1,075	1,816	3,660	75,365
2005	4,932	1,180	2,193	3,919	81,690
2006	4,883	1,135	2,169	3,849	82,948
2007	5,045	1,169	2,386	3,828	84,158
2008	5,128	1,240	2,375	3,993	85,469
2009	4,701	1,088	2,153	3,636	86,438
2010	4,608	1,164	2,167	3,604	87,514
2011	4,694	1,277	2,338	3,633	88,626
2012	4,414	1,214	2,160	3,467	89,651
2013	4,137	1,212	1,983	3,367	90,644
2014	4,604	1,206	2,497	3,313	91,651
2015	4,989	1,228	2,796	3,422	92,768
2016	5,403	1,179	3,112	3,471	93,910
2017	5,787	1,157	3,467	3,477	95,101

6.15.2 Emission estimates

Table 6.70 Net emissions from *harvested wood products* 1990–2017 (Gg CO_2-e)

Year	Emissions
1990	-7,417
1995	-7,532
2000	-7,630
2005	-7,696
2006	-6,834
2007	-6,329
2008	-6,471
2009	-5,044
2010	-4,705
2011	-4,981
2012	-4,317
2013	-4,078
2014	-4,004
2015	-4,492
2016	-4,594
2017	-4,649

6.15.3 Uncertainties and time series consistency

A qualitative assessment of uncertainty was undertaken and uncertainties for *harvested wood products* were estimated to be medium. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

6.15.4 Source specific QA/QC

Wood product data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES, 2018). Economic data from the Australian Bureau of Statistics on the wood and paper products manufacturing industry is also used as a confrontational data source.

Original development of the models used to estimate emissions in the wood products category was undertaken by Jaakko Pöyry Consulting in 1999.

6.15.5 Recalculations since the 2015 Inventory

Table 6.71 Recalculations of the HWP inventory

Year	2017 submission	2018 submission	Change		A. Sawnwood	B. Other data changes
	(Gg CO_2-e)	(Gg CO_2-e)	Change (Gg CO_2-e)	Change (%)	(Gg CO_2-e)	(Gg CO_2-e)
1990	-7,416.93	-7,416.93	0.00	0.0%	0.00	0.00
1995	-7,562.77	-7,531.64	31.13	0.4%	31.09	0.04
2000	-7,769.64	-7,630.43	139.21	1.8%	138.71	0.50
2005	-7,633.54	-7,696.24	-62.70	-0.8%	-63.67	0.97
2006	-6,821.30	-6,833.52	-12.22	-0.2%	-12.81	0.59
2007	-6,315.32	-6,328.51	-13.19	-0.2%	-12.80	-0.39
2008	-6,456.95	-6,471.33	-14.38	-0.2%	-13.45	-0.93
2009	-5,021.24	-5,043.75	-22.51	-0.4%	-19.17	-3.34
2010	-4,688.55	-4,704.71	-16.16	-0.3%	-16.21	0.05
2011	-4,950.33	-4,981.48	-31.15	-0.6%	-31.18	0.03
2012	-4,299.98	-4,316.98	-17.00	-0.4%	-17.05	0.05
2013	-4,072.17	-4,078.22	-6.05	-0.1%	-6.10	0.05
2014	-3,982.06	-4,004.30	-22.24	-0.6%	-22.29	0.05
2015	-4,412.44	-4,492.36	-79.92	-1.8%	-79.99	0.07
2016	-4,574.23	-4,594.46	-20.23	-0.4%	-20.23	0.00
2017	-4,583.16	-4,649.40	-66.24	-1.4%	-90.74	24.50

Recalculations as shown in Table 6.71 are due to revised estimates in the Australian Forest and Wood Products Statistics (ABARES 2018) and other data changes, including an update to the accuracy of historical production estimates:

A. Revised estimates in the Australian Forest and Wood Products Statistics, including an update to the accuracy of historical production estimates. Data revision from year 2000 for the table 34 Imports of roughsawn hardwood sawnwood - Imports - Tabular data of ABARES Australian forest and wood products statistics: March and June quarters 2018 imports statistics - workbook XLSX. This can be found at http://www.agriculture.gov.au/abares/research-topics/forests/forest-economics/forest-wood-products-statistics

6.15.6 Source specific planned improvements

A review will be undertaken into the interactions of the harvested wood product model with the *forest land* classification (the source of biomass gains), and the *energy* sector (source of loss). The purpose of the review is to ensure that any improved understanding in scientific and technical literature of these interactions is reflected in the operation of the model.

An investigation will be made into improving the interactions between the wood products and waste models with respect to the disposal of woodwaste and paper to solid waste disposal sites.

6.16 N_2O emissions from N fertilisation 4(I)

Nitrous oxide emissions, associated with nitrogen fertilisers, are reported under the *Agriculture* sector (3D). N_2O released from the application of N fertiliser on forests is reported as IE (agriculture). The amount of N applied to lands in Australia is obtained from national statistics of the amount of N purchased. It is not possible to split the use of N fertiliser between agriculture and forests.

N fertilisation of native forests is very rare, if occurring at all. There is a limited amount of N fertiliser applied to forest plantations in Australia. Fertiliser application in plantations is typically done to correct for nutrient deficiencies and trace element correction at establishment. N may be applied on sites where it is shown that it is a significant limiting nutrient, but as most establishments are on pasture systems, background nutrient levels are typically sufficient.

6.17 Emissions and removals from drainage and rewetting and other management of organic and mineral soils 4(II)

Australia does not estimate emissions and removals from this voluntary reporting category.

6.18 Direct and Indirect N_2O emissions from managed soils – 4(III) and 4(IV)

6.18.1 Methodology – N_2O emissions from N mineralisation associated with loss of soil organic matters

An increase in N_2O emissions can be expected following a decline in soil organic carbon stocks. This is a consequence of enhanced mineralisation of soil organic matter that takes place as a result of soil disturbance. The conversion not only results in the net loss of soil organic carbon, but the corresponding effects on mineralised nitrogen can result in N_2O emissions from the process of nitrification and denitrification.

The IPCC (2006) methods are used to calculate N_2O emissions from this source. The amount of nitrogen mineralised is calculated from the C:N ratio of soil. The C:N values used are 18 for *forest land* and forest conversion categories and 10 for *grassland remaining grassland*, reflecting the approximate median value extracted from a survey of national estimates (Snowdon *et al.* 2005). The country specific emission factor for fertiliser additions to non-irrigated crops and pastures (0.002 (Gg N_2O-N/Gg N)) is then applied.

Emissions associated with N mineralisation in *cropland remaining cropland* soils are reported in the Agriculture sector (3.D).

6.18.2 Leaching and run-off

In accordance with the IPCC Guidelines, estimates are made of emissions associated with leaching and run-off of the N mineralised through loss of soil carbon. The CS method used for estimating leaching and run-off from agricultural N sources is used.

Annual nitrous oxide production from leaching and runoff is calculated as:

$E_{ij} = M_{ij} \times FracWET_{ij} \times FracLEACH \times EF \times C_g$ .... (4IV_1)

Where M_{ij} = mass of N mineralised due to a loss of soil carbon (Gg N)

$FracWET_{ik}$ = fraction of N available for leaching and runoff (Appendix 5.J.I)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff

EF = 0.0075 (Gg N_2O-N/Gg N) IPCC (2006) default EF

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.18.3 Uncertainties and time series consistency

Further details are provided in Annex 2.

6.18.4 Source specific planned improvements

All data and methodologies are kept under review and development.

6.19 Source Category 4(v) Biomass Burning

The methods applied to estimate emissions and removals associated with biomass burnt are described under 4.A *forest land* and 4.C *grassland*.

6.20 Spatial identification of carbon

Emissions accounting facilitates government policy-makers in the targeting of land sector measures towards significant ecosystems to preserve locations of high carbon value, support efforts to sequester carbon in the landscape, and perform mitigating work in locations where carbon has been lost.

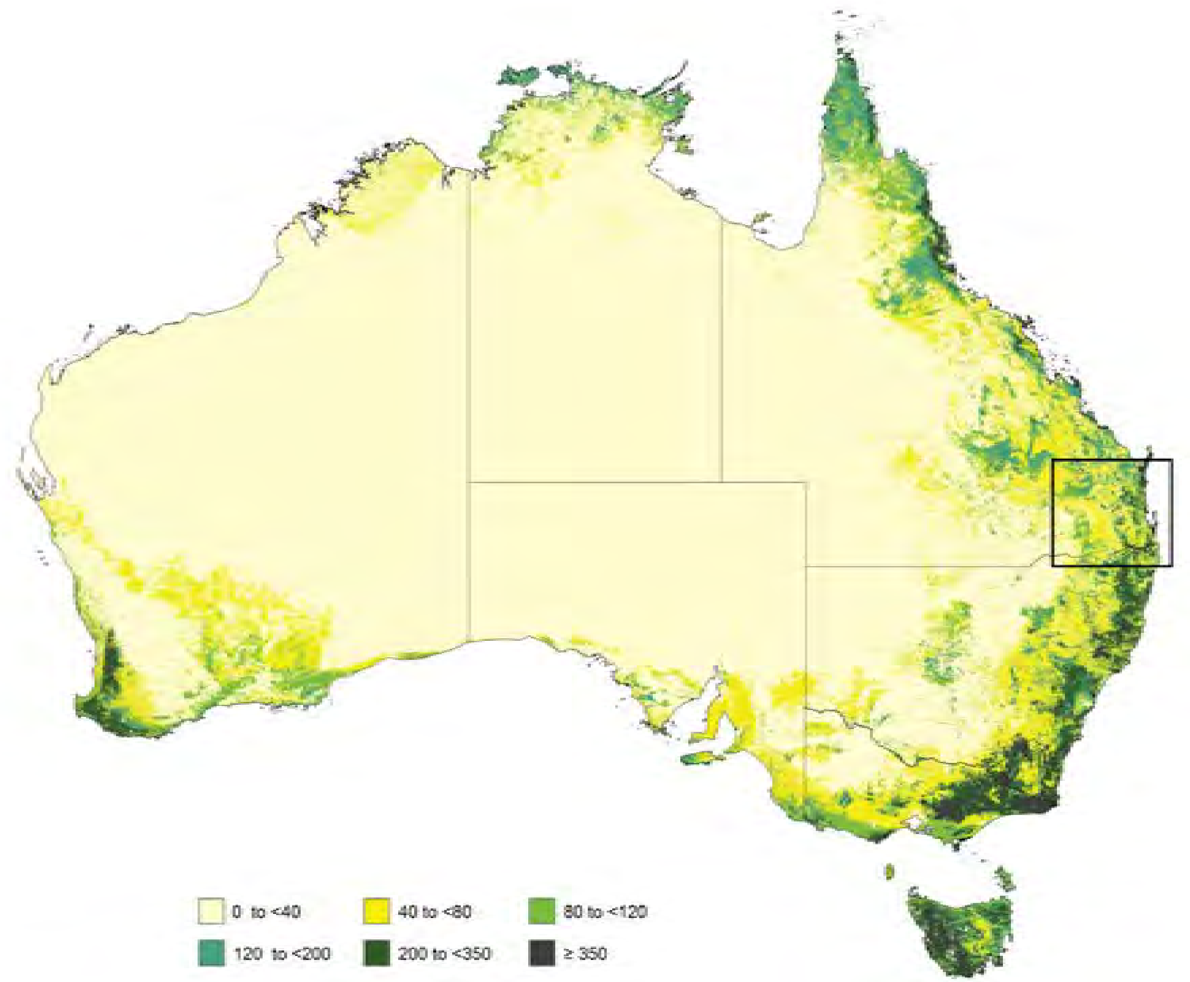
In 2017, Australia expanded the application of its FullCAM carbon modelling systems to produce high-resolution maps of carbon stock levels and carbon stock changes on the Australian continent. The FullCAM outputs are supplemented with information from those elements of the land sector that are not calculated in the FullCAM architecture to produce consistent carbon stock accounts for Australia under the System of Environmental-Economic Accounting (UN, 2014a) and its supplement on Experimental Ecosystem Accounting (UN, 2014b). As such, this system is not directly comparable with the UNFCCC accounting systems, but serves as an alternative view on available information. Further information on the construction of these accounts is described in Appendix 6.M. This accounting structure has been used as the basis for information published in the State of the Forests Report, indicator 5.1, by the Australian Bureau of Agriculture and Resource Economics in February 2019.

Figure 6.36a presents carbon stocks on the Australian continent as a carbon density measure in tonnes per hectare as calculated for 2016 Inventory. Figure 6.36b shows these carbon stocks for the South East Queensland region. These include all living biomass, debris, litter and soil carbon as assessed by FullCAM spatial simulations. Carbon density is highest in areas of forest, especially the native forests of South-Eastern Australia, South-Western Australia and the tropical rainforests of northern Queensland, where these have been undisturbed since at least 1972.

Figures 6.37a and 6.37b present the total changes, nationally and for South East Queensland, in carbon stock associated with lands converted to or from forest for the period of 1990-2005. Figures 6.38a and 6.38b present this for the period of 2005-2016. The transient impacts of wildfire are excluded from this analysis, but the continuing impacts of clearing and regrowth events observed before 1990 are included. Particularly prominent are the widespread losses in the moderately carbon-dense regions of Southern Queensland, and the gains from planting activity around the Green Triangle of south-western Victoria and south-eastern South Australia.

An aggregated account of carbon stocks in Australia was presented last year in the 2016 Inventory.

Figure 6.36a Carbon Stocks on the Australian Continent, 2016, t/ha



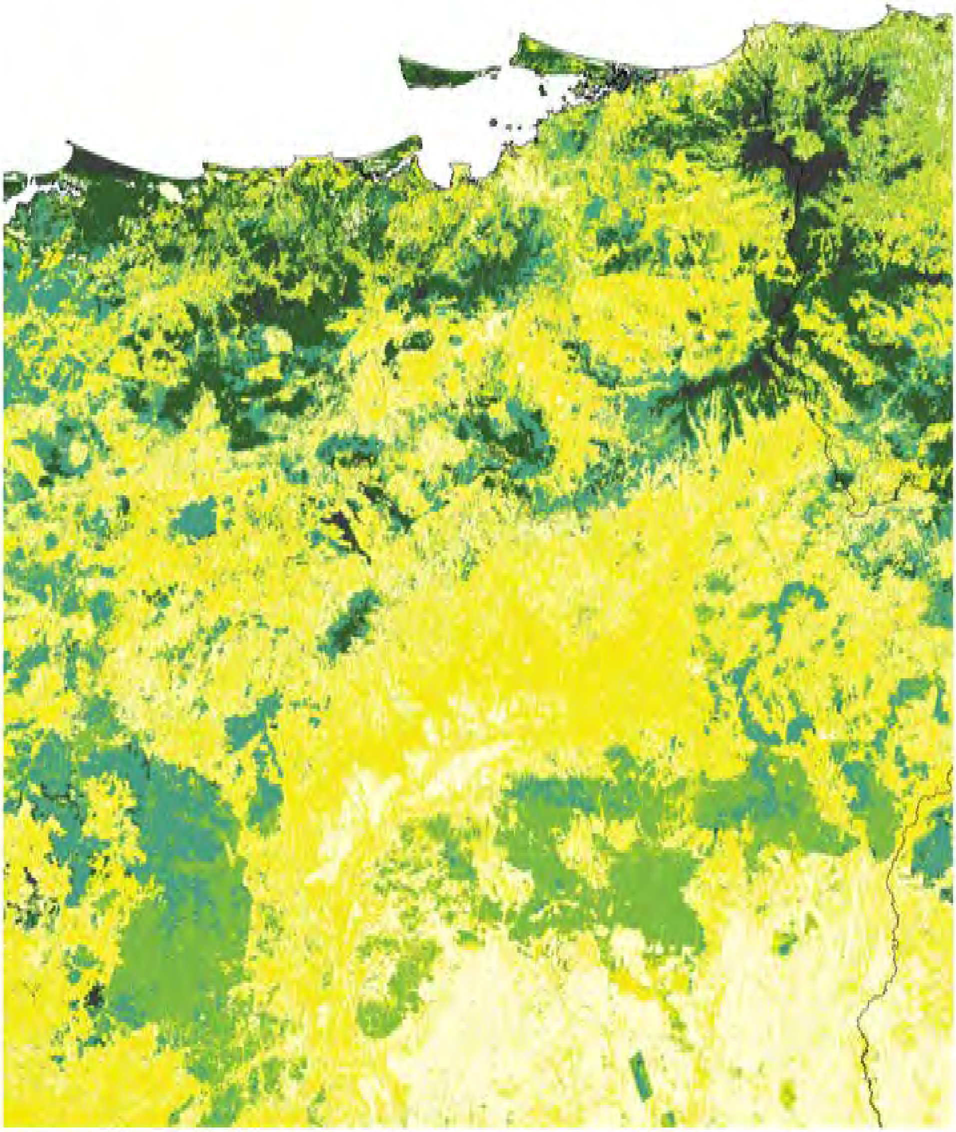
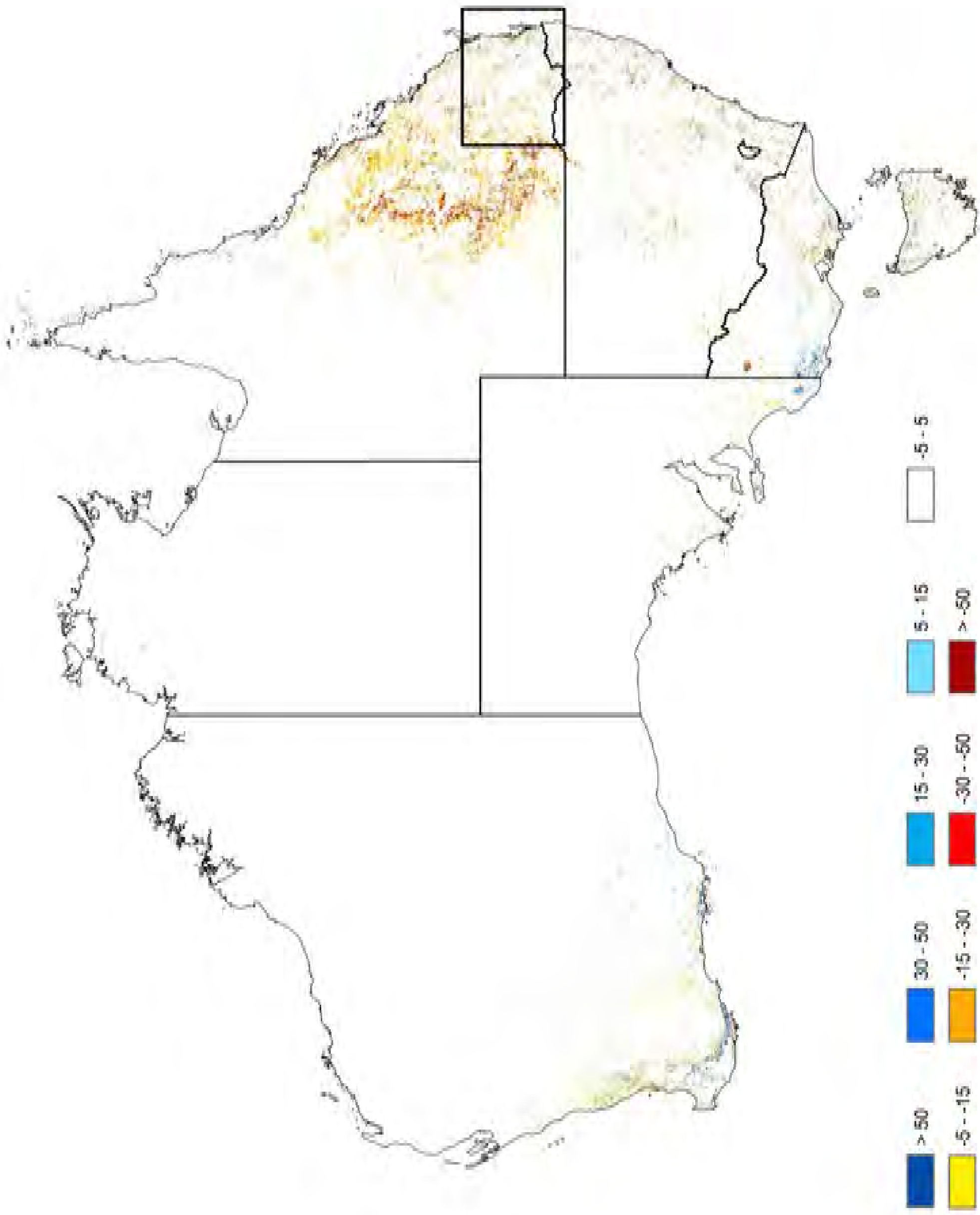


Figure 6.36b Carbon Stocks in South-East Queensland, 2016, t/ha

Figure 6.37a Carbon stock changes in Australia due to forest gains and losses 1990-2005, t/ha



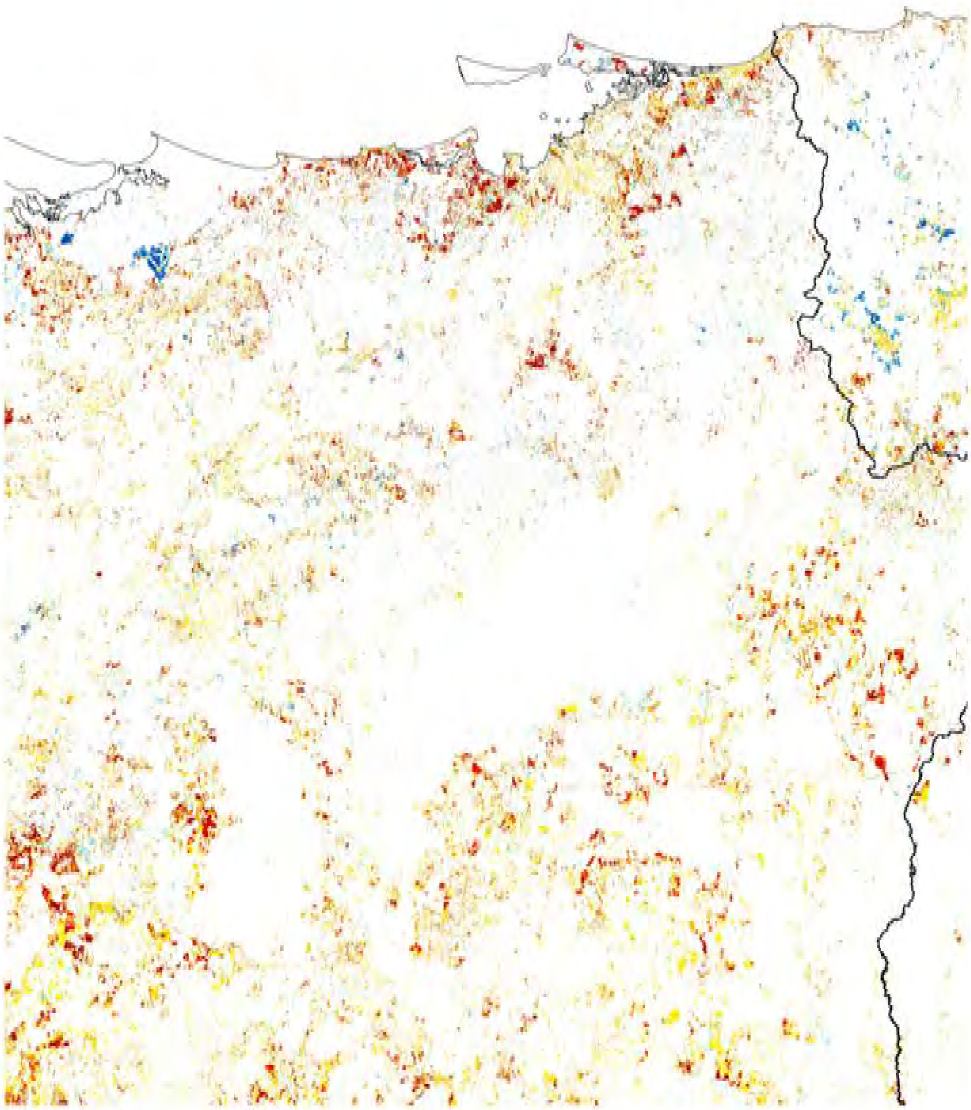
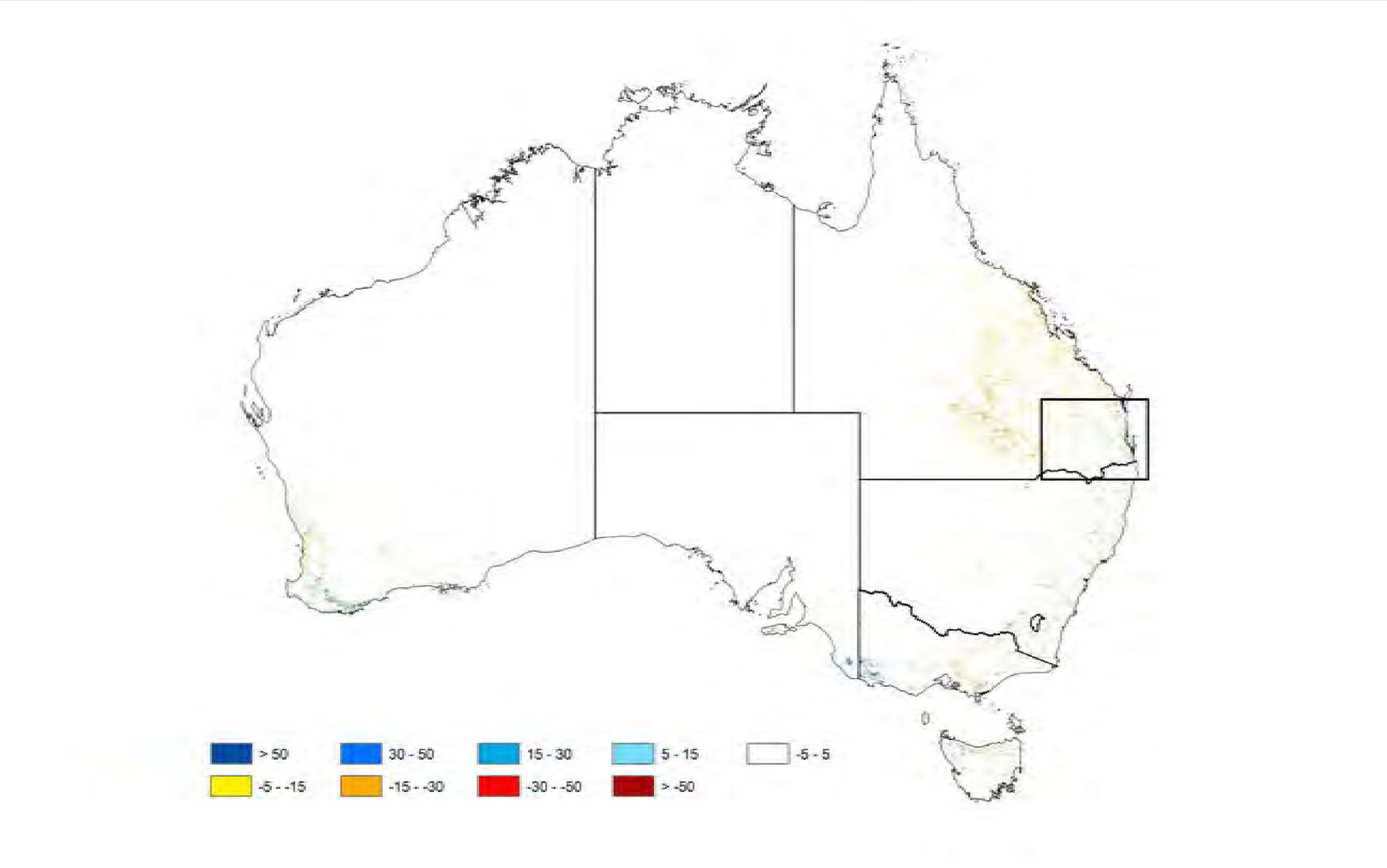


Figure 6.37b Carbon stock changes in South-East Queensland due to forest gains and losses 1990-2005, t/ha

Figure 6.38a Carbon stock changes in Australia due to forest gains and losses 2005-2016, t/ha



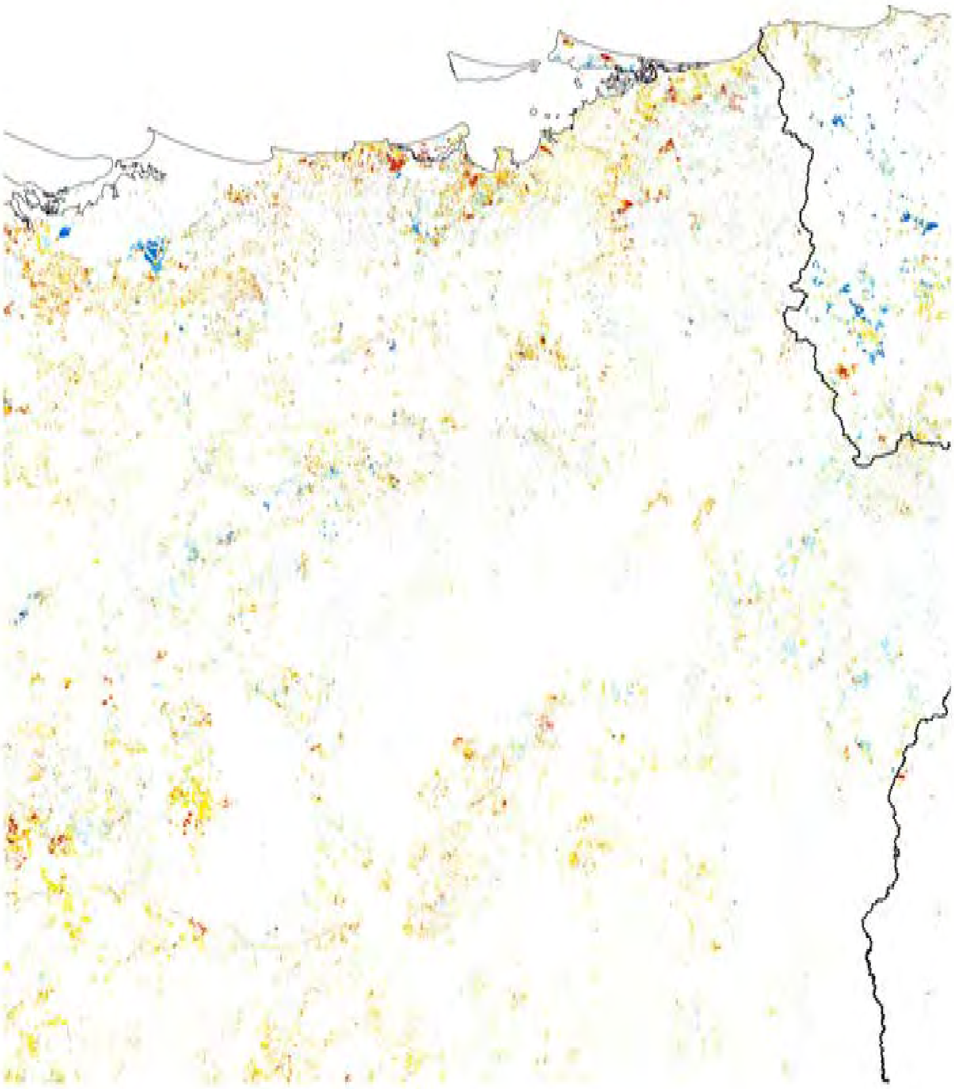


Figure 6.38b Carbon stock changes in South-East Queensland due to forest gains and losses 2005-2016, t/ha

Appendix

Appendix 6 A Land cover change

6.A.1 Introduction

The estimation of net emissions for the land sector is supported by the use of remote sensing imagery to determine a time series consistent assessment of land use change in Australia.

The Department of the Environment and Energy has assembled a series of national coverages of Landsat satellite data (MSS, TM, ETM+ and OLI) across 27 time epochs from 1972 to 2018 which are analysed to identify both where and when land use change occurs.

The archive of time series of historic cover and cover change information managed by the Department extends as far as possible given the importance of time series consistent data from 1990 to the present. The effects on emissions from land cover change are typically long lasting, and estimates of emissions from current activities will be affected by the site history. A current conversion event, for example, will likely generate fewer emissions if the forest cleared is secondary forest (regrowth after a previous deforestation) rather than a primary (mature) forest. Consequently, an extensive record of land management history is a critical input into the preparation of accurate emission estimates.

6.A.2 Monitoring change with remote sensing imagery

Satellite Data Processing

A detailed protocol of remote sensing specifications for land cover change was developed by Furby (2002) through extensive pilot testing (Furby and Woodgate, 2002) to ensure time series consistency of methods, and the provision of spatially accurate land cover change data through time. These specifications determine the exact way that images are acquired, processed and classified.

The sequence of processing stages have been streamlined since the development of the Australian Geoscience Data Cube in 2014. The process to produce the assessment of Australia-wide land cover change is:

- selecting highest quality cloud free pixels acquired during the summer season for the southern tiles and the winter season for the northern tiles, from the Data Cube;
- mosaicing[7] of multiple images to the individual map tiles for each time sequence;
- thresholding[8] through all time sequences;
- conditional probability network (CPN) analysis (Kiiveri *et al.*, 2001), each year over the entire time series; and
- attribution[9] of change to direct human-induced change.

Image acquisition and selection

The time series of available Landsat images extends from 1972 to 2018. The selection of periods for analysis, shown in Table 6.A.1, was designed to give maximum temporal resolution immediately before and after 1990 and for the period from 2004 onwards to maximise accurate detection of trends in land cover change over time.

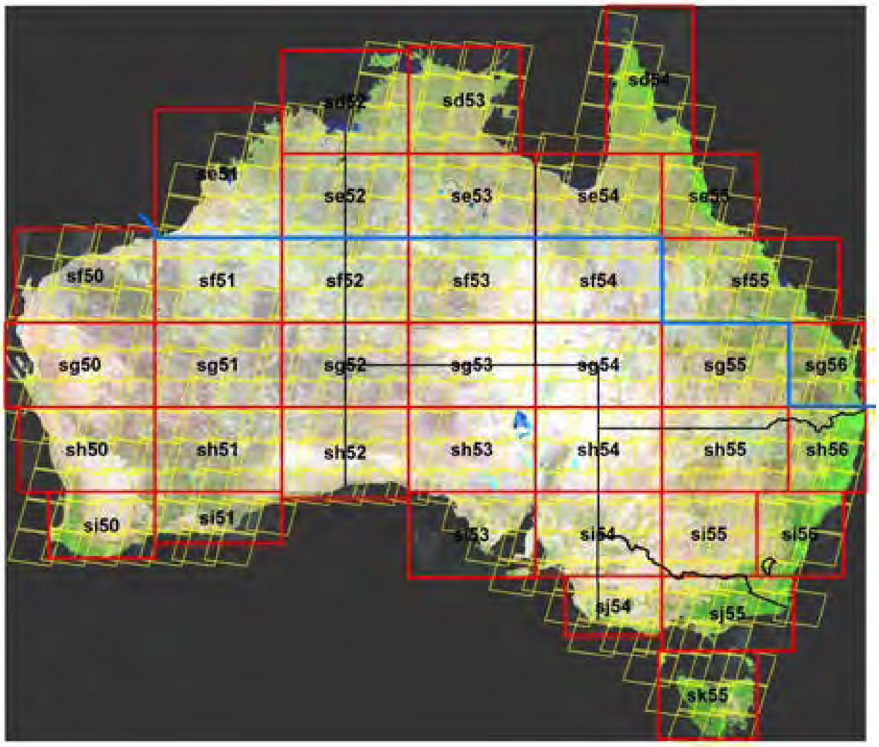
7 Mosaicing aggregates images into the map tiles shown in red in Figure 6.A.1, removing overlaps in the original 185 km*185 km images and optimising cloud removal.

8 Thresholding compares each image pixel to a reference set of spectral characteristics formed by specific band mixes (indices) that represent forest and non-forest conditions.

9 Attribution uses a combination of automation and visual inspection of the image sequence to determine the cause of land cover change and determine subsequent/existing land use.

Since 2005 imagery has been delivered on an annual basis. Figure 6.A.1 shows the 37 map tiles used in the remote sensing programme (red), the north-south seasonal divide used for image capture (blue line) and the paths/rows of Landsat imagery (yellow).

Figure 6.A.1 The 37 1:1 million scale map tiles used in the remote sensing programme



Selection of suitable Landsat scenes from the Data Cube is fully automated. For a given location, the season from which the scene should be selected is identified and the best (cloud-free) image is automatically allocated from the stack within the Data Cube. The image selection criteria (Furby, 2002) require the images to be within three months of the nominated target date. The target dates vary between the north (winter or dry season) and south (summer) of the country and aim to provide the best possible forest discrimination (see Figure 6.A.1). The precise date allocated to each land cover change (clearing and regrowth) pixel is randomly generated by *FullCAM*, within the sequence of coverage dates for the relevant map tile. This method provides a random (unbiased over a large sample) distribution of initialisation dates (timing of land cover change event) for the carbon model, within the constraint of the two dates in the overall interval of the image sequence.

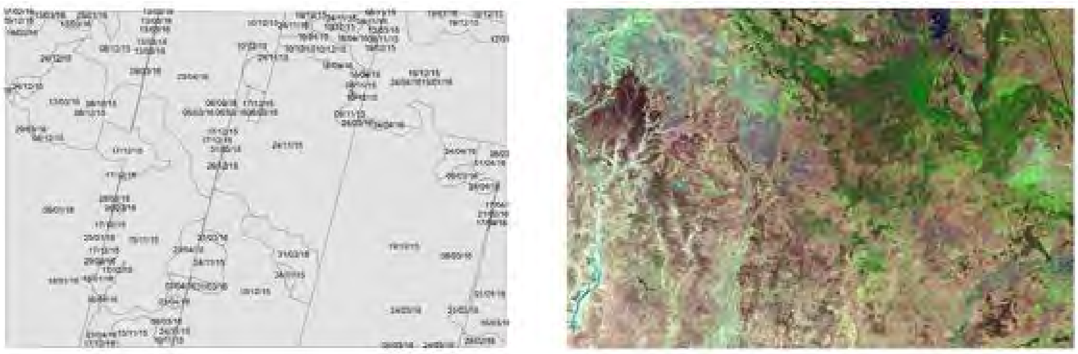
Table 6.A.1 Landsat Image sequence

Year	Resolution (m)	Time since previous image (yrs)
1972	50	-
1977	50	5
1980	50	3
1985	50	5
1988 (early)	25/50	3
1989 (end)	25/50	2
1991 (early)	25	1
1992	25	2
1995, 1998	25	3
2000, 2002, 2004	25	2
2005-2018	25	1

Mosaicing

Scene selection and compositing is automated so multiple images can be combined within each path/row to create a cloud free composite (Furby, 2016). Figure 6.A.2 shows how a mosaic is constructed using multiple images within each path and row, resulting in a composite cloud free image. However, in inherently cloudy locations, some gap filling from earlier imagery may be required.

Figure 6.A.2 Image selection procedure, to create composite cloud free imagery mosaics



Unit of analysis – spatial resolution of the imagery

The 'natural' pixel size of the 1972 to 1985 Landsat MSS (57 m × 79 m) is re-sampled to a 50 × 50 m pixel. The 30 × 30 m native resolution of the Landsat TM, ETM+ and OLI data available after 1985 is produced as 25 × 25 m pixels. This approach deals with the change in pixel size of the various Landsat sensors over time and supports the need for spatially and temporally consistent integration with other spatial data used in *FullCAM*.

To apply the pixel-by-pixel analysis over the period where the pixel size changed from 50 m to 25 m, a 50 m MSS equivalent (in both spatial and spectral resolution) is derived from the 1989 TM (25 m) data, and then forest extent is calculated separately from both the 50 and 25 m data sets. Differences in the extents of forest between these two outputs are due to "sensor change". An overlap technique is used to ensure time-series consistency such that the assessment of land cover change for 1988-89 is then based on a 50 m to 50 m comparison, while the 1989-1991 data is a 25 m to 25 m comparison. As part of continuous improvement, processing of 1988 Landsat TM data at 25m spatial resolution has been completed, replacing the 50 m resolution MSS data for 1988. Consequently the entire land cover time series data has been recalculated making use of best available data while maintaining time series consistency. This approach is consistent with good practice for ensuring time-series consistency where the instruments used to collect activity data change or degrade through time (IPCC, 2003 page 5.58).

All Landsat derived data are used at a consistent 25 m resolution for the full time series analysis by re-sampling the 50 m pixels (1972-1985 products) into four 25 m pixels. A spatial-temporal model (see the Conditional Probability Network section below) is used to reduce the effect of "mixed" isolated and edge pixels in the overlap period. The ability to determine, from 1988 onwards, the effects of land use change to 0.2 ha minimum areas is robust, given that this area is greater than the pixel resolution and the approach used removes mixed and other pixels which are temporally and spatially inconsistent.

Re-sampling Landsat TM, ETM+ and OLI sensor data to 25 m pixels is a common practice and provides consistency over the multiple resolutions of Landsat sensors while ensuring uniformity across the time series. Quality assurance and validation processes confirm that accurate results are achieved with this re-sampled data.

Use of Landsat 8 Data

Observations of recent land cover change have been derived from the latest sensor on-board the Landsat 8 satellite, Operational Land Imager (OLI). OLI is an advanced sensor designed to collect improved quality data, ensuring continuity of previous instruments – Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors. Landsat 8 products supplied through the Australian Geoscience Data Cube are in a new format known as the Australian Reflectance Grid (ARG25). ARG25 is a pre-processed product corrected for geometric distortions and calibrated as absolute surface reflectance, hence the specifications of this new product are quite different to the previous Landsat 5 and 7 data products used for the national inventory Land Cover Change Programme (LCCP). To ensure time series consistency and compatibility with the existing LCCP, a detailed technical assessment of the geometric and radiometric consistency and interoperability between these two products was undertaken.

First, geometric consistency was assessed by matching about 13,300 ground control points (GCP) drawn from the LCCP scenes held in the national inventory data library and the corresponding ARG25 scenes. Assuming that the correlation matching succeeds in correctly registering each point, the position residuals provide a measure of the accuracy of co-registration of the two datasets. This analysis showed that whilst the temporal geometric accuracy of ARG25 products is highly consistent, several GCPs had residual matching errors ranging from 1, 2 and greater than 2 pixels compared to the LCCP products. The mis-registration, if not accounted for, would result in false change being reported. To resolve this, the mean residual vector for each ground control point (GCP) was calculated and applied to the LCCP scenes to align with the ARG25 product base. The scene specific transformation coefficients ensure that the two products are aligned and consistent to within a pixel for the entire country.

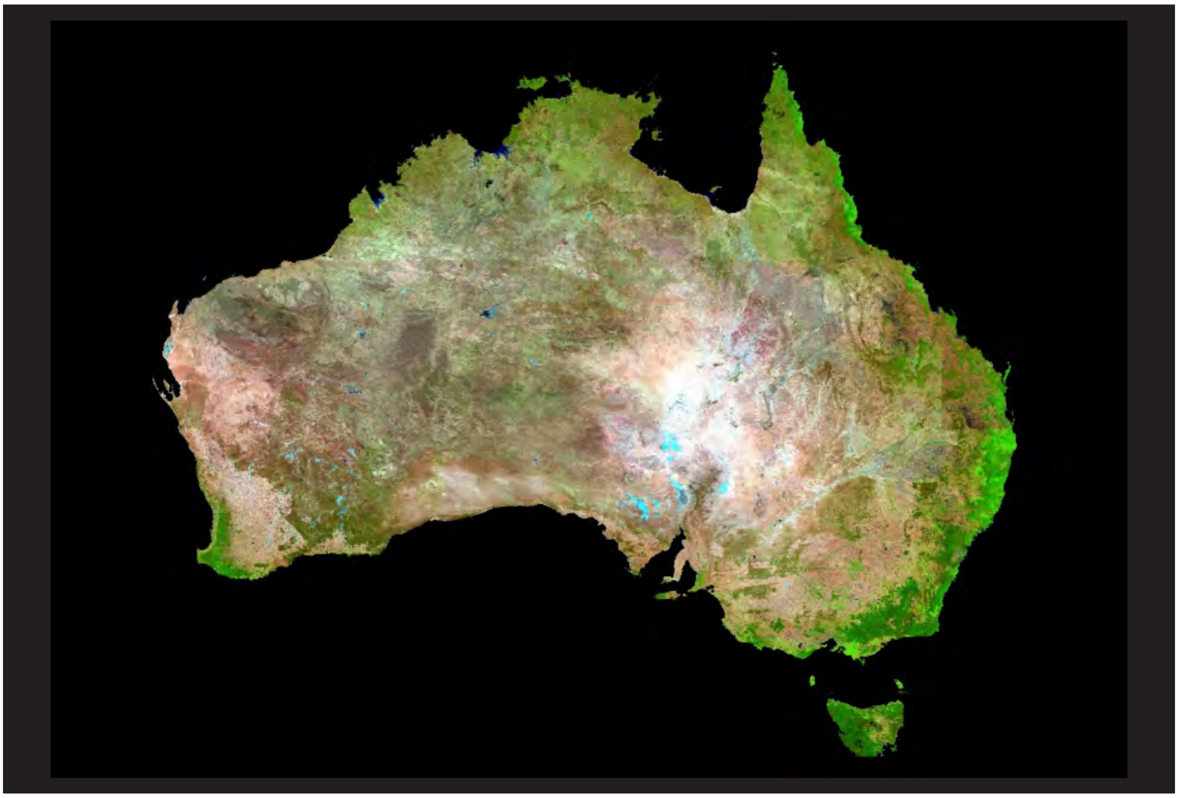
The second step in the process was to assess the radiometric consistency between the ARG25 and LCCP products using a total of 339 image pairs from the 2005 continental coverage. The two products were paired up based on the Landsat path and row, and image acquisition date. Null pixels in either image were discarded. Pixels located in very dark or very bright regions in the LCCP images were also excluded from the analysis, since such values may have potentially saturated during the pre-processing. The remaining pixels were linearly regressed against each other, assuming that the relationship will be strongly linear if both products are internally consistent in relation to radiometric characteristics. Correlation values were calculated for each band, gain, and offset combination. The gain and offset values for converting LCCP pixel values into ARG25 pixel values can be expressed as –

ARG25 = gain × LCCP pixel value + offset

The relatively high correlations found in the 2005 coverage confirm that there is a strong linear relationship, across all bands, between the LCCP values and the equivalent ARG25 image values. Based on this study a scene specific, linear transformation coefficient for each band was calculated to convert the LCCP calibrated pixel values to be consistent with the ARG25 surface reflectance values (Devereux, *et al.* 2013). The time series consistency of this method was also assessed for selected sites using eight years of surface reflectance data.

Based on this study, from 2015 the ARG25 Landsat 8 datasets (Figure 6.A.3) have been processed to a consistent quality, LCCP compatible tile based mosaic which are then subjected to image classification to derive forest probability maps.

Figure 6.A.3 2018 Landsat 8 surface reflectance image of Australia



Thresholding (forest extent >20 per cent canopy cover)

Thresholding is the process through which pixels in the land cover image sequence are identified as either forest or non-forest. Pixel identification involves comparing the spectral indices of each pixel in the land cover image sequence with reference indices that identify areas of forest in selected strata. Reference indices were established through the use of air photographs, ground data and very high resolution satellite data. Aerial photographs with known forested areas were interpreted and compared with the Landsat data of the same area and around the same time. The Landsat data spectral bands of the forested area were then identified as reference indices for a given forest and soil type. The aerial photograph interpretation was undertaken centrally by appropriately qualified and experienced interpreters. The interpreters provided brief descriptions of forest or non-forest areas at a set of known locations. These descriptions were then used in the selection of reference indices from the Landsat data.

The final reference indices allow for variability in both forest and soil type by selecting indices within homogeneous strata. The stratification to deal with this variability was achieved largely through vegetation and soils mapping. The final reference indices used to identify areas of forest/non-forest are consistent with the definition of a forest, i.e., a minimum of 20 per cent canopy cover and a minimum potential height of 2 m.

Thresholding (Sparse Woody Vegetation <20 per cent canopy cover)

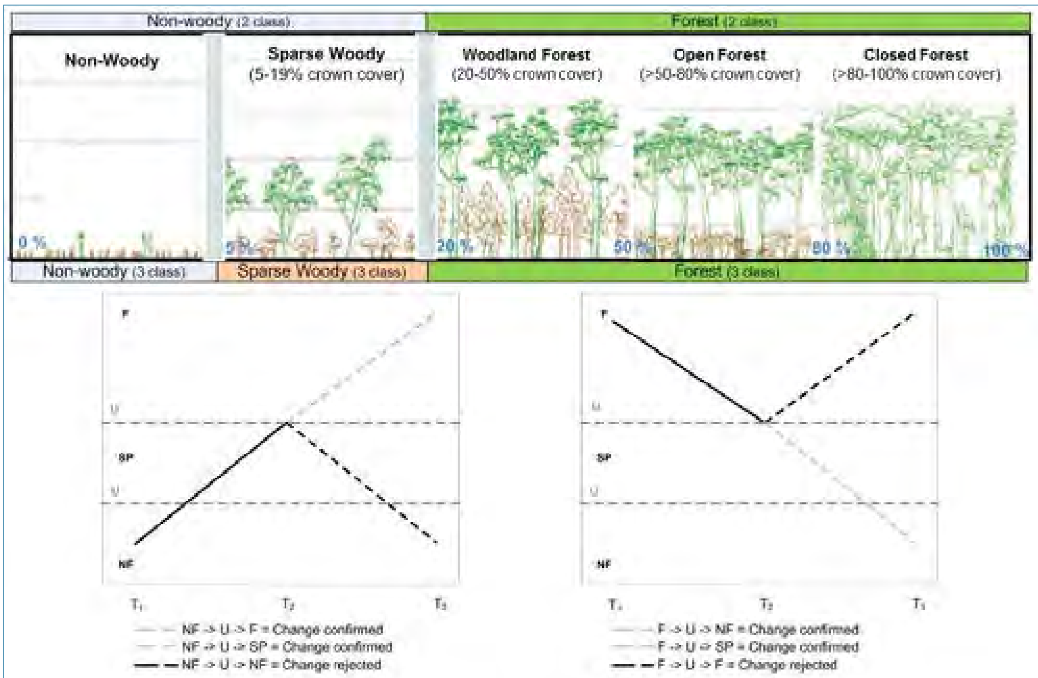
A national mapping programme has been undertaken to assess both the extent, and changes in extent, of sub-forest forms of woody vegetation using the Landsat TM, ETM+ and OLI data from 1988 to 2016 (Caccetta and Furby, 2004). This method builds on the 2-class (forest and non-forest) time series CPN classification technique, by incorporating an additional spatial measure to distinguish between sparse woody vegetation (5-7 per cent to <20 per cent canopy cover) and forest (≥ 20 per cent canopy cover). The 3-class classification better reflects the different types of woody vegetation across the Australian landscape.

The 3-class algorithm provides increased confidence and certainty in the identification of woody vegetation change. As the entire range of woody vegetation needs to be monitored for reporting under the Kyoto Protocol second commitment period and the Paris Agreement, it is essential to create a product that better encompasses all woody vegetation. In the traditional 2-class product, uncertain pixels near the 20 per cent canopy boundary were classified as uncertain forest (see Figure 6.A.4). These pixels had a lower probability of being forest and unless confirmed as forest after the CPN application, ended up being classified as non-forest. Using the 3-class algorithm, forest sites are identified using the same decision boundaries as the previous 2-class product, but a further set of decision boundaries are applied to separate the sparse and non-woody sites using a texture index and two spectral indices. This is a less conservative approach that ensures transitions between woody vegetation types are captured and allows pixels that fall in the uncertain zone to be classified as woody vegetation. Figure 6.A.5 compares the previous 2-class (forest and non-forest) product with the current 3-class outputs. Background image is from UrbanMonitor™ 2014 (Figure 6.A.5 (A)), and a Landsat false colour composite 2014 (B). Forest is highlighted green and Figure 6.A.5 (D) shows sparse vegetation (in orange) that was detected using the 3-class algorithm.

The extent of sparse woody vegetation covers the period from 1988 to 2018, except for two interior rangeland areas, for which current sparse woody coverage is limited to 2006. As sparse vegetation has now been incorporated into the 3-class woody vegetation classification, the forest extent and change data has been regenerated for the entire time series to ensure consistency from 1972 to present for all tiles.

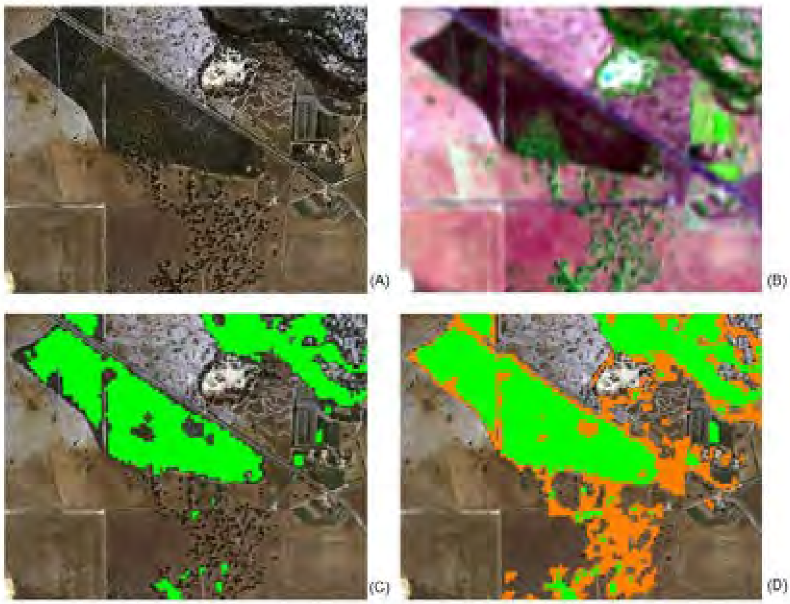
Processing for sparse includes setting woodiness thresholds to identify certain forest, certain non-forest and the uncertain region that could be classified as sparse. The thresholds vary across the landscape according to factors such as soil type, geology and rainfall (Furby, 2016). The conditional probability assigned to each pixel is a result of threshold values being compared to training regions of known vegetation classifications, and also compared to the probability values from the previous epoch at a given location. The forest cover probability images output from this process are reviewed to assess the adequacy of the thresholds and revised accordingly.

Figure 6.A.4 3-class algorithm to detect entire range of woody vegetation.



Source: Adapted from *Australia's State of the Forests Report 2013*

Figure 6.A.5 Comparison of traditional 2-class forest and non-forest product with the new 3-class product



Conditional Probability Network analysis

Remote sensing pilot testing demonstrated the need for time-series consistency in image data pre-processing, analysis and subsequent formation of time-series woody/sparse/non-woody labels. The operational standards (Furby, 2002) give explicit emphasis through documented rule sets to each of these areas. For time-series classification, these standards also include the use of a joint spatial-temporal model, in this case a Conditional Probability Network (CPN) (Caccetta, 1997; Caccetta *et al.* 2003; Kiiveri *et al.* 2001, 2003), for determining a time-series of woody/sparse/non-woody classes. This process produces superior woody extent and change results compared to a process reliant on pair-wise differencing of image pairs. The use of pair-wise differencing methods can lead to change estimates that are affected by errors due to seasonally changing land management effects (introducing large contiguous areas of false change), or by subtle sampling differences where mixed pixels have varying composition of woody/non-woody from year to year (producing many isolated false change pixels or edge effects at woody boundaries).

The land cover change programme uses Conditional Probability Network (CPN) analysis to strengthen confidence in the 'woody', 'sparse woody' and 'non-woody' classification of a pixel (previously 'forest' or 'non-forest'). This is achieved using a series of spatial and temporal rules to create woody vegetation and land cover conversion datasets. The temporal rules bias against unlikely events such as multiple one year conversions between woody and non-woody, as the CPN empirically assesses the logic of vegetation cover status of a pixel at a point in time, compared to the previous and subsequent images. This helps to eliminate false change from a single image that may be due to anomalies in the data such as unseasonal greenness, wetness or flooding, or missing data. The rules are particularly effective when the time between observations is less than that of a forest growth and harvest cycle.

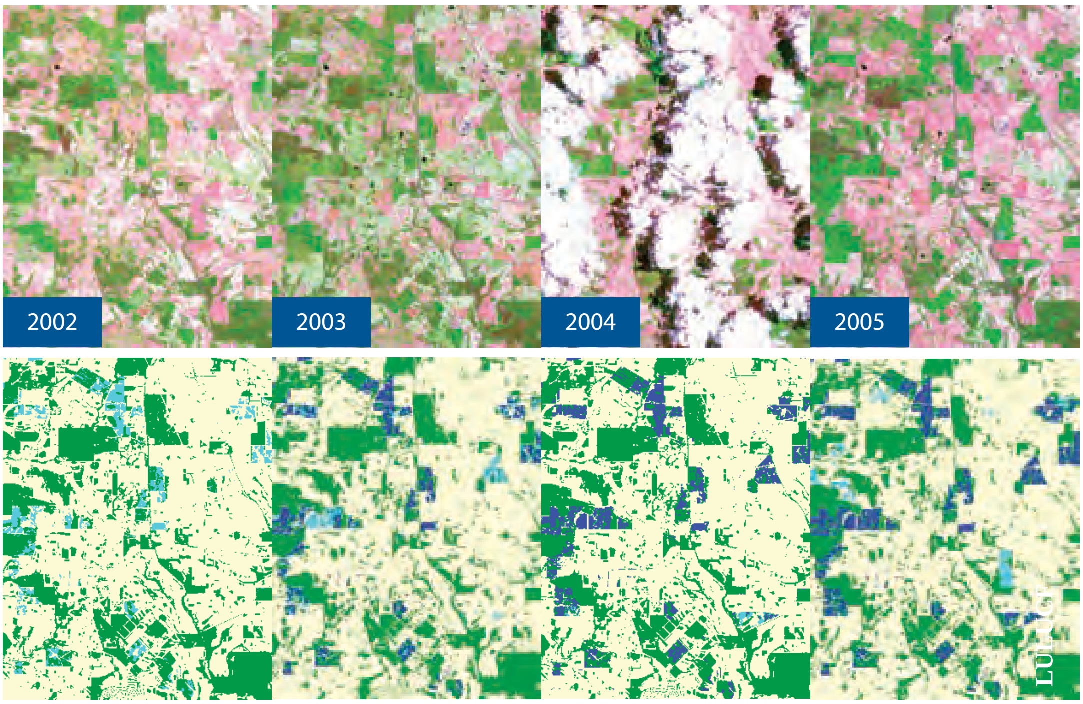
The spatial rules consider the labelling of a pixel in the context of its spatial surroundings, where labels that are consistent with the neighbouring labels are reinforced as opposed to those that are inconsistent (e.g., isolated pixels). This method evaluates the status of adjoining pixels as well as the pixel of interest, which has the effect of reducing 'flickering' false change in scattered and edge woody pixels. It also ensures that individual and small clusters of forest pixels have a high classification certainty in relation to their neighbouring pixels and through time, minimising false detection of individual woody pixels and minimising false change in woody classification that would otherwise occur as a result of small changes in the crown cover of isolated pixels. The spatial and temporal rules work together to provide spatial and temporal consistency, minimising temporally varying "mixed pixel" effects (due to spatially varying sampling from independent satellite overpass from year to year) and subsequent error in pixel and change labelling.

This comparative analysis of the same land unit over time was made possible by the accurate and consistent geographic registration and spectral calibration of the image sequences, providing the ability to 'drill' through time on a pixel-by-pixel basis. Geographic registration ensures that the same pixel is being looked at through the time sequence. It also avoids incorrect change status determination due to substitution of neighbouring pixels that could have different forest cover status, relative to the correct pixel for that location. Spectral inconsistency can also potentially increase the area attributed to clearing and regrowth events by variable status determination due to image calibration difference. This is addressed by consistent (spectral) calibration, thereby preventing the identification of false clearing or regrowth events and results in a more accurate land cover change map. Consistent registration and calibration are both required to ensure robust multi-temporal change analyses.

The CPN allows areas of missing data, such as those due to cloud cover in the Landsat imagery, to be filled in based on the cover status of the earlier and later images (see Figure 6.A.6). With the advent of optimal cloud free image selection from the Data Cube, the amount of missing data is reduced. However gap filling is still necessary in places due to imperfect automated cloud masks and the lack of available data for locations that are inherently cloudy.

There is also potential for sub-pixel shifts to change the forest/non-forest status on the edges of forest systems where a small edge portion of the pixel may have previously been just over the forest area, but a small shift in geographical registration (e.g., 10 m) would be enough to move the pixel out of the forest area. The spatial rules take the status of adjoining pixels into account and so reduce false change in isolated and edge woody pixels.

Figure 6.A.6 Images of forest extent and change, showing how the CPN gap-fills missing data due to cloudy imagery



Green: forest 2000
Blue: new forest 2000-02

Green: forest 2000
Dark Blue: new 2000-02
Light Blue: new 2002-04

Green: forest 2000
Dark Blue: 2000-04
Light Blue: 2004-05

Green: forest 2000
Dark Blue: 2000-05
Light Blue: 2005-06

Forest extent and change analysis

Once the change in forest cover status has been determined for each pixel for a point in time, the spatial relationship of each change pixel to other surrounding or nearby change pixels is assessed to identify isolated pixels with forest cover that do not form part of a forest system. This allows for the identification of pixels that are isolated trees not meeting the minimum canopy criterion defining a forest, as opposed to those pixels that may be part of sparse linear features such as roadsides and riparian zones which do meet the canopy criterion. A minimum mapping unit filter is applied to remove the isolated pixels from the data to be used for attribution.

The area of land cover change is determined as the sum of the changed pixels through time. This approach minimises inclusion of pixels that represent gaps in the forest canopy. An independent study which looked at the implication of the inclusion or exclusion of forest canopy gaps in this way found that the resultant area estimate could vary significantly between approaches (ERIC, 2001). The approach used only includes the area of forest canopy loss and not 'gaps' in the forest canopy. This provides a much lower estimate of area cleared than specified in clearing permits, which usually define the area bounded by the clearing, including gaps in forest canopy cover. Subsequent carbon stock and emissions estimates are computed consistently with the spatial area calculation method. That is, the carbon stock values should reflect the area under canopy, and are not an average that includes 'gaps' between areas of tree canopy.

Using the 3-class product allows us to identify six types of land cover changes in the landscape, namely:

- non-woody to sparse
- non-woody to forest
- sparse to forest
- sparse to non-woody
- forest to non-woody, and
- forest to sparse

Land cover changes related to forest cover gain and loss are reported as *land converted to forest* and conversions of forest land to other land classifications (sections 6.5, 6.7, 6.9, 6.11 and 6.13), whereas changes in sparse woody cover are reported in the *grassland remaining grassland*, *wetlands remaining wetlands* and *settlements remaining settlements* categories (sections 6.8, 6.10 and 6.12) consistent with the 2006 IPCC guidelines.

Attribution of change

The high resolution automated spatial assessment across the continent identifies land cover change resulting from many causes. For unique identification of conversion to another land use it is necessary to attribute the change event as either direct human-induced and permanent or due to natural temporary effects or methodological artefacts. Land cover change due to temporary tree dieback, natural dynamics of tree mortality and recruitment, drought and both seasonal and inter-annual variability (causing green 'flushes' of growth with similar spectral signals to regrowth) are also identified and excluded by means of an automated, rule based monitoring system, that monitors the temporary loss of forest cover for x number of years to determine if a permanent change in land use or deforestation has occurred. Qualified technical staff use visual image backdrops such as Landsat, Google Earth™, Planet™ and DigitalGlobe™ via Terraserver™ to differentiate permanent land use change events from those of temporary forest cover loss events such as harvesting or forest fire.

This attribution is achieved by the development of a series of 'masks' to exclude change due to:

- intermittent water features and irrigation areas that may give a false change signal;
- drought and growth flushes; and,
- terrain illumination.

In each national inventory cycle, the method of attribution is continually updated and improved to increase efficiency and reduce the subjectivity of visual attribution of change.

6.A.3 Plantation typing

To allow for more accurate modelling of emissions and removals from newly established forests (under *Grassland converted to Forest Land*), new plantings (reforestation) identified in the remote sensing imagery are mapped into three classes; native forest (environmental plantings), hardwood plantation and softwood plantation. Plantation forests are those that are identified as being due to deliberate human action and are identified by type (e.g., introduction of non-endemic species), evidence of establishment practices (e.g., rip lines) and planting patterns (e.g., rows and stand geometry). The identification of conversion from non-forest to forest follows the same general approach and same remote sensing data as described above. Plantation classes are identified by discrimination against regionally specific ground data. The method uses an automated spectral discrimination and is described in Caccetta and Chia (2004). Currently, only Landsat TM, ETM+ and OLI data is used for plantation classification. The 3-class method has also been applied to plantation typing.

6.A.4 Quality Assurance and Quality Control

Programme implementation

During the initial implementation of the remote sensing programme, pilot tests were used to train and develop industry capacity, refine methods and software and to develop logistical systems to maximise both output and opportunity for quality assurance and quality control (QA/QC). The results of the pilot studies are published in Furby and Woodgate (2002).

The approach to programme administration provides for centralised progress monitoring and QA/QC at each stage in the processing of the Landsat data. Each processing stage is a regionally defined package of work based on 37 1:1,000,000 (1:1 M) map tiles of Australia (Figure 6.A 1).

The QA/QC and data validation procedures for each of these items in the Australia's land cover change methods are summarised below – see also Furby (2002, 2016). Some of the resource intensive processes undertaken in previous years are no longer valid as multiple steps have been integrated and automated. As a result, QA/QC procedures have also been streamlined, resulting in significant savings and efficiency.

Mosaicing

All mosaiced images (quadrants and time slices) for a particular map sheet tile are assessed at the same time. Due to the automated processing of imagery in the Data Cube, QA/QC of the mosaiced imagery has been streamlined to a single step since NIR 2016. Each data set is checked to ensure completeness and consistency of the composite images (Furby, 2016).

Thresholding

QA review processes are applied to the thresholding products, during and at the end of the process. The aim is to ensure that a standard methodology has been correctly applied and that intermediate and final products are consistent with the supplied ground data and with each other, across stratification zones and map sheet boundaries. The assessment of the thresholding products is performed in several stages.

Results of the thresholding analyses are reviewed prior to mosaicing into a single forest cover probability image for each map sheet (Furby, 2016). An initial assessment report is produced, detailing the adequacy and consistency of the analyses and the accuracy of the probability images. The assessment reports advise on actions required. If the analyses or probability images appear inaccurate or inconsistent, further investigations are carried out so that the exact nature of any problem is identified, reported and fixed.

Once any required actions have been undertaken, the results are reviewed again to ensure that an adequate standard has been reached.

When the probability images have passed assessment and are mosaiced, the resultant images and key intermediate products are assessed for mosaicing accuracy, completeness and standardised formatting.

A final assessment report is completed, detailing the results of the assessment and whether any further data review is required.

CPN products

When the CPN datasets are supplied to the Geospatial team, they undergo a supplementary QA review process. The purpose of this review is to provide an independent logic check to identify any issues which may have impacts on future geospatial processing and modelling, before there is a significant resource allocation.

The review assesses the following components of the CPN products:

- An initial contents check is conducted to ensure the correct number of CPN dataset components have been supplied per tile.
- Check that designated change transitions between neighbouring epoch woody definitions are logical and correct across the time series on a pixel by pixel basis.
- Ensure that for each tile the CPN dataset's individual components for the time series contain pixel values that are within the acceptable range for that component.
- Check that for each tile the CPN dataset's individual components for the time series have correct spatial extents, geographic projection, pixel resolution and no null pixel entries.
- Produce a summary of percentage difference between the previous NIRs CPN run with the updated CPN run, to determine any variations which would be considered extreme and should be investigated further.
- A sample visual review is undertaken of the distribution of pixel values within the CPN dataset's individual components to ensure they are consistent with the previous NIR and with satellite imagery (e.g., forest classification is consistent with forest shown in associated Landsat imagery for the same year).
- For plant type designations, check they occur over the expected spatial extent when related to the associated forest cover datasets for 1990.

If any issues are found from the above assessment the dataset is returned to the remote sensing specialists for investigation. Only when all aspects of the review are satisfactorily resolved are the CPN datasets available for spatial attribution and *FullCAM* modelling.

Continuous Improvement and Verification Programme

Periodic review of the CPN products, to ensure human-induced vegetation change is not being omitted, is conducted separately to the NIR. This review is undertaken within a continuous improvement and verification programme (CIVP).

The CPN products identify woody vegetation cover and change, and undergo expert geospatial review using high resolution imagery and external datasets to isolate areas of human-induced change. This attribution of human-induced change is a vital part of each NIR. The ongoing verification programme provides an assessment of the CPN products prior to attribution, while attribution by expert operators ensures that errors of omission and commission related to human-induced clearing and regrowth are minimised in the inventory.

Figure 6.A.7 shows the history of the CIVP and the relevant details for each iteration. CIVP-3 was established as an extension of CIVP-2 in response to an ERT recommendation, to determine the commission and omission errors associated with using the CPN algorithm to assess land cover change.

Figure 6.A.7 The series of continuous improvement and verification programmes

Program:	CIVP-1	CIVP-2	CIVP-3	CIVP-4
Year:	2004	2012	2014	2017
Coverage:	37 tiles	19 tiles	19 tiles	11 tiles
Number of points:	12,564	7,680	1,214	4,520
Time series:	1972-2000	2002-2010	2001-12	2011-2014
Products assessed:	Forest & non-forest	Forest & non-forest	Change product only	Forest, sparse & non-woody, change products
Resources used for verification:	Aerial photos, satellite imagery	High resolution satellite imagery	High resolution satellite imagery	Very high resolution satellite imagery

For CIVP-4 the new CPN 3-class woody vegetation product (forest, sparse and non-woody) was assessed across 11 tiles that contribute the most emissions to the national inventory, to determine the accuracy of the product and to identify areas for improvement. The method established during CIVP-2 was followed, where 400 points were created across each tile using a stratified random sample. The vegetation classification at each point was cross-tabulated against the visual assessment of vegetation type undertaken by experienced operators using very high resolution satellite imagery (see table 6.A.2).

At points where the CPN identified change in vegetation cover between 2011-2014, an assessment of the likelihood of change during that period was also undertaken. As the CPN algorithm uses data from earlier and later years to determine vegetation change for each pixel, the time period for assessment of change in CIVP-4 was selected to ensure the change classification had stabilized using data from later years. In the latest assessment, the CPN land cover change product was verified using very high resolution satellite imagery acquired between 2009 and 2014. Imagery earlier than 2011 was consulted in case there was a lag between change being detected by the CPN in 2011 and change occurring prior to that year.

Of the 4520 points assessed across 11 tiles, 88 per cent had experienced no change (NC) across the time period. Based on the CPN classification, these points were identified as forest throughout (FT), sparse throughout (SPT), or non-woody throughout (NWT). The operator determined if these classifications were definitely correct, or probably correct, if imagery was not clear or not available at the right time. Probably non-woody throughout was not assessed as this category was considered to be difficult to distinguish from probably sparse. Table 6.A.2 shows the CPN product identified forest and non-woody areas consistently better than the identification of sparse vegetation. Commission errors indicate where the classification is deemed incorrect, while omission errors are where points should have been given the classification but weren't.

Table 6.A.2 CIVP-4 verification results for the 3-class woody vegetation product where no change was indicated

	CPN classification			
Verification	Number of points	% correct	% Commission error	% Omission error
Forest	1546	98	2	2
Sparse	685	66	24	13
Non-woody	1722	96	6	4

As sparse was a new class of woody vegetation and due to the difficulties detecting it remotely using medium resolution data, it was expected that the errors would be moderate. Despite these errors, the 3-class product has improved the prediction of woody and non-woody vegetation when compared to the previous forest and non-forest classes. Forest was predicted as correct for 96 per cent of the points in CIVP-2 compared to 98 per cent in CIVP-4, while non-forest was definitely correct 76 per cent of the time for CIVP-2 compared to 96 per cent for CIVP-4 (Lowell *et al.* 2012). Point data records from the verification programme could be used as extra sites to train the CPN algorithm and further improve the woody vegetation product.

The results for the points that had experienced change during 2011-2014 are shown in table 6.A.3, with the number of sample points for each classification cross-tabulated against the operators' assessment. Green cells indicate correct detection of change or no change (NC), red cells are erroneously detected change, lavender cells are undetected deforestation and blue cells are undetected regeneration. Of the points where the CPN had identified change (n = 550), 26 per cent were classified by the CPN as deforestation (DEF), 63 per cent were regeneration (REG) and 11 per cent indicated cyclic change (CYC). In this report DEF and REG refer to all cleared or regeneration pixels as indicated by imagery and associated processing. This is not to be confused with deforestation as used in the Kyoto Protocol that specifically refers to human-induced land conversion. A small amount of points were uncertain (U) due to poor imagery available to confirm the classification. Pixels classified as CYC suggest errors in the classification given that rapid change, such as forest to non-woody and back to forest, is unlikely to occur over such a short time.

It is imperative that errors of omission related to human-induced change are minimised to give confidence that the inventory has captured all true clearing and regeneration within the given year.

Results of the operator assessment in table 6.A.3 take into account transitions such as forest to sparse and vice versa. For the purpose of this exercise such transitions were included as the verification programme was undertaken to assess the implications of introducing a new sparse category into the vegetation classification and its impact on the change product. Therefore the 71 DEF points shown in the table are inclusive of these transitions which do not reflect vegetation clearing.

The 27 DEF points and 11 REG points that were incorrectly classified by the CPN in table 6.A.3 were subject to further evaluation by additional operators. Initial investigation indicated that 73 per cent of these points had no evidence of clearing or regrowth, however they reflected the classification and operator uncertainty between the forest-sparse and sparse-non-woody decision boundaries. The completed verification programme for the 3-class products is expected to be presented in the next NIR.

Combined errors of omission for DEF and REG were 0.4 per cent of the total 4520 points, while errors of commission were 7 per cent. These results are comparable to those of previous verification programmes (see table 6.A.4), with 0.3 per cent omission errors over 7680 points and 3 per cent commission errors. The higher commission errors in CIVP-4 are related to the addition of the sparse category into the woody vegetation product, as almost all points incorrectly identified as change had been classified by the CPN as sparse at some time in the change period. Errors may also be partly explained by the smaller sample size in CIVP-4, which we intend to extend to all tiles in future.

The commission error of 7 per cent within the CPN change products identified by CIVP-4 justifies the continuation of the attribution process by geospatial experts to ensure that non-human induced change (i.e. false positive change) does not enter the inventory accounts.

Controls

Omission errors are addressed by using external clearing and revegetation data obtained from state agencies (such as Queensland Statewide Landcover and Trees Study data) and other anecdotal evidence to identify and monitor any areas where change may have been missed. In addition, the CPN algorithm revises the last few years of data each time it is processed, based on the latest probability information. Therefore, pixels with uncertain probabilities are reassessed so omitted change is detected in the following iteration of the process and included in the subsequent NIR submission.

Table 6.A.3 Outcomes of operator assessment of CPN classification for CIVP-4

CIVP-4		Operator assessment					
		NC	DEF	REG	CYC	Uncertain	TOTAL
CPN classification	NC	3953	10	6	0	1	3970
	DEF	94	44	3	0	0	141
	REG	209	14	121	1	4	349
	CYC	42	3	2	12	1	60
	TOTAL	4298	71	132	13	6	4520

Table 6.A.4 outcomes of operator assessments in previous verification programmes

		Operator assessment					
		NC	DEF	REG	CYC	Uncertain	TOTAL
CPN classification	NC	7213	11	12	na	na	7236
	DEF	136	124	0	na	na	260
	REG	87	0	97	na	na	184
	CYC	na	na	na	na	na	na
	TOTAL	7436	135	109	na	na	7680

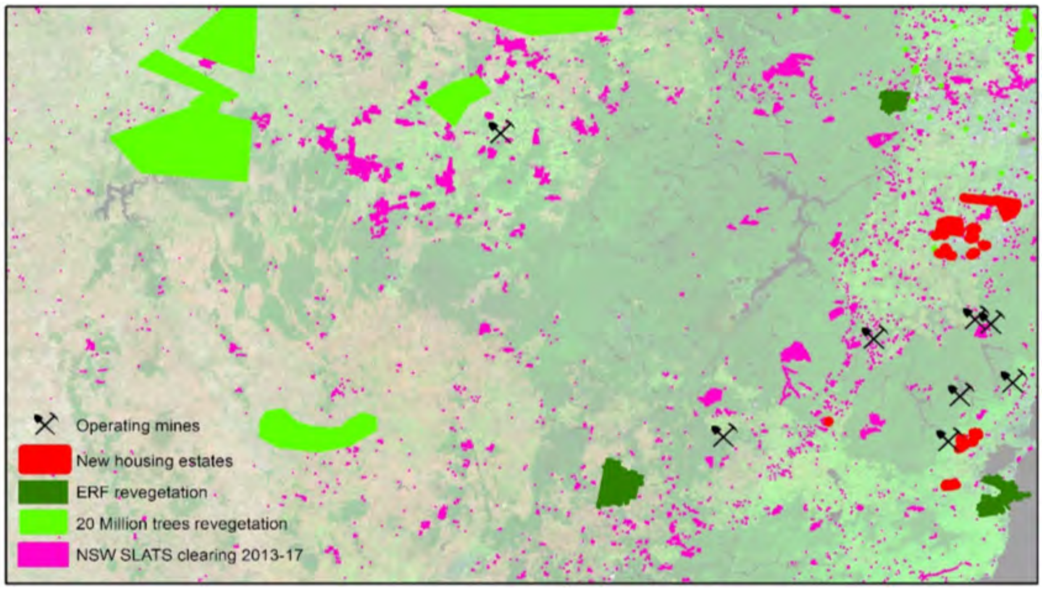
The results of the different verification programmes highlight the continued value of the attribution process, discussed in Section 6.A.2, which was essentially designed to remove false positive pixels and focus upon human-induced change only. Use of external datasets and rule based machine learning techniques currently being explored would also reduce the uncertainty in the activity data.

Attribution

The final quality control requires attribution of changes identified in cover change maps by the CPN as either direct human-induced, temporary change or methodological artifacts such as false positive change. The latter effects are well understood and include green flushing in images due to climate, terrain illumination variability, irrigation, water bodies and fire scars. The Department of the Environment and Energy staff use high resolution imagery such as Landsat, Google Earth™, DigitalGlobe™ via TerraServer™ or Planet™ for this discrimination. Results of this discrimination are then quality controlled. This attribution step provides a final quality control process designed to mitigate the risks of errors of commission and omission that were identified in the continuous improvement and verification programme and outlined in the previous section.

A recent innovation to the attribution process is the development of an Attribution Reference Database (ARD) that captures published information and anecdotal evidence of clearing, land development or reforestation activities such as those funded by state and federal government programmes (see Figure 6.A.8). The database is continually being updated and the information is used for attribution and QA/QC of satellite derived activity data. The Department has formalised co-operative arrangements with Queensland and NSW state government agencies to gain access to vegetation monitoring data used to support the current inventory cycle. It is intended that these types of arrangements will be developed with other states and become an integral part of the quality control plan for future national inventories. The use of this information provides further assurance that high quality estimates of areas of land cover change are used for the national inventory and confirms that the national inventory accounts are complete and unbiased.

Figure 6.A.8 Example of ancillary datasets in the Attribution Reference Database that were used to confirm human induced changes



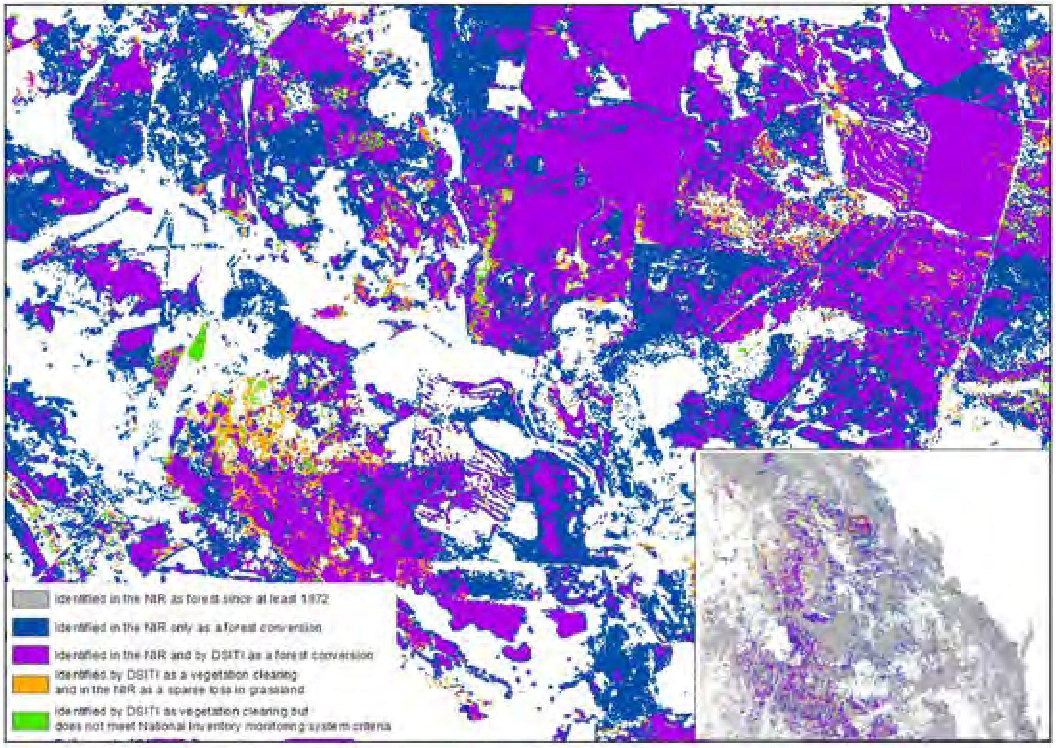
Examples of the QA/QC undertaken using external datasets stored in the ARD are outlined below.

Pixel level comparisons were undertaken of woody vegetation loss between the national inventory data and the Queensland Government Department of Environment and Science (DES) vegetation monitoring system. An assessment was made of the level of agreement between the two datasets for the period 1988 to 2015 (see Figure 6.A.9). Using the improved 3-class change data, there is a high level of agreement (within 10 per cent) between the two systems, although at a few places the clearing pattern does not match. The areas reported only in the NIR are mostly pre-1990 clearing, whilst most of the Queensland DES clearing is post-1990. At a few places, clearing is detected only in the DES dataset which is mostly picked up for the National Inventory Report as sparse woody loss reported under the *grassland remaining grassland*, *wetlands remaining wetlands* and *settlements remaining settlements* accounts.

The main difference between the systems is related to vegetation classification - the national inventory distinguishes between reporting on forest conversion (i.e. clearing in areas where woody vegetation cover meets or exceeds a canopy cover of 20 per cent and a height of 2m); and sparse woody vegetation changes reported under grasslands, whereas the Queensland system reports clearing in all woody vegetation types, independent of tree height, in a single classification. This is a significant factor that explains the majority of the difference in "land clearing" estimates reported by the two systems.

Nevertheless, the analysis showed a high level of agreement between the two systems in the detection of changes in vegetation on forest lands and sparse woody vegetation over the time series. Each area of disagreement was reviewed carefully and the national inventory revised accordingly, where appropriate, using the improved 3-class change product.

Figure 6.A.9 Pixel level comparison of the clearing data of the two systems - national inventory (1972–2015) and Queensland DES (1988–2015)

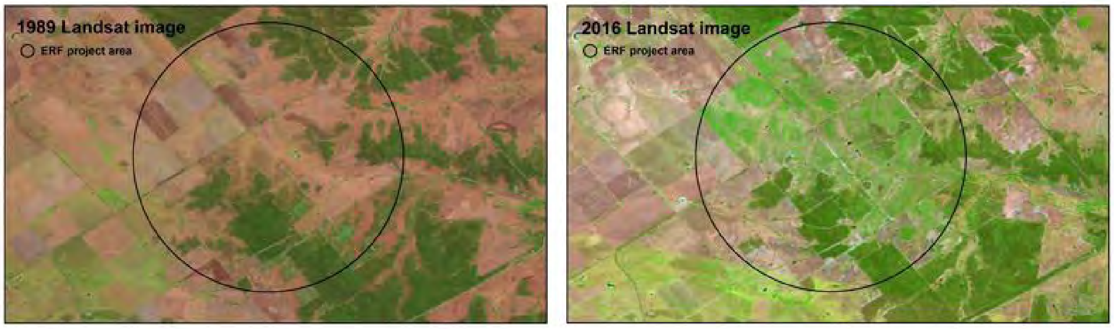


A similar process was also undertaken using vegetation monitoring data for NSW from 1988 to 2014. All areas identified by NSW Office of Environment and Heritage (OEH) as cleared in the past were checked to determine if they were already part of the national inventory. This analysis showed a high level of agreement, and areas of disagreement were carefully reviewed and the inventory revised if appropriate. Comparisons show that the National Inventory Report estimates of primary forest clearing are within 7,000 hectares of clearing reported by NSW OEH.

Additional verification of land clearing is undertaken using data reported in the media and other published reports. 2014 NIR data were compared with published information on high value agricultural clearing approvals in Queensland reported by Taylor (2015), for the period from 2012 to 2015. The analysis undertaken in 2015 indicated that, of the 94 approved sites, 75 per cent were already included in the national inventory while the remaining 25 per cent were being monitored for clearing in the future or were included in a different part of the account such as timber harvesting. In cases where clearing is not yet evident at the time of image acquisition, the national system continues to monitor potential areas and captures any confirmed clearing in subsequent years. Primary reference data such as these are continually updated and are used as part of the standard procedure in attribution and QA/QC.

Reforestation attribution also undergoes a series of QA/QC checks using data collected for the ARD. Figure 6.A.10 shows an area reforested under the Emissions Reduction Fund (ERF). Landsat imagery shows how the area had no forest cover in 1989, and a revegetation signal is visible in the 2016 image.

Figure 6.A.10 ERF data used to identify reforestation across the time series



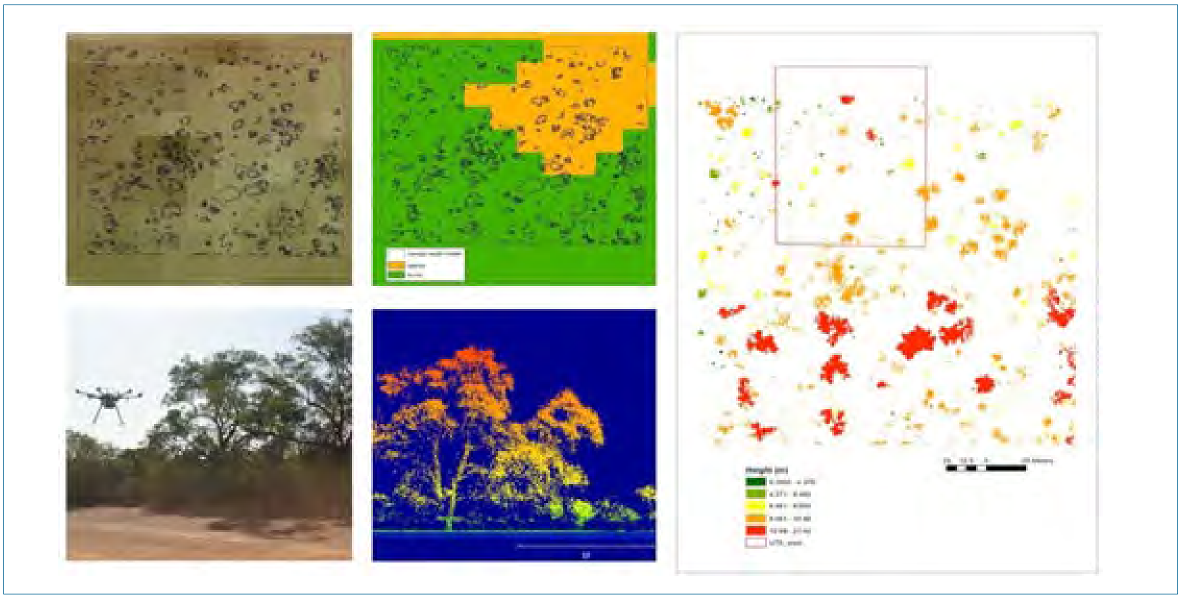
6.A.5 Refining the CPN algorithm

To address the errors of commission and omission related to the sparse classification identified in the CPN woody vegetation products (see continuous improvement and verification programme section in 6.A.4), it is necessary to refine the CPN algorithm.

Since the publication of the 2016 National Inventory Report, the Department has undertaken fieldwork to collect woody vegetation data using a LiDAR (light detection and ranging) drone and optical sensors over national parks in the Bourke region of NSW. The vegetation in this area is difficult to classify as the landscape is highly modified through clearing and grazing, vegetation responds to climatic cycles such as drought, and high resolution imagery is not always available. There are also numerous ERF projects in the area where human-induced revegetation is occurring and being monitored using the woody vegetation data.

Processing of fieldwork data is ongoing and will result in point-cloud images, canopy height models, vegetation structural data and site statistics. These will act as new regionally specific training data, used to refine the algorithm and during the CPN thresholding process. Figure 6.A.11 gives examples of the outputs from the LiDAR analysis, showing the outline of the canopy height model overlaying (L-R) 25m Landsat 2018 imagery, 3-class woody vegetation classes 2018, LiDAR canopy height model classes, fieldwork photo of vegetation structure and a height profile of the LiDAR scan. This also illustrates the issues associated with classifying sparse woody vegetation from 25m Landsat imagery, where trees are clustered and the algorithm looks to nearest neighbours to confirm a classification. LiDAR canopy height model data will also be utilised as training data for other locations across the country, where available.

Figure 6.A.11 Examples of outputs from LiDAR drone analysis



6.A.6 Plantation typing

Validation of plantation type mapping accuracy was carried out against specifically collected field data showing plantation species, stocking, condition, age and extent. This validation data was collected during a national programme of site visits. Plantation mapping achieved an accuracy of 91 per cent in terms of both species and spatial referencing for plantations identified as post-1990 plantations. Incorrect forest typing (e.g., labelling hardwood as softwood and vice versa) contributed 5 per cent of the error, with only 4 per cent being incorrect for both location and type.

6.A.7 Forest conversion prior to 1972

Forest land converted to cropland or grassland remains in the *converted* category for 50 years.

Estimates of *forest land converted to cropland or grassland* since 1972 are derived from observations of forest cover loss using Landsat satellite data.

Estimates of the area of *forest land converted to cropland* or *grassland* for the period 1940-1972 is a gap in the activity data used to prepare the estimates for the *forest conversion* categories. Approaches to the estimation of these missing data have been explored, in line with recommendations in the ARR 2010, ARR 2011 and ARR 2012 reviews of the Australian inventory. Estimates have been produced using extrapolation techniques provided in IPCC 2006 Volume 1, chapter 6. The results are compared below.

Previous studies

Graetz *et al.* (1995) estimated that 102.964 million hectares of forest were cleared between 1788 and 1990, or an average of 514,820 ha per year. Similar conclusions have been reached in the *State of the Environment Report* for Australia[10], with the area of forest cover cleared since 1788 estimated to be around 100 million hectares. A study by Barson *et al.* (2000)[11] found that approximately 92.5 million hectares of forest had been cleared since 1788.

If extrapolated to the period 1940-1972, the Graetz *et al.* estimate translates into a cumulative area cleared over the period of 16.4 million hectares.

10 State of the Environment 2011 Committee. Australia state of the environment 2011. Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities. Canberra: DSEWPaC, 2011.

11 Barson, M., Randall, L. And Bordas, V. (2000) Land cover change in Australia, Bureau of Rural Sciences, Australian Government, Canberra.

Forest conversion required to meet additional crop and livestock activity 1940-1972

The demand for additional pasture or cropland was high in the period 1940-72, reflecting relatively high prices paid for agricultural commodities. Cropping lands increased by 50 per cent, or around 6 million hectares in the period 1940-1972. For grazing activity, demand for land increased by the equivalent of 60-100 million hectares (based on agricultural activity data published by the Australian Bureau of Statistics).

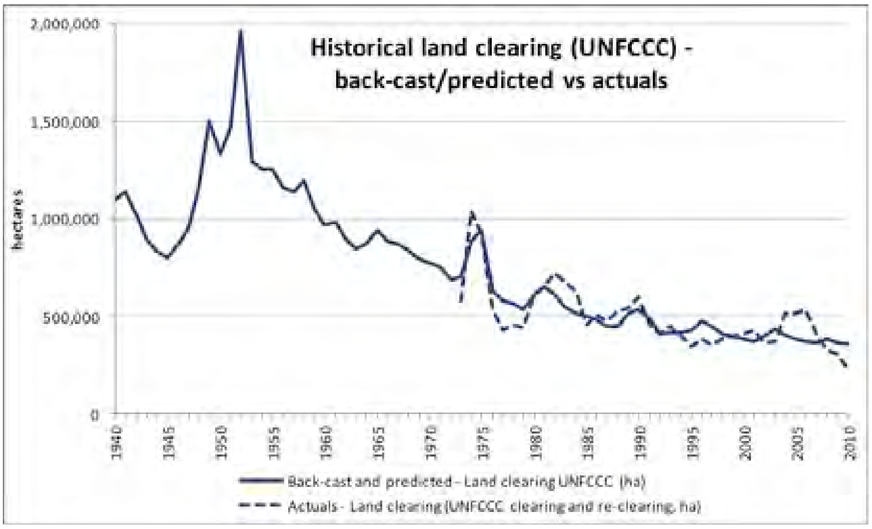
The estimated demand for grazing lands was derived from the increment in cattle and sheep numbers over the period 1940-1972. These data were converted into a demand for cleared land. The conversion was based on assumptions regarding the amount of grazing land needed to support the number of sheep and cattle indicated in the national statistics (1-2 sheep per hectare, 1 cow equal to 10 sheep based on data provided in Hamblin (2001)[12] and Henzell (2007)[13].

Not all of the additional demand for pastures would have required a clearing event. With a discount of 50 per cent, the cumulative increase in area of land needed to support the increment in livestock activity was estimated to be 60-100 million hectares in the period since 1940-1972.

Back cast regression of observed clearing on the farmers' terms of trade 1940-1972

Observed land clearing activity has also been established to respond to the farmers' terms of trade index of prices received to prices paid. A linear regression linking area cleared to the farmers' terms of trade was performed for the period where satellite-based land clearing estimates are available (1973 to 2010). The coefficients from this regression were used to back-cast land clearing activity to 1940 (Figure 6.A.12).

Figure 6.A.12 Estimated area of land clearing and actual land clearing (Source: ABARES various)



Inverted back-cast of 1973-2010 trend

Trends in area under cropland and cattle and sheep numbers indicate a peak of agricultural activity in the early 1970s. The Landsat time series indicates that the peak in land clearing in the period 1972-2013 occurred in 1974. Under this scenario it is assumed that land clearing gradually increased in the period 1940-1970 and peaked in 1974. This estimation of the historical trend was made by inverting the trend observed in the period 1973-2013.

12 Hamblin, A.P. (2001) *Land, Department of the Environment and Heritage, Canberra.*

13 Henzell, T. (2007) Australian agriculture: Its history and challenges, CSIRO publishing, Collingwood.

Table 6.A.5 Estimated land clearing 1940-1972: comparison of extrapolation methods

Extrapolation method	1940-1972 Extrapolation		1973-1990 Landsat imagery
	Cumulative land clearing (ha)	Annual clearing (ha)	Annual clearing (ha)
Graetz *et al*. average annual forest conversion 1788-1972	16,474,240	514, 820	547,222
Forest conversion required to meet additional crop and livestock activity 1940-1972	60,000,000	1,875,000	547,222
Back cast regression of observed clearing on the farmer's terms of trade 1940-1972	34,200,000	1,069,000	547,222
Back cast of 1960-1990 trend in farmers' terms of trade model with clearing peak in 1974	25,200,000	763,636	547,222

The data in Table 6.A.5 indicates that the rates of land use change observed from the Landsat record, at 547,222 hectares a year for the period 1973-1990, are similar to the long run average rate of change calculated by Graetz *et al.* (1995) of 514,820 hectares a year. Independent data on a range of economic forces, including higher prices for agricultural products and reduced costs of forest conversion for this period compared with earlier periods, anecdotal country histories and observed increases in national livestock numbers and cropping areas all indicate that the period 1940-1972 was a period of strong land use change in Australia.

The estimates of *Forest Conversion* presented in Sections 6.7 and 6.9 for 1990 are based on a limited dataset on land use change extending only from 1973-1990. Extending the observed dataset to include estimates for the missing data on land use change for the period 1940-1972 could be implemented using a range of techniques identified in IPCC 2006 based on the data presented in Table 6.A.5.

The implementation of an extended dataset on land use change to 1940 would lead to higher emissions estimates for *Forest Conversion* for the entire time series, with larger impacts at the start of the time series, 1990, than for later periods of the time series. It is assessed that the estimate for net emissions for *Forest Conversion* categories would be 13 Mt CO_2-e higher in 1990, if the land clearing trend is back cast with an assumed clearing peak in 1974 and is applied in the *FullCAM* Tier 2 model. As indicated in section 6.9.4, this step has not yet been implemented in the estimates.

Appendix 6.B FullCAM framework

Land sector reporting within Australia's National Inventory System integrates a wide range of spatially referenced data through a process based empirical model (Tier 3) to estimate carbon stock change and greenhouse gas emissions at fine spatial and temporal scales. Analysis and reporting includes all carbon pools (biomass, dead organic matter (DOM) and soil), all principal greenhouse gases (CO_2, CH_4 and N_2O), and covers both forest and non-forest land uses. A Tier 3 method is used to estimate carbon stock changes for agricultural soils, living woody biomass (excluding perennial woody horticulture) and dead organic matter. This approach has several advantages over an IPCC Tier 1 or 2 method:

- Models have the potential to improve coverage and completeness as they can extend beyond existing data to improve geographic coverage/distribution and coverage of source/sink categories by filling in gaps in data.
- Measured climate data are interpolated using a mathematical (multivariate spline) function at the 1 km scale (Appendix 6.E.3) rather than broad climatic region classification. This enables quantification of carbon stock changes at finer spatial scales.
- The method includes detailed characterisation of spatially mapped soil properties (Appendix 6.E.1) that influence soil carbon dynamics as opposed to broad soil taxonomic classification of the IPCC methodology.
- The method provides a more detailed representation of management influences and their interactions. This increases the spatial and temporal resolution of estimates compared to those that are represented by a discrete factor-based approach.
- Soil carbon stock changes are estimated on a more continuous, non-linear and dynamic, monthly basis as a function of the interaction of climate, soil, and land management compared with the linear averaging as applied in tiers 1 and 2.

6.B.1 Overview of the *FullCAM* Model Framework

FullCAM is a process based ecosystem model that calculates greenhouse gas emissions and removals in both forest and agricultural lands using a mass balance approach to carbon cycling. The *FullCAM* framework and its development are described in Richards (2001) and Richards and Evans (2004).

FullCAM has been selected for the Tier 3 method based on several criteria:

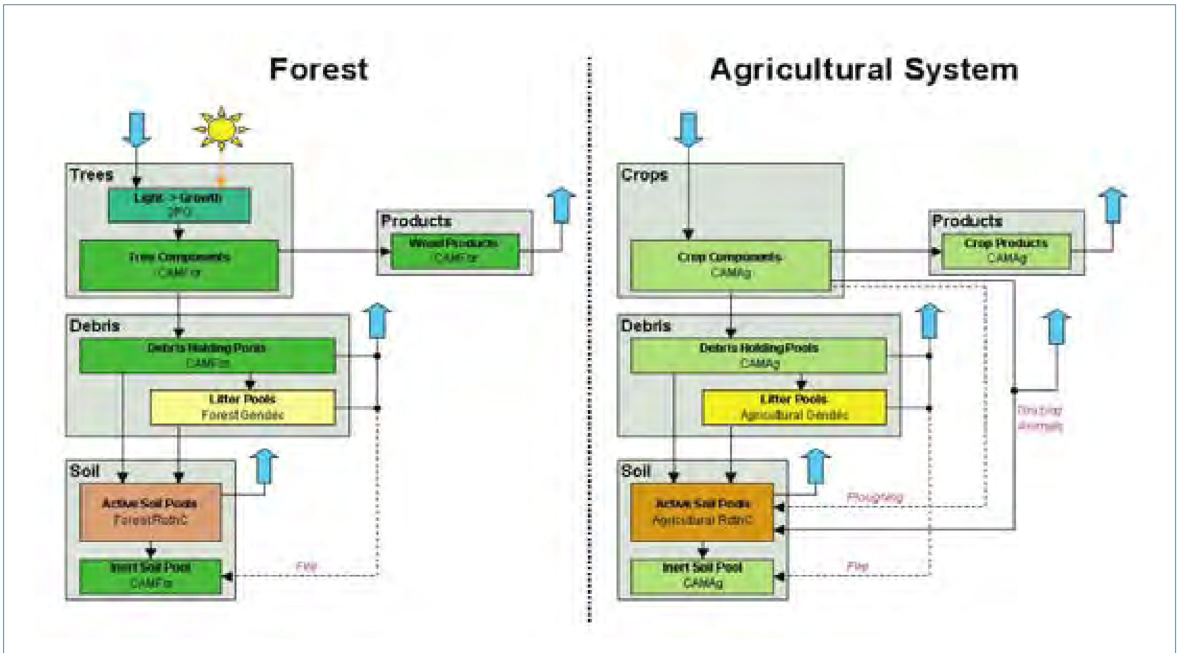
- The model has been developed in Australia and extensively tested and verified for Australian conditions (Appendix 6.B.1.3 and 6.B.5.1). In addition, the model has been widely used for simulating soil and biomass carbon dynamics at project level (Australian Government Carbon Farming Initiative and Emission Reduction Fund) and nationally.
- *FullCAM* is capable of simulating cropland, grassland, and forest eco-systems and land-use transitions between these different land uses at the 25m pixel level. As most emissions and removals of greenhouse gases occur on transitions between forest and agricultural land use, integration of agricultural and forestry modelling was essential.
- The model is designed to simulate management practices that influence soil carbon dynamics including quantification of inter-annual variability.
- *FullCAM* has components that deal with both the biological and management processes which affect carbon pools and the transfers between pools in forest, agricultural and transitional systems. The exchanges of carbon, loss and uptake between the terrestrial biological system and the atmosphere are accounted for in the full/closed cycle (mass balance) model which includes all biomass, litter and soil pools (Table 6.B 2).
    - The data required for *FullCAM* to simulate is available nationally at appropriate scales for the data in a spatially and temporally time series consistent format.

6.B.1.1 *FullCAM* Sub-Models

FullCAM has been developed as an integrated compendium model that provides the linkage between various sub-models (Figure 6.B.1). The three sub-models integrated to form *FullCAM* as used in the National Inventory are:

- *CAMFor* (Richards and Evans, 2000a), the carbon accounting model for forests. *CAMFor* is used to model carbon mass and transfers between the living tree, standing dead and debris pools of forest lands. *CAMFor* has its origins in the 1990 CO_2 Fix model of Mohren and Goldewijk (1990);
- *CAMAg* (Richards and Evans, 2000b), the carbon accounting model for cropping and grazing systems). The *CAMAg* model reflects the impacts of management on carbon accumulation and allocates masses to various plant, debris and soil pools. Yields need to be prescribed in the model;
- Rothamsted Soil Carbon Model, *Roth-C* (Jenkinson, *et al.* 1987, Jenkinson *et al.* 1991). *Roth-C* models changes in soil carbon based on the inputs of organic matter from dead plant material and soil carbon decomposition rates. It is used in conjunction with both *CAMFor* and *CAMAg*.

Figure 6.B.1 The *FullCAM* model pool structure



6.B.1.2 Sub-model integration

The sub-models described above are integrated into *FullCAM* which was developed in the programming language C++ with a graphical user interface (Richards, 2001; Richards and Evans, 2004). The individual sub-models can be applied independently or in various combinations within the *FullCAM* framework. By embedding both the forest and agricultural models within *FullCAM*, it is possible to represent transitional activities – afforestation, reforestation and deforestation (change at one site) – or a mix of agricultural and forest systems (e.g., agroforestry, discrete activities at separate sites) in a single, mass-balance model framework.

6.B.1.3 Quality assurance and quality control

Sub-model integration

The integration of the sub-models into a single compendium model was initially undertaken in Excel as a test version. The prototype forest model derived (Richards and Evans, 2000c) was subsequently tested by CSIRO (Paul *et al.* 2002a). Several independent studies to test and calibrate the model were completed on various parts, integrations and applications of the models. When there was confidence that the Excel developmental models were giving the same results as the original source code versions, the Excel models were fully documented and returned for verification to the original authors or host organisations. Modifications were only considered subsequent to this initial review. These modifications were made for a variety of reasons including efficiency in code (computational speed and resources) and in recognition of Australia's different biophysical conditions.

Model coherence and validation

Testing for coherence in a Tier 3 (Approach 3) model-based pixel by pixel inventory method requires very different techniques to those applied to checks on trends and emissions factors in Tier 1 and Tier 2 models[14]. Tests of model coherence and validation can only be meaningfully undertaken at the pixel level. This is the approach taken and is consistent with the good practice recommendations of the *2006 IPCC Guidelines*. As the robustness of the national account simply flows from the correct summing of the outputs of the individual pixels, testing the results at the individual pixel scale will validate the national results. Therefore, programmes to test model cohesion operate in two realms. The first is coherence testing by time series to validate model calibrations and verify the results at the pixel level. The second is quality control to ensure robust summation of the pixels to an aggregate national account.

Representative individual pixels in *FullCAM* simulations have been validated against field data. These validations have been undertaken by independent agencies. The results of these studies have shown that the model is robust. Examples of the independent initial biomass, debris and soil carbon validation results are shown in Appendix 6.D, section 6.B.3, and section 6.B.5, respectively.

Individual pixel models are internally checked to ensure that all emissions, removals and transfers of carbon between pools are accounted for. At each monthly time-step *FullCAM* reconciles removals due to growth, transfers between carbon stocks in pools, and emissions from pools for every pixel modelled. Taking a mass balance, full carbon-cycle approach for each pixel, and running this over an extended period, is a very rigorous way of testing the model's ability to appropriately reflect transfers between carbon pools, and hence the balance of emissions and removals. When multiple pixels are simulated, pixel results are consolidated and then reported at an aggregate level. These aggregate outputs are cross checked by both internal and external processes to ensure that the consolidation process accurately reports all spatial simulation results. The correct summing of model outputs is also critical to model performance and therefore internal and external quality control checks are made on this aspect of the model. The results from the Tier 3 model have also been compared with the results using Tier 2 methods (see section 6.3.3 and 6.7.3) and were found to be broadly consistent.

14 The change in pixel output is also strongly affected by the amount of time since the land was cleared and climate variability. As there are multiple variable factors, the implied emissions factors from the overall inventory cannot be used to test the model's coherence as the model processes can no longer be observed in anything like their original analytic unit. Analysis of IEFs in the LULUCF sector is further complicated by reporting of accumulating land areas.

Transparency and peer review

For the complex Tier 3 methods, which incorporate models and large datasets, different approaches to transparency and peer review are required. Transparency and review of the land sector accounts is founded on:

- published specifications, protocols and methods;
- published verification results;
- public release of models, tools and data ; and,
- publication in peer reviewed journals or other literature.

Australia has published six series of strategic and technical reports which document the development of *FullCAM*, the specifications, protocols and methods used, and the results of verification, validation and calibration of *FullCAM*. All reports are accessible by the public via the DE website (http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/publications/index.html). The methods and data used as part of the land sector accounts have also been extensively published in peer-reviewed papers in scientific journals.

The Australian Centre for Ecological Analysis & Synthesis undertook a modelling workshop in 2011 on improving long-term predictions of carbon and nutrient dynamics in Australia's agro-ecosystems (http://aceas.org.au/index.php?option=com_content&view=article&id=74&Itemid=76). In the workshop *FullCAM* soil carbon outputs were compared with those from DayCENT, Century and a Microsoft Excel version of RothC, initially for two sites, Hermitage and Wambiana. Preliminary results suggested little difference between outputs of the four models over the study period. Further, if input data were the same or very similar then all models appeared to simulate soil carbon stocks to within 10 t C/ha (0-30 cm soil profile) of the final result based on a measured value of soil carbon stock (2010 site data).

6.B.2 Estimating changes in forest biomass

6.B.2.1 Forest growth

Forest growth in *FullCAM* is controlled through two separate biomass increment components of the model:

- the tree yield formula (Richards and Brack (2004a), Brack *et al. (2006) and Waterworth et al. (2007);* and
- direct entry of biomass increment data.

Tree yield formula

The tree yield formula (TYF) is embedded into the *FullCAM* code and when applied within the National Inventory System provides an empirically constrained process model for the calculation of biomass increment in the living components of *forest land*. The tree yield formula allows for responses to climatic variability while empirical data and parameters constrain initial aboveground biomass, forest growth, and relative movements between pools. It is the empirical data that constrains the model to reflect extensive field data (both existing and specifically collected).

Appendix

The tree yield formula is applied to estimate the forest biomass increment in the following sub-categories:

- Forest land converted to cropland;
- Forest land converted to grassland;
- Forest land converted to wetlands;
- Forest land converted to settlements; and
- Grassland converted to forest land.

The tree yield formula is provided in Equation 6B_1:

Aboveground Tree Mass at age a = $M \times e^{(-k/a)}$.. (6B_1)

Where a = age of the tree stand

M = biomass predicted by the assumed initial biomass model (Appendix 4.D), and

k =estimated constant that determines the rate of approach towards M.

The value of *k* sets the rate of growth, where $k = 2 \times BI_a - 1.25$, and BI_a is the age (in years) of maximum aboveground biomass increment.

The long-term average annual increment between *a* and *a* + 1 years (I_a) for a stand can be estimated from the long-term average productivity (*P*) (see Appendix 6.C):

$I_a = M \times (e^{(-k/a)} - e^{(-k/(a-1))})$.. (6B_2)

However, as productivity in any given year may vary around the average due to non-average weather or other factors, the actual annual increment (I_a is adjusted by the productivity in a given year (*Pa*) as a ratio with the long-term average productivity (*Pav*):

$I_a = I_a \times P_a / Pav$.. (6B_3)

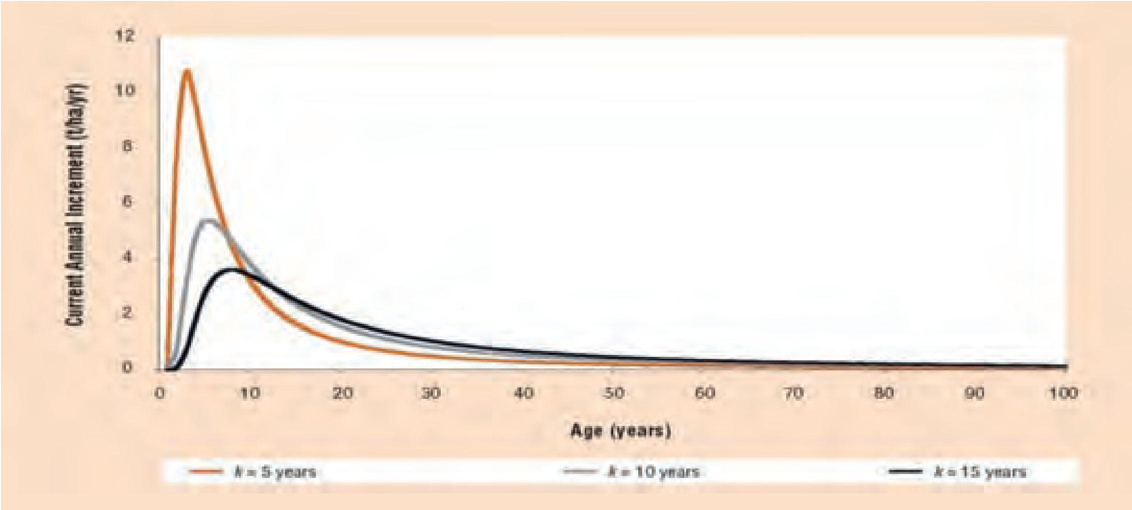
The average increment multiplier (P/Pav) in Eqn. 6B_3 needs to be close to 1.0 to enable the attainment of the long-term maximum above-ground biomass of the stand; M. Due to the formulation of FullCAM's TYF, M will not be achieved if Pav is less than the mean of the P's for the years across which the simulation is run. This was an issue for some regions of Australia when Pav was calculated using climatic data from the years 1925-2000. As outlined by Roxburgh and Paul (2019), recent improvements to FullCAM have included the more NIR-relevant Pav based on the climatic data from the years 1970-2015. This refinement in the definition of Pav contributed to a slight increase in yields of woody biomass in many regions of Australia.

This approach provides biomass stock estimates for a given land unit at any point in time that recognises prior forest disturbance, and the rates of growth for a land unit at any point in time, specific to site condition and age. The patterns of growth will show variability according to the spatial and temporal patterns of the main process drivers, e.g., water balance, captured in the productivity modelling. This ensures that the estimates of biomass in areas of regrowth are then both spatially and temporally relevant.

Maximum aboveground biomass increment

One of the key parameters in the tree yield formula is the age of maximum aboveground biomass increment (BI_a). Figure 6.B.2 presents the results of an analysis of the effects of varying age of maximum aboveground biomass increment over the range of three to eight years. While the early age growth increments are very sensitive to BI_a, even by age 18 there is little difference in the annual aboveground biomass growth increment (Figure 6.B.2).

Figure 6.B.2 Effects of varying age of maximum current annual increment for three values of parameter k (5, 10 and 15 years), corresponding to BL_a = 3.1, 5.6 and 8.1 years, respectively



Available national data and literature sources were analysed to estimate BI_a for regrowth forests (i.e., those identified by remote sensing as recovering from clearing since 1972). This analysis was based largely on the work of West and Mattay (1993). This was a challenging task due to the lack of growth data for Australia's native forests, in particular for the drier woodlands. Available data, such as that reported by West and Mattay (1993), suggest that the age of maximum current annual increment (CAI) for stem volume is within a small range (12-20 years) for most species and is largely independent of site productivity. For the *forest land converted to cropland, forest land converted to grassland, forest converted to wetlands and forest land converted to settlements* sub-categories the age of maximum aboveground biomass increment is set to 10 for all species based on the following:

- available data for production native forests which yields a central estimate of 14 years for maximum volume increment (range 12-20);
- the age of maximum volume increment is reduced by one to two years to account for increased allocation of biomass growth to non-stem (wood volume) components as trees are establishing, in particular just before canopy closure;
- the age of maximum volume increment is further reduced by one to two years to allow for the lag in detection of regrowth by remote sensing data (i.e., accounting for the time until detection of trees becomes possible); and,
- a final reduction is applied to account for the rapid site occupancy of woodland species which regenerate from root stock left after clearing, allowing more rapid growth following the removal of grazing pressures.

The effect of these adjustments is that a BI_a of ten is equivalent to an effective age of maximum current annual increment in stemwood volume of around 14 years. A BIa of ten is higher than that found in most eucalypt plantations, which reach this peak between two to seven years. Plantation management aims to achieve maximum growth rates as quickly as possible and probably represent the best achievable early age growth rates when compared to natural forests.

Direct entry of biomass increment data

When the direct entry of biomass increment data component of *FullCAM* is in use, the model uses these data in calculations and so there is no calculation of biomass increment within *FullCAM*. The direct entry of biomass increment data component of *FullCAM* is applied in the source category *forest land remaining forest land*.

6.B.2.2 Partitioning of biomass

FullCAM applies allocation scaling parameters to predict the partitioning of biomass to stem wood, branches, bark, foliage and coarse and fine roots. This time-series input table specifies biomass allocation for each year of growth, thereby enabling the prediction of how growth is attributed to the six components of biomass over time. Generally, the units used in the allocation input table are growth increments of branches, bark, foliage, coarse roots and fine roots components relative to that of the stem, with the input for stem thereby being 1.00 at each time step.

For aboveground biomass, allocation input tables adjust the relative allocation to wood, branches, bark and foliage, with the total aboveground biomass (AGB) being set by FullCAM's TYF (Eq. 6B.a). In contrast, predicted belowground biomass (BGB) is determined by allocation to coarse roots (BGB_C) and fine roots (BGB_F) as defined in the allocation input table. The allocation of biomass in FullCAM also determines the management- or disturbance-induced impacts on C stocks. Accurate biomass allocation predictions are important when predicting changes in on-site C stocks following events such as fire, pruning, thinning or harvesting. This is because these events affect the different pools of biomass in different ways.

Calibration of partitioning parameters

As outlined in detail by Paul and Roxburgh (2017), a large dataset on biomass partitioning of tree or shrubs has recently been collated for Australia. These data provided a useful means to revise FullCAM input tables of allocation of biomass. This database included a total of 3,005 individual trees or shrubs with measurement of partitioning of AGB, and 1,115 individuals with measurements of the relative allocation of BGB_C to AGB, where BGB_C is the biomass of coarse roots (>2 mm diameter). For all forest type, BGB_F were predicted from AGB using a global empirical model (Mokany *et al.* 2006).

Previously, FullCAM allocation inputs varied with stand age only. But the new expanded datasets on biomass partitioning facilitated the development of new empirical models that demonstrated that, at least for some types of forests, AGB partitioning and R:S varies not just with stand age, but also with the stands total AGB, average rainfall, density, and species or species-mix.

These empirical models were incorporated into an Allocation Calculator that was then used to generate the time-series allocation inputs tables required by FullCAM. This was done for the 51 forest types, each utilising specific empirical models within the Calculator based on their categorisation into either: environmental or mallee plantings; hardwood plantation; softwood plantation; native forest, or; woodland and shrublands. The mean site quality and typical rainfall in their regions of growth were inputs into the Calculator.

An example of the how the revised predictions of biomass partitioning compare to that observed is given below (Table 6.B.1) for native forests systems, where datasets were collated from 46-168 different sources as described by Paul and Roxburgh (2017). Datasets were collated from 46-168 different sources. Predictions were for the relevant 20-100 year old stands. Further details, and results for other forest types, are described by Paul and Roxburgh (2017).

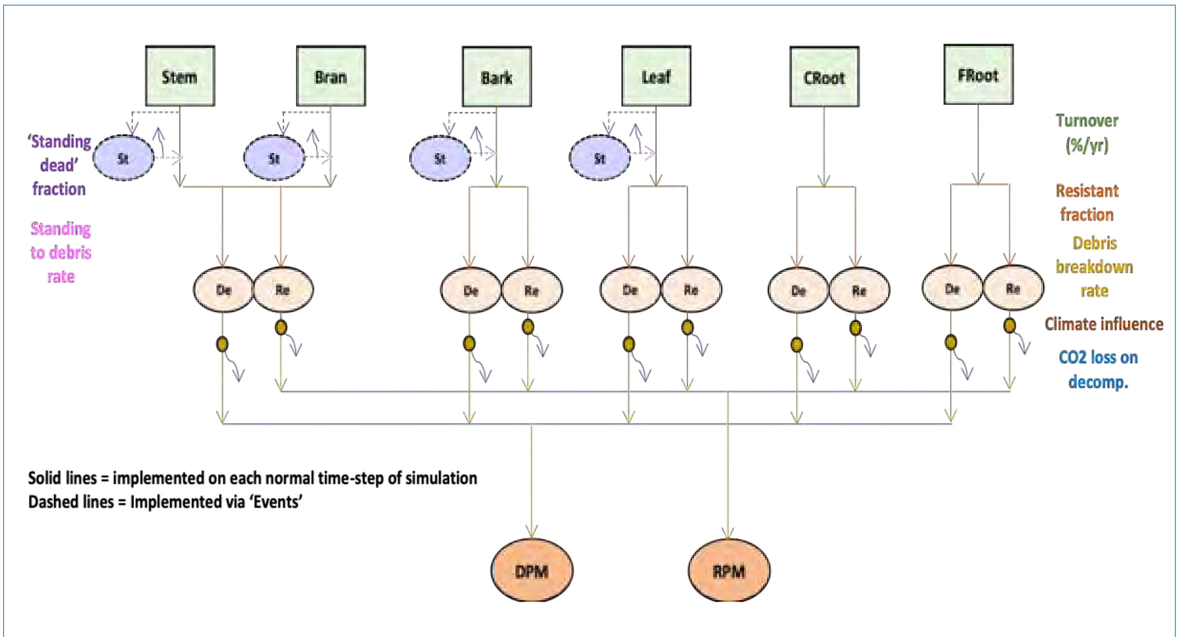
Table 6.B.1 Mean (± SD) observed and predicted biomass ratios for native forest

Ratio of biomass components	Observed	Predicted
Wood:AGB	0.65 ± 0.12	0.52-0.54
Bark:AGB	0.12 ± 0.06	0.14-0.15
Branch: AGB	0.14 ± 0.09	0.25-0.26
Foliage: AGB	0.05 ± 0.06	0.06-0.09
BGBC: AGB	0.33 ± 0.14	0.19-0.39

6.B.3 Estimating changes in forest standing dead

FullCAM allows for the modelling of standing dead pools following disturbance events such as wildfires, prescribed burns, management burns (e.g. slash burns and site preparation burns), clearing or commercial harvesting (Paul and Roxburgh 2019b). At each such event, a proportion of each pool of live biomass may be assumed to be disturbed to such an extent that it will slowly die. The rates of such senescence will be relatively slow when compared to the relatively fast rates of breakdown of pools of debris, which were calibrated to litter bag decomposition studies.

Figure 6.B.3 FullCAM model structure with regard to standing dead (st) pools, and how these may be created from live biomass pools following disturbance events, and their slow transfer of carbon into the decomposable (De) and resistant (Re) pools of debris due to the slow process of standing dead senescence.



Based on data presented in Table 6.B.2 below, it was also assumed that rates of senescence were 0.83 per cent mo^{-1} for standing dead stem or branch wood, 1.25 per cent mo^{-1} for standing dead bark, and 1.67 per cent mo^{-1} for standing dead foliage. In contrast to live biomass pools above-ground, it is assumed that any coarse or fine roots below-ground affected by disturbances are converted to debris, not standing dead pools. There is a paucity of data on the fate of biomass decomposed from standing dead pools; namely the split between atmospheric emissions (CO_2-C loss) and material passed into the debris pools. Given standing dead pools generally have poor contact with soil and hence, decomposers, the assumption made was that the carbon use efficiency during senescence of standing dead pools was be relatively poor, with 90 per cent of the material being lost as CO_2-C and only 10 per cent being converted to debris carbon. This assumption was consistent with that applied by Paul and Roxburgh (2019a).

Table 6.B.2 Collation of decomposition constants (k) fitted to a single exponential decay model of observed in situ decay of coarse woody debris, from South-West, Western Australia.

Species	Component (& diameter, cm)	In situ decomposition time (yrs)	*k*	Source
Eucalyptus diversicolor	Twigs (<0.5)	1.5	-0.120	O'Connell *et al.* (1987)
E. diversicolor	Stem (2.5)	2	-0.046	O'Connell *et al.* (1997)
E. diversicolor	Stem (4.3)	2	-0.030	O'Connell *et al.* (1997)
E. diversicolor	Stem (8.4)	2	-0.022	O'Connell *et al.* (1997)
E. diversicolor	Twigs (0.8)	2	-0.107	O'Connell *et al.* (1997)
E. diversicolor	Twigs (1.1)	2	-0.120	O'Connell *et al.* (1997)
E. diversicolor	Twigs (1.4)	2	-0.094	O'Connell *et al.* (1997)
Acaia urophylla	Stem (1.9)	2	-0.115	O'Connell *et al.* (1997)
Acaia urophylla	Stem (3.7)	2	-0.109	O'Connell *et al.* (1997)
Bossiaea laidlawiana	Stem (1.7)	2	-0.114	O'Connell *et al.* (1997)
Bossiaea laidlawiana	Stem (4.3)	2	-0.093	O'Connell *et al.* (1997)
Trymalium spathulatum	Stem (1.8)	2	-0.123	O'Connell *et al.* (1997)
Trymalium spathulatum	Stem (4.0)	2	-0.081	O'Connell *et al.* (1997)
E. diversicolor	Stem (10-15)	5	-0.174	Brown *et al.* (1996)
E. marginata	Branch (3-5)	5	-0.067	Brown *et al.* (1996)
Pinus pinaster	Branch (3-5)	5	-0.049	Brown *et al.* (1996)
Allocasurian fraseriana	Branch (3-5)	5	-0.072	Brown *et al.* (1996)
Banksia grandis	Branch (3-5)	5	-0.133	Brown *et al.* (1996)
E. calophylla	Branch (3-5)	5	-0.215	Brown *et al.* (1996)

6.B.4 Estimating changes in forest debris

FullCAM allows for the modelling of debris accumulation and decay based on forest growth and management. Debris accumulates from the turnover of live plant material (e.g., branches, bark, leaves, and roots) to dead organic matter (DOM) (e.g. litter, coarse woody debris and dead roots). The turnover rates determine the amount of material being added to the debris pool. Decomposition rates determine the rates of loss of carbon back to the atmosphere and soil as the debris breaks down. The balance of these two factors determines the amount of debris on site excluding the effects of management.

In the absence of forest disturbances such as harvest or fire, debris mass increases with age to a steady state where the addition of forest material to the debris pools and loss from decomposition is in balance. Debris pools are also increased by the addition of slash material following harvest and decreased by any residue management techniques, in particular residue burning.

6.B.4.1 Calibration of rates of turnover and decomposition

Recent work on reviewing field studies with litter traps (Paul and Roxburgh, 2017) has greatly expanded the Australian database of forest turnover rates based on that previously available. Measurements of litterfall via litter trap studies were collated from across a range of forest types:

- Environmental plantings: 4
- Hardwood and softwood plantations: 16 and 29, respectively.
- Native forests and woodlands: 83 and 24, respectively.

As described by Paul and Roxburgh (2017), these 156 litter trap studies were used to determine average rates of litterfall of foliage, twigs and bark from different forest types. Where required, average per cent Foliage, per cent Twig and per cent Bark observed for the different forest types were used to 'fill-gaps' for studies where the total litterfall was not partitioned into these components. Similarly, where the stand-based mass of foliage, twigs and bark were not measured, these were predicted using FullCAM and the revised allocation input tables. Average rates of foliage turnover were then calculated to refine foliage turnover for each for environmental or mallee plantings, hardwood plantations, softwood plantations, native forests and woodlands/shrublands. As there was insufficient evidence to justify different rates of turnover of twigs and bark based on forest type, a single rate of twig litterfall, and a single rate of bark litterfall, were calculated to refine the inputs of branch and bark turnover. These values were applied across all forest types.

Recent work on reviewing litter bag studies (Paul and Roxburgh, 2017) has also greatly expanded the Australian database of forest decomposition rates. Measurements of litter decomposition were available from litter bag studies installed under a range of forests, including:

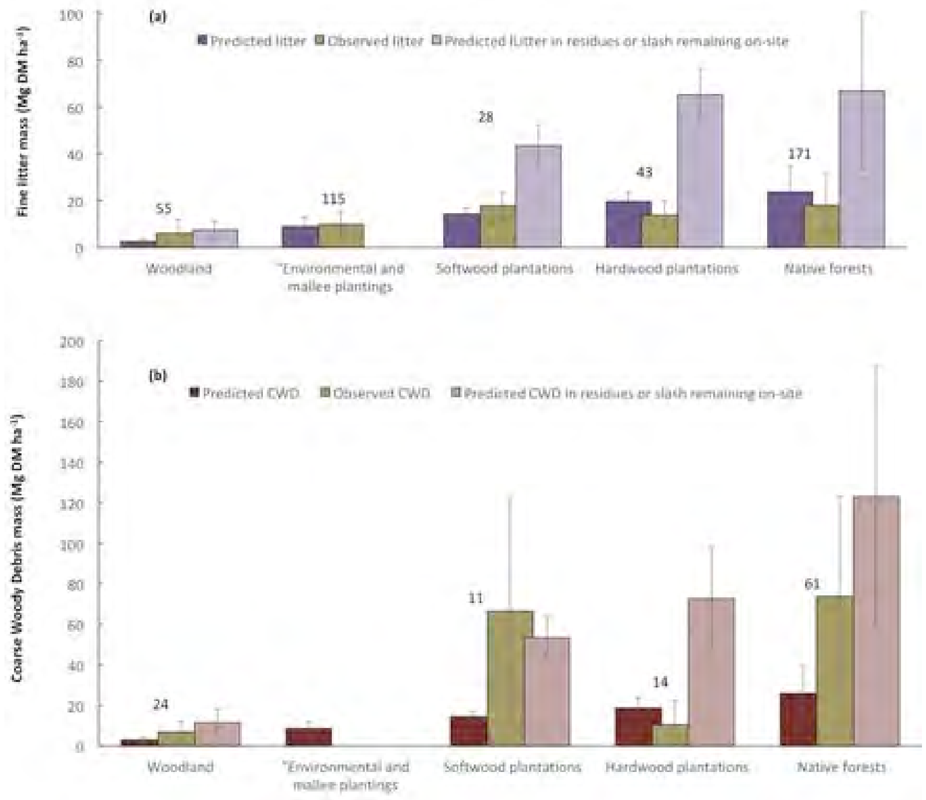
- Eucalypt-dominant stands; 23, 13 and 59 measurements of decomposition of deadwood, bark litter and foliage litter, respectively.
- Softwood plantations; 28 measurements of decomposition of needle litter.

Simple double- or single-pool decay functions are commonly calibrated to datasets obtained from litterbag studies. On review of these, it was found that single-pool models were justified for deadwood and bark litter, while a two-pool double models were justified for foliage litter. Hence for all forest types, FullCAM inputs of the fraction of debris that was resistant was set to 100 per cent for deadwood and bark, while for foliage it was set to the average values observed from the fitting of the double-pool decay function to litterbag studies of foliage. On average, the resistant fraction of pine needle litter was higher than that of eucalypt leaves, and so the revised FullCAM parameter for resistant fraction of foliage debris was higher (set at 83 per cent) for softwood plantations than all other forest types (set at 77 per cent). These proportions, as well as the rate parameters, derived from calibration of the decay functions were used as inputs into FullCAM as described by Paul and Roxburgh (2017).

Rates of decomposition in FullCAM are influenced by temperature and rainfall using the options of either 'Mulch-style' or 'Soil-style' sensitivity. Decomposition was particularly sensitive to climate using a 'Soil-style' approach. Given the lack of data on how climate impacts rates of decomposition, the more conservative approach of using 'Mulch-style' sensitivity was applied; with sensitivity values of 1 being used as per previous NIRs.

As a result of revising the parameters for rates of turnover and decomposition, predictions of inputs and outputs from the debris pool were changed. Figure 6.B.4 below (taken from Paul and Roxburgh, 2017) shows that, for the various forest types, using these revised parameters, prediction of litter mass and coarse woody debris was generally within the bounds on one standard deviation in the average observed stocks of these pools. Both the observed and predicted masses of debris will be strongly influenced by the management regime (e.g. harvesting or fire).

Figure 6.B.4 Predicted and observed (a) litter mass, and (b) coarse woody debris (CWD) under various forest types, including: mature (100 year) woodlands; relatively young (20 year) environmental and mallee plantings; softwood plantations of multiple rotations; hardwood plantations of multiple rotations, and; mature (100 year) native forest



For woodlands and native forests, predictions are at 100 years when left uncleared, and when assumed to be cleared, the year 99 of simulation. For plantations, predictions the average observed across multiple rotations simulated over a 100 year period, or that predicted in the year post the final clearing event. Number labels represent the number of observations that were used to calculated the average observed litter or CWD. Error bars represent the standard deviations of the means. Predicted means were based on the simulation of 5 woodlands, 21 environmental or mallee plantings, 5 softwood plantations, 6 hardwood plantations, and 4 native forests (Paul and Roxburgh 2017).

6.B.5 Estimating changes in forest soils

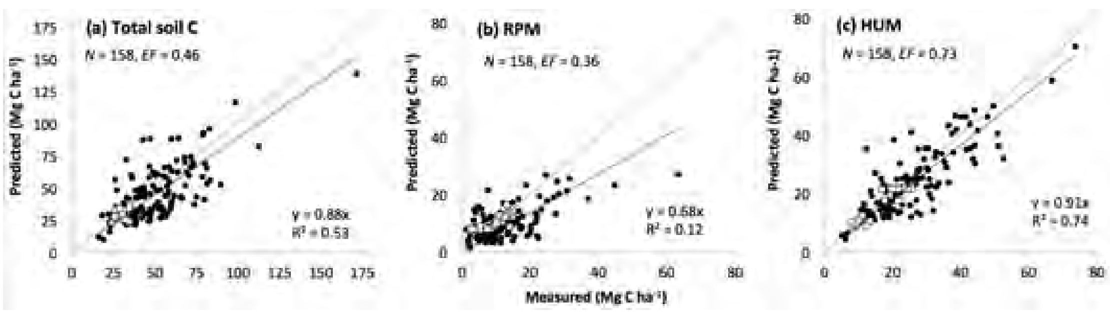
Soil can often be the largest storage of C in forests, and many pools of soil C significantly change in response to land use change, or changes in management. However, the modelling of stocks of soil C is complicated given: (i) stocks are the balance of C inputs from debris decomposition, and outputs from turnover of soil pools, and; (ii) many of the important processes influencing soil C are difficult to measure. Hence, there is a paucity of data for inputs such as root turnover and decomposition, the fraction of C lost as CO_2 on decomposition, and turnover rates of the soil pools. Having measurements of the various pools of soil C simulated by FullCAMs RothC sub-model (e.g. RPM, HUM etc., Baldock *et al.* 2013a,b), together with measurements of biomass, and litter mass, have has been useful to constrain the calibration of some of these parameters (e.g. Paul and Polglase 2004b; Paul *et al.* 2017b; Paul *et al.* 2018).

6.B.5.1 Calibration of key parameters influencing predictions of pools of soil C under forests

Recent datasets of measurement of biomass, litter and pools of soil C were collated from a wide range of forest types across Australia (Paul and Roxburgh 2017). This included 124 paired environmental planting sites (Paul *et al.* 2017b) and 20 fertiliser and irrigation treatment plots under hardwood and softwood plantations (Paul and Polgase 2004a).

As described in detail by Paul and Roxburgh (2017), these studies found no justification to adjust any of the RothC parameters calibrated for agricultural soils (Table 6.B.5). The approach used was to effectively 'tune' rates of root turnover and decomposition, and the fraction of CO_2-C loss on debris decomposition, to ensure that predicted pools of soil C match that observed, while at the same time constraining predictions of biomass, litterfall and litter mass to that observed. In the absence of any justification to assume otherwise, the values of the parameters for root turnover and decomposition, and the fraction of CO_2-C loss on debris decomposition, were assumed to be the same, regardless of forest type. With such constraints, obtaining high efficiencies of calibration of pools of soil C was challenging. Nonetheless, efficiencies of prediction of total soil C pools was still 43 per cent (and 31 per cent for RPM and 69 per cent for HUM) (Figure 6.B.5).

Figure 6.B.5 Relationship between observed and predicted carbon stocks (Mg C ha^{-1}) in surface soil (0-30 cm) for: (a) total soil organic carbon; (b) RPM pool of soil C; and (c) HUM pool of soil C



Datasets used in figure 6.B.5 are described by Paul and Polgase (2004a) and Paul *et al.* (2017b). Black circles represent the paired-site environmental plantings. White squares represent the hardwood and softwood repeated-measured forestry trials.

6.B.6 Estimating changes in crop and pasture biomass and debris

6.B.6.1 Biomass

The model uses crop and pasture yield data and the proportional allocation of dry matter to different plant components to estimate annual dry matter accumulation in agricultural ecosystems.

An earlier analysis (Unkovich *et al.* 2009) defined the relevant crops for carbon accounting purposes (Table 6.B.3) at the Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010).

Table 6.B.3 Field crops accounting for ≥95 per cent (●), and additional crops for ≥99 per cent (O) of field crop sowings for Australia as a whole, and in each Australian State in 2006 (from Unkovich *et al.* 2009)

Crop	Aust.	NSW	Vic.	Qld	SA	WA	Tas.
Wheat (*Triticum spp*)	●	●	●	●	●	●	●
Barley (*Hordeum vulgare*)	●	●	●	●	●	●	●
Narrow-leaf lupin (*Lupinus angustifolius*)	●	O	O		O	●	
Canola (*Brassica napus*)	●	●	●		●	●	
Oat (*Avena sativa*)	●	●	●	O	●	O	●
Sorghum (Sorghum vulgare)	●	●		●			
Sugarcane (*Saccarum officinarum*)	●	O		●			
Cotton (*Gossypium hirsutum*)	●	●		●			
Triticale (*Triticum durum x Secale cereale*)	●	●	●		●		●
Chickpea (*Cicer arietinum*)	O	O	O	●			
Field Pea (*Pisum sativum*)	O		●		●	O	
Faba bean (*Vicia faba*)	O	O	O		O		
Rice (*Oryza sativa*)	O	●					
Sunflower (*Heliantus annus*)	O	O		●			
Lentil (*Lens culinaris*)	O		●				
Maize (Zea mays)		O		O			
Vetch (*Vicia sativa*)			O		O		
Mung bean (*Phaseolus aureus*)				O			
Peanut (*Arachis hypogaea*)				O			
Soybean (*Glycine max*)				O			
Millet (*Pennisetum spp*)				O			
Oil Poppies (*Papaver somniferum*)							●

The available data have been reviewed to develop appropriate harvest indices for each plant type to enable conversion from mass of saleable product to total plant mass (Unkovich *et al.* 2010). The proportional allocation of dry matter to plant components were determined from estimates by expert field agronomists and include allocation to roots, GBF (grains, buds and fruit), stalks and leaves, coarse roots and fine roots. The crop types and plant partitioning used in the model are shown in Table 6.B.4.

The crop and pasture yield data for each cropping system, SA2 region and soil type are estimated in *FullCAM* (see Appendix 6.E.3)

Table 6.B.4 Plant partitioning by crop and pasture type

Species Name	Yield Allocation to Grains, Buds or Fruit (fraction)	Yield Allocation to Stalks (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Annual & perennial (incl. Mulga)	0.00	0.00	0.53	0.00	0.47
Annual grass	0.00	0.00	0.53	0.00	0.47
Annual legume	0.00	0.00	0.53	0.00	0.47
Annual legume irrigated	0.00	0.00	0.53	0.00	0.47
Aristida-Bothriochloa	0.00	0.30	0.47	0.00	0.23
Barley	0.00	0.00	0.53	0.00	0.47
Black speargrass	0.00	0.00	0.53	0.00	0.47
Blady grass	0.00	0.00	0.53	0.00	0.47
Blue lupin	0.00	0.00	0.53	0.00	0.47
Bluebush/Saltbush	0.00	0.00	0.53	0.00	0.47
Bluegrass-browntop	0.00	0.21	0.56	0.00	0.23
Canola	0.00	0.28	0.49	0.00	0.23
Chickpea	0.10	0.33	0.13	0.22	0.22
Cotton – irrigated	0.10	0.33	0.13	0.22	0.22
Cotton – rainfed	0.00	0.23	0.54	0.00	0.23
Faba bean	0.00	0.28	0.49	0.00	0.23
Field pea	0.00	0.00	0.53	0.00	0.47
Grass only – brigalow/gidyea	0.00	0.00	0.53	0.00	0.47
Grazed cereal	0.00	0.00	0.53	0.00	0.47
Grazed cereal – irrigated	0.00	0.00	0.53	0.00	0.47
Grazed vetch	0.00	0.26	0.51	0.00	0.23
Lentil	0.00	0.00	0.53	0.00	0.47
Lucerne	0.00	0.00	0.53	0.00	0.47
Lucerne irrigated	0.31	0.38	0.08	0.00	0.23
Maize	0.00	0.20	0.57	0.00	0.23
Millet	0.00	0.00	0.53	0.00	0.47
Mitchell grass	0.00	0.00	0.53	0.00	0.47
Monsoonal annual	0.00	0.00	0.53	0.00	0.47
Monsoonal perennial	0.00	0.23	0.54	0.00	0.23
Mung bean	0.00	0.22	0.55	0.00	0.23
Narrow-leaf lupin	0.00	0.00	0.53	0.00	0.47
Oat	0.00	0.00	0.53	0.00	0.47
Oil poppies	0.00	0.00	0.53	0.00	0.47
Peanut	0.00	0.00	0.53	0.00	0.47
Perennial grass	0.00	0.00	0.53	0.00	0.47
Perennial grass Irrigated	0.00	0.00	0.53	0.00	0.47
Perennial grass/clover	0.00	0.31	0.46	0.00	0.23
Perennial legume	0.00	0.00	0.53	0.00	0.47
Queensland bluegrass	0.00	0.352	0.418	0.00	0.23

Species Name	Yield Allocation to Grains, Buds or Fruit (fraction)	Yield Allocation to Stalks (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Rice	0.00	0.23	0.54	0.00	0.23
Samphire	0.00	0.00	0.53	0.00	0.47
Sorghum	0.64	0.00	0.13	0.00	0.23
Soybean	0.31	0.31	0.15	0.00	0.23
Spinifex	0.00	0.275	0.495	0.00	0.23
Sugarcane	0.00	0.00	0.53	0.00	0.47
Sunflower	0.00	0.30	0.47	0.00	0.23
Triticale	0.00	0.275	0.495	0.00	0.23
Tropical grass	0.00	0.00	0.50	0.00	0.50
Vetch	0.00	0.30	0.48	0.00	0.22
Wheat	0.00	0.26	0.44	0.00	0.30

Carbon contents of crop and grass species

Plant dry matter is converted to carbon using a crop carbon content value that is specific to the species in use, in the model. These average values for crop species are sourced from Roth-C (https://www.rothamsted.ac.uk/rothamsted-carbon-model-rothc). These values are a ratio of 1.44 for DPM/RPM for agricultural crops and improved grassland, and a ratio of 0.67 for unimproved grassland.

6.B.6.2 Debris

The amount of plant residue generated and available onsite by a crop or grass species is dependent on both the plant growth and management practice. As well as containing the crop/pasture growth and species data, the relational database describes the agricultural management practices, (e.g., stubble management) applied to each crop/pasture (see section 6.E.3). These parameters describe how much of the crop mass becomes litter residue, the rate of residue decomposition, and how much of the decomposed residue is incorporated into the soil carbon pools.

Initial crop litter mass and decomposition rates and carbon use efficiency

The initial mass of litter assigned, decomposition rates and carbon use efficiency for each decomposable and resistant plant pool are shown in Table 6.B.5.

Table 6.B.5 Initial litter mass and decomposition rates and carbon use efficiency for crop systems

Plant Component	Initial Mass t ha^{-1}	Decomposition Rate yr^{-1}	Carbon Use Efficiency<?>
Grains, Buds, Fruit (Resistant)	0.01	0.1	60%
Grains, Buds, Fruit (Decomposable)	0	0.3	60%
Stalks (Resistant)	0.01	0.1	60%
Stalks (Decomposable)	0.01	0.3	60%
Leaves (Resistant)	0.01	0.1	60%
Leaves (Decomposable)	0.01	0.3	60%
Coarse Roots (Resistant)	0.01	1	60%
Coarse Roots (Decomposable)	0.01	1	60%
Fine Roots (Resistant)	0.01	1	60%
Fine Roots (Decomposable)	0.01	1	60%

Crop turnover rates

Turnover represents the natural shedding of material by the plant. Turnover moves directly to the debris pool. All parts of a plant are subject to turnover, including roots. Root sloughing in response to grazing is included in the model which maintains the relative ratio of aboveground to belowground plant mass when grazed. Table 6.B.6 shows the monthly turnover rates applied to crop and pasture systems.

Table 6.B.6 Turnover rates applied to crop and pasture systems

Plant Component	Turnover Rates $month^{-1}$	
	Pasture species	Annual crop species
Grains, Buds, Fruit	0	0
Stalks	0	0.008
Leaves	0.07	0.07
Coarse Roots	0	0.008
Fine Roots	0.125	0.125

6.B.7 Estimating changes in soil carbon

The Rothamsted soil carbon model (*Roth-C*) is a soil carbon model developed by Jenkinson *et al.* (1991). *Roth-C* models changes in soil carbon based on the inputs of organic matter from dead plant material and soil carbon decomposition rates. Within *Roth-C* there are five soil carbon pools generally defined by classes of resistance to decomposition. Plant residues are firstly split into decomposable and resistant plant material. Turnover rates for each soil pool are determined by rainfall, temperature, groundcover and evaporation other than decomposition rate constants specific to each soil carbon pool. *Roth-C* is used in conjunction with both *CAMFor* and *CAMAg* to model soil carbon stocks in the national account.

Model was initialised using measureable soil carbon fractions (see Appendix 6.E) by replacing the key conceptual pools namely DPM, RPM and HUM defined in the *Roth-C* model. *Roth-C* model also utilises clay content and the initial topsoil moisture deficit as inputs to carry out soil carbon simulations.

6.B.7.1 Model calibration, validation and verification

Calibration of *Roth-C* was undertaken using available long-term field trial data, which had sufficiently detailed and complete long-term data to enable calibration of the model against long-term field measurements. Only a minimum of data supplementation was accepted at these calibration sites. Other sites with incomplete long-term data, but providing a robust temporal pattern of carbon change under known management and climate, were used for model validation and verification (Skjemstad and Spouncer, 2002).

Calibration and validation

Two agricultural and seven forestry long term trial sites were selected for estimating changes in soil carbon. One agricultural site was located on a monsoonal subtropical environment with heavy clay soil and the other was located in a temperate Mediterranean climate with a light textured soil. At each agricultural site, archival soil samples (0-30 cm depth) collected throughout the life of the trials were fractionated into particulate organic carbon (POC), charcoal (char-C) and humic (HUM) pools (Skjemstad and Spouncer, 2003).

The soil carbon model (*Roth-C*) used to calculate changes in soil carbon stocks caused by shifts in agricultural practice was independently calibrated and validated (Skjemstad and Spouncer 2003). The results were found to be sensitive to the partitioning of carbon between the various soil fractions (Janik *et al.* 2002; Skjemstad *et al.* 2004; Paul and Polglase, 2004b).

Testing of the seven forestry sites and two agricultural sites confirmed the model calibrations for soil carbon pool allocations for both forestry and agricultural sites. Details of the calibration and testing of the model are provided in Paul *et al.* (2002b and 2003b).

Model validation used existing time-series data and new paired-site comparisons to test model predictions of change. Calibration of the model demonstrated that the measureable soil carbon fractions (POC, HUM and Char-C pools/ROC) fitted well with the modelled carbon pools (RPM, HUM and IOM) as defined in *Roth-C*, A full description of the model calibration and validation results for agriculture can be found in Skjemstad and Spouncer (2003).

In general terms the coefficient of variation for modelled outputs of soil carbon is around 5 per cent (Janik *et al.* 2002), whereas the coefficient of variation for measured soil carbon is 15-40 per cent (McKenzie *et al.* 2000a and b; Janik *et al.* 2002). Further details are provided in Murphy *et al.* (2002), Harms and Dalal, (2003) and Griffin *et al.* (2002).

More recently Chappell and Baldock (2017) were commissioned by the Department of the Environment and Energy to enhance the reliability of soil carbon change estimates provided by the *FullCAM* framework. A local optimisation was performed separately for each of the 103 plots of the calibration and verification sites (Skjemstad and Spouncer 2003) allowing optimisation of three initial stocks of SOC pools (RPM, HUM and IOM) and the decomposition rate constant parameters (RPM and HUM). The optimised values of the initial soil carbon pools were then used in a separate global optimisation of the same measurement data but with optimisation of only the decomposition parameters (RPM and HUM).

The results are shown in Table 6.B.7.

Table 6.B.7 Roth-C model including soil redistribution globally fitted decomposition rates and their goodness of fit

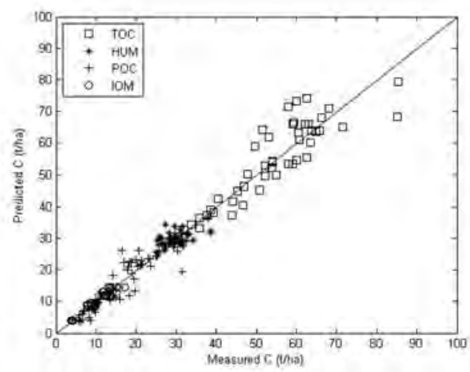
Global optimisation	RPM y^{-1}	HUM y^{-1}	RMSE ($C\ t\ ha^{-1}$)
Calibration sites	0.207	0.021	0.234
Verification sites	0.149	0.029	0.095
All sites	0.173	0.028	0.090

Source: Chappell and Baldock (2017)

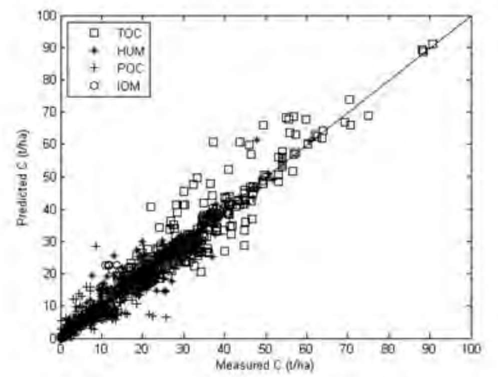
Figure 6.B.6a (below) shows a plot of measured C for all site data of Brigalow and Tarlee against Roth-C predicted C using the optimised values of the decomposition parameters RPM=0.207 y^{-1} and HUM=0.021 y^{-1}. The RMSE of the global model fitting was 0.234 (C t/ha) which describes the error associated with model predictions using the parameter values calibrated against these data.

Figure 6.B.6 Global optimisation of the *Roth-C* model (using decomposition parameters for RPM and HUM) against the measured C of the RPM (POC), HUM (HOC) and IOM (ROC) pools of the calibration site Brigalow and Tarlee (a), the verification sites only (b) and the calibration verification sites combined (c) and verification of selected sites using the FullCAM model (d)

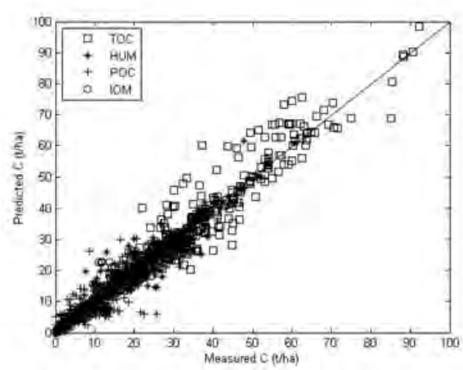
(a)



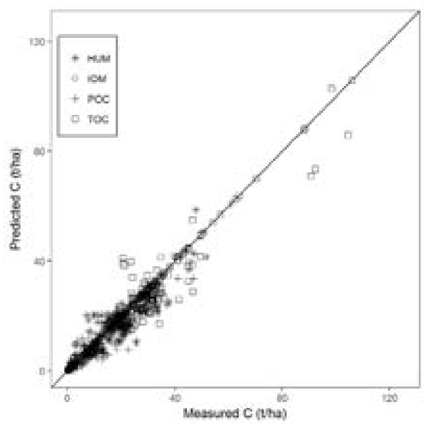
(b)



(c)



(d)

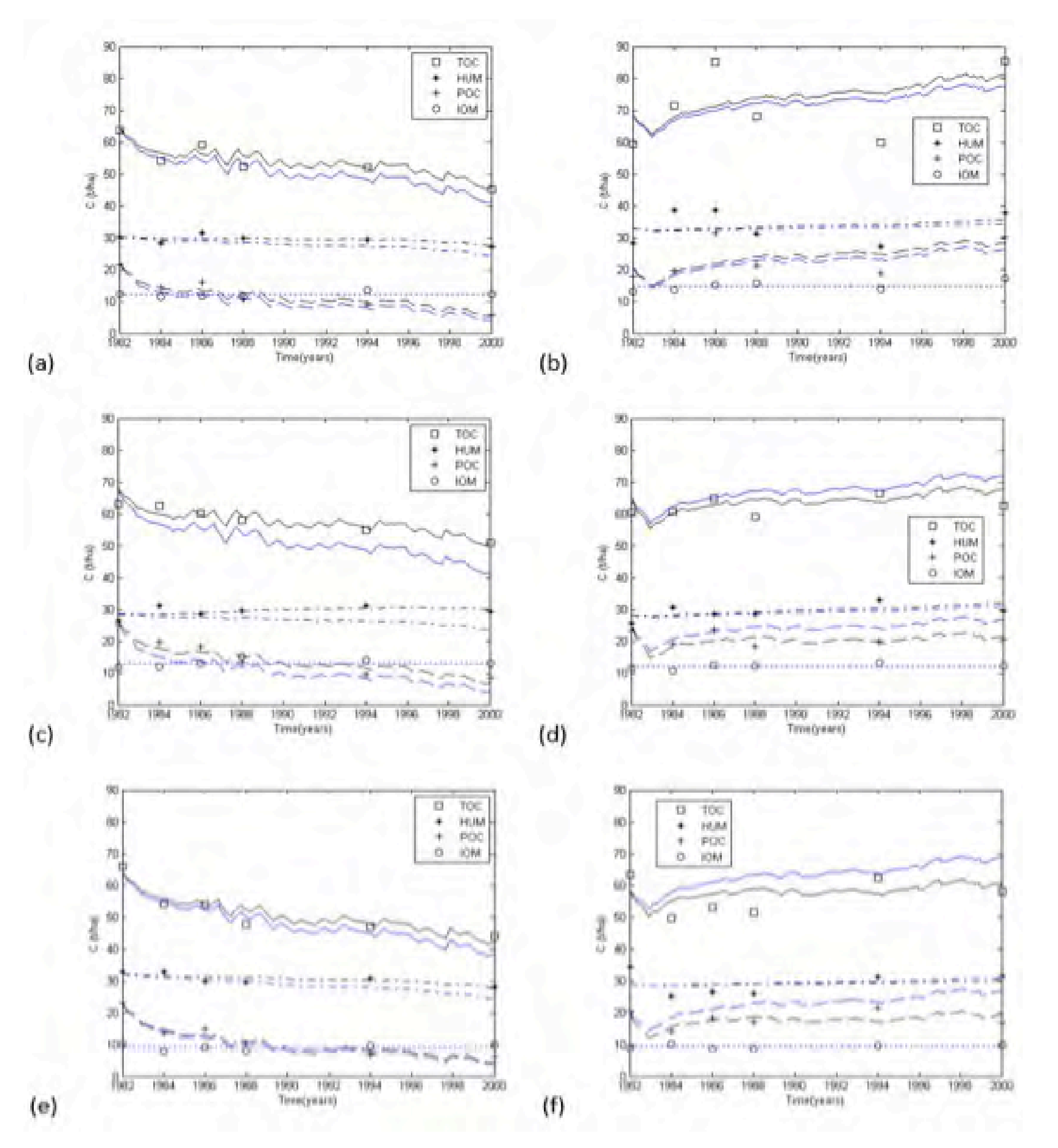


Source: Chappell and Baldock (2017) and the unpublished work carried out by the DoEE (2017)

Figure 6.B.6b shows a plot of measured C for all site verification data against *Roth-C* predicted C using the optimised values of the decomposition parameters RPM=0.149 y^{-1} and HUM=0.029 y^{-1}. The RMSE of the global model fitting was 0.095 (C t/ha). Figure 6.B.6c shows a plot of measured C for all sites (calibration and verification) data against *Roth-C* predicted C using the optimised values of the decomposition parameters RPM=0.173 y^{-1} and HUM=0.028 y^{-1}. The RMSE of the global model fitting was 0.090 (C t/ha). Evidently, the previously recommended values of RPM = 0.15 y^{-1} and HUM = 0.02 y^{-1} are within the variation found across the plots and sites around Australia but these values are smaller than the globally fitted decomposition rates. As such the decomposition parameters have been adjusted to reflect this latest research and provide the most robust calibration of *FullCAM*. Further verification using FullCAM revealed that correlation between measured and simulated total soil carbon reported 0.94 correlation while RMSE value was reported as 5.74 C t/ha.

Figure 6.B.7 shows the behavior of *Roth-C* model temporal simulations for two sites in Brigalow with RPM and HUM soil decomposition rate constants values obtained from local and global optimization process. Even though the local optimise rate constant values mimic much closer representativeness with simulated data and measureable fractions, global optimise parameters also produced very similar pattern.

Figure 6.B.7 Brigalow continuous wheat (a, c & e) and Brigalow continuous pasture (b, d & f) with Roth-C local model fits (black line) and global model fits (blue line) using decomposition parameter values RPM=0.173 and HUM=0.028.



Source: Chappell and Baldock (2017)

Verification of FullCAM Outputs

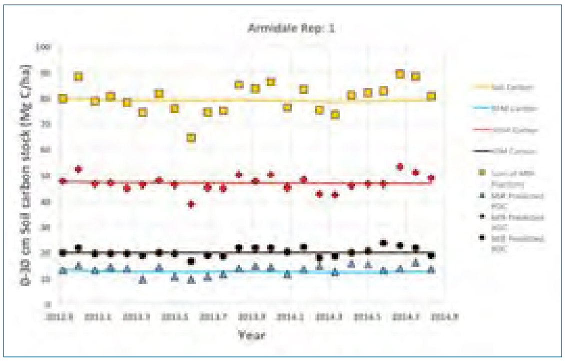
Independent soil carbon measurements undertaken through the Filling the Research Gap (FtRG) program, funded by the Australian Government Department of Agriculture and Water Resources, were used to verify the FullCAM simulations.

Figure 6.B.8 shows comparison of selected FullCAM plot simulations with field data (MIR predicted) collected by CSIRO Agriculture and Food, under the FtRG program. These sites represent the major cropping regions of the country. For this verification, we used site specific climate data, soil carbon fractions measured using mid-infrared spectroscopy, while temporal carbon inputs were added based on the cropping regimes included in the FullCAM database.

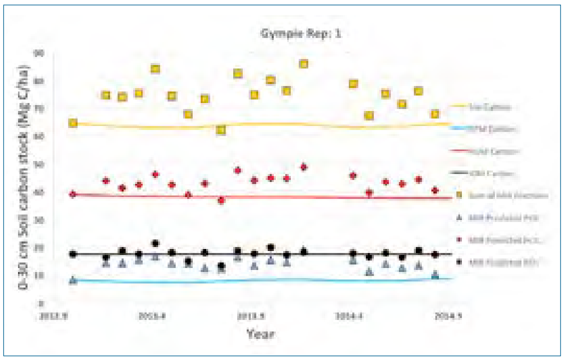
This verification exercise confirmed the reliability of FullCAM estimates as indicated by overall RMSE value of 9.21 C t/ha and correlation value of 0.60 for the temporal values recorded for 20 sites.

Figure 6.B.8 FullCAM outputs (solid lines) using global decompositions parameters with field measured (MIR predicted) (dotted points) total soil carbon and its fractions for the selected sites (a) Armidale, (b) Gympie, (c) Hamilton and (d) Narrabri.

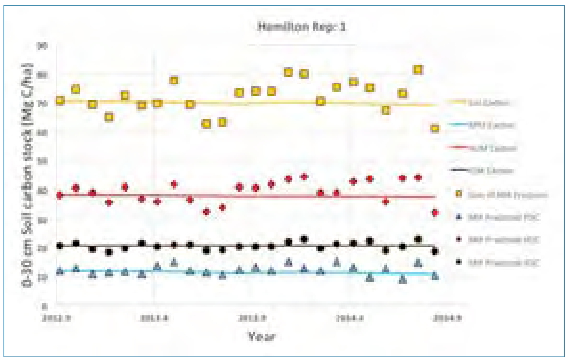
(a)



(b)



(c)



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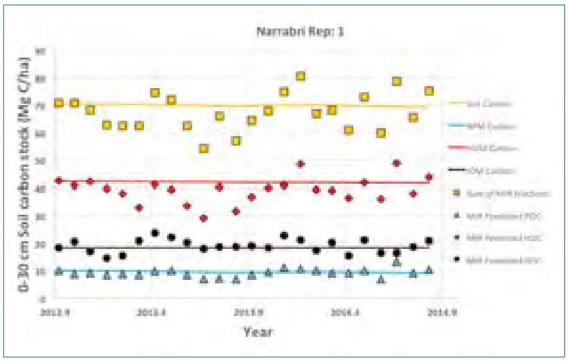
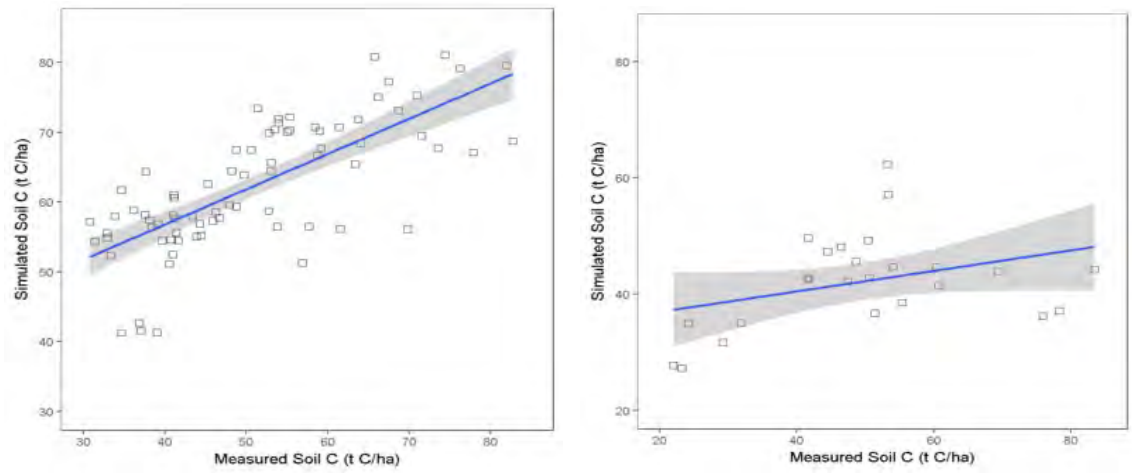


Additionally, FullCAM outputs were assessed using a second of set of independent field data collected by the Department of Economic Development, Jobs, Transport and Resources (DEDJTR) – Victoria State Government (n=77 sites) and CSIRO Agriculture and Food (n = 25 sites). In this case, soil fractions data was not available and total soil carbon measurements were obtained for one time only. The results showed an RMSE error of 14.4 C t/ha and 16.8 C t/ha and correlation between measured and simulated soil carbon values as 0.73 and 0.36 for the DEDJTR and CSIRO Agriculture and Food respectively (Figure 6.B.9).

Figure 6.B.9 Verification of FullCAM estimates using measured soil carbon data from the DEDJTR (a) and CSIRO Agriculture and Food (b)

(a) (b)



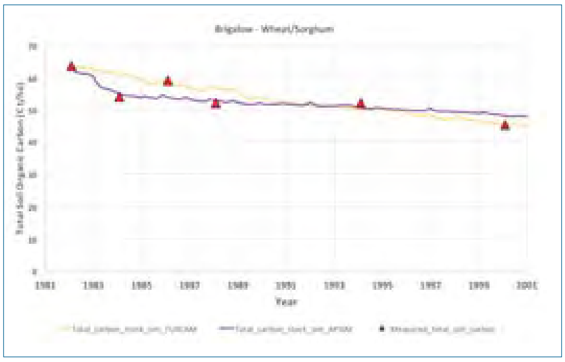
Comparison of the FullCAM estimates with APSIM outputs

FullCAM outputs were also compared with the Agricultural Production Systems siMulator model (APSIM) version 7.0 as shown in Figure 6.B.10. APSIM is internationally recognized as a highly advanced simulator of agricultural systems. It contains a suite of modules which enable the simulation of systems that cover a range of plant, animal, soil, climate and management interactions (Keating *et al.*, 2003). For this comparison, APSIM results for four sites were provided by CSIRO Agriculture and Food (Luo *et al.*, 2015). Both FullCAM and APSIM were run using the same set of field measurements.

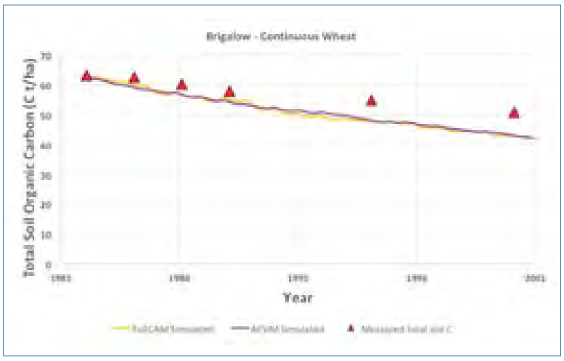
The correlation analysis for the temporal simulations between FullCAM and APSIM for each month reported 0.92, 0.99, 0.98, 0.99 for four sites in Brigalow – Wheat/Sorghum, Brigalow – Continuous Wheat, Tarlee – Wheat/Fallow and Tarlee – Continuous Wheat respectively indicating high level of confidence in the outputs. The FullCAM model, which is specifically designed for carbon accounting purposes, was able to replicate the APSIM, which was designed for agricultural system modelling.

Figure 6.B.10 Comparison of FullCAM simulations with APSIM simulations for the selected sites (a) Brigalow – Wheat/Sorghum, (b) Brigalow – continuous Wheat, (c) Tarlee – Wheat/Fallow and (d) Tarlee – continuous Wheat

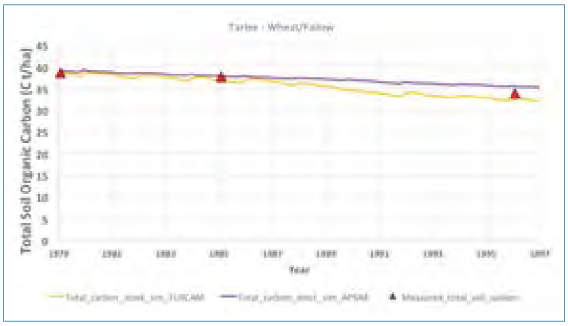
(a)



(b)



(c)



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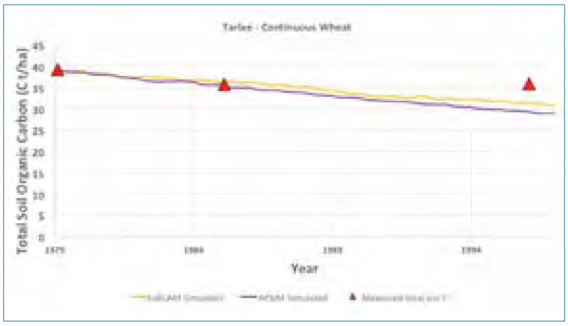


Comparison of soil carbon response to changes in management practices

Subsequent to the implementation of the baseline map of organic carbon in Australian soil (Viscarra Rossel; *et al.*, 2014), the Australian three-dimensional soil grid (Clay) (Viscarra Rossel; *et al.*, 2015), updated species (Table 6.B.2) and management practices (section 6.E.4) as well as the optimisation of the decomposition rates (*Calibration and Validation*), the Department of Environment and Energy undertook a modelling exercise in which the *FullCAM* was used to simulate the effects on soil carbon of changes in practices to manage stubble, tillage and the amount of crop biomass as well as estimate the effects of a change in land use from a continuous cropping to a pasture system and a continuous pasture to rotational cropping system.

Given the impact of climate and soil properties on the technical potential of soil carbon enhancement and the uncertainty distribution around the technical potential, seven sites were selected to reflect four main temperature and moisture regimes (Cool-Wet; Cool-Dry; Warm-Wet; Warm-Dry) defined in accordance with the 2006 IPCC Guidelines. For each of the sites selected, the Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010) in which the site is located was identified.

For each of the seven selected sites, statistics (minimum, mean and maximum values and standard deviations of the values) for the percentage of soil that is clay by weight and total were determined for the SA2 in which the selected sites were located and regression analysis on the percentage of soil that is clay by weight and total soil carbon for the SA2s was carried out to determine the correlation coefficient between the two key soil properties.

The minimum, mean and maximum values, and standard deviations for the percentage of soil that is clay by weight and total soil carbon were applied as risk variables in the Monte-Carlo analysis using @Risk (Palisade

Corporation, 2005). Parameterisation was designed to ensure that values that would not occur within the SA2 of the selected site were not used in the Monte-Carlo analysis. This approach ensures regional specificity by removing/reducing skew/bias and normalises the outputs according the input data so that the outcomes are truly reflective of that particular SA2, while allowing for the inherent variability in climate and soil type across the Australian landscape and, more specifically, the SA2.

The correlation between the percentage of soil that is clay by weight and total carbon, (including the 1:1 correlation between the soil fractions and the total soil carbon) was applied in the Monte-Carlo simulation correlation matrix to ensure proportionality of soil fractions and clay were observed.

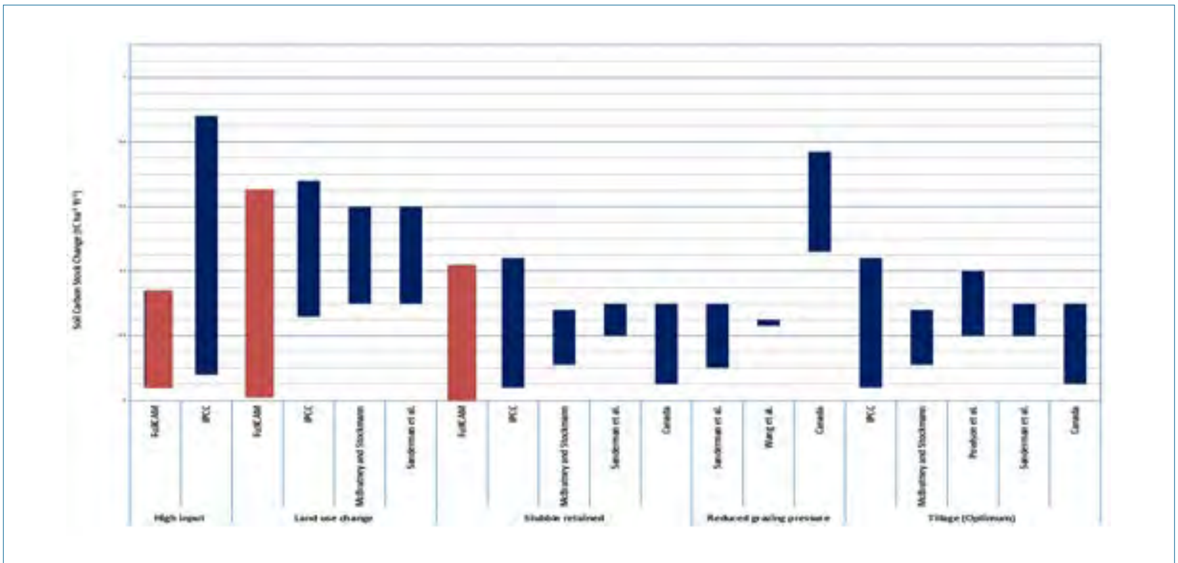
A truncated normal distribution was applied to the Monte-Carlo simulations to ensure the probability distribution of the output value for soil carbon stock is bounded above and below by the minimum and maximum values for the input risk variables.

The Monte-Carlo simulations were run for a full 1000 simulations as opposed to ceasing when convergence was met. This repeated sampling enabled the output value for soil carbon stock to converge on as close to the most probable technical potential value attainable for the SA2.

Factual (baseline) and counter-factual (scenario) simulations of selected activities identified in the 2006 IPCC Guidelines and the 2013 IPCC Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (KP) Supplement were run in *FullCAM*.

National values for the estimated response of soil carbon to changes in various management practices are presented in Figure 6.B.8. The results are within expected ranges and consistent with empirical literature and international practice. The model does not generate a single value, but a range of values where the distribution of values generated by the model is presented for each of the changes in management practices. The distribution of values demonstrates the variability in outcomes modeled by *FullCAM*, mainly reflecting spatial variations in soil quality, which is entirely expected from empirical experience across Australia. Figure 6.B.11 illustrates the variation in outcomes of differences in soil carbon sequestration and/or reduction in the rate of losses in a sensitivity scenario where the yields were increased by 20 per cent over a period of years.

Figure 6.B.11 Comparison for soil carbon response to changes in management practices for *FullCAM* and from domestic empirical literature and international practice



Appendix 6.C The forest productivity index

To derive the spatial and temporal patterns of forest growth the simplified form of the *3-PG* model (Landsberg≈and Waring 1997; Coops *et al.* 1998; Coops *et al.* 2001) was used to provide relative indices of growth potential (productivity indices[15]) at a 1 km grid scale on a monthly basis since 1970. The site-based, multi-temporal productivity indices are used to support a generalised empirical growth model. All modelling is done on the basis of aboveground biomass with subsequent factors to account for belowground (fine and coarse root) material.

A truncated version of the *3-PG* model (Landsberg and Waring 1997), retaining the essential features of biomass net primary production (*NPP*) estimation, without the carbon partitioning procedures is used to provides a site index of plant productivity that is independent of the type of forest present.

The essence of the model is the calculation of the amount of photosynthetically active radiation absorbed by plant canopies (*APAR*). *APAR* is calculated (Equation 6C_1) as half the amount of short-wave (global) incoming radiation (*SWRadn*) absorbed by plant canopies.

$$APAR = SWRadn \times 0.5 \times (1-e^{(-0.5 \times LAI)}) \times \text{days in month} \quad (6C\_1)$$

Where *LAI* is the Leaf Area Index and the coefficient 0.5 is a general value for the extinction coefficient. *LAI* is derived by the expression *ln*(1-FPAR)/(-0.5) where FPAR is calculated by (NDVI * 1.0611) + 0.3431. *APAR* is multiplied by a factor that converts it to biomass.

This, in effect, amalgamates two steps, the conversion of absorbed CO_2 into initial carbon products (gross primary production) and the loss of a proportion of those products by respiration to give NPP. The value of the conversion factor (ε, gm Biomass MJ^{-1} APAR) used was obtained from literature (Potter *et al.* 1993; Ruimey *et al.* 1994; Landsberg and Waring 1997).

There is substantial variation in ε values, but no clear pattern in relation to plant type, so a value of *1.25 gm Biomass* MJ^{-1} APAR was used based on expert judgement. As the resultant output from the model is used as an index of 'productivity' (the Forest Productivity Index) and not as an absolute mass increase value, precision in the conversion factor is not critical. This NPP value assumes that there are no other constraints on growth. To account for the effects of other factors the potential NPP is reduced by modifiers reflecting non-optimal nutrition, soil water status, temperature and atmospheric vapour pressure deficits.

Calculation of growth modifying factors

Modifiers are dimensionless factors with values between zero (complete restriction of growth) and 1 (no limitation). Modifiers used in this way are discussed by Landsberg (1986), McMurtrie *et al.* (1992) and Landsberg and Waring (1997).

The modifying factors are:

Soil fertility: Because of natural variation and the considerable uncertainty surrounding soil fertility values, only three levels of soil fertility were used; high (effective modifier = 1), medium (effective modifier = 0.8) and low (effective modifier = 0.6), giving ε values of 1.25, 1 and 0.75, respectively. These were applied for each pixel, depending on soil type, before environmental modifiers were applied. Information on soils and their characteristics was obtained from McKenzie *et al.* (2000a).

15 A generic model of Net Primary Productivity derived a classification of productivity, on a scale of 1-30. Temporal and spatial variability is identified by a change in classification. This is not a linear relationship with biomass growth increment.

Vapour Pressure Deficit (VPD): VPD is a measure of atmospheric drought. VPD affects stomatal, and hence canopy conductance as trees regulate their water use. This can lead to reduced growth even where soil water content is high. The VPD modifier equation (6C_2) used is:

$$VPDmod = e^{(-0.05 \times VPD)} \quad (6C\_2)$$

This modifier essentially acts as a control on the rate of water loss and is conditional upon soil water content (see below).

Soil Water Content: This is derived from water balance calculations, which take into account the maximum soil water holding capacity (Equation 6C_6) in the root zone of plants. Plant water use (Equation 6C_4) is calculated from the equation for equilibrium evaporation (Equation 6C_3, see Landsberg and Gower 1997; p. 79), modified by feed-back from current soil water content, and a conventional water balance equation (Equation 6C_5):

$$EqEvapn = ((0.67 \times NetRadn * (1-0.05)) / 2.47) \times \text{days in month} \quad (6C\_3)$$
$$Transpiration = EqEvapn_j \times SWmod_{j-1} \quad (6C\_4)$$
$$WaterBal = (Rain \times (1-interception)) - Transpiration \quad (6C\_5)$$
$$SoilWaterContent_j = SoilWaterContent_{j-1} + WaterBal_j \quad (6C\_6)$$

Initial Soil Water Content was taken as 0.75 x SWcapacity. Soil Water Content carries over from one time step to the next. The soil moisture calculation sequence was run for 3 years, after which Soil Water Content had essentially equilibrated to stable monthly values. Soil Water Content values in year 3 were therefore used in the analysis. The soil water modifier (*Swmod*, Equation 6C_8) was calculated from the moisture ratio (*MoistRatio*, Equation 6C_7), which is Soil Water Content normalised to SWcapacity. The equation describes the variable effect of MoistRatio across the range from wet soil (MoistRatio ≈1) to dry soil (MoistRatio ≈0).

$$MoistRatio = SoilWaterContent/SWcapacity \quad (6C\_7)$$
$$SWmod = 1 / (1 + ((1-MoistRatio)/0.6)^{0.7}) \quad (6C\_8)$$

The soil water and VPD modifiers are not multiplicative; the lowest one applies. The argument is that if plant growth (conversion of radiant energy into biomass) is limited more by VPD than soil water (i.e., if VPDmod < SWmod) then soil water is not a limiting factor, even if soil water content is relatively low. The converse applies, that is, if SWmod < VPDmod, soil water is the limiting factor.

Temperature: The growth of any plant species is limited by temperatures outside the optimum range for that species. Since plants are dealt with in a generic way the assumption was made that, in any particular region, the plants are well-adapted to the temperature range. The equation (6C_9) describing the effect of temperature is:

$$T_{mod} = ((T_{av} - T_{low}) / (T_{opt} - T_{low})) \times ((T_{high} - T_{av}) / (T_{high} - T_{opt})) \quad (6C\_9)$$

T_{av} is the average monthly temperature, T_{min} is the monthly average temperature below which plant growth stops, T_{max} is the monthly average temperature above which plant growth stops and T_{opt} is the optimum temperature for growth $(T_{min} + T_{max})/2$. The temperature modifier (T_{mod}) is 1 when $T_{av} = T_{opt}$.

Equation (6C_9) gives a hyperbolic response curve, with $T_{mod} = 0$ when $T_{av} = T_{min}$ or T_{max}. T_{min} is set to ½ the minimum temperature of the coldest month (if the minimum temperature of the coldest month is greater than or equal to 0oC, T_{min} was set to the minimum temperature of the coldest month plus ½ the minimum temperature of the coldest month if the minimum temperature of the coldest month is less than 0oC). T_{max} is set to 5˚C above the maximum temperature of the hottest month of the year and T_{opt} as equal to the average of T_{min} and Tmax. Consequently, T_{mod} generally had relatively small effects on the calculation of NPP.

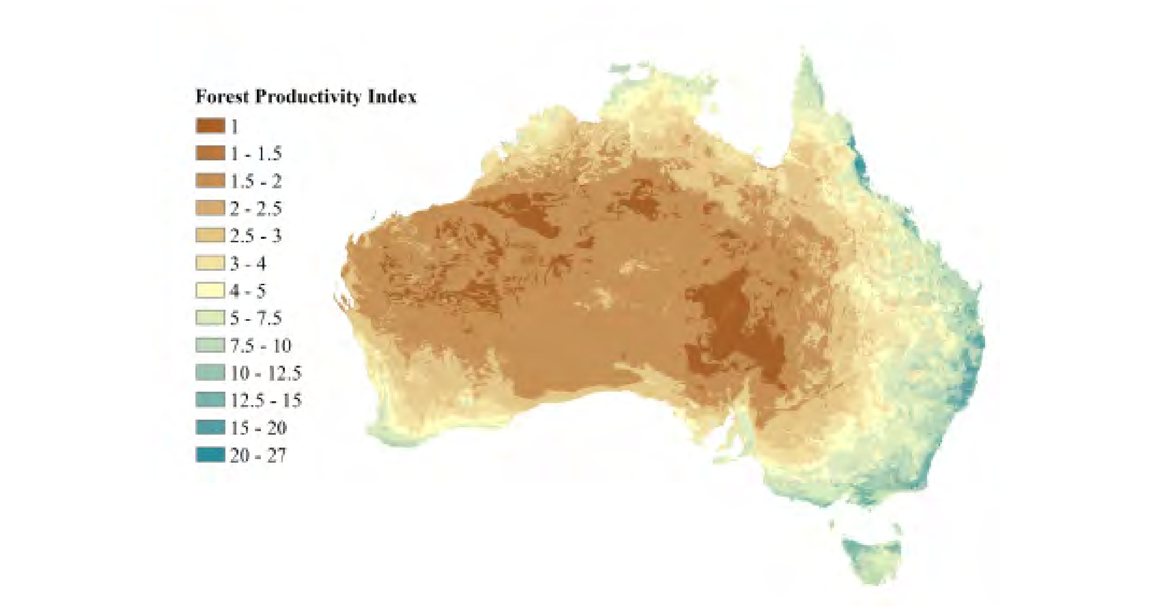
A frost modifier is included, using the simple assumption that frost temporarily inactivates the photosynthetic mechanism in foliage, so there is no growth on a frost day. The modifier is, therefore, simply the ratio of number of frost days/month to the number of days in the month.

Calculation of the forest productivity index

The Forest Productivity Index (FPI) is calculated both temporally and spatially using the monthly (since 1968) 1km grid climate and site information described in Appendix E. A further 250 m long-term average FPI is also calculated, using a slope and aspect corrected APAR calculation (Figure 6.C.1).

These productivity maps are used to describe the spatial and temporal variation in forest biomass and growth.

Figure 6.C.1 250m slope and aspect corrected productivity index map



Appendix 6.D Initial forest biomass

The initial forest biomass layer is used to estimate the initial biomass of forests on lands that is incremented in the following sub categories:

- Forest land converted to Cropland;
- Forest land converted to Grassland;
- Forest land converted to Wetlands (flooded lands); and
- Forest land (terrestrial) converted to Settlements.

An estimate of biomass (the assumed initial biomass) of mature forests is required to estimate emissions due to first time clearing events. The assumed initial biomass is applied to all first time clearing events whenever they occur. The assumed initial biomass for a pixel is calculated based on a regression model of the relationship between the Forest Productivity Index and measured biomass (Raison *et al.* 2003; Richards and Brack, 2004a), with subsequent modifications by Roxburgh *et al.* (2019) (described below).

Calibration data

Biomass measurements used in the calibration include all forest conditions except those with visible evidence of recent disturbance such as clearing, harvest or fire since 1970. The lands may, however, have an ongoing low level disturbance such as grazing and low intensity fires.

In the collection of the calibration plot data, caution was exercised to exclude forest 'gaps' contained in some field measurements. Plots taken as part of fixed-grid or transect systems could potentially fall in gaps in sparse forests. As the remote sensing programme at 25 m resolution is capable of separating such forest gaps from clearing events, the forest carbon mapping needs to represent the biomass of forested plots, not of that averaged over the gaps.

In the update by Roxburgh *et al.* (2019) the original calibration database was augmented with forest biomass observations from the TERN/AusCover National Biomass Library (http://www.auscover.org.au/purl/biomass-plot-library). This library is a collation of stem inventory and biomass estimates compiled from federal, state and local government departments, universities, private companies and other agencies. Of the approximately 14,500 site biomass records in the database, 5,739 were deemed consistent with the requirements for estimating initial mature biomass.

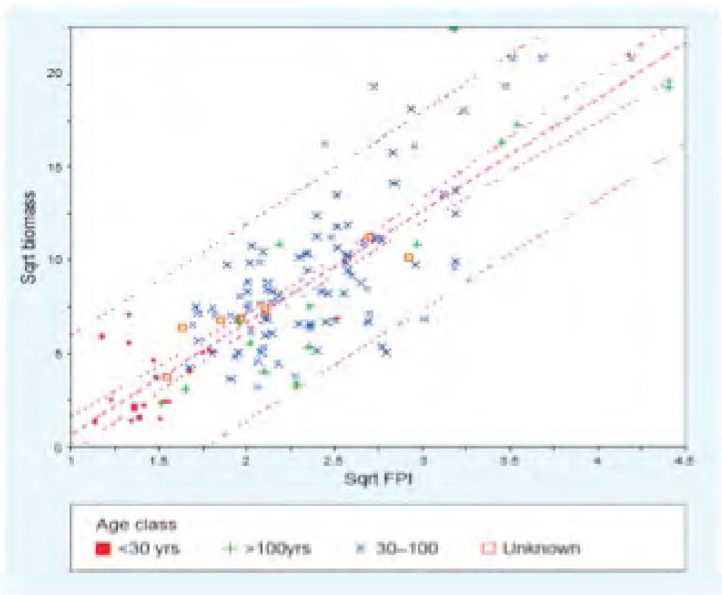
Assumed initial biomass relationship

For the original calibration of FullCAM the initial forest biomass for an individual forest site was fitted to the productivity map. The red line in Figure 6.D.1 represents the line of best fit for predicting the initial forest biomass of an individual forest site.

A regression found a significant relationship ($p < 0.01$, $r^2 = 0.68$) between the stand biomass measures (*M*) and the Long-Term Forest Productivity Index (*P*) (Equation 6D_1). A square root transformation was required to meet assumptions of normality and homogeneity (Figure 6.D.1).

$$M = (6.011 \times \sqrt{P} - 5.291)^2 \qquad (6D\_1)$$

Figure 6.D.1 The assumed initial biomass relationship



The goodness of fit of Equation (6D_1) to the measured data ($r^2 = 0.68$, $p < 0.01$) confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates although with some suggestion of under-prediction of high-biomass productive forests. The outer 95 per cent confidence limits (outer pair of dotted lines) show the reliability for predicting biomass at any individual site, and the inner 95 per cent confidence intervals (inner pair of dotted lines) show the confidence in the line of best fit being able to represent the variability in the field data at the national scale.

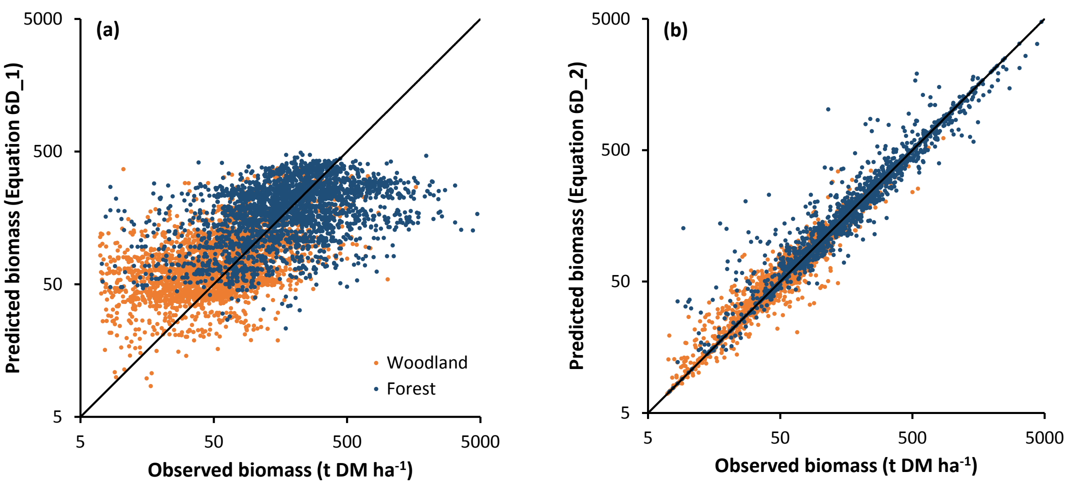
Applying Equation 6D_1 to the data from the TERN/AusCover National Biomass Library suggested the biomass predictions were accurate up to approximately 300-400 t DM ha^{-1}, after which point there was a strong tendency for the equation to under-predict actual biomass, such that all biomass observations greater than 500 t DM ha^{-1} are predicted to be less than 500 t DM ha^{-1} (Figure 6.D.3a). To correct for this bias, a spatially-explicit modifier (λ) was calculated based on the observed discrepancy between the observed and predicted biomass. Because of issues regarding non-normality and variability in the data, the non-parametric 'Random Forest' ensemble machine learning algorithm was used to estimate λ, using as predictor variables elevation, soil organic carbon content, and 21 climatic variables (Roxburgh *et al.* 2017). The revised model predictions, for pixel *i*, were therefore calculated as:

$$M_i = \lambda_i \times (6.011 \times \sqrt{P_i} - 5.291)^2 \qquad (6D\_2)$$

For regions in which the current model (Equation 6D_1) is consistent with the new data then λ is expected to be close to 1.0; for regions where biomass is being under-predicted then λ is expected to be >1, and for regions where biomass is being over-predicted then λ is expected to be <1.

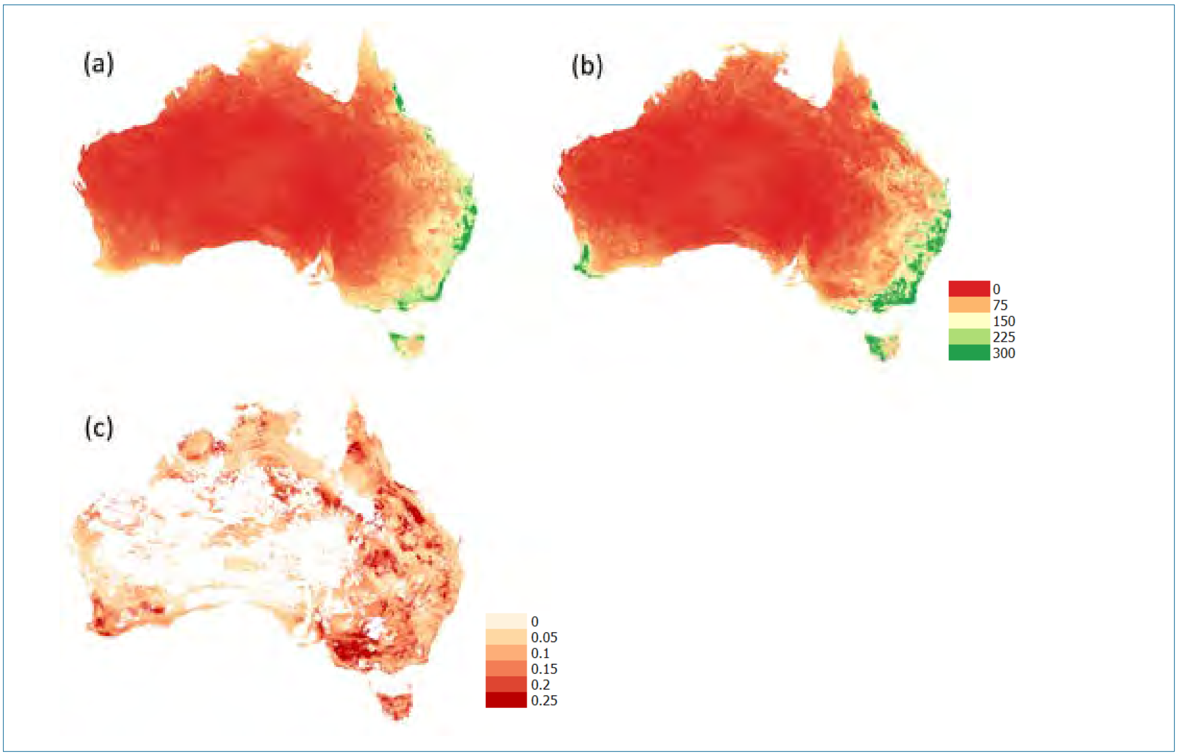
Under Equation 6D_1, and when applied to the full biomass database, the overall root mean square error (RMSE) was 239 t DM ha^{-1}, with a model efficiency (EF) of 0.14 and a mean absolute (ME) error confirming an overall bias of -35 t DM ha^{-1} (Figure 6.D.2a). Under Equation 6D_2, which includes the modifier λ, the model fit statistics all improved, with reductions in the RMSE and ME to 62 t DM ha^{-1} and -0.2 t DM ha^{-1} respectively, and a model efficiency (EF) of 0.94 (Figure 6.D.2b). The revised model is therefore characterized by a much closer fit to the 1:1 line, and negligible bias over the full range of forest biomass (equivalent statistics when observations were withheld as part of model validation testing are given in the next section).

Figure 6.D.2 (a) Observed vs. predicted biomass for the predictions using Equation 6D_1. (b) Observed vs. predicted biomass for the predictions using Equation 6D_2. 'Woodland' indicates sites with a canopy cover up to 50 per cent (i.e. including some sites classified as sparse woody vegetation with canopy cover 5-20 per cent). 'Forest' indicates sites with a canopy cover >50 per cent. Lines are the 1:1 relationship, where observations equal predictions.



The initial assumed biomass at a chosen resolution for the entire continent can then be calculated by applying Equation (6D_2) to the FPI mapping (Appendix 6.C) and is shown in Figure 6.D.3a. The revised map of M (Figure 6.D.3b) differs from the original (Figure 6.D.3a) most obviously in the increased biomass density (i.e. darker green) in the taller forests of Western Australia, Tasmania, Victoria and New South Wales. Other regional-scale differences include declines in predicted initial biomass for the northern territory, and coastal Queensland.

Figure 6.D.3 (a) Original FullCAM maximum biomass layer (t DM ha^{-1}). (b) Revised maximum biomass layer (t DM ha^{-1}). (c) Coefficient of variation (standard deviation / mean) of *M*, calculated over 100 replicate Random Forest model fits. White areas in (c) were excluded from analysis, and in (b) are filled with values from the original maximum biomass layer.



While the goodness of fit and lack of bias in error estimates (Figure 6.D.2b) provides confidence in the application of Equation (6D_2) as a model to predict biomass at maturity, there is an obvious scatter in the data which is somewhat masked by the logarithmic scales on which the figures are displayed. This is attributable to the range of age classes and forest histories used in the model, the differing methods used in the field estimation, an inherent variability between the 'plot' locations used to scale to one hectare mass estimates compared to the average condition reflected in the 250 m resolution productivity estimation, and to natural variability in forest biomass.

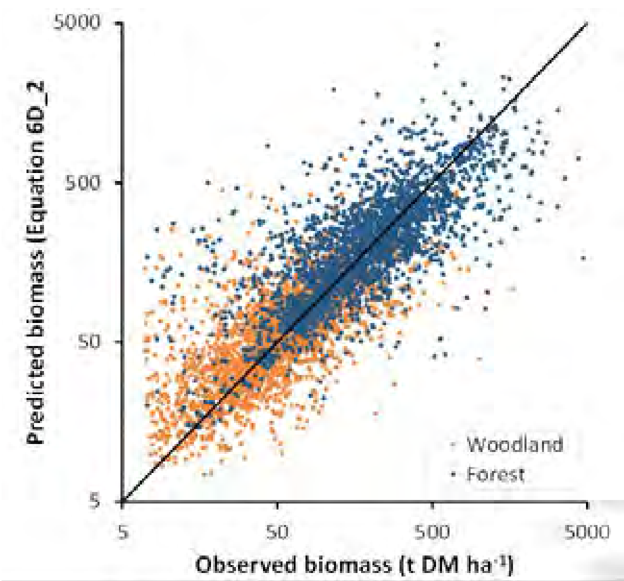
Validation and verification of assumed initial biomass

As part of the modeling procedure to predict λ the empirical database of 5,739 records was split at random into a 70 per cent model fitting (calibration) subset and a 30 per cent withheld (validation) subset. This was repeated 100 times as part of a Monte-Carlo estimation procedure, generating 100 separate models that were then used to estimate the mean and uncertainty of the predictions. Each observation therefore had the opportunity to be included both for model fitting (results shown in Figure 6.D.2b) and also for independent validation, where withheld observations are used to estimate the error associated with the prediction of 'new' observations not included in the model fitting procedure (Figure 6.D.4).

Appendix

As expected, the scatter around the 1:1 line was larger when sites were used for independent validation (compare Figure 6.D.2b with Figure 6.D.4), with a RMSE of 201 t DM ha^{-1}, a model efficiency (EF) of 0.4, and a mean absolute (ME) error indicating a an overall bias of -8 t DM ha^{-1}, corresponding to an error of approximately 5 per cent at the continental scale.

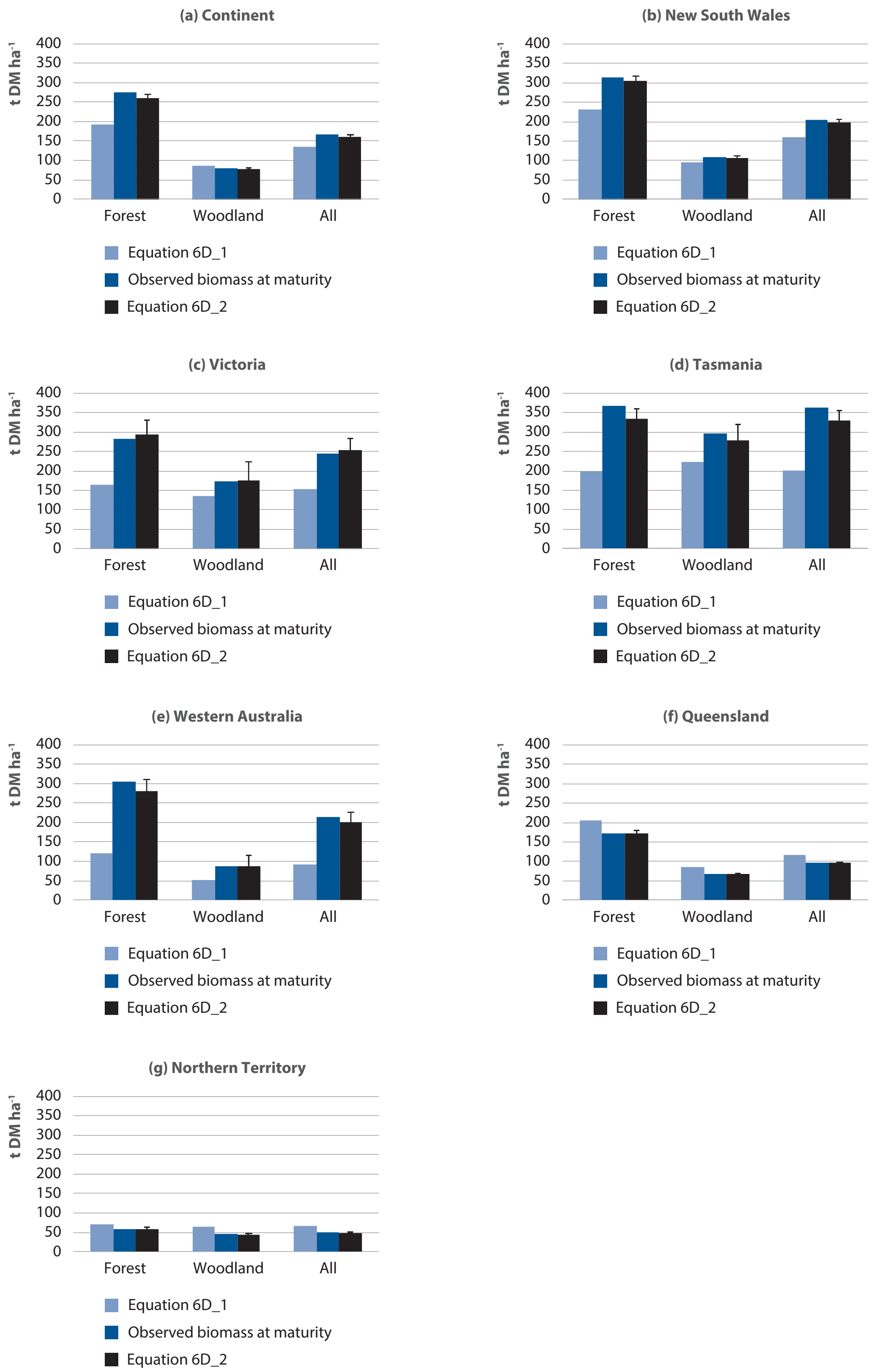
Figure 6.D.4 Observed vs. predicted biomass for the predictions using Equation 6D_2 when observations were withheld from model fitting and used for model validation. 'Woodland' indicates sites with a canopy cover up to 50 per cent (i.e. including some sites classified as sparse woody vegetation with canopy cover 5-20 per cent); 'Forest' indicates sites with a canopy cover >50 per cent. Line is the 1:1 relationship, where observations equal predictions



The validation results can be more readily interpreted when the data is summarised regionally (Figure 6.D.5). At the continental scale, and for woodland forests with a canopy cover 20-50 per cent, there was a slight decline in predicted biomass at maturity when comparing Equation 6D_1 (92 t DM ha^{-1}) to Equation 6D_2 (86 t DM ha^{-1}). In contrast, for forests with a canopy cover greater than 50 per cent, the average biomass increased, from 193 to 260 t DM ha^{-1}. At the scale of individual states these forest increases were more pronounced; for example in Western Australia (119 to 280 t DM ha^{-1}), Tasmania (198 to 334 t DM ha^{-1}), Victoria (165 to 295 t DM ha^{-1}), and New South Wales (231 to 305 t DM ha^{-1}). Overall, comparison of the medium grey and dark grey bars in Figure 6.D.5 show that predictions from Equation 6D_2, for the validation subset, are all consistent with the observations.

When model predictions are averaged geographically then similar trends are apparent, with minor differences at the continental scale for woodland forests (48 t DM ha^{-1} using Equation 6D_1 and 49 t DM ha^{-1} using Equation 6D_2), and increases in the >50 per cent canopy cover forest class (172 t DM ha^{-1} using Equation 6D_1 and 234 t DM ha^{-1} using Equation 6D_2).

Figure 6.D.5 Comparison of mean above-ground biomass across the 5739 observed data points with the mean biomass from the original (Equation 6D_1) and revised (Equation 6D_2) predictions of above-ground biomass. South Australia is excluded due to lack of data. Error bars for Equation 6D_2 are the standard deviations of predictions across 100 replicate Monte-Carlo analyses



Appendix 6.E Other FullCAM input data

6.E.1 Soil carbon input data

Initial soil carbon layer

To estimate soil carbon stock changes *FullCAM* requires spatial soil data including soil type, clay content and a pre-disturbance or initial soil carbon content. The soil data is used to derive water holding capacity which along with soil clay content determines the rate of decomposition of plant residues and the allocation of carbon to the different soil pools (Richards, 2001; Webb, 2002).

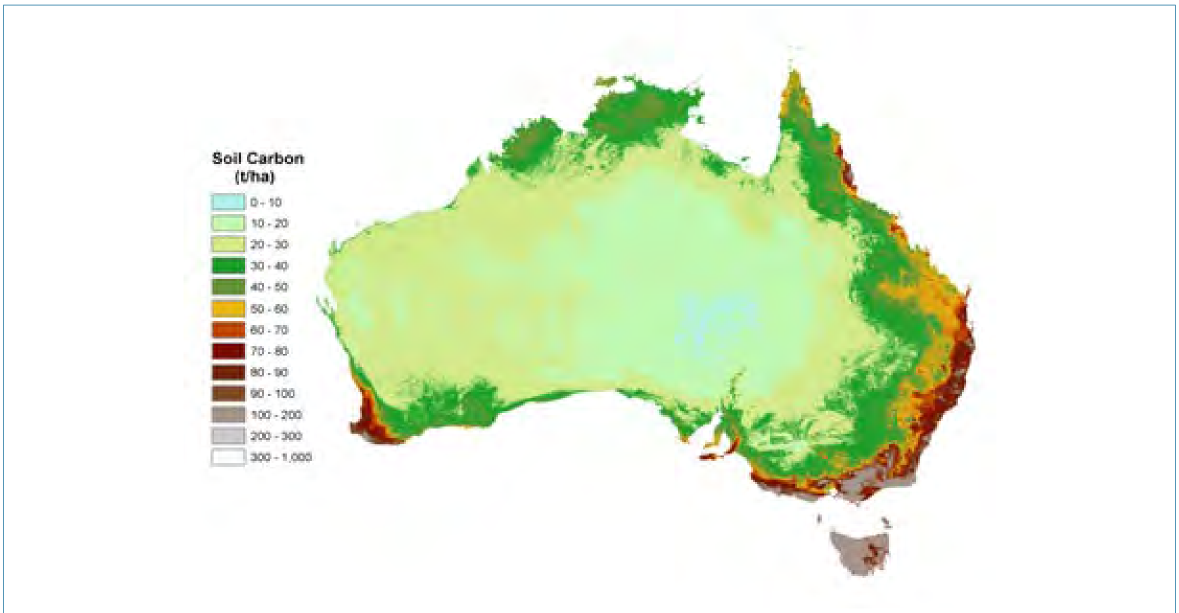
Viscarra-Rossel *et al.* (2014) has derived spatially explicit estimates, and their uncertainty, of the distribution and stock of organic carbon in the soil of Australia. This was achieved through the assembly and harmonisation of data from Australia's National Soil Carbon Research Program (SCaRP), the National Geochemical Survey of Australia (NGSA) and the Australian Soil Resource Information System (ASRIS) to produce the most comprehensive set of data on the current stock of organic carbon in soil of the continent.

A fine spatial resolution baseline map of organic carbon at the continental scale was produced by combining the bootstrap, a decision tree with piecewise regression on environmental variables, and geostatistical modelling of residuals. Values of stock were predicted at the nodes of a 3-arc-sec (approximately 90 m) grid and mapped together with their uncertainties. Baselines of soil organic carbon storage over the whole of Australia, its states and territories, and regions that define bioclimatic zones, vegetation classes and land use were then calculated.

Viscarra-Rossel *et al.* (2014) determined that the average amount of organic carbon in Australian topsoil is estimated to be 29.7 t ha^{-1} with 95 per cent confidence limits of 22.6 and 37.9 t ha^{-1} The total stock of organic carbon in the 0–30 cm layer of soil for the continent is 24.97 Gt with 95 per cent confidence limits of 19.04 and 31.83 Gt.

Figure 6.E.1 shows the baseline map of organic soil carbon in Australian soil to support national carbon accounting and monitoring under climate change. Soil carbon content was corrected to methodological standards where the initial method of measurement was known; otherwise the data were considered unusable and were not included in the final product.

Figure 6.E.1 Baseline map of organic carbon in Australian Soil (Viscarra-Rossel *et al.* 2014)



Soil carbon fractions

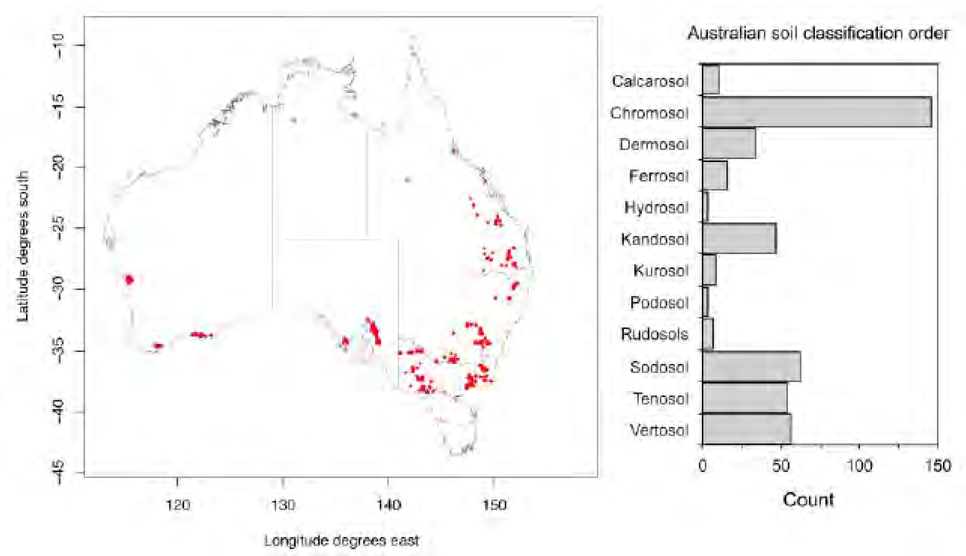
Measureable soil carbon fractions that can be replaced the conceptual pools of the Roth-C model which is used to simulate soil carbon changes within the FullCAM are used to initilise the FullCAM model. These fractions are defined by their differences in turnover times and biological significance (Baldock *et al.*, 2014).

Fine spatial resolution continental scale maps of the soil carbon fractions (particulate organic carbon (POC), humic organic carbon (HOC) and resistant organic carbon (ROC)) are generated by CSIRO Land and Water using a methodology that is similar to that used to derive the baseline map of organic carbon in Australian soil (Viscarra-Rossel *et al.* (2014).

There were 400 soil data points with measurements of POC, HOC, and ROC. Largely, these data originated from the Soil Carbon Research Program (SCaRP), and a small number are from two smaller projects that were funded under the Department of Agriculture (DA) Filling the Research Gap (FTRG) Programs. The data represented all Australian Soil Classification Orders but they were sparsely distributed across Australia and represented soil that is mostly under agriculture, but also forests. The spatial distribution of the data is shown in Figure 6.E.2.

The visible near-infrared and mid-infrared spectra of the 400 soil samples were recorded and spectroscopic calibrations were derived to predict POC, HOC and ROC of other soil samples for which data on the organic carbon fractions were not available. The calibrated models were used to predict the fractions of around 4,000 soil samples that cover the extent of Australia and represent all land use types, and all climatic and bio-geographical regions.

Figure 6.E.2 Spatial distribution of soil organic carbon fractions (POC, HOC, ROC) and the number of observations per Australian Soil Classification order.

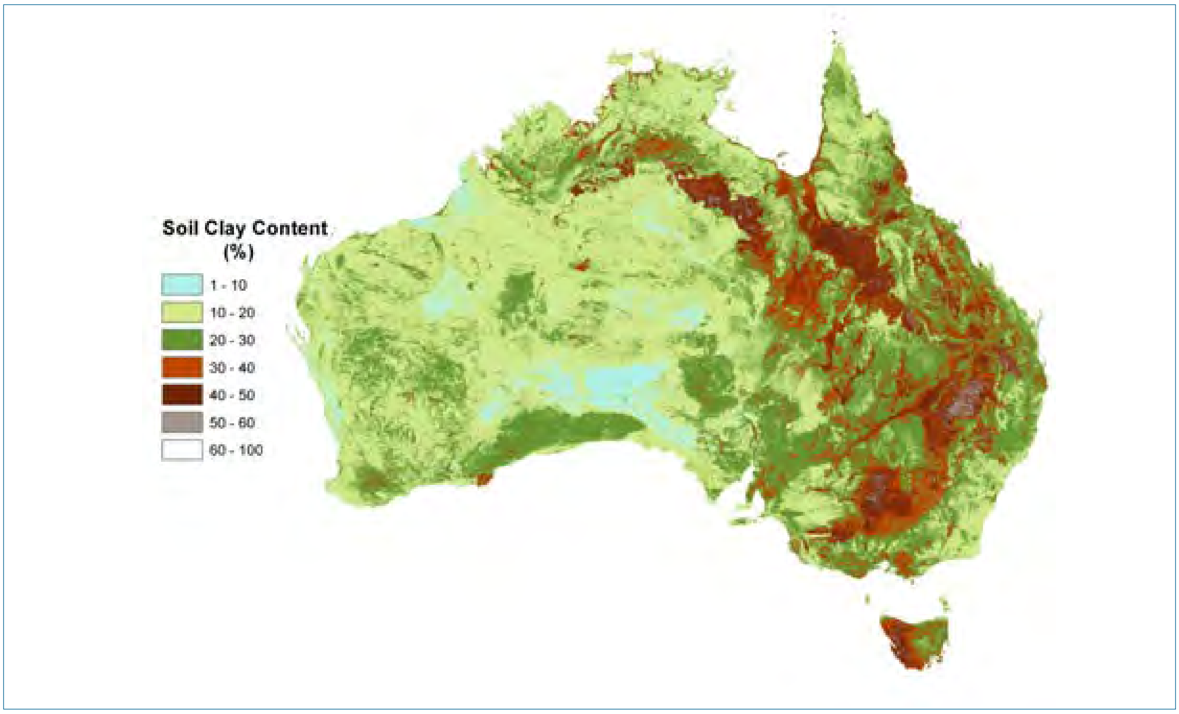


Once the spectroscopic predictions were made, the spatial modelling of the data was performed by combining the bootstrap, a decision tree with piecewise regression on environmental variables and geostatistical modelling of residuals. The spatial models were validated with an independent data set and the fine spatial resolution continental maps of the soil carbon fractions have been incorporated in *FullCAM* to ensure internal consistency of spatial soil inputs. In calculation of soil carbon fraction stocks for FullCAM, respective fractions were allocated based on the total soil carbon stock map produced by Viscarra Rossel *et al.* (2014) multiplied by the respective soil carbon fraction.

Soil clay content

A map of clay content was also developed (Figure 6.E.3) by Viscarra-Rosel *et al.* (2015). The Soil and Landscape Grid of Australia-wide Soil Attribute Maps were generated using measured soil attribute data from existing databases in the national soil site data collation and spectroscopic estimates made with the CSIRO's National spectroscopic database (Viscarra Rossel & Webster, 2012). The spatial modelling was performed using decision trees with piecewise linear models and kriging of residuals. Fifty environmental covariates that represent climate, biota, terrain, and soil and parent material were used in the modelling. Uncertainty was derived using a bootstrap (Monte Carlo-type) approach to derive for each pixel a probability density function (pdf), from which we derived 90 per cent confidence limits. The approach is described in Viscarra Rossel *et al.* (2015a).

Figure 6.E.3 The Australian three-dimensional soil grid (Clay): Australia's contribution to the GlobalSoilMap project (Viscarra-Rossel, submitted)



6.E.2 Climate data

Model sensitivity testing identified that inter-annual climate variability has a significant effect on both soil (Janik *et al.* 2002) and forest (Brack and Richards, 2002) carbon stock change. The use of long-term (temporal) average and regionally (spatial) averaged climate data was shown to be inadequate to support spatially and temporally disaggregated carbon modelling, frequently generating spurious results when tested. To account for the effects of climate both spatially and temporally over the modelled period, 1970–2008, weather station data from the Bureau of Meteorology for rainfall, minimum and maximum temperature, evaporation and solar radiation were obtained. Monthly climate surfaces (maps) at 1 km resolution for each variable were then derived using the ANUCLIM (McMahon *et al.* 2000) techniques.

Raw data

Within the Bureau of Meteorology database there are approximately 1,200 weather stations recording temperature, 13,000 stations recording rainfall, 300 stations recording evaporation and 700 stations recording frost days. Precise location data were available for some 2,500 weather stations, providing a quality reference set of points from which to spatially interpolate climate surfaces. Version 2 of the 9 second (approximately 250 m resolution) national digital elevation model (AUSLIG, 2001) was used to provide terrain (elevation and aspect) mapping to support the spline functions used in the ANUCLIM software.

Derived outputs

The weather station climate data are interpolated (modelled) using mathematical (multivariate spline) functions that reflect influences on micro-climate such as elevation. Climate maps are derived at variable resolutions (grid sizes), again using the ANUCLIM software (Kesteven *et al.* 2004). The list of outputs and their resolution is shown in Table 6.E.1. Figures 6.E.4 and 6.E.5 illustrate national long-term average annual climate maps generated using the ANUCLIM software.

The surface interpolation from weather station data provides climate mapping which is both temporally (monthly) and spatially (at select resolution) relevant to the application of the *FullCAM* modelling.

Table 6.E.1 List of climate and productivity maps developed for land sector reporting in the National Inventory System

Climate Variable	Description
Rainfall	1 km resolution continentally, monthly 1968-2017
Temperature	1 km resolution min., max., and average continentally, monthly 1968-2017
Evaporation	1 km resolution continentally, monthly 1968-2017
Frost Days	1 km resolution continentally, monthly 1968-2017
Long-term productivity	250 m resolution
Annual productivity	(sum of monthly) 1 km resolution (1970–2017)

Figure 6.E.4 Long-term average annual evaporation

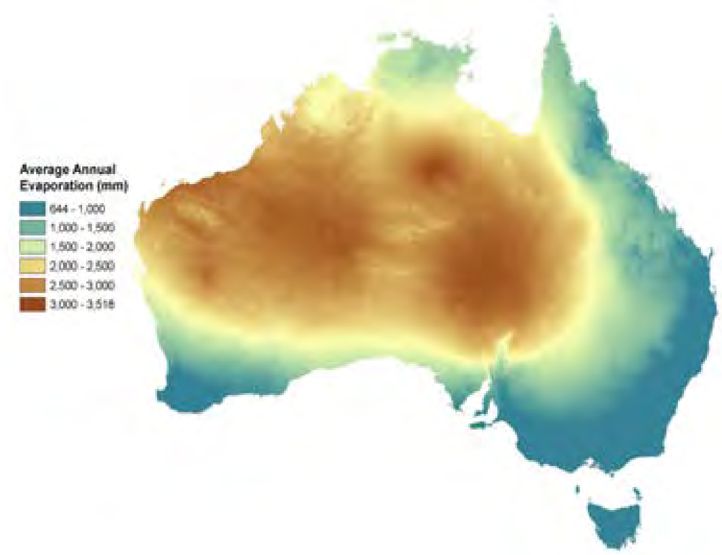
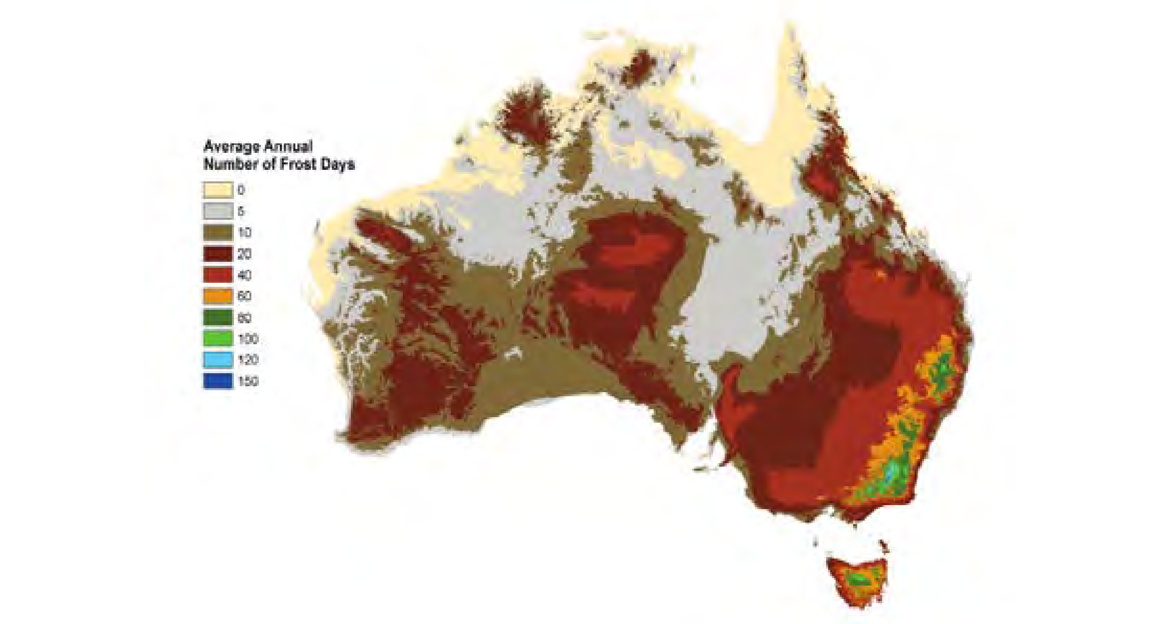


Figure 6.E.5 Long-term average number of frost days per year



6.E.3 Land use and land management

Land use and management data

Land management practices in both agriculture and forestry in Australia have varied considerably over time depending on species, region, desired products and site conditions. In 2014 the Department of Environment and Energy commissioned CSIRO to collate all available information regarding agricultural management systems to ensure a consistent, nationally available compilation of this information.

For the forest management data program, a focus group was established comprising researchers and practitioners to give all management issues (e.g., forest and crop type, burning, harvesting and thinning) a jurisdictional (geographic) and temporal coverage. All available information was collated and supplemented with expert knowledge to give completeness where records were not available. The information gathered by these groups for use in the management databases is documented in Swift and Skjemstad (2002) and Raison and Squire (2008).

Cropping systems

For cropping systems the crop species identified by Unkovich *et al.* (2009) (section 6.B.5.1) were sourced from the Australian Bureau of Statistics agricultural census small area data in electronic format.

The collated datasets were concorded to the then new, Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010). All years between 1983 and 1997 were concorded to 1996 statistical local area boundaries (Australian Bureau of Statistics 2000), the 2001 at 2001 statistical local area boundaries (Australian Bureau of Statistics 2002), the 2006 at 2006 statistical local area boundaries (Australian Bureau of Statistics 2008) and for 2011 on 2011 statistical local area boundaries (Australian Bureau of Statistics 2013). This concordance ensured spatial consistency across the time series.

The datasets were used to extract the area of each of the crops listed in table 6.B.2 for each SA2 to construct a time series dataset from 1983 to 2011 to cover 99 per cent of total crop sowing areas in each Australian State. Since the ABS has more recently (post 2001) changed from annual agricultural censuses to five yearly census, five yearly data blocks, in synchrony with the recent censuses were used to represent management epochs (Table 6.E.2).

Table 6.E.2 Agricultural census year data used to provide crop representation for five-year periods

Census Year	Applied to
1983	1970-1984
1986	1985-1989
1991	1990-1994
1996	1995-1999
2001	2000-2004
2006	2005-2009
2011	2010-2014
2016	2015-2017

The year 1983 is the earliest time that data are available electronically and this is thus used to populate the time series back to the 1970 start point.

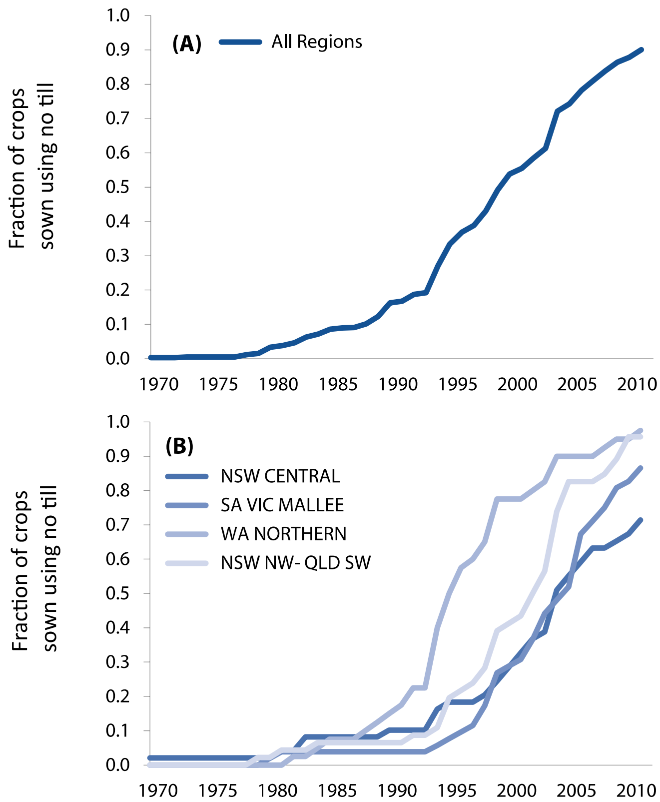
Cropping systems have evolved over time with the use of herbicides to control weeds instead of tillage and sowing machinery adapted to sow into standing stubble of antecedent crops. This means that there has been a significant change over time in the extent of tillage and the incorporation of crop residues into soils which might influence carbon return to soils, carbon cycling and soil carbon stocks.

Two datasets assisted in informing these changes in management over time.

Time series data on the adoption of no till practices on a region by region basis is available through a survey in 2008 of the "Adoption of no-till cropping practices in Australian grain growing regions" (Llewellyn and D'Emden 2009; Llewellyn *et al.* 2012), and includes farmer estimates of the historical adoption of no-till seeding systems, back to 1960. This dataset is the only available resource describing the adoption of no till seeding systems across the Australian grain cropping zone on a temporal and spatial basis. This dataset, updated in 2014, provides opportunity to describe changes in the intensity of tillage on croplands over time. A second dataset, available from the Australian Bureau of Statistics, provides detailed information at SA2 scale on the management of crop stubbles in 2010–2011. Using these two data sources a time series dataset of tillage x stubble management at SA2 scale has been developed.

Details of the survey and the broad outcomes are given in Llewellyn and D'Emden (2009) and Llewellyn *et al.* (2012). The dataset provides information on the fraction crops established using "no till" seeding systems on a "regional" basis. In this case the regions were clusters of Statistical Local Areas (Trewin 2004). These regional data were used to populate an SA2 level dataset.

Figure 6.E.6 Adoption of changed tillage practices in Australia: 1970–2013

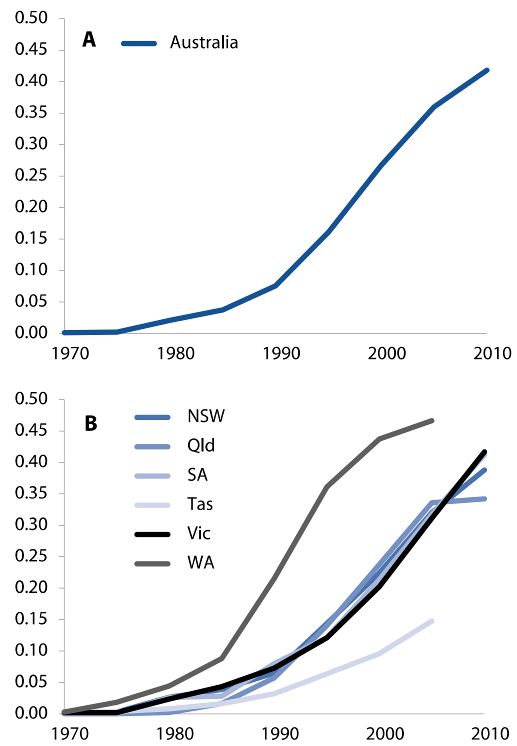


Note: Fraction of crops sown with no till (single pass) seeding technology across (A) the Australian grain belt, and (B) for four of thirteen regional areas Calculated from a revised dataset of Llewellyn *et al.* (2012).

The Llewellyn *et al.* (2012) dataset was used to produce regional scalars (0-1) describing the adoption of no till crop established from 1970 until 2010[16]. This was then applied against the 2011 ABS point census to created SA2 level data back in time. As a result the data of Figure 6.E.6 were normalised such that the value for 2010 was 1.0, and the preceding years scaled proportionately. These time series values were then applied to the 2011 ABS SA2 level census data to provide the historical no till fraction. The national and state level trends are shown to be about half that apparent in the Llewellyn *et al.* (2012) dataset.

16 When the data of Figure 6.E.6 and 6.E.7 were compared with the ABS survey of land management (2011) (ABS 2013b) it was found that the fraction of crops sown with "no till" were very much higher in the Llewellyn *et al.* (2012) dataset than that apparent in the ABS census of 2011 (ABS 2013a). This may be because the ABS census was for all cropping land, whereas the Llewellyn survey was very much skewed toward farmers who were primarily grain growers. It is likely that dedicated grain growers have larger cropping areas and invest in efficient no-till systems compared to mixed farmers or farmers with relatively small holdings. The ABS survey data was explicitly for the total area sown within an SA2.

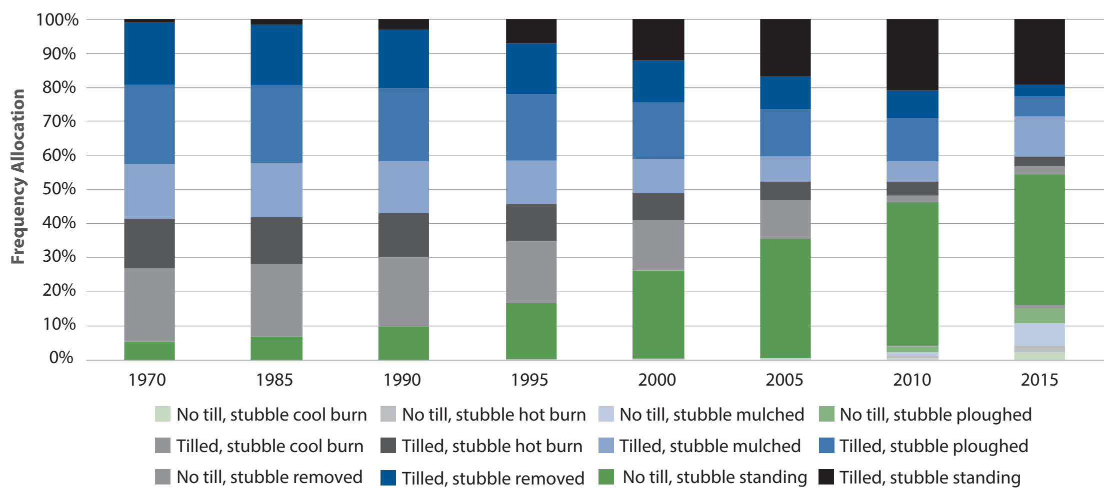
Figure 6.E.7 Adoption of changed tillage practices in Australia by state: 1970–2013



Note: Estimated fraction of crops sown with no till (single pass) seeding technology across (A) the Australian grain belt, and (B) for each of the primary Australian cropping States, calculated by scaling the 2011 ABS census data according to the data of Figure 6.E.6.

Changing management practices over time is one of the primary drivers for trends in emissions from Australian crop and pasture lands. Figure 6.E.8 illustrates the changing management practices for all crop species in Australia since 1970 for each epoch taken from Table 6.E.2. The benefit of changing management practices seen within the first 10 years and the diminishing returns afterwards, are a result of the soil carbon stock attempting to reach a new equilibrium. Peaks in net gains or removals attributed to SOC generally are not caused by management change, but are experienced during regional drought or flood events in which the net balance between C inputs and C losses is altered.

Figure 6.E.8 Changing allocation of management practices for cropland since 1970, generated from the management crop management frequency database embedded in the FullCAM



One of the key operational challenges for any process-based model that simulates changes in carbon dynamics in spatio-temporal mode is to implement the changes occurring in the crop management practices over space and time related to tillage operations and stubble management within the simulation setup.

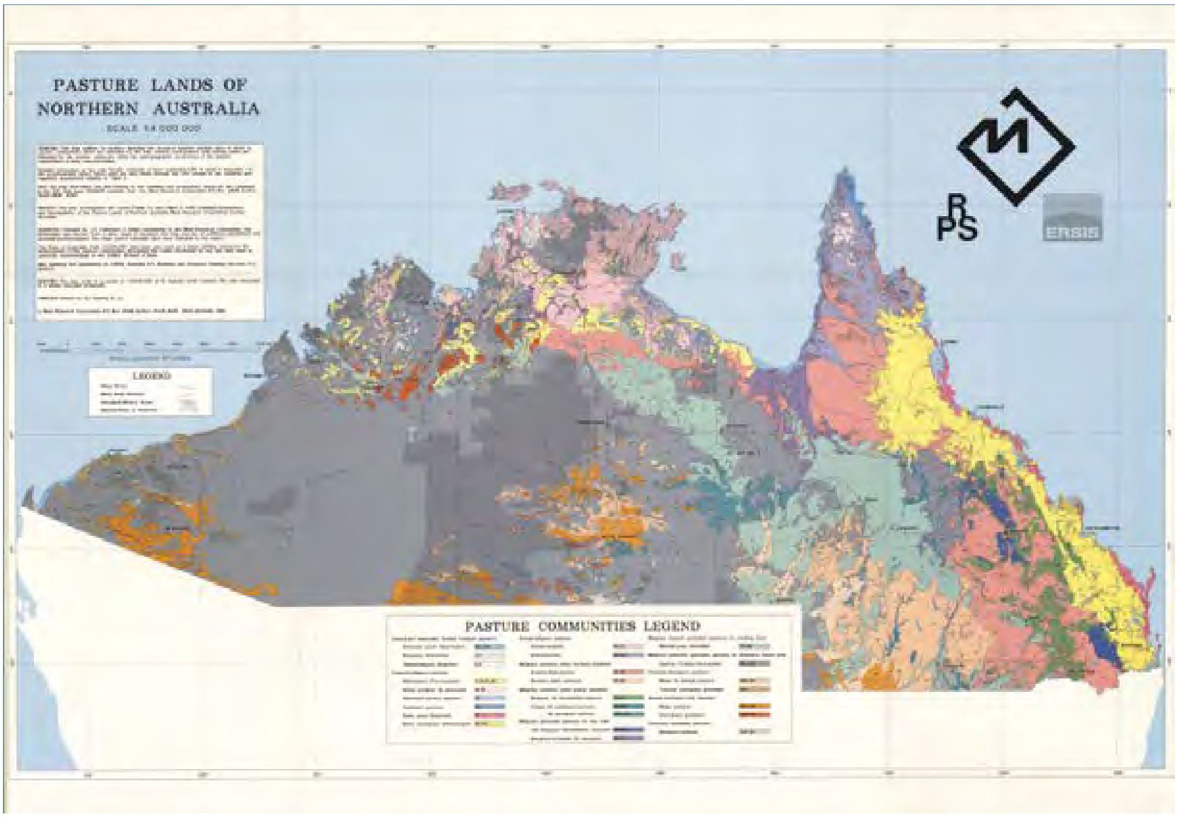
Based on the information collected by Llewellyn and D'Emden (2009) and Llewellyn *et al.* (2012) and using farmer estimates of the historical use of no-till seeding systems back to 1960 clearly shows that there is an increasing trend in adoption of no-tillage practices in Australian grain growing regions (Figure 6.E.8).

New functionality has been added to FullCAM to be able to retain a given management practice or species at the plot level based on reported Agricultural census data. Farming practices which show an increasing adoption rate are based on no-tillage practices and include stubble retention and no-till practices prior to cropping. This FullCAM functionality can also be applied at the species level and is used to simulate regions of pasturelands comprised of native grass species which have remained unchanged over time.

Grazing systems

As with the data preparation for cropping systems, the pasture species identified in Table 6.B.2 were concorded to the then new, Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010) (see Figure 6.E.10) and the recent ABS censuses were used to represent management epochs (Table 6.E.2). The species and management data were, however, collated from a number of sources. Grassland types in southern Australia after 2000 were sourced from Donald (2012) and, prior to 2000, were obtained from the Australian Temperate Pastures Database (Hill *et al.*, 1998). The digitised map (Figure 6.E.9) of the pasture lands of Northern Australia (Tothill and Gillies 1992) provided data for northern Australia for all years and grassland types.

Figure 6.E.9 Pasture Lands of Northern Australia

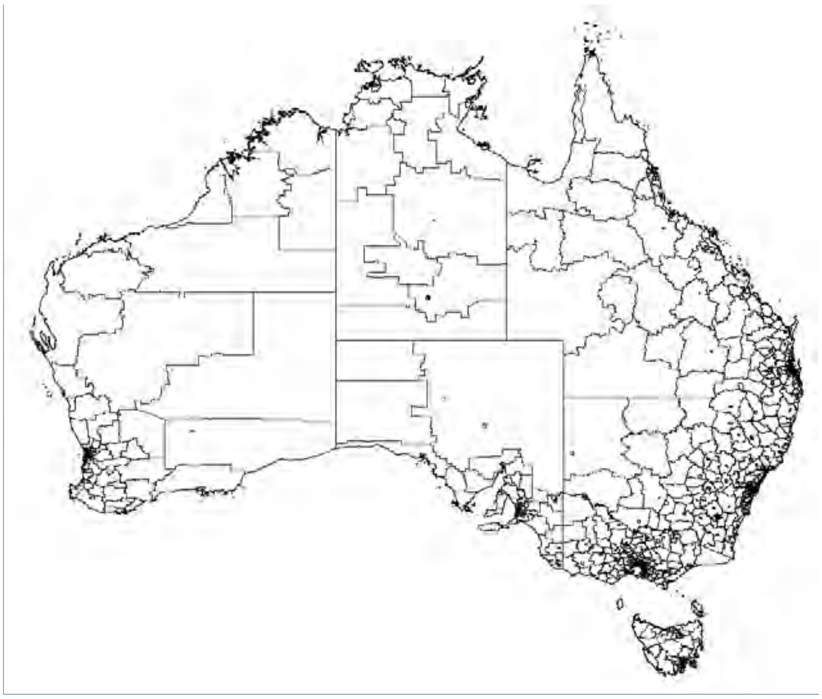


The information collected describes 527 grazing and cropping systems, with associated management practice data also held within the *FullCAM* model relational database. Table 6.E.3 provides an example of the data collected. Allocation to a land use and management system is designated according to the relative frequency of land use and management for each soil type in each SA2 region in each year. For each of these systems the key management practices, such as the use of fire, when grazing is applied, ploughing and herbicide treatment, were implemented in the model.

Table 6.E.3 Example land use table

SA2	Start Year	End Year	Agriculture Species	Management practice
31173	2010	2014	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 122, 10y, 1 burn
71050	1990	1994	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 122, 2y, 0 burns
71055	1990	1994	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 244, 2y, 0 burns
31177	2010	2014	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 244, 5y, 1 burn
31503	1985	1989	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 30, 1y, 0 burns
51207	1990	1994	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, 0 burns
71068	2000	2004	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, 0 burns
71065	2005	2009	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, 0 burns
71068	2000	2004	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, 8 burns
31406	2000	2004	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, 8 burns
71055	2000	2004	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, 8 burns
11238	2000	2004	Barley	Barley, No till, stubble cool burn
11238	2010	2014	Barley	Barley, No till, stubble hot burn
11238	1990	1994	Barley	Barley, No till, stubble mulched
11238	1995	1999	Barley	Barley, No till, stubble ploughed
11238	2005	2009	Barley	Barley, No till, stubble removed
11238	2000	2004	Barley	Barley, No till, stubble standing
11238	2005	2009	Barley	Barley, Tilled, stubble cool burn
11238	1995	1999	Barley	Barley, Tilled, stubble hot burn
11238	2005	2009	Barley	Barley, Tilled, stubble mulched
11238	1990	1994	Barley	Barley, Tilled, stubble ploughed
11238	1990	1994	Barley	Barley, Tilled, stubble removed
11238	2010	2014	Barley	Barley, Tilled, stubble standing

Figure 6.E.10 Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010)



6.E.4 Crop and pasture yield

Crop/pasture growth model

FullCAM uses crop and pasture yield data in the estimation of biomass accumulation in agricultural systems. Yield data is estimated using a crop/pasture growth model developed by *CSIRO Land and Water* to generate estimates based on rainfall availability during the growth period (Unkovich *et al.* 2009). The model uses a water balance routine to estimate daily evapotranspiration, using fixed crop x region specific splits for bare soil evaporation or crop water use (transpiration) to estimate crop and pasture productivity. Two plant production modules are used, one to accommodate annual crops and pastures (Figure 6.E.11), and the second for perennial pasture systems (Figure 6.E.12). The two modules cover summer and winter grain and forage crops, sugarcane, sown and native pastures, and grass growth in rangeland ecosystems.

Figure 6.E.11 Conceptual model of annual crop growth module

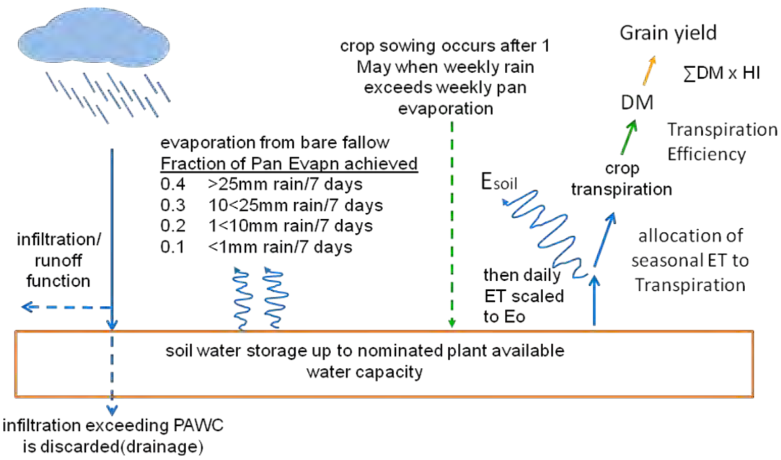
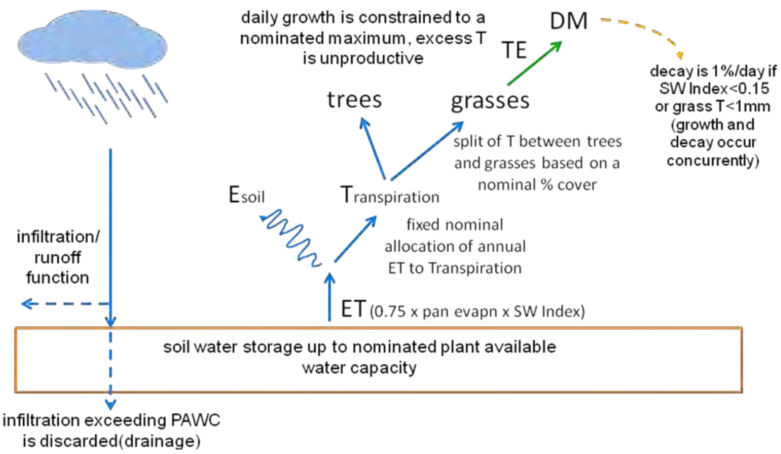


Figure 6.E.12 Conceptual model of perennial grass/pasture module



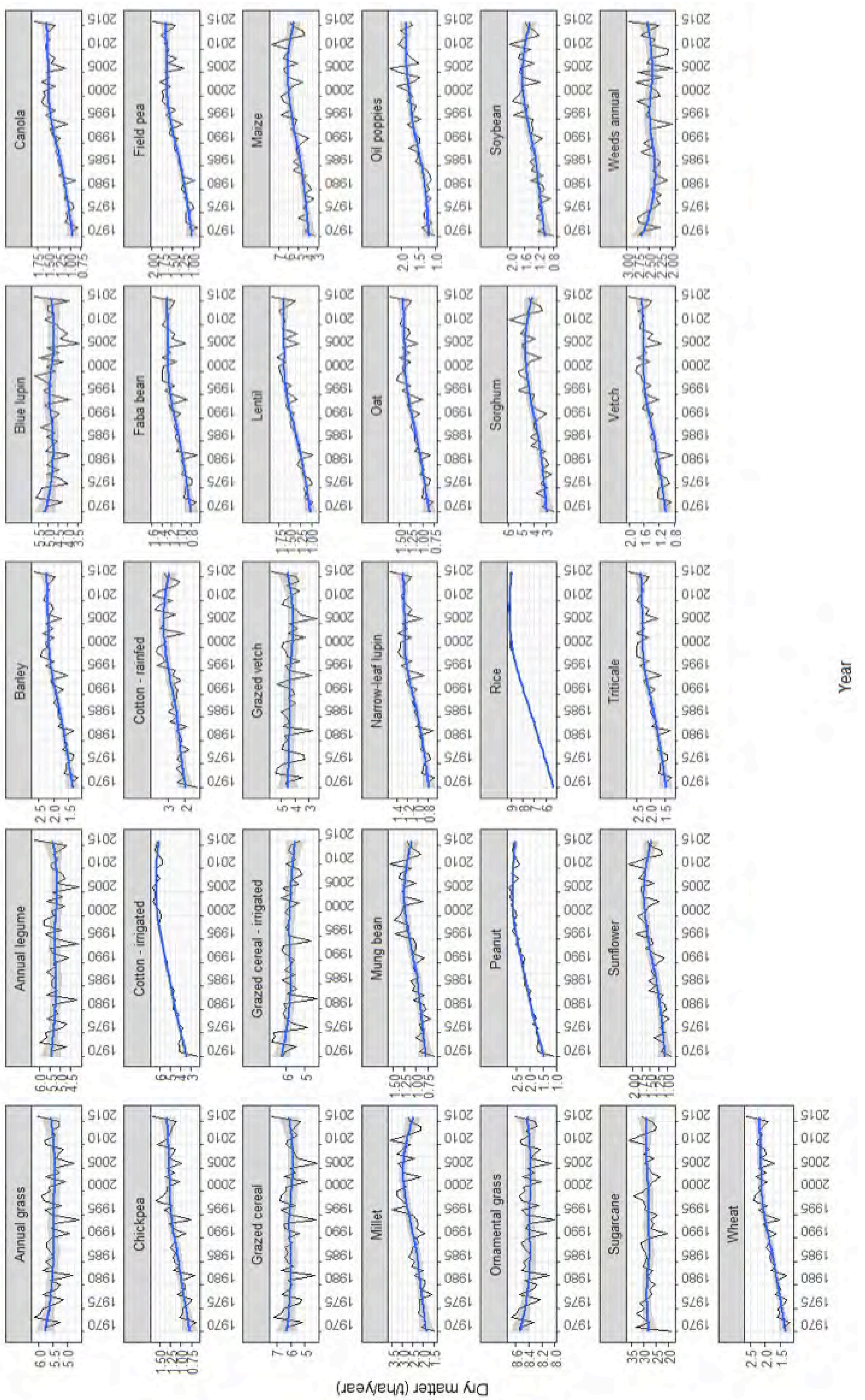
Productivity improvement trends

As the model of crop growth is based on recent agricultural management practices it is necessary to scale the modelled dry matter production through time according to long term trends in farm crop productivity. Taking 2000 as the base year, modelled yields have been scaled from this time at the indicative rate (1.36 per cent pa) for the 1970–2000 time period. While this rate of change also includes yield increases due to improvements in crop harvest index (Unkovich *et al.* 2010) these have not removed from the dry matter productivity increases because HI is currently held constant in FullCAM.

Yields validation in FullCAM

Figure 6.E.13 depicts the variation of Australia wide average annual yield for major crops. The yields show high fluctuations due to factors such as climate with the blue line denoting the general trend of the yields for considered crops from 1970 – 2016. Annual yield data plays a major role in the flow of carbon masses within the FullCAM model, with residues incorporated into soil over the growing period and after the harvest event. Most crops show an increasing trend from 1970 with a slight decline post 2010.

Figure 6.E.13 Australian average crop yields for crop, tonnes dry matter/ha/year, 1970-2016



Verification of the model

CSIRO has tested the model construct output against a database of crop yield data (Unkovich *et al.* 2014) and, in general (regional) testing, the modules accounted for about 50 per cent of the variance in annual crop grain yield or of shoot dry matter of perennial pastures on any given day. In site specific tests the annual grain crop model was able to explain up to 80 per cent of the variance in crop yield.

Annual species growth model

The annual growth model is designed to model annual crop growth. Crop growth being for a plant that is planted, grown and then harvested in an annual rotation. This model accounts for varying growth periods given crops do not grow for the entire year. The growth modelled is a process within FullCAM of assigning the proportions of species yields generated by the CSIRO to specific time increments.

The annual growth formula is a sigmoidal curve fitted with different parameters specific to individual crops by CSIRO Agriculture and Food and aligns with the work carried out by Unkovich, (2013). The formula gives the step (or daily) fraction, which is a factor applied to yield to produce the daily portion of growth (Figure 6.E.14).

Figure 6.E.14 Exponential equation for calculating fractional daily growth for an annual crop/pasture, where the value on the numerator is equivalent to the total growth for an annual crop/pasture cycle

$$Daily \quad fraction = \frac{1}{1 + e^{\left(\frac{An\_season\_day \ \mathrm{sigmoidalGrowthA} * An\_max\_days}{\mathrm{sigmoidalGrowthB} * An\_sow\_day * An\_max\_days}\right)}}$$

Perennial species growth model

Running model simulations with perennial species under the annual growth model is unrealistic as it has no ability to simulate an ongoing growth cycle. This has an impact on the fidelity of grassland simulations, producing results that do not represent perennial growth and produce less soil carbon capture than generally expected from a perennial pasture species.

The CSIRO has provided monthly data for perennial grass species in Australia. Combined with a perennial growth model in FullCAM, this data is used for estimating standing dry matter for perennial species within the grassland account.

Perennial species growth is derived from the use of a combination of *growth* and *die-off* and an *initial standing dry matter value* to generate a value for standing dry matter at a point in time. This creates a time series for standing dry matter that is utilised as an input in FullCAM simulations for the different perennial grass species.

Appendix 6.F Post-1990 Plantations – forest growth model

Forest growth model

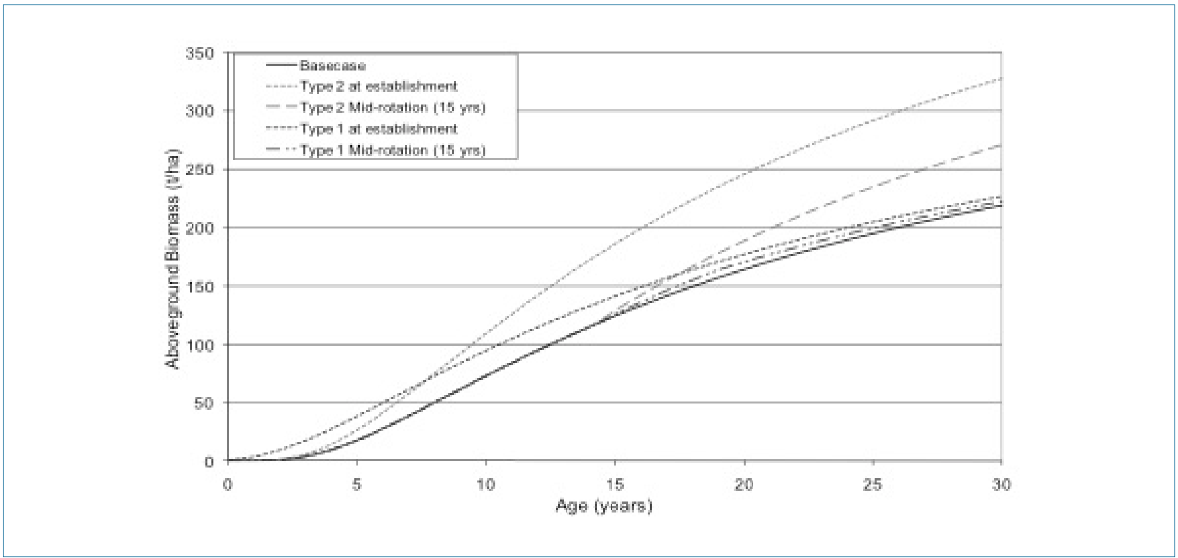
Plantations commonly produce more biomass than native forest systems in Australia, at least in the short to medium term (15-40 years). For example, Baker and Attiwill (1985) showed that *Pinus radiata* achieved 70-100 per cent of the biomass of an 80 year old native forest, grown under similar conditions, in only 20 to 24 years. These growth differences are driven by factors such as nutrient addition, reduction in insect herbivory associated with the use of non-endemic species or through control of pests, site-specific species matching and management, and possibly greater physiological efficiency in utilising site resources by the introduced species.

The initial assumed biomass model (Appendix 6.D) and methods to estimate removals, due to regrowth post clearing, represent forest systems without significant management input and is well suited to the *forest land converted to grassland* and *cropland* sub-categories. However, in plantation systems with significant management inputs, such as fertiliser application or intensive site preparation, and species specific site matching, additional model parameters are needed to accurately estimate forest growth.

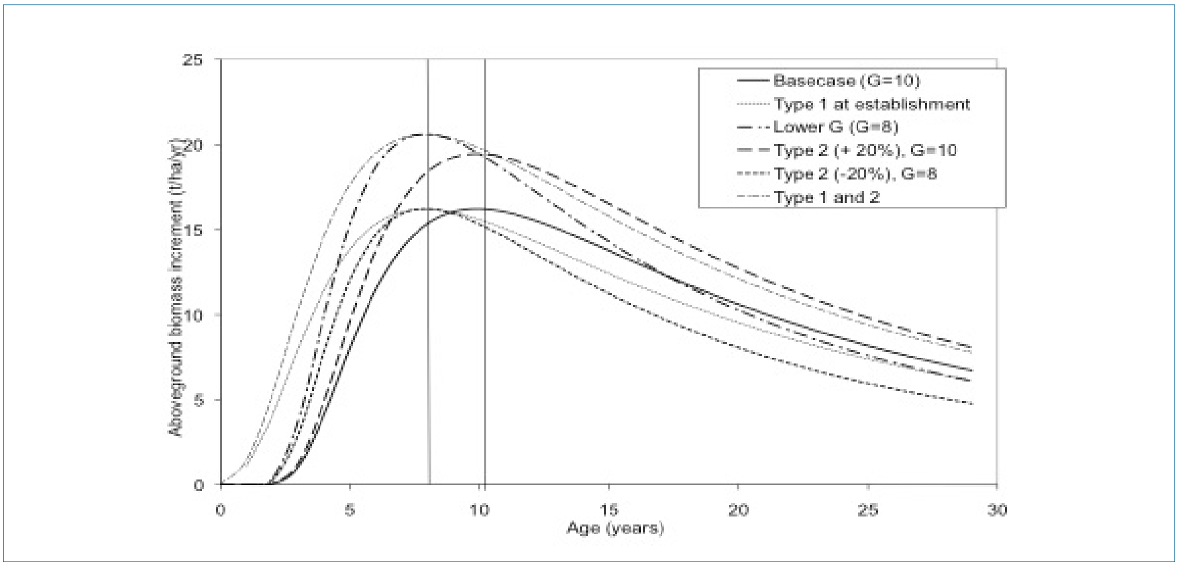
To account for the effects of management practices on growth the native forest regrowth model (the Tree Yield Formula, Appendix 6.B) is supplemented to include functions that represent Type 1 and Type 2 growth responses (Snowdon and Waring, 1984) (Figure 6.F.1). Type 1 management practices advance or retard stand development (effectively age), but do not increase underlying site productivity over the life of the rotation. Weed control at establishment, and nitrogen fertiliser application after thinning, are examples of Type 1 responses (Snowdon, 2002). Type 2 treatments increase (or decrease) a site's carrying capacity in the longer term. Phosphorus application, which in Australia can lead to long-term increase in site productivity (i.e., over several rotations) (Snowdon, 2002) is an example of a Type 2 response.

Figure 6.F.1 Effect of Type 1 and Type 2 management practices on (a) cumulative and (b) annual growth

(a)



(b)



Snowdon (2002) developed methods for including Type 1 and 2 effects in hybrid growth models. These have been implemented in the forest growth component of the *FullCAM* model. In the model, Type 1 forest treatment events are simulated by varying the developmental stage or age of the stand, moving the forest back and forth along the growth curve depending on the degree of treatment (see Equation 3). Type 2 treatments simply change the asymptote (i.e., *M*; see Equation 6F_4) from the time the treatment is applied. These methods lend themselves well to application in the hybrid empirical-process based structure of *FullCAM*.

A further effect that must be accounted for is the impact of establishing regionally non-endemic plantation species. This effect is expressed through a plantation species multiplier (*r*; see Equation 6F_1). It is similar to a Type 2 response being applied from the time a species is planted until final harvest. The *r* multiplier is based on the long term average Forest Productivity Index (*P*; see Appendix 6.C) for each point, the type of plantation established and is stratified by State and National Plantation Inventory (NPI) region (Figure 6.14). This allows the model to account for variations in growth between regions that cannot be accounted for easily from climatic and broad scale site information (e.g., Sheriff *et al.* 1996; Turner *et al.* 2001), while still accounting for the significant variation that occurs within each region due to site factors.

Calculation of r

The plantation species multiplier (*r*) was determined for each major plantation species on a regional basis. Regional long-term forest productivity index values of plantation areas in each National Plantation Inventory (NPI) region and State were determined by overlaying the long-term forest productivity index (*P*) spatial data, with areas of hardwood and softwood plantation as identified by the plantation type mapping from the remote sensing programme. The average Mean Annual Volume Increment (MAVI) data for each plantation species in each State and NPI region was obtained from Turner and James (1997), Turner and James (2002), Snowdon and James (2008) and Ferguson *et al.* (2002). The values are either based on or represent the data used in Australia's National Forest Inventory (NFI). Minimum and maximum MAVI values that are not available in the NFI data were estimated for each species and NPI region, based on Snowdon and James (2008) and the following assumptions:

- MAVI values of the NFI are the average for the region, not the most common growth rate;
- Minimum MAVI values are effectively set by commercial viability. These are generally not lower than 12 m^3 ha^{-1} yr^{-1}, (although this may vary for certain species within regions, such as Pinus pinaster in dry regions in West Australia); and
- Maximum MAVI values are unlikely to exceed 30 m^3 ha^{-1} yr^{-1} in long rotation systems and 35 m^3 ha^{-1} yr^{-1} in short rotation systems.

Environmental plantings are considered similar to regenerating native forest and assigned an *r* value of 1 (no management/species effect). The distribution of plantations according to plantation typing was mapped to the *P* data to verify that the minimum and maximum values were reasonable given the assumptions applied. For the calculation of *r*, the minimum and maximum *P* values were assumed to be the 5 per cent and 95 per cent of the total distribution of area for each plant type. As species is not identified in the plantation type data, where a plantation type (i.e., hardwood/softwood) consisted of different species with distinct productivity ranges (e.g., *P. pinaster* and *P. radiata* in Western Australia are both softwoods but *P. pinaster* is commonly established in low rainfall areas), the *P* for the dominant species was set values from regions with similar species and conditions, with the other species ranging from the minimum P value to the lowest P value of the dominant species. The MAVI and *P* data used for calibrating *r* are shown in Table 6.F.1.

The *r* value required to adjust the base case native forest growth model to the documented plantation MAVI growth rates and the estimated minimum and maximum MAI's for each State, NPI region and species was calculated based on assumptions of species characteristics and forest management (Equation 6F_1). As the MAVI growth data is not spatially explicit it was assumed that low *P* values represent low MAVI values and high *P* values represent high MAVI values. This is justified through the strong relationship between *P* data and native forest biomass stocks (see Appendix 6.D), and studies using the productivity data in plantation systems that show relationships between *P* and stand height and basal area, but with significant regional variation (Ford, 2004). Expansion factors at final harvest were calculated using the equations from Snowdon *et al.* (2000) and the average rotation length. While the expansion factor data show considerable variability at young ages, there is little variation in older stands, providing a high degree of certainty in these values. Species specific basic wood density values at maturity were obtained from Illic *et al.* (2000) and Polglase *et al.* (2004). Similar to the expansion factors, the range of density values decreases as the stands mature. For species in which management typically includes a thinning prior to final harvest, typically longer rotation sawlog plantations, the basic density value was reduced by 10 per cent to account for the age-related effects and the thinned volume added to the final total harvest biomass. The percentage of maximum potential biomass achieved by final harvest was calculated based on estimates of age of maximum biomass increment, described in the next section.

Appendix

Table 6.F.1 Range of FPI (P) values on which plantation types occur, the minimum, average and maximum growth rates (Mean Annual Volume Increment, $m^3\ ha^{-1}\ yr^{-1}$) and rotation length

NPI	Plantation type	Species	FPI low	FPI mean	FPI high	Min MAI	Average MAI	Max MAI	Rotation length
Western Australia	Softwood	Pinus radiata	5.0	7.0	11.2	12	20	30	30
Western Australia	Softwood	Pinus pinaster	3.8	5.5	8.0	6	11	16	35
Western Australia	Hardwood	Eucalyptus globulus SR	4.0	6.7	11.9	12	17	30	12
Western Australia	Hardwood	Eucalyptus globulus LR	5.0	7.0	11.9	12	18	27	25
Tasmania	Softwood	Pinus radiata	5.3	10.0	15.3	12	19	30	30
Tasmania	Hardwood	Eucalyptus globulus SR	6.0	11.5	15.5	14	23	30	10
Tasmania	Hardwood	Eucalyptus nitens SR	5.3	10.0	14.5	12	15	27	15
Tasmania	Hardwood	Eucalyptus nitens LR	6.0	11.5	15.5	14	19	27	25
Green Triangle	Softwood	Pinus radiata	4.8	7.4	11.5	12	21	30	35
Green Triangle	Hardwood	Eucalyptus globulus SR	4.8	7.7	11.5	12	17	27	12
Green Triangle	Hardwood	Eucalyptus globulus LR	6.0	8.2	11.5	14	20	25	25
South Australia - Lofty Block	Softwood	Pinus radiata	5.3	6.6	10.6	12	21	27	35
South Australia - Lofty Block	Hardwood	Eucalyptus globulus SR	4.3	6.5	10.4	12	17	27	12
South Australia - Lofty Block	Hardwood	Eucalyptus globulus LR	5.0	7.5	10.4	12	20	25	25
Central Victoria	Softwood	Pinus radiata	5.5	8.0	14.1	12	18	27	35
Central Victoria	Hardwood	Eucalyptus globulus SR	5.3	7.3	13.9	12	18	27	12
Central Victoria	Hardwood	Eucalyptus globulus LR	6.0	8.0	13.9	14	18	25	25
Murray Valley	Softwood	Pinus radiata	5.3	9.4	12.4	12	20	27	30
Murray Valley	Hardwood	Eucalyptus globulus SR	5.3	8.6	13.0	12	16	25	13
Murray Valley	Hardwood	Eucalyptus globulus LR	6.5	9.0	13.0	12	18	25	25
Central Gippsland	Softwood	Pinus radiata	5.9	9.0	16.6	12	20	30	30
Central Gippsland	Hardwood	Eucalyptus globulus SR	5.8	10.4	16.9	12	18	27	12
Central Gippsland	Hardwood	Eucalyptus nitens LR	7.0	13.0	16.9	12	18	27	25
Bombala-East Gippsland	Softwood	Pinus radiata	6.4	11.0	14.9	12	16	27	35
Bombala-East Gippsland	Hardwood	Eucalyptus globulus SR	6.4	9.5	15.1	12	19	27	12
Southern Tablelands	Softwood	Pinus radiata	5.1	7.0	12.4	12	16	27	30
Central Tablelands	Softwood	Pinus radiata	5.3	9.0	11.7	12	16	25	30
Northern Tablelands	Softwood	Pinus radiata	6.2	9.9	16.6	12	16	25	30
Northern Tablelands	Hardwood	Eucalyptus globulus SR	4.7	8.4	16.1	12	16	25	14
Northern Tablelands	Hardwood	Nth Coast Eucs LR	7.4	11.7	16.1	12	14	20	30
North Coast	Softwood	SouthernPines	8.1	12.5	22.3	12	15	25	30
North Coast	Softwood	Hoop pine	8.1	12.5	22.3	9	13	20	40
North Coast	Hardwood	Nth Coast Eucs SR	7.6	10.8	19.6	12	18	27	12
North Coast	Hardwood	Nth Coast Eucs LR	8.0	10.8	19.6	12	18	25	35
South East Queensland	Softwood	SouthernPines	6.3	11.1	21.2	12	13	25	30
South East Queensland	Softwood	Hoop pine	6.3	11.1	21.2	8	13.4	20	40
South East Queensland	Hardwood	Nth Coast Eucs SR	6.0	9.0	21.0	12	18	27	12
South East Queensland	Hardwood	Nth Coast Eucs LR	7.0	11.5	21.0	12	18	25	35
Northern Queensland	Softwood	SouthernPines	6.7	10.4	17.5	12	13	25	30
Northern Queensland	Softwood	Hoop pine	6.7	11.8	25.0	8	13.4	20	50
Northern Queensland	Hardwood	Nth Coast Eucs SR	6.6	10.2	20.9	12	18	27	12
Northern Queensland	Hardwood	Nth Coast Eucs LR	9.0	15.0	20.9	12	18	25	35
Northern Territory	Hardwood	Acacia	6.4	8.4	11.0	20	25	35	8
Northern Territory	Hardwood	NT eucs	6.4	8.5	11.0	8	12	20	30

r = (MAVI x Rotation Length x Basic Density x Expansion Factor) / M .... (6F_ 1)

A $\log_e$-$\log_e$ (ln-ln) model was then fitted to the r and P data by plantation type (hardwood/softwood) (Figure 6.F.2) (Equation 6F_2). Residuals were homogenously distributed. P, NPI region and rotation length (short or long) were found to be significant effects. A separate model based on state was also developed using the same regression to allow predictions for the small area (< 5 per cent) of hardwood and softwood plantations identified outside the NPI regions. There was no significant interaction between NPI and rotation length and no apparent bias in the results.

$\ln(r) = b_{0\,+}\, b_1 * \mathrm{Ln}(Pav)$ .... (6F_2)

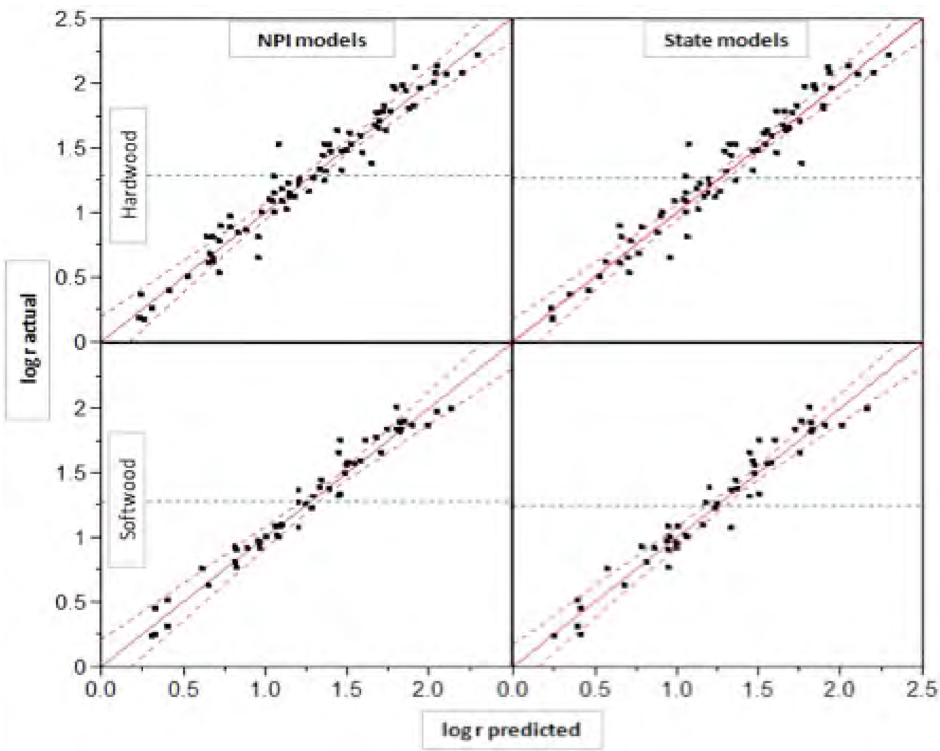
Where r = non-endemic species multiplier

b_0= value based on NPI region and rotation length (long or short)

b_1= value based on if the plantation occurs in an NPI region or a state.

Pav = long-term (1970-2018) average FPI value.

Figure 6.F.2 Actual vs predicted r values for hardwood and softwood plantations by State and NPI



The analysis showed that plantation forests established on sites with high P values require lower r values than those on sites with lower P values. This was expected, as plantations on low quality sites will often respond better, in percentage response, to good site preparation methods and adequate fertilizer addition (Turner, 1984; Snowdon and James, 2008), leading to a more 'even' range of carbon uptake rates compared with native systems.

The age of maximum biomass increment

The age and magnitude of maximum current annual biomass increment (Max I_B) varies with species, site productivity and management. The age of Max I_B is not typically reported in forest growth studies as it generally occurs before the age of first commercial thinning when direct measurements of stem volume are less commercially important and, hence, less frequent. However, it is generally considered that the age of Max I_B occurs at or around the time of canopy closure (Gower *et al.* 1994; Ryan *et al.* 1997; Law *et al.* 2003). For the purpose of calibrating the model this was assumed to be the case.

In addition to underlying site conditions (soils and climate), fertilisation and improvements in establishment techniques over the past 30 years have reduced the age of canopy closure and promoted early growth in long-rotation plantation systems (Boomsma and Hunter, 1990; Snowdon and James, 2008). Management systems which aim for high biomass outputs with a lower concern for stemwood quality and form (i.e., short rotation pulpwood plantations) will also tend to lower the age of maximum biomass increment through high stocking rates and more intensive initial management.

In FullCAM the age of maximum biomass increment can be modified through direct manipulation of *G* or through applying Type 1 effects prior to *G* (see Appendix 6.B; Equation 6F_5). Varying *G* affects both the age and magnitude of Max I_B. Where a Type 1 response is applied prior to *G* (i.e. between ages 0 and *G*), the effective age of Max I_B is lowered without affecting the magnitude of growth. The majority of management effects on early age growth, such as weed control and good site establishment methods, are modelled by applying Type 1 effects at planting. This also provides extra flexibility in adjusting stand growth based on specific management regimes. Hence, the unaffected *G* value (i.e., that with little or no management) can be calculated based on the actual age of Max I_B and the sum of Type 1 effects on early age growth due to management (Equation 6F_3):

$$G = G_{man} + T1_{pre\text{-}g} \qquad (6F\_3)$$

Where G_{man} = age of maximum biomass increment with management

G = age of maximum biomass increment assuming no management

$T1_{pre\text{-}g}$ = sum of the Type 1 age advance events applied prior to *G*

For native ecosystems an age of maximum current annual growth increment (CAI) of ten years is applied. Many commercial plantations are managed for aggressive early growth that shortens the period to harvest. This is most evident in short rotation (approximately ten year) pulpwood plantations. Silviculture, in particular a dense stocking rate of trees per hectare, is used to supply this early growth. In some instances this can bring the age of maximum current annual increment to being as low as 2-3 years after establishment. Each plantation type/management regime combination is assigned a specific age of maximum current annual increment based on location.

Calibration of G

Values for G were calibrated for each species within each NPI region based on rotation length and the approximate sum of Type 1 effects at planting. Canopy closure (effectively G_{man} in the model) in *P. radiata* plantations established over the last 20 years generally occurs between the ages of seven and 12 years depending on site quality and management (Snowdon and James 2008). On poor quality sites with little management or site improvement it may take even longer. Improved establishment and early age management practices adopted in the last 20 to 30 years, in particular after the late 1970's, have reduced the age of canopy closure by about two to three years (Boomsma and Hunter, 1990; Snowdon and James, 2008) and were modelled as Type 1 effects. Equation (6F_4) was calibrated based on 'unaffected stands' by adding 2 years of Type 1 effect to the current age of canopy closure (Equation 6F_3), resulting in a range of nine to 14 years for *G*. Regionally specific data for *G* and G_{man} was not available so this range was applied for all long rotation systems. However G_{man} DEs vary by region and time depending on management practices. Long-rotation eucalypt plantations are still relatively uncommon and little is known about their future management and prospects. Given the paucity of data it was assumed that long-rotation eucalypt plantations are similar in management to other long rotation systems, although they may reach canopy closure slightly earlier depending on growth conditions, as discussed below. To account for the effect of site productivity on *G* a simple linear relationship between *G* and *M* was included (Equation 6F_4). The results of the calibration are shown in Waterworth *et al.* (2007).

Canopy closure tends to occur much earlier in short rotation plantations due to species characteristics, higher stocking rates, more intensive management and better site/species matching. *Eucalyptus* species tend to reach canopy closure much more quickly than *Pinus* species given suitable conditions, and hence increase in mass much faster during the early stages of development (Myers *et al.* 1996). Therefore G for short rotation plantations was set 2 to 3 years earlier than for long rotation systems.

Final model form used for post-1990 plantations

$G = s \times M + c$ .... (6F_ 4)

Where G = age of maximum biomass increment of unaffected stand

s = multiplier to account for site productivity

M = unadjusted maximum biomass value

c = region/species dependent intercept

The modified tree yield formula that is used to calculate forest growth for the post-1990 *plantations* sub-category is therefore:

$I_a = r \times M \times ((y_2 \times e^{-k/d}) - (y_1 \times e^{-k/d-1})) \times (P/P_{av})$ .... (6F- 5)

Where I_a =Aboveground mass increment of the trees, in t DM ha^{-1}

a = Age of trees

r = non-endemic species multiplier

M = maximum aboveground biomass (calculated from P)

y_1 =Type 2 site multiplier at age, a

y_2 = Type 2 site multiplier at age, a-1

$k = 2 * G$

Where, G = Tree age of maximum growth

d = Adjusted age of the trees, in years

= a + sum over each treatment of

0	if a <= W
v * (a – W) / U	if a >= W and a <= W + V
v	if a > W +U

Where, *for each Type 1 treatment,*

v = the age advance due to the treatment, either positive or negative, in years

U = the advancement period, in years

W = the age, a, at which the treatment was applied, in years.

P= the actual FPI over the period d_a to d_{a-1}

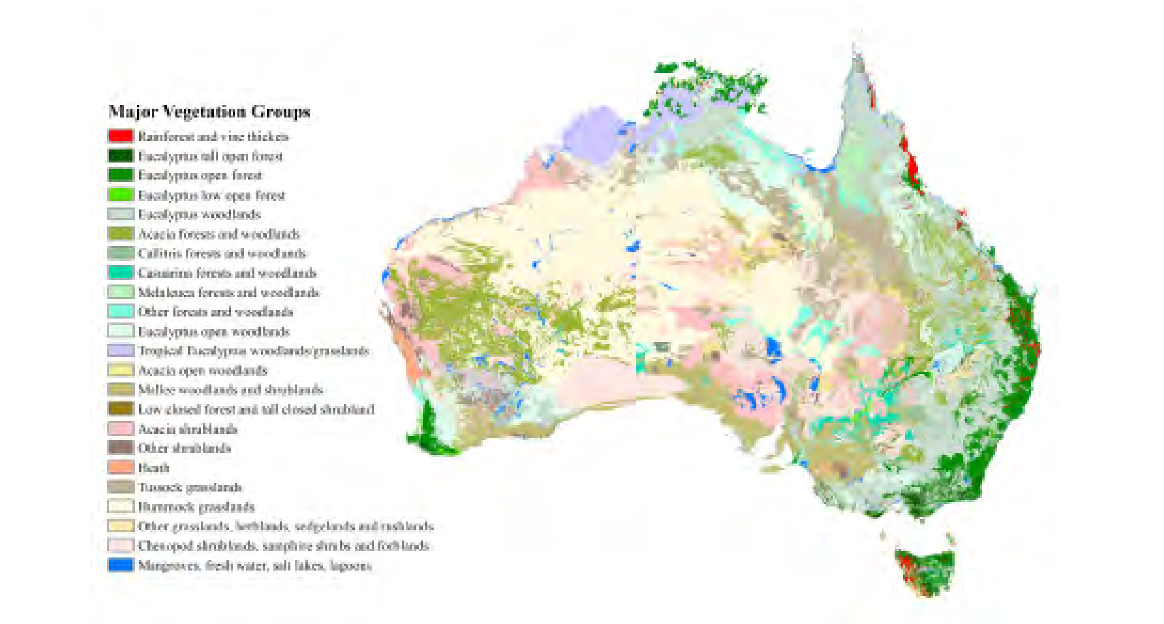
Pav=Long term (1970-2018) average FPI value

Appendix 6.G Major vegetation groupings classified by the national vegetation information system

The Major Vegetation Groups (MVG) (Figure 6.G.1) are used to specify the biomass allocations of *forest land converted to cropland* or *grassland*. In addition, the MVG are used to spatially disaggregate the land included in the *forest land converted to cropland* or *grassland* classifications in the CRF tables.

The National Vegetation Information System (NVIS, see NLWRA, 2001) provides a composite of the best available vegetation mapping in Australia. For the *forest land converted to cropland* and *forest land converted to grassland* category, various forest characteristics (e.g., forest floor coarse woody debris and litter) are associated with the forest types extracted from the NVIS. The NVIS collates and provides, in a consistent taxonomy and classification, the best available vegetation maps from all available sources. For the purposes of carbon accounting the Level III MVG categories were applied. These vegetation types are described in below.

Figure 6.G.1 Major vegetation groups (MVG)



In addition to the 'current' vegetation mapping which represents a composite of recently collected data, the NVIS also modelled forest distributions to infer a pre-European settlement (i.e., pre 1770) vegetation map. Some of the land clearing identified by Australia's land cover change programme pre-dated the current vegetation mapping (which was generally based on data from 1990 onwards). This meant that areas identified as cleared land in the NVIS could have been forested between 1972 and the date used in the NVIS mapping. In these instances, the vegetation type allocation was drawn from the 1770 modelled (inferred) vegetation map.

Group 1. Rainforest and vine thickets

Rainforest communities in Australia are mostly confined to the wet and cooler areas or climatic refuges in eastern Australia, apart from the semi-evergreen vine thickets of the Brigalow Belt and the monsoonal vine thickets that are found in the tropics in Western Australia and the Northern Territory. Community types include cool temperate rainforest, sub-tropical rainforest, tropical rainforest, vine thickets, and semi-deciduous and deciduous vine thickets. Rainforests were cleared extensively in the late 19th or early 20th centuries for high value timbers, dairying, tobacco/sugar cane or other agricultural production. The best known examples of this are the "Big Scrubs" of Illawarra and northern New South Wales and the Atherton Tableland in north Queensland.

Group 2. Eucalyptus tall open forest

These communities are restricted to all but the wetter areas of eastern Australia from the margins of the wet tropical rainforests of north Queensland to Tasmania, and the south west of Western Australia, often in rugged mountainous areas. At their maximum development in Tasmania and parts of Victoria, they contain the world's tallest flowering plants, with some trees rising to heights in excess of 100 m. These communities are typified by a well-developed often broad-leaved shrubby understorey or sometimes tree ferns and are mostly found adjacent to, or in association with, rainforest communities. Extensive areas of these communities were cleared for agriculture and grazing early in the 20th century, particularly where they occurred in association with rainforests. Major areas remain today in crown reserves as State Forests or National Parks.

Group 3. Eucalyptus open forest

This group is widespread along the sub-coastal plains, foothills and ranges of the Great Dividing Range in eastern Australia and the sub-coastal ranges of the south west of Western Australia. Generally this group has a shrubby understorey which is low to moderate in height, but in drier sites they may have a grassy understorey with scattered shrubs and/or cycads. There has been widespread clearing of these communities for grazing and agriculture in the major agricultural zones of eastern Australia and the south west of Western Australia. The rate of clearing in these communities by the early 20th century saw the development of crown reserves for the protection of forests, either as national parks or as production forests, and the establishment of forestry departments within several jurisdictions.

Group 4. Eucalyptus low open forest

This group contains a series of montane communities of the Great Dividing Range such as Snow Gum, Red Stringybark and Scribbly Gum, and the drier Jarrah communities in the south west of Western Australia. Extensive areas of these communities have been cleared principally for grazing.

Group 5. Eucalyptus woodland

This group is widespread throughout the mountain ranges and plains west of the divide in Eastern Australia and east of the sub-coastal ranges of south west Western Australia. This group includes a series of communities, which have come to typify inland Australia. For example the box (poplar box, white box, yellow box etc.) and ironbark woodlands of eastern Australia are included in this group. The Eucalyptus woodlands have been extensively cleared and modified, particularly in the agricultural zones of eastern Australia and in south west Western Australia. In many regions only small isolated fragments remain today, in many instances found only along creeks and road verges.

Group 6. Acacia forest and woodland

Brigalow (*Acacia harpohylla*) and Mulga (*A. aneura*) dominate this group with mulga covering large parts of the arid interior of the continent. A series of other acacias such as Lancewood (*A. shirelyii*) and Myall (*A. pendula*) are also included. Mulga is one of the most widespread species on the continent, occurring on a series of forest, woodland and shrubland communities. The Mulga and Brigalow communities of eastern Australia have been extensively cleared for grazing and agriculture and in many regions only scattered remnants are found today. Mulga communities in the arid interior have not been subject to clearing to the same degree but many areas have been subject to modification by grazing pressures from cattle/sheep and feral animals, and increased macropod populations supported by the increased availability of water from bores.

Group 7. Callitris forest and woodland

Cypress Pine forests are found mostly in a series of discrete regions, notably in the Brigalow Belt, but also in the arid areas in South Australia and in association with mallee communities near the South Australia – Victoria border. Extensive areas have been cleared for grazing in the Brigalow Belt and in the Mallee bio regions in particular, but major areas are included in State Forests and other crown reserves in Queensland and New South Wales.

Group 8. Casuarina forest and woodland

Containing both Casuarina and Allocasuarina genera, these occur in a series of quite distinct communities, notably foredune (*C. equisetifolia*) communities, swamp (*C. glauca*) communities, riverine (*C. cunninghamiana*) and desert (*C. cristata*) communities. These communities have been extensively cleared in many coastal areas for agriculture, or for industrial uses or urban developments. Areas in the arid zone are subject to modification by grazing of domestic stock and from feral herbivores.

Group 9. Melaleuca forest and woodland

These cover substantial areas in the tropical north, but are also found in temperate climates most often in or adjoining coastal or montane wetlands. These communities have been extensively cleared in many coastal areas for agriculture or housing near major cities. Extensive areas remain in the tropical north, in particular southern Cape York Peninsula.

Group 10. Other forest and woodland

This is a diverse group of communities, some of which such as Banksia woodland are comparatively restricted in their extent, but may be locally abundant. It also includes a series of mixed communities of the arid zone, which are not dominated by any particular species. These communities have been extensively cleared in many coastal areas for agriculture or urban uses. Extensive areas remain in the arid zone but are subject to modification by grazing of domestic stock and from feral herbivores.

Group 11. Eucalyptus open woodland

These cover extensive areas of the arid zone or drier tropical north mostly with a shrubby or grassy ground layer. Little of this group has been cleared. Many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 12. Tropical eucalyptus woodland/grassland

This group contains the so-called tall bunch-grass savannas of north Western Australia and related Eucalyptus woodland and Eucalyptus open woodland communities in the Northern Territory and in far north Queensland, including Cape York Peninsula. They are typified by the presence of a suite of tall annual grasses, notably Sorghum spp, but do not include communities in more arid sites where *Triodia spp* becomes more dominant. The fundamental difference between how Western Australia and the Northern Territory and Queensland describe these vegetation communities, necessitated their separation into a separate MVG.

Group 13. Acacia open woodland

These also cover extensive areas of the arid zone or drier tropical north mostly with a shrubby or grassy ground layer such as Blue Grass (*Dicanthium sericeum*). Eucalyptus species such as the Yapunyah (*E. thozetiana*) may also be present. Little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 14. Mallee woodland and shrubland

Multi-stemmed eucalyptus trees in association with a broad range of other shrubs or grasses cover extensive areas of the southern arid zone from Victoria to the south west of Western Australia. The mallee communities in Victoria and parts of South Australia have been extensively cleared, with only isolated remnants remaining in some areas, but these communities are still widespread in the arid zone of South Australia and Western Australia. These are subject to modification by grazing of domestic stock and from feral herbivores.

Group 15. Low closed forest and closed shrubland

These dense communities are found mostly in coastal environments, for example Kunzea and Leptospermum scrubs, or sub-coastal plains e.g., Banksia scrubs, and can cover significant areas. They also occur in rugged mountainous areas, such as sub-alpine areas in Tasmania. They have been extensively cleared in many coastal areas for agriculture or urban development.

Group 16. Acacia shrubland

Mulga, Gidgee and mixed species communities of the central Australian deserts dominate this group, but it also includes a series of other desert acacia communities. Little of this group has been cleared outside of the major agricultural zones, but they have been subject to modification by grazing from domestic stock and from feral herbivores.

Group 17. Other shrubland

This is a diverse group containing a series of communities dominated mainly by genera from the Mrytaceae family. Kunzea, Leptospermum and Melaleuca shrublands are important component of this group, but it also includes a suite of mixed arid zone communities and other communities dominated by typical inland genera such as Eremophila and Senna. This group has been extensively cleared in the agricultural regions and in coastal areas adjoining major cities. In the arid zone, little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 18. Heath

This group includes the stunted (< 1 m tall) vegetation of the coastal sand masses, typified by the family Epacridaceae and also other dense low shrublands in sub-coastal or inland environments, mostly on drainage impeded soils or natural hollows or depressions. The communities have been cleared for sand mining, agriculture and urban development.

Group 19. Tussock grassland

This group contains a broad range of native grasslands from the Blue Grass and Mitchell Grass communities in the far north to the temperate grasslands of Southern New South Wales, Victoria and Tasmania. The group contains many widespread genera including Aristida, Astrebla, Austrodanthonia, Austrostipa, Crysopogon, Dichanthium, Enneapogon, Eragrostis, Eriachne, Heteropogon, Poa, Themeda, Sorghum and Zygochloa and many mixed species communities. Extensive areas of this group have been cleared and replaced by exotic pasture species and most other areas have been subject to modification by grazing, weed invasion and land management practices associated with grazing domestic stock, such as frequent fire and the application of fertilisers.

Group 20. Hummock grassland

The spinifex (*Triodia spp.* and *Plechrachne spp.*) communities of the arid lands are quintessential to the Australian outback. These cover extensive areas of the continent either as the dominant growth form with the occasional emergent shrub or small tree (either acacia or eucalypt). They are also a conspicuous element of other communities such as open woodlands. Little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 21. Other grassland, herbland, sedgeland and rushland

This diverse group contains a series of communities, some of which are restricted within the landscape, some of which occur as mosaics and others that are otherwise too small or diffuse across the landscape to be easily discerned at a continental scale.

Group 22. Chenopod shrub, samphire shrub and forbland

The chenopods such as Saltbush (*Atriplex spp.*) and Bluebush (*Maireana spp.*), cover extensive areas of the arid interior on saline soils. They are also associated with the ephemeral salt lakes of these arid areas, often in association with samphires such as *Halosarcia* species. Similarly, some forbland communities contain a mix of species including samphires and chenopods. Other forblands containing Asteraceae species are found in Queensland.

Group 23. Mangrove, tidal mudflat, samphire, claypan, salt lakes, bare areas, sand, rock, lagoons and freshwater lakes

Mangroves vary from extensive tall closed forest communities on Cape York Peninsula to low closed forests or shrublands in southern regions. Samphires are found in the coastal mudflats and marine plains, adjoining mangrove areas in many instances, but they also cover extensive marine plains inland from the southern Gulf of Carpentaria and other parts of the tropical north. In the harsh environments of the arid interior extensive areas devoid of vegetation can be found as bare ground, either sand dune, claypan or salt lakes. Similarly, the coastal sand masses can often contain extensive areas of bare sands, mostly as active dunes. In mountainous areas, large areas of bare rock or scree may be a feature of the landscape. This is particularly the case where large rocky outcrops dominate the landscape, such as Uluru and the Olgas in central Australia, Bald Rock in northern New South Wales and many examples of large monadnocks in the south west of Western Australia. There can be widespread clearing or infilling of mangroves and tidal mudflats in coastal areas near urban major centres for industrial uses or urban developments.

Appendix 6.H Tier 2 forest conversion model

Forest land converted to cropland and *grassland* emissions estimates are based on the Tier 3 Approach 3 model and national time-series of Landsat satellite data. Verification of the use of the Tier 3 model to estimate emissions from this sub-category was performed through comparison with a Tier 2, Approach 2 method. The Tier 2 model was developed as an excel spreadsheet model. This model formed the basis for reporting emissions prior to the implementation of the Tier 3, Approach 3 methods and has been subsequently enhanced. The Tier 2 model is used to estimate changes in biomass from the conversion of 'mature' forest, the regrowth of forest on previously cleared land, the growth of crops and grasses on cleared land, and the subsequent re-clearing of a proportion of this regrowth.

The model also calculates changes in the dead organic matter (DOM) and soil pools and emissions (CO_2 and non-CO_2) associated with burning.

The annual area converted or re-cleared (activity data) were the same as those used as input to the Tier 3 model for Forest land converted to Cropland and Grassland.

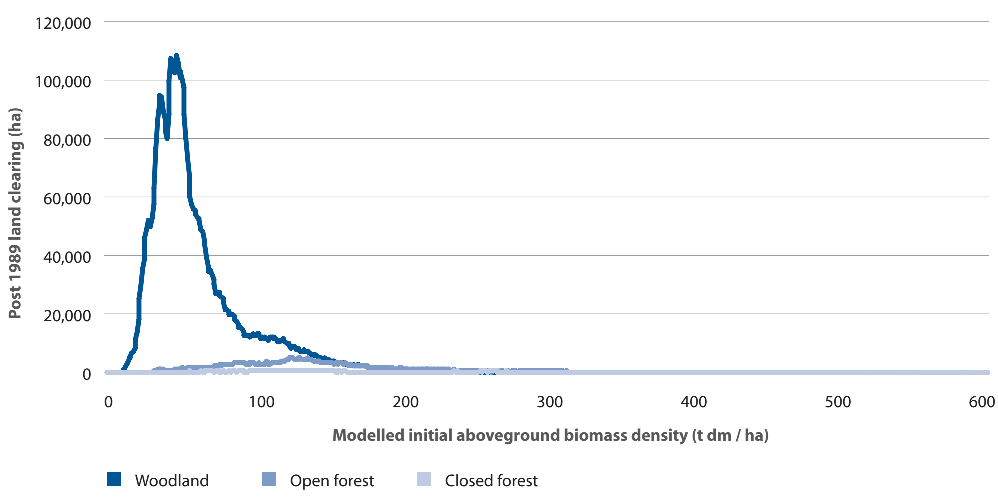
In the Tier 2 model land clearing is stratified into three broad forest classes:

- closed (tropical forest);
- open (predominantly eucalypt forest); and
- woodland forest

This stratification was undertaken by overlaying the areas cleared from the remote sensing analysis on the major vegetation groups of the National Vegetation Information System (NVIS; see Appendix 6.G).

Figure 6.H.1 shows that the majority of land clearing since 1989 has occurred in woodland forests.
This information was used in the Tier 2 model to allocate the area cleared in each year to clearing of woodland, open forest and closed forest (Table 6.H.1).

Figure 6.H.1 Initial assumed biomass of land cleared post-1989 which has entered Australia's deforestation accounts



Carbon pools

Biomass – aboveground and below ground trees

To determine the biomass of each forest class that is used in the Tier 2 model, analysis was undertaken of the initial assumed above ground biomass of the lands that are within Australia's deforestation account. To undertake this analysis the simulated cells layer for lands within the deforestation account were intersected with the initial assumed above ground biomass surface. Table 6.H.1shows the results of this analysis. The estimates are expressed as averages within three forest types – closed forest, open forest and woodland. The area converted from forest land to cropland and grassland areas were allocated to the three forest types by matching their locations to the locations of Australia's major vegetation groups.

Table 6.H.1 Tier 2 forest coefficients used to estimate emissions and removals from first time forest clearing

	Closed Forest	Open Forest	Woodland Forest
Proportion of annual clearing (%)	2	10	88
Initial biomass of forests(a)(b) (t dm ha^{-1})	198.7	152.8	67.6
Root : shoot ratio	0.25	0.25	0.40
Debris onsite mass(b) (t dm ha^{-1})	100	75	50
Initial soil carbon (t C ha^{-1})	70	73	60
Proportion of area subject to forest regrowth (%)	25	25	25

(a) Aboveground biomass.
(b) Used for all States and Territories.

Areas of previously cleared land that re-grew to forest are assumed to achieve their original biomass in 25 years. The biomass of forest subject to reclearing is 32 per cent of the mature biomass.

Biomass – above ground and below ground herbaceous species

Sequestration associated with the growth of crop and grass species is included in the model on land which is not subject to forest regrowth. Table 6.H.2 provides the biomass increment parameters applied to estimate this variable. These parameters are multiplied by the total area of clearing recorded each year to estimate the biomass accumulated by crop and grass species on cleared land.

Table 6.H.2 Biomass accumulated by crop and grass species on cleared land

	Crops	Grasses
Proportion of cleared land (%)	15	60
Above ground mass, including debris (tdm ha-1)	4.0	4.2
Root : shoot ratio	0.5	0.5

Dead organic matter

The forest debris onsite prior to forest clearing is presented in Table 6.H.1. Debris associated with crops and grasses is included with living biomass (Table 6.H.2). Forest debris, including initial debris and debris remaining after forest conversion, was assumed to decay over a period of 10 years (IPCC, 2003).

Soil carbon

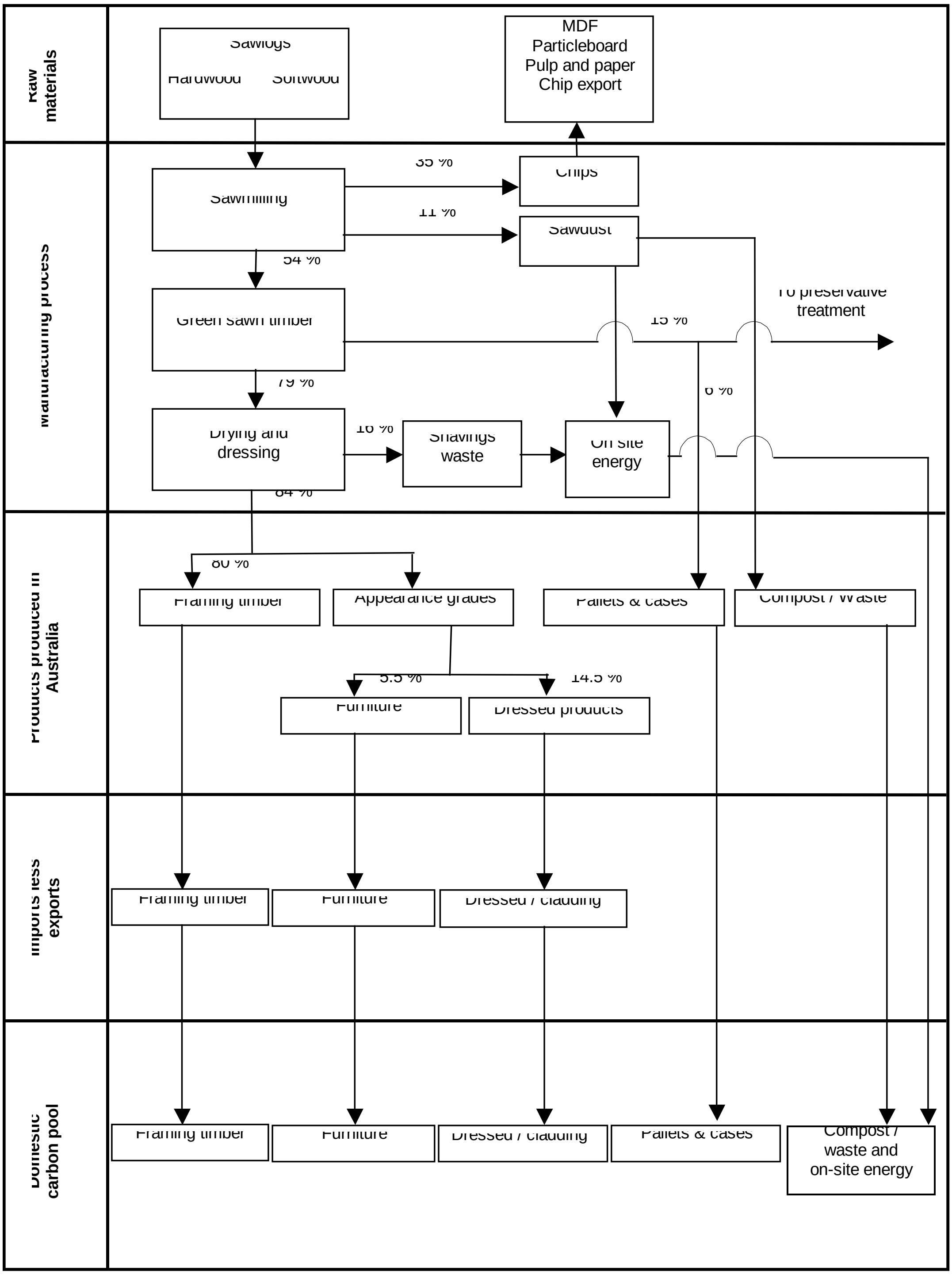
Emissions of soil carbon following conversion are estimated by applying the Roth C model for all first time cleared land (See Appendix 6.B). The Roth C model was parameterised with climate data (rainfall, temperature, open pan evaporation) from a representative site in central Queensland.

Non CO_2 emissions

Non-CO_2 (CH_4 and N_2O) emissions were estimated by multiplying the CO_2 emissions from onsite burning and onsite burning of debris with a 'non-CO_2 to CO_2' coefficient. The non-CO_2 to CO_2 coefficient incorporates the ratio of mass of non-CO_2 gas to the mass of carbon it contains, the ratio of non-CO_2 gas emitted to carbon emitted, the ratio of the amount of CO_2 with equivalent greenhouse gas effect to an amount of non-CO_2 gas and the fraction of CO_2 that is carbon by weight.

Appendix 6.I Wood flows by sector

Figure 6.I.1 National Inventory Model – Sawmilling wood flows*



* percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

Figure 6.I.2 National Inventory Model for Wood Products – Wood flows in preservative treated products

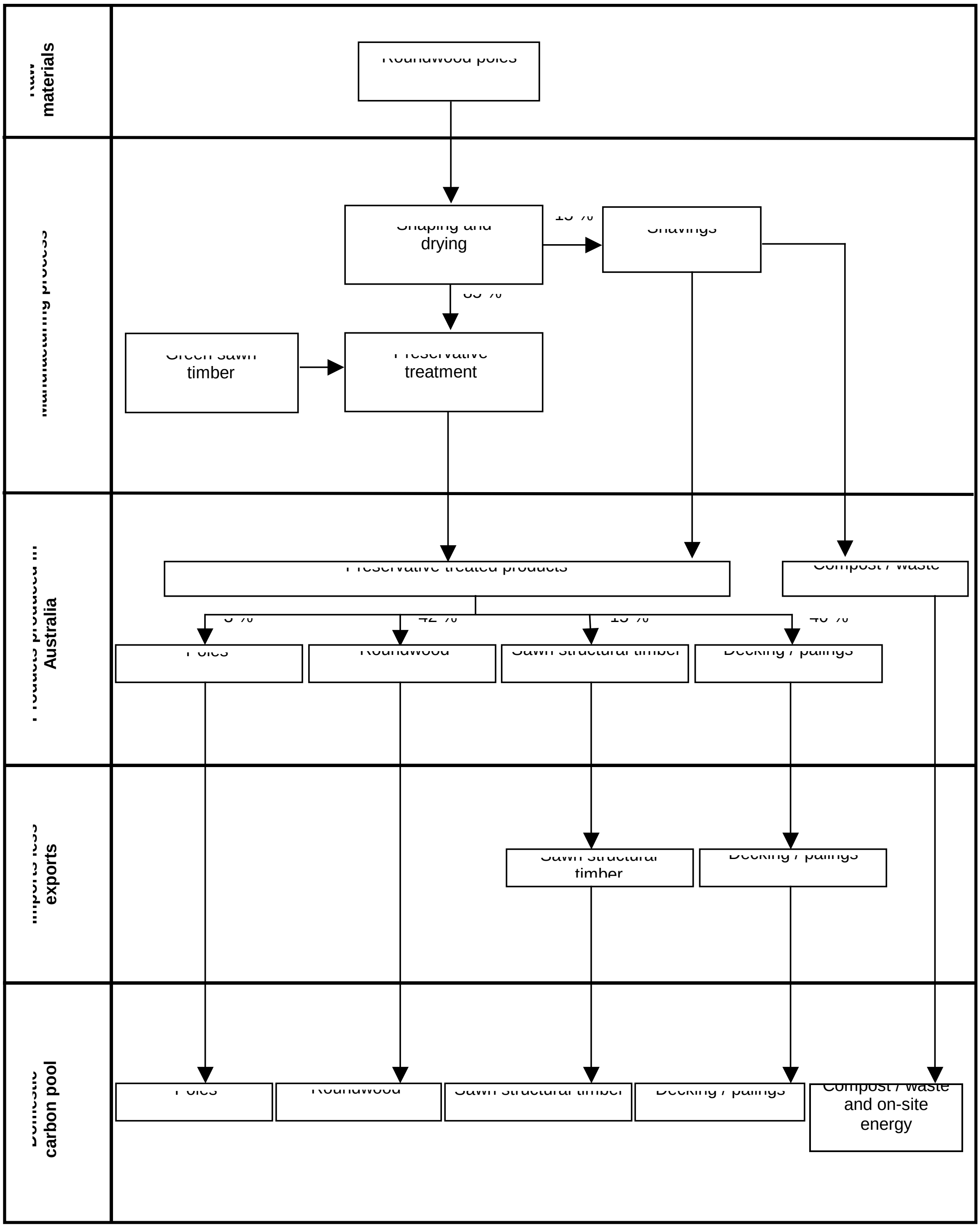


Figure 6.I.3 National Carbon Accounting Model for Wood Products – Wood Flows in plywood production

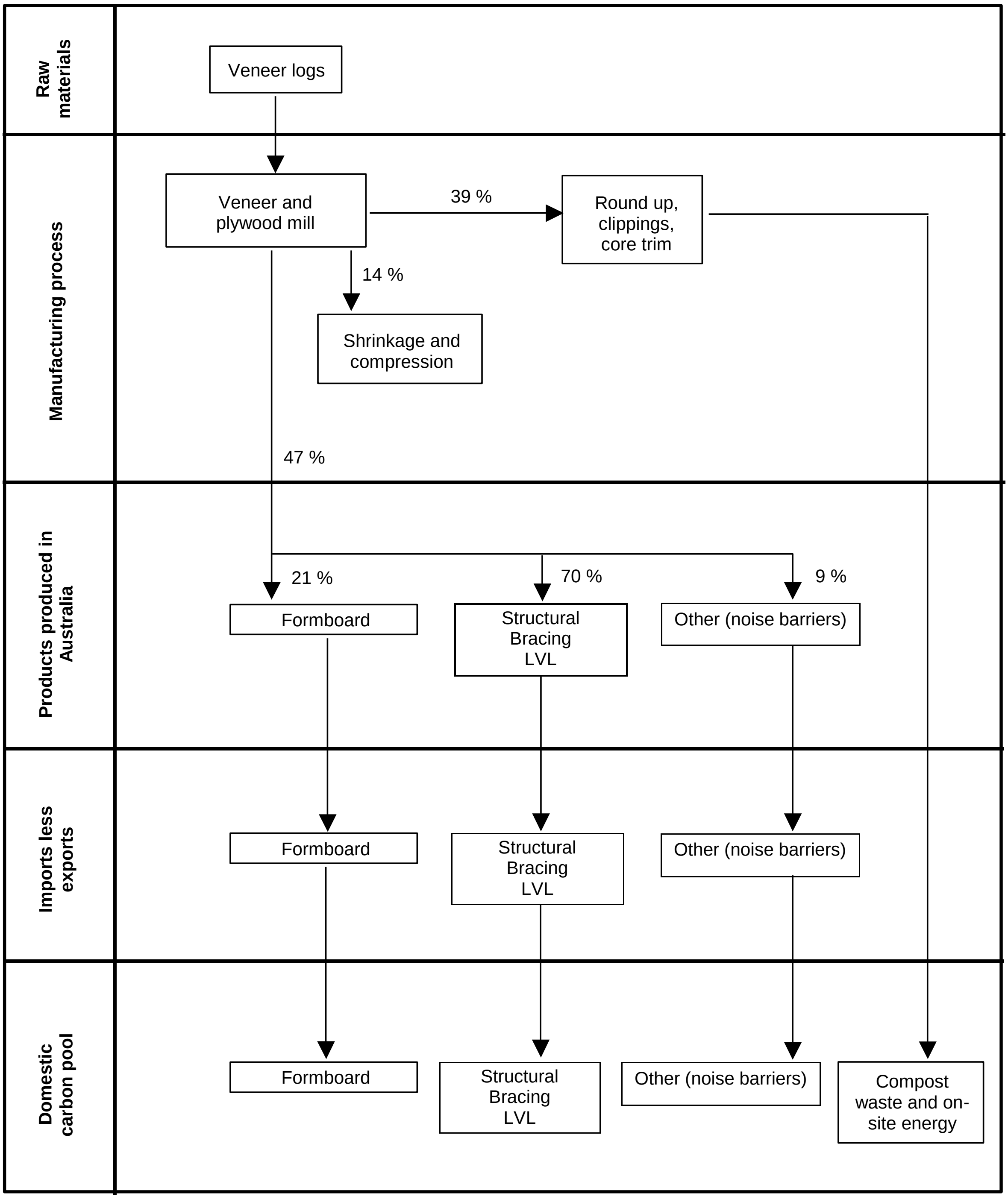


Figure 6.I.4 National Inventory Model for Wood Products – Wood flows in plywood production

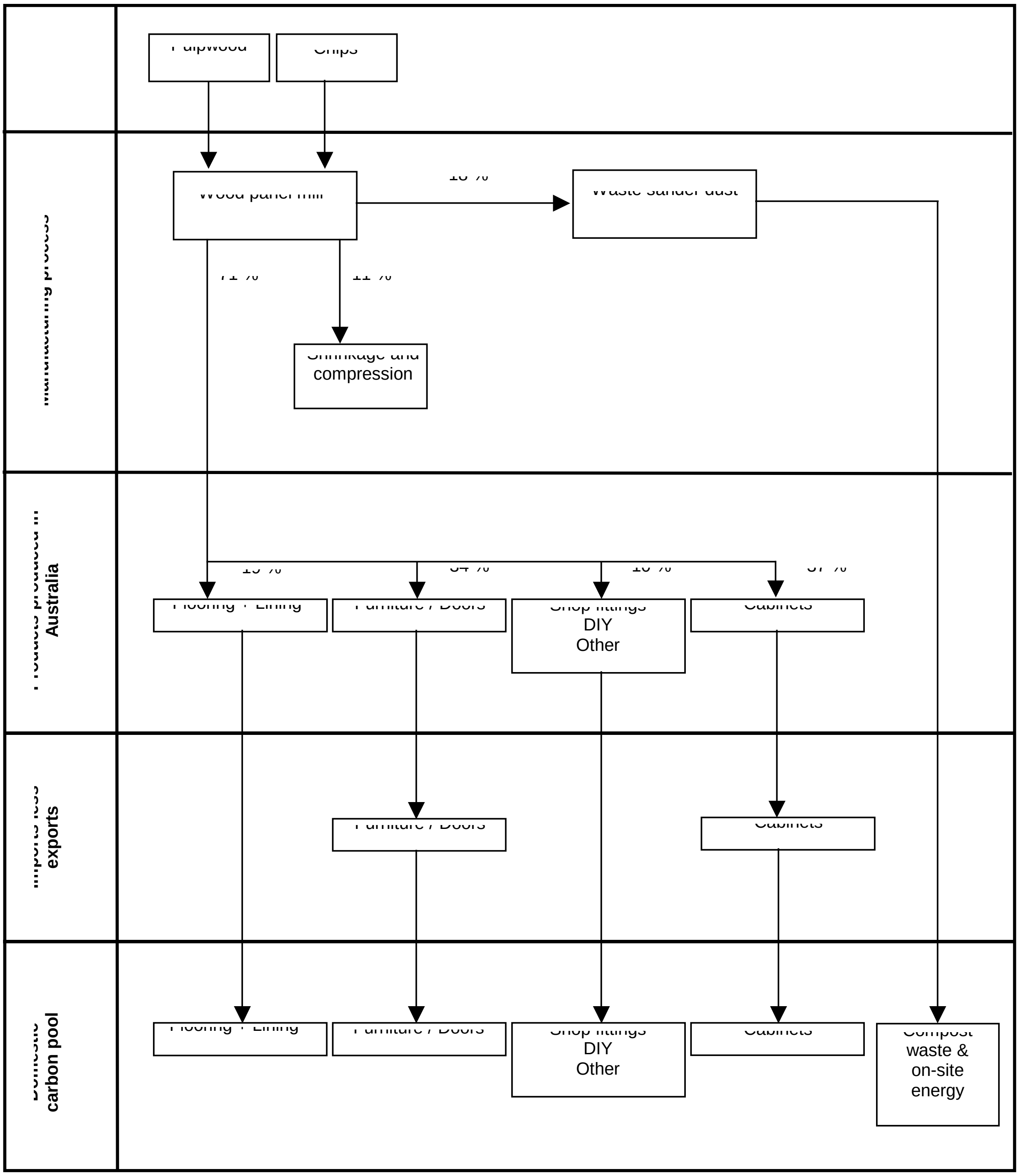
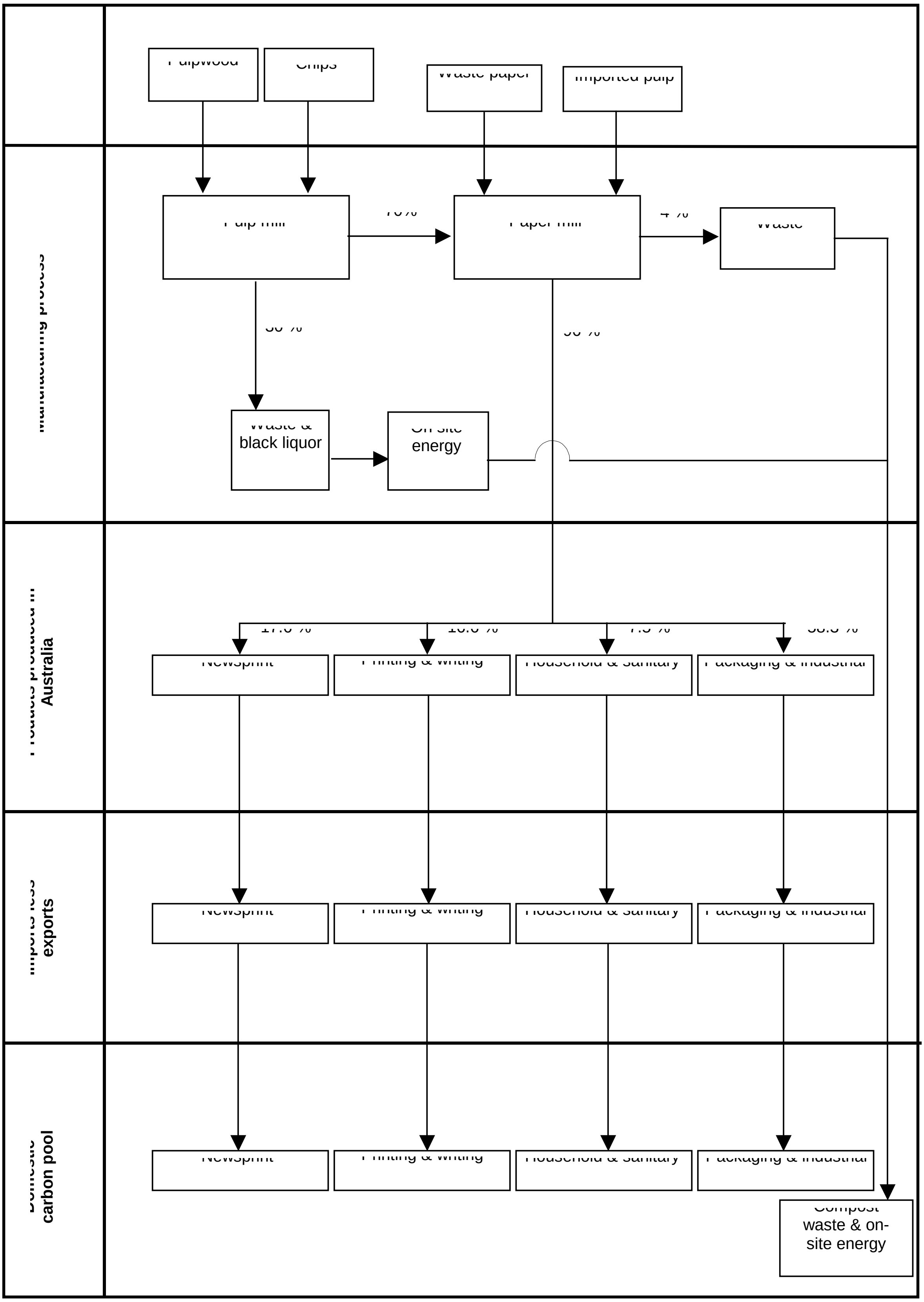
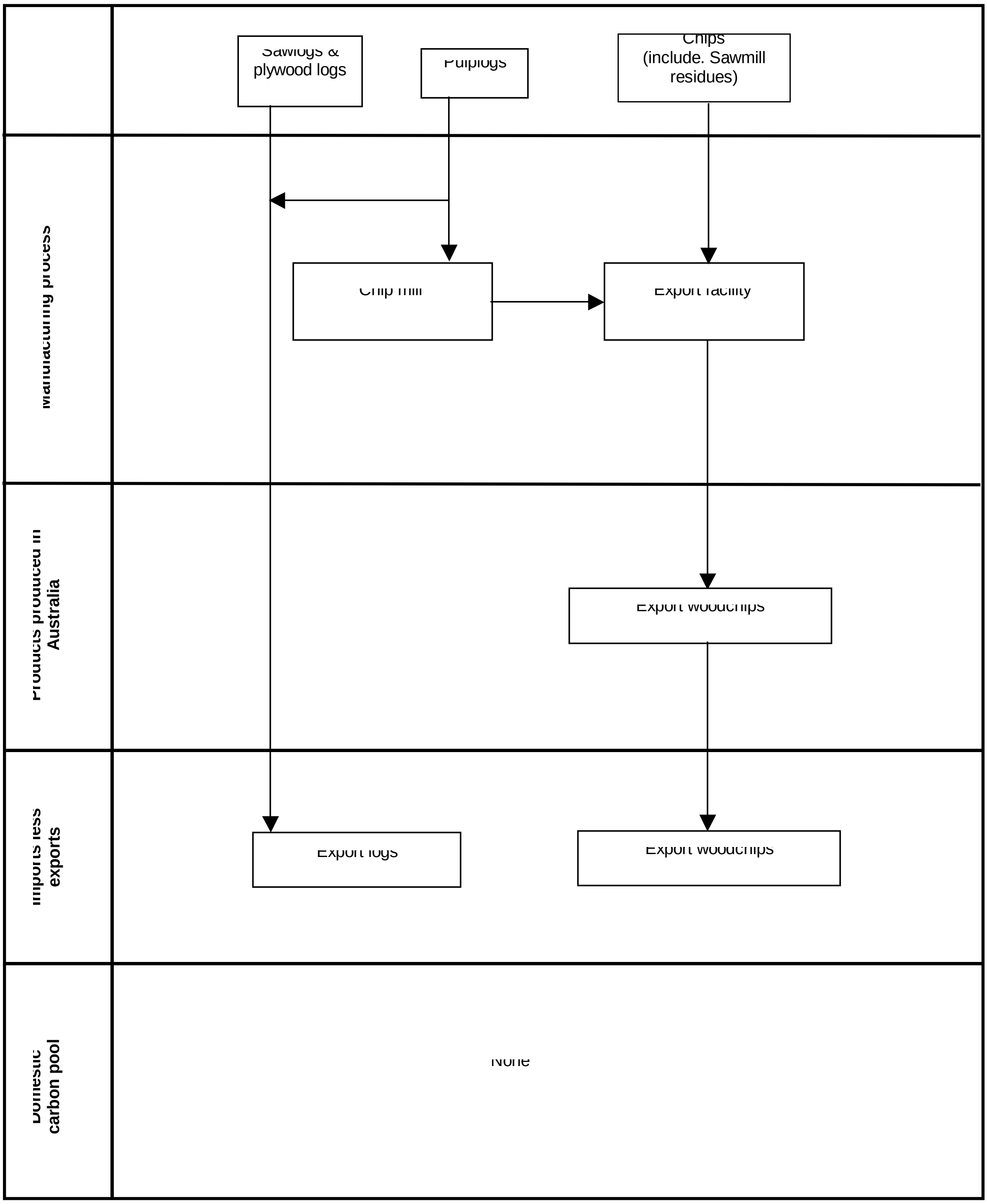


Figure 6.I.5 National Inventory Model for Wood Products – Wood flows in MDF and particleboard manufacture*



* percentages shown for particleboard manufacture – see model for details on MDF

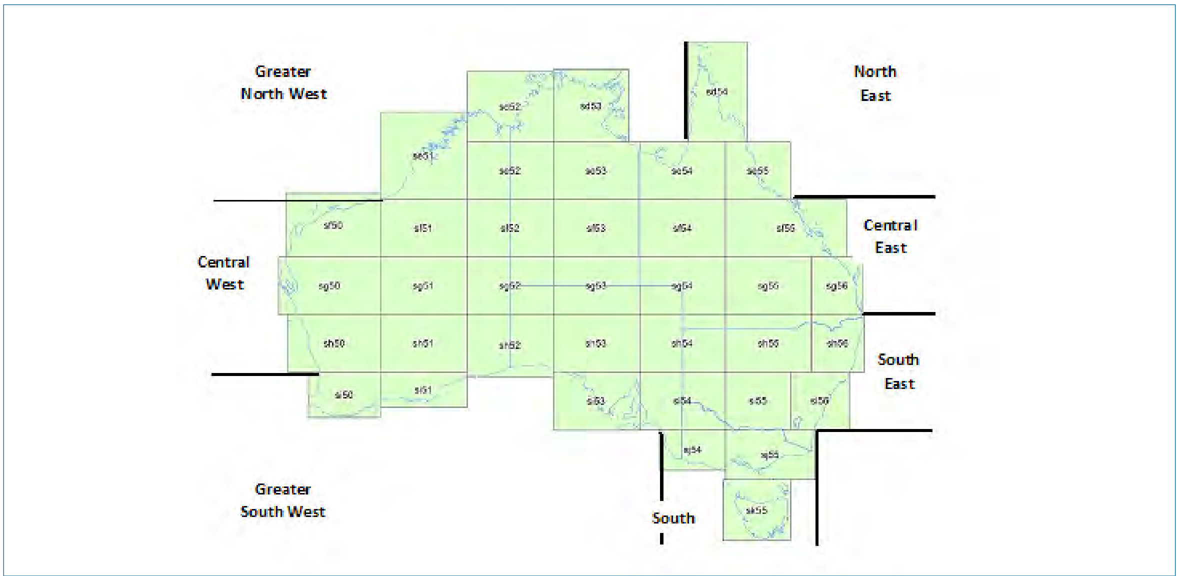
Figure 6.I.6 National Inventory Model for Wood Products – Wood flows in pulp and paper manufacture



Appendix 6J Wetlands – model parameter values and source documents

The Tier 1 IPCC default values for above ground biomass (AGB), below ground biomass (BGB), dead organic matter (as woody and non-woody litter), and soil organic carbon (SOC), were replaced with values relevant to Australia's varied coastal regions, based on a review of the national and international scientific literature (Table 6.J.1).

Figure 6.J.1 Australian coastal regions related to the development of model parameters for coastal wetlands



Where possible, weighted averages of multiple reported parameter values are calculated for each of seven coastal regions (Table 6.J.1). The seven coastal regions (Figure 6.J.1) are constructs that correspond, approximately, to combinations of mangrove biogeographical regions defined in Cresswell (Cresswell 2012), and also fully incorporate sets of spatial tiles that return areas of vegetation clearance and revegetation used in the analysis of land use and land use change.

Mangrove species common to and across several coastal regions are identified and their relative abundances within each coastal region estimated from surveys undertaken in Australia (Table 6.J.2). Only one species of mangrove (*Avicennia marina*) exists in Victoria and South Australia so that this species had a relative abundance score of 1 in these states.

Finally, tidal marsh is a generic classification in this study. It incorporates all the vegetated, non-forested intertidal habitats that comprise combinations of sparse vegetation (salt marsh mixed with individual mangrove plants), herbs, saline grasses, sedges and rushes. Because tidal marshes form neighbouring and ecotone communities with mangroves any conversion of mangroves to settlement will also result in the clearance of tidal marsh. An estimate of emissions due to this associated clearance of tidal marsh is provided in this inventory. The relative proportions of mangrove, tidal marsh and unvegetated (salt pan, mud flat, tidal flat) within the intertidal wetland used for the modelled estimates are in table 6.J.3 below.

Table 6.J.1 Mangrove (MG) and tidal marsh (TM) parameter values. The values are weighted averages of values obtained from the scientific literature. References are in Table 6.J.4

Habitat and Coastal Sector	Carbon fraction	Wood density (g cm^{-3})	AGB (t ha^{-1})		BGB (t ha^{-1})		Standing stock woody litter (t DM ha^{-1})		Standing stock non-woody litter (t DM ha^{-1})		Min SOC Mg ha^{-1}	Mean SOC Mg ha^{-1}
			Min	Mean/Max	Min	Mean/Max	Min	Mean/Max	Min	Mean/Max	Min	Mean/Max
MG, NE	0.48	0.75	1.33	354.16	0.67	179.94	0.01	9.44	0.01	1.98	31.3	621
MG, Central E	0.48	0.68	1.2	90.08	0.8	60.05	0.01	9.44	0.01	1.98	31.3	343
MG, SE	0.46	0.68	0.9	92.87	1.1	114.38	0.01	0.76	0.01	0.16	31.3	285
MG, South	0.45	0.77	0.87	121	1.13	157	0.01	0.76	0.01	0.16	31.3	145
MG, Greater SW	0.45	0.77	0.3	101	1.7	238	0.01	0.76	0.01	0.16	31.3	205
MG, Central W	0.45	0.77	0.3	101	1.7	238	0.01	0.68	0.01	2	31.3	118
MG, Greater NW	0.47	0.76	1.34	406.19	0.66	199.34	0.01	0.68	0.01	2	31.3	367
TM, NE	0.41	0	0	6.4	0	18	0	0	0	0.02	n/a	125
TM, Central E	0.41	0	0	6.4	0	18	0	0	0	0.02	n/a	125
TM, SE	0.41	0	0	7	0.00	5	0	0	0	0.02	n/a	191
TM, South	0.41	0	0	7	0	5	0	0	0	0.02	n/a	169
TM, Greater SW	0.41	0	0	6.4	0	18	0	0	0	0.02	n/a	147
TM, Central W	0.41	0	0	6.4	0	18	0	0	0	0.02	n/a	413
TM, Greater NW	0.41	0	0	6.4	0	18	0	0	0	0.02	n/a	413

Table 6.J.2 The relative abundance of common mangrove species used in the modelling. References are listed in Table 6.J.5

Mangrove species	Abundance relative to other mangrove species within each coastal region						
	North East (NE)	Central East (Cent E)	South East (SE)	South (S)	Greater South West (Greater SW)	Central West (Central W)	Greater North West (Greater NW)
Avicennia marina	0.18	0.15	0.65	1	1	1	0.3
Aegiceras corniculatum	0.1	0.4	0.35	0	0	0	0.14
Excoecaria agallocha	0.01	0.01	0	0	0	0	0
Ceriops tagal australis	0.2	0.18	0	0	0	0	0.35
Rhizophora stylosa	0.25	0.14	0	0	0	0	0.1
Bruguiera sp	0.2	0.1	0	0	0	0	0.1
Sonneratia alba	0.01	0.02	0	0	0	0	0
Lumnitzera racemosa	0.05	0	0	0	0	0	0.01

Table 6.J.3 The relative proportion of mangrove, tidal marsh and unvegetated (salt pan, mud flat, tidal flat) within the intertidal wetland. References are listed in Table 6.J.5

Tile	Coastal Region	Mangrove relative area	Tidal marsh relative area	Un-vegetated relative area
sd54	North East Coast	0.4614	0.4178	0.1208
se55	North East Coast	0.6484	0.2968	0.0548
sf55	Central East Coast	0.4194	0.4867	0.0939
sg56	Central East Coast	0.4607	0.1968	0.3425
sh56	South East Coast	0.5346	0.2402	0.2252
si56	South East Coast	0.3655	0.3950	0.2395
sj55	South Coast	0.0570	0.1778	0.7652
sj54	South Coast	0.0013	0.8372	0.1616
sk55	South Coast	0.0000	0.0000	0.0000
si54	Greater South West Coast	0.5279	0.2973	0.1748
si53	Greater South West Coast	0.2100	0.5716	0.2184
sh53	Greater South West Coast	0.0000	0.2000	0.8000
sh52	Greater South West Coast	0.0000	0.2000	0.8000
si51	Greater South West Coast	0.0000	0.2000	0.8000
si50	Greater South West Coast	0.0177	0.4138	0.5685
sh50	Greater South West Coast	0.5541	0.0252	0.4206
sg50	Central West Coast	0.5787	0.2762	0.1451

Tile	Coastal Region	Mangrove relative area	Tidal marsh relative area	Un-vegetated relative area
sf50	Central West Coast	0.1304	0.7036	0.1660
se51	Greater North West Coast	0.1980	0.6152	0.1868
sd52	Greater North West Coast	0.2947	0.6601	0.0452
sd53	Greater North West Coast	0.2860	0.6399	0.0741
se53	Greater North West Coast	0.2860	0.6399	0.0741
se54	Greater North West Coast	0.1347	0.8265	0.0388

Table 6.J.4 Source documents for informing the development of species-specific or locality-specific parameter and emission factor values in Table 6.J.1. Full details are provided in the source documents list following Table 6.J.5

Species / habitat type	Carbon fraction	Wood density	AGB/BGB	Litter production and Litter standing stock	SOC
Avicennia marina	(Adame *et al*. 2015), (Bulmer, Schwendenmann, and Lundquist 2016b), (Bulmer, Schwendenmann, and Lundquist 2016a), (Bhattacharyya, Mitra, and Raha 2015), (Rodrigues *et al*. 2015), (Patil *et al*. 2014), (Perera and Amarasinghe 2014)	(Duke, Mackenzie, and Wood 2013), (Santini *et al*. 2013)	(Alongi *et al*. 2003), (Alongi, Clough, and Robertson 2005), (Mackey 1993), (Burchett *et al*. 2009), (Bulmer, Schwendenmann, and Lundquist 2016a), (Bulmer, Schwendenmann, and Lundquist 2016b), (Lichacz, Hardiman, and Buckney 2009), (Saintilan 1997b), (Saintilan 1997a), (Comley and McGuinness 2005), (Tamooh *et al*. 2008), (Briggs 1977), (Clough and Attiwill 1975), (Hutchings and Saenger 1987)	(Clarke 1994), (Duke, Bunt, and Williams 1981), (Duke 1982), (Mackey and Smail 1995), (May 1999), (Duke 1988), (Metcalfe 1999), (Imgraben and Dittmann 2008), (Woodroffe 1982), (Gladstone-Gallagher, Lundquist, and Pilditch 2014), (Saenger and Snedaker 1993), (Conacher *et al*. 1996), (Goulter and Allaway 1979), (Woodroffe *et al*. 1988), (Murray 1985)	(Carnell *et al*. 2015), (Livesley and Andrusiak 2012), (Saintilan *et al*. 2013), (Lovelock *et al*. 2013), (Page and Dalal 2011), (Matsui 1998), (Howe, Rodríguez, and Saco 2009), (Brown *et al*. 2016), (KELLEWAY *et al*. 2015), (Salmo, Lovelock, and Duke 2013), (Kaly, Eugelink, and Robertson 1997)
Aegiceras sp.	(Hossain *et al*. 2016)	(Duke, Mackenzie, and Wood 2013)	(Lichacz, Hardiman, and Buckney 2009), (Saintilan 1997b), (Saintilan 1997a)		
Ceriops sp.	(Binh and Nam 2014), (Slim *et al*. 1996), (Duke, Burrows, and Mackenzie 2015)	(Clough and Scott 1989), (Duke, Mackenzie, and Wood 2013)	(Duke, Burrows, and Mackenzie 2015), (Robertson and Daniel 1989), (Saintilan 1997a), (Comley and McGuinness 2005)		
Lumnitzera sp.	(Perera and Amarasinghe 2013), (Perera and Amarasinghe 2014)	(Duke, Mackenzie, and Wood 2013)	(Perera and Amarasinghe 2013), (Krishnanantham, Seneviratne, and Jayamanne 2015), (Duke, Mackenzie, and Wood 2013)		
Rhizophora sp.	(Rodrigues *et al*. 2015), (Kauffman *et al*. 2011), (Perera and Amarasinghe 2014), (Slim *et al*. 1996), (Duke, Burrows, and Mackenzie 2015)	(Clough and Scott 1989), (Duke, Mackenzie, and Wood 2013)	(Alongi *et al*. 2003), (Alongi, Clough, and Robertson 2005), (Duke, Burrows, and Mackenzie 2015), (Robertson and Daniel 1989), (Comley and McGuinness 2005), (Tamooh *et al*. 2008)		
Sonneratia sp.	(Kauffman *et al*. 2011), (Bhattacharyya, Mitra, and Raha 2015),	(Duke, Mackenzie, and Wood 2013)	(Ball and Pidsley 1995), (Tamooh *et al*. 2008)		
Bruguiera sp.	(Kauffman *et al*. 2011), (Perera and Amarasinghe 2013), (Duke, Burrows, and Mackenzie 2015)	(Clough and Scott 1989), (Duke, Mackenzie, and Wood 2013)	(Duke, Burrows, and Mackenzie 2015), (Robertson and Daniel 1989), (Comley and McGuinness 2005)		
Excoecaria sp.	(Bhattacharyya, Mitra, and Raha 2015), (Perera and Amarasinghe 2014)	(Duke, Mackenzie, and Wood 2013)	(Saintilan 1997a), (Duke, Mackenzie, and Wood 2013), (Bhattacharyya, Mitra, and Raha 2015)		

Species / habitat type	Carbon fraction	Wood density	AGB/BGB	Litter production and Litter standing stock	SOC
Tidal marsh	(Hemminga *et al*. 1996), (Cartaxana and Catarino 1997)	n/a	(Clarke and Jacoby 1994), (Lichacz, Hardiman, and Buckney 2009), (Macreadie, Hughes, and Kimbro 2013)	(Van Der Valk and Attiwill 1983)	(Carnell *et al*. 2016), (Carnell *et al*. 2015), (Kelleway *et al*. 2016), (Macreadie, Hughes, and Kimbro 2013), (Macreadie *et al*. 2017), (Livesley and Andrusiak 2012), (Saintilan *et al*. 2013), (Lovelock *et al*. 2013), (Page and Dalal 2011), (Howe, Rodríguez, and Saco 2009), (Brown *et al*. 2016), (KELLEWAY *et al*. 2015), (Salmo, Lovelock, and Duke 2013)
Un-vegetated intertidal	n/a	n/a	n/a	n/a	(Maher and Eyre 2010), (Beasy and Ellison 2013)

Table 6.J.5 Sources of biogeographical information that informed the relative abundance of mangrove species within mangrove habitats (Table 6.J.2), and the distribution of mangrove, tidal marsh and unvegetated habitats in each state and territory (Table 6.J.3). Full details are provided in the source documents list in Table 6.J.12 below.

State/Territory	Source documents
National	(Bridgewater and Cresswell 1999), (Suzuki and Saenger 1996), (Bridgewater and Cresswell 2003), (Cresswell 2012), (Macnae 1966), (NLWRA 1998)
Queensland	(Danaher and Stevens 1995), (Danaher 1995b), (Bruinsma and Duncan 2000), (Bruinsma 2001), (Danaher 1995a), (Bruinsma *et al.* 1999), (Bruinsma and Danaher 2001), (Bruinsma 2000), (Bruinsma and Danaher 2000), (Dowling and Stephens 1998), (Dowling 1986), (Dowling 1978), (Accad *et al.* 2016), (BUNT 1996), (Bunt 1997), (Bunt and Bunt 1999), (Bunt and Williams 1981), (Bunt *et al.* 1991), (Roder *et al.* 2002), (Duke *et al.* 2017), (Duke, Burrows, and Mackenzie 2015), (Mackenzie *et al.* 2012)
New South Wales	(Creese *et al.* 2009), (Astles *et al.* 2010), (West *et al.* 1984), (West, Laird, and Williams 2004), (Outhred and Buckney 2009), (Clarke and Hannon 1967)
Victoria	(Keough *et al.* 2011), (Boon 2012), (Boon 2015), (Boon *et al.* 2015), (French *et al.* 2014), (Ross 2000)
Tasmania	(Kirkpatrick and Glasby 1981), (Prahalad 2014), (Prahalad 2016a), (Prahalad 2016b), (Prahalad 2009), (Prahalad, Kirkpatrick, and Mount 2012), (Prahalad and Jones 2013), (Prahalad and Pearson 2013)
South Australia	(Edyvane 1999), (Foulkes and Heard 2003), (Cann, Scardigno, and Jago 2009), (Rumblelow, Speziali, and Bloomfield 2010), (Scientific Working Group 2011)
Western Australia	(Duke *et al.* 2010), (Cresswell, Bridgewater, and Semeniuk 2011), (Cresswell and Semeniuk 2011), (Pen, Semeniuk, and Semeniuk 2000), (Semeniuk 1985), (Semeniuk 1983), (Semeniuk 1980), (Semeniuk, Semeniuk, and Unno 2000), (Semeniuk, Tauss, and Unno 2000)
Northern Territory	(Duke *et al.* 2010), (O'Grady, McGuinness, and Eamus 1996), (McGuinness 2003), (Coupland, Paling, and McGuinness 2005), (Lee 2003), (Moritz-Zimmermann, Comley, and Lewis 2002), (Duke *et al.* 2017)

Table 6.J.6 Species relative abundance within each Coastal Region. References are listed in Table 6.J.8.

Species	North East Coast	Central East Coast	South East Coast	South Coast	Greater South West Coast	Central West Coast	Greater North West Coast
Amphibolis antarctica	0	0	0	0.1	0.35	0.84	0
Cymodocea sp.	0.1	0.1	0	0	0	0.07	0.3
Enhalus acroides	0	0	0	0	0	0.01	0.05
Halodule uninervis	0.35	0.35	0	0	0.05	0.01	0.1
Halophila sp.	0.45	0.4	0.13	0.1	0.05	0.01	0.45
Posidonia sp.	0	0	0.46	0.1	0.5	0.05	0
Thalassia hemprichii	0.05	0.05	0	0	0	0.01	0.1
Zostera muelleri	0.05	0.1	0.41	0.7	0.05	0	0

Table 6.J.7 Seagrass model parameter values obtained from the scientific literature. References are listed in Table 6.J.9

Parameter	Species	North East Coast	Central East Coast	South East Coast	South Coast	Greater South West Coast	Central West Coast	Greater North West Coast
Carbon fraction	Amphibolis antarctica	0	0	0	0.3	0.3	0.3	0
	Cymodocea sp.	0.3	0.3	0	0	0	0.3	0.3
	Enhalus acroides	0	0	0	0	0	0.3	0.3
	Halodule uninervis	0.3	0.3	0	0	0.3	0.3	0.3
	Halophila sp.	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Posidonia sp.	0	0	0.3	0.3	0.3	0.3	0
	Thalassia hemprichii	0.3	0.3	0	0	0	0.3	0.3
	Zostera muelleri	0.3	0.3	0.3	0.3	0.3	0	0
BGB (t ha^{-1})	Amphibolis antarctica	0	0	0	2.77	2.77	2.77	0
	Cymodocea sp.	0.6	0.6	0	0	0	0.6	0.6
	Enhalus acroides	1.52	1.52	0	0	0	1.52	1.52
	Halodule uninervis	0.07	0.07	0	0	0.07	0.07	0.07
	Halophila sp.	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Posidonia sp.	0	0	3.4	3.4	3.4	3.4	0
	Thalassia hemprichii	3	3	0	0	0	3	3
	Zostera muelleri	1.8	1.8	1.8	1.8	1.8	0	0
SOC (t ha^{-1})	Amphibolis antarctica	0	0	0	28	28	38	0
	Cymodocea sp.	63	63	0	0	0	63	63
	Enhalus acroides	51	51	0	0	0	51	51
	Halodule uninervis	52	52	0	0	52	52	52
	Halophila sp.	86	86	86	86	86	86	86
	Posidonia sp.	0	0	60	200	200	60	0
	Thalassia hemprichii	24	24	0	0	0	24	24
	Zostera muelleri	81	31	151	182	182	0	0

Table 6.J.8 Sources of biogeographical and relative abundance data for seagrass species within Australian state waters. Full details are provided in the source documents list in Table 6.J.12 below.

State/Territory	Source documents
National	(Short *et al*. 2007)
Queensland	(Lee Long, Mellors, and Coles 1993; Lee Long, McKenzie, and Coles 1997; Lee Long *et al*. 1998; Lee Long *et al*. 2002; Campbell *et al*. 2002; Abal and Dennison 1996; Carruthers *et al*. 2002; Poiner, Staples, and Kenyon 1987; Coles *et al*. 1994; Coles *et al*. 1996)
New South Wales	(Astles *et al*. 2010; Fyfe 2004; King 1988; Larkum and West 1990; Meehan and West 2002; Sanderson 1997; West 2010; Williams and Meehan 2004)
Victoria	(Roob and Ball 1997; Roob, Werner, and Morris 1998; Blake, Roob, and Patterson 2000; Blake and Ball 2001; O'Hara, Norman, and Staples 2002; Ball and Blake 2007b, 2007a; Walker 2011; Monk *et al*. 2011; Pope, Monk, and Ierodiaconou 2013; Ball 2013)
Tasmania	(Barrett *et al*. 2001)
South Australia	(Edyvane 1999; Bourman, Maurray-Wallace, and Harvey 2016)
Western Australia	(Carruthers *et al*. 2007; Walker, Kendrick, and McComb 1988; Hillman, McComb, and Walker 1995; McMahon *et al*. 1997)
Northern Territory	(McKenzie 2008; Roelofs, Coles, and Smit 2005; Poiner, Staples, and Kenyon 1987; Kenyon, Conacher, and Poiner 1997)

Table 6.J.9 Sources of seagrass model parameter values. Full details are provided in Table 6.J.12.

Carbon fraction	BGB	SOC
(Duarte 1990; Moore and Wetzel 2000)	(McKenzie 1994; Duarte *et al*. 1998; Paling and McComb 2000)	(Lavery *et al*. 2013; Brown *et al*. 2016; Carnell *et al*. 2015)

Table 6.J.10 List of locations subject to capital dredging projects recorded for the period 1990 to 2016. Shapefiles (Kettle, 2017) of each project provide a polygon representing the dredge footprint and area excavated.

State	Location name	Commencement Year	Polygon Area (km^2)
NSW	Port Macquarie Marina	2001	0.0392
NSW	Newcastle Port	2005	3.08
NSW	Port Macquarie Marina	2008	0.136
NSW	Port Macquarie Marina	2008	0.0392
NT	Bing Bong	1994	0.238
NT	Port Darwin	2000	2.44
NT	Port of Groote Eylandt	2010	0.07
NT	Port Darwin	2011	0.27
Qld	The Jetty Precinct	1993	0.14
Qld	Port Hinchinbrook Marina	1995	0.206
Qld	Laguna Quays Marina	1995	0.114
Qld	Port of Karumba	1996	0.75
Qld	Nelly Bay Marina	2002	0.148
Qld	Abell Point Marina	2003	0.252
Qld	Hay Point Harbour	2006	0.4
Qld	Port of Hay Point	2007	6.25
Qld	Ephraim Island Marina	2007	0.4764

State	Location name	Commencement Year	Polygon Area (km^2)
Qld	Gladstone Marina	2009	0.514
Qld	Keppel Bay Marina	2010	0.227
Qld	Port of Gladstone	2011	11.9
Qld	Port of Gladstone	2011	4.38
Qld	Port of Brisbane	2011	3.46
Qld	Port Denison	2011	0.26
Qld	Port of Weipa	2012	2.94
Qld	Brisbane Airport Middle Banks	2014	6.07
Qld	Port of Cooktown	2014	0.11
SA	Port Vincent Marina (CYSA)	1996	0.09
SA	Copper Cove Marina	2005	0.25
SA	Port of Whyalla	2013	0.466
SA	Whyalla Marina	2013	0.076
SA	Whyalla Wharf	2013	0.06
Vic	Port Melbourne	2007	25.3
Vic	Port Melbourne	2007	8.27
Vic	Portland Marina	2012	0.902
Vic	Queenscliff Harbour	2012	0.158
Vic	Yaringa Marina	2014	0.05
WA	Port of Bunbury	1994	0.92
WA	Port Dampier	1995	7.76
WA	Exmouth Harbour	1997	0.282
WA	Albany Waterfront Marina	2000	0.093
WA	Port of Geraldton	2003	1.45
WA	Port of Geraldton	2003	1.05
WA	Hillarys Boat Harbour	2004	0.265
WA	Fremantle Harbour	2005	1.53
WA	Jurien Bay Boat Harbour	2005	0.152
WA	Emu Point Boat Harbour	2006	0.049
WA	Rous Head Harbour	2007	0.183
WA	Cockburn Marine Complex	2009	7.44
WA	Barrow Island	2009	1.4
WA	Barrow Island	2009	0.271
WA	Casuarina Boat Harbour	2009	0.04
WA	Port Walcott	2010	14.4
WA	Port Dampier	2010	0.408
WA	Wheatstone LNG Port	2011	0.167
WA	Casuarina Boat Harbour	2015	0.04

Table 6.J.11 Seagrass habitat extent shapefiles

State or national seagrass extent	Source Credit	Date accessed	Accessed at
Australia, base layer	World Imagery: DigitalGlobe (2016) Vivid - Australia	28/08/2017	http://goto.arcgisonline.com/maps/World_Imagery
Australia, national seagrass set	CSIRO (2015): Seagrass Dataset - CAMRIS. v1. CSIRO. Data Collection.	28/08/2017	http://metadata.imas.utas.edu.au/geonetwork/srv/eng/metadata.show?uuid=332e13ec-ba09-4457-add5-f8e3ca8b6c54
NSW	NSW Department of Primary Industries, New South Wales Government (2013). Estuarine Macrophytes of NSW.	05/09/2017	http://metadata.imas.utas.edu.au/geonetwork/srv/en/meta data.show?uuid=281FAA64-F6F3-400C-A48F-D342E4ABCA83
NT	Mount, R.E. and P.J. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project - National Intertidal-Subtidal Benthic Habitat (NISB) Map	31/08/2017	https://demo.ands.org.au/northern-territory-national-map-plus/644037?source=suggested_datasets
NT	Smit, N (2011). Darwin Harbour marine habitats. Department of Environment and Natural Resources, Northern Territory Government.	31/08/2017	http://metadata.imas.utas.edu.au/geonetwork/srv/eng/metadata.show?uuid=2e754ed7-caab-4640-a133-5ead9e077edb
QLD	James Cook University (2014). Torres Strait Seagrass Mapping Consolidation.	05/09/2017	http://metadata.imas.utas.edu.au/geonetwork/srv/eng/metadata.show?uuid=e7ea913e-2528-4ece-847c-a25722e11c1f
QLD	Department of National Parks, Sport and Racing, Queensland Government (2008). Moreton Bay broadscale habitats 2008.	05/09/2017	http://metadata.imas.utas.edu.au/geonetwork/srv/eng/metadata.show?uuid=806decf7-1260-44b8-b5a0-cc96a746cedc
QLD	TropWATER, JCU: NESP TWQ 3.1 - Collation of spatial seagrass data (meadow extent polygons, species presence/absence points) from 1984 - 2014 for the Great Barrier Reef World Heritage Area (GBRWHA)	05/09/2017	http://eatlas.org.au/data/uuid/77998615-bbab-4270-bcb1-96c46f56f85a
QLD	Mount, R.E. and P.J. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project - National Intertidal-Subtidal Benthic Habitat (NISB) Map	05/09/2017	https://demo.ands.org.au/queensland-national-intertidal-map-plus/644047?source=suggested_datasets
SA	Mount, R.E. and P.J. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project - National Intertidal-Subtidal Benthic Habitat (NISB) Map	30/09/2017	https://demo.ands.org.au/south-australia-national-map-plus/644036?source=suggested_datasets

Appendix

State or national seagrass extent	Source Credit	Date accessed	Accessed at
Vic	The State of Victoria, Department of Economic Development, Jobs, Transport and Resources, 2017, Port Phillip Bay seagrass mapping at nine aerial assessment regions in April 2011	26/09/2017	https://www.data.vic.gov.au/data/dataset?q=seagrass
Vic	The State of Victoria, Department of Economic Development, Jobs, Transport and Resources, 2017, Port Phillip Bay 1:25,000 Seagrass 2000	26/09/2017	https://www.data.vic.gov.au/data/dataset?q=seagrass
Vic	Mount, R.E. and P.J. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project - National Intertidal-Subtidal Benthic Habitat (NISB) Map	26/09/2017	http://geonetwork-dev.tern.org.au/geonetwork/srv/eng/catalog.search#/metadata/DEC149CF-9C87-469F-A041-894C76941048
WA	Mount, R.E. and P.J. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project - National Intertidal-Subtidal Benthic Habitat (NISB) Map	05/09/2017	http://geonetwork-dev.tern.org.au/geonetwork/srv/eng/catalog.search#/metadata/58215F4D-7E0A-4B66-8D3F-DBCA95EF6FCD

Table 6.J.12 Source documents list for Mangrove/Tidal marsh

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Ball, David. 2013. "Mud Islands Seagrass and Coastline Mapping 2011/12." In. Melbourne: Parks Victoria.

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Appendix 6.K Biomass burning

There are six different types of biomass burning events (Table 6.K.1). With the exception of prescribed burns (which are based on State agency reports), biomass burning events are monitored via monthly Advanced Very High Resolution Radiometer imagery (AVHRR, 1988-present, with 1970-1987 gap-filling as per Meyer 2016). The FullCAM-predicted impacts of fire were predicted at the pixel resolution of 25 × 25 m, with the fire events only being applied to a proportion of cells randomly selected within the fire scar in accordance with the assumed fire patchiness, *P*. *P* has been shown to vary between the six different burning events (Table 6.K.1). For fire events not detected using AVHRR imagery (i.e. prescribed fires and fires prior to 1988), assumptions were made in order to simulate spatial and temporal variations in fires. As outlined in Table 6.K.2, these assumptions were based on available estimates of typical fire return intervals, time of year fires occur, area of the fire scar, and the proportion of EDS to LDS burns in tropical savanna fire zones where available from previous studies and expert opinion (Meyer *et al*. 2009; Murphy *et al*. 2013). To introduce variation in the simulated fire events, uniform probability distribution functions were applied to vary these assumptions between what was deemed to be their upper and lower bounds.

Table 6.K.1 Assumed patchiness (*P*, varying between 0 and 1) in various fire zones of Australia. Data sources: Meyer *et al*. (2015) and Roxburgh *et al*. (2015).

Fire zone	Fire type	Patchiness (*P*)
Southern Australian forests & woodlands	Prescribe	0.650
	Wildfire	0.800
Tropical savanna Woodland; > 1000 mm MAR	EDS	0.709
	LDS	0.889
Tropical savannaWoodland; < 1000 mm MAR	EDS	0.790
	LDS	0.970

Table 6.K.2 'Rules' applied when simulating prescribed fires or wildfires prior to 1988; including, typical return intervals, Julian days at which fires occur, area of the fire scar, and relative proportion of EDS and LDS fires in the tropical savanna woodlands. All wildfires were assumed to have scar areas of 3000×3000 m while all other fires were assumed to have scar areas of 1500×1500 m. Based on empirical evidence and expert option as outline by Murphy *et al*. (2013) and Meyer *et al*. (2015).

Region	Vegetation subclass	Wildfires		Prescribed burns or savanna fires[1]		*Proportion of EDS (or LDS) fires*
		Fire return interval (yrs)	*Julian day at which fire occurs*	Fire return interval (yrs)	*Julian day at which fire occurs*	
Temperate	Tall eucalypt forest (B)	31-185	15±30	5-15	105±30[2]	~
	Eucalypt forest (C)	8-147	334±60	5-15	105±30[2]	~
	Rainforest (D)	154-318	105±30	5-15	105±30[2]	~
	Heath (E)	31-154	344±60	5-15	105±30[2]	~
	Eucalypt woodland[3] (H)	31-182	15±30	5-15	105±30[2]	~
	Mallee (N)	31-182	344±60	5-15	105±30[2]	~

Region	Vegetation subclass	Wildfires		Prescribed burns or savanna fires[1]		*Proportion of EDS (or LDS) fires*
		Fire return interval (yrs)	*Julian day at which fire occurs*	Fire return interval (yrs)	*Julian day at which fire occurs*	
Arid & Semi-arid	Tussock grassland (K)	31-182	344±60	5-15	105±30[2]	~
	Acacia shrubland (mulga) (P)	27-156	344±60	5-15	105±30[2]	~
	Tussock grassland (T)	27-156	344±60	5-15	105±30[2]	~
	Acacia woodland (Brigalow) (J)	31-182	344±60	5-15	105±30[2]	~
Tropical Semi-arid	Acacia woodland (O)	31-154	288±30	5-15	105±30[2]	~
	Eucalypt woodland (Q)	8-147	344±60	5-15	105±30[2]	~
	Chenopod shrubland (R)	27-156	344±60	5-15	105±30[2]	~
	Hummock grassland (S)	7-125	288±30	5-15	105±30[2]	~
Tropical	Rainforest (tropical) (A)	154-308	288±30	5-15	105±30[2]	~
	Eucalypt forest & woodland[3] (I)	8-147	288±30	5-15	105±30[2]	~
Monsoonal	NT	~	~	5-8	166±60 (258±30)	0.41 (0.59)
	Melaleuca Woodland QLD	~	~	5-8	166±60 (258±30)	0.20 (0.80)
	(Other) WA	~	~	3-7	166±60 (258±30)	0.30 (0.70)
	NT	~	~	3-6	166±60 (258±30)	0.31 (0.69)
	Open Forest Mixed QLD	~	~	15-18	166±60 (258±30)	0.06 (0.94)
	(hOFM) WA	~	~	1-5	166±60 (258±30)	0.41 (0.59)
	NT	~	~	2-6	166±60 (258±30)	0.58 (0.42)
	Shrubland Hummock QLD	~	~	6-9	166±60 (258±30)	0.08 (0.92)
	(hSHH) WA	~	~	3-6	166±60 (258±30)	0.36 (0.64)
	NT	~	~	2-6	166±60 (258±30)	0.43 (0.57)
	Woodland Hummock QLD	~	~	6-9	166±60 (258±30)	0.14 (0.86)
	(hWHu) WA	~	~	2-6	166±60 (258±30)	0.36 (0.64)
	NT	~	~	1-5	166±60 (258±30)	0.51 (0.49)
	Woodland Mixed QLD	~	~	3-6	166±60 (258±30)	0.15 (0.85)
Savanna	(hWMi) WA	~	~	1-5	166±60 (258±30)	0.41 (0.59)
Woodland	NT	~	~	4-8	135±60 (288±30)	0.34 (0.66)
	Open woodland, mixed QLD	~	~	4-7	135±60 (288±30)	0.22 (0.78)
	(lOWM) WA	~	~	3-6	135±60 (288±30)	0.34 (0.66)
	NT	~	~	4-8	135±60 (288±30)	0.40 (0.60)
	Shrubland Hammock QLD	~	~	4-7	135±60 (288±30)	0.21 (0.79)
	(lSHH) WA	~	~	3-6	135±60 (288±30)	0.38 (0.62)
	NT	~	~	4-7	135±60 (288±30)	0.32 (0.68)
	Woodland Hammock QLD	~	~	5-8	135±60 (288±30)	0.11 (0.89)
	(lWHu) WA	~	~	2-6	135±60 (288±30)	0.40 (0.60)
	NT	~	~	3-7	135±60 (288±30)	0.28 (0.72)
	Woodland, Mixed grass QLD	~	~	9-12	135±60 (288±30)	0.18 (0.82)
	(lWMi) WA	~	~	11-14	135±60 (288±30)	0.37 (0.63)
	NT	~	~	2-6	135±60 (288±30)	0.41 (0.59)
	Woodland, Tussock grass QLD	~	~	11-14	135±60 (288±30)	0.18 (0.82)
	(lWTu) WA	~	~	2-6	135±60 (288±30)	0.37 (0.63)

[1] Fire return intervals reported by Meyer *et al*. (2015) were divided by *P* as described in the text.
[2] Exception is 243±30 in WA, and 151±30 in Qld.
[3] When simulating wildfires prior to European settlement, it was assumed that areas of cleared land deemed by Murphy *et al*. (2013) to be 'temperate pasture' or 'tropical and subtropical pasture' were 'temperate eucalypt woodland' and 'tropical eucalypt forest and woodland'.

For all biomass burning events simulated by FullCAM, it is assumed that the live biomass recovers post-burning. As outlined in detail by Paul and Roxburgh (2019), for wildfire simulations (which were not assumed to be stand-replacing fires, and hence only had relatively small impacts on live biomass pools), recovery of live woody biomass was assumed to take 12 years, with the exception of foliage, which took only 3 years. For all other biomass burning simulations, it was assumed that recovery of live woody biomass took 2 years, with the exception of foliage, which took only 0.5 years.

Grass under woody vegetation can be a key component of fine fuel pools. Hence, when simulating biomass burn events, FullCAM is configured to simulate woody vegetation as well as a perennial grass understorey, with the assumed growth rates and die-off rates provided in Table 6.K.3. The proposal area occupied by grass is given by the parameter, A_{grass} (Table 6.K.4).

As outlined in detail by Paul and Roxburgh (2019), the model was calibrated to ensure that the overall emissions and fuel dynamics were consistent with previous estimates under typical conditions. This gave litterfall rates and A_{grass} estimates as shown in Table 6.K.4, and estimates of C loss from live biomass and debris are provided in Tables 6.K.5 and 6.K.6, respectively. Generally, by the time of a return fire event, all of the standing dead material was assumed to have decomposed. However, for any remaining stem, branch or bark standing dead material, the total C lost on burning was assumed to be 31 per cent for intense fires and 14 per cent for less intense fires. For any remaining foliage standing dead material, the total C lost on burning was assumed to be 85 per cent for intense fires and 70 per cent for less intense fires. Of the C lost on burning standing dead pools, there was an assumed 0.90:0.10 split of CO_2-C-to-debris loss of C.

Table 6.K.3 Average growth and die-back (Tonnes DM) simulated for the three different grasses simulated within the fire zones; Perennial grasses in southern fire zones, Monsoonal perennial grass in the high rainfall savanna fire zones, and spinifex in the low rainfall savanna zones.

Region	Perennial grass		Monsoonal perennial grass		Spinifex	
	Growth	Die-off	Growth	Die-off	Growth	Die-off
Jan	5.4057	0.6705	2.0179	0.1355	1.6832	0.1668
Feb	5.3894	0.5999	2.4964	0.1593	2.0796	0.2167
Mar	5.2980	0.7154	2.9649	0.2361	2.2741	0.3767
Apr	5.1781	0.7528	3.1075	0.4244	2.0318	0.4742
May	5.0460	0.7874	2.7842	0.6468	1.7083	0.4086
June	4.9243	0.7369	2.3243	0.5667	1.4555	0.3085
July	4.8606	0.7315	1.9136	0.4512	1.2583	0.2482
Aug	4.9193	0.7143	1.5874	0.3364	1.0939	0.1936
Sept	5.0720	0.6554	1.3596	0.2407	0.9713	0.1436
Oct	5.2462	0.6400	1.2091	0.1882	0.9076	0.1152
Nov	5.4136	0.6020	1.1927	0.1483	0.9775	0.1071
Dec	5.4677	0.6624	1.5185	0.1307	1.2547	0.1421

Table 6.K.4 Values applied in FullCAM for rates of litterfall of foliage, bark and branches (*L*, per cent month-1), and the proportional area occupied by grasses (A_{grass}). Note, rates of litterfall for southern fire regions were based on litterfall studies as reviewed by Paul and Roxburgh (2017).

Region		Vegetation subclass	State	*L* (% month^{-1})			A_{grass}
				Foliage	*Bark*	*Branch*	
Southern	~	~	NSW	2.708	0.409	0.738	0.05
			TAS	2.708	0.409	0.738	0.40
			WA	2.708	0.409	0.738	0.00
			SA	2.708	0.409	0.738	0.35
			Vic	2.708	0.409	0.738	0.20
			Qld	2.708	0.409	0.738	0.50
			ACT	2.708	0.409	0.738	0.10
Savanna	> 1000 mm MAR	Open Forest mixed (hOFM)	NT	2.083	0.375	0.375	0.28
			QLD	0.604	0.125	0.108	0.30
			WA	1.917	0.392	0.358	0.25
		Woodland Mixed (hWMi)	NT	3.083	0.350	0.233	0.15
			QLD	1.667	0.233	0.167	0.15
			WA	2.667	0.300	0.200	0.15
		Woodland Hummock (hWHu)	NT	3.333	0.708	0.708	0.20
			QLD	1.333	0.333	0.350	0.20
			WA	2.667	0.583	0.583	0.20
		Shrubland Hummock (hSHH)	NT	3.333	0.283	0.308	0.30
			QLD	1.250	0.042	0.117	0.40
			WA	2.167	0.150	0.267	0.35
		Melaleuca woodland (Other)	NT	0.750	0.250	0.125	0.25
			QLD	1.333	0.267	0.167	0.35
			WA	1.750	0.458	0.250	0.20
	< 1000 mm MAR	Woodland with tussock grass (lWTu)	NT	2.833	0.667	0.167	0.75
			QLD	0.917	0.375	0.108	0.70
			WA	0.267	0.833	0.208	0.80
		Woodland with mixed grass (lWMi)	NT	2.250	0.433	0.267	0.01
			QLD	1.167	0.250	0.167	0.01
			WA	2.667	0.433	0.267	0.01
		Woodland with hummock grass (lWHu)	NT	1.667	0.625	0.100	0.65
			QLD	1.583	0.583	0.100	0.65
			WA	2.333	0.750	0.100	0.65
		Open woodland with mixed grass (lOWM)	NT	2.500	0.333	0.042	0.35
			QLD	2.917	0.333	0.042	0.35
			WA	2.000	0.250	0.042	0.35
		Shrubland with hummock grass (lSHH)	NT	2.500	0.333	0.042	0.35
			QLD	2.917	0.333	0.042	0.40
			WA	2.000	0.250	0.042	0.35

Table 6.K.5 Values of calibrated FullCAM parameters for the percentage of live biomass-C that was assumed to be converted to either CO_2-C or the standing dead pool (t ha^{-1}) as a result of fire. Two pairs of values are provided. The first pair represents percentage C loss to CO_2-C & standing dead (t ha^{-1}) in low intensity fire types (prescribed or EDS). The second pair, given in parenthesis, represents percentage C loss to CO_2-C & standing dead in high intensity fires type (wildfire or LDS).

Region		Vegetation subclass	State	*Stem*	*Branches*	*Bark*	*Foliage*
Southern forests and woodlands	~	~	ACT	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			NSW	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			Qld	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			SA	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			TAS	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			Vic	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			WA	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
Savanna Woodland	> 1000 mm MAR	Open Forest Mixed (hOFM)	NT	1&0 (2&0.5)	1&0 (2&1)	2&0 (3&3)	2&0 (3&10)
			QLD	1&0 (2&0.5)	1&0 (2&1)	2&0 (3&3)	2&0 (3&3)
			WA	1&0 (2&1)	1&0 (2&3)	2&0 (3&3)	2&0 (3&5)
		Woodland Mixed (hWMi)	NT	1&0 (2&1)	1&0 (2&1)	2&0 (3&5)	2&0 (3&10)
			QLD	1&0 (2&0.5)	1&0 (2&1)	2&0 (3&5)	2&0 (3&10)
			WA	1&0 (2&1)	1&0 (2&1)	2&0 (3&5)	2&0 (3&7)
		Woodland Hummock (hWHu)	NT	1&0 (2&1)	1&0 (2&5.5)	2&0 (3&5.5)	2&0 (3&10)
			QLD	1&0 (2&1)	1&0 (2&2.5)	2&0 (3&2.5)	2&0 (3&3)
			WA	1&0 (2&2)	1&0 (2&5)	2&0 (3&5)	2&0 (3&10)
		Shrubland Hummock (hSHH)	NT	1&0 (2&1)	1&0 (2&2)	2&0 (3&2)	2&0 (3&10)
			QLD	1&0 (2&0)	1&0 (2&0)	2&0 (3&1)	2&0 (3&5)
			WA	1&0 (2&1)	1&0 (2&2)	2&0 (3&2)	2&0 (3&10)
		Melaleuca woodland (Other)	NT	1&0 (2&0)	1&0 (2&2)	2&0 (3&5)	2&0 (3&7)
			QLD	1&0 (2&1)	1&0 (2&1)	2&0 (3&5)	2&0 (3&5)
			WA	1&0 (2&1)	1&0 (2&1)	2&0 (3&3)	2&0 (3&3)
	< 1000 mm MAR	Woodland with tussock grass (lWTu) 11	NT	1&0 (2&1)	1&0 (2&1)	2&0 (3&7.5)	2&0 (3&15)
			QLD	1&0 (2&1)	1&0 (2&0)	2&0 (3&1)	2&0 (3&1)
			WA	1&0 (2&1)	1&0 (2&1)	2&0 (3&10)	2&0 (3&10)
		Woodland with mixed grass (lWMi)	NT	1&0 (2&0.5)	1&0 (2&1)	2&0 (3&2)	2&0 (3&5)
			QLD	1&0 (2&0)	1&0 (2&1)	2&0 (3&2)	2&0 (3&7)
			WA	1&0 (2&0)	1&0 (2&2)	2&0 (3&4)	2&0 (3&10)
		Woodland with hummock grass (lWHu)	NT	1&0 (2&0)	1&0 (2&1)	2&0 (3&10)	2&0 (3&10)
			QLD	1&0 (2&0)	1&0 (2&0)	2&0 (3&3)	2&0 (3&8)
			WA	1&0 (2&0)	1&0 (2&2)	2&0 (3&10)	2&0 (3&10)
		Open woodland with mixed grass (lOWM)	NT	1&0 (2&0)	1&0 (2&1)	2&0 (3&5)	2&0 (3&5)
			QLD	1&0 (2&0)	1&0 (2&1)	2&0 (3&5)	2&0 (3&10)
			WA	1&0 (2&0)	1&0 (2&1)	2&0 (3&5)	2&0 (3&10)
		Shrubland with hummock grass (lSHH)	NT	1&0 (2&0)	1&0 (2&1)	2&0 (3&5)	2&0 (3&5)
			QLD	1&0 (2&0)	1&0 (2&1)	2&0 (3&5)	2&0 (3&15)
			WA	1&0 (2&0)	1&0 (2&1)	2&0 (3&5)	2&0 (3&10)

Table 6.K.6 Values of calibrated FullCAM parameters for the percentage of debris-C that was assumed to be converted to CO_2-C as a result of fire. Two values are provided. The first represents low intensity fire types (prescribed or EDS). The pair, given in parenthesis, represents high intensity fires type (wildfire or LDS). For all fire types, it was assumed that no debris-C was converted to inert soil C as a result of fire.

Region		Vegetation subclass	State	*Deadwood*	*Bark litter*	*Foliage litter*
Southern forests and woodlands	~	~	ACT	18 (55)	25 (65)	55 (90)
			NSW	18 (55)	25 (65)	53 (85)
			Qld	18 (50)	28 (65)	40 (90)
			SA	18 (50)	25 (65)	30 (90)
			TAS	18 (50)	25 (65)	30 (90)
			Vic	18 (50)	25 (65)	50 (85)
			WA	18 (55)	25 (65)	55 (85)
Savanna Woodland	> 1000 mm MAR	Open Forest mixed (hOFM)	NT	20 (35)	35 (50)	75 (99)
			QLD	20 (40)	20 (70)	70 (99)
			WA	25 (55)	25 (60)	75 (99)
		Woodland Mixed (hWMi)	NT	20 (50)	20 (70)	75 (99)
			QLD	30 (60)	40 (75)	75 (90)
			WA	20 (50)	20 (70)	75 (99)
		Woodland Hummock (hWHu)	NT	20 (45)	25 (65)	75 (99)
			QLD	15 (45)	20 (55)	70 (95)
			WA	20 (50)	25 (70)	75 (99)
		Shrubland Hummock (hSHH)	NT	20 (50)	25 (75)	70 (95)
			QLD	25 (30)	30 (55)	75 (99)
			WA	25 (60)	25 (75)	75 (95)
		Melaleuca woodland (Other)	NT	20 (45)	25 (60)	70 (95)
			QLD	25 (55)	25 (60)	80 (95)
			WA	25 (50)	30 (60)	80 (90)
	< 1000 mm MAR	Woodland with tussock grass (lWTu)	NT	15 (40)	20 (40)	80 (99)
			QLD	13 (25)	13 (40)	75 (90)
			WA	22 (40)	22 (40)	80 (90)
		Woodland with mixed grass (lWMi)	NT	15 (30)	25 (30)	80 (90)
			QLD	15 (30)	20 (30)	90 (99)
			WA	10 (30)	20 (30)	85 (99)
		Woodland with hummock grass (lWHu)	NT	25 (50)	25 (50)	75 (99)
			QLD	20 (30)	20 (30)	80 (99)
			WA	5 (30)	10 (30)	80 (99)
		Open woodland with mixed grass (lOWM)	NT	25 (30)	25 (30)	80 (90)
			QLD	25 (30)	30 (40)	80 (95)
			WA	20 (30)	20 (30)	80 (95)
		Shrubland with hummock grass (lSHH)	NT	25 (30)	25 (30)	80 (90)
			QLD	25 (30)	25 (30)	80 (95)
			WA	25 (30)	25 (30)	80 (99)

The calibrated parameters given in Tables 6.K.4-6 ensured that FullCAM-predicted pre-fire fuel loads, and emissions on burning, were consistent with NIR estimates under typical conditions (Paul and Roxburgh 2019).

Figure 6.K.1 Comparison between FullCAM-predicted: (a) fuel loads, and (b) emissions of CO_2-C and that expected based on previous NIR-based estimates for coarse and fine fuels for the 37 fire zones and under both intense fires (wildfires in southern fire zones; LDS burns in savanna fire zones) and less intense fires (prescribed burns in southern fire zones, or EDS burns in savanna fire zones).

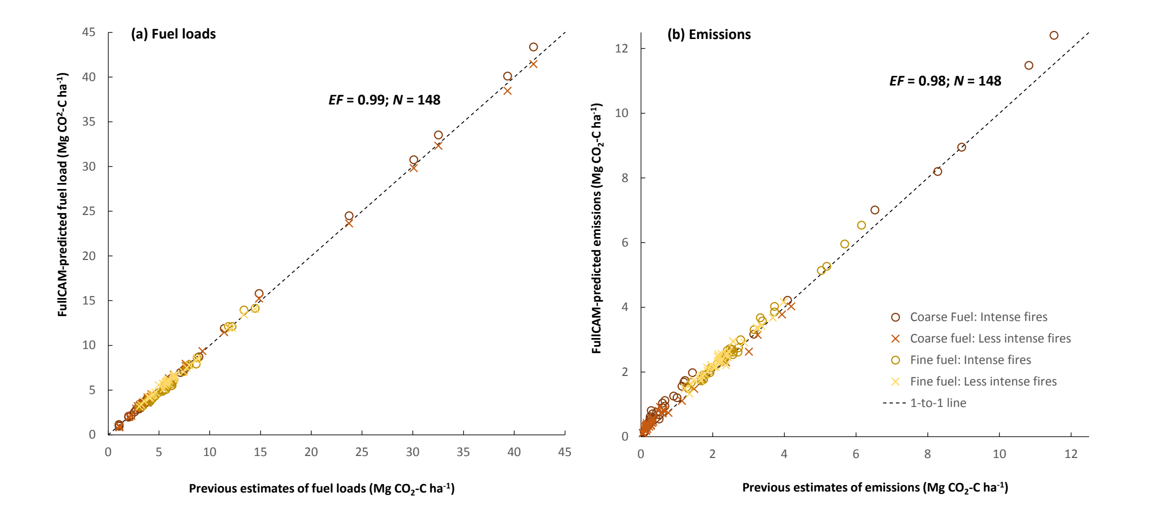


Table 6.K.7 Nitrogen to Carbon ratio in fuel burnt (C)

Vegetation class	Vegetation subclass	Rainfall zone	Fuel Size	Percent
Wet/dry tropical zone	Shrubland Hummock	High	Coarse	0.00810
Wet/dry tropical zone	Woodland Hummock	High	Coarse	0.00810
Wet/dry tropical zone	Melaleuca woodland	High	Coarse	0.00810
Wet/dry tropical zone	Woodland Mixed	High	Coarse	0.00810
Wet/dry tropical zone	Open Forest mixed	High	Coarse	0.00810
Wet/dry tropical zone	Shrubland Hummock	High	Fine	0.00960
Wet/dry tropical zone	Woodland Hummock	High	Fine	0.00960
Wet/dry tropical zone	Melaleuca woodland	High	Fine	0.00960
Wet/dry tropical zone	Woodland Mixed	High	Fine	0.00960
Wet/dry tropical zone	Open Forest mixed	High	Fine	0.00960
Wet/dry tropical zone	Shrubland Hummock	High	Heavy	0.00810
Wet/dry tropical zone	Woodland Hummock	High	Heavy	0.00810
Wet/dry tropical zone	Melaleuca woodland	High	Heavy	0.00810
Wet/dry tropical zone	Woodland Mixed	High	Heavy	0.00810
Wet/dry tropical zone	Open Forest mixed	High	Heavy	0.00810
Wet/dry tropical zone	Shrubland Hummock	High	Shrub	0.00930
Wet/dry tropical zone	Woodland Hummock	High	Shrub	0.00930
Wet/dry tropical zone	Melaleuca woodland	High	Shrub	0.00930
Wet/dry tropical zone	Woodland Mixed	High	Shrub	0.00930
Wet/dry tropical zone	Open Forest mixed	High	Shrub	0.00930
Wet/dry tropical zone	Shrubland (heath) with hummock grass	Low	Coarse	0.00389
Wet/dry tropical zone	Woodland with hummock grass	Low	Coarse	0.00389
Wet/dry tropical zone	Open woodland with mixed grass	Low	Coarse	0.00389

Vegetation class	Vegetation subclass	Rainfall zone	Fuel Size	Percent
Wet/dry tropical zone	Woodland with mixed grass	Low	Coarse	0.00389
Wet/dry tropical zone	Woodland with tussock grass	Low	Coarse	0.00389
Wet/dry tropical zone	Shrubland (heath) with hummock grass	Low	Fine	0.01070
Wet/dry tropical zone	Woodland with hummock grass	Low	Fine	0.01130
Wet/dry tropical zone	Open woodland with mixed grass	Low	Fine	0.01020
Wet/dry tropical zone	Woodland with mixed grass	Low	Fine	0.01180
Wet/dry tropical zone	Woodland with tussock grass	Low	Fine	0.01050
Wet/dry tropical zone	Shrubland (heath) with hummock grass	Low	Heavy	0.01497
Wet/dry tropical zone	Woodland with hummock grass	Low	Heavy	0.01497
Wet/dry tropical zone	Open woodland with mixed grass	Low	Heavy	0.01497
Wet/dry tropical zone	Woodland with mixed grass	Low	Heavy	0.01497
Wet/dry tropical zone	Woodland with tussock grass	Low	Heavy	0.01497
Wet/dry tropical zone	Shrubland (heath) with hummock grass	Low	Shrub	0.00389
Wet/dry tropical zone	Woodland with hummock grass	Low	Shrub	0.00389
Wet/dry tropical zone	Open woodland with mixed grass	Low	Shrub	0.00389
Wet/dry tropical zone	Woodland with mixed grass	Low	Shrub	0.00389
Wet/dry tropical zone	Woodland with tussock grass	Low	Shrub	0.00389
Subtropical/semi-arid zone	Savanna Grassland	NA	Aggregated	0.00870
Temperate Zone	Temperate Grassland	NA	Aggregated	0.01200
Temperate Zone	Temperate Forests	NA	NA	0.01100

Table 6.K.8 Molecular Mass conversion factors

Conversion	Value
N to N_2O	44/28
C to CH_4	16/12
C to CO_2	44/12
N to NO_x	46/14
C to CO	28/12
C to NMVOC	14/12

Table 6.K.9 CH_4 Emission Factors (Gg CH_4-C/Gg C)

Vegetation class		Rainfall Zone	CH_4 EF (Gg CH_4-C/Gg C)				
			Aggregated	Fine	Coarse	Heavy	Shrub
Tropical Zone[(a)]	Woodland hummock	High	NA	0.0031	0.0031	0.01	0.0031
	Shrubland hummock	High	NA	0.0015	0.0015	0.01	0.0015
	Woodland mixed	High	NA	0.0031	0.0031	0.01	0.0031
	Open forest mixed	High	NA	0.0031	0.0031	0.01	0.0031
	Melaleuca woodland	High	NA	0.0031	0.0031	0.01	0.0031
	Shrubland (heath) with hummock grass	Low	NA	0.0013	0.0013	0.0111	0.0013
	Woodland with mixed grass	Low	NA	0.0017	0.0017	0.0158	0.0017
	Open woodland with mixed grass	Low	NA	0.0012	0.0012	0.0111	0.0012
	Woodland with tussock grass	Low	NA	0.0016	0.0016	0.0158	0.0016
	Woodland with hummock grass	Low	NA	0.0015	0.0015	0.0158	0.0015
Subtropical and semi-arid zone	(b)	NA	0.0012	NA	NA	NA	NA
Temperate Forest	(c)	NA	NA	0.0025	0.0126	NA	NA
Temperate Grasslands	(d)	NA	0.0035	NA	NA	NA	NA

(a) Russell-Smith *et al.* (2015)
(b) Meyer and Cook (2011)
(c) Roxburgh *et al.* (2015)
(d) Hurst *et al.* (1994 a, b)

Table 6.K.10 N_2O Emission Factors (Gg N_2O-N/Gg N)

Vegetation class		Rainfall zone	N_2O EF (N_2O-N/GgN)				
			Aggregated	Fine	Coarse	Heavy	Shrub
Tropical zone [(a)]	Woodland hummock	High	NA	0.0075	0.0075	0.0036	0.0075
	Shrubland hummock	High	NA	0.0066	0.0066	0.0036	0.0066
	Woodland mixed	High	NA	0.0075	0.0075	0.0036	0.0075
	Open forest mixed	High	NA	0.0075	0.0075	0.0036	0.0075
	Melaleuca woodland	High	NA	0.0075	0.0075	0.0036	0.0075
	Shrubland (heath) with hummock grass	Low	NA	0.0059	0.0059	0.0146	0.0059
	Woodland with mixed grass	Low	NA	0.006	0.006	0.0146	0.006
	Open woodland with mixed grass	Low	NA	0.006	0.006	0.0146	0.006
	Woodland with tussock grass	Low	NA	0.012	0.012	0.0146	0.012

Vegetation class		Rainfall zone	N_2O EF (N_2O-N/GgN)				
			Aggregated	Fine	Coarse	Heavy	Shrub
	Woodland with hummock grass	Low	NA	0.006	0.006	0.0146	0.006
Subtropical and semi-arid zone	[b]	NA	0.0066	NA	NA	NA	NA
Temperate Forest	[c]	NA	NA	0.0111	0.0067	NA	NA
Temperate Grasslands	[d]	NA	0.0076	NA	NA	NA	NA

(a) Russell-Smith *et al.* 2009; Lynch *et al.* (2015).
(b) Meyer and Cook (2011)
(c) Roxburgh *et al.* (2015)
(d) Hurst *et al.* (1994 a, b)

Table 6.K.11 Emission Factors (CO, NMVOC and NO_x)

Gas	Unit	Tropical and semi – arid Emission Factor	Temperate Emission Factor
CO	Gg CO-C/Gg C	0.078	0.091
NMVOC	Gg NMVOC-C/Gg C	0.0091	0.022
NO_x	Gg NO_x-N/Gg N	0.21	0.15

Hurst *et al.* (1994 a, b)

Appendix 6.L Activity Data - Annual areas of forest conversions and sparse woody transitions

The following tables provide National and State/Territory times series (1990 – 2017) of annual areas of:

- primary forest conversion to other land uses and secondary conversion (reclearing) of forest that has emerged on previously cleared land (Table 6.L.1.a);
- for each year, the area of identified regrowth on previously cleared land and the resultant net clearing of forest when combined with the previous table, (kha) (Table 6.L.1.b);
- gain and loss of sparse woody vegetation across grasslands, wetlands and settlements (Table 6.L.5)

Tables 6.L.2-6.L.4, show primary and secondary conversion and cleared forest regrowing – by ABARES land use region; BoM river region; and IBRA 7 bioregion for each of the three years from 2014-15 to 2016-17 years.

Tables 6.L.6 to 6.L.14 provide disaggregated information on areas of forest clearing and regrowth, and the associated carbon emissions and removals, nationally and by state/territory across the time period from 1990 to 2017.

Table 6.L.1.a Annual areas of forest cleared over the period 1990 to 2017 (kha)

	National		NSW		NT		QLD		SA		TAS		VIC		WA		ACT	
	Primary Conversion	Reclearing	Primary Conversion	Reclearing	Primary Conversion	Reclearing	Primary Conversion	Reclearing	Primary Conversion	Reclearing	Primary Conversion	Reclearing	Primary Conversion	Reclearing	Primary Conversion	Reclearing	Primary Conversion	Reclearing
1990	594.2	320.6	66.4	61.9	2.3	2.1	424.4	212.4	13.4	7.0	12.0	3.8	16.9	14.0	58.8	19.1	0.2	0.2
1991	478.7	347.8	51.4	72.5	1.9	1.9	342.0	218.4	9.5	7.1	14.1	7.3	13.3	17.4	46.4	22.9	0.1	0.4
1992	376.6	383.8	39.6	80.0	2.8	2.7	283.4	248.0	6.8	8.2	6.5	6.9	10.5	19.1	26.9	18.3	0.1	0.4
1993	267.3	307.8	25.9	54.2	0.9	1.4	202.5	210.8	4.3	5.8	5.4	4.9	7.0	15.5	21.2	15.0	0.1	0.1
1994	272.4	330.6	26.8	56.3	0.9	1.5	208.3	228.5	3.6	5.7	4.7	4.1	6.0	18.6	22.0	15.9	0.0	0.1
1995	217.1	252.6	19.6	46.7	0.8	1.3	164.5	167.3	3.0	4.7	4.7	4.0	5.3	14.4	18.9	14.0	0.0	0.2
1996	222.5	285.9	17.9	54.6	1.3	2.1	173.7	191.8	2.6	5.1	3.8	3.5	5.5	13.5	17.6	15.1	0.0	0.3
1997	221.1	277.6	18.2	53.4	1.4	2.2	171.2	184.5	2.7	5.0	4.2	4.1	5.7	13.4	17.7	14.7	0.1	0.2
1998	224.9	294.6	17.0	52.7	0.9	1.7	180.4	205.9	2.6	5.4	3.7	3.6	5.5	12.5	14.7	12.7	0.1	0.2
1999	262.0	369.6	19.4	69.3	0.9	1.8	217.0	260.7	2.8	7.2	3.3	4.0	5.7	14.0	12.9	12.3	0.1	0.3
2000	268.7	336.8	17.3	56.6	0.8	1.9	227.9	243.7	2.5	6.7	3.1	3.0	4.5	11.1	12.5	13.5	0.1	0.3
2001	311.4	388.4	18.0	60.1	0.8	2.5	268.3	285.0	3.2	8.4	3.3	3.0	4.2	9.3	13.6	19.8	0.0	0.4
2002	279.7	345.4	16.2	51.8	0.8	2.3	231.6	247.5	2.9	8.0	3.1	3.0	11.2	13.0	13.7	19.4	0.1	0.4
2003	224.8	361.7	15.4	58.4	0.8	2.3	160.0	234.3	2.6	8.7	3.8	6.2	26.1	26.8	16.0	24.2	0.2	0.8
2004	234.5	388.8	17.3	64.6	0.9	2.4	176.1	251.6	3.0	11.1	4.2	6.1	16.7	26.1	16.3	26.0	0.2	0.8
2005	291.5	554.5	20.4	88.6	1.4	5.3	235.4	366.2	3.6	16.6	5.1	7.6	7.4	34.1	17.9	35.2	0.1	0.8
2006	245.3	524.1	17.6	101.0	1.3	6.6	189.8	306.2	4.0	17.6	4.3	7.4	9.6	42.2	18.7	42.3	0.1	0.7
2007	204.0	485.7	16.4	96.5	1.7	5.4	154.4	294.6	3.6	13.9	4.1	7.2	6.5	29.3	17.3	38.3	0.0	0.6
2008	141.4	377.1	11.4	63.2	1.4	3.8	104.5	236.9	2.1	9.0	4.2	9.9	5.1	22.6	12.5	31.4	0.0	0.2
2009	106.0	337.5	9.9	69.4	0.9	3.4	71.5	191.0	2.2	9.3	3.8	7.8	6.9	25.9	10.9	30.2	0.0	0.4
2010	83.0	320.6	9.0	74.9	0.7	3.5	51.2	166.1	2.0	10.8	3.7	8.3	4.9	25.2	11.6	31.4	0.0	0.3
2011	67.2	301.4	9.2	75.2	0.5	2.1	41.0	164.6	1.5	11.1	2.7	6.6	1.8	15.2	10.5	26.4	0.0	0.2
2012	58.3	316.2	9.5	73.3	0.4	2.7	37.0	188.4	1.5	11.7	1.4	4.6	1.3	13.0	7.2	22.4	0.0	0.2
2013	61.3	412.8	8.8	72.9	0.5	2.9	40.3	271.2	1.8	15.3	1.5	4.7	1.5	21.4	6.8	24.0	0.0	0.1
2014	60.0	367.4	8.2	54.9	0.5	2.7	38.7	239.5	1.9	15.9	1.8	5.0	2.0	25.1	6.8	24.2	0.0	0.1
2015	59.1	343.4	8.1	46.0	0.7	2.9	36.8	229.8	1.3	11.9	1.6	5.8	1.9	20.2	8.7	26.6	0.0	0.1
2016	66.3	415.9	9.9	52.1	1.0	5.3	42.1	297.7	0.6	8.8	1.4	6.1	1.4	17.5	9.8	28.4	0.0	0.1
2017	46.0	318.2	9.4	45.9	0.4	2.8	30.7	230.9	0.4	5.3	1.0	4.9	0.8	12.4	3.3	16.0	0.0	0.1

Table 6.L.1.b Annual areas of identified regrowth and resultant net clearing of forest over the period 1990 to 2017 (kha)

	National		NSW		NT		QLD		SA		TAS		VIC		WA		ACT	
	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing
1990	231.7	683.1	44.8	83.5	1.2	3.2	149.4	487.5	4.7	15.7	3.7	12.0	8.5	22.3	19.3	58.6	0.2	0.3
1991	251.2	575.3	53.1	70.7	1.4	2.3	153.6	406.7	5.9	10.8	5.5	15.8	9.9	20.7	21.4	47.9	0.2	0.3
1992	265.6	494.8	62.7	56.8	2.3	3.2	152.6	378.7	6.3	8.8	4.5	9.0	13.2	16.4	23.7	21.5	0.1	0.4
1993	228.7	346.4	49.4	30.7	1.7	0.7	138.2	275.1	8.3	1.8	3.7	6.7	12.2	10.3	15.2	21.0	0.2	0.0
1994	250.0	353.1	51.6	31.4	1.8	0.6	152.3	284.5	12.0	-2.7	4.1	4.8	12.9	11.7	15.1	22.8	0.2	0.0
1995	188.0	281.7	38.5	27.9	1.7	0.4	112.6	219.3	9.2	-1.5	3.9	4.8	8.7	11.0	13.2	19.8	0.1	0.1
1996	185.9	322.5	36.8	35.7	1.7	1.8	116.4	249.1	6.9	0.8	2.8	4.5	7.4	11.6	13.9	18.8	0.1	0.2
1997	179.9	318.8	36.4	35.2	1.7	1.9	110.6	245.1	7.1	0.6	3.1	5.2	7.3	11.8	13.6	18.7	0.1	0.2
1998	189.0	330.5	37.1	32.5	1.9	0.7	114.3	272.1	5.8	2.2	3.0	4.4	8.9	9.0	17.9	9.4	0.1	0.2
1999	240.4	391.2	50.2	38.5	2.4	0.2	133.8	343.9	5.4	4.5	6.0	1.3	14.4	5.4	27.8	-2.6	0.3	0.1
2000	190.8	414.7	42.1	31.8	1.9	0.7	100.1	371.5	5.3	3.9	4.9	1.2	12.3	3.4	24.0	2.1	0.2	0.1
2001	202.1	497.6	46.6	31.6	2.0	1.3	102.6	450.7	8.4	3.1	5.1	1.1	13.0	0.4	24.2	9.2	0.2	0.2
2002	198.2	426.8	46.9	21.0	1.8	1.3	105.2	373.9	7.5	3.4	4.6	1.5	11.3	13.0	20.8	12.3	0.2	0.4
2003	240.0	346.5	66.7	7.0	2.9	0.2	124.2	270.1	7.7	3.6	5.5	4.5	12.2	40.6	20.5	19.7	0.1	0.9
2004	252.5	370.9	71.1	10.9	3.0	0.3	128.4	299.3	8.9	5.2	6.1	4.2	14.0	28.8	20.9	21.3	0.1	0.8
2005	324.6	521.4	84.8	24.3	3.0	3.7	174.3	427.3	11.8	8.5	9.0	3.7	17.9	23.6	23.7	29.4	0.2	0.8
2006	314.1	455.3	76.8	41.7	2.8	5.1	171.6	324.4	10.9	10.7	10.1	1.5	17.6	34.2	24.1	36.9	0.1	0.7
2007	339.5	350.2	75.0	37.9	2.8	4.4	192.9	256.2	10.8	6.7	6.6	4.6	23.4	12.4	27.8	27.7	0.3	0.4
2008	447.2	71.3	88.3	-13.6	2.7	2.5	277.7	63.7	13.9	-2.8	6.6	7.5	28.2	-0.5	29.3	14.6	0.4	-0.2
2009	517.1	-73.6	97.1	-17.9	2.6	1.7	336.1	-73.5	19.0	-7.5	6.8	4.8	25.5	7.3	29.8	11.3	0.2	0.2
2010	458.1	-54.5	90.5	-6.6	2.8	1.4	278.3	-60.9	21.0	-8.2	7.8	4.2	28.8	1.3	28.8	14.1	0.2	0.1
2011	442.5	-73.9	73.3	11.1	3.2	-0.6	259.4	-53.8	22.8	-10.1	9.3	-0.1	42.1	-25.1	32.3	4.7	0.2	0.0
2012	525.5	-150.9	69.2	13.6	2.1	1.0	342.3	-117.0	24.0	-10.8	9.7	-3.7	38.3	-24.0	39.5	-9.8	0.3	-0.1
2013	518.5	-44.5	81.1	0.6	1.7	1.8	321.5	-10.0	21.3	-4.2	10.0	-3.7	31.3	-8.3	51.2	-20.3	0.5	-0.3
2014	577.4	-149.9	81.9	-18.8	2.3	1.0	378.4	-100.1	16.2	1.6	9.7	-2.9	32.1	-5.0	56.3	-25.3	0.6	-0.5
2015	536.4	-134.0	86.2	-32.0	2.6	1.0	353.7	-87.0	16.0	-2.8	8.1	-0.7	31.8	-9.7	37.4	-2.0	0.8	-0.7
2016	526.2	-44.1	83.5	-21.5	2.0	4.3	353.5	-13.7	17.7	-8.3	6.6	0.9	29.5	-10.5	32.9	5.3	0.6	-0.5
2017	384.2	-20.0	58.4	-3.1	2.2	1.0	253.5	8.1	13.0	-7.4	6.5	-0.6	22.0	-8.8	28.4	-9.0	0.3	-0.1

Table 6.L.2 Activity in ABARES Land Use regions, 3 years to June 2017 (kha)

	2015			2016			2017		
	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth
1 – Conservation and natural environments									
1.1 Nature conservation	0.6	4.0	9.2	0.5	4.6	8.8	0.4	3.0	6.6
1.2 Managed resource protection	1.1	3.2	3.3	1.1	3.3	2.9	2.5	2.4	2.1
1.3 Other minimal use	11.3	23.2	39.8	12.5	24.8	39.4	6.8	16.3	27.8
2 Production from relatively natural environments									
2.1 Grazing native vegetation	36.9	238.4	382.3	43.7	305.9	375.4	31.6	241.9	266.2
2.2 Production native forests	2.2	7.5	12.7	2.1	7.0	14.3	1.0	4.1	10.6
3 Production from dryland agriculture and plantations									
3.1 Plantation forests	0.7	5.4	5.1	0.9	7.3	4.4	0.5	6.1	3.3
3.2 Grazing modified pastures	1.8	20.4	30.3	1.2	19.0	26.3	0.7	13.6	20.8
3.3 Cropping	1.5	13.1	15.7	1.1	13.5	15.9	0.5	7.7	15.0
3.4 Perennial horticulture	0.0	0.1	0.2	0.0	0.1	0.2	0.0	0.1	0.1
3.5 Seasonal horticulture	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
3.6 Land in transition	0.1	0.7	0.9	0.2	1.4	0.8	0.1	0.7	0.6
4 Production from irrigated agriculture and plantations									
4.0 Production from irrigated agriculture and plantations	-	-	-	-	-	-	-	-	-
4.1 Irrigated plantation forests	0.0	0.4	0.2	0.0	0.3	0.3	0.0	0.1	0.3
4.2 Grazing irrigated modified pastures	0.0	0.5	0.6	0.0	0.6	0.6	0.0	0.4	0.8
4.3 Irrigated cropping	0.2	3.2	3.2	0.2	3.8	3.9	0.1	2.4	6.6
4.4 Irrigated perennial horticulture	0.0	0.1	0.3	0.0	0.2	0.2	0.0	0.2	0.2
4.5 Irrigated seasonal horticulture	0.0	0.3	0.3	0.0	0.4	0.3	0.0	0.2	0.4
4.6 Irrigated land in transition	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1
5 Intensive uses									
5.0 Intensive uses	-	-	0.0	-	-	-	-	0.0	-
5.1 Intensive horticulture	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.0
5.2 Intensive animal production	0.0	0.3	0.4	0.0	0.3	0.4	0.0	0.3	0.4
5.3 Manufacturing and industrial	0.0	0.3	0.3	0.0	0.3	0.3	0.0	0.3	0.3
5.4 Residential and farm infrastructure	1.4	9.3	14.0	1.4	10.9	14.2	1.0	8.0	9.2

	2015			2016			2017		
	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth
5.5 – Services	0.2	1.6	2.3	0.2	1.9	2.0	0.1	1.5	1.4
5.6 – Utilities	0.0	0.2	0.3	0.0	0.2	0.3	0.0	0.2	0.3
5.7 – Transport and communication	0.3	3.1	4.9	0.2	2.7	4.4	0.2	2.1	3.0
5.8 – Mining	0.3	2.0	3.1	0.2	1.8	4.0	0.1	1.6	2.7
5.9 – Waste treatment and disposal	0.0	0.2	0.2	0.0	0.2	0.2	0.0	0.1	0.1
6 – Water									
6.0 – Not elsewhere defined	-	0.0	0.0	-	0.0	0.0	-	0.0	0.0
6.1 – Lake	0.0	0.4	0.4	0.0	0.5	0.4	0.0	0.4	0.4
6.2 – Reservoir/dam	0.1	1.8	2.5	0.1	2.2	2.5	0.1	2.1	2.0
6.3 – River	0.1	0.6	1.6	0.1	0.7	1.2	0.1	0.7	0.8
6.4 – Channel/aqueduct	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1
6.5 – Marsh/wetland	0.3	2.3	2.1	0.3	1.7	2.5	0.2	1.6	2.1
6.6 – Estuary/coastal waters	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1
Undefined	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.1
All lands	**59.1**	**343.5**	**536.5**	**66.3**	**416.0**	**526.3**	**46.0**	**318.3**	**384.3**

Table 6.L.3 Activity in BoM River regions, 3 years to June 2017 (kha)

	2015			2016			2017		
	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth
Gulf Of Carpentaria	1.9	10.1	8.0	1.9	7.5	8.6	3.0	6.3	5.3
Indian Ocean	0.3	1.8	2.1	0.2	1.5	2.4	0.1	0.8	2.1
Lake Eyre	3.0	11.8	33.3	2.4	19.9	41.1	2.1	18.1	28.4
Murray-Darling	20.4	121.6	194.7	23.1	145.3	183.2	19.7	115.2	131.5
North East Coast	18.2	132.1	193.8	22.5	172.2	194.4	13.3	126.7	147.1
North Western Plateau	-	0.0	0.0	-	0.0	0.0	-	0.0	0.0
South Australian Gulf	0.4	2.4	5.2	0.3	2.0	5.4	0.1	0.9	4.4
South East Coast	4.0	28.5	48.5	3.8	28.1	45.9	3.0	26.3	26.8
South West Coast	7.5	21.0	31.9	8.4	23.0	27.6	2.6	13.0	23.0
South Western Plateau	1.2	5.2	8.1	1.2	4.9	9.0	0.7	2.9	6.6
Tasmania	1.6	5.7	7.7	1.4	6.0	6.3	1.0	4.8	6.3
Timor Sea	0.5	2.9	2.5	0.9	5.4	1.8	0.4	3.1	2.3
Undefined	0.1	0.3	0.7	0.0	0.3	0.5	0.0	0.2	0.4
All lands	**59.1**	**343.5**	**536.5**	**66.3**	**416.0**	**526.3**	**46.0**	**318.3**	**384.3**

Table 6.L.4 Activity in IBRA7 regions, 3 years to June 2017 (kha)

	2015			2016			2017		
	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth
Arnhem Coast	0.4	0.6	0.4	0.5	0.5	0.3	0.1	0.2	0.3
Arnhem Plateau	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0
Australian Alps	0.0	0.1	0.5	0.0	0.1	0.4	0.0	0.1	0.1
Avon Wheatbelt	1.1	5.5	6.2	0.9	5.8	5.6	0.5	3.4	4.7
Brigalow Belt North	4.8	33.5	87.6	7.5	47.0	91.7	4.4	51.2	67.4
Brigalow Belt South	12.0	77.7	111.4	12.5	113.4	99.8	7.7	72.0	92.6
Ben Lomond	0.3	0.6	1.4	0.3	0.7	1.0	0.2	0.8	0.9
Broken Hill Complex	-	0.0	0.0	-	0.0	0.1	-	0.0	0.1
Carnarvon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Central Arnhem	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Central Kimberley	-	0.0	0.0	-	0.0	0.0	-	0.0	0.0
Channel Country	0.0	0.5	0.8	0.0	0.4	1.3	0.0	0.4	1.1
Central Mackay Coast	1.2	4.6	14.9	2.4	9.5	14.8	1.3	5.2	7.7
Coolgardie	0.8	1.7	2.1	0.9	1.8	2.2	0.6	1.0	2.5
Cobar Peneplain	1.5	6.8	8.0	2.4	8.7	6.8	3.2	8.8	4.2
Cape York Peninsula	2.2	2.5	4.2	1.5	2.5	3.4	2.8	2.6	2.7
Daly Basin	0.0	0.7	0.7	0.1	1.5	0.6	0.0	1.1	0.4
Darwin Coastal	0.1	0.7	0.8	0.1	0.9	0.5	0.0	0.4	0.9
Dampierland	0.0	0.1	0.0	-	0.1	0.1	0.0	0.0	0.1
Desert Uplands	2.3	30.5	17.4	2.0	26.8	17.1	0.8	15.3	6.5
Davenport Murchison Ranges	-	0.0	0.0	-	0.0	0.0	-	0.0	0.0
Darling Riverine Plains	0.1	6.2	7.3	0.1	7.6	9.8	0.1	5.5	9.3
Einasleigh Uplands	1.0	6.9	5.2	1.7	8.0	5.4	0.9	3.1	4.8
Esperance Plains	0.4	2.7	4.5	0.5	3.1	3.8	0.3	2.3	3.5
Eyre Yorke Block	0.3	2.7	8.6	0.3	2.4	9.9	0.1	1.5	6.6
Flinders Lofty Block	0.1	0.5	0.8	0.0	0.5	0.7	0.0	0.2	0.5
Furneaux	0.3	0.7	1.3	0.3	0.7	1.0	0.2	0.6	0.8
Gascoyne	0.0	0.0	0.0	-	0.0	0.0	-	0.0	0.0
Gawler	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.1
Geraldton Sandplains	0.5	2.7	4.4	0.5	2.4	4.4	0.2	1.2	3.0
Gulf Fall and Uplands	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Gulf Coastal	-	0.0	-	-	0.0	0.0	-	-	0.0
Gulf Plains	0.6	6.9	1.9	0.3	3.3	2.9	0.1	2.7	1.2
Great Victoria Desert	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.1
Hampton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jarrah Forest	1.7	5.3	8.2	1.7	5.8	7.1	0.8	3.6	5.0
Kanmantoo	0.2	0.8	1.1	0.1	0.6	1.3	0.0	0.3	1.2
King	0.1	1.0	0.9	0.2	1.0	0.6	0.2	0.9	0.6
Mallee	2.4	3.1	3.8	3.3	3.5	3.0	0.2	1.1	3.3
Murray Darling Depression	1.7	11.9	15.7	1.4	10.4	15.6	1.3	7.7	12.6
Mitchell Grass Downs	2.0	5.5	21.3	1.3	10.1	27.1	1.4	10.2	22.5
Mount Isa Inlier	0.0	0.2	0.1	0.0	0.1	0.1	0.0	0.1	0.1

	2015			2016			2017		
	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth	Primary Conversion	Reclearing	Identified regrowth
Mulga Lands	8.5	42.9	74.0	10.8	54.5	68.4	9.0	46.9	37.9
Murchison	0.2	0.7	0.6	0.2	0.7	0.6	0.1	0.3	0.7
Nandewar	0.4	4.0	1.8	0.3	3.9	2.1	0.3	2.8	1.6
Naracoorte Coastal Plain	0.2	4.4	1.1	0.1	2.9	1.2	0.1	1.4	1.4
New England Tablelands	0.6	3.8	7.0	0.6	3.7	8.1	0.5	2.7	5.8
NSW North Coast	0.9	3.2	7.2	0.8	3.0	9.5	0.6	3.0	6.5
Northern Kimberley	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NSW South Western Slopes	0.4	3.0	10.5	0.3	2.8	8.9	0.3	2.6	6.0
Nullarbor	0.0	0.3	0.1	0.0	0.2	0.1	0.0	0.1	0.1
Ord Victoria Plain	0.0	0.2	0.1	0.0	0.3	0.0	0.0	0.1	0.1
Pine Creek	0.0	0.3	0.2	0.0	0.4	0.1	0.0	0.2	0.2
Riverina	0.1	2.1	4.0	0.0	1.8	5.0	0.0	1.1	6.5
South East Coastal Plain	0.2	3.4	3.7	0.2	3.0	3.2	0.1	2.2	2.5
South East Corner	0.2	1.1	4.5	0.2	1.4	3.7	0.3	2.3	1.1
South Eastern Highlands	0.9	8.1	31.3	0.7	10.3	25.2	0.7	11.1	11.3
South Eastern Queensland	4.2	19.4	17.4	4.7	22.0	26.9	4.0	18.9	14.3
Simpson Strzelecki Dunefields	-	0.0	0.0	-	-	-	-	0.0	0.0
Stony Plains	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0
Sturt Plateau	0.1	0.4	0.2	0.2	0.6	0.1	0.1	0.2	0.1
Southern Volcanic Plain	0.0	2.0	2.2	0.0	1.7	1.5	0.0	1.5	1.4
Swan Coastal Plain	1.3	3.6	5.3	1.6	3.9	4.2	0.4	1.9	3.7
Sydney Basin	0.6	3.9	9.8	0.7	4.9	6.9	0.6	5.0	3.9
Tanami	-	-	0.0	-	-	-	-	0.0	-
Tasmanian Central Highlands	0.0	0.2	0.2	0.0	0.1	0.2	0.0	0.1	0.1
Tiwi Cobourg	0.1	0.1	0.1	0.0	1.1	0.2	0.1	0.6	0.2
Tasmanian Northern Midlands	0.1	0.5	1.4	0.1	0.4	0.9	0.0	0.4	0.7
Tasmanian Northern Slopes	0.2	0.8	0.3	0.2	0.9	0.3	0.1	0.9	0.4
Tasmanian South East	0.4	1.1	1.9	0.2	1.0	2.1	0.2	0.7	2.6
Tasmanian Southern Ranges	0.1	0.1	0.3	0.1	0.2	0.3	0.0	0.1	0.2
Tasmanian West	0.0	0.7	0.3	0.0	1.1	0.2	0.0	0.4	0.1
Victoria Bonaparte	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.4	0.1
Victorian Midlands	0.5	6.3	5.1	0.5	5.5	4.4	0.2	3.2	3.9
Warren	0.1	0.6	1.7	0.1	0.7	1.4	0.1	0.5	1.4
Wet Tropics	0.2	2.2	2.0	0.6	3.4	1.3	0.4	2.8	1.8
Yalgoo	0.1	0.1	0.4	0.1	0.1	0.4	0.1	0.1	0.3
Undefined	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All lands	**59.1**	**343.5**	**536.5**	**66.3**	**416.0**	**526.3**	**46.0**	**318.3**	**384.3**

Table 6.L.5 Annual areas of sparse woody vegetation gains and losses over the period 1990 to 2017 (kha)

	National		NSW		NT		QLD		SA		TAS		VIC		WA		ACT	
	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses
1990	1,128.6	2,186.5	115.3	193.6	206.4	318.1	559.1	1,005.1	34.1	71.7	3.0	7.3	6.4	23.7	204.1	566.8	0.1	0.2
1991	1,196.3	1,966.7	122.7	173.7	223.2	315.2	529.1	820.7	43.6	72.5	2.9	7.8	7.0	16.0	267.6	560.5	0.1	0.2
1992	1,163.5	1,933.4	104.5	144.1	239.5	415.6	487.0	838.8	49.7	53.2	1.1	5.7	6.0	15.5	275.6	460.4	0.1	0.2
1993	1,010.0	993.8	75.9	94.1	196.4	190.8	416.5	453.6	53.4	29.2	1.2	3.9	6.6	9.3	259.9	212.9	0.2	0.1
1994	1,077.1	1,009.2	79.5	97.4	206.7	195.1	450.0	462.4	60.2	27.5	1.5	2.0	7.6	6.4	271.4	218.4	0.3	0.1
1995	915.8	737.8	60.8	82.2	181.0	131.3	360.3	285.1	46.8	29.0	1.4	2.0	4.8	6.5	260.4	201.6	0.2	0.1
1996	968.6	762.8	55.2	92.2	215.5	129.9	377.6	289.4	37.9	33.1	1.0	1.8	3.3	6.9	278.0	209.4	0.1	0.1
1997	983.1	774.4	56.1	93.3	225.0	134.9	370.6	286.8	39.3	34.2	1.1	2.1	3.4	7.2	287.5	215.8	0.2	0.1
1998	979.0	815.2	79.6	78.0	187.8	159.4	380.7	326.6	38.6	35.1	1.0	1.9	4.9	6.1	286.2	208.0	0.2	0.1
1999	1,432.7	1,133.7	118.9	75.4	279.3	255.0	609.1	481.5	53.7	56.3	1.5	1.9	7.6	5.8	362.3	257.6	0.3	0.1
2000	1,099.7	1,065.3	104.3	68.8	247.4	238.0	419.5	437.6	49.7	47.2	1.5	1.3	8.1	5.0	268.9	267.4	0.3	0.1
2001	1,038.1	1,172.2	108.0	77.0	249.0	254.2	357.8	485.5	53.9	45.3	1.8	1.1	10.9	4.7	256.3	304.2	0.3	0.1
2002	967.6	1,141.5	98.5	82.1	237.7	249.4	349.7	468.9	47.7	41.9	1.6	1.2	10.7	4.8	221.4	292.9	0.2	0.2
2003	1,065.0	1,242.4	107.0	104.9	206.4	308.8	448.5	430.3	45.0	41.3	1.6	2.7	12.5	6.3	243.9	347.9	0.2	0.3
2004	1,161.3	1,336.4	139.8	119.1	214.7	324.0	449.0	477.1	41.0	60.8	1.5	2.8	12.0	10.3	303.1	342.0	0.2	0.3
2005	1,540.1	1,929.2	184.6	150.8	299.9	492.9	516.8	759.2	44.5	85.4	1.7	3.1	13.0	17.8	479.1	419.6	0.4	0.4
2006	1,964.6	1,771.2	171.7	181.1	378.7	395.3	693.8	706.4	59.0	78.2	2.3	2.5	12.5	20.0	646.3	387.2	0.3	0.5
2007	2,242.0	1,859.7	206.8	206.1	485.2	388.0	728.4	784.6	75.9	74.1	2.8	2.0	13.9	14.8	728.9	389.4	0.1	0.6
2008	2,444.3	1,473.9	238.8	141.9	470.5	310.3	913.4	542.1	85.8	70.4	3.3	2.8	14.7	14.0	717.6	392.0	0.1	0.4
2009	2,488.7	1,349.5	272.4	181.2	537.5	236.1	841.3	492.5	103.7	51.3	6.2	2.2	19.7	14.8	707.7	370.8	0.2	0.5
2010	2,992.9	1,454.5	257.0	249.9	742.5	254.9	1,046.5	485.8	114.9	53.7	7.3	4.0	24.6	13.1	799.5	392.8	0.5	0.4
2011	3,057.7	1,576.7	264.5	203.0	647.1	316.6	1,082.5	534.1	129.1	66.4	4.6	6.0	37.6	10.6	891.4	439.6	0.7	0.3
2012	2,808.6	1,962.8	310.2	179.6	519.1	501.6	927.1	693.4	128.0	86.2	6.1	4.2	51.2	10.1	865.5	487.6	1.2	0.2
2013	2,605.7	2,886.2	393.1	193.4	366.4	712.8	777.2	1,283.6	125.3	116.8	7.4	4.3	43.5	18.7	891.2	556.4	1.6	0.2
2014	2,656.2	2,540.9	363.6	188.5	436.9	585.0	731.6	1,021.4	124.8	140.9	6.8	5.5	47.7	22.1	943.4	577.2	1.4	0.2
2015	2,257.4	2,616.5	312.9	208.8	415.2	873.1	608.9	850.1	130.8	122.2	6.4	5.1	44.2	26.4	738.1	530.5	1.0	0.4
2016	2,831.9	2,309.9	342.2	220.1	434.2	683.8	1,131.6	704.9	151.7	89.1	7.7	3.6	38.1	27.8	725.6	580.2	0.9	0.4
2017	2,059.7	1,467.3	311.3	146.5	369.4	255.8	659.5	542.6	158.6	64.7	10.6	2.1	44.2	19.5	505.0	435.9	1.0	0.1

Table 6.L.6 UNFCCC Forest conversions – National annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1990	594.2	118.9	320.6	13.3	38.5	231.7	845.9	-4.3	683.1
1991	478.7	105.2	347.8	13.4	36.7	251.2	986.3	-5.0	575.3
1992	376.6	72.5	383.8	12.6	28.2	265.6	1,124.6	-5.7	494.8
1993	267.3	58.8	307.8	11.7	28.5	228.7	1,289.8	-7.3	346.4
1994	272.4	50.0	330.6	12.1	24.6	250.0	1,408.5	-6.5	353.1
1995	217.1	45.2	252.6	11.8	22.1	188.0	1,565.2	-8.2	281.7
1996	222.5	38.0	285.9	10.0	24.5	185.9	1,635.0	-9.6	322.5
1997	221.1	40.9	277.6	12.3	20.7	179.9	1,707.2	-10.3	318.8
1998	224.9	38.5	294.6	12.9	21.1	189.0	1,759.3	-11.2	330.5
1999	262.0	43.7	369.6	15.4	25.7	240.4	1,779.2	-11.4	391.2
2000	268.7	44.8	336.8	17.3	20.6	190.8	1,864.7	-13.0	414.7
2001	311.4	46.0	388.4	17.6	30.2	202.1	1,867.5	-12.1	497.6
2002	279.7	48.3	345.4	20.1	23.1	198.2	1,905.0	-10.9	426.8
2003	224.8	39.8	361.7	18.0	24.7	240.0	1,924.2	-11.1	346.5
2004	234.5	38.9	388.8	20.0	23.7	252.5	1,963.4	-12.1	370.9
2005	291.5	48.3	554.5	26.1	24.9	324.6	1,908.0	-11.3	521.4
2006	245.3	48.0	524.1	28.0	22.0	314.1	1,919.8	-10.4	455.3
2007	204.0	43.3	485.7	27.3	26.0	339.5	1,918.8	-10.7	350.2
2008	141.4	31.8	377.1	19.5	24.2	447.2	1,995.0	-11.5	71.3
2009	106.0	25.3	337.5	16.6	20.0	517.1	2,201.6	-11.2	-73.6
2010	83.0	21.9	320.6	17.3	29.8	458.1	2,481.5	-13.6	-54.5
2011	67.2	18.0	301.4	15.0	21.8	442.5	2,711.2	-14.8	-73.9
2012	58.3	14.2	316.2	13.3	22.9	525.5	2,918.5	-15.2	-150.9
2013	61.3	13.1	412.8	14.9	22.7	518.5	3,143.8	-15.5	-44.5
2014	60.0	15.1	367.4	16.3	19.5	577.4	3,387.6	-16.0	-149.9
2015	59.1	12.1	343.4	13.0	14.8	536.4	3,704.8	-17.0	-134.0
2016	66.3	15.1	415.9	16.0	12.7	526.2	3,918.0	-20.8	-44.1
2017	46.0	12.5	318.2	15.0	13.7	384.2	4,191.0	-21.0	-20.0

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table 6.L.7 UNFCCC Forest conversions – QLD annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1990	424.4	64.6	212.4	7.3	22.5	149.4	523.4	-1.7	487.5
1991	342.0	58.4	218.4	7.1	21.4	153.6	619.5	-1.9	406.7
1992	283.4	40.5	248.0	6.8	14.7	152.6	706.5	-2.0	378.7
1993	202.5	33.5	210.8	6.4	16.6	138.2	794.2	-2.7	275.1
1994	208.3	29.6	228.5	6.7	13.1	152.3	860.9	-2.3	284.5
1995	164.5	26.4	167.3	6.2	12.6	112.6	953.3	-3.3	219.3
1996	173.7	23.7	191.8	5.4	14.7	116.4	988.3	-3.7	249.1
1997	171.2	25.5	184.5	6.5	11.2	110.6	1,031.1	-4.5	245.1
1998	180.4	24.2	205.9	6.9	13.6	114.3	1,053.7	-5.0	272.1
1999	217.0	31.6	260.7	9.3	16.6	133.8	1,050.7	-4.7	343.9
2000	227.9	32.4	243.7	10.3	11.9	100.1	1,076.1	-5.5	371.5
2001	268.3	33.7	285.0	10.9	21.4	102.6	1,044.6	-4.7	450.7
2002	231.6	35.1	247.5	12.2	14.0	105.2	1,036.3	-3.7	373.9
2003	160.0	24.7	234.3	9.8	18.0	124.2	1,035.6	-3.4	270.1
2004	176.1	22.3	251.6	10.3	15.5	128.4	1,039.4	-4.0	299.3
2005	235.4	30.4	366.2	13.7	16.2	174.3	975.2	-3.3	427.3
2006	189.8	29.0	306.2	13.6	13.6	171.6	975.0	-3.1	324.4
2007	154.4	25.1	294.6	12.1	19.2	192.9	960.8	-3.3	256.2
2008	104.5	18.8	236.9	9.6	15.3	277.7	989.4	-3.4	63.7
2009	71.5	13.1	191.0	7.4	12.7	336.1	1,133.9	-3.3	-73.5
2010	51.2	9.9	166.1	6.4	22.0	278.3	1,347.1	-4.7	-60.9
2011	41.0	8.1	164.6	5.6	13.2	259.4	1,497.7	-5.2	-53.8
2012	37.0	7.0	188.4	5.5	14.2	342.3	1,616.6	-5.9	-117.0
2013	40.3	6.6	271.2	6.4	15.7	321.5	1,762.0	-5.6	-10.0
2014	38.7	7.2	239.5	7.1	13.0	378.4	1,903.4	-6.1	-100.1
2015	36.8	6.1	229.8	6.1	8.9	353.7	2,107.0	-6.2	-87.0
2016	42.1	6.9	297.7	7.9	9.0	353.5	2,227.4	-7.7	-13.7
2017	30.7	6.7	230.9	8.1	9.2	253.5	2,395.3	-7.4	8.1

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table 6.L.8 UNFCCC Forest conversions – NSW annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1990	66.4	26.4	61.9	3.9	6.5	44.8	166.3	-1.6	83.5
1991	51.4	19.7	72.5	3.6	6.0	53.1	189.1	-1.9	70.7
1992	39.6	15.5	80.0	3.7	5.2	62.7	214.2	-2.1	56.8
1993	25.9	11.7	54.2	3.1	3.5	49.4	256.9	-2.9	30.7
1994	26.8	10.5	56.3	3.5	3.8	51.6	285.4	-2.6	31.4
1995	19.6	9.1	46.7	3.5	3.5	38.5	318.8	-3.0	27.9
1996	17.9	6.3	54.6	2.7	3.3	36.8	333.8	-3.6	35.7
1997	18.2	6.8	53.4	3.4	2.9	36.4	347.9	-3.5	35.2
1998	17.0	6.3	52.7	3.6	2.3	37.1	360.3	-3.7	32.5
1999	19.4	6.1	69.3	4.1	3.2	50.2	363.1	-4.0	38.5
2000	17.3	6.4	56.6	4.8	3.6	42.1	384.0	-4.3	31.8
2001	18.0	5.9	60.1	4.2	3.5	46.6	392.3	-4.3	31.6
2002	16.2	6.3	51.8	4.9	2.9	46.9	409.1	-4.0	21.0
2003	15.4	4.9	58.4	4.0	2.2	66.7	420.6	-4.3	7.0
2004	17.3	4.9	64.6	4.6	2.4	71.1	447.4	-4.7	10.9
2005	20.4	7.8	88.6	6.5	2.6	84.8	461.1	-4.7	24.3
2006	17.6	7.4	101.0	6.8	2.5	76.8	478.3	-4.2	41.7
2007	16.4	7.4	96.5	8.0	1.6	75.0	486.9	-4.2	37.9
2008	11.4	4.8	63.2	4.9	3.2	88.3	516.2	-4.8	-13.6
2009	9.9	4.0	69.4	4.3	2.2	97.1	552.5	-4.7	-17.9
2010	9.0	3.5	74.9	4.6	1.7	90.5	593.6	-5.8	-6.6
2011	9.2	3.6	75.2	5.2	3.0	73.3	629.1	-6.1	11.1
2012	9.5	3.6	73.3	4.9	3.1	69.2	648.2	-5.3	13.6
2013	8.8	3.4	72.9	5.5	2.7	81.1	663.8	-5.5	0.6
2014	8.2	3.7	54.9	5.2	1.8	81.9	704.1	-5.6	-18.8
2015	8.1	2.9	46.0	3.6	2.0	86.2	752.2	-5.8	-32.0
2016	9.9	3.2	52.1	3.6	1.1	83.5	800.2	-7.2	-21.5
2017	9.4	3.3	45.9	3.8	1.6	58.4	849.1	-7.2	-3.1

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands

Table 6.L.9 UNFCCC Forest conversions – VIC annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1990	16.9	7.6	14.0	0.9	1.7	8.5	37.2	-0.4	22.3
1991	13.3	5.7	17.4	0.9	1.6	9.9	42.3	-0.4	20.7
1992	10.5	3.9	19.1	0.8	1.4	13.2	47.7	-0.5	16.4
1993	7.0	3.6	15.5	0.9	1.9	12.2	57.0	-0.6	10.3
1994	6.0	2.2	18.6	0.7	1.7	12.9	63.7	-0.6	11.7
1995	5.3	2.1	14.4	0.8	1.1	8.7	72.2	-0.7	11.0
1996	5.5	1.7	13.5	0.7	1.3	7.4	76.2	-0.8	11.6
1997	5.7	1.8	13.4	0.9	1.3	7.3	79.1	-0.9	11.8
1998	5.5	1.7	12.5	0.9	0.9	8.9	82.2	-0.9	9.0
1999	5.7	0.9	14.0	0.6	1.0	14.4	86.2	-1.0	5.4
2000	4.5	0.9	11.1	0.7	0.8	12.3	96.6	-1.1	3.4
2001	4.2	1.5	9.3	0.8	1.2	13.0	105.0	-1.1	0.4
2002	11.2	1.7	13.0	1.0	1.3	11.3	112.3	-1.1	13.0
2003	26.1	4.4	26.8	1.7	1.1	12.2	110.7	-1.2	40.6
2004	16.7	5.2	26.1	2.1	1.4	14.0	109.9	-1.1	28.8
2005	7.4	2.7	34.1	2.4	1.4	17.9	105.8	-1.1	23.6
2006	9.6	4.4	42.2	3.6	1.6	17.6	99.9	-0.9	34.2
2007	6.5	3.7	29.3	3.1	1.2	23.4	100.3	-0.8	12.4
2008	5.1	2.3	22.6	1.9	1.4	28.2	109.3	-0.9	-0.5
2009	6.9	3.3	25.9	1.9	1.3	25.5	119.8	-0.9	7.3
2010	4.9	3.8	25.2	3.0	1.4	28.8	128.0	-0.9	1.3
2011	1.8	1.2	15.2	1.1	2.3	42.1	146.8	-1.0	-25.1
2012	1.3	0.6	13.0	0.8	1.6	38.3	180.6	-1.4	-24.0
2013	1.5	0.6	21.4	0.9	1.0	31.3	205.7	-1.7	-8.3
2014	2.0	0.8	25.1	1.3	1.2	32.1	220.8	-1.5	-5.0
2015	1.9	0.7	20.2	1.2	0.7	31.8	238.8	-1.8	-9.7
2016	1.4	0.8	17.5	1.2	0.5	29.5	258.2	-2.3	-10.5
2017	0.8	0.6	12.4	1.0	0.7	22.0	278.3	-2.4	-8.8

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands

Table 6.L.10 UNFCCC Forest conversions – WA annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1990	58.8	13.4	19.1	0.7	5.3	19.3	80.2	-0.5	58.6
1991	46.4	12.7	22.9	1.0	5.1	21.4	90.6	-0.6	47.9
1992	26.9	6.6	18.3	0.7	4.5	23.7	104.1	-0.8	21.5
1993	21.2	4.6	15.0	0.5	4.8	15.2	120.4	-0.8	21.0
1994	22.0	5.0	15.9	0.7	3.9	15.1	127.7	-0.7	22.8
1995	18.9	4.8	14.0	0.7	3.3	13.2	135.8	-0.9	19.8
1996	17.6	3.8	15.1	0.6	3.5	13.9	141.0	-1.0	18.8
1997	17.7	4.2	14.7	0.8	3.6	13.6	147.2	-1.0	18.7
1998	14.7	3.8	12.7	0.8	3.1	17.9	154.1	-1.1	9.4
1999	12.9	2.9	12.3	0.7	3.2	27.8	165.1	-1.2	-2.6
2000	12.5	3.0	13.5	0.8	3.0	24.0	185.1	-1.4	2.1
2001	13.6	2.9	19.8	1.0	2.4	24.2	196.9	-1.4	9.2
2002	13.7	3.0	19.4	1.2	3.2	20.8	209.1	-1.3	12.3
2003	16.0	3.6	24.2	1.6	2.2	20.5	214.7	-1.5	19.7
2004	16.3	3.9	26.0	1.8	3.1	20.9	218.6	-1.4	21.3
2005	17.9	4.4	35.2	2.0	3.1	23.7	216.5	-1.4	29.4
2006	18.7	4.4	42.3	2.5	2.8	24.1	212.1	-1.5	36.9
2007	17.3	4.6	38.3	2.7	2.8	27.8	209.5	-1.4	27.7
2008	12.5	3.6	31.4	2.0	3.1	29.3	213.8	-1.4	14.6
2009	10.9	2.9	30.2	1.8	2.7	29.8	219.7	-1.4	11.3
2010	11.6	3.0	31.4	2.1	3.2	28.8	224.8	-1.2	14.1
2011	10.5	3.5	26.4	2.0	2.1	32.3	232.3	-1.4	4.7
2012	7.2	2.0	22.4	1.3	2.7	39.5	246.0	-1.5	-9.8
2013	6.8	1.5	24.0	1.1	2.2	51.2	265.5	-1.5	-20.3
2014	6.8	2.1	24.2	1.5	2.3	56.3	296.4	-1.7	-25.3
2015	8.7	1.4	26.6	1.1	2.3	37.4	330.5	-1.8	-2.0
2016	9.8	3.2	28.4	1.9	1.6	32.9	344.1	-2.1	5.3
2017	3.3	1.3	16.0	1.0	1.3	28.4	363.3	-2.5	-9.0

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands

Table 6.L.11 UNFCCC Forest conversions – TAS annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1990	12.0	3.5	3.8	0.2	1.1	3.7	6.3	-0.0	12.0
1991	14.1	6.6	7.3	0.5	1.4	5.5	8.7	-0.0	15.8
1992	6.5	4.3	6.9	0.4	1.4	4.5	12.1	-0.1	9.0
1993	5.4	3.9	4.9	0.5	0.6	3.7	15.1	-0.1	6.7
1994	4.7	2.0	4.1	0.2	1.1	4.1	17.6	-0.1	4.8
1995	4.7	2.0	4.0	0.3	1.0	3.9	20.4	-0.1	4.8
1996	3.8	1.8	3.5	0.3	1.0	2.8	22.7	-0.1	4.5
1997	4.2	1.8	4.1	0.3	1.0	3.1	23.3	-0.2	5.2
1998	3.7	1.8	3.6	0.3	0.8	3.0	24.6	-0.2	4.4
1999	3.3	1.5	4.0	0.3	1.0	6.0	25.9	-0.2	1.3
2000	3.1	1.4	3.0	0.3	1.0	4.9	30.6	-0.3	1.2
2001	3.3	1.3	3.0	0.3	0.9	5.1	34.1	-0.2	1.1
2002	3.1	1.4	3.0	0.3	1.0	4.6	37.8	-0.3	1.5
2003	3.8	1.6	6.2	0.4	0.9	5.5	38.6	-0.3	4.5
2004	4.2	1.8	6.1	0.5	0.7	6.1	40.4	-0.4	4.2
2005	5.1	2.1	7.6	0.6	0.8	9.0	41.6	-0.5	3.7
2006	4.3	1.9	7.4	0.6	1.0	10.1	45.5	-0.4	1.5
2007	4.1	1.4	7.2	0.5	0.6	6.6	50.4	-0.5	4.6
2008	4.2	1.6	9.9	0.6	0.7	6.6	49.4	-0.4	7.5
2009	3.8	1.4	7.8	0.6	0.7	6.8	50.1	-0.4	4.8
2010	3.7	1.3	8.3	0.6	1.1	7.8	50.4	-0.4	4.2
2011	2.7	1.2	6.6	0.6	1.2	9.3	53.0	-0.4	-0.1
2012	1.4	0.6	4.6	0.3	0.8	9.7	58.6	-0.5	-3.7
2013	1.5	0.4	4.7	0.3	0.5	10.0	64.6	-0.6	-3.7
2014	1.8	0.7	5.0	0.4	0.8	9.7	70.6	-0.5	-2.9
2015	1.6	0.6	5.8	0.5	0.4	8.1	75.4	-0.6	-0.7
2016	1.4	0.6	6.1	0.7	0.5	6.6	78.3	-0.7	0.9
2017	1.0	0.4	4.9	0.7	0.7	6.5	80.6	-0.6	-0.6

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands

Table 6.L.12 UNFCCC Forest conversions – SA annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1990	13.4	2.8	7.0	0.3	1.3	4.7	27.8	-0.1	15.7
1991	9.5	1.8	7.1	0.2	1.1	5.9	30.4	-0.1	10.8
1992	6.8	1.1	8.2	0.2	0.7	6.3	33.6	-0.1	8.8
1993	4.3	1.1	5.8	0.2	1.1	8.3	37.7	-0.2	1.8
1994	3.6	0.6	5.7	0.1	1.0	12.0	43.5	-0.1	-2.7
1995	3.0	0.6	4.7	0.2	0.5	9.2	53.6	-0.2	-1.5
1996	2.6	0.5	5.1	0.1	0.7	6.9	60.8	-0.2	0.8
1997	2.7	0.5	5.0	0.2	0.8	7.1	65.7	-0.2	0.6
1998	2.6	0.5	5.4	0.2	0.4	5.8	70.5	-0.3	2.2
1999	2.8	0.4	7.2	0.2	0.7	5.4	73.1	-0.3	4.5
2000	2.5	0.5	6.7	0.3	0.3	5.3	75.5	-0.4	3.9
2001	3.2	0.5	8.4	0.3	0.7	8.4	76.8	-0.4	3.1
2002	2.9	0.6	8.0	0.4	0.6	7.5	81.6	-0.4	3.4
2003	2.6	0.5	8.7	0.4	0.3	7.7	84.9	-0.4	3.6
2004	3.0	0.5	11.1	0.4	0.6	8.9	87.3	-0.4	5.2
2005	3.6	0.6	16.6	0.6	0.8	11.8	87.7	-0.4	8.5
2006	4.0	0.6	17.6	0.6	0.4	10.9	89.5	-0.3	10.7
2007	3.6	0.7	13.9	0.7	0.6	10.8	92.0	-0.4	6.7
2008	2.1	0.4	9.0	0.4	0.5	13.9	97.2	-0.4	-2.8
2009	2.2	0.3	9.3	0.3	0.3	19.0	105.0	-0.4	-7.5
2010	2.0	0.4	10.8	0.4	0.3	21.0	116.8	-0.5	-8.2
2011	1.5	0.3	11.1	0.3	0.1	22.8	130.2	-0.7	-10.1
2012	1.5	0.3	11.7	0.3	0.5	24.0	144.8	-0.6	-10.8
2013	1.8	0.3	15.3	0.4	0.6	21.3	158.1	-0.5	-4.2
2014	1.9	0.4	15.9	0.6	0.5	16.2	168.2	-0.5	1.6
2015	1.3	0.3	11.9	0.4	0.5	16.0	175.9	-0.7	-2.8
2016	0.6	0.2	8.8	0.3	0.2	17.7	185.6	-0.8	-8.3
2017	0.4	0.1	5.3	0.2	0.2	13.0	199.3	-0.9	-7.4

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands

Table 6.L.13 UNFCCC Forest conversions – NT annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1990	2.3	0.6	2.1	0.1	0.0	1.2	4.4	-0.0	3.2
1991	1.9	0.3	1.9	0.1	0.1	1.4	5.2	-0.0	2.3
1992	2.8	0.4	2.7	0.1	0.1	2.3	5.9	-0.0	3.2
1993	0.9	0.4	1.4	0.1	0.1	1.7	7.8	-0.0	0.7
1994	0.9	0.2	1.5	0.1	0.1	1.8	9.0	-0.0	0.6
1995	0.8	0.2	1.3	0.1	0.0	1.7	10.3	-0.0	0.4
1996	1.3	0.2	2.1	0.1	0.0	1.7	11.1	-0.0	1.8
1997	1.4	0.3	2.2	0.1	0.1	1.7	11.8	-0.0	1.9
1998	0.9	0.3	1.7	0.1	0.0	1.9	12.8	-0.0	0.7
1999	0.9	0.2	1.8	0.1	-0.0	2.4	13.9	-0.0	0.2
2000	0.8	0.2	1.9	0.1	0.0	1.9	15.5	-0.0	0.7
2001	0.8	0.2	2.5	0.1	0.0	2.0	16.2	-0.0	1.3
2002	0.8	0.2	2.3	0.1	0.0	1.8	17.2	-0.0	1.3
2003	0.8	0.2	2.3	0.1	0.0	2.9	17.8	-0.0	0.2
2004	0.9	0.2	2.4	0.1	0.0	3.0	19.4	-0.0	0.3
2005	1.4	0.2	5.3	0.2	0.0	3.0	19.2	-0.1	3.7
2006	1.3	0.3	6.6	0.2	0.0	2.8	18.9	-0.0	5.1
2007	1.7	0.3	5.4	0.2	0.0	2.8	18.5	-0.0	4.4
2008	1.4	0.2	3.8	0.2	0.0	2.7	19.2	-0.1	2.5
2009	0.9	0.2	3.4	0.2	0.0	2.6	19.9	-0.0	1.7
2010	0.7	0.1	3.5	0.2	-0.0	2.8	20.2	-0.1	1.4
2011	0.5	0.1	2.1	0.2	-0.1	3.2	21.5	-0.1	-0.6
2012	0.4	0.2	2.7	0.2	-0.0	2.1	22.9	-0.1	1.0
2013	0.5	0.1	2.9	0.2	-0.0	1.7	23.1	-0.1	1.8
2014	0.5	0.2	2.7	0.2	-0.0	2.3	22.9	-0.1	1.0
2015	0.7	0.2	2.9	0.2	0.0	2.6	23.2	-0.1	1.0
2016	1.0	0.2	5.3	0.2	-0.0	2.0	21.9	-0.1	4.3
2017	0.4	0.2	2.8	0.3	-0.1	2.2	22.0	-0.1	1.0

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands

Table 6.L.14 UNFCCC Forest conversions – ACT annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1990	0.19	0.062	0.23	0.003	0.009	0.16	0.34	-0.005	0.26
1991	0.13	0.045	0.39	0.007	0.007	0.19	0.45	-0.006	0.34
1992	0.10	0.029	0.44	0.007	0.004	0.15	0.57	-0.008	0.40
1993	0.05	0.024	0.14	0.007	0.008	0.17	0.68	-0.009	0.03
1994	0.05	0.021	0.14	0.005	0.005	0.18	0.80	-0.009	0.01
1995	0.05	0.021	0.15	0.006	0.005	0.15	0.95	-0.010	0.06
1996	0.05	0.019	0.25	0.010	0.002	0.10	1.04	-0.014	0.20
1997	0.05	0.022	0.25	0.013	0.005	0.10	1.09	-0.013	0.20
1998	0.05	0.021	0.24	0.015	0.005	0.13	1.14	-0.011	0.16
1999	0.10	0.030	0.29	0.015	0.007	0.31	1.19	-0.014	0.08
2000	0.06	0.038	0.27	0.019	0.008	0.23	1.43	-0.017	0.10
2001	0.04	0.011	0.36	0.018	0.008	0.20	1.55	-0.017	0.19
2002	0.07	0.009	0.44	0.021	0.007	0.15	1.58	-0.014	0.35
2003	0.18	0.050	0.82	0.057	0.013	0.13	1.30	-0.012	0.88
2004	0.16	0.059	0.83	0.075	0.016	0.14	1.07	-0.008	0.85
2005	0.13	0.048	0.83	0.078	0.012	0.17	0.91	-0.007	0.80
2006	0.09	0.032	0.73	0.044	0.021	0.13	0.73	-0.004	0.68
2007	0.05	0.023	0.58	0.045	0.007	0.25	0.53	-0.004	0.38
2008	0.01	0.005	0.22	0.014	0.002	0.39	0.62	-0.005	-0.15
2009	0.01	0.003	0.40	0.013	0.004	0.18	0.67	-0.004	0.24
2010	0.02	0.007	0.32	0.022	0.017	0.20	0.60	-0.004	0.14
2011	0.01	0.006	0.19	0.013	0.023	0.20	0.63	-0.005	0.00
2012	0.01	0.003	0.16	0.009	0.018	0.29	0.71	-0.004	-0.12
2013	0.02	0.007	0.14	0.012	0.004	0.46	0.88	-0.007	-0.30
2014	0.03	0.012	0.12	0.011	0.010	0.62	1.24	-0.009	-0.47
2015	0.02	0.013	0.09	0.009	0.008	0.77	1.79	-0.013	-0.67
2016	0.01	0.002	0.09	0.005	-0.001	0.60	2.48	-0.019	-0.50
2017	0.01	0.005	0.14	0.009	0.002	0.30	2.96	-0.026	-0.15

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands

Appendix 6.M Carbon Stock Accounting

Carbon stock accounting is conducted under the principles of the System of Environmental-Economic Accounting (UNSD, 2014a) and Experimental Ecosystem Accounting (UNSD, 2014b). By compiling estimates from sources consistent with the National Inventory, this establishes a third and alternative accounting perspective of the underlying data. Some scope differences exist, and so comparisons between the accounting structures should be made with this in mind.

These accounts were inspired by the work of Judith Ajani and Peter Comisari (2014), and developed with collaborative assistance from the ABS in development of experimental ecosystem accounts for the Great Barrier Reef catchment areas (ABS, 2017). The accounts remain subject to ongoing improvements as methods are consolidated and feedback from stakeholders is incorporated. Future improvements may cause further deviation from the approaches and scope of the UNFCCC and Kyoto greenhouse accounts.

As with emissions accounts, the primary source of data for carbon stock accounts are the spatial simulations of Landsat imagery in the FullCAM architecture. Emissions estimation is based off of carbon stock change calculations, making carbon stock levels readily obtainable from the simulation results. Due to the simulation projects being designed for only emissions reporting, special treatments must needs be made to account for the limitations of these simulation projects, such as rebasing soil carbon levels (Table 6.M.1). Project results are summed and adjusted for sources of carbon stocks and their changes calculated outside of the FullCAM architecture.

Changes in carbon stocks are attributed to one of four types of change:

- *Reclassifications* are the movement of carbon from one type of land use to another, such as through land clearing and reclearing, plantation establishment, or other forms of regeneration.
- *Transfers to wood products* includes the carbon in logs removed from a forest during a harvesting event.
- *Fire and regrowth from fire* includes the immediate losses of carbon in deadwood and litter due to a fire event, and the subsequent recoveries within the forest. Contributions of recovery are counted in the years where the regrowth occurs rather than in the year where the fire occurred. The impacts of non-anthropogenic Natural Disturbances are included in this account.
- *Net growth and decay* includes all other changes in carbon stocks, including the growth of trees and the loss of woody material left or burned on a harvesting site following a harvesting event. This also includes the gains or losses of carbon associated with a reclassification of land use after the movement between land uses has been assessed under reclassifications.

Table 6.M.1 Sources of carbon stock data, compilation matrix

Data Source	Special treatments and adjustments
Tier 3 FullCAM simulations – Deforestation	• Expanded to include coverage for growth transitions occurring before the first clearing event.
Tier 3 FullCAM simulations – Afforestation / Reforestation	• Expanded to include all transitions occurring before the first post-1989 planting event.
Tier 3 FullCAM simulations – Additional Land converted to Forest	• Expanded to include coverage for forest cover loss transitions occurring before the first forest growth event. • Expanded to include all transitions occurring before the first post-1989 growth event in locations subject to emissions reduction fund project areas. • Added 2016 stock levels for unprotected and fire-affected areas not in scope of the emissions inventory. • Added 2006 stock levels for areas of central Australia otherwise not simulated.
Tier 2 models – Forest Management	• Added stocks from the series used to calculate emissions for multiple use forests, harvested private native forests and pre-1990 plantations, as per the Forest Management scope.
Tier 3 FullCAM simulations – Forests remaining Forests (project in development, not yet in use for NIR)	• Added 2016 stock levels for all areas associated with forest not experiencing anthropogenic transitions. Results by state and major vegetation group are scaled to the 2016 forest extent, less areas already accounted for by other sources.
Tier 2 models – Fire and Fuelwood	• Adjustments applied to stocks for the emissions series on fuelwood, wildfire and prescribed burning. The full impact of natural disturbances are included. Levels are set in 1999 and are cast forward and back using the source's emissions series.
Tier 3 FullCAM simulations – Grasslands	• Assessment of stocks in 2016 for above-ground biomass, and in 1972 for below-ground biomass, applied to the full series. Results are scaled to the 2016 extent of grasslands, settlements wetlands and other lands, less areas already accounted for from other sources. The NIR emissions series is used to cast back stock changes relating to changes in soil management practices.
Tier 2 models – Sparse Transitions	• Added stocks for sparse woody vegetation on grasslands, wetlands and settlements, drawn directly from the associated revegetation models of sparse extent and transitions.
Tier 1 models – Wetlands converted to Croplands and Grasslands	• Adjustments to stock series applied for the emissions series of Wetlands converted to Croplands and Grasslands, casting forward and back from the 2015 level estimate.
Tier 3 FullCAM simulations – Croplands	• Assessment of stocks in 2016 for above-ground biomass, and in 1972 for below-ground biomass, applied to the full series. The NIR emissions series is used to cast back stock changes relating to changes in soil management practices. • Total stocks scaled to include areas excluded from the simulation due to being classified as areas of Woody Horticulture.
Tier 2 models – Woody Horticulture	• Added stocks of living biomass for areas of woody horticulture, discerned from the parameters of the stock-change based emissions model.
Tier 2 models – Mangroves and Tidal Marshes	• Added stocks based on a 2016 assessment of mangrove and tidal marsh extent using the same parameters as applied in the tier 2 model. Levels are set in 2010 and are cast forward and back using the source's emissions series.
Tier 2 models – Harvested Wood Products	• Source data used as-is.
Tier 2 models – Solid Waste	• Only the modelled results for paper and wood products' carbon accumulated are incorporated. See note (e) below.

Further notes

a) Where 1972 values rather than 2016 values are used, this is due to uncertainty around the FullCAM modelling of soil carbon stocks in the absence of transition events on grasslands and croplands. Stock initialisation is taken as the most reliable estimate of levels in such circumstances pending further improvements to FullCAM.

b) Where 2006 levels are used on central Australian tiles, it is because this is the latest set of Landsat images processed for these locations.

c) Where 1999 levels are used for forests, it is because this was identified as the median year for maximum above-ground biomass calculations in native forests.

d) Seagrasses have not been incorporated into the accounts.

e) Only solid waste disposal data on paper and wood products are included from the waste sector on the basis that other sources of carbon in landfill and waste streams do not have their creation accounted for in the accounts. For example, the growing and harvesting of food is excluded from the accounts and so it would be in error to include the carbon of food waste in landfill.

f) Harvested wood products and solid waste models are operated on the basis of carbon stock changes, facilitating the direct utilization of their models without needing to transform emissions series. The direct loss of carbon in landfill from paper and wood products in the form of methane is also accounted for in the tier 2 waste models as a direct loss rather than as a flux on CO_2 emissions and so no further adjustment to model results is required.

g) Due to carbon stock accounts having not been recompiled based on the 2017 Inventory updates as at the time of publication, the results of accounting are not shown in this NIR. Images of carbon stock densities are shown for the purpose of demonstrating capability, and will be subject to revision as accounts are recompiled.

7 Waste

7.1 Overview

Total estimated waste emissions for 2017 were 11.8 Mt CO_2-e, or 2.3 per cent of total net national emissions (excluding *LULUCF*) (Table 7.1). The majority of these emissions were from solid waste disposal, contributing 8.3 Mt CO_2-e or 70.0 per cent of waste emissions. *Wastewater treatment and discharge* contributed a further 3.2 Mt CO_2-e (27.3 per cent) of waste emissions while *waste incineration* and *biological treatment* of solid waste contributed 0.03 Mt CO_2-e (0.3 per cent) and 0.28 Mt CO_2-e (2.3 per cent) respectively. *Waste* emissions are predominantly methane-generated from anaerobic decomposition of organic matter. Small amounts of carbon dioxide are generated through the incineration of solvents and clinical waste and nitrous oxide through the decomposition of human wastes.

Table 7.1 Waste sector, Australia 2017, 2018.

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)				
	CO_2	CH_4	N_2O	Total	Preliminary 2018 (CO_2-e)
5 WASTE	31	11,084	673	11,788	11,892
A. Solid waste disposal	NA	8,256	NA	8,256	8,087
B. Biological treatment of solid waste	NA	110	167	277	277
C. Incineration and open burning of waste	31	NA	NE	31	31
D. Wastewater treatment and discharge	NA	2,719	505	3,224	3,497

7.1.1 Trends

Waste emissions decreased by 41.1 per cent (8.2 Mt CO_2-e) over the period from 1990 to 2017 but increased by 5.0 per cent (0.6 Mt CO_2-e) over the period 2016 to 2107.

Preliminary estimates of Waste sector emissions for 2018 are 11.9 Mt CO_2-e. This estimate is prepared using NGER facility data for 2017/18 and State disposal data for 2016/17. These estimates will therefore be subject to revision in the official inventory submission in 2020.

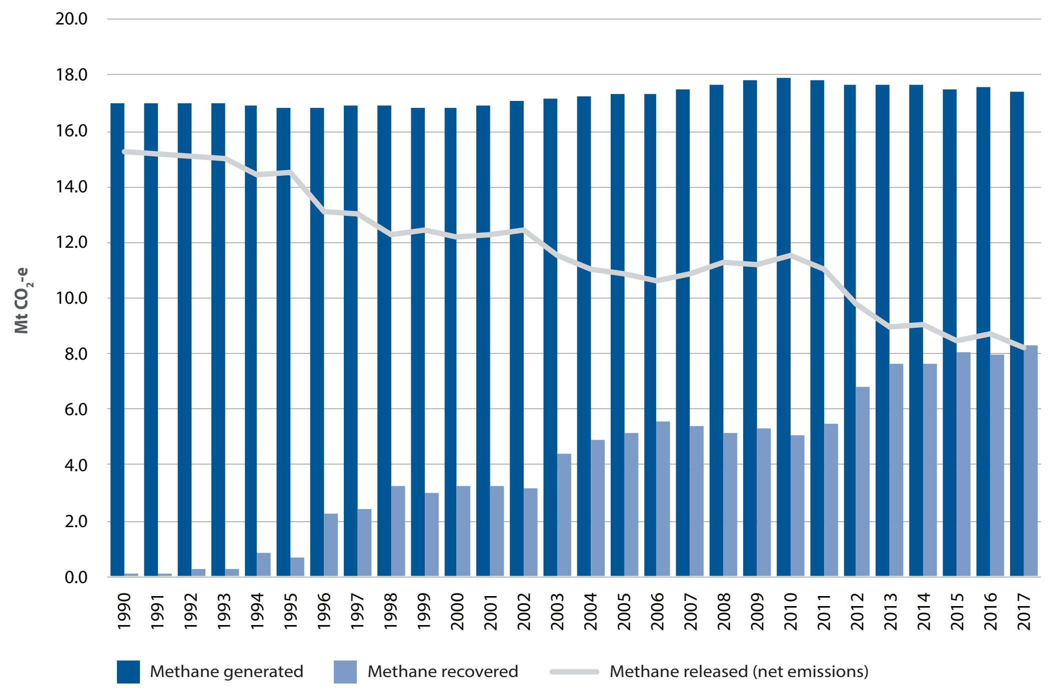
Emissions from municipal *solid waste disposal* decreased by 46 per cent (7.0 Mt CO_2-e) over the period 1990 to 2017 (Figure 7.1) and decreased by 5.0 per cent (0.17 Mt CO_2-e) from 2016 to 2017. This decline since 1990 is mainly due to increases in methane recovery over the time-series. As waste degradation is a slow process, estimates of methane generation reflect waste disposal levels and composition over several decades. In recent years, as rates of recycling have increased, paper disposal in particular has declined as a share of total waste disposed. Total waste disposal has also declined in recent years as alternative waste treatment options are becoming more viable, driven by state and territory waste management policy.

Rates of methane recovery from solid waste have improved substantially, increasing from a negligible amount in 1990 to 8.3 Mt CO_2-e of methane in 2017.

Emissions from the *Biological treatment of solid waste* have increased by 1.6 per cent (0.004 Mt CO_2-e) since 2016. Emissions of CO_2 from the incineration of solvents and clinical waste decreased by 65 per cent (0.06 Mt) between 1990 and 2017.

Wastewater treatment and discharge emissions decreased by 31.1 per cent (1.5 Mt CO_2-e) over the period 1990 to 2017, with an decrease of 5.5 per cent (0.2 Mt CO_2-e) from 2016 to 2017. Changes in estimates for *wastewater treatment and discharge* emissions are largely driven by changes in industry production, population loads on centralised treatment systems and the amount of methane recovered for combustion or flaring.

Figure 7.1 Trends in methane generation, recovery and emissions from solid waste disposal, 1990–2017



7.2 Overview of source category description and methodology – waste

Table 7.2 Summary of methods and emission factors used to estimate emissions from waste

Greenhouse Gas Source And Sink Categories	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
5. Waste	T2	CS	T2	CS,D	CS	D
A. Solid waste disposal	NA	NA	T2/3	D	NA	NA
B. Biological treatment of solid waste	NA	NA	T1	CS	T1	CS
C. Incineration and open burning of waste	T2	CS	T2	CS	T2	CS
D. Wastewater treatment and discharge	NA	NA	T2/3	CS,D	CS	D

T1= Tier 1, T2 = Tier 2, CS = country specific, M = model, D = default, NE = not estimated, NA = not applicable

7.3 Source Category 5.A Solid Waste Disposal

7.3.1 Source category description

The anaerobic decomposition of organic matter in a landfill is a complex process that requires several groups of microorganisms to act in a synergistic manner under favourable conditions. Emissions emanate from waste deposited over a long period (in excess of 50 years in the Australian inventory). The final products of anaerobic decomposition are CH_4 and CO_2. Emissions of CO_2 generated from solid waste disposal are considered to be from biomass sources and therefore are not included in the waste sector of the inventory. CO_2 produced from the flaring of methane from waste is also considered as having been derived from biomass sources.

Solid waste treatment in Australia

Common with the practice in many other developed economies, solid waste is processed in Australia via four main mechanisms:

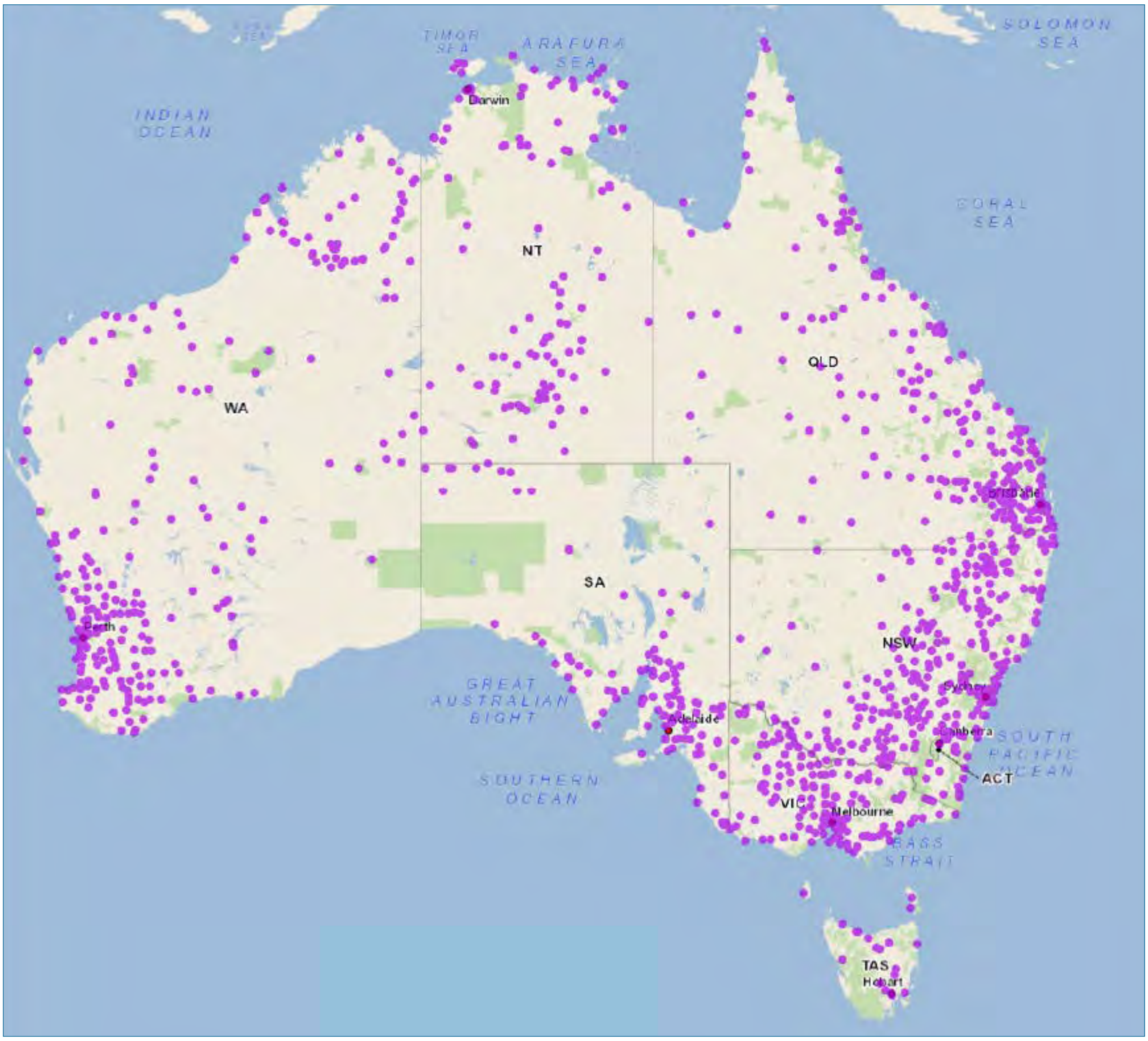
- landfill;
- biological treatment/composting;
- incineration; and
- recycling/reuse.

There are approximately 665 operating landfills in Australia DEWHA (2009). It is reported in Waste Generation and Resource Recovery in Australia (DSEWPaC and Blue Environment Pty Ltd, 2013) that these landfills receive around 21 Mt of waste. This amount equates to approximately 44 per cent of the estimated total waste generated (48 Mt). The balance of waste, 56 per cent of waste material generated, is recycled or reprocessed (including biological treatment/composting) while a negligible amount is treated thermally (incinerated). Figure 7.2 shows the physical locations of the major landfills in Australia. The map shows that landfills are clustered around the large population centres around Australia's coastline.

A landfill industry survey conducted by the Waste Management Association of Australia (WMAA) in 2007 found that a relatively small number of sites are responsible for the bulk of the waste received in Australia. Of the landfills surveyed, 39 process more than 200 kt of waste per year, 24 process between 100 kt and 200 kt per year, 32 process between 50 kt and 100 kt per year, 38 process between 25 kt and 50 kt per year, 61 process between 10 kt and 25 kt per year and the remainder (around 55 per cent of the total number of landfills) process less than 10 kt each per year.

Overall, these statistics show the concentrated nature of the landfill industry in Australia. The top 8 per cent of landfills (i.e. the top 39) manage over 55 per cent of total waste received while almost 90 per cent of solid waste sent to landfill in Australia is received in 133 large landfills with capacity to process 25 kt or more of waste each year. In terms of waste management practices in place at Australian landfills, 11 per cent of landfills have a landfill gas collection system in place. However, in the larger scale landfills, this practice is more common meaning that around 40 per cent of the methane generated is collected for either flaring or energy generation.

Figure 7.2 Australian landfill locations



Source: Geoscience Australia

Common management practices amongst larger landfills include the use of leachate collection systems (38 per cent of landfills). Landfill designs include 38 per cent of landfills with clay cell liners in place, 9 per cent use HDPE cell liners while 7 per cent use GCL liners. In terms of capping practices, 59 per cent of landfills use clay capping, whilst 12 per cent of landfills use either HDPE, GCL or evapotranspiration caps.

7.3.2 Activity data

The Australian methodology for calculating greenhouse gas emissions from solid waste is consistent with the IPCC tier 2 First Order Decay (FOD) Model (IPCC 2006). The methodology deployed utilises a dynamic model driven by landfill data provided by the relevant State/Territory Government agencies responsible for waste management together with facility-level data obtained under the NGER system. Although the structure of the methodology is constant across States, climate-specific parameters introduce variations in estimated emissions depending on location. The model tracks the stock of carbon estimated to be present in the landfill at any given time. Emissions are generated by the decay of that carbon stock, and reflect waste disposal activity over many decades. The methodology is fully integrated with the results of the Harvested Wood Products (HWP) model reported in Chapter 6.

Waste

7.3.3 Australian waste generation and disposal to landfill

Quantities of waste disposed to landfill are collected by State Government agencies (and in most cases also published). A mix of steady growth and some declines in waste tonnages disposed to landfill has been observed in Australia's States and Territories since 1990 reflecting, in part, differences in population growth and the impact of State government policies on waste management (Figure 7.5). In addition to total disposal in each State/Territory, disposal at individual landfills is obtained under the NGER system for landfills meeting the reporting thresholds. Approximately 80 per cent of total disposal is covered by NGER facility data (see Figure 7.3). The residual disposal not covered by the NGER system is calculated as the total disposal reported for each state and territory minus the sum of NGER disposal in each State and Territory. Figure 7.4 shows the relationship between State and Territory reported disposal and disposal reported under NGERS.

Figure 7.3 NGERS waste disposal coverage 1990–2017

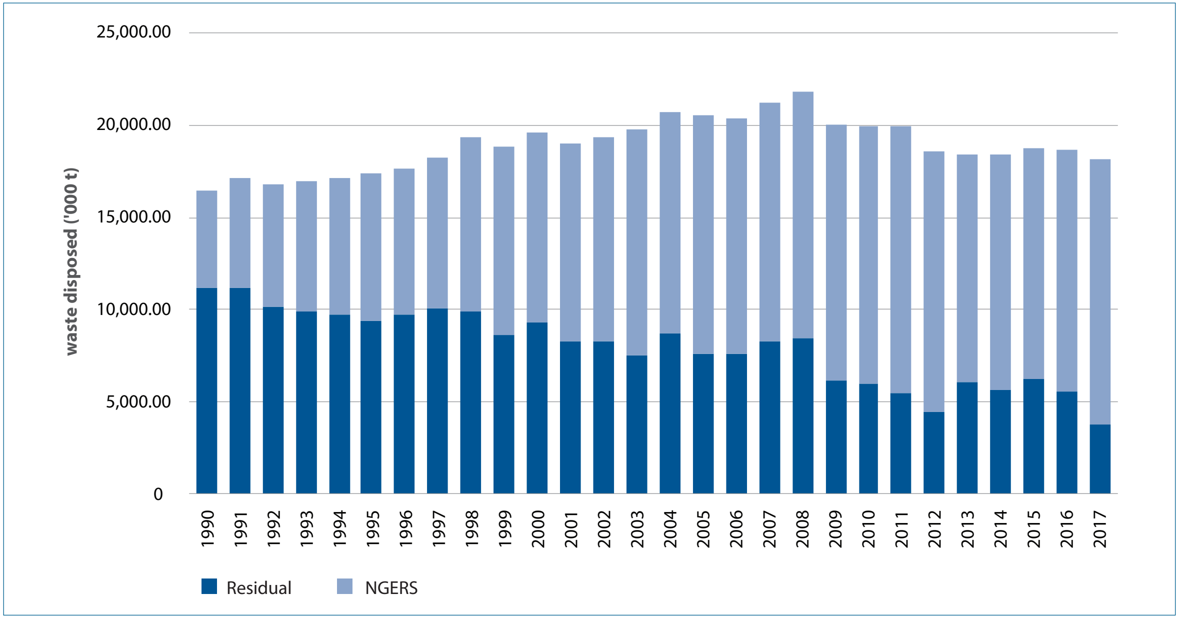
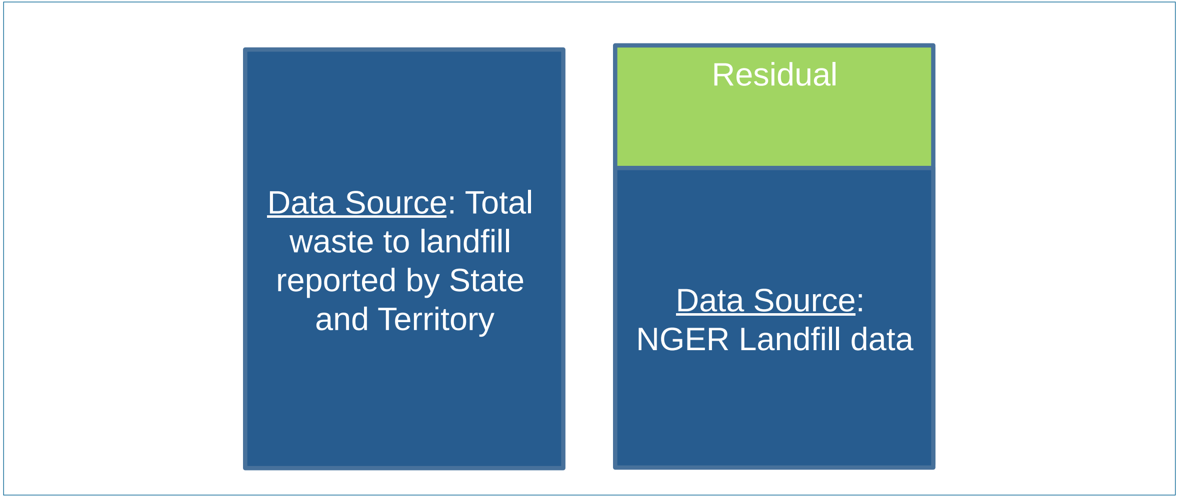
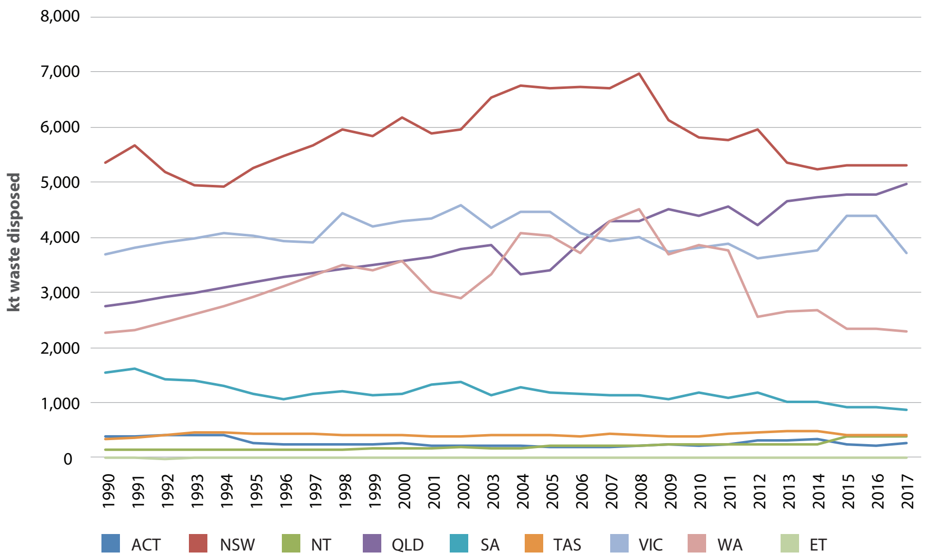


Figure 7.4 Relationship between State and Territory reported disposal and NGERS reported disposal.



It is important to note that activity data reported in this NIR and the accompanying CRF tables are for waste disposal to landfill as opposed to waste generated. State and Territory landfill levy schemes are applied specifically to waste disposed and the NGER system reporting requirements have also been designed to be consistent with this principle.

Figure 7.5 Solid waste to landfill by state 1990–2017



Source: DoEE and NGER 2017

7.3.3.1 Waste streams

Total waste to landfill data is disaggregated into three major waste streams, defined according to relevant State and Territory Government legislation and broadly consistent with the following:

- municipal solid waste – waste generated by households and local government in their maintenance of civic infrastructure such as public parks and gardens;
- commercial and industrial waste – waste generated by business and industry, for example shopping centres and office blocks or manufacturing plants; and,
- construction and demolition waste – waste resulting from the demolition, erection, construction, alteration or refurbishment of buildings and infrastructure. Construction and demolition waste may also include hazardous materials such as contaminated soil or asbestos.

State/Territory and NGER data have been used to determine the stream percentages. Where disaggregated historical data cease, the stream shares have been held constant back to 1940 (Table 7.3).

Table 7.3 Waste streams: municipal, commercial and industrial, construction and demolition: percentages by State: 2017

	NSW	VIC	QLD	NT	SA	WA	TAS	ACT
Municipal Solid Waste	29%	44%	30%	42%	34%	36%	39%	39%
Commercial and Industrial	46%	34%	32%	19%	32%	36%	42%	43%
Construction and Demolition	25%	22%	38%	38%	34%	29%	19%	18%

Source: DoEE and NGER 2017
Note: External Territories waste stream breakdown is assumed to be the same as QLD.

Some States include clean fill (uncontaminated inert solid material) in their waste to landfill estimates provided and this has an influence on the waste stream proportions, however, as this type of waste is largely inert, there is little effect on the final emissions estimate.

7.3.3.2 Individual waste types

Each waste stream is further disaggregated into a mix of individual waste type categories that contain significant fractions of biodegradable carbon. The categories considered are as follows:

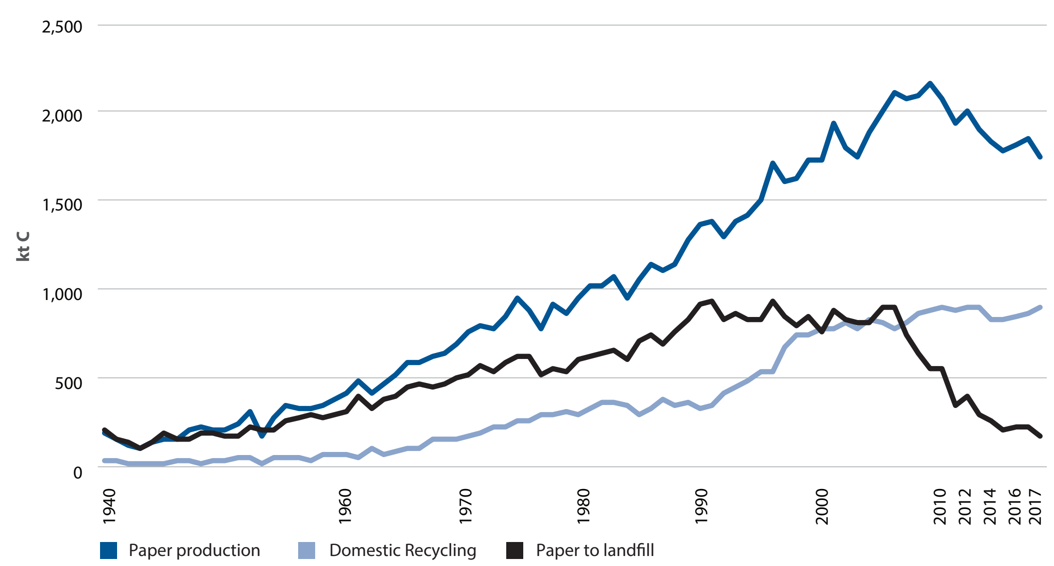
- Food;
- Paper;
- Garden and green;
- Wood;
- Wastes from the production of harvested wood products;
- Textiles;
- Sludge (including biosolids);
- Nappies;
- Rubber and leather; and,
- Inert (concrete, metal, plastics, glass, soil etc).

Harvested wood products – Paper, wood and wood waste generation and disposal

The solid waste disposal estimates and composition are integrated with the wood, wood waste and paper disposal estimates output from the harvested wood products model. These quantities of disposal are used to adjust the waste mix percentages for NGER facilities reporting default waste composition and the non-NGER residual proportion of the waste load going to landfill. This adjustment is undertaken to ensure that the total wood, wood waste and paper disposed to all Australian landfills is consistent with the output of the harvested wood products model.

The amount of paper disposed to landfill reflects those factors that affect the amount of paper in stock reaching the end of its useful life and therefore available for disposal and the changes that have occurred in disposal behaviour – particularly the shift in disposal from landfill to recycling that has occurred since the late 1980s (Figure 7.6). Data on paper and wood reaching the end of their useful life is relatively robust given the long data series available for paper and wood product production, trade and consumption and the assumptions about lifetimes of products reported in Appendix 7.I. This function is a constrained form of the function specified in Section 12.2.2 in IPCC 2006.

Figure 7.6 Paper consumption, recycling and disposal to landfill – Australia: 1940–2017



Source: Refer to Table 7.6

Over time the amount of paper waste generated for disposal will be consistent with the amount of paper consumption given the short life time assumed for this product. Overall paper consumption is estimated to have risen from 380 kt in 1940 to reach 3,498 kt in 2017 (ABARES 2018) reflecting both increasing population and increasing per capita consumption levels. In terms of carbon, these consumption estimates translate into an estimated 190 kt C in 1940 and 1,749 kt C in 2017 (Table 7.4). Per capita consumption of paper has increased from an estimated 26 kg C per person in the 1940s to 71 kg C per person in 2017. Reflecting the growth in paper consumption, waste paper generation is estimated to have increased from 245 kt C in 1940 to 1,782 kt C in 2017.

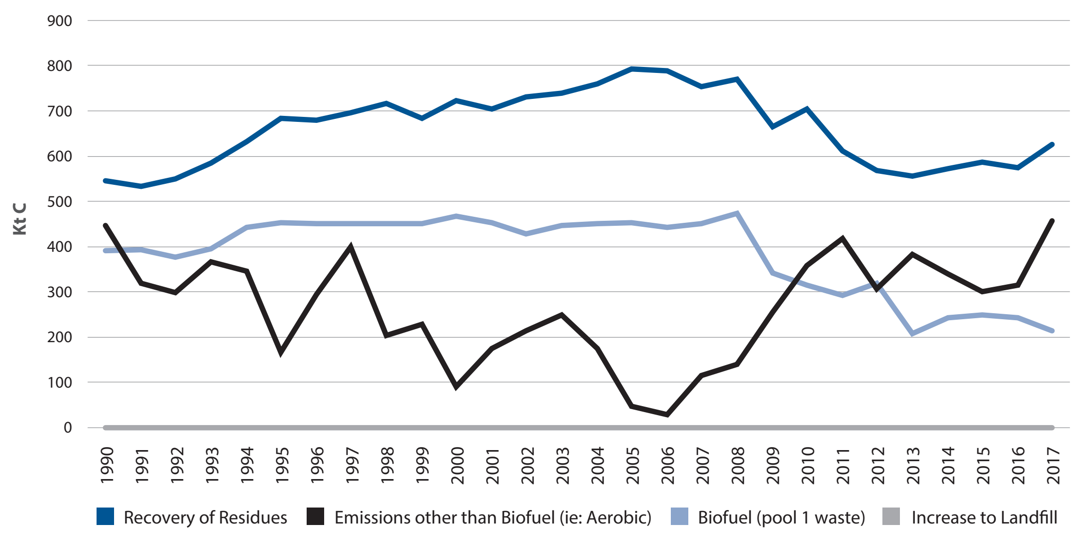
The proportion of paper waste generated that reaches landfill depends critically on the amount of paper diverted to other disposal paths. In Australia, an increasing trend to paper recycling has led to a decrease in the proportion of paper disposed to landfill. The amount of waste paper disposed to domestic recycling as a share of product reaching the end of its useful life has increased from an estimated 25 per cent in 1990 to 53 per cent in 2017, with a sharp jump recorded in the late 90's reflecting in part the effectiveness of a number of State Government waste management initiatives. The share of paper disposed to landfill has declined commensurately. There is also an increasing quantity of waste paper that is exported which is included in the recycling proportion cited above.

The generation of wastes from the production of harvested wood products, mainly sawmill residues and commercial offcuts, is also a significant source of waste generation and reflects two conflicting trends. The overall production of harvested wood products, particularly sawnwood from hardwoods, increased significantly between 1940 and 1960. Production has increased significantly again since the early 1990s, particularly sawnwood from softwood species and paper production, which has offset declines in the production of sawnwood from hardwood species. The ratio of waste generated to harvested wood product produced has fallen over time, however, reflecting both efficiencies in production and the changes in the mix of products produced and offsetting the effect of the overall increase in production to a large extent. In 1940, the ratio of waste generated to wood and paper product produced was 83 per cent. By 2017, this ratio had fallen to 9 per cent.

The amount of wastes, generated from the production of harvested wood products, that are disposed to landfill depends critically on how much of the wastes are estimated to have been diverted to other disposal paths or uses including the quantities combusted for energy [17], the quantities of fibre used in the production of other products (paper) and the quantities disposed to aerobic treatment processes. Of these three possible alternative disposal options, there has been rapid growth in the disposal of wastes to aerobic treatment processes in recent years with a concomitant reduction in wood wastes going to landfill (Figure 7.7). For this submission, a change in the assumption determining the amount of sawmill residue sent to landfill has been made to reflect information confirming that residues are almost entirely combusted or treated onsite (Ximenez pers comm.).

17 Non-CO_2 emissions associated with the combustion of HWP wastes are accounted for in the energy sector. CO_2 emissions are reported as a memo item.

Figure 7.7 Estimated wood product wastes production, recycling, aerobic treatment processes and disposal to landfill – Australia: 1990–2017



Source: Refer to Table 7.6

Table 7.4 Paper consumption, waste generation and disposal: Australia, 1940 to 2017

	Apparent paper consumption	Per capita paper consumption	Closing stock of paper product	Total paper available for disposal/ waste generation	Paper recycling	Paper disposal to landfill	Recycling share of total disposal	Disposal to landfill as share of total disposal
	kt C	kg C/head	kt C	kt C	kt C	kt C		
1940	190	26	200	245	27	204	0.14	0.83
1990	1,386	81	764	1,362	340	930	0.25	0.68
2000	1,935	101	1,044	1,853	771	875	0.42	0.47
2005	2,114	104	1,156	2,054	773	894	0.38	0.44
2008	2,168	101	1,193	2,136	881	548	0.41	0.26
2009	2,081	95	1,168	2,105	890	544	0.42	0.26
2010	1,934	87	1,099	2,004	881	340	0.44	0.17
2011	2,006	89	1,106	1,999	890	387	0.45	0.19
2012	1,908	83	1,074	1,939	891	289	0.46	0.15
2013	1,836	79	1,033	1,878	820	249	0.44	0.13
2014	1,779	75	998	1,813	832	202	0.46	0.11
2015	1,812	75	1,003	1,808	845	211	0.47	0.12
2016	1,845	76	1,019	1,828	853	210	0.47	0.12
2017	1,749	71	986	1,782	894	158	0.50	0.09

Source: DoEE estimates: derived from ABARES 2018, Department of National Development 1969, Jaakko Pöyry Consulting 2000, Recycled Organics Unit 2009. See Table 7.6.

Table 7.5 Wood product production, waste generation and disposal: Australia, 1940 to 2017

	HWP production	HWP waste generation	Ratio of HWP waste generation to HWP production	Shares of HWP waste generation combusted (for energy)	Share of HWP waste disposed to landfill	Share of HWP waste disposed to aerobic treatment	Share of HWP waste used in other products
	kt C	kt C					
1940	1,467	831	0.57	0.34	0.00	0.66	0.00
1990	4,287	1,383	0.32	0.28	0.00	0.32	0.39
2000	5,680	1,279	0.23	0.36	0.00	0.07	0.57
2005	6,223	1,291	0.21	0.35	0.00	0.04	0.61
2008	6,511	1,384	0.21	0.34	0.00	0.10	0.56
2009	5,963	1,262	0.21	0.27	0.00	0.20	0.53
2010	5,985	1,377	0.23	0.23	0.00	0.26	0.51
2011	6,016	1,322	0.22	0.22	0.00	0.32	0.46
2012	5,606	1,192	0.21	0.27	0.00	0.26	0.48
2013	5,285	1,148	0.22	0.18	0.00	0.33	0.48
2014	5,759	1,155	0.20	0.21	0.00	0.29	0.50
2015	6,126	1,137	0.19	0.22	0.00	0.26	0.52
2016	6,537	1,133	0.17	0.21	0.00	0.28	0.51
2017	7,085	1,298	0.18	0.17	0.00	0.35	0.48

Source: DoEE: derived from ABARES 2018, Department of National Development 1969, Jaakko Pöyry 2000. See Table 7.6.

Table 7.6 Principal data sources and key assumptions made with respect to disposal of paper; waste from HWP production and wood

	Paper	Waste from HWP production	Wood
Waste generation inputs			
(1) Production and apparent consumption	ABARES 2018; Jaakko Pöyry 2000, Department of National Development 1969.	Not applicable.	ABARES 2018; Jaakko Pöyry 2000, Department of National Development 1969.
(2) End of useful product life	End of useful life function specified in Jaakko Pöyry 2000 (See Appendix 7.I).	Not applicable.	End of useful life function specified in Jaakko Pöyry 2000 (See Appendix 7.I).
(3) Waste generation	Derived from (1) and (2).	Jaakko Pöyry 2000 (See Appendix 7.I).	Derived from (1) and (2).
Method of disposal			
Landfill	Balance of paper waste generation (3) and paper disposed through recycling, combustion and aerobic decay.	Balance of HWP production waste generation (3) and wastes disposed through recycling, combustion and aerobic decay. All waste assumed treated onsite rather than sent to landfill	Determined exogenously based on GHD (2008) and Hyder Consulting (2008).
Recycling	Source: ABARES 2018, Jaakko Pöyry 2000.	Source: Jaakko Pöyry 2000, Australian Plantations Products and Paper Industry Council (2006).	Balance of waste generation from wood reaching end-of-useful life and wood disposed to landfill, combustion and aerobic decay.
Combusted for energy / waste incineration	0% assumed combusted for energy or incineration.	Derived as the balance of wood and wood waste combusted by manufacturing industry (Source: DIS 2015 and ABARES 2018) and assumptions on combustion of wood. No data is available on waste incineration.	Combusted for energy: 5% of product disposal (see Appendix 7.I). Source: Jaakko Pöyry 2000. Zero percent of product disposal assumed to be incinerated (i.e. not for energy).
Aerobic treatment processes	3% of product assumed to decay due to aerobic processes based on expert judgement. Source: Jaakko Pöyry 2000.	Source: Recycled Organics Unit (2009). Prior to 1995, 3% of product assumed to decay due to aerobic processes. Source: Jaakko Pöyry 2000.	Decay assumed to be 0% based on expert judgement. Source: Jaakko Pöyry 2000.

The key data sources and assumptions made in relation to the estimation of the data presented in Table 7.4 and Table 7.5 are reported in Table 7.6. The amount of paper disposed to landfill is estimated as the balance of the amount of paper waste generated from paper in stock reaching the end of its useful life and the amount of paper disposed to recycling, combustion and aerobic treatment processes. This estimator ensures completeness and consistency with the estimates of the stock of harvested wood products presented in Appendix 7.I and is considered to produce robust estimates because of the high quality of the available data on apparent paper consumption (ABARES 2018 and the Department of National Development 1969) and paper recycling (ABARES 2018). It also allows for the share of paper in total waste disposed to landfill to vary in response to observed rapid changes in disposal behaviour, in particular, the rapid increase in recycling of paper in Australia.

Similarly, data on the wastes from HWP production are considered robust because of the availability of high quality data on HWP production (ABARES 2018 and the Department of National Development 1969) and on the combustion of wood and wood waste (DIS 2015). Data on the amount of wastes disposed to aerobic treatment processes is available from the Recycled Organics Unit of the University of New South Wales. The other important assumption set out in Table 7.6 concerns the percentage of wastes lost through incineration. No data is currently available on the amount of waste incinerated as opposed to combusted for energy. Obtaining more accurate data on this variable is difficult. Consequently, the assumption made has been the subject of sensitivity testing, which demonstrates that waste disposed to landfill is inversely related to the assumption on incineration, indicating that there is limited risk of the estimates of waste disposed to landfill used in the inventory being underestimates.

Table 7.7 Additions and deductions from harvested wood products: 2017

	kt C
Additions to the HWP carbon stock	
Apparent consumption of HWP	3,477
Generation of HWP wastes	1,298
Total additions	4,775
Deductions from the HWP carbon stock	
Disposal to landfill	158
Disposal through combustion for energy/ waste incineration	215
Disposal through aerobic decay	1,187
Recycling/use in other products	1,520
Total deductions	3,080
Net increment in HWP stock	1,695

Combustion of HWP for energy reduces the amount of the HWP stock and is effectively recorded as a reduction in stock (or, equivalently, a source of emissions). In 2017, the reduction in carbon stock from combustion for energy of HWP and wastes generated from HWP production is estimated at 215 ktC. This source of emissions is effectively recorded within the HWP category. Non-CO_2 emissions from the combustion of these products are recorded in Fuel Combustion 1.A. Similarly, the disposal of HWP to landfill reduces the stock of product and is also effectively recorded as a reduction in stock (or source of emissions) against the HWP category. In 2017, the reduction in carbon stock from disposal to landfill is estimated at 158 ktC. Half of this carbon will also eventually be converted to methane in the landfills (effectively, the carbon is counted twice).

Long-term storage of harvested wood products in landfill

Estimates of CO_2 emissions from landfill are estimated using the assumption that landfill gas is 50 per cent CO_2 and are reported under the Harvested Wood Products sub-category Harvested Wood Products in Solid Waste Disposal Sites. The principles of the conservation of mass and carbon are respected and no double counting of carbon occurs. Refer to section 6.13 for further details.

Back casting of total waste disposed to landfill

The data available from State Government agencies on total waste disposed to landfill does not extend to the period prior to 1990. Nor are there any possibilities for filling in the gaps with future surveys. In these circumstances, IPCC 2006 notes that a range of splicing and extrapolation techniques are available.
The technique chosen to determine the historical time series was a surrogate-data technique where the drivers used to determine total waste to landfill were the amount of waste generated from paper consumption and

the estimated amount of waste generated from the production of harvested wood products. These data were chosen because published datasets of production and consumption of these variables, which are closely related to disposal, were available back to 1936. The surrogate technique applied was to assume that the total waste to landfill is perfectly correlated with the sum of paper and wood wastes available for disposal to landfill for years prior to 1990. This assumption ensures that the more general underlying influences affecting waste generation impact these estimates since: a) rising per capita incomes and rising population are reflected in rising demand for paper consumption and consequent waste generation and b) changes in production functions over time (improvements in efficiency) are reflected in the amount of waste generated in HWP.

For disposal data reported under the NGER system, information is available on the entire operational life of the landfills extending to the pre-1990 period. Where these disposal data are available, they have been used. However, it must be noted that this represents only a small proportion of currently operating landfills.

Waste mixes disposed to landfill

Waste composition is determined in two ways. For landfills covered by the NGER system, their reported waste composition is used directly. Where these data are not available, country-specific waste mix percentages are used. These waste mix percentages are obtained as outlined below.

The base waste mix percentages are derived as a simple average of waste mixes presented in studies conducted by GHD (2008) and Hyder Consulting (2008), except for data on paper and wastes from the production of harvested wood products disposed to landfill which are based on data and assumptions set out in Table 7.8 Actual waste mix percentages change over time as the amount of wood waste and paper entering landfills vary – percentages for 2017 are reported in Table 7.8.

Table 7.8 Individual waste type mix: percentage share of individual waste streams disposed to landfill 2017

	Municipal Solid Waste	Commercial & Industrial	Construction & Demolition
Food	38.5%	23.2%	0.0%
Paper [(a)]	3.0%	4.4%	0.5%
Garden and Green	18.5%	4.9%	2.1%
Wood [(a)]	0.8%	7.4%	4.8%
Waste from HWP production [(a)]	0.0%	0.0%	0.0%
Textiles	1.7%	4.9%	0.0%
Sludge	0.0%	1.8%	0.0%
Nappies	4.4%	0.0%	0.0%
Rubber and Leather	1.3%	4.3%	0.0%
Inert (concrete, metal, plastics and glass, soil etc)	31.9%	49.1%	92.6%

Source: Derived from GHD 2008 and Hyder Consulting 2008; (a) DoEE estimates based on data and assumptions in Table 7.6 and GHD 2008.

Table 7.9 Total waste and individual waste types disposed to landfill (kt): Australia

Year	Total waste to landfill [a,b]	Food [b]	Paper [b]	Garden [b]	Wood and wood waste [b]	Textiles, Sludge, Nappies, Rubber and Leather [b]	Other [b]
	kt	kt	Kt	kt	kt	kt	kt
1940	10,444	1,978	933	1,878	1,925	421	4,726
1990	16,366	3,238	2,307	1,358	716	832	7,916
2005	20,472	3,691	2,219	1,582	925	1,081	10,974
2008	21,692	4,197	1,361	1,758	1,026	1,235	12,115
2009	19,897	3,926	1,351	1,628	916	1,181	10,895
2010	19,813	4,055	847	1,712	909	1,201	11,088
2011	19,849	3,969	963	1,664	864	1,222	11,167
2012	18,445	3,950	719	1,607	851	1,213	10,104
2013	18,398	4,034	621	1,616	842	1,236	10,048
2014	18,458	3,941	505	1,640	842	1,222	10,307
2015	18,730	4,019	527	1,589	842	1,246	10,507
2016	18,707	3,813	526	1,564	842	1,232	10,730
2017	18,192	3,773	396	1,502	843	1,164	10,514

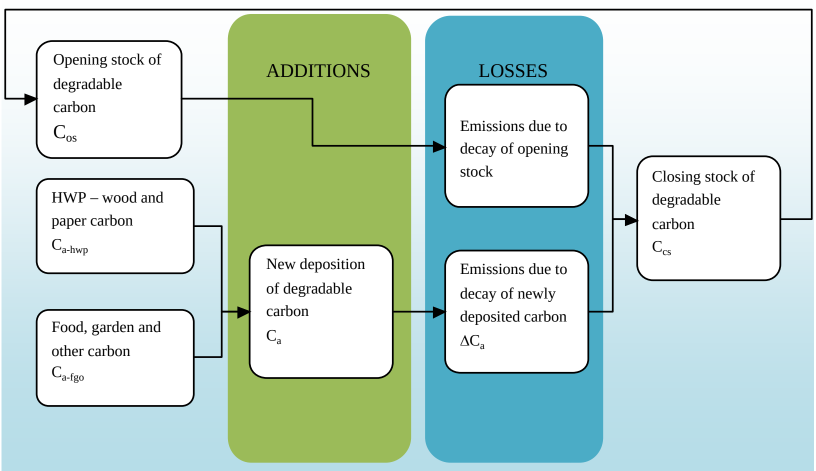
(a) State Government Agencies; (b) Department of the Environment and Energy estimates.

7.3.4 Methodology

The Australian methodology for the estimation of emissions from solid waste disposal utilises the IPCC tier 2 FOD model presented in the Guidelines for National Greenhouse Gas Inventories (IPCC 2006).

The key parameters determining the amount of methane emissions are the fraction of degradable organic carbon in each individual waste type (DOC); the rate of decay assumed for each individual waste type (decay function 'k'); the fraction of degradable organic carbon that dissimilates through the life of the waste type (DOC_f); the methane correction factor (MCF) and the amount of methane captured for combustion. The model is explained in detail in IPCC 2006. The model takes account of the stock of carbon in a landfill by keeping track of additions of carbon through waste disposal and losses due to anaerobic decay. The concept of the carbon stock model approach is illustrated in Figure 7.8.

Figure 7.8 Carbon stock model flow chart for solid waste to landfill



Carbon enters the landfill system via new deposition of waste C_a. Deposition is based on wood and paper carbon transferred from the HWP carbon pool $C_{a\text{-}hwp}$ and carbon in food, garden and other waste derived from data provided by State and Territory waste authorities $C_{a\text{-}fgo}$. A portion of the newly deposited carbon decays in the first year ΔC_a and the remainder contributes to the closing stock of carbon C_{cs}. Additionally, the opening stock of carbon decays over the year ΔC_{os} with the remainder going to the year's closing stock. The closing stock then becomes the next year's opening stock C_{os}. The total change in carbon stock is estimated simultaneously with estimated emissions of methane.

$C_{cs} = C_{os} - \Delta C_{os}$ (emissions lost from opening stock) $+ C_a - \Delta C_a$ (emissions lost from new deposition)

In Australia field work estimating methane generated at particular landfills (Bateman 2009, Dever *et al.* 2009 and Golder Associates 2009) has demonstrated that there is potentially a wide variation in methane generation rates across Australian landfills. In Australia, this is interpreted as principally reflecting:

- differences in waste composition at landfills, reflecting both the differing values of degradable organic carbon (DOC) of individual waste types and differing values of degradable organic carbon of individual waste types that is dissimilable (DOC_f); and
- differences in the decay rate 'k' reflecting differences in waste composition, management regimes or local climatic conditions.

7.3.4.1 Degradable organic carbon

Values for the degradable organic carbon (DOC) content for each waste mix category used in the model are listed in Table 7.10. The source for these parameters is IPCC (2006).

Table 7.10 Key model parameters: DOC values by individual waste type

Waste Type (wet)	DOC
Food	0.15
Paper	0.40
Garden and Green	0.20
Wood and waste from HWP production	0.43
Textiles	0.24
Sludge	0.05
Nappies	0.24
Rubber and Leather	0.39
Other	-

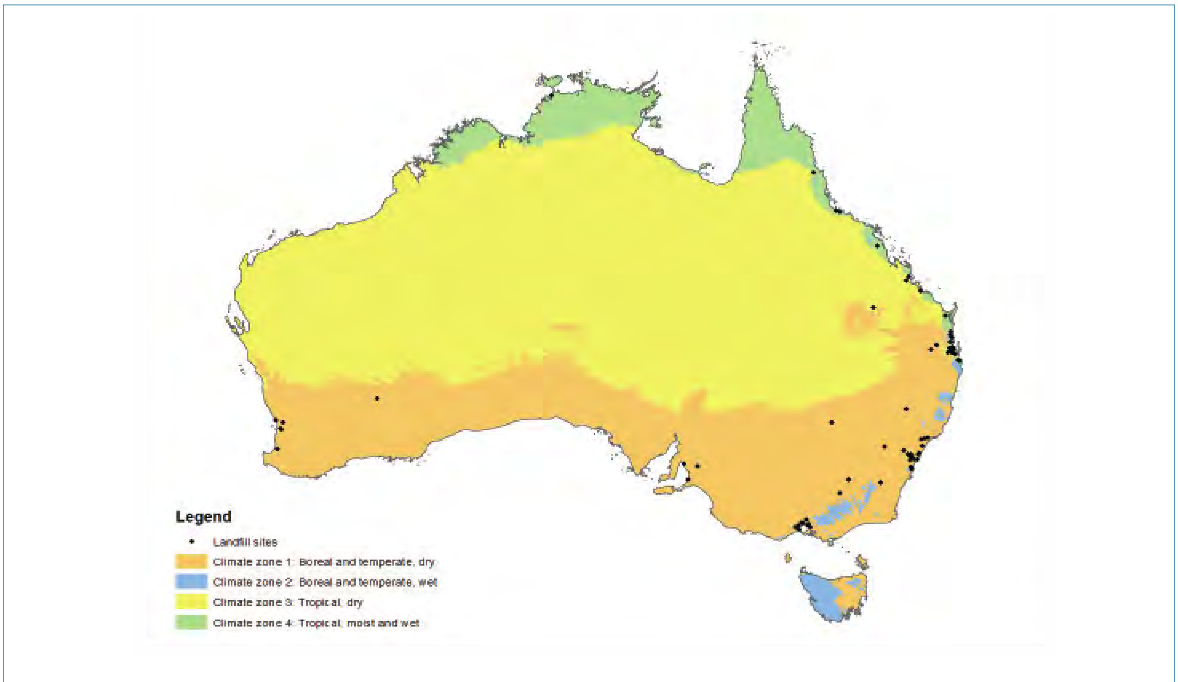
Source: IPCC 2006.

7.3.4.2 Decay function values 'k'

The half-lives and associated decay rate constants 'k' values for each waste mix category applied in the FOD model are consistent with those provided in IPCC 2006.

Waste

Figure 7.9 Australian climate zones and major landfill locations



Decay rate constants are applied to disposed waste in two ways. For landfills covered by the NGER system, the geographical location of the landfill is used to determine which of the 4 IPCC climatic zones is applicable. The distribution of the climate zones across Australia is illustrated in Figure 7.9. The map above has been produced on the basis of average monthly grids of rainfall, pan-evaporation and average temperature from Bureau of Meteorology records between 1970 and 2010.

For the proportion of disposed waste which is not covered by the NGER system, decay rate constants are assigned according to the prevailing climatic conditions at the landfill sites of the principal cities in each State and Territory. In each State, average annual temperature and annual rainfall data for the principal landfill sites were taken from data published by the Australian Bureau of Meteorology. The assumptions of climatic conditions for each State/Territory and 'k' values for each waste mix category are outlined in Table 7.11.

Table 7.11 Key model parameters: 'k' values by individual waste type and State

State / Territory	Climate description	Waste mix category	k value
NSW	Wet Temperate	Food	0.185
		Paper and Textiles	0.06
		Garden and Green	0.10
		Wood	0.03
		Textiles	0.06
		Sludge	0.185
		Nappies	0.04
		Rubber and leather	0.06
VIC, WA, SA, TAS, ACT	Dry Temperate	Food	0.06
		Paper and Textiles	0.04
		Garden and Green	0.05
		Wood	0.02
		Textiles	0.04
		Sludge	0.06
		Nappies	0.04
		Rubber and leather	0.04
QLD, NT	Moist and Wet Tropical	Food	0.4
		Paper and Textiles	0.07
		Garden and Green	0.17
		Wood	0.035
		Textiles	0.07
		Sludge	0.4
		Nappies	0.07
		Rubber and leather	0.07

Source: IPCC 2006.

7.3.4.3 Fraction of degradable organic carbon dissimilated (DOC_f)

DOC_f is an estimate of the fraction of carbon in waste that is ultimately degraded anaerobically and released from solid waste disposal site (SWDS) and reflects the fact the some carbon in waste does not degrade or degrades very slowly under anaerobic conditions (IPCC 2006,Vol 5 p3.13).

Values of DOC_f for individual waste types that are appropriate for Australia have been selected based on well documented research on DOC_f values contained in Barlaz 1998, 2005 and 2008 and Wang *et al.* 2011. These estimates provide an upper limit of an appropriate DOC_f value. The approach adopted, while conservative, is based on the recommendations of Guendehou (2010) after consultations with a range of experts in the industry GHD (2010), Hyder Consulting (2010) and Blue Environment (2010).

The results of the Barlaz work are presented in Table 7.12 which shows reported values for the initial carbon content and carbon remaining after decomposition and the derived DOC_f value.

Table 7.12 DOC_f values for individual waste types derived from laboratory experiments

Waste type	Initial total organic carbon (kg/dry kg)	Organic carbon remaining after decomposition (kg/dry kg)	DOC_f (A-B)/A
	A	B	
Newsprint	0.49	0.42	0.15
Office paper	0.4	0.05	0.88
Old corrugated containers	0.47	0.26	0.45
Coated paper	0.34	0.27	0.21
Branches	0.49	0.38	0.23
Grass	0.45	0.24	0.47
Leaves	0.42	0.3	0.28
Food	0.51	0.08	0.84

Source: Derived by Hyder Consulting 2009 in consultation with Morton Barlaz.

For paper, the Barlaz work translates into a range of DOC_f values, for four classes of paper types meaning that it is important to understand the types of paper waste entering the landfill waste system in order to assign the appropriate weights for each of the Barlaz results. Newsprint contains high levels of lignin, which inhibits decomposition in anaerobic conditions, while office paper contains almost no lignin and therefore experiences high levels of decomposition even under anaerobic conditions. In addition, the Barlaz paper classes are not exhaustive of all paper types. Allowance must be made for non-identified paper classes. In these cases, consideration must be given to the possible chemical composition of the paper and theoretical approaches to the estimation of methane potential.

Consequently, it was necessary to make use of available waste audit data to compile a weighted average DOC_f value for the "paper and cardboard" waste mix category. Based on paper waste composition data presented in GHD 2008 and Lamborn 2009, the proportions of paper types corresponding to the Barlaz DOC_f categories have been derived for Australian landfills (Table 7.13).

Given that the classes of paper analysed by Barlaz were not comprehensive, a DOC_f value is also required to be assumed for 'other' paper. One factor important to the analysis of decomposition under anaerobic conditions relates to the amount of cellulose and hemicellulose in the product (see for example, Lamborn 2009). In the case of the paper types analysed with DOC_f values, the reported cellulose and hemicellulose proportions in the product range from 51.7 for coated paper up to 91.3 for office paper (Barlaz 1998). For the classification of 'other' paper, the value of cellulose and hemicellulose reported by Lamborn 2009 is 72.0 – which is very much in the middle of the range reported for the waste paper types for which DOC_f values are available. Consequently, the assumption made is that the DOC_f for the 'other' paper is the weighted average of the paper types for which DOC_f values are available.

Table 7.13 Derivation of a weighted average DOC_f value for paper

Paper type	Composition (% of total paper in analysis) [a]	Cellulose and hemicellulose (%) [b]	DOC_f [c]
Newspaper	4%	54.6	15%
Office paper	11%	91.3	88%
Cardboard	58%	67.2	45%
Coated Paper	1%	51.7	21%
Other paper	25%	72.0	49%
Weighted average of above			**49%**

(a) Lamborn 2009, (b) Barlaz 1998, (c) Hyder consulting 2009, except for 'other paper'.

Micales and Skog (1996) published a range of methane potentials for a comprehensive list of paper types (based on data in Doorn and Barlaz 1995) which show that methane potentials range between 0.054 g CH_4/g refuse for newspaper and 0.131 g CH_4/g refuse for office paper. These results also suggest that the range of DOC_f values shown in Table 7.12 above derived from Barlaz data encompass the broad range of paper types that may be present in Australian landfills and the degradabilities observed in the experimental data.

For wood products, Australia has selected a value of 0.10 to apply to all wood deposited in landfills in Australia based on the mid-point of observations of DOC_f values for various wood species examined in Wang *et al.* 2011 which included results for softwood, hardwood, plywood and MDF as well as some Australian wood species. Results from these laboratory-based experiments suggest that, particularly for the Australian wood species examined, very little anaerobic degradation occurs. Follow up studies by Australian researchers (Ximenes *et al.* 2013) for a range of engineered wood products (particleboard, MDF and high pressure laminate) observed carbon loss factors no higher than 1.6 per cent while previous field studies (Gardner *et al.* 2008b and Gardner *et al.* 2004) also indicate that low DOC_f values are likely for timber products.

For food waste the DOC_f value of 0.84 reported in Table 7.14, based on the work of Barlaz 1998 has been used.

For garden and park waste a DOC_f value of 0.47 based on the work of Barlaz 1998 has been used. This value assumes the upper estimate calculated by Barlaz for "leaves" and "grass". On this assumption, it represents a conservative upper limit on the likely true DOC_f value for this category.

For the remaining waste categories in the inventory the IPCC default value of 0.5 has been retained. This includes values for textiles, sludge, nappies, and rubber and leather which require additional research to be undertaken before waste type specific values are adopted.

The complete list of DOC_f values for each inventory waste mix type is presented in Table 7.14. As indicated in the QA/QC section, the weighted average DOC_f value for Australian landfills is estimated to be 62 for 2017.

Table 7.14 Key model parameters: DOC_f values by individual waste types

Waste type	DOC_f value
Food	0.84
Paper and paper board	0.49
Garden and park	0.47
Wood	0.10
Wood waste	0.10
Textiles	0.50
Sludge	0.50
Nappies	0.50
Rubber and Leather	0.50
Inert waste (including concrete, metal, plastic and glass)	0.00

7.3.4.4 Methane correction factor (MCF)

An important parameter for the emissions calculation is the methane correction factor (MCF) which is intended to represent the extent of anaerobic conditions in landfills. It is assumed that all *solid waste disposal on land* in Australia is disposed to well-managed landfills, hence a methane correction factor of 1.0 has been applied to all years. Data from a Waste Management Association of Australia (WMAA 2007) survey on waste management practices undertaken in 2007 was reviewed for this inventory and considered to provide strong evidence that the landfills in Australia adopt management practices that are consistent with the IPCC characterisation of well-managed landfills. 71 per cent of landfills, receiving an estimated 95 per cent of waste, operate with some form of permanent cover. The balance of landfills are assumed to operate within the meaning of well-managed landfills, as defined by the IPCC.

7.3.4.5 Delay time

The IPCC default delay time of six months (M =13) has been used to reflect the fact that methane generation does not begin immediately upon deposition of the waste. Under this assumption, and given that all waste is assumed to be delivered at the mid-point of the year, anaerobic decay is set to start, on average, on the first day of the year following deposition.

7.3.4.6 Fraction of decomposition that results in methane (F)

The IPCC default value of 0.5 is assumed for this inventory, reflecting the assumption that the decomposition of organic carbon under anaerobic conditions is equally split between the generation of methane and the generation of carbon dioxide.

7.3.4.7 Oxidation factor (OF)

The IPCC default value of 0.1 is assumed for this inventory, reflecting the proportion of methane generated by the decomposition of organic carbon under anaerobic conditions that is oxidised before the gas reaches the surface of the landfill.

7.3.4.8 Methane capture

Net emissions are derived after accounting for methane recovery undertaken at the landfill site. The quantity of methane recovered for flaring and power is based upon reported methane capture under the NGER system for 2009 onwards and industry survey for the years 1990–2008.

Methane capture reported by landfill gas capture companies is measured according to the gaseous fuels measurement provisions set out in the *NGER (Measurement) Determination*. Under these provisions, a range of options are available to reporters including indirect measurement on the basis of invoices or electricity dispatched or direct measurement at the point of consumption using gas measuring equipment operated in accordance with set standards. Under these reporting provisions, landfill gas companies must also specify whether the collected gas is combusted for power generation, flared or sent offsite for other uses.

Methane recovered (R(t)) is subtracted from the amount generated before applying the oxidation factor, because only landfill gas that is not captured is subject to oxidation in the upper layer of the landfill.

Emissions from the combustion of landfill gas for power generation are reported in the energy sector (1.A.1.a – public electricity and head production)

7.3.5 Emission estimates

7.3.5.1 Methane

Additions to and losses from the pool of organic carbon in landfills including both degradable and non-degradable organic carbon from all waste types are presented in Table 7.15. Half of the carbon losses are assumed to result in the generation of methane (assuming that F, the share of carbon decay resulting in methane, is the IPCC default value of 0.5). The other half is assumed to be carbon dioxide and is effectively estimated when this carbon is deducted from the pool of carbon in the harvested wood product pool.

Table 7.15 Methane generation and emissions, Australia: 1990 to 2017

Year	Carbon additions to landfill (kt C)	Carbon loss (through emissions) (kt C)	Methane generated (Gg CH_4) [a]	Methane capture (Gg CH_4)	Net methane (Gg CH_4)
1990	2,225	1,017	680	2	610
2000	2,385	1,008	673	129	490
2005	2,457	1,036	692	207	436
2008	2,307	1,059	708	205	452
2009	2,176	1,068	714	215	449
2010	2,012	1,071	715	204	460
2011	2,022	1,067	713	221	443
2012	1,902	1,058	707	272	391
2013	1,868	1,055	705	305	360
2014	1,809	1,058	707	306	360
2015	1,824	1,049	701	323	340
2016	1,737	1,054	704	318	348
2017	1,681	1,045	698	331	330

Note: (a) methane generated prior to oxidation.
Source: Department of the Environment and Energy estimates.

7.3.5.2 Non-methane volatile organic compounds (NMVOC)

Small quantities of NMVOC are contained in landfill gas emitted from landfills in Australia. Some of these NMVOC are generated by the decomposition process and others are residuals from the particular types of waste dumped in the landfill.

The CSIRO Division of Coal and Energy Technology in Sydney (Duffy *et al.* 1995) investigated NMVOC emissions from four landfills in the Sydney region. They found significant concentrations, up to 10 parts per million by volume (ppmv), for approximately 60 different compounds. Researchers in the UK (Baldwin and Scott 1991) have found between 2,200 and 4,500 milligrams per cubic metre (mg/m^3) of NMVOC present in landfill gas.

In Australian landfills, liquid waste is rarely disposed of with solid waste whereas co-disposal is common practice in the UK. On this basis the lower range of 2,000 mg/m^3 found by the UK researchers is used for NMVOC emissions from Australian landfills unless other site-specific information is available.

It is assumed that NMVOC emissions from landfills comprise 0.2 per cent of total landfill gas emissions; the average methane fraction of landfill gas as generated before release to the atmosphere is 0.5. This quantity is a weighted mean for all previous years of waste data used to calculate any inventory year's data and the proportion of methane emitted after oxidation is 0.9.

7.4 Source Category 5.B Biological Treatment of Solid Waste

Emissions from the biological treatment of solid waste were 274 Gg CO_2-e in 2017.

Biological treatment of solid waste through processes such as windrow composting and enclosed anaerobic digestion is considered an emerging treatment pathway in Australia and one where a small amount of activity data has become available under the NGER system (2009 onwards) and through an annual industry survey.

Anaerobic digestion at biogas facilities

To date, no facilities have reported emissions associated with the anaerobic digestion of solid waste at biogas facilities under NGERS.

According to the Australian Clean Energy Finance Corporation bioenergy projects are not widely deployed in Australia (CEFC 2015). The majority of bioenergy capacity in Australia is associated with the consumption of bagasse in the sugar industry.

There are three known facilities in operation in Australia that could be classed as anaerobic digestion facilities. The Richgro facility in Jandakot Western Australia became operational in 2015 and has the capacity to process up to 140 tonnes of food waste per day.

Another facility known as Earthpower has been operating in Sydney since 2003 and can process up to 130 tonnes of organic waste per day. As with the Richgro facility, emissions of less than 1,000 tonnes of CO_2-e are estimated.

A third facility has been commissioned in the Yarra valley in Victoria as of May 2017. The facility has the capacity to process around 90 tonnes of food waste per day.

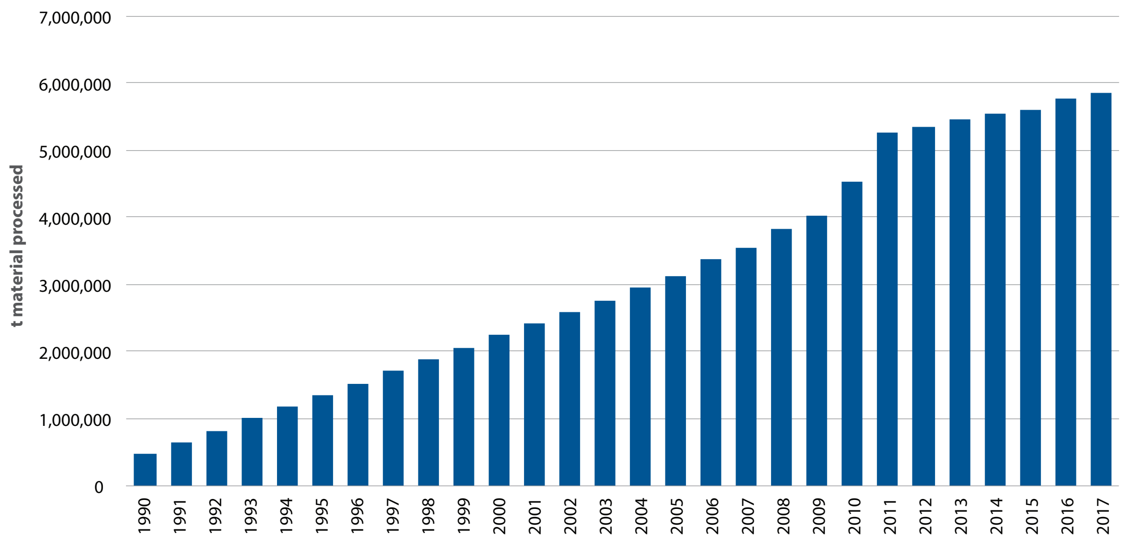
When the IPCC default CH_4 EF of 0.8 g CH_4/kg wet waste treated is applied to the total quantity of waste processed at these 3 facilities. Annual emissions of around 2.6 Gg of CO_2-e result. This is well below the significance threshold for reporting. Accordingly this source is reported as 'Not Estimated'.

There are also a number of biogas facilities associated with agricultural activities in operation in Australia. Emissions associated with these operations are reported under 3.B manure management or 5.D.2 Industrial wastewater treatment where appropriate.

Methodology

Australia has applied the tier 1 method from the *2006 IPCC Guidelines* to derive estimates of emissions based upon the total amount of material processed through composting and anaerobic digestion. Activity data are obtained from an annual industry survey undertaken by the Recycled Organics Unit at the University of New South Wales. Survey data cover the years 2004 to 2010 with extrapolation used to derive activity data for the years 1990 to 2003 (ROU various years). The time-series of quantities of waste material processed via composting is shown in Figure 7.10.

Figure 7.10 Quantities of material processed via composting 1990–2017



Choice of emission factors

Australia has adopted country-specific emission factors for CH_4 and N_2O emissions from composting based on research conducted by Amlinger (2008) covering the composting of bio-waste, loppings and home composting material. The emission factors are shown in Table 7.16.

Table 7.16 Composting emission factors (t CO_2-e/t material processed) used in the Australian inventory

	CH_4 emission factor (t CO_2-e/t material processed)	N_2O emission factor (t CO_2-e/t material processed)
Composting	0.019	0.03

The country-specific emission factors have been drawn from the document *Update of emission factors for N_2O and CH_4 for composting, anaerobic digestion and waste incineration* (DHV 2010) which itself cites Amlinger 2008 as the source of its recommended emission factors. DHV 2010 presents a synthesis of all available research data covering emissions from the biological treatment of solid.

These emission factors are considered suitable for use in Australia's inventory due to the following:

1. Emission factors fall within the IPCC default ranges.

While the CH_4 and N_2O emission factors chosen are towards the lower end of the default range, it has been concluded by Alminger (2008) that values in excess of 0.065 t CO_2-e / t material processed probably indicate some kind of system mis-management such as insufficient aeration or mechanical turning. The mid-range IPCC default factors according to this conclusion would suggest a level of system mismanagement not thought to occur in Australia.

2. Waste types considered by Amlinger (2008) are representative of waste types commonly processed via biological treatment in Australia (namely bio-waste and greenwaste).

GHD 2010 cites typical materials treated by the various biological processes in Australia:

- Source separated garden organics;
- Source separated garden organic organics with biosolids;
- Source separated garden organics with food waste;
- Source separated garden organics with food waste and biosolids;
- Source separated food waste; and
- Mixed residual waste containing food waste and paper.

3. The technologies examined (windrow composting processes) are reflective of those commonly used in Australia. The Recycled Organics Unit identifies aerobic windrow composting as the dominant form of biological treatment of solid waste currently employed in Australia.

7.5 Source Category 5.C Incineration and Open Burning of Solid Waste

Emissions are estimated from the incineration of solvents and municipal and clinical waste. Incineration estimates include a quantity of solvent generated through various metal product coating and finishing processes. In this instance, incineration is used as a method to minimize emissions of solvents and VOCs to the atmosphere and leads to emissions of CO_2. Data on the incineration of solvents prior to 2004 is based on company data after which emissions from this source have been based on data estimated by the DE.

Carbon dioxide emissions from incineration of solvents are estimated by converting the volume of solvent incinerated (Litres) to the weight of solvent (using specific volume factor of 1229 L/t), deriving the energy content of the mass of solvent (using the energy content of 44 GJ/t), and using a carbon dioxide emission factor per petajoule of solvent (69.6 Gg/PJ).

Between 1990 and 1996, there were three incinerators receiving municipal solid waste. These were located in New South Wales and Queensland. All three incinerators ceased operations in the mid-1990's.

In addition to the incineration of municipal solid waste, a quantity of clinical waste is incinerated in four major facilities located in Queensland, New South Wales, South Australia and Western Australia. Data on the quantities of municipal solid waste incinerated are based upon published processing capacities of the three incineration plants prior to decommissioning. Data on the quantities of clinical waste incinerated have been obtained from a per-capita waste generation rate derived from data reported under the NGER system, by O'Brien (2006b) and an estimate of State population reported by the Australian Bureau of Statistics.

The quantity of CO_2 emitted as a result of the incineration of municipal and clinical waste is based upon the quantity of waste incinerated, the carbon content of the waste and the proportion of that carbon which is of fossil origin and the efficiency of the combustion process (oxidation factor). The country-specific fossil carbon content of municipal waste of 7 per cent is based upon empirical data presented in NGGIC (1995) for incineration activities occurring in 1990. Of this 7 per cent of fossil carbon in municipal waste, it is estimated that 80 per cent of this carbon is combustible (NGGIC 1995). Emissions of N_2O from the incineration of municipal solid waste are also estimated based on a country-specific emission factor of 0.00015 Gg of N_2O/Gg of waste taken from NGGIC (1995). The carbon content factors used in the emissions estimation are shown in Table 7.17. Emissions of methane from the incineration of municipal solid waste have been calculated based on the energy content of "Non-Biomass municipal materials if recycled and combusted to produce heat or electricity" of 12.2 GJ/t MSW used for NGERS and a CH_4 emission factor of 30 kg CH_4/TJ MSW taken from the 2006 IPCC Guidelines.

The 2006 IPCC guidelines do not provide default CH_4 and N_2O emission factors for the incineration of clinical waste and solvents. Furthermore, when the highest 2006 IPCC default EFs for CH_4 and N_2O listed for municipal solid and general industrial waste incineration are applied to the AD for clinical waste and solvents incineration, emissions estimates contribute around 0.0001 per cent (0.7 Gg CO_2-e) of total emissions from all sectors. Accordingly, emissions of CH_4 and N_2O from this source are not estimated in the inventory on the grounds that emissions fall below the significance threshold.

Table 7.17 Parameters used in estimation of waste incineration emissions

	Municipal Solid Waste [(a)]	Clinical Waste [(b)]
Proportion of waste that contains fossil carbon	0.07	
Proportion of waste that is carbon		0.6
Proportion of fossil carbon containing products that is carbon	0.80	
Fossil carbon content as a proportion of total carbon		0.4
Oxidation factor	1	0.95
Energy content of Non-Biomass municipal materials if recycled and combusted to produce heat or electricity (GJ/t)	12.2	

Source: (a) NGGIC 1995 / NGERS, (b) IPCC 2000.

7.6 Source Category 5.D Wastewater Treatment and Discharge

7.6.1 Source category description

The anaerobic decomposition of organic matter in wastewater results in emissions of methane while chemical processes of nitrification and denitrification in wastewater treatment plants and discharge waters give rise to emissions of nitrous oxide.

Large quantities of CH_4 are not usually found in wastewater due to the fact that even small amounts of oxygen are toxic to the anaerobic bacteria that produce the CH_4. In wastewater treatment plants, however, there are a number of processes that foster the growth of these organisms by providing anaerobic conditions.

As methane is generated by the decomposition of organic matter, the principal factor which determines the methane generation potential of wastewater is the amount of organic material in the wastewater stream. This is typically expressed in terms of Chemical Oxygen Demand (COD). COD is a measure of the oxygen consumed during total chemical oxidation (both biodegradable and non-biodegradable) of all material in the wastewater (IPCC 2006).

Nitrous oxide, N_2O, is also generated from municipal wastewater treatment plants. Nitrogen, which is present in the form of urea in urine and also as ammonia in domestic wastewater, can be converted to another compound—nitrate (NO_3). Nitrate is less harmful to receiving waters since it does not take oxygen from the water. The conversion of nitrogen to nitrate is usually done by secondary and tertiary wastewater treatment plants using special bacteria in a process called nitrification. Following the nitrification step some facilities will also use a second biological process, known as denitrification. Denitrification further converts the nitrogen in the nitrates to nitrogen gas, which is then released into the atmosphere. Nitrification and denitrification processes also take place naturally in rivers and estuaries. N_2O is a by-product of both nitrification and denitrification.

Municipal wastewater treatment plants in Australia treat a major portion of the domestic sewage and commercial wastewater, and a significant part of industrial wastewater. Approximately 5 per cent of the Australian population is not connected to the domestic sewer and instead utilise on-site treatment of wastewater such as septic tank systems (WSAA 2005). Some industrial wastewater is treated on-site and discharged either to an aquatic environment or to the domestic sewer system which then feeds into a municipal wastewater treatment plant. A schematic diagram of the pathways for the treatment of wastewater in Australia is shown in Figure 7.11.

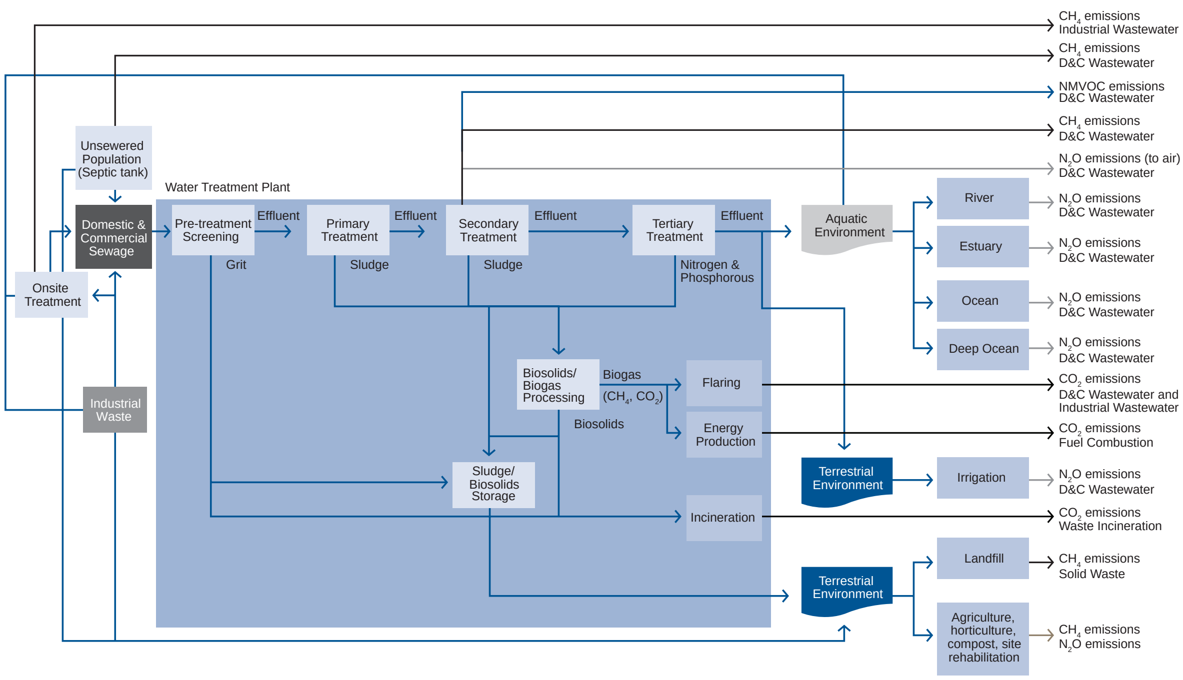
Consistent with IPCC *good practice*, methane emissions from effluent discharge to receiving waters is not reported in the inventory. Similarly, N_2O emissions from any form of industrial wastewater discharge and from discharge of municipal wastewater to ocean and deep ocean waters or used in irrigation are considered negligible and are not reported in the inventory.

Sludge removed from wastewater treatment plants is either disposed to landfill or can be further treated to produce biosolids and then used in a land application such as agriculture, horticulture, composting or site rehabilitation. Emissions of methane from disposal of sludge in a landfill are included in the solid waste sector. Emissions of nitrous oxide from land application are included in the agriculture sector under 3.D Agricultural soils.

Methane generated at wastewater treatment facilities may be captured and combusted for energy purposes or flared. The amount of CH_4 captured or flared is subtracted from the total CH_4 generated. Quantities of sludge biogas combusted for the production of energy and the associated non-CO_2 emissions are reported in the *stationary energy* sector.

Carbon dioxide emissions are not reported in the *wastewater treatment and discharge* sector except where they are derived from non-biomass sources of carbon.

Figure 7.11 Pathways for Wastewater



Waste

Wastewater treatment in Australia

A survey of the Australian wastewater industry was conducted by Department of Climate Change in 2009 (DCC 2009) to gather information on the operational characteristics of the wastewater sector including the location of discharge points, treatment levels, effluent volumes and type of aquatic environment to which the effluent flowed. The utilities which participated in the survey were selected on the basis of two criteria: that they serviced more than 50,000 customers and that these customers were living in coastal areas. The 11 utilities in Australia which met these criteria were asked to take part in the survey and 10 of these provided a response. In total, the respondents represented wastewater utilities which operate more than 100 facilities and treat wastewater for over 60 per cent of the Australian population, all of which were living in coastal cities or communities.

More than three quarters of Australia's total population live in coastal areas. According to data from the Australian Bureau of Statistics (ABS 2009e), in 2009 the total Australian population was approximately 22 million people and around 16 million of these were living in capital cities and major centres on the coast of Australia. The residual population not covered by the DCC survey was approximately eight million people and it is estimated that at least three million of these people were also living on the coast of Australia.

The survey found that wastewater treatment facilities in Australia predominantly process wastewater to a secondary or tertiary treatment level before discharging the wastewater into an aquatic environment. However, some large facilities process the wastewater to a primary level only. As the treatment level increases from primary to secondary to tertiary, the number of unit operations used to treat the wastewater and the amount of organic matter and nitrogen removed before discharge to an aquatic environment increases.

Proportions of Australia's population connected to each treatment level are presented in Table 7.18 together with data for the residual population not covered by the survey which has been extrapolated from the survey data where possible. Nitrogen entering and leaving each treatment level is also shown in Table 7.18. The data clearly show that more complex treatment systems remove a greater proportion of nitrogen and thus generate more N_2O.

Table 7.18 Wastewater treatment plants by level of treatment

Wastewater Treatment Level	Population serviced		Annual quantity of nitrogen entering the system (tonnes of N)		Annual quantity of nitrogen in effluent discharged (tonnes of N) (c)	
Primary	2,761,280	13%	15,931	14%	16,169 (d)	66%
Secondary	6,960,027	32%	27,333	25%	6,170	25%
Tertiary	3,231,570	15%	15,849	14%	2,001	8%
Residual – Coastal Area	3,131,923 (a)	14%	18,040 (b)	16%	N/A	N/A
Residual – Inland Area	5,880,487 (a)	27%	33,872 (b)	31%	N/A	N/A
Total	**21,965,287**		**111,024**		**24,341**	

(a) Estimated using data from Australian Bureau of Statistics 2008a.
(b) Estimated using the IPCC default method and protein intake of 0.036 tonnes per year and IPCC default, 0.16 tonnes of nitrogen per tonne of protein.
(c) Total nitrogen discharged does not include the nitrogen discharged for the residual.
(d) Nitrogen discharged from primary treatment is greater than nitrogen received due to the lower removal rate for primary systems and the transfer of wastewater between plants.

The survey also examined the discharge practices of Australian wastewater facilities. The effluent discharged by wastewater treatment plants enters one of four classes of aquatic environment which are defined as follows:

- River means all waters other than estuarine, ocean or deep ocean waters;
- Estuarine waters means all waters (other than ocean or deep ocean waters):
    - (a) that are ordinarily subject to tidal influence, and
    - (b) that have a mean tidal range greater than 800 mm (being the average difference between the mean high-water mark and the mean low-water mark, expressed in millimetres, over the course of a year);
- Ocean means all waters except for those waters enclosed by a straight line drawn between the low-water marks of consecutive headlands and deep ocean waters; and
- Deep ocean means all waters, except for river and estuarine waters, that are more than 50 metres below the ocean surface.

Survey results shown in Table 7.19 indicate that the majority of effluent is discharged to either ocean or deep ocean outfalls. Only a small proportion of effluent from coastal treatment plants is discharged to a river environment (9 per cent). However, when the non-coastal population is taken into consideration, this proportion becomes 29 per cent, with the additional assumption that all wastewater generated from the non-coastal population is also discharged to river. The residual population also includes the population that is unsewered; estimated at approximately 5 per cent of the Australian population. As the type of discharge environment is critical to emissions of N_2O from discharge, this information is also included in Table 7.19 and shows a large proportion of nitrogen discharged goes to deep ocean outfalls, typically more than two kilometres from the coastline at a depth of 50 metres or more.

Table 7.19 Effluent discharged from wastewater treatment plants by type of aquatic environment for 2008 and 2009

Type of aquatic environment	Population serviced		Annual volume of effluent discharged (kilolitres)		Annual quantity of nitrogen entering the plant (t)		Annual quantity of nitrogen in effluent discharged (t)	
River	2,564,463	12%	117,734,320	9%	11,545	10%	1,334	5%
Estuary	2,920,629	13%	187,480,682	14%	16,862	15%	1,775	6%
Ocean	4,405,912	20%	385,746,932	29%	23,055	20%	6,376	22%
Deep Ocean	3,015,430	14%	360,797,519	27%	17,601	15%	16,562	57%
Residual – Coastal Area	3,178,366 [(a)]	14%	N/A	N/A	18,307 [(b)]	16%	N/A	N/A
Residual – Inland Area	5,880,487 [(a)]	27%	269,972,736	20%	28,384 [(b)]	25%	3,162 [(c)]	11%
Total	**21,965,287**		**1,321,732,189** [(d)]		**115,756**		**29,210** [(d)]	

(a) Estimated using data from Australian Bureau of Statistics 2008a.
(b) Estimated using the IPCC default method and protein intake of 0.036 tonnes per year and IPCC default, 0.16 tonnes of nitrogen per tonne of protein
(c) Data value estimated from extrapolation of survey data for river discharge
(d) Total effluent and nitrogen discharged does not include the nitrogen discharged for the residual coastal population.

Sludge treatment and disposal practices were also examined in the survey. Results show that approximately 87 per cent of the nitrogen in sludge transferred out of treatment plants was reported as being used in a land application and 13 per cent was reported as being sent to landfills. The sludge generated by the residual population not covered by the survey has been estimated by extrapolating the data from the survey using a per-capita sludge generation value. Emissions from sludge sent to landfills are included in the solid waste sector while emissions from biosolids (treated sludge) used in a land application are included in agriculture.

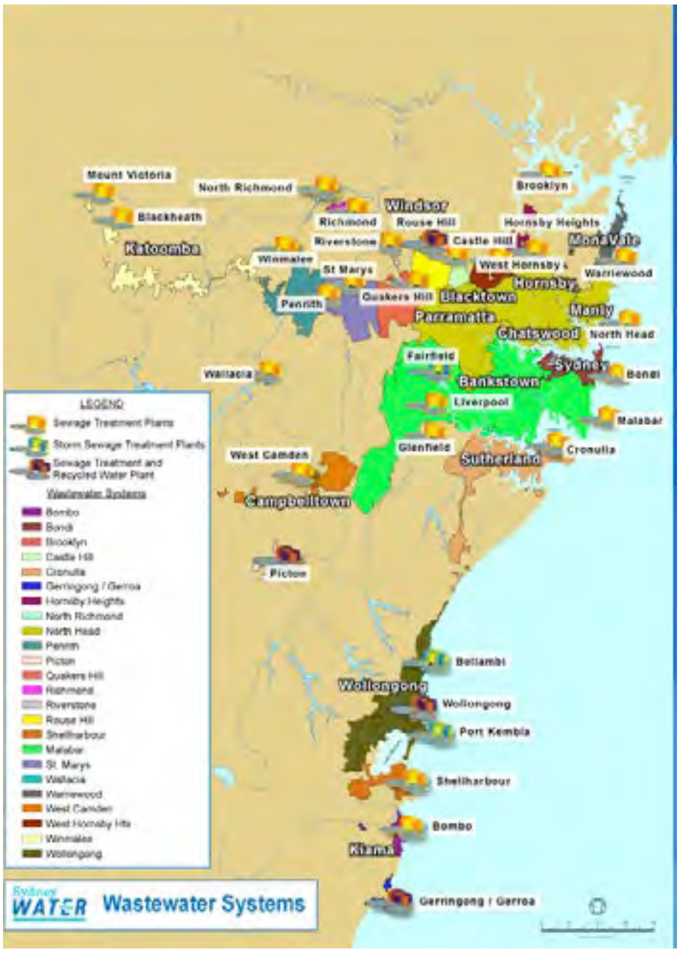
Table 7.20 Survey data for sludge reuse and disposal in 2008 and 2009

	Nitrogen (t)	% Contribution
Sludge to Landfill	1,435	13%
Sludge Reused in Land Application	5,494	49%
Residual Population – Sludge	4,336 (a)	38%
Total	**11,264**	**100%**

(a) Data value estimated from extrapolation of survey data for sludge

Sectoral snapshot: Sydney Water's effluent discharge Sydney Water Corporation is Australia's largest wastewater utility, with around 30 facilities servicing approximately 20 per cent of Australia's population mainly living in the cities of Sydney and Wollongong. In addition to providing annual reports on each facility to the New South Wales state government, Sydney Water also publish information about their operations on their website at www.sydneywater.com.au. A map of Sydney Water's operations is shown in Figure 7.10 and information made available on their website has been summarised in Table 7.21 below. The data in Table 7.21 shows that 17 of Sydney Water's facilities discharge into a river, however, most of the effluent discharged by volume, approximately 87 per cent, enters ocean and deep ocean waters.

Figure 7.12 Sydney Water Wastewater Systems



Source: Sydney water

Table 7.21 Sydney Water Corporation Wastewater Treatment Plants 2008

	Discharge Type	Discharge Point	Level of Treatment	Total volume of treated wastewater discharged to the waterway (million litres)	Estimated population Serviced	Total discharge load to waterway (kg)	
						BOD	Total nitrogen
Inland sewage treatment plants							
St Marys	River	South Creek (a tributary of South Creek)	Tertiary treatment	14,829	139,700	57,925	63,824
Quakers Hill	River	South Creek (Breakfast Creek, a tributary of Eastern Creek)	Tertiary treatment	13,816	144,400	36,693	64,606
Riverstone	River	South Creek (Eastern Creek, a tributary of South Creek)	Tertiary treatment	743	8400	1,532	5,796
Brooklyn	River	Hawkesbury River at Kangaroo Point	Tertiary treatment	14	500	36	127
West Hornsby	River	Waitara Creek, a tributary of Berowra Creek	Tertiary treatment	5,210	53,500	9,876	21,645
West Camden	River	Matahill Creek, a tributary of the Nepean River	Tertiary treatment	3,913	49,700	13,156	49,545
North Richmond	River	Redbank Creek, a tributary of the Hawkesbury River	Tertiary treatment	341	3,760	886	2,005
Richmond	River	Discharging mainly to irrigation schemes for a local university campus and golf course. Excess flows are discharged to an inland waterway (Rickabys Creek).	Tertiary treatment	391	7,800	675	1,671
Winmalee	River	Unnamed tributary of the Nepean River	Tertiary treatment	6,792	56,300	22,005	66,220
Hornsby Heights	River	Calna Creek, a tributary of Berowra Creek	Tertiary treatment	2,496	28,300	6,058	7,826
Rouse Hill	River	Second Ponds Creek, a tributary of Cattai Creek (partial discharge only)	Tertiary treatment plant and recycled water plant	4,355	63,100	6,168	31,662
Castle Hill	River	Cattai Creek	Tertiary treatment	3,134	24,900	13,157	46,805
Penrith	River	Boundary Creek, a tributary of the Nepean River	Tertiary treatment	9,541	96,800	18,776	39,799
Wallacia	River	Warragamba River	Tertiary treatment	242	2,670	721	1,351
Blackheath	River	Hat Hill Creek, a tributary of the Grose River	Tertiary treatment	424		1,676	10,983
Mount Victoria	River	Fairy Dell Creek, a tributary of the Cox's River	Tertiary treatment	72		843	885
Gerringong Gerroa	Recycled or to wetland	Treated wastewater is mainly discharged to an irrigation scheme for a local dairy farm.	Tertiary treatment		11,000	326	201

	Discharge Type	Discharge Point	Level of Treatment	Total volume of treated wastewater discharged to the waterway (million litres)	Estimated population Serviced	Total discharge load to waterway (kg)	
						BOD	Total nitrogen
Coastal sewage treatment plants							
Wollongong (incl. Bellambi and Port Kembla STPs)	Ocean	Reuse at Bluescope steelworks with remainder discharging to the ocean via an extended outfall one kilometre from the shoreline	Tertiary treatment	21,238	199,000	142,551	377,149
Shellharbour	Ocean	Ocean via a nearshore outfall (at Barrack Point).	Secondary treatment	6,681	60,000	29,557	121,904
Bombo	Ocean	Ocean via a shoreline outfall at the headland north of Bombo Beach	Secondary treatment	1,372	13,300	7,212	11,683
North Head	Deep Ocean	Ocean Outfall – The outfall discharges 3.7 km from the shoreline at 65 m maximum water depth	Primary treatment	138,623	1,240,000	34,096,767	6,816,185
Malabar (incl. Liverpool, Glenfield and Fairfield STPs)	Deep Ocean	Ocean Outfall – outfall discharges 3.6 km from the shoreline at 82 m maximum water depth	Primary treatment	185,415	1,690,000	38,204,663	7,669,426
Bondi	Deep Ocean	Ocean outfall 2.2 km from the shoreline at 63 m maximum water depth	Primary treatment	45,256	480,000	9,441,442	2,218,050
Cronulla	Ocean	Ocean via a shoreline outfall at Potter Point	Tertiary treatment	26,930	200,000	84,719	551,882
Warriewood	Ocean	Ocean via a shoreline outfall at Turimetta Head	Secondary treatment	6,878	59,000	71,445	216,595
TOTAL (for all plants)				**498,782**	**4,647,335**	**82,268,865**	**18,397,999**

7.6.2 Domestic wastewater (5.D.1) methodology

7.6.2.1 Methane emissions from wastewater treatment at municipal wastewater treatment plants (MWTPs)

Methane emissions from the treatment of wastewater at municipal wastewater treatment plants are estimated according to the default method set out in IPCC 2006, which relates emissions to the total quantity of organic waste treated at the MWTP. The emission factors applied to this quantity of organic waste are derived from a consideration of the type of treatment process used at the MWTP and the degree to which the organic waste is treated anaerobically.

Activity data: organic waste in wastewater

Quantities of organic waste in wastewater treated at individual MWTPs have been obtained under the NGER system (2009 onwards). Around 60 per cent of facilities reporting under the NGER system (numbering 75 in total and servicing around 60 per cent of Australia's population) measured the quantity of COD entering their facility directly. The weighted average per-capita COD entering these facilities is.0.0688 tonnes of COD per person per year.

For the remainder of the category's facilities, a country-specific value of 0.0585 tonnes of COD per person per year (NGGIC 1995) was used for the amount of organic waste in wastewater received at their sites.

Utilities reporting under the NGER system are also required to report the quantities of COD leaving their facility in effluent and treated in the form of sludge. Sludge refers to the solids generated in the wastewater treatment process. All wastewater treatment plants produce sludge requiring disposal. Sludge generated in Australia is often treated in sludge lagoons, sludge drying beds or anaerobic digesters. Treatment of this sludge can produce methane if it is allowed to decompose anaerobically. The amount of methane generated is variable depending on the type of treatment applied to the sludge. Biosolids are the product of sludge treatment suitable for use in land applications. Emissions from application of biosolids to land are included in the agriculture sector. Sludge and biosolids may also be sent to landfill. Emissions arising from the decomposition of sludge disposed to landfill are included in the solid waste sector.

As with the COD entering the facilities, NGER facility-specific data on COD sludge leaving the facility has been used where this variable has been measured directly. Where this data was unavailable, a country-specific fraction of COD removed and treated as sludge of 0.54 has been applied (NGGIC 1995).

Methodology

Emissions generated from the treatment of COD in wastewater are estimated according to the following equation:

$$CH_{4(t)} = (COD_{in} - COD_{sl} - COD_{out}) * EF_t$$

Where $CH_{4(t)}$ is the estimated CH_4 emissions from the treatment of sewage at wastewater plants

COD_{in} is the amount of COD input entering into wastewater treatment plants

COD_{sl} is the amount of COD treated separately as sludge

COD_{out} is the amount of COD effluent discharged from wastewater treatment plants into aquatic environments

EF_t is the emission factor for wastewater treated by wastewater plants.

Emissions generated from the treatment of sludge are estimated according to the following equation:

$$CH_{4(t)} = (COD_{sl} - COD_{trl} - COD_{tro}) * EF_{sl}$$

Where $CH_{4(t)}$ is the estimated CH_4 emissions from the treatment of sewage at wastewater plants

COD_{sl} is the amount of COD treated separately as sludge

COD_{trl} is the amount of COD as sludge removed and sent to landfill

COD_{tro} is the amount of COD as sludge removed and to a site other than landfill

EF_{sl} is the emission factor for sludge treated by wastewater plants.

Under the NGER system reporting provisions, wastewater facilities must characterise the type of treatment process used in terms of the fraction of COD (as both sludge and wastewater) treated anaerobically. This parameter is defined as the methane conversion factor (MCF). The 2006 IPCC default MCF values and the definition of the corresponding treatment processes associated with these defaults in Australia are shown in Table 7.22. Facilities reporting under the NGER system select the most appropriate MCF value for their operational circumstances.

Table 7.22 MCF values listed by wastewater treatment process

Classes of wastewater treatment in 2006 IPCC Guidelines	MCF Values	Applicable Wastewater Treatment Processes
Managed Aerobic Treatment	0.0	• Preliminary treatment (i.e. screens and grit removal) • Primary sedimentation tanks (PST) • Activated sludge processes, inc. anaerobic fermentation zones and anoxic zones for biological nutrient removal (BNR) • Secondary sedimentation tanks or clarifiers • Intermittently decanted extended aeration (IDEA), intermittently decanted aerated lagoons (IDAL) and sequencing batch reactors (SBR) • Oxidation ditches and carrousels • Membrane bioreactors (MBR) • Mechanically aerated lagoons • Trickling filters • Dissolved air flotation • Aerobic digesters • Tertiary filtration • Disinfection processes (e.g. chlorination inc. contact tanks, ultraviolet, ozonation) • Mechanical dewatering (e.g. centrifuges, belt filter presses)
Unmanaged Aerobic Treatment	0.3	• Gravity thickeners • Imhoff tanks
Anaerobic Digester / Reactor	0.8	• Anaerobic digesters • High-rate anaerobic reactors (e.g. UASB)
Anaerobic Shallow Lagoon (< 2 m deep)	0.2	• Facultative lagoons • Maturation / polishing lagoons • Sludge drying pans
Anaerobic Deep Lagoon (> 2 m deep)	0.8	• Sludge lagoons • Covered anaerobic lagoons

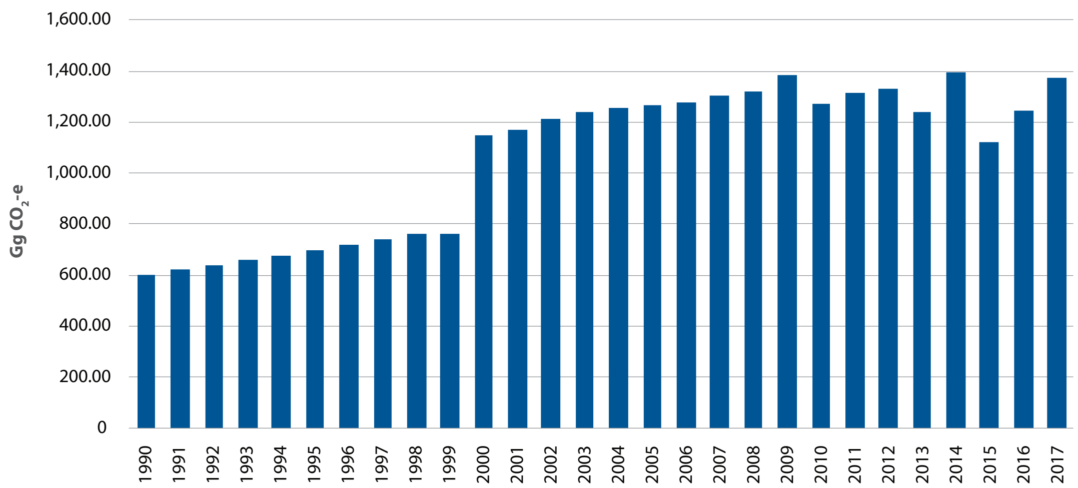
Source: WSAA 2011

Emission factors for each facility for wastewater and sludge are derived using equation 6.2 in IPCC 2006. The IPCC default maximum methane producing capacity (B_o) of 0.25 kg CH_4/kg COD is used for all facilities.

Methane capture

Methane recovered for combustion for energy or flared is deducted from the estimated methane generated and is based on directly measured quantities of methane captured for combustion and flaring reported under the NGER system (2009 onwards)for the years 2009 onwards. For 1990–2008, recovery is based upon a consideration of historical changes in methane capture capacity at individual wastewater treatment plants. A capture time-series for each wastewater utility has been established based on capture rates for 1990 reported in NGGIC 1995 and on subsequent reported commissioning of cogeneration plants, odour control system upgrades, and general plant capacity upgrades. Figure 7.13 shows the time-series for methane capture from domestic and commercial wastewater treatment. The significant increase in capture from the year 2000 corresponds to an improvement in capture capacity due to the commissioning of cogeneration facilities at a number of key wastewater treatment facilities serving particularly large populations. The small decline in capture in 2010 reflects a combination of changes to treatment processes (i.e. a shift to aerobic treatment) and reported declines in flaring and combustion of sludge biogas for energy production. The decline in capture in 2016 is due declines in capture levels reported under the NGER System at that time.

Figure 7.13 Methane capture from domestic and commercial wastewater treatment 1990–2017



No data is available on the precise split of methane recovery between wastewater and sludge treatment. For the purposes of reporting in table 5.B.s1 of the CRF table, methane recovery is allocated between wastewater and sludge such that emissions generated from the treatment of sludge are captured and the balance of reported capture is then allocated to wastewater treatment.

Choice of emission factor

There is a proportion of the wastewater treatment sector where no facility-specific data is available under NGER. The choice of parameters applicable to the residual portion of the sector was made in accordance with the decision tree described in Section 1.4.1.

As treatment processes employed at individual facilities are highly technology specific, it was not considered reasonable to extrapolate the factors obtained from NGER data to the facilities in the residual portion of the sector. Consequently, the per-capita COD and region-specific MCF values from NGGIC 1995 were used for 2009 for the residual of the category where no facility-specific data under NGER was available.

Waste

Time-series consistency

The use of NGER data has required careful consideration of time-series consistency issues. Facility-level activity data and emission factors are available from 2009 onwards. In order to preserve time-series consistency, facility-level activity data obtained under NGER has been back-cast as a fixed proportion of total population serviced in each state. Constant facility level MCF values and the proportion of methane generated that was captured in 2009 have been used with the back-cast activity data. This approach to maintaining time series consistency was based on the consideration that the larger-scale facilities covered by NGER utilise well established infrastructure and treatment processes that have not undergone significant changes since 1990.

The residual portion of the sector, for which no NGER facility-specific data is available, has been handled as described above for the entire time-series.

7.6.2.2 Methane emissions from on-site domestic and commercial wastewater treatment

IPCC 2006 default method for estimating methane emissions is used to estimate emissions from on-site domestic and commercial wastewater treatment. The total unsewered population on a State by State basis is calculated according to the Australian Bureau of Statistics (ABS 2009e) and WSAA data (WSAA 2005). It is assumed that each person in unsewered areas in Australia produces 0.0585 tonnes of COD per person per year (NGGIC 1995). The amount of COD that settles out as solids and undergoes anaerobic decomposition (MCF) is assumed to be 50 per cent, which is the IPCC default fraction for total urban wastewater (IPCC 2006). IPCC 2006 default emission factor of 0.25 kg CH_4/kg COD is used.

Sludge is also generated by on-site domestic and commercial wastewater treatment. Septic tank systems must be emptied occasionally of the sludge that accumulates inside the system. This sludge is typically transferred to a municipal wastewater treatment facility for further treatment.

7.6.2.3 Nitrous oxide emissions from domestic and commercial wastewater treatment

The methodology used to estimate N_2O emissions from domestic and commercial wastewater treatment utilises a detailed IPCC 2006 methodology and comprises estimates for emissions from sewage treatment at a wastewater plant; emissions from discharge of effluent into aquatic environments; and emissions from disposal of treated sludge to land.

$$\text{Total } N_2O\text{-}N = N_2O_{(t)}\text{-}N + N_2O_{(d)}\text{-}N + N_2O_{(l)}\text{-}N$$

Where N_2O-N is the estimated N_2O emissions from domestic and commercial wastewater treatment

$N_2O_{(t)}$-N is the estimated N_2O emissions from sewage treatment at a wastewater plant

$N_2O_{(d)}$-N is the estimated N_2O emissions from discharge of effluent

$N_2O_{(l)}$-N is the estimated N_2O emissions from application of treated sludge to land

N_2O emissions from sewage treatment at wastewater treatment plants

The emissions of N_2O from sewage treatment at wastewater treatment plants are estimated using the following equation:

$$N_2O_{(t)}\text{-}N = (N_{in} - N_{out} - N_{trl} - N_{tro}) * EF_6$$

Where $N_2O_{(t)}$-N is the estimated emissions from the treatment of sewage at wastewater plants

N_{in} is the amount of nitrogen input entering into wastewater treatment plants

N_{out} is the amount of nitrogen effluent discharged from wastewater treatment plants into aquatic environments

N_{trl} is the amount of nitrogen removed from wastewater treatment plants as sludge and disposed to landfill

N_{tro} is the amount of nitrogen removed from wastewater treatment plants as sludge and disposed at a site other than landfill (reused in land applications) and

EF_6 is the emission factor for sewage treated by wastewater plants

The total nitrogen input entering wastewater treatment plants for Australia in 2009 is obtained from facility specific measurements under NGER and, in addition, DCC 2009 yielded nitrogen treatment and discharge data for a group of utilities not captured under NGER. In total, facility level data obtained under NGER and DCC 2009 covered 108 facilities.

Estimates of the remainder of the nitrogen entering the national system is based on the residual population not covered by the facilities reporting under NGER or DCC 2009 and the average nitrogen input received by the wastewater plants per person serviced by the plants derived from the NGER system (2009 onwards)and DCC 2009 facility data. Together with the IPCC good practice assumption for the fraction of nitrogen in protein, 0.16 kg N/kg protein, the facility level data translates into a per capita protein consumption level of 104.9 kg per person per day in 2017.

Estimates of nitrogen leaving the system as effluent or as sludge disposed to landfill or to a land application, N_{out}, N_{trl} and N_{tro} have also been obtained by facility under the NGER system and DCC (2009).

The emission factor for the estimation of N_2O emissions from wastewater treatment, EF_6, is the IPCC 2006 default, 0.01 kg N_2O-N/kg N.

N_2O emissions from discharge of effluent

The effluent discharged into an aquatic environment may enter directly into a river, estuary, ocean surface waters or deep ocean environment depending on the location of the wastewater outfall of each treatment plant. As extensive facility-level information has been collected from verifiable sources on the quantities of nitrogen discharged by location of outfall, Australia is able to use a more detailed country-specific method rather than the IPCC tier 1 method while using IPCC (1997) default factors available for each aquatic receiving environment.

The emissions of N_2O from the discharge of effluent are estimated using the following equation:

$$N_2O_{(d)}\text{-}N = N_{outr} * (EF_{5\text{-}r} + EF_{5\text{-}e}) + N_{oute} * (EF_{5\text{-}e})$$

Where

$N_2O_{(d)}$-N is the emissions from discharge of effluent

N_{outr} is the amount of nitrogen discharged into rivers which then flows into an estuary

N_{oute} is the amount of nitrogen discharged into estuaries

$EF_{5\text{-}r}$ is the emission factor for rivers

$EF_{5\text{-}e}$ is the emission factor for estuaries

The amount of nitrogen discharged by aquatic environment for 2014 is obtained by facility under the NGER system and DCC 2009.

The IPCC 2006 default initial emission factors are 0.0025 kg N_2O-N/kg N for wastewater discharged into rivers (EF_{5-r}) and 0.0025 kg N_2O-N/kg N for wastewater discharged into estuaries (EF_{5-e}) (IPCC 2006 11.24). For wastewater discharged into rivers, the final emission factor is cumulative, (EF_{5-r} + EF_{5-e}), as it is assumed that the wastewater passes from the river system, through the estuaries and then into the sea. For wastewater discharged directly into an estuary, only (EF_{5-e}) is applied.

While the IPCC *Guidelines* state that nitrous oxide emissions resulting from sewage nitrogen are estimated from 'nitrogen discharge to aquatic environment' (IPCC 2006 page 6.25) it only an N_2O emission factor based on discharge to rivers and estuaries. Consequently, it is considered that there is no IPCC default method available for the estimation of emissions from effluent discharged directly to ocean waters. Nor is there any empirical literature available on emissions from disposal to ocean waters in Australia – such a study would be prohibitively expensive at this time. The results of the limited number of studies conducted that relate to ocean bodies outside of Australia are not considered appropriate to Australian marine conditions. They are, nonetheless, reviewed in the QA-QC section of this Chapter.

Ocean waters are defined to include only those bodies of water that are beyond the straight line drawn between the low-water marks of consecutive headlands so that waters within headlands, such as bays and basins, are included as part of the estuarine waters. Consequently, the delineation of ocean waters is considered conservative.

Table 7.23 IPCC emission factors for disposal of effluent by type of aquatic environment

Type of Aquatic Environment	Emission factor for initial disposal
River (EF5-r).	0.0025 kg N_2O-N/kg N
Estuary (EF5-e).	0.0025 kg N_2O-N/kg N

Source: IPCC 2006 page 11.24.

N_2O emissions from the application of treated sludge to land

The emissions of N_2O from the application of treated sludge to land is estimated using the following equation:

$$N_2O_{(l)}\text{-}N = N_{tro} * EF_7$$

Where $N_2O_{(l)}$-N is the emissions from treated sludge applied to the land

N_{tro} is the amount of nitrogen removed as treated sludge and applied to the land

EF_7 is the emission factor for treated sludge applied to land

The amount of nitrogen applied to land is obtained by facility under the NGER system (2009 onwards) and DCCEE (2009b). The emission factor for the application of treated sewage to land is 0.009 kg N_2O-N/kg N applied and is consistent with the N_2O emission factors for manure applied to crops and pastures (Bouwman *et al.* 2002). Emissions from the application of sludge to agricultural land are reported under agricultural soils (3.D) consistent with good practice.

Non-methane volatile organic compounds (NMVOC)

There has been little research into the release of NMVOC from wastewater treatment plants. BOD values obtained and used for calculations of methane emissions are used for the calculation of NMVOC from domestic and commercial wastewater and for industrial wastewater. A default value of 0.3 kg NMVOC/ tonne BOD for municipal wastewater treatment plants is used.

7.6.3 Industrial wastewater (5.D.2) methodology

Technologies for dealing with industrial wastewater in Australia are varied. Some industrial wastewater is treated entirely on-site, while a large amount is treated entirely off-site at municipal wastewater treatment plants. Increasingly industrial wastewater is partially treated on-site before being recycled or discharged to the sewer and treated at municipal wastewater treatment plants. This is due to trade waste discharge licence compliance requirements for a certain quality of wastewater to be achieved prior to sewer discharge.

Most of the industrially produced COD in wastewater comes from the manufacturing industry. According to the IPCC, sectors like food and beverage manufacturing produce significant amounts of COD, some of which is anaerobically treated. Some concentrated industrial wastewater is removed from factories in tankers operated by specialised waste disposal services. This wastewater is usually transported to a special treatment facility.

The methodology to determine the amount of CH_4 generated from industrial wastewater is based on IPCC 2000 and focuses on the 9 industrial sectors which are considered to generate the most significant quantities of wastewater in Australia:

- Dairy production;
- Pulp and paper production;
- Meat and poultry processing;
- Organic chemicals production;
- Sugar production;
- Beer production;
- Wine production;
- Fruit processing; and
- Vegetable processing.

Organic waste in wastewater

Quantities of organic waste in wastewater treated at industrial facilities have been obtained under the NGER system for 2009 onwards. Where available, the quantity of COD treated at each facility has been taken from direct measurements reported under the NGER system. Where facility-specific data under the NGER system are unavailable, estimates are based on country-specific wastewater and COD generation rates shown in Table 7.25.

NGER data are used where industry coverage is considered sufficient to provide a representative picture of wastewater treatment practices in a given industry. In the 2016 Inventory submission, NGER data covering the pulp and paper, beer and sugar, dairy, meat and poultry, wine, fruit and vegetables and organic chemicals industries are used.

Completeness

An analysis has been undertaken of the proportions of current production and facility numbers covered by NGERS. Where company/ facility coverage is complete or there is robust information about the composition and operational circumstances of the industry, it is possible to conclude that any residual production is not subject to onsite anaerobic wastewater treatment. This is the case for Pulp & paper, sugar and beer production. For the paper industry, NGERS covers all paper producing entities. Three of these four companies report emissions some form of anaerobic wastewater treatment. In the sugar industry, there are 8 producers operating 24 facilities. Five of these facilities do not undertake onsite anaerobic wastewater treatment. In the beer industry, there are three major producers operating 10 breweries. Nine of these breweries are covered by NGERS reporting. The tenth brewery does not operate onsite anaerobic wastewater treatment.

For the remaining commodities considered under industrial, wastewater treatment, NGERS coverage is not complete and emissions from residual wastewater are estimated using national statistics on production levels and commodity-specific parameters.

Table 7.24 provides further details of the consideration of residual commodity production and associated onsite wastewater treatment.

Table 7.24 Commodity production, coverage and residual wastewater treatment 2017

	Total commodity production	NGERS commodity production	% NGER coverage	Residual treatment
Dairy Production (litres)	9,016,000,000	1,132,052	12.6%	Residual based on total national production and commodity-specific parameters
Pulp and Paper Production (tonnes)	3,235,000	1,640,010	51%	All facilities covered by NGERS. Residual production not subject to onsite WW treatment or aerobic processes
Meat and Poultry Production (tonnes)	4,364,864	3,328,265	76%	Residual based on total national production and commodity-specific parameters
Organic Chemicals Production	1,837,591	42,165	2%	Residual based on total national production and commodity-specific parameters
Sugar Production (tonnes)	4,804,000	4,302,937	90%	All facilities covered by NGERS. Residual production not subject to onsite WW treatment or aerobic processes
Beer Production (Litres)	1,826,515,964	856,980,390	47%	2 of 3 major producers covered by NGERS. The remaining producer does not have on-site wastewater treatment.
Wine Production (Litres)	843,463,948	285,073,020	34%	Residual based on total national production and commodity-specific parameters
Fuit Processing (tonnes)	3,668,199	271,295	7%	Residual based on total national production and commodity-specific parameters
Vegetable Processing (tonnes)	2,994,556	46,375	2%	Residual based on total national production and commodity-specific parameters

Table 7.25 Country-specific COD generation rates for industrial wastewater, 2017

Commodity	Wastewater generation rate (m^3 wastewater/ t commodity produced)	COD generation rate (kg COD/m^3 wastewater generated)
Dairy	5.7	0.9
Pulp and Paper	26.7	0.4
Meat and Poultry	13.7	6.1
Organic Chemicals [(a)]	C	C
Sugar	0.4	3.8
Beer	5.3	6.0
Wine	23.0	1.5
Fruit	20.0	0.2
Vegetables [(a)]	C	C

Source: NGER 2017 (a) facility-level parameters obtained for organic chemical and vegetable production under the NGER system are confidential (C).

Choice of methane conversion factor

Emission factors for each facility for wastewater and sludge are derived using equation 6.2 in the IPCC 2006. The IPCC default maximum methane producing capacity (B_o) of 0.25 kg CH_4/kg COD is used for all facilities.

Under the NGER system reporting provisions, industrial wastewater facilities must characterise the type of treatment process used in terms of the fraction of COD (as both sludge and wastewater) treated anaerobically. This parameter is defined as the methane conversion factor (MCF). As with COD, data on facility-specific MCF values at industrial wastewater facilities are available for all listed commodities. Country-specific MCF values outlined in Table 7.26 are the weighted average MCF values based on data reported under NGERS.

Table 7.26 Methane conversion factors for industrial wastewater emissions, 2017

Commodity	MCF wastewater	MCF Sludge
Dairy	0.7	0.6
Pulp and Paper	0.3	0.0
Meat and Poultry	0.6	0.3
Organic Chemicals [(a)]	C	C
Sugar	0.3	0.04
Beer	0.8	0.8
Wine	0.6	0.5
Fruit	0.04	0.04
Vegetables [(a)]	C	C

Note: These values represent weighted averages where facility-level MCF values are reported.
Source: NGER 2017 (a) facility-level parameters obtained for organic chemical and vegetable production under the NGER system are confidential (C).

7.6.3.1 Methane emissions from disposal of sludge generated by industrial wastewater treatment

A proportion of the COD generated in the industrial wastewater is ultimately treated as sludge. Quantities of COD treated as sludge have been obtained for the dairy, paper, meat and poultry, sugar, beer, wine, fruit and vegetable processing industries from the NGER system. For the organic chemicals, a constant fraction of COD of 0.15 is assumed to be treated separately as sludge (NGGIC 1995).

Methane capture

Estimates of the quantities of methane captured have been obtained from the NGER system for dairy, paper, meat and poultry, sugar, beer, wine, fruit and vegetable processing facilities for 2009 onwards and derived from facility-level data in O'Brien (2006a) and NGGIC (1995) for the years 1990–2008. For organic chemicals for which NGER data has not been used, the sources are O'Brien (2006a) and NGGIC (1995).

As with domestic and commercial wastewater treatment, no data is available on the precise split of methane recovery between wastewater and sludge treatment. For the purposes of reporting in Table 5.B.s1 of the CRF table, methane recovery is allocated between wastewater and sludge on the basis of emissions generated from sludge treatment as a proportion of total capture with the balance being allocated to wastewater.

Table 7.27 Methane recovered as a percentage of industrial wastewater treatment 2017

Commodity	Fraction of methane recovered/flared (%)
Dairy	34%
Pulp and Paper	2%
Meat and Poultry	34%
Organic Chemicals	2%
Sugar	0%
Beer	64%
Wine	51%
Fruit	0.3%
Vegetables	5%

Source: NGER 2017.

Time-series consistency

Time-series consistency has been maintained through the interpolation of MCF values and proportions of methane captured for pulp and paper , sugar, dairy, meat and poultry, wine and fruit and vegetables for 1990–2008. For the beer industry, facility-specific MCF values and quantities of methane captured were available for the years 2003 to 2005. For the years 1990–2002 in the beer time series, the 2003 values for MCF and proportion of methane generated that was captured have been used. For the years 2006 – 2008, the 2009 NGER MCF and proportion of methane captured have been applied. This introduces a step change in the methane capture estimates for beer in 2006 where the amount of methane captured doubles, reflecting a doubling in treatment plant capacity in the beer industry during 2006.

For the organic chemicals where NGER data have not been used, time-series consistency is ensured through the use of a consistent methodology and associated parameters.

7.6.3.2 Nitrous oxide emissions from industrial wastewater

Nitrogen generated and discharged to the sewer system is ultimately treated at centralised municipal wastewater treatment plants. As N_2O emissions estimates at these plants are estimated based on the measurement of nitrogen entering the plant, this value is also inclusive of any nitrogen originating from industrial sources. Therefore emissions of N_2O from *industrial wastewater* are included in the estimate of N_2O emissions from *domestic wastewater*.

7.7 Uncertainties and time series consistency

7.7.1 Waste sector

The uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Time-series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to emission factors or methodologies occur, a full time-series recalculation is undertaken.

7.7.2 Wastewater treatment and discharge

Facility level data on nitrogen entering the domestic and commercial wastewater system is used for the years 2008 onwards, as reported in DCC 2009 and under the NGER system (2009 onwards). Time-series consistency has been maintained for the estimates of Australia's protein per capita intake through the following assumptions. The protein per capita consumption value for the years 1990 to 1993 of 99.4 g/day (36.28 kg/year) is sourced from the Australian Institute of Health and Welfare (AIHW) (de Looper and Bhatia 1998). The values for 1994 to 1998 are based upon data presented in AIHW 2002. Linear interpolation was used to derive values for 1999 to 2007, which is the period for which no data are available. The following table shows the time series for values used for protein per capita consumption.

Table 7.28 Estimates of implied protein per capita: Australia: 1990–2017

Year	Protein per capita g/capita/day
1990	99.4
2000	100.0
2005	97.6
2008	96.1
2009	98.3
2010	87.3
2011	85.2
2012	90.6
2013	89.8
2014	94.4
2015	103.6
2016	109.0
2017	92.5

Source: de Looper and Bhatia 1998 (1990-1993), AIHW 2002 (1994 – 1998), DCC 2009 (2008), NGER 2009 onwards.
Note: interpolation used for years 1999 to 2007 inclusive.

7.8 Source specific QA/QC

7.8.1 Solid waste disposal

Emissions from solid waste disposal reflect a large amount of activity data and assumptions in relation to parameters in the IPCC first order decay model. Consequently, an intensive and systematic quality control system is required to ensure that emission estimates meet the required quality characteristics of accuracy, completeness, comparability, time series consistency and transparency.

The quality control system has established measures to test the key data inputs and emissions estimates against each of these criteria.

The solid waste sector category is covered by the general QC measures undertaken for inventory identified in Section 1.6. In particular, emissions are estimated subject to the application of carbon balance constraints that ensures completeness; that carbon is tracked from harvest to disposal and that consistency between the harvested wood product and landfill pools is maintained. Estimates of carbon stored in wood products and in landfills are provided in Annex 6.

Quality assurance in relation to key parameters and the overall method for the sector was provided through review by an international external expert not involved in the inventory process (Guendehou 2009). Independent external review provides assurance that the approach adopted by Australia is consistent with the approaches adopted by other parties.

Additionally, as part of a systematic quality control process the emission estimates obtained for the Australian inventory are compared with those reported by other parties. Methane generation at landfills in Australia was assessed against the reported estimates of methane generated at landfills across all Annex I parties. It was concluded that the implied emission factor for Australian landfills was not significantly different to the mean implied emission factor for all Annex I parties.

Key parameters such as waste type fractions have been the subject of consultations with industry and industry experts. In particular, external experts have been utilised or review of available waste audit data, MCF, DOC_f and oxidation rates.

Analysis of available waste audit data utilised in this inventory was undertaken independently by two external expert consultancies (Hyder consulting 2008, GHD 2008).

The methane correction factor (MCF), which is intended to represent the extent of anaerobic conditions in landfills, was reviewed for this inventory by GHD 2010. The assessment of GHD confirmed that an MCF factor of 1.0 is appropriate for Australian landfills.

Country specific values for DOC_f for individual waste types were selected after consultation with independent consultants (GHD 2010, Hyder consulting 2010, Blue Environment 2010) and reviewed by an international expert reviewer not involved in the preparation of the inventory (Guendehou 2010). Guendehou concluded that the approach adopted lead to a significant improvement in the emission estimates.

Oxidation rates were reviewed (GHD 2010). Following the review, it was decided to retain the IPCC default assumption of 10 per cent until further research can be undertaken.

When NGER data were used for methane capture for the first time in the inventory in 2010, it was important to ensure time-series consistency was maintained. In order to ensure this was the case, the DCCEE engaged the external consultant who was previously used to collect methane capture information from landfill gas capture companies to undertake a QC analysis of the NGER capture data. Data were assessed for completeness and consistency with previously reported values. Capture estimates were compared with data available from the renewable energy certificate register as well as the NSW Greenhouse Gas Reduction Scheme register. The analysis confirmed that methane capture for energy generation was complete and consistent with previously reported data. For methane flaring, the analysis highlighted a completeness issue with respect to flaring occurring at local council landfills (in general, councils are not required to report under the NGER (2009 onwards) system). Therefore, this portion of flaring activity data had to be estimated for 2009 based on previously reported data.

Through this QC project, the DoEE was able to ensure continuity of expertise and knowledge used in the compilation of previous inventory submissions.

CRF table checks

The CRF tables are populated automatically using a piece of software developed in Australia called the CRF wizard. The CRF wizard is the interface between our Australian Greenhouse Emissions Information System (AGEIS) and the CRF reporter tool. The wizard undertakes the process of merging AGEIS data into CRF reporter XML output files.

In order to check CRF data are merged correctly by the wizard, there are general checks that are undertaken:

Emissions

- Check overall aggregate emissions exactly match those output by our AGEIS software – if there is a mismatch then go to 2.
- Check sectoral totals match AGEIS output – if there is a mismatch then go to 3
- Check sub-sectoral emissions by gas match AGEIS output by gas
- These steps are taken iteratively until Aggregate CO_2-e exactly match the AGEIS output.

Activity data

Activity data issues are identified using 3 main approaches:

- Check implied emission factor time-series fluctuations. Where implied emission factors change beyond the expected levels, then AD are assessed and corrected manually where necessary.
- Check time-series AD using CRF reporter chart functionality
- Sectoral experts perform manual checks of AD

CRF additional information

CRF additional information is more difficult to check than emissions or AD. Additional information is not generated by AGEIS in many cases. Most additional information is calculated within the calculation spread-sheets that are used as a QC check for AGEIS output.

CRF additional information QC these checks rely on manual crosschecking between the CRF reporter information and the spread-sheets used to derive additional information.

7.8.2 Wastewater treatment and discharge

The quality of the data utilised in this report has been assessed against facility data available through the State Government EPA licensing system. The Australian wastewater industry is heavily regulated by State Governments, which administer relevant state legislation such as the *Environmental Protection Act* 1994 in Queensland and the *Protection of the Environment Operations Act* 1997 in New South Wales. Under this legislation the State Governments issue environment protection licences to each premises treating wastewater. The licences require compliance with strict conditions including limits on odours, noise and organic matter and nutrients (nitrogen and phosphorus) discharged to water catchments. Annual reports must be submitted by wastewater facility operators to their state government to demonstrate their compliance and some of this information is publicly available through public registers, the National Pollutant Inventory and, in some cases, the operator's own website.

The protein per capita intake applied in this inventory was compared with an estimate calculated using the nitrogen entering treatment plants reported by Sydney Water in DCC 2009 and the population for Sydney Water's service area in 2007 according to the Australian Bureau of Statistics (Sydney Water services the cities of Sydney and Wollongong excluding Gosford and Wyong). A comparison of the calculated values for protein per capita is presented in Table 7.29 below.

Table 7.29 Estimates of implied protein per capita for Sydney Water Corporation: 2008, 2009

	Population	Protein per capita g/capita/day 2009
Sydney Water Estimated Population Serviced (DCC 2009)	4,262,840	98.3
ABS Population for Sydney and Wollongong (excluding Gosford and Wyong) in 2007	4,307,057	97.3
Inventory values used for residual population connected to the sewer	6,734,007	98.3

The estimated population serviced as reported by Sydney Water in DCC (2009) is less than the 2007 population reported by the Australian Bureau of Statistics (ABS 2007). Sydney Water's estimate of population serviced excludes four of the smaller facilities and the unsewered population and is derived from forecast dwellings in the NSW Government's Metropolitan Development Program (MDP) for 2007/08. The protein per capita values calculated using the Sydney Water estimated population therefore provide a more appropriate estimate of the protein per capita value than those derived from the ABS population figures. Per capita protein consumption based on Sydney Water population serviced and DCC 2009 has been estimated as 98.3 g/day for 2009.

The protein per capita consumption for the 2017 Inventory, derived from NGER facility data, has decreased slightly to 92.5 g/day. Facility data received under the NGER system for the first 5 years of reporting indicates a degree of volatility associated with this factor. Those facilities reporting the underlying data, however, do undertake frequent sampling and analysis and must also adhere to legislated requirements to ensure the data is representative and free from bias. Nitrous oxide emissions are concentrated in rivers and estuaries where the processes for N_2O production can take place in both the water column and the sediments. N_2O emissions also arise from ocean waters in the continental shelf region; however, while these emissions may occur from human activity, they also occur naturally and are very difficult to isolate empirically.

A good understanding of how N_2O emissions occur in the continental shelf region and the influences of human activity on them is still being formed. Nitrous oxide formation is very dependent on regional conditions and chemistry and location of outfalls. Some studies have been undertaken which attempt to measure or characterise the N_2O in the continental shelf regions of Europe (Bange 2006, Barnes and Owens 1998), Canada (Punshon and Moore 2004) and North China (Zhang *et al.* 2008). A literature survey of four such studies determined an average emission rate for continental shelf/oceanic coastal waters of 0.0018 kg N_2O-N/kg N discharged. The regions studied, however, are influenced by very different marine conditions to those in Australian waters and also do not consider the effects of treated wastewater discharges (Foley and Lant, 2007). The regional marine conditions are a major influence on the production of N_2O (Zhang *et al.* 2008). An appropriate method and emission factor for estimating N_2O emissions from wastewater discharged to coastal and continental shelf waters would require further research.

A reconciliation of the quantity of sludge transferred from wastewater treatment to landfills and the sludge entering the landfills has been undertaken. To estimate the sludge transferred from industrial wastewater treatment it is assumed that 40 per cent of the sludge removed from the wastewater is sent to landfill. The conversion of COD to wet sludge is calculated by assuming the volatile solids proportion of dry solids is in the range of 60 – 90 per cent and the dry content matter of wet sludge is 15 per cent. For domestic and commercial wastewater, the tonnes of nitrogen sent to landfill are converted to wet sludge using a nitrogen content range of 40,000 to 80,000 mgN per kg dry solids and a dry content matter of wet sludge of 15 per cent.

Using these assumptions an estimate of the minimum and maximum possible quantities of wet sludge sent to landfill has been calculated for 1990 to 2016. The range of estimates for each year was found to be very large. In 2014, the minimum quantity of wet sludge sent to landfill from wastewater treatment was 621 kt while the maximum quantity was estimated to be 248 kt. These values are significantly higher than the estimate of wet sludge disposed to landfills estimated under the solid waste sector (less than 100 kt). This comparison highlights the challenges in converting quantities of nitrogen and COD to a quantity of wet sludge disposed to landfill. The assumptions and parameters such as nitrogen content of dry solids require further investigation to determine their suitability and exact magnitude.

The wastewater sector source categories are also covered by the general QA/QC of the greenhouse gas inventory in section 1.6.

7.9 Recalculations since the 2016 Inventory

7.9.1 Solid waste disposal

No recalculations were required for emissions associated with *solid waste to landfill.*

Table 7.30 5.A Solid Waste: recalculation of methane emissions (Gg CO_2-e)

	2018 Submission Gg CO_2-e	2019 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.A Solid Waste Disposal				
1990	15,240	15,240	0	0.00%
2000	12,238	12,238	0	0.00%
2005	10,900	10,900	0	0.00%
2008	11,307	11,307	0	0.00%
2009	11,229	11,229	0	0.00%
2010	11,502	11,502	0	0.00%
2011	11,064	11,064	0	0.00%
2012	9,775	9,775	0	0.00%
2013	9,001	9,001	0	0.00%
2014	9,012	9,012	0	0.00%
2015	8,510	8,510	0	0.00%
2016	8,694	8,694	0	0.00%

7.9.2 Wastewater treatment and discharge

A recalculation was performed for domestic wastewater treatment and discharge due an updated of the annual per capita protein intake based on updated NGER data.

Table 7.31 5.D Domestic wastewater: recalculation of emissions (Gg CO_2-e)

	2018 Submission Gg CO_2-e	2019 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.D.1 Domestic Wastewater				
1990	2,327	2,321	-6.20	-0.27%
2000	1,853	1,844	-9.57	-0.52%
2005	1,915	1,906	-9.55	-0.50%
2008	2,066	2,056	-10.27	-0.50%
2009	2,072	2,038	-34.08	-1.64%
2010	2,208	2,149	-59.00	-2.67%
2011	2,062	1,943	-118.70	-5.76%
2012	1,766	1,731	-35.25	-2.00%
2013	1,524	1,687	162.74	10.68%
2014	1,731	1,858	127.42	7.36%
2015	1,835	2,058	222.49	12.12%
2016	2,028	2,028	-	0.00%

No recalculations were required for emissions associated with industrial wastewater.

Table 7.32 5.D Industrial wastewater: recalculation of emissions (Gg CO_2-e)

	2018 Submission Gg CO_2-e	2019 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.D.2 Industrial Wastewater				
1990	2,356	2,356	-	0.00%
2000	1,446	1,446	-	0.00%
2005	1,405	1,405	-	0.00%
2008	1,417	1,417	-	0.00%
2009	1,413	1,413	-	0.00%
2010	1,317	1,317	-	0.00%
2011	1,257	1,257	-	0.00%
2012	1,194	1,194	-	0.00%
2013	1,388	1,388	-	0.00%
2014	1,328	1,328	-	0.00%
2015	1,085	1,085	-	0.00%
2016	1,382	1,382	-	0.00%

7.9.3 Incineration and open burning of waste

No recalculations have been made to Incineration and open burning of waste.

Table 7.33 5.C Incineration: recalculation of emissions (Gg CO_2-e)

	2018 Submission Gg CO_2-e	2019 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.C Incineration and Open Burning of Waste				
1990	87	87	-	0.00%
2000	28	28	-	0.00%
2005	28	28	-	0.00%
2008	29	29	-	0.00%
2009	30	30	-	0.00%
2010	30	30	-	0.00%
2011	30	30	-	0.00%
2012	30	30	-	0.00%
2013	30	30	-	0.00%
2014	31	31	-	0.00%
2015	30	30	-	0.00%
2016	31	31	-	0.00%

7.9.4 Biological treatment of solid waste

No recalculations have been made to biological treatment of solid waste.

Table 7.34 5.B Biological Treatment of Solid Waste: recalculation of emissions (Gg CO_2-e)

	2018 Submission Gg CO_2-e	2019 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.B Biological Treatment of Solid Waste				
1990	22	22	0	0.00%
2000	106	106	0	0.00%
2005	148	148	0	0.00%
2008	181	181	0	0.00%
2009	190	190	0	0.00%
2010	215	215	0	0.00%
2011	250	250	0	0.00%
2012	254	254	0	0.00%
2013	258	258	0	0.00%
2014	262	262	0	0.00%
2015	266	266	0	0.00%
2016	273	273	0	0.00%

7.10 Source specific planned improvements

7.10.1 Solid waste disposal

The DoEE initiated a move to the use of tier 3 methods for the estimation of emissions from solid waste disposal in the 2013 submission. The availability of facility-level data collected under the NGER system has enabled a facility-specific and spatially explicit approach to be adopted for the largest landfills which has supplemented the previous State-based approach which continues to be used for the non-NGER proportion of the landfill sector.

Facility-level data used in this submission are limited to waste disposal quantities and composition and methane capture for all landfill facilities triggering NGER system reporting thresholds. Decay rate constants have been assigned to each landfill based on their individual geospatial coordinates and BOM climate data.

Under the NGER system, operators of landfills are encouraged to undertake audits of waste data received and to collect data on methane generation rates to enable the operator to determine a facility-specific 'k' value so that 'k' will reflect both localised climate and management conditions. However, to date, no landfills have undertaken these measurements. The DoEE will continue to review the availability of data and where available these will be used to ensure that the decay functions applied at individual landfills reflect both local climatic conditions and facility management practices. The latter is particularly important as practices can vary considerably – for example, two in every five landfills practice leachate control which would significantly increase the value of 'k' at a landfill facility.

Initial testing of the methods at landfills has demonstrated the value of ensuring that local climate and management practices are explicitly taken into account. The methods to be used to determine 'k' are provided in the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*.

For the residual disposal not covered by the NGER system reporting, The DoEE will explore the possibility of estimating emissions at a more spatially disaggregated level to enable climatic variation to be accounted for in the residual estimates. The implementation of this planned improvement will depend of the availability of disposal data at a more disaggregated level than is currently available.

As part of the in-country review of Australia's 2008 national inventory, the Expert Review Team encouraged the DoEE to develop country-specific DOC values. This will be explored over coming years to determine the best empirical approach to support the development of such values.

During the 2015 review, the ERT encouraged Australia to assess the possibility of using a monthly time-step rather than annual in the FOD model. While Australia is fully compliant with the requirements of the 2006 IPCC Guidelines, this potential improvement will be kept under consideration, subject to the availability of necessary resources to enable the analysis to be undertaken.

7.10.2 Wastewater treatment and discharge

The DoEE will keep industrial wastewater model parameters and methods under review based on facility level data reported under the NGER system.

7.10.3 Incineration and open burning of waste

The DoEE will review NGER system reports with a view to the potential inclusion of additional facility data for future inventory submissions.

7.10.4 Biological treatment of solid waste

The ERT reviewing Australia's 2017 Inventory submission recommended that Australia provide more information in the NIR on the choice of proxy for extrapolating composting AD. Accordingly, Australia is reviewing the use of population data as a proxy and investigating whether a more appropriate driver is available. It is anticipated that this work will be complete in the next inventory submission.

8 Other (CRF Sector 6)

Australia does not report any emissions under CRF sector 6, ‘Other’.

9 Indirect CO_2 and nitrous oxide emissions

For the purpose of paragraph 29 of decision 24/CP.19, Australia has elected not to report indirect CO_2 and nitrous oxide emissions. Information on indirect CO_2 and nitrous oxide emissions in the *Energy* and *Agriculture* sectors can be found in Chapters 3 and 5 respectively.

10 Recalculations and improvements

Emissions processes are pervasive and complex and, consequently, emissions estimation techniques and data sources for the Australian inventory continue to be refined, updated and improved.

More generally, the development effort behind recalculations is undertaken in line with the *Inventory Improvement Plan* for the Australian inventory. This plan is aimed at reducing existing emission estimate uncertainties as much as possible, with development focused on key source categories, sources with high uncertainties and where implementation of new methods is feasible (for example, as a result of new data becoming available). The Australian improvement plan also responds to international expert reviews and changes in international practice. Some of the elements of the improvement program are set out in section 10.4.

10.1 Explanations and justifications for recalculations

Key reasons for recalculations in this inventory are given in the sectoral chapters and are summarised in Table 10.1. Principal reasons include revisions of activity data, the inclusion of additional sources of data or from refinements in the estimation methodology including in response to recommendations of previous UNFCCC expert reviews. To ensure the accuracy of the estimates, and to maintain consistency of the series through time, recalculations of past emission estimates are undertaken for all previous years.

submission, and are in addition to recalculations made in the 2016 submission on the 2015 submission which was the subject of the most recent UNFCCC review.

Table 10.1 Recalculations in the 2017 inventory (compared with the 2016 inventory) key reasons and quantitative impact

Sector		Category	Reason for Recalculation	Further Explanation and quantitative impact
1.A	Energy Industries	1.A.1	Revisions by Department of the Environment and Energy (DoEE) to the Australian Energy Statistics (AES) due to the incorporation of improved activity data available under the NGER. 1.A.1.a Electricity and heat production Minor recalculations were made in 1.A.1.a Electricity in years 2012 to 2015 as a result of updates to the AES estimates for biomass and natural gas. 1.A.1.c Manufacturing of solid fuels and other energy industries Revisions were made to the AES to the petroleum products nec fuels.	Section 3.3.5 of NIR Volume 1.
	Manufacturing Industries and Construction	1.A.2	Revisions by DoEE to the AES due to the incorporation of improved activity data available under the NGER. Recalculations were made in response to revisions by the Department in the fuel consumption reported in the Australian Energy Statistics that better aligns with NGER and results in improvements in time series consistency. 1.A.2.b Non-ferrous metals The main driver for recalculations for 2012 to 2015 was AES revisions to the petroleum product nec fuels. 1.A.2.g Other (a) The main driver for recalculations for 2011 to 2016 was AES revisions to the natural gas, diesel fuels and petroleum product nec fuels.	See Section 3.4.5 of NIR Volume 1.

Sector		Category	Reason for Recalculation	Further Explanation and quantitative impact
	Transport	1.A.3.	Minor recalculations resulted from revised data from the Department of Defence for fuel consumption in military transport. This resulted in a revision of the allocation of total national fuel sales to military use and domestic use in road transport and aviation. In addition, a minor recalculation for road transport was made as a result of revised data on the motor vehicle fleet population. It is expected that further recalculations for key transport fuels will be made for future releases of the AES, resulting in additional recalculations for emissions estimates. These are expected to be minor refinements of recalculations presented in this submission.	See Section 3.5.5 of NIR Volume 1
	Other Sectors	1.A.4	1.A.4.a Commercial/institutional The main driver was the revision in the consumption of ADO and natural gas fuels in the Commercial/ institutional sector. 1.A.4.b Residential and 1.A.4.c Agricultural, forestry and fishing Minor recalculations were made to increase accuracy and consistency applied to all non-CO_2 emission factors in sectors which prompted minor changes to non- CO_2 emissions.	See Section 3.6.5 of NIR Volume detailed at the sub-category level in Table 3.26.
	Other	1.A.5	Minor recalculations to Military Transport with the inclusion of updated data from the Department of Defence.	Section 3.7.5 Table 3.28
1.B	Fugitive Emissions	1.B.1	There were no recalculations affecting this subsector in the 2019 submission.	
	Fugitive Emissions	1.B.2	Revised natural gas sales figures relating to natural gas distribution was provided in the Australian Energy Update 2018 (DoEE 2018), which resulted in minor recalculations for estimates of emissions for 1B2biii5 Distribution.	Further detail is available in NIR Volume 1, sections 3.9. Recalculations, are quantified in Table 3.46.
2	Industrial Processes	2.A	There were no recalculations affecting this subsector in the 2019 submission.	
		2.B	There were no recalculations affecting this subsector in the 2019 submission.	
		2.C	There were no recalculations affecting this subsector in the 2019 submission.	
		2.D	There were no recalculations affecting this subsector in the 2019 submission.	

Sector		Category	Reason for Recalculation	Further Explanation and quantitative impact
		2.F	A. Recalculations have occurred throughout the time-series as a result of the calibration of annual leakage rates for HFC emitting equipment from 2006 onwards to CSIRO atmospheric measurements. B. a correction to the unit charge of split systems from 2006 onwards. C. a revision to the method for aerosol emissions to ensure all charge is lost over 3 years. D. updates to CSIRO atmospheric SF6 observation data from 2010 onwards	Section 4.9.3 of NIR Volume 1
		2.H	There were no recalculations affecting this subsector in the 2019 submission.	
3	Agriculture	3.A	Recalculations of enteric fermentation have occurred due to: A. a revision to the milk production data for 2012/ 2013/ 2014, 2015 and 2016. B. a revision to the regional breakdowns of beef cattle pasture for 2012, 2013, 2014, 2015 and 2016. C. a revision to 'other livestock' population numbers for 2016. D. a revision to 'sheep' population numbers for 2016. E. a revision to 'swine' population numbers for 2016.	5.3.8
		3.B	A recalculation of manure management occurred due to: A. a revision to the 2015 milk production data for 2012/ 2013/ 2014, 2015 and 2016. B. a revision to the regional breakdowns of beef cattle pasture for 2012, 2013, 2014, 2015 and 2016. C. a revision to 'other livestock' population numbers for 2016. D. a revision to 'sheep' population numbers for 2016. E. a revision to 'swine' population numbers for 2016.	5.4.11
		3.C	There were no recalculations affecting this subsector in the 2018 submission.	5.5.5
		3E	All emissions have been re-allocated to 4.A.1 Forestland remaining forestland, 4.C.1 Grassland remaining grassland and 4.C.2 Land converted to grassland. New methods and revised fire scar analysis.	4.A.1 4.C.1 4.C.2
		3F	Recalculations of Field Burning of Agricultural Residues have occurred due to an update of soybean production data in 2015.	5.8.4
		3G	There were no recalculations affecting this subsector in the 2018 submission.	5.9.5
		3H	A recalculation has occurred in the 2015 inventory year due to a revision in urea consumption data.	5.10.5

Sector		Category	Reason for Recalculation	Further Explanation and quantitative impact
4	LULUCF	4.A.1	Recalculations of *Forest land remaining Forest land* estimates have occurred due to: A. *Other native forests*: methodological change: moving to Tier 3, Approach 3 spatial simulation of fires using FullCAM in tropical forests and for temperate wildfires B. *Pre- 1990 plantations*: Methodological change: moving to Tier 3, Approach 3 spatial simulation of pre-1990 plantations using FullCAM C. Harvested native forests: Age structure of managed forest estate updated over the full time series to reflect data on forests harvested in 2017. Corrections to harvesting activity data in 1990.	Section 6.4.5
		4.A.2	Recalculations of *Land converted to Forest Land* have occurred due to: For *cropland* and *grassland converted to forest land*: A. improvement to the key site productivity parameter in FullCAM's growth model B. inclusion of 'Standing Dead' debris pool C. improvements in FullCAM simulation and updates to spatial input datasets D. additional refinements to FullCAM to reduce uncertainty and address minor issues. For *wetlands converted to forest land*: Refinements in geospatial identification of mangrove afforestation/ reforestation areas.	Section 6.5.5
		4.B.1	Recalculations of *Cropland Remaining Cropland* have occurred due to: A. a change in the reporting method for emissions from soil carbon to a stock change approach (i.e. managed land proxy). B. enhanced geospatial monitoring. C. revised time series of climate data in FullCAM for simulating soil decay rates. D. the inclusion of the latest land census survey data for land management practices. E. improvements to the parameterisation of the FullCAM fire event. F. improvements to the modelling of the resistant debris pool in FullCAM. G. updated parameterisation of the resistant fraction of crop and pasture species. H. updated root: shoot ratios for crop and posture species	Section 6.6.5

Sector	Category	Reason for Recalculation	Further Explanation and quantitative impact
	4.B.2	Recalculations of *Land converted to Cropland* have occurred in the sub-category *forest land converted to cropland*. This is due to: A. improvements to the characterisation of tree growth under the FullCAM tree yield formula; B. the addition of new and revised geospatial source information; C. updates to the management of spatial information; and D. the implementation of Standing Dead behaviour in tree systems.	Section 6.7.5
	4.C.1	Recalculations of *Grassland Remaining Grassland* have occurred due to changes in pasture management and in shrub transitions. Changes in pasture management: A. a change in the reporting method for emissions from soil carbon to a stock change approach (i.e. managed land proxy). B. enhanced geospatial monitoring. C. revised time series of climate data in FullCAM for simulating soil decay rates. D. improvements to the parameterisation of the FullCAM fire event. E. improvements to the modelling of the resistant debris pool in FullCAM. F. updated parameterisation of the resistant fraction of pasture species. G. updated root:shoot ratios for crop and pasture species H. changes in live biomass I. activity data for grass and shrub transitions has been revised due to improvements in image classification and expanded national coverage.	Section 6.8.5
	4.C.2	Recalculations of *Land converted to Grassland* have occurred in the sub-category *forest land converted to grassland*. This is due to: A. improvements to the characterisation of tree growth under the FullCAM tree yield formula; B. the addition of new and revised geospatial source information; C. updates to the management of spatial information; and D. the implementation of Standing Dead behaviour in tree systems.	Section 6.9.5

Sector		Category	Reason for Recalculation	Further Explanation and quantitative impact
		4.D.1	Recalculations of *Wetlands Remaining Wetlands* have occurred due to: A. revision of activity data for the 2016 aquaculture production to align with that reported in the Australian Fisheries and aquaculture statistics 2017 (ABARES, 2018) B. revised activity data for grass and shrub transitions due to improvements in image analysis and expanded national coverage; C. under the revisions for non-temperate fire management described under forests remaining forests, reporting of these emissions from fire has been extended to *wetlands remaining wetlands* where they are observed to occur on wetlands.	Section 6.10.5
		4.D.2	Recalculations of *Land converted to Wetlands* have occurred due to improvements in remote sensing of forest cover change and in FullCAM modelling parameters.	Section 6.11.5
		4.E.1	Recalculations of *Settlements remaining Settlements* have occurred due to revisions to activity data for grass and shrub transitions due to improvements in image analysis and expanded national coverage .	Section 6.12.5
		4.E.2	Recalculations of *Land converted to Settlements* have occurred due to: A. refinements to FullCAM modelling of terrestrial forests – as detailed in section 6.9.5, recalculation of *forest land converted to grassland*; B. refinements in geospatial identification of mangrove forest converted to settlements areas; and C. refinements to activity area for tidal marsh converted to settlements flowing from refinements in identification of mangrove transitions.	Section 6.13.5
		4.G	Recalculations of *Harvested Wood Products* have occurred due to: A. revised estimates in the Australian Forest and Wood Products Statistics (ABARES 2018) and other data changes, including an update to the accuracy of historical production estimates.	Section 6.15.5
6	Waste	5.D.1	A recalculation was performed on *Domestic and commercial wastewater treatment and discharge* due to an update of the annual per capita protein intake, based on updated NGER data.	Section 7.9.2 of NIR Volume 2

10.2 Implications for emission levels

The impact of the recalculations on emission levels for the sectors excluding *LULUCF* was an increase in the estimate of total emissions; these increases were 28.1 Mt or 4.9 per cent in 1990 and 5.4 Mt or 1.0 per cent in 2016 compared with last year's submission (see Table 10.3). The recalculations including the *LULUCF* sector resulted in an increase in the estimate of total emissions for 1990 of 27.8 Mt or 17.8 per cent and a decrease of 7.8 Mt or 32.3 per cent in 2016 compared with last year's submission (see Table 10.3).

Table 10.2 gives the estimated recalculations for this submission for each category for 1990 and the past nine years.

Table 10.2 Estimated recalculations for this submission (compared with last year's submissions 1990, 2008–2016)

Sector	1990 Mt	2008 Mt	2009 Mt	2010 Mt	2011 Mt	2012 Mt	2013 Mt	2014 Mt	2015 Mt	2016 Mt
1.A Fuel Combustion	0.0	-0.3	-0.7	-0.7	-0.4	-0.7	-0.7	-0.8	-1.3	-1.1
1.A.1, 2, 4, 5 Stationary Energy	0.0	0.0	-0.3	-0.3	0.0	-0.2	0.0	-0.1	-0.4	0.0
1.A.3 Transport	0.0	-0.3	-0.4	-0.4	-0.4	-0.5	-0.7	-0.8	-0.9	-1.1
1.B Fugitives	0.0	0.0	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	-0.3
2 Industrial Processes	0.0	-0.6	-0.2	-0.8	-1.1	-1.8	-1.7	-1.4	-1.0	-1.2
4 Agriculture	0.2	0.1	0.1	-0.1	-0.3	-0.3	-0.4	-0.1	0.0	0.1
6 Waste	0.0	0.0	0.0	-0.1	-0.1	0.0	0.2	0.1	0.2	0.1
5 Core Land Use, land use change and forestry (excl. CRC & GRGCroplands remaining) and Grasslands remaining)	1.3	11.7	7.8	6.2	6.4	9.7	7.2	2.3	9.4	2.6
Sub-total Total Inventory less cropgrass lands (excl. Croplands remaining and Grasslands remaining)	1.5	10.9	6.7	4.4	4.2	6.8	4.3	-0.1	7.0	0.2
5. Additional LULUCF – Croplands Remaining and Grasslands Remaining	26.6	16.7	25.7	19.7	13.1	27.3	19.3	12.2	7.4	5.2
Total Recalculation	28.1	27.6	32.4	24.1	17.4	34.1	23.6	12.1	14.4	5.4

10.3 Implications for emission trends, including time series consistency

The full time series of estimated recalculations is set out in Table 10.3. The net effect of the recalculations on aggregate emission trends for the sectors excluding *LULUCF* is an increase of emission estimates between 0.0 and 0.8 per cent. The net effect of the recalculations on aggregate emission trends for the sectors including LULUCF is between a decrease of 2.0 per cent and an increase of 1.9 per cent of emission estimates.

Table 10.3 Estimated recalculations for this submission (compared with last year's submission 1990–2016)

	Including LULUCF				Excluding LULUCF			
	Previous estimate	Current Estimate	Difference		Previous estimate	Current Estimate	Difference	
	Mt CO_2-e	Mt CO_2-e	Mt	%	Mt CO_2-e	Mt CO_2-e	Mt	%
1990	576.8	604.9	28.1	4.9	420.1	420.3	0.2	0.1
1991	553.2	583.0	29.8	5.4	421.3	421.4	0.1	0.0
1992	517.9	522.0	4.0	0.8	426.1	425.7	-0.4	-0.1
1993	496.2	503.9	7.7	1.6	426.3	426.2	0.0	0.0
1994	493.2	495.0	1.9	0.4	426.4	426.3	-0.1	0.0
1995	490.5	482.6	-7.9	-1.6	435.9	434.9	-0.9	-0.2
1996	492.9	489.6	-3.3	-0.7	442.9	442.5	-0.4	-0.1
1997	508.5	500.5	-7.9	-1.6	454.9	454.6	-0.3	-0.1
1998	515.9	502.5	-13.3	-2.6	468.8	468.4	-0.4	-0.1
1999	536.4	516.6	-19.9	-3.7	474.5	474.0	-0.5	-0.1
2000	547.0	536.2	-10.8	-2.0	485.3	485.0	-0.3	-0.1
2001	567.4	564.8	-2.6	-0.5	492.7	492.5	-0.2	0.0
2002	567.9	562.0	-5.9	-1.0	496.6	496.3	-0.3	-0.1
2003	572.0	572.5	0.5	0.1	498.9	498.1	-0.8	-0.2
2004	577.0	582.0	5.0	0.9	516.3	515.9	-0.4	-0.1
2005	604.7	610.6	5.9	1.0	522.4	521.8	-0.6	-0.1
2006	614.9	611.5	-3.5	-0.6	527.0	526.4	-0.5	-0.1
2007	616.7	627.0	10.3	1.7	534.6	533.1	-1.4	-0.3
2008	588.1	615.7	27.6	4.7	537.8	537.0	-0.8	-0.2
2009	578.2	610.6	32.4	5.6	542.0	540.9	-1.1	-0.2
2010	561.9	586.0	24.1	4.3	539.2	537.3	-1.9	-0.4
2011	550.3	567.7	17.4	3.2	540.4	538.3	-2.2	-0.4
2012	524.6	558.7	34.1	6.5	543.6	540.6	-3.0	-0.5
2013	514.1	537.7	23.6	4.6	533.3	530.4	-2.9	-0.5
2014	521.0	533.1	12.1	2.3	527.3	525.0	-2.4	-0.4
2015	517.2	531.6	14.4	2.8	537.6	535.2	-2.4	-0.4
2016	525.0	530.4	5.4	1.0	549.2	546.8	-2.4	-0.4

10.4 Planned improvements – national inventory systems

Priorities for the inventory development process have been set out in the *National Inventory Systems Inventory Improvement Plan* and have been informed by analysis of key sources and key trends. The overall aim of inventory improvement is to improve the accuracy and reduce uncertainties associated with the national inventory estimates.

The Department has implemented systematic review processes into the national inventory system to drive continuous improvements in inventory quality. *The Quality Assurance-Quality Control Plan* is an integral part of this process. In terms of emission estimation methodologies, these annual processes are principally implemented by the following.

Review of selection of methods

Decisions are made each year as to whether IPCC tier 1, 2 or 3 methods should be applied for a category, implementing QC Measure 3.A.1 (i) as set out in the *National Inventory Systems Quality Assurance-Quality Control Plan*. Method selection is reviewed in light of enhanced national data collection at facility or project level data available from private sources; public empirical literature; and in relation to updates in international guidelines and international practice.

Review of model parameters and emission factors – model validation and calibration

This review implements QC Measures 3.A.1 (ii)-(iv) set out in the *National Inventory Systems Quality Assurance-Quality Control Plan*. The measures provide for review of model parameters in light of new data collected from private measurements or from public empirical research and provide either evidence to validate existing parameters or a basis for improving the parameters or method specification based on newly available information.

External factors

The key external catalysts for inventory improvement include:

Changing international practice

The Department actively monitors the implementation of inventory guidelines by other Parties to the UNFCCC / Kyoto Protocol to ensure comparability of national inventories. More specifically, the Department also monitors the implementation of other major domestic reporting systems. The European Union, for example, has established facility-level methods for the estimation of emissions for its emission trading system while the United States Environment Protection Agency has established similar methods for its mandatory reporting system. These major systems may set new benchmarks of international practice that the Department monitors and evaluates for their potential implications for Australia.

Enhancements to Australian National Greenhouse Accounts Framework

Australia's national inventory system incorporates an integrated national greenhouse accounts framework. This builds common approaches and estimation methods from national to State to company, facility and project levels across the national greenhouse accounts. Investment will also be undertaken in a set of regional greenhouse accounts, including in support of the national income accounts framework, and a carbon stock account, including for Australia's forest lands which will provide complementary information for the national inventory.

Responses to Quality Control Outcomes and Quality Assurance reviews

Responses to quality assurance reviews are an integral part of the inventory improvement process – in particular, the UNFCCC ERT reviews, the review by the Australian National Audit Office and public consultations on NGER methods. As part of the national inventory development process all issues identified by the UNFCCC ERT review teams are assessed for their implications for the national inventory. A full set of UNFCCC ERT recommendations, and Australia's responses to these recommendations, are included in Annex 6. Areas for inventory improvement are identified each year in the *Evaluation of Outcomes* document.

10.4.1 Investment in national inventory systems

Ultimately, the quality of emission estimates depends on the quality of measurement, data management and quality control systems.

Investment in the National Measurement System

The national inventory system relies on a large number of measurements undertaken by private organisations. For this inventory, data collected for the energy, *industrial process and waste* sectors is largely obtained through the National Greenhouse and Energy Reporting (NGER) System. Estimation methods used for NGER are governed by the *National Greenhouse and Energy Reporting (Measurement) Determination 2008* and are designed to be consistent with the national inventory estimation methods. Improvements in accuracy of measurement will flow into improvements in the quality of the national inventory.

In support of the Carbon Farming Initiative, new standards are being developed to support improved measurements across the land sector. The Department has supported the development of sampling and testing protocols for the direct measurement of Soil Organic Carbon at paddock scale. New measurement protocols are also being developed for the measurement of vegetation for rangelands vegetation. The new standards are designed to support confidence in data collected under private measurement systems and should be considered in conjunction with the Emission Reduction Fund's compliance and enforcement regime.

Investment in Research and Development

The national inventory system utilises public funding for research into greenhouse gas measurement in Australia. In recent years there has been a focus on the land based sectors given the land sectors contribute significant key categories, the extent of the sectors, the relatively high cost of private measurement and the relatively high variability of spatial and temporal emission processes.

National Inventory quality control systems

The Department will continue to invest in the quality control framework that provides a systematic approach to the assessment of new information on emissions as it emerges over time.

In relation to NGER, a systematic assessment of all new facility-specific information received will be undertaken to test the quality of existing tier 2 country-specific parameters. New information will be assessed against predetermined criteria for applicability. As a test of the quality of the existing parameters, the new information will either verify values currently used in the inventory or be used to update the parameters.'

New functionalities have been introduced into the AGEIS to achieve efficiencies in the QC process for this submission, which mitigate the risk of transcription errors during QC activity checks, and centralise all QC activities for review and archiving. As a result AGEIS can conduct tier 1 and tier 2 quality controls based on user-defined selections of QC activities. It can also populate the National Inventory Systems: *Evaluation of Outcomes* document to record the results of the monitoring program designed to implement the risk mitigation strategies and quality control measures detailed in the QA/QC Plan. The Department will continue to invest in enhanced quality control and output reporting systems for the *LULUCF* sector.

Australia has a small network of atmospheric monitoring stations that provide data on atmospheric greenhouse gas concentrations which, when combined with air dispersion models, provide a complementary verification system to the estimates presented in this national inventory. In this submission, estimates are presented for PFCs, HFCs and SF_6. Work on other gases, particularly methane and nitrous oxide, is ongoing.

Investment in IT systems

Investment in IT software systems including the Australian Greenhouse Emissions Information System (AGEIS) and *FullCAM* for *LULUCF* is a critical part of the improvement plan. Investment will be focused on the integration of the AGEIS and *FullCAM* systems, increasing the flexibility of the *FullCAM* with regard to the possibility of producing specific parameters and intermediate outputs to support enhanced quality control systems as well as regional accounts; and the development of project level tools to support the Emission Reduction Fund.

10.5 Improvements to activity data

The Department is investing in an ongoing program to review and to update the quality of activity data used in the national inventory.

Outside the sectors covered by NGER and the Emission Reduction Fund (ERF), the Department has been seeking to update the following activity data sources to improve their reliability, completeness, time series consistency or accuracy. Much of the improvements will occur in spatially explicit data for the land sectors, as efforts are made to better provide for the progressive implementation of the *2006 IPCC Guidelines*.

Improved mapping of forest areas and forest management activities

Investment in the use of remote sensing techniques to support estimates of forest management activities is ongoing, utilising available spatial information for calibration. Time-series mapping of the transfer of harvested native forests to conservation reserves and improved accuracy of mapping of harvested native forest areas, public and private and including mapping of areas that are not available for harvesting due to, inter alia, codes of practice. The Department is collaborating with CSIRO and GeoScience Australia to advance the use of more high-resolution imagery such as Sentinel in future submissions.

Integrated estimation of emissions from forest management and biomass burning

The Department is working to integrate the estimation and reporting of forest management and biomass burning in *FullCAM* to improve accuracy and coherence of emissions estimates and to support the development of ERF methods. This will include the integration of spatial mapping of fire events across all forests and grasslands in *FullCAM*.

Mapping of sparse woody vegetation cover for the Grasslands remaining grasslands category

Enhancement of the mapping of time series sparse woody vegetation across Australia through remote sensing has been completed by CSIRO to improve the consistency of this data and, in combination with research into fire dynamics, will be used to improve estimates of emissions from grasslands remaining grasslands and savanna burning.

Wetlands

Australia's inventory now includes estimates for the *Wetlands* land classification under voluntary implementation of the *2013 Wetlands Supplement*. The initial focus is on coastal wetlands, (Sections 6.10, 6.11 and 6.13 of Volume 2).) and current coverage includes emissions due to the removal of seagrass by capital dredging, and the removal of mangroves and tidal marsh due to development activity. Carbon removal associated with the planned establishment or reforestation of mangroves is also estimated.

Emissions or removals involving land management practices and conversions of wetland forests, such as mangroves, are calculated using Australia's spatially explicit approach to estimating forest land conversions. This year, additional spatial analysis of satellite imagery improved our capture of the national extent of Australia's mangroves, and has resulted in a small recalculation for mangrove-related emissions and removals.

Where a remote imaging approach is not applicable, as in locating the position and extent of capital dredging projects, then the Department reviews available environmental impact documentation to access data on those management activities. State and territory Environmental Protection Authorities and other relevant government and private organisations are consulted to continuously improve the capture of relevant management activities affecting coastal wetlands, as well as inform future improvement with further implementation of the *2013 Wetland Supplement*.

10.6 Updates to method and method selection

10.6.1 Using National Greenhouse and Energy Reporting System and other private sources of data for model validation and calibration

NGER establishes a framework to encourage the private measurement of key emissions data. Sources covered by NGER include *energy (fuel combustion), energy (fugitive emissions), industrial processes and product use* and *waste*.

Data made available under NGER from private measurements of facility-specific emission factors and other parameters is used to systematically review or validate existing tier 2 model parameters in relevant sectors. If a tier

2 model parameter is not validated by new NGER data, then the inventory parameter may be recalibrated or the equation may be re-specified in accordance with the provisions of the Inventory Improvement plan.

Each year, as new data or information is collected under NGER, the method selected to estimate emissions for a source will be reviewed. At this stage there is a presumption that the inventory will transition to tier 3 methods over time as more data based on private measurements of emission parameters becomes available, assuming that data preconditions for a more disaggregated tier 3 structure to be implemented have been met.

10.6.2 Using data from public research for method development and model validation and calibration

New information generated by publicly funded research programs or other sources also provide opportunities to test the validity of existing parameters, to consider changes to model structures, or to develop new methods.

Major areas of inventory where research data are being used for these purposes include the following:

Land sector

Enhanced calibration of modelling of forest eco-system dynamics reflecting biomass data collected and available from TERN and related research.

Enteric fermentation

Research on enteric fermentation emissions from livestock, co-ordinated through the Reducing Emissions from Livestock Research Program, has now produced an important dataset on methane emissions from Australian cattle and sheep. A process to review the sheep data has been initiated to determine if changes are required to the current methods.

Coastal wetlands

The implementation of a wetlands account in Australia's greenhouse gas inventory includes the development and ongoing improvement of methods to estimate emissions from coastal wetlands. Empirical research into carbon processes and related emissions and removals arising from activities affecting coastal wetlands are a vitally important input to successful implementation. The Department has established an informal expert advisory group of academic and government wetland specialists to advise on the development and ongoing enhancement of methods to model wetlands carbon processes and to encourage well-targeted empirical research to inform the further development and enhancement of these models.

Emissions from animal waste

The National Agricultural Manure Management Program (NAMMP) has been funded by the Australian Government to provide data on emissions from manure management systems and animal waste applied to soils. As data from the NAMMP are published the results will be used to check the quality of the EFs selected in the inventory. Where new studies give values that are significantly different from the current EFs these factors are identified for review.

Waste

The DOCf, decay and oxidation values applicable to Australian waste types in Australia under both laboratory conditions and in situ across various regions of Australia continue to be monitored by the Department for possible elaboration and future update given the emerging character of this field of research. For example, for the 2016 submission the Department revised the fraction of wood subject to decay in light of new research.

Oil and gas fugitives

A new method introduced in the previous submission involving including Australian gas compositions in emissions calculations was further refined from the Australian averages of CH_4 and CO_2 to basin and field specific composition averages of CH_4 and CO_2. These averages were collected from a variety of technical papers by Geoscience Australia (GA), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and from public company reports.

10.6.3 Elaboration of national inventory methods

In general, Australia is planning to implement tier 3 models and approaches wherever appropriate in order to enhance accuracy of emission estimates, particularly of the land sector.

Within the land sectors, development activity will build on existing inventory models contained in *FullCAM* and will need to take into account:

- existing and future guidance under the UNFCCC inventory reporting guidelines;
- emerging empirical data from publicly-funded research programs into the effects on emissions and removals of changes in land management actions;
- the integration of project level data generated, for example, through the Emission Reduction Fund;
- the importance of modelling long term responses to land management actions while abstracting from short term, temporal effects that are ephemeral in nature to ensure policy relevance;
- costs of data management and associated complexities; and
- the need for transparency and other related factors identified in the IPCC Workshop, 'Use of Models and Facility-Level Data in Greenhouse Gas Inventories, Report of the IPCC Expert Meeting on Use of Models and Measurements in GHG Inventories', 9-11 August 2010, Sydney, Australia.[18]

Model development will be progressed across all land sectors. In particular, it is intended that the *FullCAM* will be extended to provide an improved modelling framework for the consideration of new data as it becomes available:

- use of more advanced, high resolution imagery to support forest detection of changes in forest cover;
- methods for forest lands remaining forests will be elaborated over time to provide for a tier 3 spatially explicit method with additional estimation of forest carbon stocks as well as fluxes;
- methods for spatial modelling of sparse woody vegetation across Australia's grasslands;
- fire mapping will be incorporated to support improved estimates of emissions and carbon stocks across both forests and grasslands;
- grassland modelling will be developed to ensure the reconciliation of vegetation and livestock models; and
- modeling of wetlands emissions and removals resulting from management activities and changes in management practices will be developed and enhanced over time.

18 Reporting requirements include basis and type of model, application and adaptation of the model, main equations/processes, key assumptions, domain of application, how the model parameters were estimated, description of key inputs and outputs, details of calibration and model evaluation, uncertainty and sensitivity analysis, QA/QC procedures adopted and references to peer-reviewed literature.

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National Inventory Report 2017

Volume 3

The Australian Government Submission to the United Nations Framework Convention on Climate Change

Australian National Greenhouse Accounts

May 2019

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PART 2: SUPPLEMENTARY INFORMATION REQUIRED UNDER ARTICLE 7.1 OF THE KYOTO PROTOCOL

11. Kyoto Protocol LULUCF

In accordance with decision 1/CMP.8, this Part of the Report contains supplementary information to fulfill reporting requirements under Article 7 of the KP (decisions 6/CMP.9, 2/CMP.8, 2 and 4/CMP.7, 15/CMP.1 and 2, 3 and 4/CMP.11 and net emissions estimates compiled using reporting rules and guidance applicable to the KP CP2, including guidance contained in IPCC 2014.

Decision 1/CMP.8 provides that, pending the entry into force of the KP Doha Amendment that establishes the CP2 (2013 – 2020), KP Parties will continue to implement KP commitments and other responsibilities in a manner consistent with their national legislation and domestic processes. The Australian Government submitted its instrument of acceptance to the Doha Amendment on 9 November 2016.

11.1 General Information

11.1.1 Definition of forest and other criteria

Forests include all vegetation with a tree height of at least 2 metres and crown canopy cover of 20 per cent or more and lands with systems with a woody biomass vegetation structure that currently fall below but which, *in situ,* could potentially[1] reach the threshold values of the definition of forest. Young natural stands and all plantations which have yet to reach a crown density of 20 per cent or tree height of 2 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of either human intervention, such as harvesting, or natural causes, but which are expected to revert to forest.

The forest cover definition is consistent with the definition used in Australia's National Forest Inventory that has been used for reporting to the Food and Agriculture Organisation and Montreal Process. Australia has adopted a minimum forest area of 0.2 ha (Table 11.1).

Forest use is typically evident by human disturbance, such as in commercial forest harvest, or clearly delineated by land tenure, such as conservation reserves. In extensive systems, such as grazed woodlands, there is a continuum in the intensity and intent of use.

Table 11.1 Selection of parameters for defining 'forest' under the KP

Parameter	Range	Selected value
Minimum land area	0.05 – 1 ha	0.2
Minimum crown cover	10 – 30%	20
Minimum height	2 – 5 m	2

11.1.2 Elected activities under Article 3.4

For the second KP commitment period, Australia will report on *forest management* and has elected to report emissions and removals from the following Article 3.4 activities:

- *cropland management*
- *grazing land management*
- *revegetation.*

1 This potential is evidenced from the Landsat series in that the land has previously supported forest.

11.1.3 Precedence conditions and hierarchy among Article 3.4 activities

Australia has implemented a hierarchy of Article 3.4 activities into its land classification system. *Forest management*, as a mandatory activity takes precedence over the other Article 3.4 activities, consistent with IPCC requirements. The hierarchy of Article 3.4 activities is applied as follows:

1) *forest management*;

2) *cropland management*;

3) *grazing land management*; and

4) *revegetation*.

Australia's system for the classification of land in the UNFCCC and KP LULUCF inventories is described in more detail in section 6.3 in Volume 2 of the NIR and in section 11.2 below.

11.2 Land-related information

11.2.1 Description of how the definitions of each activity under Article 3.3 and 3.4 have been implemented and applied consistently over time

Deforestation under the KP is a subset of *forest conversion* and includes only lands where there has been direct human-induced conversion of forest to alternative land uses since 1 January 1990.

Conversion of *forest lands* to alternative land uses prior to 1990 are accounted for under *cropland management or grazing land management* to enable complete accounting under CP2.

Forest management is a subset of *forest land remaining forest land* and includes those forests managed under a system of practices designed to support commercial timber production such as harvest or silvicultural practices or practices that are designed to implement specific sink enhancement activities.

Forests included under this definition include multiple-use public forests, plantations established prior to 1990, privately managed native forest land where *forest management* activities (harvesting and silvicultural practices) have been observed to occur; and forests where regulated sink enhancement activities occur.

Forest lands outside of the multiple-use public forests and pre-1990 plantation lands are also monitored for signs of harvesting and silvicultural practices in order to achieve complete accounting for these management practices. If a harvest event is observed, the net emissions are reported under the *forest management* category and all future net emissions on that land continue to be reported under that category.

Afforestation/reforestation is a subset of *land converted to forest land* and includes only those forests established since 1 January 1990 on land that was continuously clear of forest from 1972 until the end of 1989. Forests under *land converted to forest land* may be established through planting events either for commercial timber or for other reasons, known as 'environmental plantings', or by regeneration from natural seed sources on lands regulated for the protection of forests.

Cropland management includes all land that is used for continuous cropping, lands managed as crop-pasture rotations and *land converted to cropland from grassland*. As noted above, *forest land converted to cropland* prior to 1990 is also included under *cropland management*. *Land converted to forest land* is excluded from *cropland management*.

Perennial crops including orchards and vineyards are included under *cropland management*. Units of land where orchards were established on land clear of forest on 31 December 1989 are included in the *cropland management* and not the *afforestation/reforestation* classification.

Grazing land management lands include permanent *grasslands*; biomass burning in forests in northern Australia; and forests established by regeneration from natural seed sources on lands not regulated for the protection of forests (which means they are not classified as *afforestation/reforestation*). *Forest lands* are not double counted in Australia's land classification systems as Australia has applied a 'narrow' approach to *forest management*, allowing certain specified forests (northern forests subject to fire and unprotected forests as outlined above) not identified as being managed for timber to be included under *grazing land management*.

A forest observed to be deforested, or observed to be subject to a forest management practice, is reported under *deforestation* or *forest management* categories in preference to *grazing land management* in accordance with the hierarchy used for Australia's inventory.

Revegetation includes establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of *afforestation/reforestation.* It is restricted to settlements and wetlands.

While there are some essential differences between the KP and UNFCCC classification systems, it is possible to reconcile them. For the most part, the differences have become either less pronounced or less significant as the coverage of land activities adopted by the Australian Government has increased over time. In Table 11.2, a concordance between UNFCCC and KP classifications used in the preparation of net emission estimates in this Report is presented.

Table 11.2 Reconciliation table between UNFCCC and KP classifications

UNFCCC	KP
Forest land	
Forest land – multiple-use public forest	*forest management*
Forest land – pre-1990 plantations	*forest management*
Forest land – harvested private native forests	Monitored for *forest management activity*
Forest land – other native forest	Monitored for *forest management activity*
Forest land – biomass burning in non-temperate areas	*grazing land management*
Land converted to forest	
New plantations since 1990	*afforestation/reforestation*
Native regeneration since 1990 – direct human-induced	*afforestation/reforestation*
Forest land previously converted to other land uses since 1990	*deforestation*
Forest land previously converted to cropland prior to 1990	*cropland management*
Forest land previously converted to grassland, wetland or settlement prior to 1990	*grazing land management*
Cropland	
Cropland – permanent	*cropland management*
Forest land converted to cropland since 1990	*deforestation*
Forest land converted to cropland prior to 1990	*cropland management*
Grassland converted to cropland	*cropland management*
Grassland	
Grasslands – permanent	*grazing land management*
Forest land converted to grassland since 1990	*deforestation*
Forest land converted to grassland – pre-1990 conversion	*grazing land management*

UNFCCC	KP
Settlements	*revegetation* may occur
Forest land converted to settlements	*deforestation*
Wetlands	
Wetlands – sparse woody vegetation	*revegetation* may occur
Wetlands – biomass burning in non-temperate areas	*grazing land management*
Forest land converted to wetland – post-1990	*deforestation*
Forest land converted to wetlands – since-1990	*deforestation*

11.2.2 Identification of geographical locations

All lands under the reporting categories of *afforestation/reforestation*, *deforestation*, *cropland management* and *grazing land management* are monitored using a Reporting Method 2 land identification system (IPCC, 2014, Chapter 2.2.2) based on the Landsat time series in conjunction with ABARES Land Use Map Version 5. The methods of mapping forest extent and change in extent are outlined in Chapter 6 (Appendix 6.A).

The exact geographic location of each unit of land entering the *afforestation/reforestation* and *deforestation* accounts is mapped at 25 m resolution using continental coverages of Landsat data.

Land is tracked and simulated in FullCAM at a pixel by pixel (25m x 25m) level and the carbon stock change on each pixel is tracked from the start of the simulation to the reporting year. The outputs of the simulations are stored in a datacube which can be queried using the FullCAM Outputs Analysis System (OASys).

The consistent tracking through time of individual units of land down to 0.2 ha results in millions of estimation units. For the purpose of reporting under Article 3.3 and Article 3.4, the areas are summed into larger reporting units. This is achieved by co-locating the areas of change on maps that represent logical identification codes. The initial divisions are the Australian states and territories. For *afforestation/reforestation* the areas are then reported by 3 broad types of forest: softwood, hardwood and native. Allocations to these classifications are obtained from more detailed analysis of the Landsat data (see Appendix 6.A).

Lands subject to *forest management* are monitored using Reporting Method 1 under IPCC (2014) Chapter 2.2.

11.2.3 Methodology used to develop the land transition matrix

The land transition matrix is developed using the forest extent data derived from Australia's Landsat archive consistent with the data for the UNFCCC reporting categories (Table 6.3 in Section 6.3).

Table 11.3 Land area subject to KP LULUCF activities in 2017

Activity	Area in 2017 (k ha)
Afforestation and Reforestation	8,046.53
Deforestation	10,385.30
Forest Management	10,841.74
Cropland Management	39,468.82
Grazing Land Management	529,623.59
Revegetation	18,215.98
Wetland drainage and rewetting	NA
Other	152,418.05
Total	**769,000.00**

11.2.3.1 Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation

Land where forest cover loss is identified as being human-induced and where it is not expected that the forest will be regenerated or replanted is classified as *deforestation* land.

In cases where there is a temporary change in forest cover due to natural events (e.g. fire, drought) or where changes occur within a land tenure where it is expected that the land will revert to forest (e.g. harvested forest, national park), the land is monitored for a period of time, depending upon the land tenure and use, consistent with the guidance provided in section 2.6.2.1 of IPCC 2014.

Areas that have entered the monitoring system continue to be classified as *forest land* provided that the time since forest cover loss is shorter than the number of years within which tree establishment is expected (Table 11.4). After the specified monitoring period, however, lands that have lost forest cover due to direct human-induced actions, have undergone land use change, and failed to regenerate are classified as *deforestation*.

Table 11.4 Monitoring period for Article 3.3 and 3.4 lands

Land classification	Monitoring period (x years)
Afforestation/reforestation	8
Settlements	10
Forest management	12

11.2.3.2 Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

Areas of land that have entered the monitoring system described above and have been without forest cover for less than the monitoring periods in Table 11.4, (that is, forest or plantation re-establishment has not been confirmed), amounted to 745,272 hectares in 2017 (Table 11.5).

In accordance with good practice, estimates will be made at the end of the commitment period of the proportion of these areas that are not expected to regenerate.

Table 11.5 Area of land monitored for land-use change by jurisdiction in 2017 (ha)

State	Total
Australian Capital Territory	5,343
New South Wales	131,889
Northern Territory	2,413
Queensland	120,047
South Australia	37,356
Tasmania	50,660
Victoria	207,539
Western Australia	190,025
Total	**745,272**

11.3 Methods for carbon stock changes and greenhouse gas emissions and removal estimates

In general, a Tier 3, Approach 3 (Reporting Method 2 under IPCC (2014)) system is used to estimate emissions and removals under Article 3.3 and 3.4 using the same methods as used to estimate the UNFCCC inventory (Chapter 6). Tier 2 methods are used for emissions and removals under *revegetation* and under *forest management* other than pre-1990 plantations, consistent with the methods used for corresponding categories in the UNFCCC inventory (Chapter 6).

Table 11.6 Summary of methodologies and emission factors –KP Land Use Change activities

Greenhouse Gas Source And Sink	CO_2		CH_4		N_2O	
	Method applied	EF	Method applied	EF	Method applied	EF
Article 3.3 activities						
Afforestation/Reforestation						
C stock changes	T3	M				
Biomass burning(a)	IE	IE	CS	CS	CS	CS
Deforestation						
C stock changes	T3	M				
Biomass burning(a)	IE	IE	CS	CS	CS	CS
Article 3.4 activities						
Forest management						
C stock changes	T2/T3	M				
Biomass burning	T2/T3	CS/M	CS	CS	CS	CS
Cropland management						
C stock changes	T3	M				
Biomass burning(a)	IE	IE	CS	CS	CS	CS
Grazing land management						
C stock changes	T3	M				
Biomass burning	T3	M	CS	CS	CS	CS
Revegetation						
C stock changes	T2	CS				
Biomass burning	IE	IE	IE	IE	IE	IE

EF = emission factor, CS = country specific, M = Model, NO = not occurring, IE=included elsewhere, T1 = Tier 1 and T3 = Tier 3.

11.3.1 Years for which carbon stock changes and non-CO_2 emissions are reported

Carbon stock changes and non-CO_2 emissions from land subject to Article 3.3 and Article 3.4 activities are reported from the start of the commitment period in 2013.

11.3.2 Information that demonstrates that Article 3.3 activities began on or after 1 January 1990 and are direct human-induced

The land is monitored using a time series of Landsat imagery since 1972 in order to be able to demonstrate the date at which the Article 3.3 activities began.

11.3.3 Factoring out of indirect and natural emissions and removals

Indirect effects on greenhouse gas emissions and removals are not explicitly factored out although, as Australia's estimation methods utilise a process-based Tier 3 modelling approach, it is clear that the relationships between biomass, climate and atmospheric concentrations are fixed for the time series of emission estimates.

Natural emissions and removals are managed through the application of the natural disturbance provision for a range of identified natural disturbances under *forest management*.

11.3.4 Uncertainty estimates

Uncertainty estimates are provided in Annex 2.

The same methods and data are used to estimate emissions and removals in all Article 3.3 and 3.4 activities as are used for the associated UNFCCC categories.

11.4 Deforestation

11.4.1 Identification of land subject to *deforestation*

Deforestation activity (Table 11.7) is identified using methods applied to the identification of *forest conversion* under the UNFCCC and described in Appendix 6.A. *Deforestation* only includes lands where there has been direct human-induced conversion of forest to alternative land uses since 1 January 1990.

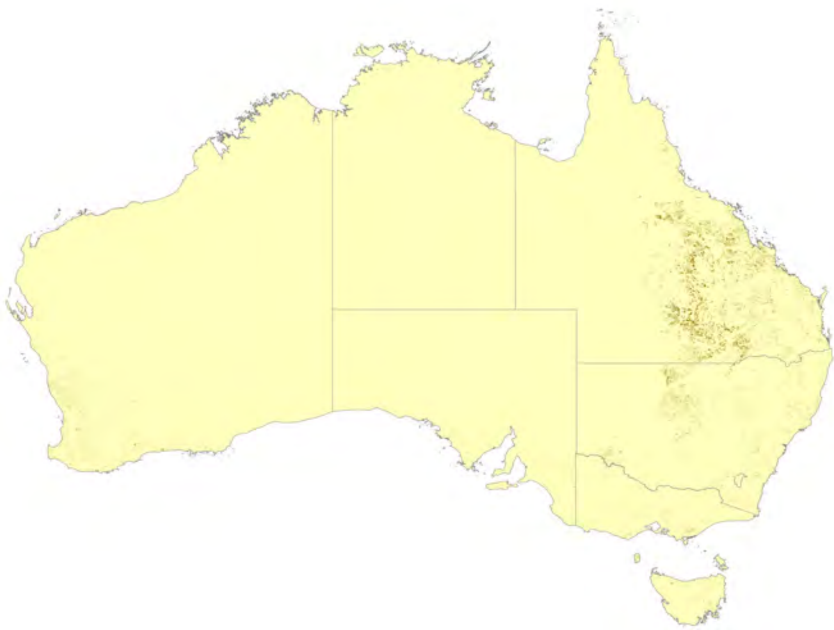
Table 11.7 Area of deforestation 1990-2017

Year	Area of deforestation (Mha)	Year	Area of deforestation (Mha)
1990	0.56	2004	7.22
1991	1.29	2005	7.77
1992	1.94	2006	8.23
1993	2.42	2007	8.61
1994	2.92	2008	8.88
1995	3.30	2009	9.09
1996	3.69	2010	9.26
1997	4.08	2011	9.42
1998	4.48	2012	9.57
1999	4.94	2013	9.75
2000	5.40	2014	9.92
2001	5.91	2015	10.08
2002	6.38	2016	10.25
2003	6.79	2017	10.39

11.4.1.1 Spatial identification of *deforestation* lands

The location of land included in the *deforestation* account is shown in Figure 11.1.

Figure 11.1 Location (in brown) of land included in the deforestation account



11.4.2 Methods for estimation of carbon stock changes and greenhouse gas emissions and removal estimates

11.4.2.1 Data

The same data sources are used for *deforestation* as for *forest conversion*, as detailed in Volume 2.

11.4.2.2 Methods

The same Tier 3, Approach 3 (Reporting Method 2 under IPCC (2014)) system is used for *deforestation* as that used to estimate *forest conversion* (see Appendices 6.B and 6.F).

11.4.2.3 Start year

Estimation of net emissions is undertaken from 1972 consistent with the available Landsat series.

11.4.2.4 Carbon pools

FullCAM estimates emissions from soil through a process involving all on-site carbon pools (living biomass, dead organic matter and soil).

11.4.3 Harvested wood products from deforestation events

Harvested wood products from deforestation events are separately identified and emissions reported according to instantaneous oxidation in accordance with paragraph 31 of the annex to Decision 2/CMP.7.

The Tier 3, Reporting Method 2 spatial monitoring system for *deforestation* is used to detect and differentiate deforestation events from harvesting on *Afforestation / Reforestation* and *Forest management* lands, as described in Section 11.2.3.

These deforestation events are modelled as part of *deforestation,* where all biomass from the deforestation event is burned on site, with no products produced.

National aggregate harvesting statistics have been allocated between harvest from *Afforestation / Reforestation*, *Forest Management* and *Deforestation* (from the deforestation event) to ensure that there is no double-counting of products produced from deforestation events. The deforestation component is excluded from the reporting of emissions estimates of the *harvested wood products* pool, as these products have already been accounted for on the basis of instantaneous oxidation.

11.4.4 Reporting of *deforestation* in 2017

11.4.4.1 Reporting of *deforestation* net emissions in 2017

Estimates of net emissions from *deforestation* are reported in Table 11.8.

Table 11.8 Estimated net emissions from deforestation (kt CO_2-e)

Year	Total
2000	70,545
2005	90,305
2008	65,317
2009	52,375
2010	53,210
2011	40,493
2012	34,924
2013	35,226
2014	36,914
2015	26,735
2016	29,110
2017	26,076

11.4.4.2 Estimation of AAUs to be cancelled for deforestation in 2013 to 2017

In the reporting period, 2013-2020, one AAU is to be cancelled for every tonne of emissions reported from the deforestation activity (the same approach as for emissions from sources in the energy, industrial processes and product use, agriculture, waste sectors). Estimates of AAUs to be cancelled in 2013 to 2017 are presented in Table 11.9.

Table 11.9 Estimated AAUs to be cancelled for deforestation net emissions (t CO_2-e)

Year	AAUs to be cancelled
2013	35,225,939
2014	36,914,175
2015	26,734,959
2016	29,110,151
2017	26,076,361

11.4.5 Quality Assurance – Quality Control

Deforestation activity is identified using methods applied to the identification of forest lands converted to grass and other lands under the UNFCCC and is described in detail in Section 6.6 of Volume 2 of the NIR.

Table 11.10 provides a reconciliation between emissions reported under the KP *deforestation* account (Table 11.10, Component A) and the UNFCCC accounts for *forest land converted to other land uses*. Differences between these two classifications arise because the *deforestation* account considers lands with a history of anthropogenic forest loss since 1990. It includes emissions from these lands where forest has subsequently regrown and is accounted for in the UNFCCC accounts for *land converted to forest* (component E), but does not include the ongoing emissions and removals from lands cleared prior to 1990 (component B). Emissions from nitrogen leeching and run-off (component C) are not in scope of any part of the KP accounts, and emissions from non-temperate fire management (component D) are allocated exclusively to *grazing land management* irrespective of the land's conversion history.

Table 11.10 Reconciliation of emissions from UNFCCC forest conversion and KP deforestation and other classifications

Year	Deforestation	Clear in 1990, regrown and remains vegetated	Nitrogen leeching and runoff	Non-temperate fire management	Forest regrown on lands cleared since 1990	Total UNFCCC Forest land converted to other land uses
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)
Component	**A**	**B**	**C**	**D**	**E**	**A+B+C+D-E**
2008	65,317	5,367	59	29	-8,057	78,830
2009	52,375	4,454	54	31	-7,944	64,858
2010	53,210	8,320	88	24	-10,140	71,782
2011	40,493	5,382	110	39	-11,451	57,475
2012	34,924	6,375	72	32	-11,790	53,194
2013	35,226	6,683	51	30	-11,918	53,909
2014	36,914	5,456	65	31	-12,341	54,807
2015	26,735	3,948	49	34	-13,324	44,090
2016	29,110	3,264	50	15	-16,288	48,727
2017	26,076	3,772	46	24	-16,550	46,467

11.4.6 Recalculations

Further descriptions of the recalculations is provided in the corresponding LULUCF category in Chapter 6, namely *forest land converted to grasslands.*

Table 11.11 *Deforestation*: recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	Deforestation				Reasons for Recalculations			
	2018 submission	2019 submission	Change		A. FullCAM tree growth	B. New geospatial data	C. Management of spatial information	D. Standing dead
	(Gg CO_2 -e)	(Gg CO_2 -e)	(Gg CO_2 -e)	%				
1990	63,026	61,810	-1,216	-2%	88	3,160	-454	-4,010
1995	67,832	67,338	-495	-1%	548	2,686	-1,667	-2,062
2000	71,072	70,545	-526	-1%	394	2,811	-1,355	-2,376
2005	87,698	90,305	2,607	3%	2,542	3,974	-641	-3,268
2006	88,453	90,597	2,143	2%	3,035	4,987	-3,176	-2,703
2007	81,922	87,776	5,855	7%	3,780	3,661	495	-2,081
2008	59,810	65,317	5,508	9%	1,647	2,781	1,707	-628
2009	50,419	52,375	1,956	4%	1,407	1,928	-1,304	-75
2010	50,231	53,210	2,979	6%	1,401	1,628	-36	-14
2011	40,183	40,493	309	1%	115	1,329	-1,495	361
2012	32,750	34,924	2,175	7%	-727	1,146	1,181	575
2013	34,546	35,226	680	2%	-610	1,193	-351	448
2014	37,569	36,914	-655	-2%	-567	1,475	-1,723	160
2015	28,449	26,735	-1,714	-6%	-1,662	876	-1,263	335
2016	30,323	29,110	-1,213	-4%	-1111	-174	130	-58

11.5 Afforestation & reforestation

11.5.1 Identification of land subject to *afforestation/reforestation*

Afforestation/reforestation activity is identified using methods applied to the identification of *land converted to forest* under the UNFCCC and described in Appendix 6.A. Plantations for timber, environmental plantings and the promotion of natural seed sources are included within the *afforestation/reforestation* classification. Emissions from *harvested wood products* associated with hardwood plantation timber harvested since 2000 are also included.

The natural regeneration of forests from natural seed sources are identified in areas consistent with the intentions of land use regulatory systems and reflect the deliberate decisions of land managers to not maintain pasture for grazing. To qualify as a *forest land* converted from natural seed sources, the land must have been clear of forest throughout the period 1972-1989 and must have converted to forest land after 1 January 1990.

Conversions to forest land can be supported through a range of government programs and regulatory processes including from offsets created under State vegetation management acts or under major project approval processes. The *Emission Reduction Fund* is used to encourage these outcomes.

The identification of regeneration of forest from natural seed sources as *afforestation/reforestation* is explained further in section 11.5.1.2 below. The area of *afforestation/reforestation* is presented in Table 11.12.

Table 11.12 Area of *afforestation/reforestation* 1990-2017

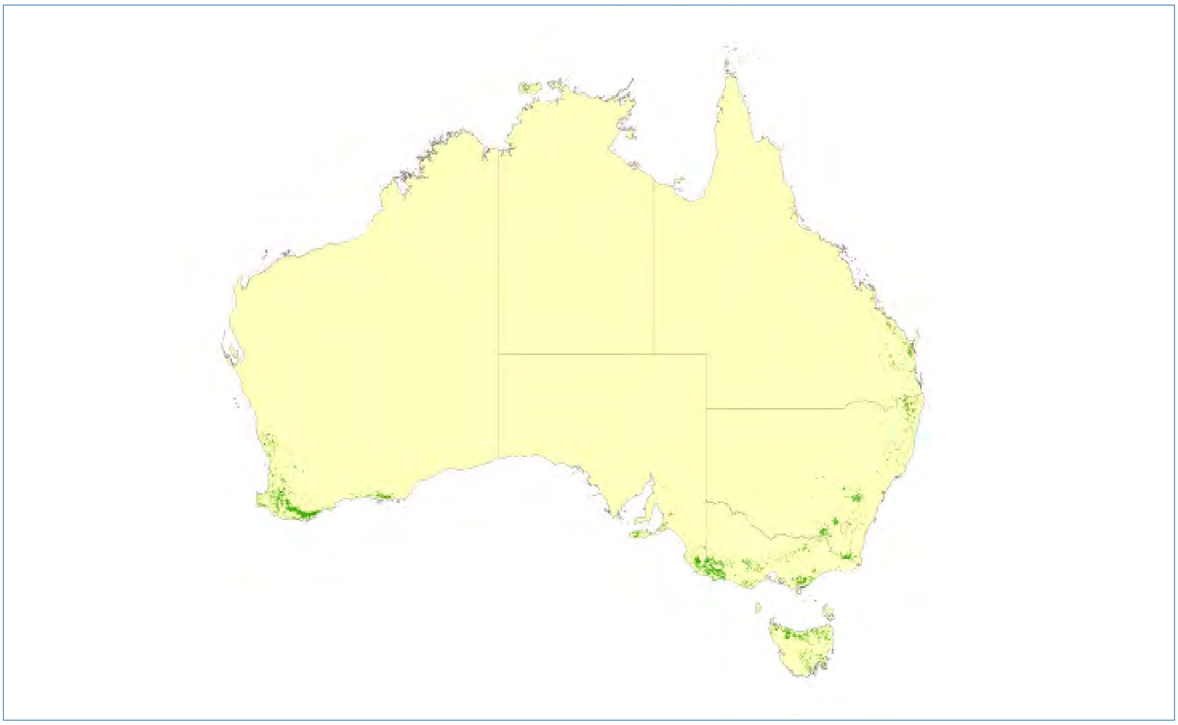
Year	Area of *afforestation/reforestation* estate (M ha)
1990	0.25
1991	0.75
1992	1.16
1993	1.43
1994	1.70
1995	1.94
1996	2.15
1997	2.36
1998	2.57
1999	2.82
2000	3.03
2001	3.26
2002	3.46
2003	3.67
2004	3.89
2005	4.15
2006	4.39
2007	4.61
2008	4.81
2009	5.02
2010	5.27
2011	5.58
2012	5.89
2013	6.23
2014	6.63
2015	7.03
2016	7.54
2017	8.05

Australia's *afforestation/reforestation* estate has increased in area over the period 1990-2017 (Table 11.12).

11.5.1.1 Spatial identification of *afforestation/reforestation* lands

Afforestation/reforestation activities are identified in relation to a 1990 base map of forest land derived from the land monitoring program (Appendix 6.A). The location of land from plantings included in the *afforestation/reforestation* account is shown in Figure 11.2.

Figure 11.2 Location (in green) of plantation land included in the *afforestation/reforestation* account



11.5.1.2 Identification of regeneration of native forests as *afforestation/reforestation*

It is estimated that there were approximately 5.87 million hectares of land which was not forest on 31 December 1989 (and was not forested at any time between 1972 and 1989), which was subsequently converted to *forest land* through natural regeneration and remained forest.

All lands in South Australia, Tasmania, Victoria and Western Australia have been identified as subject to land clearing restrictions. In Queensland, lands mapped as high value regrowth under the *Vegetation Management Act 1999* and land that is included in the Collaborative Australian Protected Area Database (CAPAD) is considered protected. In the remaining jurisdictions (Australian Capital Territory, New South Wales and the Northern Territory) further analysis of land clearing regulations is required to include all protected lands. In NSW, in particular, the area identified as protected is likely to be a significant under estimate. The focus of current analysis is to improve the estimated area of protected land in New South Wales.

Carbon abatement projects of the Australian Government's Emission's Reduction Fund are also spatially identified and included in the protected lands irrespective of their presence in or absence from other identified protected areas.

Every two years, the Australian Government collects information on protected areas from state and territory Governments and other protected area managers, which is published in the Collaborative Australian Protected Area Database (CAPAD).

CAPAD is used to provide a national perspective of the conservation of biodiversity in protected areas. It also allows Australia to regularly report on the status of protected areas to meet international obligations such as those in the Convention on Biological Diversity (CBD). Australian protected area information is also included in the World Database on Protected Areas (WDPA).

Australia has in force a framework of federal, state and territory legislation and guidelines regulating clearing of native vegetation and forests (see below). These laws establish a framework whereby land that has naturally regenerated to meet the forest definition has been allowed to do so as a result of a deliberate management decision not to clear those lands.

While dedicated vegetation management legislation emerged in some states in the 1990s, land management activities have been, and continue to also be, regulated by more general land planning legislation introduced prior to, or around, 1990. A more complete listing of relevant state and territory legislation governing land clearing is provided below.

State and territory native vegetation clearance statutes

New South Wales

- *Native Vegetation Act 2003*
- *Threatened Species Conservation Act 1995*
- *Environmental Planning and Assessment Act 1979 (Local Environmental Plan)*

Victoria

- *Victorian Planning Provision (Clause 52.17)*
- *Planning and Environment Act 1987*
- *Flora & Fauna Guarantee Act 1988*
- *Catchment and Land Protection Act 1994*

Queensland

- *Vegetation Management Act 1999 (prior to this, the Land Act 1994 and the Environmental Protection Act 1994*
- *Sustainable Planning Act 2009*
- *Integrated Planning Act 1997*
- *Nature Conservation Act 1992*

Western Australia

- *WA Environmental Protection Act 1986*

South Australia

- *SA Native Vegetation Act 1991*

Tasmania

- *Tasmania Forest Practices Act 1985*

Australian Capital Territory

- *ACT Planning and Development Act 2007*
- *Nature Conservation Act 1980*

Northern Territory

- *NT Planning Act 2002*
- *NT Planning Scheme*
- *Pastoral Land Act 1994*

A primary aim of the emergence of specific – purpose legislation, such as Queensland's *Vegetation Management Act 1999*, was to unify and make more consistent existing regulatory measures and, in particular, ensure consistency between regulations that applied to leasehold and freehold land (government and private lands).

While the legislative instruments in place have clearly evolved, the list shows that relevant regulations to govern the management of native vegetation have been in place over a long period of time in all States and Territories.

Examples of administrative processes include compliance with regional ecosystem plans established under legislation, individually negotiated property management plans or additional approval processes/permit processes for clearing.

Permits for conversion of all forests to grasslands for agriculture are required in the Northern Territory, Western Australia, Victoria, South Australia and Tasmania, with minor exceptions. The relevant acts and regulations specify exemptions from the current approval process for the routine maintenance of agricultural land but only for lands with regrowth of an age that is less than a specified number of years (usually between five and ten years) and only where a permit to clear has been previously issued. Effectively a legal consequence through an approval process is associated with all revegetation actions.

In Queensland the administrative processes are more complex. Legal consequences derive from a combination of regional ecosystem plans issued under regulation, individual property agreements and land clearing permits.

A similar mix of instruments is applied in New South Wales. Protected regrowth is native vegetation that has grown since 1 January 1990 (or 1983 in the Western District), but is protected because it has grown on vulnerable land or has been identified as protected regrowth in a Property Vegetation Plan (PVP), an environmental planning instrument, a natural resources management plan or an interim protection order under the NV Act. It also includes native vegetation that is regrowth that has been grown or preserved with the assistance of public funds granted for biodiversity conservation purposes.

The national regulatory framework, together with the raft of legislative instruments and other policies and measures in place at national and State and Territory level, demonstrate that land managers have a legal need for activities to prevent an undesired regrowth of an area to forest and that the regrowth of an area as forest should take place only where desired by land managers based on land managers' decisions. *Deforestation* of these lands is possible only under certain circumstances and several administrative steps must be taken before it is legally allowed.

At the national level, there are many relevant Federal Government programs which also aim to promote vegetation cover either directly or indirectly, such as through carbon or biodiversity objectives.

These measures continue past actions by the Federal Government to promote vegetation outcomes across the country over a long period of time. For example, in the 'Our Country Our Future' package announced 20 July 1989, the measures included the National Soil Conservation Program, Save the Bush, the National Weeds Strategy, the One Billion Trees Program and the Decade of Landcare Plans. There have been many measures in the period since this package was put in place.

Currently the Emissions Reduction Fund promotes regeneration from natural seed sources through a direct subsidy program.

These Federal Government programs operate in addition to land management legislation operated by State and Territory governments identified above.

11.5.2 Methods for carbon stock changes and emissions and removal estimates

11.5.2.1 Data

The same data sources are used for *afforestation/reforestation* as for *land converted to forest land* in the UNFCCC inventory (see Appendix 6.A and 6.G).

11.5.2.2 Methods

For *afforestation/reforestation*, the same tier 3, Approach 3 system is used as for *land converted to forest land* under the UNFCCC inventory (see Appendix 6.A and 6.G). The use of the tier 3, Approach 3 (reporting method 2 under IPCC (2014)) system means that the combined reporting of *afforestation* and *reforestation* does not affect the area of land reported or estimates of the emissions and removals.

HWP associated with harvesting in short rotation hardwood plantation areas from 2000 onwards are assumed to have occurred in plantations established after 31 December 1990 and are included in *afforestation/reforestation*, and are calculated consistent with the methods for *forest management* set out in 11.6.3.2.

11.5.2.3 Start year

Estimation of net emissions is undertaken from 1972 consistent with the available Landsat series.

11.5.2.4 Carbon pools

FullCAM estimates emissions from soil through a process involving all on-site carbon pools (living biomass, dead organic matter and soil).

11.5.3 Reporting of *afforestation/reforestation* in 2017

11.5.3.1 Reporting of *afforestation/reforestation* net emissions in 2017

Estimates of net emissions from *afforestation/reforestation* are reported in Table 11.13.

Table 11.13 Estimated net emissions from *afforestation/reforestation* (kt CO_2-e)

Year	Total
2008	-23,304
2009	-23,157
2010	-24,926
2011	-30,096
2012	-27,839
2013	-25,913
2014	-25,932
2015	-25,004
2016	-28,289
2017	-29,355

11.5.3.2 Estimation of *afforestation/reforestation* Accounting Quantity in 2013-17

For land activity categories other than *deforestation*, credits (called RMU credits) are issued against the reduction in net emissions relative to a specified benchmark base year or reference level.

For *afforestation/reforestation* estimates of net emissions in the reporting year are used to estimate the amount of RMU credits (the accounting quantity) to be issued. The estimated quantities of RMUs to be issued for 2013-16 are contained in Table 11.14.

Table 11.14 Estimated Accounting Quantity for *afforestation/reforestation* (t CO_2-e)

Year	Accounting Quantity (RMU credits)
2013	-25,913,084
2014	-25,932,141
2015	-25,004,465
2016	-28,289,106
2017	-29,354,617

* Note: Negative values indicate that RMUs are to be issued.

11.5.4 Quality Assurance – Quality Control

Refer to Chapter 6.6.

11.5.5 Recalculations

The quantification of the recalculation components is shown in Table 11.15. Descriptions of the reasons for the recalculations are provided in the corresponding LULUCF sub-category in Chapter 6, namely *land converted to forest land* (section 6.5.5).

Table 11.15 *Afforestation/reforestation*: recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2018 submission	2019 submission	Change		Reasons for Recalculation: A. FullCAM improvement - update of key growth parameter productivity in TYF	B. FullCAM improvements - Inclusion of 'Standing Dead' debris pool	C. Improvements in simulation and updates to input datasets	D. Additional refinements to FullCAM
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2-e)	(% change)	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	
1990	164	448	284	173%	-4	-25	159	153
1995	-2,670	-3,579	-910	34%	-1,232	-213	965	-430
2000	-11,336	-13,437	-2,101	19%	-2,554	-740	3,070	-1,877
2005	-16,567	-18,798	-2,231	13%	-2,738	-1,795	3,275	-972
2006	-17,388	-21,141	-3,752	22%	-2,574	-2,066	2,782	-1,895
2007	-18,239	-20,696	-2,457	13%	-2,593	-1,728	3,176	-1,311
2008	-20,981	-23,304	-2,323	11%	-3,116	-1,048	3,803	-1,962
2009	-21,083	-23,157	-2,074	10%	-3,175	-105	2,985	-1,779
2010	-22,152	-24,926	-2,775	13%	-3,409	-64	2,509	-1,811
2011	-26,210	-30,096	-3,886	15%	-4,097	455	2,586	-2,830
2012	-25,863	-27,839	-1,975	8%	-4,092	607	3,345	-1,835
2013	-24,775	-25,913	-1,138	5%	-4,142	575	4,125	-1,697
2014	-23,766	-25,932	-2,167	9%	-4,398	808	4,155	-2,732
2015	-22,104	-25,004	-2,900	13%	-4,564	1,114	3,513	-2,963
2016	-21,127	-28,289	-7,162	34%	-4,735	1,112	-184	-3,355

11.6 Article 3.4 activities – Forest management

Forest management comprises emissions and removals from *forest lands* that are managed under a defined system of practices, and includes emissions from harvested wood products and natural disturbances relating to *forest management* lands. Forest harvesting is the key driver of anthropogenic emissions and removals from *forest management* over the medium term.

In accordance with Decision 2/CMP.7, *forest management* is accounted against an emissions reference level that represents policies and practices in place as at December 2009. Australia's forest management reference level (FMRL) was reported in its 2011 *Forest Management Reference Level Submission* (DCCEE, 2011).

A summary of responses to the reporting requirements contained in Decision 2/CMP.7 is contained in section 11.10.2.

11.6.1 Identification of land subject to *forest management*

Forest lands are identified using methods applied to the identification of forest under the UNFCCC and described in Appendix 6.A. *Forest Management* lands are a subset of *Forest lands* identified using the narrow approach in accordance with practices specified in section 11.6.2.

Forest management lands include:

- all commercial plantations not included under Article 3.3 (i.e. plantations established on or before 31 December 1989);
- all public land available for timber harvesting as at December 2009, specifically multiple-use public forests as identified by the Montreal Process Implementation Group 2008;
- other forest lands (comprising forest lands that were in formal conservation reserves as at December 2009, privately managed native forests and extensively grazed woodlands) where the following activities are observed:
  - harvesting since 1990, and
  - direct human-induced activities which aim to recover the forest from a degraded state, such as enrichment planting, conducted after December 2009.

All forest lands are monitored for harvesting since 1990 because the management intent of forest land outside of plantations, multiple-use public forests and conservation areas is not known. Once an activity is identified, the land on which it occurs is transferred to the *forest management* lands account. This enables the balanced and complete accounting of emissions and removals over time from this activity.

Table 11.16 shows the area of land included under each of these components of *forest management*.

Table 11.16 Land subject to *forest management*

Forest management sub-classifications	Modelled area (M ha)
Multiple use forests	9.2
Private native forests (where harvest has been observed and which have been included in forest management)	0.9
Pre-1990 plantations (commercial plantations not included under Article 3.3)	0.7
Total forest area	10.8

11.6.2 Identification of management practices

Forest management includes lands where management practices for the purpose of sustainable production of wood and wood fibre occur, such as:

- harvesting of forests, including thinning, selective harvesting and clearfell;
- silvicultural practices used for forest management;
- slash management, pest control, or fertilisation;
- protection of natural resources within the areas of land available for harvesting; and
- the application of codes of forest practice.

11.6.2.1 Policies included in the reference level projection

Australia has a comprehensive domestic framework designed to achieve the conservation and sustainable management of all of its forests. This framework includes:

- A national policy framework – Australia's 1992 National Forest Policy Statement (NFPS) promotes the conservation and sustainable management of forests.
- Regional Forest Agreements (RFAs) – RFAs have legal status via the national Regional Forests Agreement Act 2002. RFAs are 20-year plans underpinning regional approaches to balance conservation and production from native forests and cover the majority of production forest regions in Australia. In addition to forest conservation provisions, RFAs provide certainty for sustainable timber supply.
- Australia's Sustainable Forest Management Framework of Criteria and Indicators 2008 – this is an internationally recognised framework for sustainable forest management applied to Australia's forests.
- State and territory frameworks – jurisdictional legislation and codes of practice are applied to ensure environmentally responsible forestry practices.
- Forest certification – independent third party forest certification applies to most of Australia's production forests.

At the national level, Australia uses the international Montreal Process Criteria and Indicators as the framework for monitoring and measuring the management of forests.

Harvesting in native forests in Australia is regulated both at the national and State level. In 1992, Commonwealth and State governments agreed to a National Forest Policy statement establishing a regime for balancing ecologically sustainable forest management and harvesting with establishment of a Comprehensive, Adequate and Representative (CAR) reserve system to protect areas of environmental and heritage value such as old growth forests. This regime involved scientific research and consultation (called Comprehensive Regional Assessments) to support 20-year Regional Forest Agreements that provide certainty for forest-based industries, forest-dependent communities and conservation.

These agreements represent an important part of the policy context for regulating harvest rates in native multiple-use public forests in Australia. Regional Forest Agreements cover more than 39 million hectares, and in the four states New South Wales, Tasmania, Victoria and Western Australia nearly 17 million hectares are protected from logging under the CAR reserve system (MPIG, 2013). Additionally, the amount of wood that can be harvested from multiple-use public forests under Regional Forest Agreements is regulated using sustainable yield calculations designed to ensure the environmental attributes and the productive capacity of the forest are maintained. There are additional constraints on harvesting from native forests in areas that are reserved for conservation, water or heritage protection or other purposes. The application of codes of forest practice can also restrict harvesting in some areas (MPIG, 2013).

For native forests subject to harvesting (multiple-use public forests and harvested private native forests) inclusion of the relevant pre-2009 policies has been achieved by extrapolating the average harvest rates during the period 2002-2009 to the projection period. This projected harvest rate (Table 11.17) was used to model projected emissions during the FMRL period.

Table 11.17 Forest management reference level harvest rates

	Harvesting area (ha)
Reference Level harvesting (2002-2009 average)	108,166

For pre-1990 plantations, it is assumed in the reference level that harvesting occurs when plots reach maturity based on standard growth rates and rotation lengths, an assumption which is not affected by policy changes.

11.6.3 Methods used to establish the Forest Management Reference Level and for *forest management* reporting

11.6.3.1 Methods for estimating emissions in FMRL and reporting of *forest management*

The methods used in reporting of emissions from *forest management* and for calculation of the technical correction are described below in accordance with IPCC (2014), Chapter 2.7.2. Equivalent methods have been used for *forest management* as for the corresponding UNFCCC forest category (as described in Vol 2 Chapter 6). Consistent with *forest lands remaining forest lands,* emissions from *forest management* have been estimated using a Tier 2, Reporting Method 1 approach (IPCC, 2006; IPCC, 2014).

The emissions and removals from multiple-use public forests and harvested private native forests are estimated using the non-spatially explicit Estate modelling capability of *FullCAM*. This model enables the use of age-based growth data and incorporates the effects of differing silvicultural treatments on the generation and management of harvest slash. The forest classification and related characteristics including biomass and growth rates used to estimate carbon stock changes and emissions are the same as those described for the *harvested native forests* model in Chapter 6.4.1.1. Management and harvesting practices used in the model are also described in Chapter 6.4.1.1, and in Chapter 6.4.2 regarding emissions from post-harvest regeneration burning (slash burning).

The annual change in living biomass in native forests subject to harvesting is the net result of uptake due to forest growth (above and belowground as determined from the growth models) and losses due to forest harvesting. The forest type and harvest type influence the proportions of biomass transferred to the harvested wood products pool or residue material (including belowground biomass) moved to dead organic matter.

Emissions from consumption of fuelwood are estimated using the same methodology described in Chapter 6.4.4. It has been estimated that 19 per cent of emissions from consumption of wood and wood-waste is attributable to *forest management* lands.

The methods used to estimate carbon stock change and emissions for pre-1990 plantations are the same as those described in Chapter 6.4.2.

11.6.3.2 Harvested wood products

A tier 3, country specific method is used to estimate harvested wood products from forest management. In accordance with IPCC (2014) section 2.8.4 and paragraph 30 of the annex to Decision 2/CMP.7, Tier 3 or country specific methods can be used provided transparent and verifiable activity data is available and methods applied are at least as detailed and accurate as the default factors described in paragraph 29 of the annex to Decision 2/CMP.7

The general approach to estimating carbon stock changes in HWPs is set out in Section 4G – *harvested wood products* in Volume 2. The HWP model relies on the log harvest, HWP production and trade data contained in the Australian Forest Product Statistics (ABARES 2016a). In this submission, *forest management* includes HWP derived from softwood; all native hardwood; and all plantation hardwood harvests prior to the year 2000. HWP derived from harvests from all hardwood plantations from the year 2000 onwards are included in *afforestation/reforestation*. HWP stored in solid waste disposal sites is not included.

Consistent with decision 2/CMP.7, only HWP sourced from domestic forests are considered and exported material is included. Estimates are reported according to 3 broad HWP pools: Paper; Sawn wood; and Wood based panels. Accordingly, the 5 pool structure of HWP model used for the UNFCCC inventory is aggregated in the following way for the purposes of reporting:

- Paper and paper-board – pool 1 (Very short term paper and paper products);
- Sawn wood – pool 4 and pool 5 (long and very long term products); and,
- Wood based panels – pool 2 and pool 3 (short and medium term products).

11.6.3.3 Data

The same data sources are used for *forest management* as for *forest land remaining forest land*, as detailed in Chapter 6.4.1.1, Appendix 6.A and 6.G.

11.6.3.4 Start year

Estimation of net emissions is undertaken from 1970.

11.6.3.5 Carbon pools

FullCAM estimates emissions from soil through a process involving all on-site carbon pools (living biomass, dead organic matter and soil).

11.6.4 Natural Disturbances

In Australia, wildfire is the most widespread and frequent natural disturbance event which causes significant losses of carbon stock to the atmosphere.[2] Other natural disturbances include drought, storm damage, tropical cyclones, and pests and pathogens.

Decision 2/CMP.7 outlines rules for the reporting of natural disturbances in national inventories (the natural disturbances provision).[3]

Country specific approaches to the natural disturbance provision may be implemented as long as the approach is consistent with an expectation that net credits or net debits generated under the treatment of disturbances is zero (decision 2/CMP.7, annex, paragraph 33 (a)).

The natural disturbance provision has been applied to the estimates of emissions from *forest management*.

2 Natural disturbances are defined in Decision 2/CMP.7 as: Non-anthropogenic events or non-anthropogenic circumstances. For the purposes of this decision, these events or circumstances are those that cause significant emissions in forests and are beyond the control of, and not materially influenced by, a Party. These may include wildfires, insect and disease infestations, extreme weather events and/or geological disturbances, beyond the control of, and not materially influenced by, a Party. These exclude harvesting and prescribed burning.

3 Annex to decision 2/CMP.7, paragraph 33.

For the Kyoto Protocol, emissions include all gases from all wildfires on lands identified as *forest management* lands. The approach differs to that used in Chapter 6 since the natural disturbance provision is applied to the estimates of emissions rather than to the activity data as in Chapter 6.

11.6.4.1 Monitoring system for wildfires

A monitoring system based on the Advanced Very High Resolution Radiometer (AVHRR) has been implemented to identify and map natural disturbance impacts due to wildfire on *forest management* lands. The new system has been designed to comply with the following safeguard mechanisms prescribed under decision 2/CMP.7, which relate to:

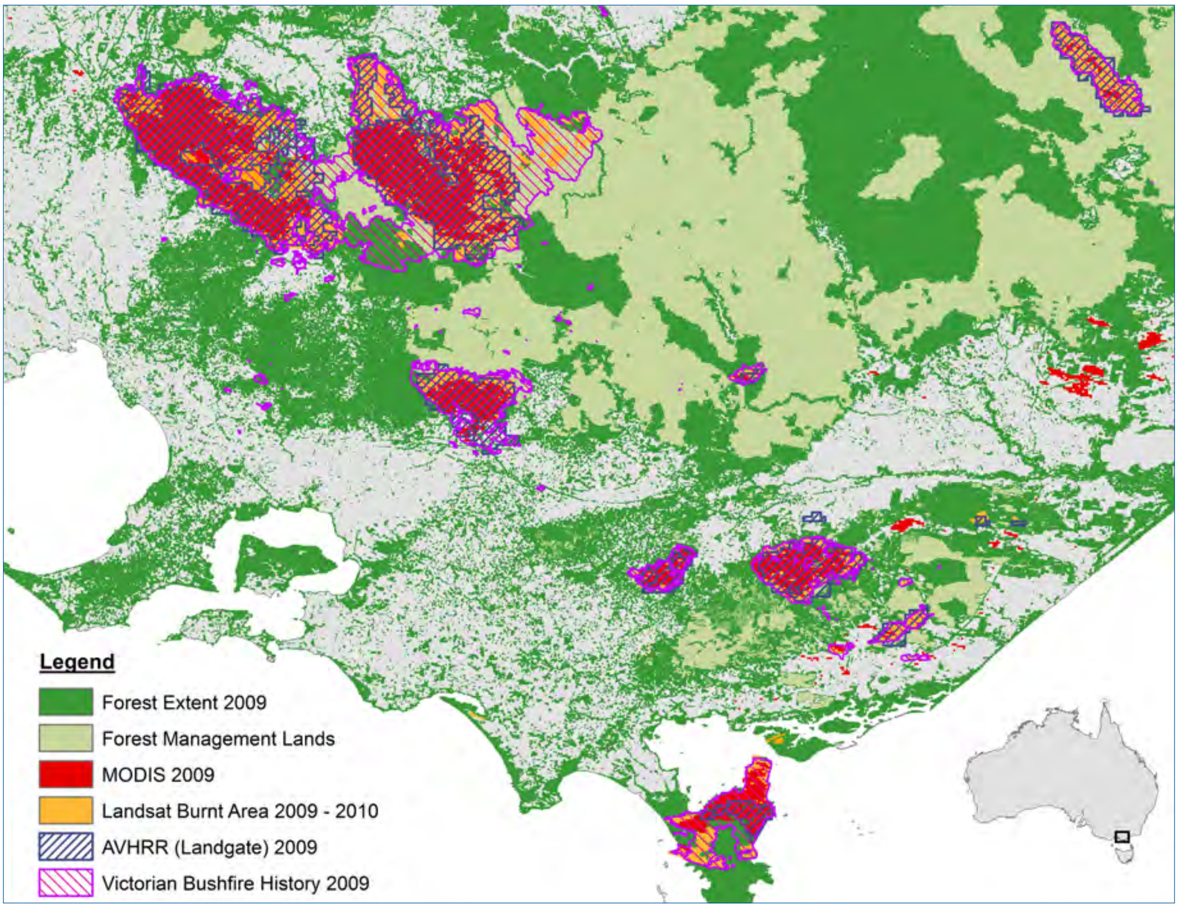
- the use of geolocated time series wildfire activity data,
- coverage of all forest management lands,
- the ability to monitor if there is a permanent land use change on those lands following a wildfire event during the commitment period,
- the inclusion of emissions associated with salvage logging in the accounting,
- identification of lands where the natural disturbance is followed by another disturbance event, in order to avoid double counting, and
- when using remote sensing data, a Party needs to identify the temporal, and spatial resolutions, calibration and validation of wildfire datasets using complementary ancillary and/or ground truth data.

The AVHRR burnt area product produced by the Western Australian Land Information Authority (Landgate), is tailored to Australian conditions and based on the visual interpretation of fire areas by experienced operators. The data was assessed by the Royal Melbourne Institute of Technology (RMIT) (Lowell, 2014), and compared with a range of alternative datasets, and was found to be the most suitable and highest quality time series data available (Figure 11.3). The datasets considered by the RMIT included:

1. Monthly AVHRR burnt area products (1990 to 2014), obtained from the Western Australian Land Information Authority (Landgate);
2. Monthly MODIS burnt area 500m products (2000 to 2013), obtained from the global database maintained by the University of Maryland, USA;
3. Limited coverage of wildfire data from the Landsat series of satellites; and
4. Reference bushfire history data supplied by state agencies.

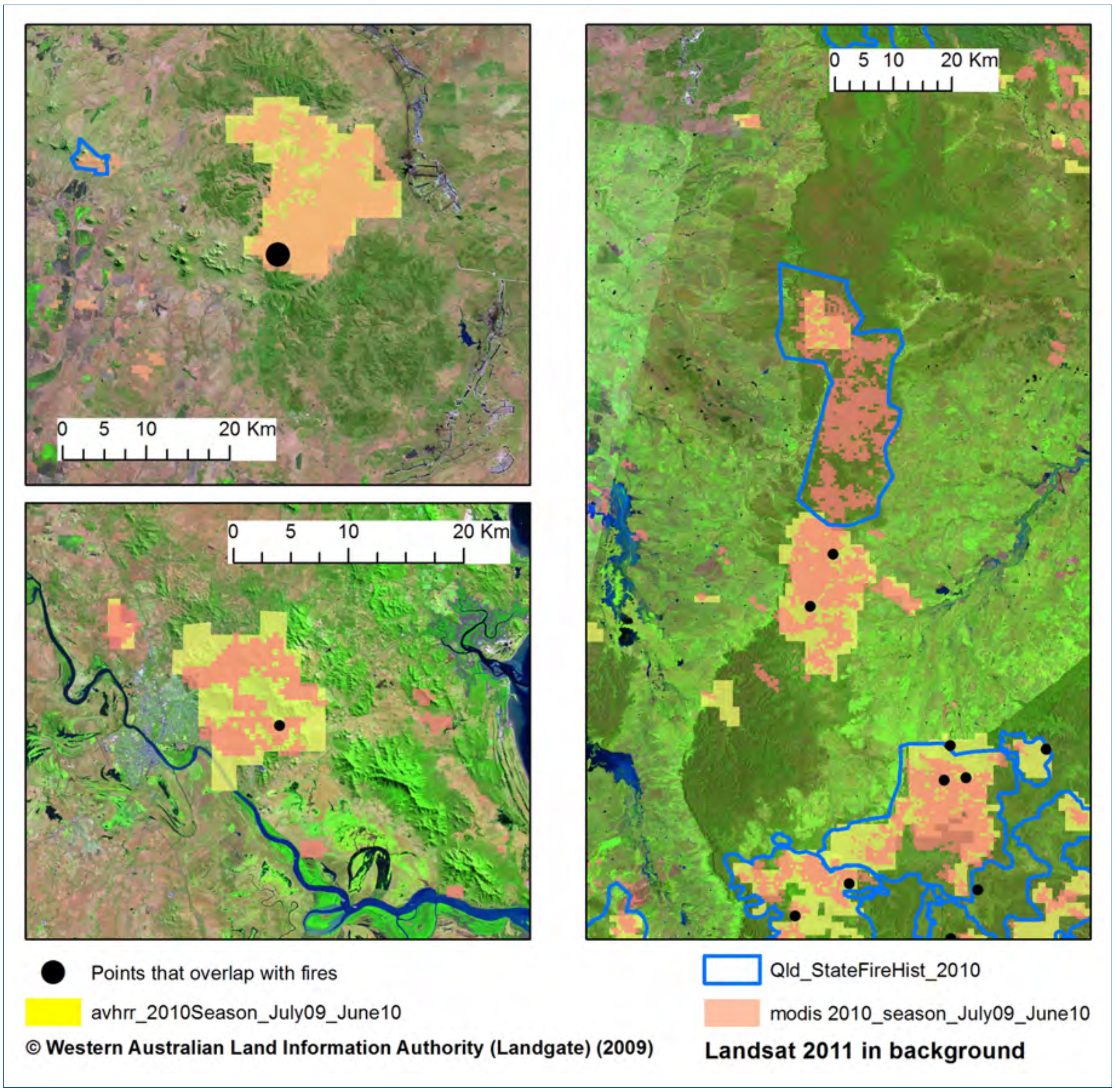
The overall quality of the post-2000 AVHRR burnt area products had a low commission error (5.4 per cent) which indicates that 94.6 per cent of the wildfire detected in the Landgate AVHRR burnt area product were correctly classified (Figure 11.4). The omission error was around 11 per cent after accounting for the undetected low-intensity prescribed burns (22 per cent) and smaller fires below the minimum mapping unit (9 per cent) which the 1km resolution AVHRR optical sensors were not expected to detect.

Figure 11.3 Comparison of 4 bushfire datasets over a part of Victorian multiple-use public forests



The overall quality of the post-2000 AVHRR burnt area products had a low commission error (5.4 per cent) which indicates that 94.6 per cent of the wildfire detected in the Landgate AVHRR burnt area product were correctly classified (Figure 11.4). The omission error was around 11 per cent after accounting for the undetected low-intensity prescribed burns (22 per cent) and smaller fires below the minimum mapping unit (9 per cent) which the 1km resolution AVHRR optical sensors were not expected to detect.

Figure 11.4 Validation of MODIS burnt area (orange), AVHRR burnt area (yellow) using the fire history data from Queensland (blue) derived from Landsat satellites. Black dots represent sampling points



Prescribed burns are estimated on the basis of State agency reports, as these fire types are hard to detect from coarser resolution satellite missions, such as the AVHRR sensor.

In addition to the calculation of annual wildfire extent, the system has been designed to monitor post-fire regrowth to ensure that there is no permanent land use change following a fire event (see Section 11.2.3.1). The system also monitors for incidences of multiple fires affecting the same lands within the commitment period (Figure 11.5, Figure 11.6) to avoid double-counting.

Figure 11.5 AVHRR based burnt area frequency for the period from 1988 to 2018

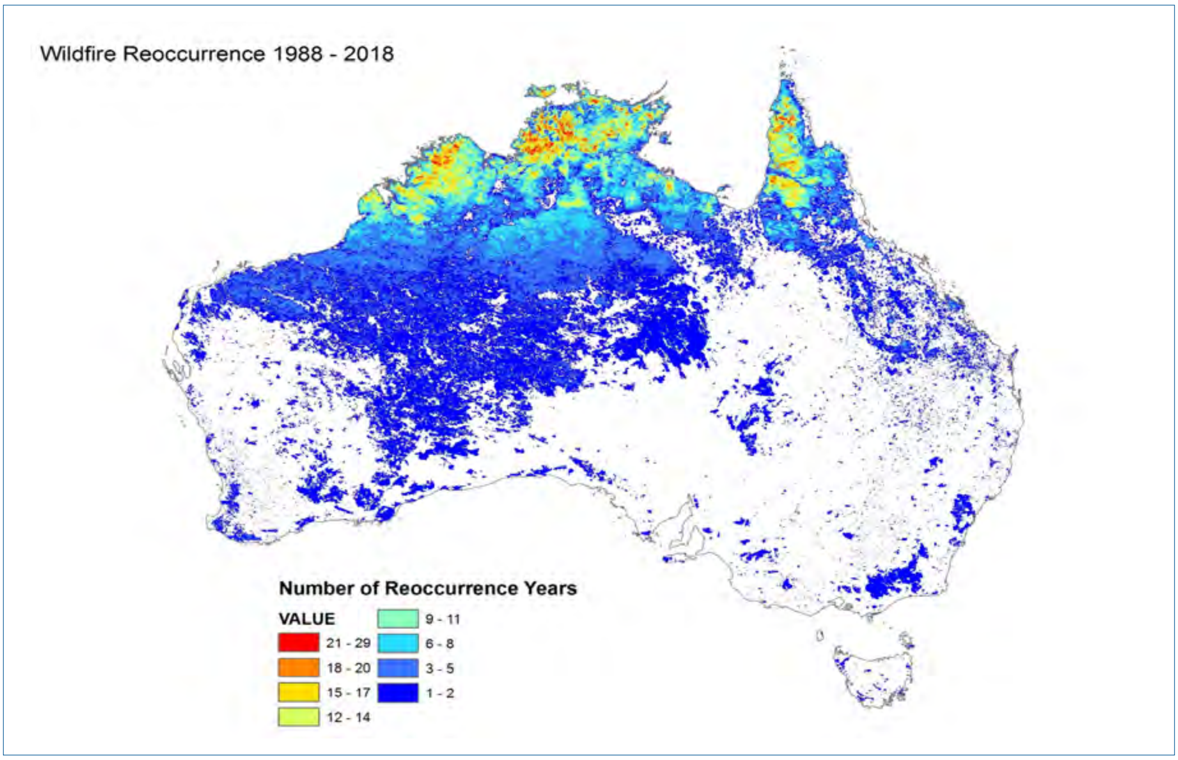
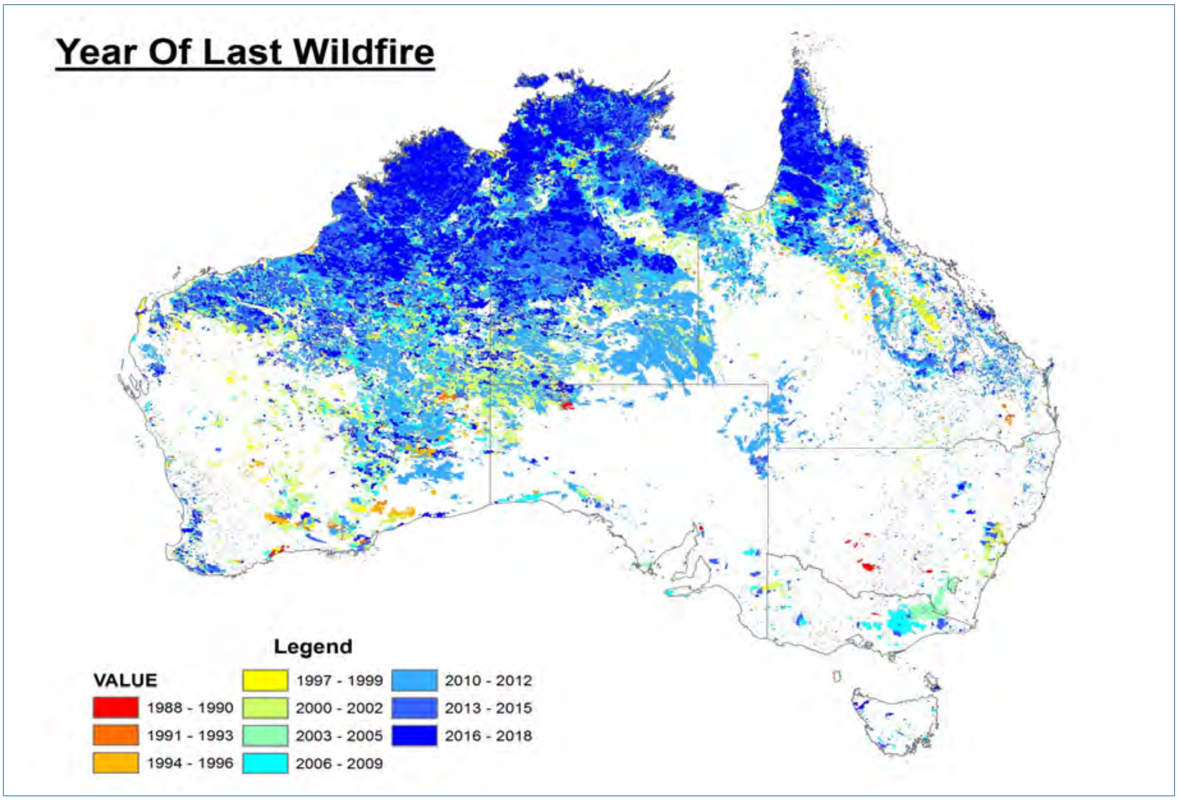


Figure 11.6 Year since last burn for the period from 1988 to 2018



The system will be subject to regular enhancements over time as remote sensing and data processing technologies evolve and as new information becomes available.

11.6.4.2 Method to estimate natural disturbance emissions and subsequent removals on *forest management* lands

The methodology used by Australia to estimate wildfire emissions and subsequent removals on *forest management* lands is consistent with the methodology applied to the *Forest land remaining Forest land* classification which is documented in section 6.4.3.

11.6.4.3 The Background Level and the Margin

Australia has calculated a background level and margin using the IPCC default method (see IPCC 2014, page 2.48-2.50) for the natural disturbance of wildfire. The background level and margin are presented in Table 11.18.

Table 11.18 Components of Australia's background level and margin for wildfire

Parameter	Value
Calibration period	2000-2012
Method used	IPCC default
Background level	3.40 Mt CO_2-e
Margin	3.65 Mt CO_2-e
Background level plus margin	7.04 Mt CO_2-e
Number of excluded years	Four
Excluded years	2003, 2007, 2009, 2010

IPCC quality criteria for the construction of the background level plus margin

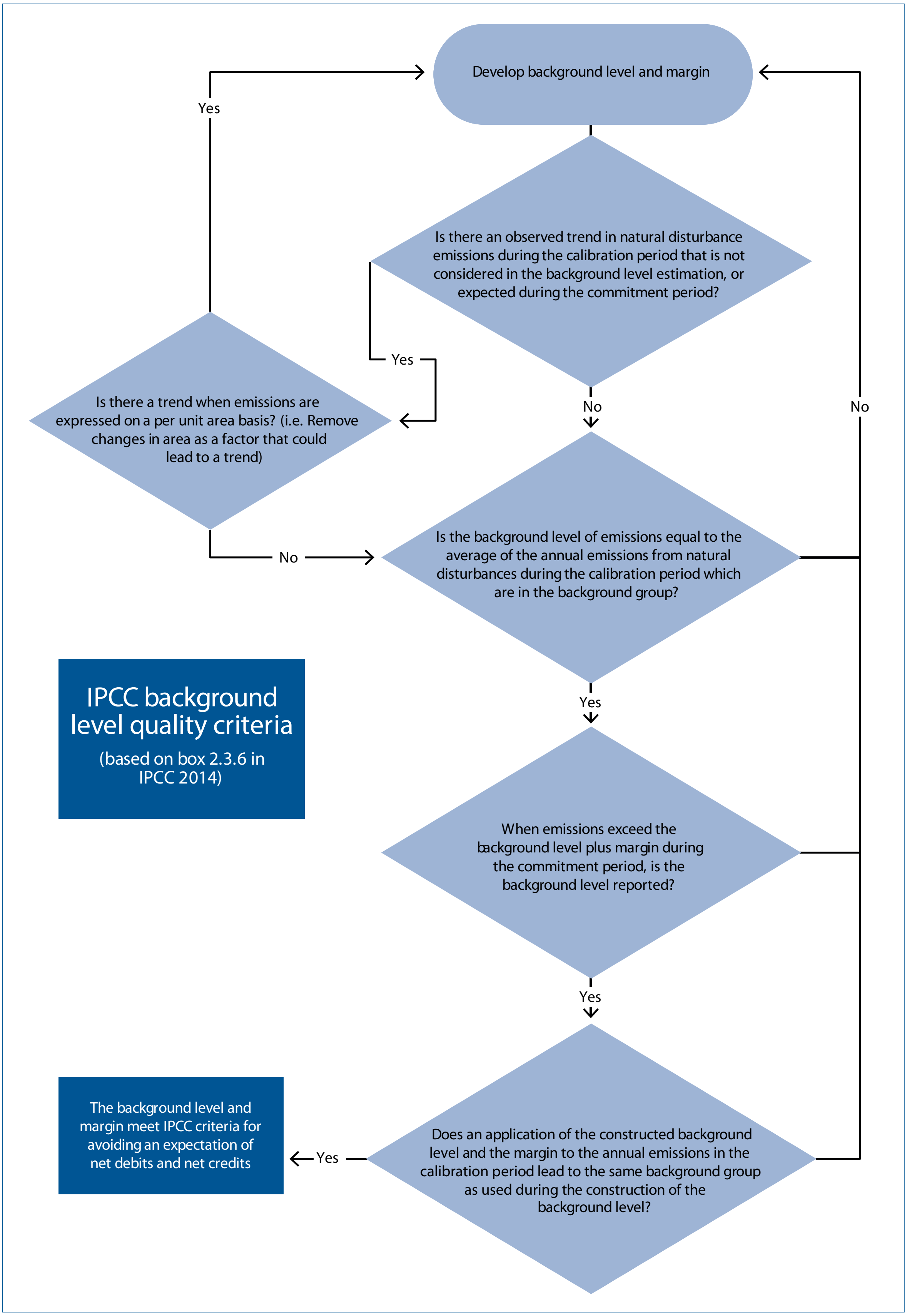
Four criteria for determining whether the data used to construct the background level and margin could result in an expectation of net credits or net debits are set out in Box 2.3.6 of IPCC (2014) page 2.50:

1. Trend – If there is a trend in natural disturbance emissions during the calibration period that is not considered in the background level estimation, or expected during the commitment period, then this could create an expectation of net debits or net credits.
2. Balance – The background level of emissions is equal to the average of the annual emissions from natural disturbances during the calibration period which are in the background group.
3. Reporting the background level – Any emission from natural disturbances during the commitment period that falls into the background group is not separately excluded from accounting. During the commitment period, emissions are only excluded from accounting when the annual emissions are greater than the background level plus the margin. When this occurs, only those emissions that are greater than the background level are excluded.
4. Validation – A test application of the constructed background level and the margin to the annual emissions in the calibration period leads to the same background group as used during the construction of the background level.

The procedure shown in the decision tree below (Figure 11.7) was implemented to ensure that the specified background level and margin meet these four criteria.

Reporting of natural disturbances and calculation of the background level and margin are both based on gross emissions only, instead of net emissions and removals (CO_2 removals due to post-fire regrowth are not reported). When CO_2 removals are also calculated, removals from previous year's natural disturbances can effect whether subsequent years exceed the background level and margin. Exclusion of removals therefore improves transparency in the application of the iterative process to remove outliers to establish the background group, and simplifies the application of the four IPCC criteria above.

Figure 11.7 Decision tree to support the development of a natural disturbance background level that is consistent with the IPCC background level quality criteria



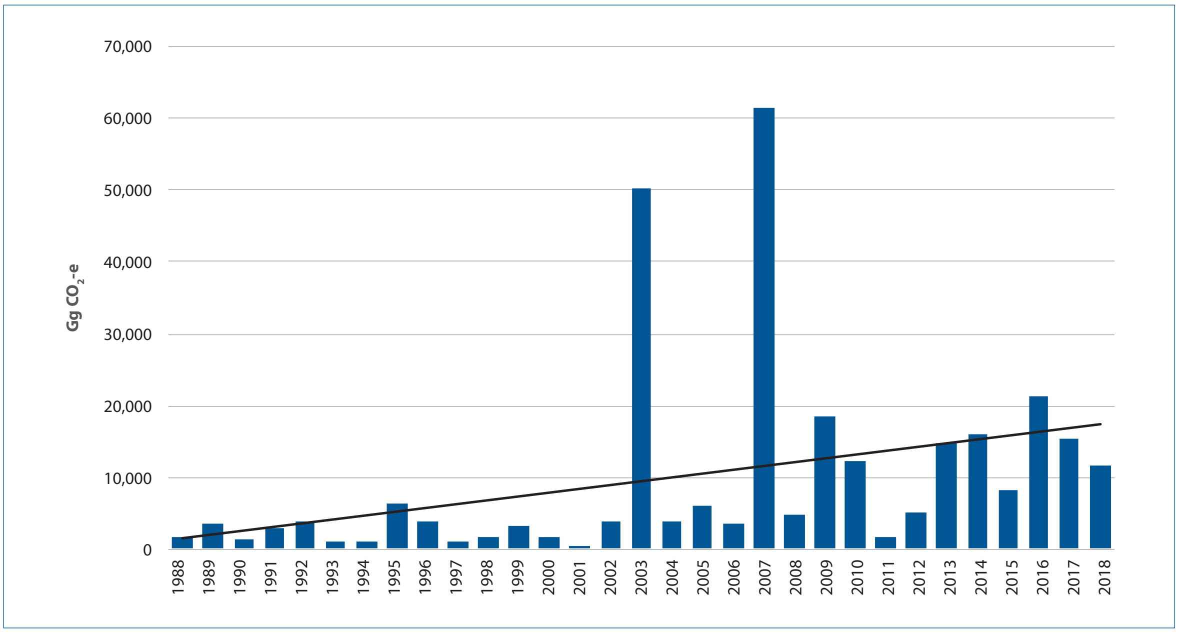
Trend criterion

Decision 2/CMP.7 indicates parties should use data from 1990-2009 – known as the calibration period – for the purpose of developing the background level and margin.

An important condition that must be satisfied is that there is no observable trend in natural disturbance emissions over the available time series. As shown in Figure 11.8, this condition is not satisfied by the full time series data on wildfire in Australia. Based on this trend assessment, the period 1988-1999 was excluded from the calibration group.

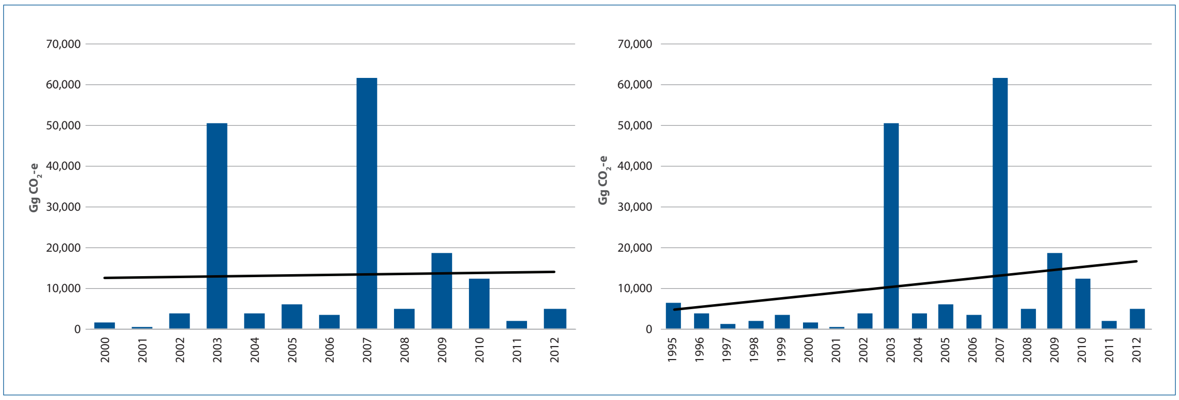
The period chosen to establish the dataset that underpins the estimation of the Background level is 2000-2012. This selected calibration group was then tested against the three IPCC quality criteria.

Figure 11.8 Wildfire burnt CO_2 emissions on *forest management* land and trend line, excluding CO_2 emissions associated with salvage logging



As shown in Figure 11.9 the slope of the trend line for the selected calibration period (2000-2012) is shallower than the slope of a longer calibration period (e.g. 1995-2012) (Figure 11.9).

Figure 11.9 Comparison of emissions trend across the selected calibration period and of a longer calibration period (1995-2012)



If the trend lines in Figure 11.9 are extended over the period 2013-2020 the increase in emissions for the selected calibration period is 1,492 kt CO_2-e while with a longer calibration period, for example 1995-2012, the increase in emissions is 12,043 kt CO_2-e.

While there remains a trend in the selected calibration period, the period 2000-2012 was selected to balance the need to limit the trend in emissions against having a calibration period that was too short.

In response to ERT recommendations, investigations were made to consider the use of a longer time series including the period 1990-2009. This was found not to be feasible due to the absence of readily-available, reliable and consistent source data prior to 1988. While some data on historic natural disturbances exists, it is more difficult to source data for fires other than natural disturbances between intervening popularly-reported events in most Australian States, which would be essential for the derivation of a useful time series.

Balance criterion

To meet the balance criterion, the calculated background level must equal the average of the annual emissions from natural disturbances during the calibration period which are in the background group.

The performance of the calculated background level against the balance criterion is shown in Table 11.19, which shows the calculated background level meets the balance criterion.

Table 11.19 Test of the balance criterion for a background level based on the 2000-2012 calibration group

Years included in background group	Wildfire emissions Mt CO_2-e
2000	1.63
2001	0.37
2002	3.87
2004	3.73
2005	6.05
2006	3.45
2008	4.77
2009	1.75
2011	4.94
2012	3.40
Average of background group	3.40
Background level	3.40
Difference	0.00
Balance criterion met?	Yes

Reporting of the background level

Emissions should only be excluded from accounting when annual emissions are greater than the background level plus margin, and when this occurs only those emissions and removals exceeding the background level should be excluded (that is, the background level should be reported). Table 11.20 shows that only emissions exceeding the background level are excluded in years where the natural disturbances provision is applied.

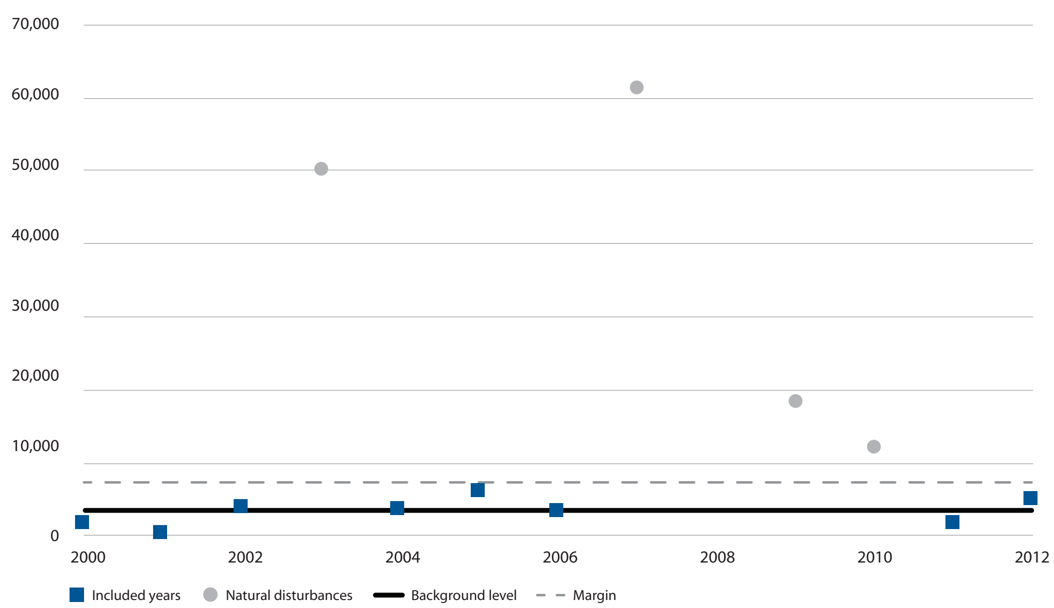
Table 11.20 Reported wildfire emissions and excluded natural disturbance emissions

Year	Reported emissions (after excluding natural disturbances)	Natural disturbance emissions that are excluded from reporting
	($kt\ CO_2$-e)	
2000	1,634	0
2001	374	0
2002	3,867	0
2003	3,397	46,926
2004	3,728	0
2005	6,054	0
2006	3,453	0
2007	3,397	58,093
2008	4,770	0
2009	3,397	15,155
2010	3,397	8,899
2011	1,754	0
2012	4,935	0
2013	3,397	11,453
2014	3,397	12,603
2015	3,397	4,696
2016	3,397	17,772
2017	3,397	11,951

Validation criterion

To satisfy the validation criterion, the emissions in any of the background group years should not exceed the background level plus margin. As shown in Figure 11.10, emissions in the background group years do not exceed the background level plus margin. The validation criterion has been met.

Figure 11.10 Background level and background level plus margin based on the 2000-2012 calibration data set



11.6.4.4 Demonstration that the expectation of net credits/net debits is zero.

According to IPCC (2014) (section 2.3.9.6, step 5) it is *good practice* for parties to ensure that the method applied to the development of the background level and margin does not lead to the expectation of net credits or net debits.

The Department of the Environment and Energy monitors the implementation of the background level and margin to ensure that there is no expectation of net debits or net credits associated with the implementation of the natural disturbance provision. If such a situation arises a technical correction will be applied to the FMRL.

11.6.4.5 Ensuring that emissions caused by salvage logging on land subject to natural disturbance are transparently reported

Emissions from salvage logging are included in estimates for multiple-use public forests, harvested private native forests and pre-1990 plantations. Estimates of forest harvesting are based on log production information that includes the products of salvage logging. These production statistics do not differentiate between material sourced from conventional clear felling and salvaging activities following wildfire or other natural disturbances.

A review of salvage harvesting by ABARES (Finn *et al.*, 2015) identified that this is a very minor activity compared to either total harvesting activity or total areas burned. Salvage harvesting is generally opportunistic, determined as much by commercial factors as biophysical factors. However it does occur more often in forest and plantation types which are located in areas with sufficient harvesting capacity. A time series of emissions associated with salvage logging has been developed utilising industry data on the national sales of salvaged pine, and state government reporting in states where salvage harvesting of multiple use forests is known to occur (Table 11.21). In recent years, multiple use forest salvage harvesting has predominantly occurred in ash forests where the combination of economic factors are conducive to salvage harvesting practices. Estimates of biomass volumes per hectare or per unit of harvested wood are based on harvesting parameters from FullCAM. Estimates of wood density and carbon content are drawn from parameters used in the modelling of *harvested wood products*.

Table 11.21 Estimates of salvage logging activity and emissions

Year ending 30th June	Pine plantation salvage harvests (m^3)[5]	Multiple Use Forest salvage harvests (m^3)[6]	Modeled emissions (kt CO_2-e C)[7]
2007	496,416	18,923	441
2008	425,350	98,383	472
2009	389,591	71,551	411
2010	438,792	114,511	502
2011	516,658	86,836	536
2012	179,179	10,564	163
2013	111,708	0	94
2014	101,138	0	85
2015	76,187	602	65
2016	86,850	492	74
2017	106,016	883	90

5 Based off the Australian Pine Log Price Index (stumpage), KPMG, 2018
6 Based off collections by the Victorian State Government, Department of Economic Development, Jobs, Transport and Resources, 2018
7 assumes instant oxidation of harvest area biomass

11.6.4.6 Information that natural disturbance events were beyond the control of the party (IPCC 2014, page 2.36)

In Australia, wildfires threaten life and property, and are addressed in disaster response plans and management arrangements in each state and territory. Common frameworks for national, state and territory fire management policies include: reducing the likelihood of fires occurring, for example through fuel reduction burning and fire bans; managing or controlling the fire during its occurrence; monitoring programs and early warning systems; and firefighting operations. In addition to such disaster management policies, there is also a significant research effort into understanding and better managing wildfires, and following many significant fire events, inquests or enquiries are held to assess the disaster response and potential for improvement.

There are fire management policies and plans in place at the national and the state and territory level to control for the risks, events and consequence of wildfire to the extent that this is possible. These documents set out frameworks for:

- Reducing the likelihood of a wildfire occurring, for example, through the use of prescribed burning;
- Managing or controlling the disturbance during its occurrence;
- Monitoring programs and early warning systems; and
- Firefighting operations.

The implementation of plans and strategies to avoid and minimise risks to life and property from wildfires is documented in the following section.

National level

The National Bushfire Management Policy Statement for Forests and Rangelands (FFMG 2014)[4] outlines Australian, state and territory government objectives and policies for the management of landscape-level fire in Australia's forests and rangelands. The statement was developed by the Forest Fire Management Group, a national body within the Council of Australian Governments, with the role of providing information to governments on major forest fire-related issues, policies and practices affecting land management. The Australasian Fire and Emergencies Authorities Council is the national peak organisation that provides advice on a range of polices and standards. Research on bushfires is performed by a number of organisations, including:

- the Bushfire Cooperative Research Centre, which brings together experts from universities;
- the Commonwealth Scientific and Industrial Research Organisation (CSIRO);
- other Australian, state and territory government organisations, and;
- the private sector for long-term programs of collaborative research.

The national Bureau of Meteorology publishes fire weather warnings and has a role in the declaration of fire bans when weather conditions are conducive to the spread of dangerous bushfires. Warnings are generally issued within 24 hours of the potential onset of hazardous conditions. Warnings are also broadcast on radio and television.

Fire agencies determine Fire Danger Ratings. In most States and Territories, fire agencies declare fire bans based on a range of criteria including forecast weather provided by the Bureau.

The Bureau also incorporates Total Fire Ban Advices into warnings, if one is being enforced at the time of issue, and an action statement from local fire authorities detailing areas where the ban is in effect.

4 https://www.semc.wa.gov.au/riskmanagement/Documents/NationalBushfireManagementPolicy_2014.pdf

Fire Weather Warnings are distributed through the media, fire agencies and other key emergency service organisations. Warnings are normally issued in the afternoon for the following day so to be available for evening television and radio news broadcasts. Warnings are renewed at regular intervals and generally at the same time major forecasts are issued. However, warnings may be issued or amended and reissued at any time if a need is identified. If there is a Fire Weather Warning current, the Bureau will mention this in State, Territory and District weather forecasts for that area.

In each State the issue of a Fire Weather Warning has different impacts on restrictions for lighting fires.

The Bureau of Meteorology does not have the power to declare a Total Fire Ban. This responsibility resides with designated fire agencies in each State and Territory. However, in South Australia, Northern Territory, Victoria, New South Wales and Tasmania, the Bureau does issue Total Fire Ban Advices to assist publicising and distributing the message. The Bureau also includes information about the existence of current fire bans in weather forecasts and warnings.

The areas covered by fire bans do not align with Bureau forecast districts in New South Wales, Tasmania and Northern Territory.

State and territory level

Each state and territory has published a document which sets the framework for the management of bushfires. These plans include information on the use of public information campaigns and requirements around the declaration and publication of fire bans and fire danger ratings during fire seasons. In Queensland the documents are published for a number of regions within the state, rather than at the state level.

New South Wales

The aim of the State Bush Fire plan is to set out the arrangements for preparedness, prevention, mitigation, response to and recovery from bush fire events by combat, participating and support agencies in NSW, including Lord Howe Island.

This plan describes the arrangements for the control and coordination by the New South Wales Rural Fire Service (NSW RFS) Commissioner for the response to Class 2 & 3 bush and grass fires, including those managed under the provisions of section 44 of the Rural Fires Act 1997, and the provisions for emergency warnings at all classes of fires.

These arrangements ensure that the two combat agencies, NSW RFS and Fire & Rescue NSW, are able to manage small scale bush and grass fires, utilising assistance from the other fire-fighting authorities being the National Park & Wildlife Service and Forestry Corporation NSW.

The current NSW State Bush Fire plan is available at www.emergency.nsw.gov.au

Victoria

Victoria's State Bushfire Plan provides an overarching view of responsibilities of agencies, government and communities in bushfire management.

The first version of the State Bushfire Plan was developed in 2012 in conjunction with the Country Fire Authority, the Metropolitan Fire Brigade, the Department of Environment and Primary Industries and the Fire Services Commissioner.

The second version of the State Bushfire Plan was produced in 2014, with updates to reflect the changes in Victorian emergency management legislation and the emergency management sector.

The plan reflects an integrated approach and shared responsibility for bushfire management between government, agencies, business, communities and individuals.

Although intended as a reference document for fire and emergency management agencies, the State Bushfire Plan will be of equal interest to anyone who works or volunteers in bushfire management.

The State Bushfire Plan is a sub-plan of the State Emergency Response Plan, found in the Emergency Management Manual of Victoria, the principal document for guiding the State's emergency management arrangements.

Victoria's State Bushfire Plan is available at www.emv.vic.gov.au

Queensland

In Queensland, fire management policies and plans are developed at regional rather than at the state level. The Queensland government provides an overview of the approach to disaster management in Queensland at http://www.disaster.qld.gov.au/

Western Australia

Western Australia has developed a series of State Hazard Plans (Westplans) through its State Emergency Management Committee. These include a hazard plan for fire. These plans are available at semc.wa.gov.au

South Australia

In South Australia, State Emergency Management Arrangements are organized through the South Australian Fire and Emergency Services Commission, including the establishment and maintenance of the State Emergency Management Plan which include plans for fire management and response.

The South Australian State Emergency Management Plan is available at www.safecom.sa.gov.au

Tasmania

Tasmania's State Fire Management Council (SFMC) is established under Section 14 of the Fire Service Act 1979 (Tasmania). It is an independent body that has the responsibility of providing advice to the Minister and the State Fire Commission about the management of vegetation fire across Tasmania, particularly in the areas of prevention and mitigation of fires. It also formulates and promulgates policy in relation to vegetation fire management within Tasmania in relation to bushfire fuels and mitigation. The primary function of the SFMC is to develop a State Vegetation Fire Management Policy that is used as the basis for all fire management planning.

Fire protection plans for the various regions of Tasmania are maintained on the SFMC website at www.sfmc.tas.gov.au

Northern Territory

In the Northern Territory, fire management in urban areas is the responsibility of the NT Fire and Rescue Service, and in rural areas is the responsibility of Bushfires NT.

The Territory Emergency Plan and further information is available at www.pfes.nt.gov.au

Australian Capital Territory

The ACT Government Emergency Services Agency's Strategic Bushfire Management Plan is available at esa.act.gov.au

11.6.4.7 Information to identify lands where the natural disturbance is followed by another disturbance event, in order to avoid double counting (IPCC 2014, page 2.45)

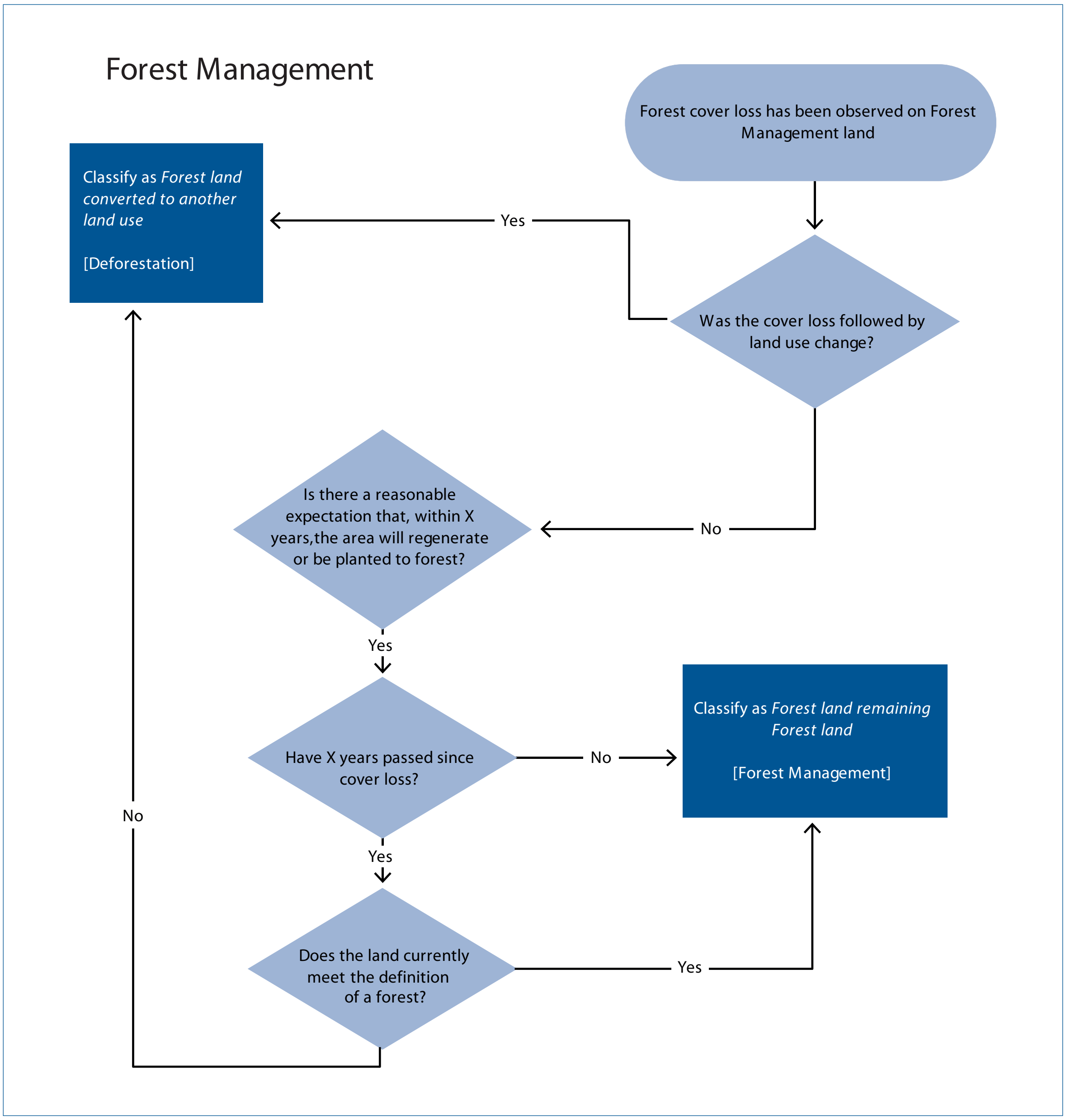
Wildfire natural disturbance events are monitored using data derived from the AVHRR sensor as described in section 11.6.4.1. The system established to monitor, track and archive the AVHRR burnt area data detects incidences of burnt areas on the same unit of land within the commitment period.

The method for estimating carbon stock changes from a natural disturbance event is documented in Volume 2, section 6.4.1.3. According to this method, the biomass consumed during a wildfire in temperate forests recovers over a number of years following the fire, modeled using Tier 3, Approach 3 spatial simulation using FullCAM. On average across Australia, fuel loads reach 95 per cent of equilibrium levels within 11 years (Roxburgh *et al.* 2015). Where repeat burning is observed before fuel loads are fully recovered, emissions from the second fire are based on the modelled fuel recovery at the time of the fire. This ensures that double-counting of emissions is avoided.

11.6.4.8 Information to identify lands where land use change has occurred after a natural disturbance (IPCC 2014, page 2.45)

All forest land is monitored for harvesting and deforestation events. *Forest management* land is monitored for 12 years following forest cover loss events (due to harvesting, fire and other disturbances) to determine if land use change has occurred (section 11.2.3.1) consistent with the requirements for determining if land is subject to *deforestation* specified in Figure 2.6.1 of IPCC (2014) (Figure 11.11).

Figure 11.11 Monitoring and classification of *forest management* land following a forest cover loss event



11.6.4.9 Information on efforts to rehabilitate the land subject to natural disturbances (IPCC 2014, page 2.53)

The need for rehabilitation of Australia's native forests following natural disturbance is dependent upon the nature of the disturbance. Australia's native forest are generally dominated by fire tolerant species. The principal fire tolerant responses in forest tree species are summarised in Table 11.22[5]. Some species however, for example Mountain Ash (*Eucalyptus regnans*) and Alpine Ash (*Eucalyptus delegatensis*) are vulnerable to frequent fires as the plants are unable to reach maturity and produce sufficient seed before the next fire.

5 Atwell, Kriedemann, and Turnbull (1999) *Plants in Action*, Macmillan Education Australia, Melbourne.

In the case of Alpine Ash there are examples of the need for re-seeding following fire to ensure the rehabilitation of the forest.[6]

Table 11.22 Adaptation of Australia forest genera to fire

Adaptation to enable natural regeneration after fire	Forest genera
Stimulation of seed release from woody capsules by heat and desiccation	Casuarina, Hakea, Banksia, Leptospermum and Eucalyptus.
Stimulation of germination of soil-stored seed by fire	Acacia
Stimulation of bud development after fire from lignotubers	Eucalyptus

11.6.5 Forest management reference level technical correction

Australia's 2011 FMRL submission (DCCEE, 2011) outlines the methods used for estimating the reference level.

There have been a number of methodological refinements since this reference level was submitted, which include changes to address the subsequently agreed rules for implementing the natural disturbances provision and calculating emissions from harvested wood products (UNFCCC, 2011). There have also been refinements to other methodological elements used in the estimation of emissions from *forest management*.

Methodological consistency between the reference level and the reporting of *forest management* in the national inventory must be demonstrated, including by making technical corrections to the FMRL if necessary. If there are any recalculations of the historical data used to establish the reference level, a technical correction must be applied.

In order to maintain such methodological consistency, a technical correction has been estimated as -3.54 Mt CO_2-e. This correction incorporates corrections to the sub-categories of *forest management* reporting (Table 11.23).

6 http://archive.premier.vic.gov.au/2014/media-centre/media-releases/7162-helicopters-sowing-alpine-ash-forest-following-harrietville-fire.html

Table 11.23 Technical correction by sub-category – summary

($Mt CO_2$-e)	Multiple-use public forests	Harvested private native forests	Pre-1990 Plantations	Prescribed burning	Included natural disturbance emissions	Fuelwood combusted	Harvested wood products	N-Mineralisation	Total
FMRL 2011 Submission	-9.93	8.94	0.27	0.19	8.68	1.29	-4.74	na	4.700
FMRL Estimate in 2015_13	-7.81	5.70	2.63	0.10	2.63	1.60	-3.73	na	1.117
FMRL Estimate in 2016_14	-9.68	7.29	2.72	0.65	3.90	-0.12	-4.87	0.03	-0.085
FMRL Estimate in 2017_15	-10.04	7.59	3.23	0.65	3.90	-0.13	-4.87	0.03	0.364
FMRL Estimate in 2018_16	-10.05	7.57	3.23	0.65	3.90	-0.13	-4.57	0.03	0.630
FMRLcorr in 2019_17	-10.05	7.57	4.16	0.65	3.40	-0.13	-4.47	0.03	1.159
Technical Correction (FMRLcorr minus FMRL 2011)	-0.12	-1.37	3.89	0.46	-5.28	-1.41	0.27	0.03	-3.541

Relevant criteria under IPCC (2014) (page 2.101) that trigger the requirement to report a technical correction include:

The method used to report emissions and removals from *forest management* changed after the adoption of FMRL.

Any of the following methodological elements used to establish the FMRL (as reported in the FMRL submission) changed after the adoption of the FMRL.

- Pools and gases
- Area under forest management
- Historical inventory data Forest characteristics and related management
- Historical harvesting rates
- Climate data assumed by models for projecting FMRL
- *Harvested wood products* (including data or methods)
- Natural Disturbances.

These criteria have been matched against the different aspects of technical correction in Table 11.24.

Table 11.24 Elements of technical correction and cross-reference with IPCC *good practice* guidance

Component of *forest management* Correction	**Technical Correction (Mt CO_2-e)**	**Factors leading to correction**	**IPCC (2013) Guidance Criteria**	**Reason for methodological change or methodological refinement (With reference to good practice in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 1)**
Total correction	**-3.54**	***(sum of corrections reported in NIR 2013 - 2017)***		
Total corrections reported in NIR 2017	**0.53**			
Harvested private native forest	0.00	Correction to historical data on wood production affecting activity data in 1990 and age-class structure of forests.	Criteria 2.c Recalculated historical data from GHG inventory	Methodological refinement as part of continuous improvement when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
Multiple-use public forests	0.00	Correction to historical data on wood production affecting activity data in 1990 and age-class structure of forests.	Criteria 2.c Recalculated historical data from GHG inventory	Methodological refinement as part of continuous improvement when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
Pre-1990 plantations	0.92	Modelling improvements to utilise Tier 3, Approach 3 fully spatial capability within FullCAM, more consistent with post-1990 plantations	Criteria 1. change of GHG reporting method	Methodological change to move to a higher tier, consistent with the inventory improvement plan (new inventory methods become available; Vol 1, Ch 5.2.1).
Natural Disturbances	-0.50	Modelling improvements to utilise Tier 3, Approach 3 fully spatial capability within FullCAM, consistent with other LULUCF sectors	Criteria 1. change of GHG reporting method	Methodological change to move to a higher tier, consistent with the inventory improvement plan (new inventory methods become available; Vol 1, Ch 5.2.1).
Harvested Wood Products	0.10	Revised estimates in the Australian Forest and Wood Products Statistics, including an update to the accuracy of historical production estimates (ABARES, 2018a)	Criteria 2.c Recalculated historical data from GHG inventory	Methodological refinement as part of continuous improvement when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
N-Mineralisation	-0.00	Recalculation to soil C pool in Harvested private native forests, multiple-use public forests, and pre-1990 plantations (due to recalculations described above)	Criteria 2.c Recalculated historical data	Methodological refinement as part of continuous improvement when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)

Component of *forest management* Correction	Technical Correction (Mt CO_2-e)	Factors leading to correction	IPCC (2013) Guidance Criteria	Reason for methodological change or methodological refinement (With reference to good practice in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 1)
Total corrections reported in NIR 2016	**0.27**			
Harvested private native forest	-0.02	The age structure of the managed forest estate has been updated over the full time series to reflect data on forests harvested in 2016 (including forest type, age structure of forests at the time of harvesting)	Criteria 2.d Recalculation of historical data - age structure of forests	Methodological refinement as part of continuous improvement of the FullCAM modelling framework when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
Multiple-use public forests	-0.01	The age structure of the managed forest estate has been updated over the full time series to reflect data on forests harvested in 2016 (including forest type, age structure of forests at the time of harvesting)	Criteria 2.d Recalculation of historical data - age structure of forests	Methodological refinement as part of continuous improvement of the FullCAM modelling framework when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
Pre-1990 plantations	0.00	Availability of annual climate data climate data	Criteria 2.f Different observed climate data as compared to what was assumed in the FMRL	Methodological refinement as part of continuous improvement of the FullCAM modelling framework when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
HWP	0.30	Recalculation to take account of new source of AD regarding wood production pre-1990	Criteria 2.c Recalculated historical data from GHG inventory	Methodological refinement as part of continuous improvement when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
N-Mineralisation	0.00	Recalculation to soil C pool in Harvested private native forests, multiple-use puglic forests, and pre-1990 plantations	Criteria 2.c Recalculated historical data	Methodological refinement as part of continuous improvement of the FullCAM modelling framework when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
Total corrections reported in NIR 2015	**0.45**			
Harvested private native forest	0.30	- Availability of annual climate data climate data - Alignment with sectoral estimation periods	Criteria 2.f Different observed climate data as compared to what was assumed in the FMRL	Methodological refinement as part of continuous improvement of the FullCAM modelling framework when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)

Component of *forest management* Correction	Technical Correction (Mt CO_2-e)	Factors leading to correction	IPCC (2013) Guidance Criteria	Reason for methodological change or methodological refinement (With reference to good practice in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 1)
Multiple-use public forests	-0.35	- Recalculation of harvesting attributable to deforestation - Availability of annual climate data climate data - Alignment with sectoral estimation periods	Criteria 2.e recalculation of historical harvest rates	Methodological refinement as part of continuous improvement of the FullCAM modelling framework when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
Pre-1990 plantations	0.51	Availability of annual climate data climate data	Criteria 2.f Different observed climate data as compared to what was assumed in the FMRL	Methodological refinement as part of continuous improvement of the FullCAM modelling framework when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
HWP	-0.01	Corrections to AD to avoid double counting of HWP from deforestation events (already accounted for on the basis of instantaneous oxidation)	Criteria 2.g HWP - New / recalculated data and / or methods; inclusion of provisions	Implementation of KP accounting rules (IPCC, 2014; Decision 2/CMP.7) (consistency with IPCC guidelines; Vol 1 Ch 5.2.1)
N-Mineralisation	-0.00	Implementation of new rounding policy for emission factor precision (all sectors, further detail on the 2016-17 ANAO Performance Audit can be found in section ES.4.1 of Volume 1).	Criteria 2.c Recalculated historical data for FL-FL or FM	Methodolgical refinement as part of continuous improvement in modelling framework following QA process (correction of errors; Vol 1, Ch 5.2.1)
Total corrections reported in NIR 2014	**-1.20**			
Harvested private native forest	1.59	Estimation and reporting of Soil Carbon pool with required model updates	Criteria 2.a inclusion of new pools or gasses	Methodological refinement to allow complete reporting of all pools and gasses required in Annex to Decision 2/CMP.7, paragraph 26 (consistency with IPCC guidelines; Vol 1 Ch 5.2.1)
Multiple-use public forests	-1.87	Estimation and reporting of Soil Carbon pool with required model updates	Criteria 2.a inclusion of new pools or gasses	Methodological refinement to allow complete reporting of all pools and gasses required in Annex to Decision 2/CMP.7, paragraph 26 (consistency with IPCC guidelines; Vol 1 Ch 5.2.1)

Component of *forest management* Correction	Technical Correction (Mt CO_2-e)	Factors leading to correction	IPCC (2013) Guidance Criteria	Reason for methodological change or methodological refinement (With reference to good practice in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 1)
Pre-1990 plantations	0.09	Revised climate, soil and clay activity data	Criteria 2.f Different observed climate data as compared to what was assumed in the FMRL	Methodological refinement as part of continuous improvement of the FullCAM modelling framework when new data becomes available (available data has changed; Vol 1, Ch 5.2.1)
Natural Disturbances	1.26	Implementation of revised model parameters from new empirical research	Criteria 2.c Recalculated historical data for FL-FL or FM	Implementation of recommendation by ERT from review of FL-FL (ARR 2015, recommendation L.27). Methodological refinement to implement new research and new empirical data, consistent with
Fuelwood	-1.71	Addressing double-counting of emissions with HWP, debris and fire	Criteria 2.c Recalculated historical data for FL-FL or FM	Avoiding double-counting of emissions (correction of error consistent with
HWP	-1.14	Corrections to implementation of KP accounting rules; including modelling of domestically produced wood products, disaggregation of HWP from Afforestation / Reforestation and Deforestation activities	Criteria 2.g HWP - New / recalculated data and / or methods; inclusion of provisions	Complete implementation of KP accounting rules (IPCC, 2014; Decision 2/CMP.7) (consistency with IPCC guidelines; Vol 1 Ch 5.2.1)
Prescribed burning	0.55	Implementation of revised model parameters from new empirical research	Criteria 2.c Recalculated historical data for FL-FL or FM	Implementation of recommendation by ERT from review of FL-FL (ARR 2015, recommendation L.27). Methodological refinement to implement new research and new empirical data, consistent with
N-Mineralisation	0.03	Reporting of Soil Carbon pool allows estimation of N Mineralisation	Criteria 2.a inclusion of new pools or gasses	Methodological refinement to allow complete reporting of all pools and gasses required in Annex to Decision 2/CMP.7, paragraph 26 (consistency with IPCC guidelines; Vol 1 Ch 5.2.1)
Technical correction reported in NIR 2013	**-3.58**	**Cumulative correction (as reported in NIR 2013)**		
Private Native Harvest				

Component of *forest management* Correction	Technical Correction (Mt CO_2-e)	Factors leading to correction	IPCC (2013) Guidance Criteria	Reason for methodological change or methodological refinement (With reference to good practice in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 1)
Calendar year Reporting	-3.24	Cumulative correction Activity data converted from financial years to calendar years, consistent with broader LULUCF inventory reporting	Criteria 2.b recalculation of area under FM, and **2.e** recalculation of historical harvest rates	Recalculation of activity data in order to ensure consistency with reporting of other Article 3.3 and 3.4 activities and
Combined	-2.77	(Tasmania & other states)		
Tasmanian harvested private native forest	-0.80	Changed time series from 1990-2020 to 1970-2020 New activity data (ABARES)	Criteria 2.b recalculation of area under FM, and **2.e** recalculation of historical harvest rates	Methodological refinement to utilise new activity data (in accordance with
Other States (NSW, Qld, WA)	-1.33	New modelling method (now FullCAM) Time series and activity data now consistent with TAS (1970-2020)	Criteria 1. change of GHG reporting method and Criteria 2.b recalculation of area under FM, and 2.e recalculation of historical harvest rates	Methodological refinement to utilise new activity data (in accordance with
Multiple-use public forests				
Calendar year Reporting	2.11	Cumulative correction Activity data converted from financial years to calendar years, consistent with broader LULUCF inventory reporting	Criteria 2.e recalculation of historical harvest rates	Recalculation of activity data in order to ensure consistency with reporting of other Article 3.3 and 3.4 activities and

Component of *forest management* Correction	Technical Correction (Mt CO_2-e)	Factors leading to correction	IPCC (2013) Guidance Criteria	Reason for methodological change or methodological refinement (With reference to good practice in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 1)
Correction for observed deforestation	2.92	Cumulative correction Annual harvesting area and total forest management estate area corrected for observed deforestation Includes projected rates of deforestation during reference level period (2013-2020) (based on historical average)	Criteria 2.b recalculation of area under FM, and **2.e** recalculation of historical harvest rates	Implementation of land classification system consistent with Article 3.3 and 3.4 and consistent with
Pre-1990s average harvest rates	4.16	Cumulative correction Early '90s average used to project backwards; reflecting an assumption of harvesting occurring on lands listed as conservation reserves as at December 2009 Using new activity data from ABARES AFWPS	Criteria 2.e recalculation of historical harvest rates	Used extrapolation to estimate pre-1990 harvest and improve consistency with post-1990 harvest data (in accordance with Ch 5.3.3.4 using trend extrapolation to resolve data gaps) Ensures that modelled emissions trends reflect only real changes in activity data (post 1990), not model artefact due to technique to resolve data gap in historical activity data
Activity Data	0.09	Cumulative correction Using new activity data – Australian Forest and Wood Products Statistics by ABARES	Criteria 2.b recalculation of area under FM, and **2.e** recalculation of historical harvest rates	Methodological refinement to utilise new activity data (in accordance with
Time series change	0.24	Cumulative correction multiple-use public forests harvest now modelled for 1970 to 2020. (Prev 1960) Using FMRL raw harvest data	Criteria 2.e recalculation of historical harvest rates	Reduces length of time for which extrapolated activity data is used (in accordance with Ch 5.3.3.4 using trend extrapolation to resolve data gaps) Consistent time series with harvested private native forest and other parts of the national inventory including UNFCCC Harvested Native Forests, to more accurately reflect emissions trends across forest management reporting

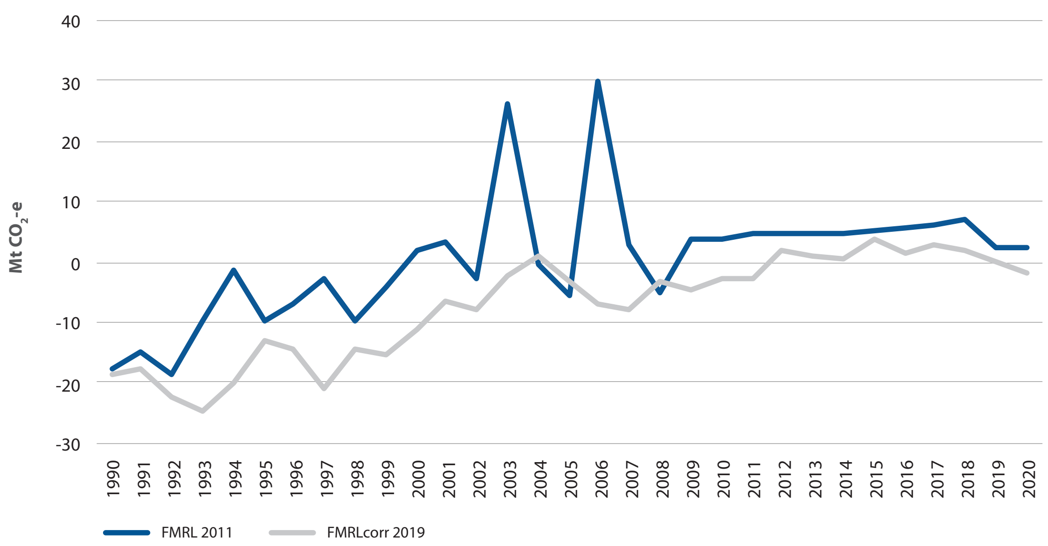
Component of *forest management* Correction	Technical Correction (Mt CO_2-e)	Factors leading to correction	IPCC (2013) Guidance Criteria	Reason for methodological change or methodological refinement (With reference to good practice in 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 1)
WA lookup	-0.04	Cumulative correction Modelling of correct subset of raw harvest data for WA Using FMRL raw harvest data	Criteria 2.e recalculation of historical harvest rates	Corrected error in activity data requiring recalculation of historical emissions trends (in accordance with good practice: Ch 5.2.1 Recalculations due to methodological changes and refinements)
NSW Allocation correction	2.00	Using additional data points to allocate harvest Using FMRL raw harvest data	Criteria 2.e recalculation of historical harvest rates	Methodological refinement to utilise new activity data (in accordance with
Prescribed Burning	-0.10	Updated GWPs from IPCC AR4 Updated activity data to maintain methodological consistency with timeseries used for reporting	Criteria 2.d recalculation of historical data on forest characteristics and related management	GWP for NO
Fuelwood	0.31	New activity data based on NGERS reporting and emissions factors from the Energy sector	Criteria 2.e recalculation of historical harvest rates	Methodological refinement to utilise new activity data (in accordance with
Pre-1990 plantations	2.36	Implementation of tree yield formula to model biomass, permitting utilisation of climate data Estimation of soil carbon pool	Criteria 2.d recalculation of historical data on forest characteristics and related management	Methodological refinement to utilise new model capability (in accordance with good practice: Ch 5.2.1 Recalculations due to methodological changes and refinements) New soil carbon and tree yield formula improves consistency with other reporting categories, including afforestation/reforestation.
Natural Disturbances	-6.04	Implementing IPCC (2014) methods and guidance, including calculation of background level and margin	Criteria 2.h new data and methods for accounting for natural distrubances	Updated supplementary methods and good practice guidance finalised after submission of the FMRL (IPCC, 2014)
Harvested Wood Products	1.01	Addressing Decision 2/CMP.7 and IPCC (2014), including by calculating emissions from the exports pool and excluding the imports pool	Criteria 2.g New/recalculated data and methods and inclusions of provisions for Harvested Wood Products	Internationally agreed rules (Decision 2/CMP.7) on accounting for harvested wood products and Updated supplementary methods and good practice guidance (IPCC, 2014) finalised after submission of the FMRL

Table 11.25 reports the technical correction for 2017 (the accounting quantity is reported below at section 11.6.6.2), and Figure 11.12 shows a plot of the temporal dynamics of the estimates underlying the $FMRL_{corr}$ and FMRL (refer to IPCC (2014) Ch 2.7.6.2).

Table 11.25 Summary table for reporting of technical correction

Summary table for technical correction (Table 2.7.2, IPCC, 2014)		
Forest Management Reference Level recalculated for the purpose of calculating the Technical Correction ($FMRL_{corr}$)	1,159	kt CO_2-e
Forest Management Reference Level (FMRL)	4,700	kt CO_2-e
Difference in Percent	-75	%
Technical Correction	-3,541	kt CO_2-e

Figure 11.12 Comparison of recalculated reference level emissions (FMRLcorr) with previous estimates (FMRL)



* Note: the FMRL includes emissions from wildfires, consistent with the reference level inscribed in the Annex to Decision 2/CMP.7. The FMRLcorr time series applies the natural disturbances provision as set out in the Annex to Decision 2/CMP.7 and described in IPCC 2014.

11.6.5.1 Rationale for calculating $FMRL_{corr}$

The details of the technical corrections are outlined in Table 11.24. The rationale for the changes reflected in the FMRL are outlined below only for the main changes since the 2016 submission.

Native forest harvesting from multiple use public forests and private native forest harvesting

Corrections to the historical wood harvesting data in 1990 have been made in order to maintain consistency with data and modelling of *forest land remaining forest land* – see chapter 6.4.5 for further information.

Pre-1990 plantations

This system of forests has been advanced to a Tier 3, Approach 3 method by implementing full spatial simulation capabilities within FullCAM – see chapter 6.4.5 for further information.

Natural disturbances

Fire regimes have been advanced to a Tier 3, Approach 3 method by implementing full spatial simulation capabilities within FullCAM. Natural disturbance emissions continue to be calculated following the rules for the Kyoto Protocol, but now draw on more detailed estimates of emissions arising from fire at a detailed spatial level. The necessary quality controls to ensure there is no expectation of net debits and credits have been conducted in accordance with the methods outlined earlier in this chapter.

Harvested Wood Products

Estimates of *harvested wood products* have been revised to account for time-series revisions to the underlying source data on forestry and wood products produced by the Australian Bureau of Agricultural and Resource Economics (2018a).

11.6.6 Reporting of *forest management* in 2017

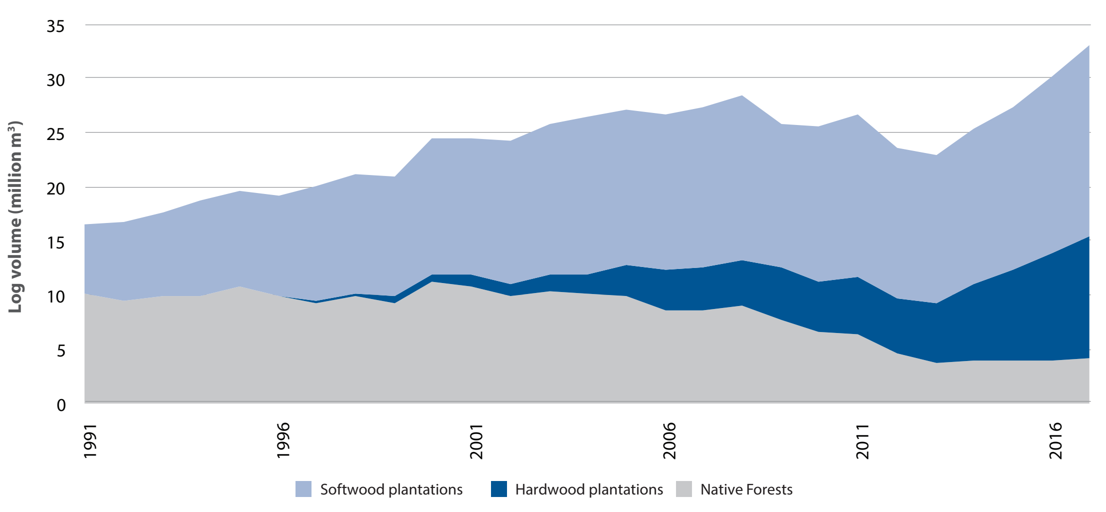
11.6.6.1 Reporting of *forest management* net emissions in 2017

In accordance with *good practice* the emissions and removals for *forest management* are estimated using the same methodologies, models and activity data as were used in the calculation of $FMRL_{corr}$, described above in Section 11.6.3.

The main factor affecting the trends in *forest management* net emissions in 2017 remains the decline in emissions from native forest harvesting from multiple-use public forests and harvested private native forests. This corresponds to a change in activity levels that also impacts on the harvested wood products pool and related emissions. The importance of this trend in activity data to overall emissions from *forest management* is shown in the correlation in Figure 11.13.

Australian forest production statistics indicate a rapid decline in production from native forest harvesting (from multiple-use public forests and harvested private native forest) has occurred since 2008-2009 (ABARES, 2018a) (Figure 11.13). This has been part of a broader structural transition in the forest production industry in Australia.

Figure 11.13 Forest production in Australia (1991-2017)



Source: ABARES (2018a)

Constraints on timber supply from native forests and favourable policy and economic conditions for plantation establishment resulted in a peak in reported new plantation establishment for hardwood plantations in the decade from 2000 (ABARES 2018a). Emissions and removals from these plantations are reported under *afforestation/reforestation*. Due to the standard rotation lengths for commonly used hardwood plantation species the new plantations established during these periods are now ready for harvest, causing rapid increases in hardwood plantation production rates (Figure 11.13).

This increase the supply of plantation hardwood in Australia, in combination with broader economic factors affecting the forest industry, has led to the observed decline in harvesting from native forests in particular through the substitution of log production from native forests with production from plantations.

Currently harvesting activity levels in multiple-use public forests and harvested private native forests are below reference levels. This decline in activity levels is reflected in reported emissions from *forest management* (Table 11.26).

Table 11.26 Estimated net emissions from *forest management* (kt CO_2-e)

Year	Multiple-use public forest (a)	Private harvested native forests	Pre-1990 plantations	Harvested wood products	Natural disturbances	Prescribed burning	Total
2000	-10,986	9,379	-6,049	-5,286	1,634	285	-11,023
2005	-11,102	7,655	-1,563	-4,929	6,054	541	-3,343
2010	-18,729	2,911	2,152	-4,176	3,397	909	-13,536
2011	-20,029	2,674	3,468	-4,499	1,754	959	-15,673
2012	-23,994	-685	4,449	-4,041	4,935	604	-18,732
2013	-26,621	-1,601	4,810	-3,556	3,397	621	-22,951
2014	-27,435	-1,239	4,012	-4,501	3,397	583	-25,183
2015	-28,012	-1,496	7,220	-4,666	3,397	512	-23,044
2016	-28,238	-1,502	4,592	-5,261	3,397	555	-26,457
2017	-28,065	-1,470	5,403	-5,881	3,397	1,001	-25,616

(a) Includes carbon stock changes due to fuelwood collection and combustion

11.6.6.2 Reporting of *forest management* Accounting Quantity in 2013-17

Estimates of the accounting quantity for *forest management* – to be used to estimate the amount of RMU credits to be issued – are reported in Table 11.27. Estimates are derived by deducting the reported net emissions in 2017 from the FMRL after technical correction up to the value of the FM cap on credits. Note that Australia has elected to account for Article 3.4 activities at the end of the commitment period, and that if this were to be accounted for now that Australia has reached its maximum credits.

Table 11.27 Estimated accounting quantity for Forest management (t CO_2-e)

Year	$FMRL_{corr}$	Forest management	Accounting Quantity (RMU credits)	Cumulative Accounting Quantity	Forest management cap on credits	RMU Credits
2013	1,159,492	-22,950,979	-24,110,471	-24,110,471		-24,110,471
2014	1,159,492	-25,183,076	-26,342,568	-50,453,039		-26,342,568
2015	1,159,492	-23,044,067	-24,203,559	-74,656,598		-24,203,559
2016	1,159,492	-26,457,041	-27,616,532	-102,273,130		-27,616,532
2017	1,159,492	-25,615,792	-26,775,284	-129,048,414	-117,214,453	-14,941,323

* Note: negative accounting quantities indicate that RMUs are to be issued.

11.6.6.3 Reporting of conversion of natural forests to planted forests (Annex to Decision 2/CMP.7, paragraph 5)

Available evidence indicates that conversion of multiple-use public forests to plantations no longer occurs in Australia as a result of state and territory regulations.

Reporting of emissions from the conversion of natural (native) forests to planted forests (plantations) is included in reported emissions under *forest management*.

11.6.7 Quality Assurance – Quality Control

11.6.7.1 Quality Control

In addition to the tests reported under section 11.6.4 (relating to the natural disturbances provision), four Quality Control tests are reported aimed at demonstrating methodological consistency and the avoidance of credits or debits between the FMRL and estimates of net emissions from *forest management* from methodological inconsistency.

(i) Comparison of the initial FMRL (DCCEE, 2011) and $FMRL_{corr}$;

(ii) Reproduction of the historical time series in the reporting of *forest management* and the forest management reference level (IPCC 2014, pages 2.100, 2.103);

(iii) A quantitative comparison of trends in native forest wood production and emissions from *forest management* from 2002 to 2013 (IPCC 2014, p2.97); and

(iv) Reconciliation of estimates used for the FMRL with estimates from *forest land remaining forest land*.

(i) Comparison of the initial FMRL (DCCEE, 2011) and $FMRL_{corr}$

Comparison of the FMRL (DCCEE, 2011) and $FMRL_{corr}$ improves transparency by highlighting the main factors generating the technical correction. There are changes in activity data and parameters for reporting on biomass burning that have been updated for the reporting of *forest management*.

However there are also methodological refinements to the subcategories of harvesting from multiple use public forests and private native forests which are the most important in terms of the trend in reported *forest management* emissions in 2017. These refinements include changes in the pools reported to include the soil carbon pool, changes in activity data that affects activity levels for the reference period of 2002-2009, and changes to the area under *forest management*. Table 11.28 shows how these changes have affected the $FMRL_{corr}$ relative to the 2011 FMRL submission.

In multiple-use public forests, the inclusion of a sink from soil carbon pool (-1.7 Mt CO_2-e) offsets the increased harvesting rate which results from utilization of new nationally consistent harvest data, so there is minimal change in estimated emissions. Soil carbon represents a net sink for multiple-use public forests, because reference harvest rate (91,250 ha/yr) relative to the total area of multiple-use public forests (9.22 Mha) means that the area which is losing soil carbon following a harvesting event is much smaller than the area in which soil carbon stocks are increasing (recovering from historical harvesting).

The main contributor to the technical correction to harvested private native forests, is the change in area of *forest management* lands, which has been revised upwards from 0.39 Mha (as estimated in the DCCEE, 2011) to 0.93 Mha (reported in this submission). This results in a larger forest area acting as a carbon sink where CO_2 removals from biomass growth is occurring, and an overall negative technical correction (-1.4 Mt CO_2-e, Table 11.28). This increase in area of forest acting as a sink is partially offset by emissions from the inclusion of the soil carbon pool. The soil carbon pool in harvested private native forests represents a source of emissions due to a relatively higher harvesting rate in proportion to forest area.

Table 11.28 Native forest harvesting reference level and key activity data

Component of FMRL Technical Correction	Technical Correction by component	Original FMRL submission			2019 FMRL ($FMRL_{corr}$)			
		RL 2011	Reference Harvest Rate	Area under FM	$FMRL_{corr}$	Included soil carbon emissions/ removals	Reference Harvest Rate	Area under FM
	($Mt CO_2$-e)	($Mt CO_2$-e)	(ha/yr)	(M ha)	($Mt CO_2$-e)	($Mt CO_2$-e)	(ha/yr)	(M ha)
Private Native Harvest	-1.4	8.9	16,764	0.39	7.6	1.0	16,915	0.93
Multiple-use public forests	-0.1	-9.9	88,537	9.4	-10.0	-1.7	91,250	9.23

(ii) Reproduction of the time series used for the FMRL using methods used to estimate net emissions for forest management

It is *good practice* to provide information that there is no expectation of net credits or net debits linked to any methodological inconsistency between $FMRL_{corr}$ and reporting for *forest management* (IPCC, 2014, pages 2.102-2.103).

Methodological consistency and the avoidance of credits or debits can be shown by reproducing the same historical time series in the reporting of *forest management* and the forest management reference level (IPCC 2014, pages 2.100, 2.103). This historical reproduction (Table 11.29) demonstrates that the difference in estimated emissions between the FMRL and the reporting of *forest management* is linked to variations in the activity data during the period since 2009 (since 2008 for HWP). Remaining model variables have been addressed in the construction of $FMRL_{corr}$, as described in Section 11.6.3.

Table 11.29 Time series comparison of FMRL and reporting of *forest management*

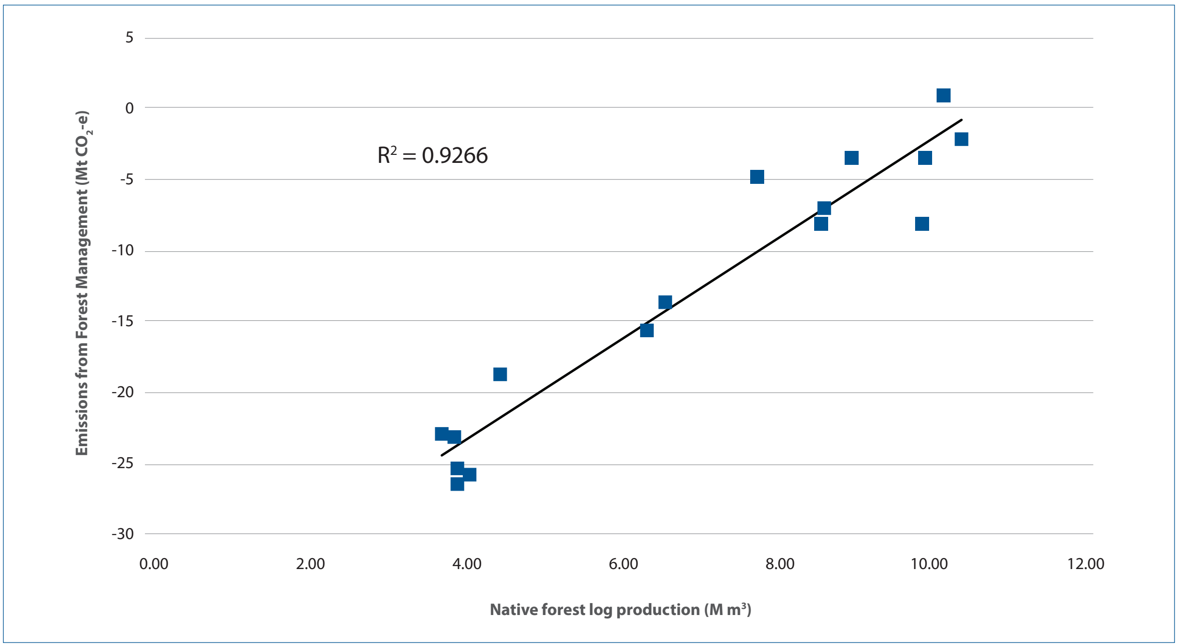
Year	Historical time series used for constructing $FMRL_{corr}$	Reporting of FM
	Emissions / Removals (kt CO_2-e)	
1990	-18,584	-18,584
1991	-17,752	-17,752
1992	-22,244	-22,244
1993	-24,693	-23,564
1994	-19,956	-19,956
1995	-12,844	-12,844
1996	-14,622	-14,622
1997	-20,892	-20,902
1998	-14,301	-14,316
1999	-15,444	-15,457
2000	-11,023	-11,023
2001	-6,497	-6,497
2002	-7,963	-7,963
2003	-2,128	-2,128

Year	Historical time series used for constructing $FMRL_{corr}$	Reporting of FM
	Emissions / Removals (kt CO_2-e)	
2004	920	920
2005	-3,344	-3,343
2006	-7,053	-7,053
2007	-8,009	-8,009
2008	-3,421	-3,420
2009		-4,752
2010		-13,536
2011		-15,673
2012		-18,732
2013		-22,951
2014		-25,183
2015		-23,044
2016		-26,457
2017		-25,616
FMRL	1,159	

(iii) Quantitative comparison of trends in native forest wood production and emissions from forest management

A quantitative comparison of trends in native forest wood production and emissions from *forest management* from 2002 to 2013 is shown in Figure 11.14 (IPCC 2014, p2.97). This provides evidence that the main factor generating the accounting quantity is the decline in harvesting activity from native forests, specifically multiple-use public forests and private native harvesting relative to the activity levels assumed in the FMRL. There are other components of *forest management* estimates, in particular associated with biomass burning, which introduce volatility into this relationship.

Figure 11.14 Correlation of estimated emissions from *forest management* and native forest log production (2002-2017)



(iv) Reconciliation of forest management with forest land remaining forest land reporting

In accordance with *good practice*, the area of lands subject to *forest management* have been reconciled against the relevant categories within *forest land remaining forest land* in Table 11.30 below.

Table 11.30 Reconciliation of UNFCCC forest lands and *forest management* lands

Forest land remaining forest land category	forest management sub-classifications	Estimated area in 2017 (M ha)
Plantations	Pre-1990 plantations (commercial plantations not included under Article 3.3)	0.7
Harvested native forests	Multiple use forests	9.2
	Private native forests (where harvest has been observed and which have been included in *forest management*)	0.9
Other native forests		127.2

Pre-1990 plantations included in *forest management* are equivalent to *plantations* reported under *forest land remaining forest land*.

The combined emissions from multiple-use public forests and private native harvesting forests are a subset of the *harvested native forest* category (Table 11.30).

Wildfire, fuelwood and prescribed burning emissions for *forest management* lands are a subset of the emissions reported for *forest land remaining forest land*. Carbon stock changes in the pool of *harvested wood products* from *forest management* lands are not reported in the corresponding categories of *forest land remaining forest land* and instead are reported in aggregate under Chapter 4G – *harvested wood products*.

Table 11.31 provides a reconciliation of emissions estimates between the reporting categories of *forest management* and *forest land remaining forest land*.

Table 11.31 Reconciliation of *forest management with forest land remaining forest land* emissions (Mt CO_2e)

Forest land remaining forest land	**Plantations**	**Harvested Native Forests**				***Harvested Native Forest Total***	**Reported differently for KP and UNFCCC (FM is a subset due to narrow approach to defining FM Lands; or different accounting rules)**					***Other Native Forest total***	***Forest land remaining forest land total***
FM	**Pre 1990 plantations**	**Multiple-use public forests**	**Private Native forest harvesting**	**N mineralisation**	**N- leaching and runoff**		**Prescribed Burning**	**Fuelwood**	**Harvested wood products**	**Natural disturbances**	**FM total**		
1990	-12,478	-11,318	6,362	33	30	-17,370	72	85	-2,734	1,393	-18,584	7,379	-9,991
1991	-11,652	-12,163	6,048	29	27	-17,711	-98	93	-2,813	2,804	-17,752	5,944	-11,767
1992	-16,514	-12,579	5,643	27	26	-23,398	287	101	-2,957	3,749	-22,244	11,515	-11,883
1993	-16,495	-11,340	5,921	26	25	-21,862	301	115	-3,222	1,129	-23,564	11,390	-10,472
1994	-12,376	-11,070	5,973	24	23	-17,427	106	110	-3,793	1,070	-19,956	7,964	-9,462
1995	-14,274	-8,440	6,998	23	22	-15,671	284	95	-3,773	6,243	-12,844	8,646	-7,025
1996	-11,334	-10,345	6,291	25	23	-15,340	130	88	-3,348	3,872	-14,622	9,586	-5,754
1997	-11,078	-13,169	5,879	24	23	-18,320	-39	88	-3,626	1,019	-20,902	3,754	-14,566
1998	-6,478	-12,938	7,523	23	22	-11,847	-81	70	-4,151	1,715	-14,316	2,115	-9,732
1999	-7,012	-14,473	6,702	30	24	-14,728	-196	56	-3,746	3,181	-15,457	2,298	-12,430
2000	-5,929	-10,746	9,571	22	21	-7,062	-334	46	-5,286	1,634	-11,023	7,268	206
2001	-3,193	-6,081	7,466	22	23	-1,763	-176	24	-4,934	374	-6,497	5,406	3,643
2002	-651	-12,528	6,539	23	24	-6,594	-125	-186	-4,902	3,867	-7,963	5,844	-750
2003	572	-8,790	7,956	21	22	-219	-17	-15	-5,251	3,397	-2,128	7,921	7,703
2004	4,669	-10,162	7,918	25	24	2,474	-28	-51	-5,180	3,728	920	6,418	8,891
2005	-1,499	-10,751	7,809	23	24	-4,393	29	-80	-4,929	6,054	-3,343	3,154	-1,239
2006	1,864	-13,065	5,390	28	28	-5,754	200	-93	-4,831	3,453	-7,053	6,278	524
2007	890	-13,122	5,629	26	26	-6,551	271	-105	-4,994	3,397	-8,009	11,086	4,535
2008	2,577	-12,403	6,219	30	27	-3,550	271	-116	-4,769	4,770	-3,420	15,258	11,708
2009	5,449	-15,404	5,107	34	28	-4,786	457	-126	-3,666	3,397	-4,752	13,921	9,136
2010	2,239	-18,420	2,987	46	38	-13,111	527	-135	-4,176	3,397	-13,536	11,720	-1,391
2011	3,502	-19,713	2,749	80	56	-13,326	598	-144	-4,499	1,754	-15,673	15,185	1,859

Forest land remaining forest land	Plantations	Harvested Native Forests				Harvested Native Forest Total	Reported differently for KP and UNFCCC (FM is a subset due to narrow approach to defining FM Lands; or different accounting rules)					Other Native Forest total	Forest land remaining forest land total
FM	Pre 1990 plantations	Multiple-use public forests	Private Native forest harvesting	N mineralisation	N- leaching and runoff		Prescribed Burning	Fuelwood	Harvested wood products	Natural disturbances	FM total		
2012	4,571	-23,779	-666	49	36	-19,788	307	-109	-4,041	4,935	-18,732	7,703	-12,085
2013	4,971	-26,457	-1,589	30	28	-23,017	337	-83	-3,556	3,397	-22,951	5,830	-17,187
2014	4,106	-27,273	-1,215	34	34	-24,314	348	-79	-4,501	3,397	-25,183	7,409	-16,905
2015	7,379	-27,840	-1,472	26	25	-21,883	221	-88	-4,666	3,397	-23,044	10,149	-11,734
2016	4,745	-28,074	-1,475	20	21	-24,762	267	-77	-5,261	3,397	-26,457	6,568	-18,194
2017	5,574	-27,906	-1,440	24	22	-23,725	681	-65	-5,881	3,397	-25,616	10,873	-12,852

11.6.7.2 Quality Assurance

The methodology for the implementation of the natural disturbances provision was reviewed in S. Federici (2016).

11.6.8 Recalculations

Further descriptions of the recalculations is provided in the corresponding LULUCF category in the *forest land remaining forest land* section of Volume 2 (section 6.4.5).

Table 11.32 *Forest management*: recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2018 submission	2019 submission	Change		Reasons for Recalculations			
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	%	A. Spatial Fire	B. Pre-1990 Plantations	C. Data updates relating to native forest harvesting	Other
1990	-17,740	-18,584	-844	-5%	-612	-213	4	-20
1995	-12,660	-12,844	-185	-1%	2,028	-2,205	7	-7
2000	-7,493	-11,023	-3,530	-47%	59	-3,583	7	-6
2005	-47	-3,343	-3,297	-7067%	-183	-3,124	7	11
2006	-3,549	-7,053	-3,504	-99%	789	-4,306	7	13
2007	-2,969	-8,009	-5,040	-170%	-499	-4,549	7	7
2008	-2,638	-3,420	-782	-30%	1,748	-2,537	7	7
2009	3,238	-4,752	-7,991	-247%	-5,413	-2,590	7	12
2010	-10,393	-13,536	-3,143	-30%	-499	-2,641	7	-3
2011	-14,780	-15,673	-893	-6%	386	-1,324	7	44
2012	-12,492	-18,732	-6,240	-50%	-3,723	-2,533	7	16
2013	-21,458	-22,951	-1,493	-7%	-499	-1,003	7	8
2014	-22,966	-25,183	-2,217	-10%	-499	-1,739	7	21
2015	-17,945	-23,044	-5,099	-28%	-5,378	543	7	-265
2016	-27,582	-26,457	1,125	4%	-499	1,902	7	-278

11.7 Cropland management

Anthropogenic emissions and removals on croplands occur as a result of changes in management practices on cropping lands, from changes in crop type – particularly between herbaceous and woody crops – and from changes in land use. *Permanent* changes in management practices generate changes in the levels of soil carbon or woody biomass stocks over the longer term – and it is this process of change or transition to a higher or lower carbon stock level that generates net sequestration or net emissions of carbon dioxide that are reported in the inventory.

11.7.1 Identification of land subject to *cropland management*

Cropland management includes all land that is used for continuous cropping and those lands managed as crop-pasture (grassland) rotations as well as the land converted to cropland from grassland.

Forest land converted to cropland from 1990-2017 is identified based on attribution of the Landsat time series and is included under *deforestation*. Forest land converted to cropland prior to 1990 is identified based on attribution of the Landsat time series and is included under *cropland management*.

Land converted to forest land, or land that is identified as forest land from the Landsat series, is excluded from croplands.

Perennial crops including orchards and vineyards are included under the *cropland* classification in the UNFCCC inventory and hence are included under *cropland management*. Units of land where orchards were established on land clear of forest on 31 December 1989 are included in the *cropland management* and not the *afforestation/reforestation* classification.

Land subject to *cropland management* is identified using a reporting method 2 land identification system (IPCC, 2014, Chapter 2.2.2). The area of *cropland management* includes all land classified as cropping land in the ABARES Land Use Map Version 5 subject to a number of amendments.

FullCAM simulates on a pixel by pixel (25m x 25m) level and the carbon stock change on each pixel is tracked from the start of the simulation to the reporting year. The outputs of the simulations are stored in a datacube which can be queried using the Outputs Analysis System (OASys). OASys supports the reporting of the geographical location of the boundaries of the area that encompass land subject to *cropland management* annually, along with the total land areas subject to this activity.

11.7.2 Identification of management practices

Changes in soil carbon stocks in croplands result from changes in management practices that influence the rates of additions or losses of soil organic carbon in the system. Permanent changes in management practices generate changes in the levels of soil carbon stocks over the longer term as the system moves to new equilibrium states.

Specified management practices affecting anthropogenic emissions and removals from *cropland management* include:

- total cropping area;
- crop type and rotation (including pasture leys);
- stubble management, including burning practices;
- tillage techniques;
- fertiliser application and irrigation;
- application of green manures (particularly legume crops);
- soil ameliorants (application of manure, compost or biochar); as well as from
- changes in land use from grassland.

Carbon dioxide emissions from the application of lime are reported under *agriculture*. Nitrous oxide emissions from the application of fertiliser are also reported under *agriculture.*

11.7.3 Methods for estimating carbon stock change and emissions due to management changes over time

Emissions and removals from *cropland management* activities are estimated using methods consistent with IPCC 2006 in conjunction with techniques described in IPCC 2014.

Carbon dioxide emissions and removals from the *cropland management* soils component are estimated using the Tier 3 model FullCAM (Appendix 6.B).

The carbon dioxide emissions and removals associated with changes in the area of perennial woody crops are estimated using the Tier 2 approach outlined in Volume 2, section 6.6.

11.7.3.1 Data

Data sources for the estimation of *cropland management* are reported in Section 6.6, Volume 2. Soil carbon and clay content values are taken from the finely disaggregated soil maps (Viscarra-Rossel *et al.*, 2014, Viscarra-Rossel, 2014) – see Volume 2, Appendix 6.E – which permit organic soils to be distinguished from mineral soils. Organic soils occur only rarely in Australia.

Data on management practices are derived from ABS statistics. The climate, site and management datasets are those used in the forest land converted to cropland estimates as described in Volume 2, Appendix 6.B and 6.E.

11.7.3.2 Methods

Carbon dioxide emissions and removals from *cropland management* soils are estimated using FullCAM (Appendix 6.B).

All on-site carbon pools (living biomass, dead organic matter (DOM) and soil) are estimated. For non-woody crops in *cropland management* the changes in the soil carbon pool are reported. Carbon stock changes from living biomass and DOM of non-woody annual crops are reported to be zero, consistent with the guidance in *2006 IPCC Guidelines for National Greenhouse Gas Inventories* that indicates that the increase in biomass stocks in a single crop year may be assumed equal to biomass losses from harvest and mortality in that year – thus there is no net accumulation of biomass carbon stocks (IPCC 2006, p5.7). In general, croplands will have little or no dead wood, crop residues or litter (IPCC 2006, p5.12). Consistent with the method outlined in the *IPCC 2006 Vol 4, 2.3.3.1*, a mean incremental value for the transitions between SOC near steady states is derived, in this case from the simulated monthly data.

Perennial woody crops are estimated using Tier 2 methods described in Volume 2.

Estimation of net emissions is undertaken from 1970 consistent with IPCC good practice (IPCC 2006, p2.137).

11.7.3.3 Carbon pools

FullCAM estimates emissions from soil as a result of an estimation process involving all on-site carbon pools (living biomass, dead organic matter and soil).

For non-woody crops, only the changes in the soil carbon pool are reported. Decision 2/CMP.7 specifies that a Party may choose not to account for a given pool, except for HWP, in a CP, if transparent and verifiable information is provided that the pool is not a source using reasoning based on sound knowledge of likely system responses (IPCC 2014, page 2.26). Carbon stock changes from living biomass and DOM of non-woody annual crops have been excluded. For annual crops, increases in biomass stocks in a single year may be assumed equal to biomass losses from harvest and mortality in that same year (IPCC 2006, p5.7) and croplands will have little or no dead wood, crop residues or litter (IPCC 2006, p5.12).

For perennial woody crops emission and removal estimates are reported for carbon stocks due to changes in cropping area. Net emissions from DOM or soil carbon have not been estimated.

11.7.4 Reporting of *cropland management* in 2017

11.7.4.1 Reporting of *cropland management* net emissions in 2017

Estimates of net emissions from *cropland management* are reported in Table 11.33.

Table 11.33 Estimated emissions from *cropland management* (kt CO_2-e)

Year	Annual crops	Woody crops	Forest converted to cropland prior to 1990	Nitrogen mineralisation	Wetlands converted to cropland	Total
1990	17,963	-69	13,960	25	232	32,111
1995	-2,165	-100	1,796	24	232	-213
2000	-8,126	-50	1,546	12	232	-6,386
2005	893	-162	919	22	232	1,904
2006	-1,499	-175	1,370	4	232	-68
2007	1,251	36	967	20	232	2,506
2008	2,218	-122	1,069	12	232	3,409
2009	4,910	-152	1,301	13	232	6,303
2010	-621	-282	1,351	19	232	700
2011	703	-363	812	18	232	1,402
2012	1,841	-109	628	10	232	2,602
2013	-26	94	1,519	18	232	1,837
2014	1,226	36	1,351	13	232	2,858
2015	-1,410	-83	915	10	232	-336
2016	-2,982	-225	562	18	232	-2,396
2017	-2,811	-269	587	5	232	-2,257

11.7.4.2 Estimation of *cropland management* Accounting Quantity in 2017

For the Article 3.4 land activity categories credits (called RMU credits) are to be issued against the reduction in net emissions relative to a specified benchmark base year or reference level. If net emissions are higher in the reporting year than in the 1990, AAUs or RMUs are to be cancelled.

For *cropland management* estimates of the accounting quantity – to be used to estimate the amount of RMU credits to be issued – are reported in Table 11.34. Estimates are derived by deducting the reported net emissions in the relevant year from the reported net emissions in 1990. Note that Australia has elected to account for Article 3.4 activities at the end of the commitment period.

Table 11.34 Estimated accounting quantity for *cropland management* (t CO_2-e)

Year	CM 1990[a]	CM Reporting year	Estimated Accounting Quantity (RMU credits)
2013	18,125,965	1,836,804	-16,289,162
2014	18,125,965	2,858,080	-15,267,885
2015	18,125,965	-335,933	-18,461,898
2016	18,125,965	-2,395,685	-20,521,651
2017	18,125,965	-2,256,834	-20,382,799

a In this report, crop land management estimates for 1990 were adjusted for the emissions reported under Forest Conversion in the UNFCCC inventory in 1990 from conversions up to 31 December 1989 and recorded in the report used to calculate the assigned amount, in order to avoid double counting.

Note: Negative values for accounting quantity indicate that RMUs are to be issued.

In order to avoid double counting of emissions from *Forest converted to cropland* in 1990 which are included in the Assigned Amount, emissions and removals associated with such conversions in 1990 are not included in the base for *cropland management* for the purposes of estimating the accounting quantity.

11.7.5 Quality Assurance – Quality Control

Refer to Chapter 6 of Volume 2 (section 6.6.4)

11.7.6 Recalculations

Further descriptions of the recalculations is provided in the corresponding LULUCF category in Chapter 6, namely *cropland remaining cropland* and *land converted to cropland*. The quantification of the recalculation components is shown in Table 11.35.

Table 11.35 *Cropland management*: recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2018 submission	2019 submission	Change		Reasons for recalculation		
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	%	A. Recalculation in *cropland remaining cropland*	B. Recalculation in *forest land converted to cropland* before 1990	C. Recalcluation in *wetland converted to cropland*
1990	12,582	32,680	20,098	159.7%	17,963	2,135	0.0
1995	1,486	-197	-1,683	-113.2%	-2,804	1,121	0.0
2000	1,246	-6,365	-7,611	-610.7%	-8,542	931	0.0
2005	-3,185	1,915	5,100	160.1%	4,792	308	0.0
2006	-3,964	-57	3,907	98.6%	3,043	864	0.0
2007	-4,434	2,511	6,946	156.6%	6,323	623	0.0
2008	-5,101	3,415	8,516	166.9%	7,765	751	0.0
2009	-5,369	6,309	11,678	217.5%	10,808	870	0.0
2010	-6,338	706	7,043	111.1%	6,140	903	0.0
2011	-4,047	1,407	5,455	134.8%	5,074	381	0.0
2012	-4,082	2,607	6,690	163.9%	6,553	136	0.0
2013	-4,659	1,840	6,499	139.5%	5,605	894	0.0
2014	-5,111	2,861	7,972	156.0%	7,010	962	0.0
2015	-4,515	-333	4,182	92.6%	3,482	700	0.0
2016	-4,692	-2,392	2,300	49.0%	1,686	653	0.0

11.8 Grazing land management

Grazing Land Management is the system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced.

11.8.1 Identification of land subject to grazing land management

Grazing land management lands includes grasslands, grasslands with sparse woody cover, and certain specified lands with forest cover – limited to situations in which the presence of grassland has been observed from the Landsat time series and where there has been no change in land use since 1990; or where burning takes place.

Grasslands are identified using a reporting method 2 land identification system (IPCC, 2014, Chapter 2.2.2). The lands included in the *grassland* category are defined in Section 6.3.1, Volume 2.

Grassland excludes all land that is used for continuous cropping, lands managed as crop-pasture rotations and land converted to cropland from grassland at any time.

The *Grassland* classification includes shrub land vegetation. Emissions and removals due to shrubland transitions are established by the methods described in Section 6.8, Volume 2 and Section 6.2, Volume 2. Activity data for shrubland transitions are based on the national mapping programme to assess both the extent, and changes in extent, of sub-forest forms of woody biomass using the Landsat TM, ETM+ and OLI data for the years from 1988 to present.

Forest land converted to grassland after 1 January 1990 is identified based on attribution of the Landsat time series and is included under *deforestation*. If the conversion occurred prior to 1990, this land is included under *grazing land management*.

Land that has been observed to be converted to *forest land* in the Landsat time series after 1 January 1990 is included under *afforestation/reforestation*.

Land that is identified as *forest land* from the Landsat series is also excluded from *grasslands* but may in certain circumstances be reported under *grazing land management*. Lands which were *grassland* in 1990, and therefore included in *grazing land management*, remain in *grazing land management* even where increases in woody cover result in the land meeting the threshold parameters for *forest* provided there is no subsequent change in land use. A change in land use occurs if the increase in woody cover occurs on lands protected as forest by national, State or Territory regulations, in which case the land would be transferred to *afforestation/reforestation.* Alternatively, if the growth occurs outside a protected forest area, no change in land use occurs and the land remains in *grazing land management*.

Land that is identified as *forest land* from the Landsat series may also be incorporated under *grazing land management* for northern and central Australia where fire management including indigenous burning takes place. The identification of fire areas in non-temperate zone forest lands and grass lands is described in Volume 2, chapter 6.8.

Forest lands are not double counted in Australia's land classification systems for KP as a 'narrow' approach to *forest management* has been applied allowing specified forests not identified as being managed for timber to be included under *grazing land management*.

FullCAM simulates on a pixel by pixel (25m x 25m) level. The outputs of the simulations are stored in a datacube which can be queried using the Outputs Analysis System (OASys). OASys supports the reporting of the geographical location of the boundaries of the area that encompass land subject to *grazing land management* annually, along with the total land areas subject to this activity.

11.8.2 Identification of management practices

The concepts underlying carbon stock changes in biomass of *grassland* are tied to management practices (IPCC 2006, p6.6).

Specified management practices affecting anthropogenic emissions and removals from *grazing land management* include:

- the area under grasslands;
- pasture management from fertilisers, irrigation and other inputs and seed selection;
- grazing management practices;
- woody biomass management; and
- fire management.

11.8.3 Methods to estimate changes in carbon stocks and emissions due to management changes over time

11.8.3.1 Data

Data sources for the estimation of changes in carbon stocks from changes in pasture management are reported in Section 6.8, Volume 2. Soil carbon and clay content values are taken from the finely disaggregated soil maps (Viscarra-Rossel *et al.* 2014, Viscarra-Rossel, 2014) – see Volume 2, Appendix 6.E which permit organic soils to be distinguished from mineral soils. Organic soils occur only rarely in Australia.

Data on management practices are derived from ABS statistics. The climate, site and management datasets are those used in the *forest land converted to cropland* estimates as described in Volume 2, Appendix 6.B and 6.E.

11.8.3.2 Methods

Pasture Management

Areas of grassland are stratified, consistent with IPCC 2006, P2.135, step 5, by climate and pasture type to distinguish between productive pastures and rangelands.

The IPCC encourages countries to use higher tier methods to develop emissions coefficients or models to represent the effects of management practices rather than those of inter-annual variability and short term temporal dynamics (IPCC 2006, p2.149).

Changes in soil carbon stocks are estimated for productive pasture regions using FullCAM in accordance with techniques described in IPCC (2006).

For productive pastures, only the changes in the soil carbon pool are reported. Decision 2/CMP.7 specifies that a Party may choose not to account for a given pool, except for HWP, in a CP, if transparent and verifiable information is provided that the pool is not a source using reasoning based on sound knowledge of likely system responses (IPCC 2014, p2.26). Carbon stock changes from living biomass have been excluded. For pastures, increases in biomass stocks in a single year may be assumed equal to biomass losses from harvest and mortality in that same year (IPCC 2006, p5.6) and will have little or no dead wood, residues or litter (IPCC 2006, p6.11).

The effects of inter-annual variability, and how they have been addressed, have been reported in Section 6.8, Volume 2.

Changes in carbon stocks for rangeland areas are assumed to be unchanged given limited pasture management activity and an arid climate.

Grazing management practices

For grazing management practices, the international literature which underpins IPCC (2014) and IPCC (2006) suggests that the impact of grazing on emissions and removals from grazing land activities can have important impacts on carbon stocks. In this report, however, the net effects of changes in grazing pressures on carbon stocks have not been estimated.

Shrub/sparse woody biomass

The methods and data used for the estimation of net emissions from woody biomass management are described in Volume 2.

Fire management

The methods and data for estimating emissions from prescribed burning and wildfires on northern and central Australian tropical, subtropical and semi-arid forest lands and grass lands is described in Volume 2, Chapter 6.4.1.1 and 6.8.1.3.

11.8.3.3 Start year

For the *grazing land management* category, FullCAM simulations commence in 1970.

11.8.3.4 Carbon pools

FullCAM estimates emissions from soil as a result of an estimation process involving all on-site carbon pools (living biomass, dead organic matter and soil).

For non-woody grasses, only the changes in the soil carbon pool are reported. Decision 2/CMP.7 specifies that a Party may choose not to account for a given pool, except for HWP, in a CP, if transparent and verifiable information is provided that the pool is not a source using reasoning based on sound knowledge of likely system responses (IPCC 2014, page 2.26). Carbon stock changes from living biomass and DOM of non-woody annual grasses have been excluded as they do not constitute a source based on reasoning provided by the guidance in IPCC 2014. Herbaceous grassland vegetation is assumed to cycle annually such that biomass gains equal biomass losses in a single year (IPCC 2014, p2.153).

For woody vegetation, changes in soil carbon stocks have not been estimated.

11.8.4 Reporting of *grazing land management* in 2017

11.8.4.1 Reporting of *grazing land management* net emissions in 2017

Estimates of net emissions for *grazing land management* are reported in Table 11.36.

Table 11.36 Estimated emissions from *Grazing land management* ($ktCO_2$-e)

Year	Grasslands	Grassland burning	Woody transitions	Forest converted to grassland prior to 1990	Wetlands converted to Grassland	Total
1990	11,936	9,976	-5,035	93,110	896	110,883
1995	-12,180	7,612	-179	7,540	896	3,690
2000	-8,539	17,220	1,119	4,674	896	15,370
2005	8,941	7,648	3,282	4,605	896	25,372
2006	4,945	11,985	3,076	3,333	896	24,234
2007	5,425	13,032	2,819	4,702	896	26,874
2008	10,306	12,017	2,178	4,147	896	29,545
2009	14,984	13,307	-459	3,029	896	31,757
2010	10,503	12,083	-2,838	6,833	896	27,478
2011	11,784	11,138	-4,871	4,418	896	23,365
2012	16,618	9,556	-6,187	5,586	896	26,470
2013	9,380	9,749	-5,881	5,025	896	19,169
2014	9,981	9,508	-5,930	3,986	896	18,442
2015	8,423	7,679	-5,447	2,927	896	14,477
2016	6,981	6,384	-5,690	2,615	896	11,186
2017	1,944	7,957	-6,049	3,096	896	7,845

11.8.4.2 Estimation of *Grazing land management* Accounting Quantity in 2013-17

For land activity categories other than *deforestation*, credits (called RMU credits) are to be issued against the reduction in net emissions relative to a specified benchmark base year or reference level. If net emissions are higher in the reporting year than in the 1990, AAUs are to be cancelled.

For *grazing land management* estimates of the accounting quantity – to be used to estimate the amount of RMU credits to be issued – are reported in Table 11.37. Estimates are derived by deducting the reported net emissions in 2016 from the reported net emissions in 1990. Note that Australia has elected to account for Article 3.4 activities at the end of the commitment period.

Table 11.37 Estimated accounting quantity for *grazing land management* (t CO_2-e)

Year	GM 1990[a]	GM Reporting years	Estimated Accounting Quantity (RMU credits)
2013	13,576,626	19,169,131	5,592,505
2014	13,576,626	18,441,663	4,865,037
2015	13,576,626	14,476,798	900,172
2016	13,576,626	11,185,619	-2,391,008
2017	13,576,626	7,844,647	-5,731,980

a In this report, *grazing land management* estimates in 1990 were adjusted to exclude emissions associated with *Forest Conversion* in the UNFCCC inventory in 1990 from conversions up to 31 December 1989 and that are included in assigned amount, in order to avoid double counting. See Table 11.34

Note: Negative Accounting Quantities indicate that RMUs are to be issued. Positive Accounting Quantities indicate cancellation of AAUs.

In order to avoid double counting of emissions from *Forest converted to grassland* in 1990 which is included in the Assigned Amount, emissions and removals associated with such conversions in 1990 are not included in the base for *grazing land management* for the purposes of estimating the accounting quantity.

11.8.5 Quality Assurance – Quality Control

Refer to section 6.8 in Volume 2.

11.8.6 Recalculations

Further descriptions of the recalculations is provided in the corresponding LULUCF category in Chapter 6, namely *grassland remaining grassland* (section 6.8.5) and *land converted to grassland* (section 6.9.5).
The quantification of the recalculation components is shown in Table 11.38.

Table 11.38 *Grazing land management*: Recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2017 submission	2018 submission	Change		Reasons for Recalculations			
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	%	A. Change in pasture management	B. Change in live biomass (sparse transitions)	C. Recalculation in *forest land converted to grassland* before 1990	D. Recalculation in *Wetland converted to Grassland*
1990	104,332	110,883	6,551	6.3%	9,792	-1,348	-1,893	0
1995	10,852	3,690	-7,163	-66.0%	-5,935	-853	-375	0
2000	12,746	15,370	2,625	20.6%	-2,223	-673	5,520	0
2005	19,092	25,372	6,280	32.9%	6,305	-826	801	0
2006	21,939	24,234	2,295	10.5%	2,317	-871	849	0
2007	21,285	26,874	5,590	26.3%	4,013	-619	2,195	0
2008	16,915	29,545	12,630	74.7%	8,026	798	3,806	0
2009	13,929	31,757	17,828	128.0%	13,410	551	3,866	0
2010	9,985	27,478	17,493	175.2%	12,480	181	4,832	0
2011	11,649	23,365	11,716	100.6%	7,779	-58	3,995	0
2012	1,765	26,470	24,705	1,399.5%	19,414	-250	5,540	0
2013	2,987	19,169	16,182	541.7%	12,669	-392	3,905	0
2014	11,697	18,442	6,744	57.7%	7,724	-558	-421	0
2015	8,941	14,477	5,536	61.9%	5,069	-515	981	0
2016	6,993	11,186	4,192	59.9%	5,950	-385	-1,373	0

11.9 Revegetation

Revegetation is a direct human-induced activity to increase carbon stocks through establishing vegetation that does not meet the definition of forest (IPCC 2014, section 2.11.1). In Australia, this includes net emissions from changes in vegetation cover that do not constitute a forest and which occur on non-grazing or cropping lands.

11.9.1 Identification of land subject to revegetation

All forms of woody vegetation are monitored as described in section 11.2. Gains and losses in shrub or sparse woody vegetation are distinguished from *deforestation* or *afforestation/reforestation* because they fall below the definition of forest land, as identified using the comprehensive 3-class vegetation monitoring system.

Gains and losses in sparse woody vegetation on grazing and cropping lands are already included as part of *grazing land management* and *cropland management*. Where these changes occur on managed wetlands and settlements they are reported as part of *revegetation*.

11.9.2 Identification of management practices

The primary management practices associated with revegetation relate to woody vegetation management.

In addition to reporting carbon stock changes due to establishment of woody vegetation on settlements and managed wetlands, to ensure accuracy and balanced accounting, losses of such vegetation are also included in revegetation activities.

11.9.3 Methods to estimate changes in carbon stocks and emissions due to management changes over time

11.9.3.1 Data

The remote sensing data used for the estimation of net emissions from woody biomass management are the same as those described for grass and shrub transitions in *settlements remaining settlements*, and *wetlands remaining wetlands* in NIR Sections 6.10.1 and 6.12.1, respectively.

11.9.3.2 Methods

The methods used for the estimation of net emissions from woody biomass management are the same as those described for grass and shrub transitions in *settlements remaining settlements*, and *wetlands remaining wetlands* in NIR Sections 6.10.1 and 6.12.1, respectively.

11.9.3.3 Start year

Estimation of net emissions is undertaken from 1970 consistent with IPCC good practice (IPCC 2014, p 2.137)

11.9.3.4 Carbon pools

Currently available data only supports modelling of aggregated carbon stock changes due to revegetation. These represent changes across all 5 carbon pools, however they are reported under above-ground biomass, as this reflects the most significant pool for this subcategory. Scoping work to facilitate disaggregation by carbon pool through use of tier 3 FullCAM approaches has been completed, and the implementation of the planned improvements for this disaggregation has begun.

11.9.4 Quality Assurance – Quality Control

The QA/QC for *revegetation* estimates are the same as those described in *settlements remaining settlements*, and *wetlands remaining wetlands* in NIR Sections 6.10.1 and 6.12.1, respectively.

11.9.5 Reporting of *revegetation* in 2016

Estimates of net emissions from *revegetation* are reported in Table 11.39 and the estimated accounting quantity is reported in Table 11.40.

Table 11.39 Estimated emissions from *revegetation* (ktCO_2-e)

Year	Net Emissions (kt CO_2-e)
1990	277
1995	368
2000	272
2005	165
2006	250
2007	291
2008	313
2009	266
2010	264
2011	234
2012	69
2013	34
2014	40
2015	50
2016	3
2017	10

Table 11.40 Estimated accounting quantity for *revegetation* (t CO_2-e)

Year	RV 1990[a]	RV Reporting year	Estimated Accounting Quantity (RMU credits)
2013	276,927	34,114	-242,813
2014	276,927	40,068	-236,859
2015	276,927	49,994	-226,933
2016	276,927	2,533	-274,394
2017	276,927	9,927	-267,001

11.9.6 Recalculations

Further description of the recalculations is provided in the corresponding LULUCF sub-categories in Chapter 6 of Volume 2, namely sparse woody vegetation within *wetlands remaining wetlands* (section 6.10.5) and *settlements remaining settlements* (section 6.12.5).

Table 11.41 *Revegetation*: Recalculation of total CO_2-e emissions (Gg), 1990-2016

Year	2017 submission	2018 submission	Change	
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	%
1990	199	277	78	39%
1995	314	368	55	17%
2000	226	272	46	20%
2005	102	165	63	62%
2006	185	250	65	35%
2007	217	291	74	34%
2008	198	313	115	58%
2009	120	266	146	122%
2010	122	264	142	116%
2011	96	234	138	143%
2012	-99	69	167	169%
2013	-117	34	151	129%
2014	-99	40	139	141%
2015	-73	50	123	168%
2016	-102	3	105	102%

11.10 Other information

11.10.1 Key category analysis

The key category analysis for Article 3.3 and relevant Article 3.4 activities are reported in Annex 1 and in Table 11.42.

Table 11.42 Summary overview for key categories for land use, land use change and forestry activities under the Kyoto Protocol

Key Categories of Emissions and Removals	Gas	Criteria used for Key Category Identification			Comments
		Associated category in UNFCCC inventory is key	Category contribution is greater than the smallest category considered key in the UNFCCC inventory (including LULUCF)	Other	
Deforestation	CO_2	forest land converted to grassland	TRUE	NA	
Deforestation	CH_4	forest land converted to grassland	TRUE	NA	
Deforestation	N_2O	forest land converted to grassland	FALSE	NA	
Forest management	CO_2	forest land remaining forest land	TRUE	NA	Australia has applied the narrow approach to forest management. As a result the forest land remaining forest land classification does not directly correspond to the forest management activity.

Key Categories of Emissions and Removals	Gas	Criteria used for Key Category Identification			Comments
		Associated category in UNFCCC inventory is key	Category contribution is greater than the smallest category considered key in the UNFCCC inventory (including LULUCF)	Other	
Afforestation/ Reforestation	CO_2	grassland converted to forest land	TRUE	NA	
Grazing land management	CO_2	grassland remaining grassland, land converted to grassland (conversion prior to 1990)	TRUE	NA	
Grazing land management	CH_4	grassland remaining grassland, land converted to grassland (conversion prior to 1990)	TRUE	NA	
Grazing land management	N_2O	grassland remaining grassland, land converted to grassland (conversion prior to 1990)	TRUE	NA	
Cropland management	CO_2	cropland remaining cropland, land converted to cropland (conversion prior to 1990)	TRUE	NA	

11.10.2 Provision of information relating to KP-LULUCF activities under Article 3, paragraphs 3 and 4

Annex II to decision 2/CMP.8 sets out the requirements for the reporting of Information on land use, land-use change and forestry activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol in annual greenhouse gas inventories. The following table is provided to assist the assessment of compliance with the reporting requirements set out in this decision.

Table 11.43 Australia's compliance with the requirements of 2/CMP.8.

Provision of information relating to KP-LULUCF activities under Article 3, paragraphs 3 and 4	
Information item	**Reference/additional information**
Emissions by sources and removals by sinks are clearly distinguished from emissions from categories included in Annex A to the Kyoto Protocol	Refer to CRF tables and Volume 1 Executive Summary and Ch.11
Information on how inventory methodologies have been applied taking into account the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories and any relevant supplementary guidance recognising the principles laid out in decision 16/CMP.1	Refer to NIR Vol.2 and Vol.3, Ch.11
Information on geographical location of the boundaries of areas that encompass:	
Units of land subject to activities under Article 3, paragraph 3	Refer to Table 11.5, Figures 11.1 and 11.2 and Vol.2 Appendix 6.A
Units of land subject to activities under Article 3, paragraph 3, which would otherwise be included in land subject to forest management or elected activities under Article 3, paragraph 4	Refer to Table 11.5, Figures 11.1 and 11.2 and Vol.2 Appendix 6.A
Land subject to forest management or elected activities under Article 3, paragraph 4	Refer to Table 11.5 and Section 11.6
Information on the spatial assessment unit for determining the area of accounting for afforestation, reforestation and deforestation	Refer to section 11.2.2
Information on GHG emissions/removals resulting from activities under Article 3, paragraph 3, and Article 3, paragraph 4, for all geographical locations reported in the current and previous years since the beginning of the commitment period or the onset of the activity, whichever comes later	Refer to sections 11.4, 11.5, 11.6, 11.7, and 11.8
Information on carbon pools (above-ground/below-ground biomass, litter, dead wood and soil organic carbon) that are not accounted for	All carbon pools are accounted for. Refer to CRF table NIR-1.
When a Party applies the provisions for natural disturbances, information demonstrating that these emissions in any single year exceed the background level(s), including a margin, when needed. For this purpose the Party shall include information showing:	
That all lands subject to exclusion due to natural disturbances are identified	Refer to section 11.6.4.1
How annual emissions resulting from natural disturbances and the subsequent removals are estimated and excluded from accounting	Refer to sections 11.6.4.2 and 11.6.4.3
That no land-use change has occurred on lands for which the provisions in decision 2/CMP.7, annex, paragraph 33, are applied	Refer to section 11.6.4.8
That events and circumstances were beyond the control of the Party	Refer to section 11.6.4.6
The efforts taken to rehabilitate the land for which the provisions contained in decision 2/CMP.7, annex, paragraph 33, are applied	Refer to section 11.6.4.9
That emissions associated with salvage logging were not excluded from accounting	Refer to section 11.6.4.5

Provision of information relating to KP-LULUCF activities under Article 3, paragraphs 3 and 4	
Information item	**Reference/additional information**
If not accounted for by instantaneous oxidation, information on GHG emissions/removals resulting from changes in the HWP pool accounted for in accordance with decision 2/CMP.7, including:	
Activity data for the HWP categories used for estimating the pool removed from domestic forests, for domestic consumption and for export	Refer to CRF table 4.G and NIR section 11.6.3.1.
Half-lives used in estimating emissions/removals for the HWP categories used	Refer to CRF table 4.G and NIR section 6.15.1.
Whether emissions from HWP originating from forests prior to the start of the second commitment period have been included in the accounting, if the forest management reference level is based on a projection	Emissions from HWP originating from forests prior to the start of the second commitment period have been included in the accounting. Refer to Sections 11.6.3 and 6.15.1.
How emissions from the HWP pool accounted for in the first commitment period on the basis of instantaneous oxidation have been excluded from the accounting for the second commitment period	Australia estimates a time-series consistent with the second commitment period requirements, as per methods described in sections 11.6.3.1 and 6.15.1.
How the HWP resulting from deforestation have been accounted on the basis of instantaneous oxidation	Refer to Section 11.4.3
How CO_2 emissions from HWP in SWDS and from wood harvested for energy purposes have been accounted on the basis of instantaneous oxidation	Transfers from the HWP pool to the landfill pool result in a reduction in HWP carbon stock and therefore an instantaneous oxidation. For information on the CO_2 emissions associated with the combustion of fuelwood, refer to section 6.4.2.
How emissions/removals from changes in the HWP pool accounted for do not include imported harvested wood products	Refer to section 11.6.3.1
Information on anthropogenic GHGs from LULUCF activities under Article 3, paragraph 3, and Article 3, paragraph 4, factoring out removals from:	
Elevated CO_2 concentrations above pre-industrial levels	Refer to Section 11.3.3
Indirect nitrogen deposition	Refer to NIR Vol 1, Ch.4, CRF tables and section 11.3.3
The dynamic effects of age structure resulting from activities prior to 1 January 1990	Refer to Section 11.3.3
Specific information to be reported for activities under Article 3, paragraph. 3:	
Activities under Article 3, paragraph 3, that began on or after 1 January 1990 and before 31 December of the last year of the commitment period, and are directly human-induced	Refer to Sections 11.2, 11.3, 11.4 and 11.5
How harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation	Refer to section 11.2.3.1
Specific information to be reported for activities under Article 3, paragraph 4:	
Activities under Article 3.4 that occurred since 1 January 1990 and are human induced	Refer to sections 11.6, 11.7 and 11.8
Cropland management, grazing land management, revegetation, wetland drainage and rewetting: emissions/ removals reported for each year of the commitment period and for the base year for each of the elected activities on the geographical locations reported	Refer to sections 11.7, 11.8, 11.9 and CRF tables
Emissions/removals from activities under Article 3, paragraph 4, are not accounted for under activities under Article 3, paragraph 3	Refer to Vol.2 Appendix 6.A
Information on how emissions arising from the conversion of natural forests to planted forests are accounted for	Refer to section 11.6.6.3 and CRF table NIR 2.1

Provision of information relating to KP-LULUCF activities under Article 3, paragraphs 3 and 4	
Information item	**Reference/additional information**
Methodological consistency between the reference level and reporting for forest management	Refer to section 11.6.5
Technical corrections made pursuant to decision 2/CMP.7, annex, paragraph 14	Refer to section 11.6.5
Forest management: if emissions/removals from the harvest and conversion of forest plantations to non-forest land were included, information how requirements set out in decision 2/CMP.7, annex, paragraphs 37–39 were met, including:	
The identification of all lands and associated carbon pools subject to decision 2/CMP.7, annex, paragraph 37, including the geo-referenced location and year of conversion	Australia has not applied this provision.
A demonstration that the forest plantation was first established through direct human-induced planting and/or seeding of non-forest land before 1 January 1990, and, if the forest plantation was re-established, that this last occurred on forest land through direct human-induced planting and/or seeding after 1 January 1960	Australia has not applied this provision.
A demonstration that a new forest of at least equivalent area to the harvested forest plantation is established through direct human-induced planting and/or seeding of non-forested land that did not contain forest on 31 December 1989	Australia has not applied this provision.
A demonstration that this newly established forest will reach at least the equivalent carbon stock that was contained in the harvested forest plantation at the time of harvest, within the normal harvesting cycle of the harvested forest plantation, and, if not, a debit would be generated under Article 3, paragraph 4	Australia has not applied this provision.

12. Information on accounting of Kyoto Units

12.1 Summary of information reported in the Standard Electronic Format Tables

In accordance with decisions 1/CMP.8, 2/CMP.8 and 3/CMP.11, Annex I Parties are required to report information on KP units for the first commitment period and for the CP2 for the reported year 2018. This information has been submitted in the standard electronic format (SEF) tables (Tables 12.1 to 12.28).

12.1.1 SEF reporting for commitment period 1 (CP1)

Table 12.1 SEF Table 1, Total quantities of Kyoto Protocol units by account type at beginning of reported year 2018

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Party holding accounts	127,650,775	NO	NO	21,768,290	NO	NO
Entity holding accounts	NO	NO	NO	NO	NO	NO
Article 3.3/3.4 net source cancellation accounts	115,625,564	NO	108,941,877	NO		
Non-compliance cancellation account	NO	NO	NO	NO		
Other cancellation accounts	3,149,326	367,766	NO	3,375,615	NO	NO
Retirement account	2,711,153,478	NO	NO	NO	NO	NO
tCER replacement account for expiry	NO	NO	NO	NO	NO	
lCER replacement account for expiry	NO	NO	NO	NO		
lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	**2,957,579,143**	**367,766**	**108,941,877**	**25,143,905**	**NO**	**NO**

Table 12.2 SEF Table 2(a), Annual internal transactions for the reported year 2018

Transaction type	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Art6 issuance and conversion												
Party verified projects		NO					NO		NO			
Independently verified projects		NO					NO		NO			
Art3.3 and 3.4 issuance or cancellation												
3.3 Afforestation reforestation			NO				NO	NO	NO	NO		
3.3 Deforestation			NO				NO	NO	NO	NO		
3.4 Forest management			NO				NO	NO	NO	NO		
3.4 Cropland management			NO				NO	NO	NO	NO		

Transaction type	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
3.4 Grazing land management			NO				NO	NO	NO	NO		
3.4 Revegetation			NO				NO	NO	NO	NO		
Art 12 afforestation and reforestation												
Replacement of expired tCERs							NO	NO	NO	NO	NO	
Replacement of expired lCERs							NO	NO	NO	NO		
Replacement for reversal of storage							NO	NO	NO	NO		NO
Replacement for non-submission of certification report							NO	NO	NO	NO		NO
Other cancellation							NO	NO	NO	490	10	NO
Subtotal		**NO**	**NO**				**NO**	**NO**	**NO**	**490**	**10**	**NO**

Transaction type	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Retirement	NO	NO	NO	NO	NO	NO

Table 12.3 SEF Table 2(b), Annual external transactions for the reported year 2018

Transfers and acquisitions	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
CDM	NO	NO	NO	490	10	NO	NO	NO	NO	NO	NO	NO
Sub-total	NO	NO	NO	490	10	NO	NO	NO	NO	NO	NO	NO

	Additional Information											
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Independently verified ERU								NO				

Table 12.4 SEF Table 2(c), Total annual transactions for the reported year 2018

Transaction type	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Total (Sum of table 2(a) and 2(b))	NO	NO	NO	490	10	NO	NO	NO	NO	490	10	NO

Table 12.5 SEF Table 3, Expiry, cancellation and replacement for the reported year 2018

Transaction or event type	Expiry, cancellation and requirement to replace		Replacement					
	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Temporary CERs (tCERs)								
Expired in retirement and replacement accounts	NO							
Replacement of expired tCERs			NO	NO	NO	NO	NO	
Expired in holding accounts	NO							
Cancellation of tCERs expired in holding accounts	NO							
Long-term CERs (lCERs)								
Expired in retirement and replacement accounts		NO						
Replacement of expired lCERs			NO	NO	NO	NO		
Expired in holding accounts		NO						
Cancellation of lCERs expired in holding accounts		NO						
Subject to replacement for reversal of storage		NO						
Replacement for reversal of storage			NO	NO	NO	NO		NO
Subject to replacement for non-submission of certification report		NO						
Replacement for non-submission of certification report			NO	NO	NO	NO		NO
Total			**NO**	**NO**	**NO**	**NO**	**NO**	**NO**

Table 12.6 SEF Table 4, Total quantities of Kyoto Protocol units by account type at end of reported year 2018

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Party holding accounts	127,650,775	NO	NO	21,768,290	NO	NO
Entity holding accounts	NO	NO	NO	NO	NO	NO
Article 3.3/3.4 net source cancellation accounts	115,625,564	NO	108,941,877	NO		
Non-compliance cancellation account	NO	NO	NO	NO		
Other cancellation accounts	3,149,326	367,766	NO	3,376,105	10	NO
Retirement account	2,711,153,478	NO	NO	NO	NO	NO
tCER replacement account for expiry	NO	NO	NO	NO	NO	
lCER replacement account for expiry	NO	NO	NO	NO		
lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	**2,957,579,143**	**367,766**	**108,941,877**	**25,144,395**	**10**	**NO**

Table 12.7 SEF Table 5(a), Summary information on additions and subtractions for the reported year 2018

	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Starting values												
Issuance pursuant to Article 3.7 and 3.8	2,957,579,143											
Non-compliance cancellation							NO	NO	NO	NO		
Carry-over	NO	NO		NO								
Sub-total	2,957,579,143	NO		NO			NO	NO	NO	NO		
Annual transactions												
Year 0 (2007)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 1 (2008)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 2 (2009)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 3 (2010)	NO	NO	NO	1	NO	NO	NO	NO	NO	1	NO	NO
Year 4 (2011)	NO	NO	23,032,901	126,851	NO	NO	49,650,531	NO	NO	75,851	NO	NO
Year 5 (2012)	NO	NO	23,262,032	102,714	NO	NO	44,164,557	NO	NO	123,712	NO	NO
Year 6 (2013)	NO	150,000	23,834,852	530,972	NO	NO	11,894,403	150,000	46,294,933	515,872	NO	NO
Year 7 (2014)	NO	100,000	25,907,257	713,954	NO	NO	NO	100,000	38,543,673	530,098	NO	NO
Year 8 (2015)	NO	118,935	12,904,835	28,124,304	NO	NO	13,065,399	118,935	24,103,271	6,584,972	NO	NO
Year 9 (2016)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 10 (2017)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 11 (2018)	NO	NO	NO	490	10	NO	NO	NO	NO	490	10	NO
Sub-total	NO	368,935	108,941,877	29,599,286	10	NO	118,774,890	368,935	108,941,877	7,830,996	10	NO
Total	**2,957,579,143**	**368,935**	**108,941,877**	**29,599,286**	**10**	**NO**	**118,774,890**	**368,935**	**108,941,877**	**7,830,996**	**10**	**NO**

Table 12.8 SEF Table 5(b), Summary information on replacement for the reported year 2018

	Expiry, cancellation and requirement to replace		Replacement					
	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Previous CPs			NO	NO	NO	NO	NO	NO
Year 1 (2008)		NO	NO	NO	NO	NO	NO	NO
Year 2 (2009)		NO	NO	NO	NO	NO	NO	NO
Year 3 (2010)		NO	NO	NO	NO	NO	NO	NO
Year 4 (2011)		NO	NO	NO	NO	NO	NO	NO
Year 5 (2012)	NO	NO	NO	NO	NO	NO	NO	NO
Year 6 (2013)	NO	NO	NO	NO	NO	NO	NO	NO
Year 7 (2014)	NO	NO	NO	NO	NO	NO	NO	NO
Year 8 (2015)	NO	NO	NO	NO	NO	NO	NO	NO
Total	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**

Table 12.9 SEF Table 5(c), Summary information on retirement for the reported year 2018

Year	Retirement					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 1 (2008)	NO	NO	NO	NO	NO	NO
Year 2 (2009)	NO	NO	NO	NO	NO	NO
Year 3 (2010)	NO	NO	NO	NO	NO	NO
Year 4 (2011)	NO	NO	NO	NO	NO	NO
Year 5 (2012)	NO	NO	NO	NO	NO	NO
Year 6 (2013)	NO	NO	NO	NO	NO	NO
Year 7 (2014)	NO	NO	NO	NO	NO	NO
Year 8 (2015)	2,711,153,478	NO	NO	NO	NO	NO
Total	**2,711,153,478**	**NO**	**NO**	**NO**	**NO**	**NO**

Table 12.10 SEF Table 6(a), Memo item: Corrective transactions relating to additions and subtractions for the reported year 2018

Additions						Subtractions					
AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs

Table 12.11 SEF Table 6 (b), Memo item: corrective transactions relating to replacement for the reported year 2018

Requirement for replacement		Replacement					
tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs

Table 12.12 SEF Table 6(c), Memo item: Corrective transactions relating to retirement for the reported year 2018

Retirement					
AAUs	ERUs	RMUs	CERs	tCERs	lCERs

12.1.2 SEF reporting for commitment period 2 for the reported year 2018

Table 12.13 SEF Table 1, Total quantities of Kyoto Protocol units by account type at beginning of reported year 2018

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Party holding accounts	NO	NO	NO	11,925,019	NO	NO
Entity holding accounts	NO	NO	NO	NO	NO	NO
Retirement account	NO	NO	NO	NO	NO	NO
Previous period surplus reserve account	NO					
Article 3.3/3.4 net source cancellation accounts	NO	NO	NO	NO		
Non-compliance cancellation account	NO	NO	NO	NO		
Voluntary cancellation account	NO	NO	NO	1,484,884	NO	NO
Cancellation account for remaining units after carry-over	NO	NO	NO	NO	NO	NO
Article 3.1 ter and quater ambition increase cancellation account	NO					
Article 3.7 ter cancellation account	NO					
tCER cancellation account for expiry					NO	
lCER cancellation account for expiry						NO
lCER cancellation account for reversal of storage						NO
lCER cancellation account for non-submission of certification report						NO
tCER replacement account for expiry	NO	NO	NO	NO	NO	
lCER replacement account for expiry	NO	NO	NO	NO		
lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	**NO**	**NO**	**NO**	**13,409,903**	**NO**	**NO**

Table 12.14 SEF Table 2(a), Annual internal transactions for the reported year 2018

Transaction type	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Article 6 issuance and conversion												
Party-verified projects		NO					NO		NO			
Independently verified projects		NO					NO		NO			
Article 3.3 and 3.4 issuance or cancellation												
3.3 Afforestation and reforestation			NO				NO	NO	NO	NO		
3.3 Deforestation			NO				NO	NO	NO	NO		
3.4 Forest management			NO				NO	NO	NO	NO		
3.4 Cropland management			NO				NO	NO	NO	NO		
3.4 Grazing land management			NO				NO	NO	NO	NO		
3.4 Revegetation			NO				NO	NO	NO	NO		
3.4 Wetlands drainage and management			NO				NO	NO	NO	NO		
Article 12 afforestation and reforestation												
Replacement of expired tCERs							NO	NO	NO	NO	NO	
Replacement of expired lCERs							NO	NO	NO	NO		
Replacement for reversal of storage							NO	NO	NO	NO		NO
Cancellation for reversal of storage												NO
Replacement for non-submission of certification report							NO	NO	NO	NO		NO
Cancellation for non-submission of certification report												NO
Other cancelation												
Voluntary cancellation							NO	NO	NO	804,165	NO	NO
Article 3.1 ter and quater ambition increase cancellation							NO					
Subtotal		NO	NO				NO	NO	NO	804,165	NO	NO

Transaction type	Retirement					
	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Retirement	NO	NO	NO	NO	NO	NO
Retirement from PPSR	NO					
Total	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**

Table 12.15 SEF Table 2(b), Annual external transactions for the reported year 2018

Total transfers and acquisitions	Additions						Subtractions					
	Unit type						Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
CDM	NO	NO	NO	2,835,928	NO	NO	NO	NO	NO	NO	NO	NO
CH	NO	NO	NO	89,010	NO	NO	NO	NO	NO	663,827	NO	NO
EU	NO	NO	NO	1,458,014	NO	NO	NO	NO	NO	975,901	NO	NO
GB	NO	NO	NO	523,516	NO	NO	NO	NO	NO	759,157	NO	NO
NL	NO	NO	NO	500	NO	NO	NO	NO	NO	8,000	NO	NO
SE	NO	NO	NO	NO	NO	NO	NO	NO	NO	63,920	NO	NO
Sub-total	NO	NO	NO	4,906,968	NO	NO	NO	NO	NO	2,470,805	NO	NO

Table 12.16 SEF Table 2(c), Annual transactions between PPSR accounts for the reported year 2018

Transfers and acquisitions between PPSR accounts	Additions						Subtractions					
	Unit type						Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Subtotal	NO						NO					

Table 12.17 SEF Table 2 (d) Share of proceeds transactions under decision 1/CMP.8, paragraph 21 – Adaptation Fund - for the reported year 2018

	Amount transferred or converted						Amount contributed as SoP to the adaptation fund					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
First international transfers of AAUs	NO						NO					
Issuance of ERU from Party-verified projects		NO						NO				
Issuance of independently verified ERUs		NO						NO				

Table 12.18 SEF Table 2(e), Total annual transactions for the reported year 2018

	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Total (Sum of sub-totals in table 2a and table 2b)	NO	NO	NO	4,906,968	NO	NO	NO	NO	NO	3,274,970	NO	NO

Table 12.19 SEF Table 3, Expiry, cancellation and replacement for the reported year 2018

Transaction or event type	Requirement to replace or cancel		Replacement							Cancellation					
	Unit type		Unit type							Unit type					
	tCERs	lCERs	CERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Temporary CERs															
Expired in retirement and replacement accounts	NO			NO	NO	NO	NO	NO							
Expired in holding accounts	NO													NO	
Long-term CERs															
Expired in retirement and replacement accounts		NO		NO	NO	NO	NO								
Expired in holding accounts		NO													NO
Subject to reversal of storage		NO		NO	NO	NO	NO		NO						NO

Transaction or event type	Requirement to replace or cancel			Replacement						Cancellation					
	Unit type			Unit type						Unit type					
	tCERs	lCERs	CERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Subject to non-submission of certification Report		NO		NO	NO	NO	NO		NO						NO
Carbon Capture and Storage CERs															
Subject to net reversal of storage			NO							NO	NO	NO	NO		
Subject to non-submission of certification report			NO							NO	NO	NO	NO		
Total	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**

Table 12.20 SEF Table 4, Total quantities of Kyoto Protocol units by account type at end of reported year 2018

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Party holding accounts	NO	NO	NO	13,557,017	NO	NO
Entity holding accounts	NO	NO	NO	NO	NO	NO
Retirement account	NO	NO	NO	NO	NO	NO
Previous period surplus reserve account	NO					
Article 3.3/3.4 net source cancellation accounts	NO	NO	NO	NO		
Non-compliance cancellation account	NO	NO	NO	NO		
Voluntary cancellation account	NO	NO	NO	2,289,049	NO	NO
Cancellation account for remaining units after carry-over	NO	NO	NO	NO	NO	NO
Article 3.1 ter and quater ambition increase cancellation account	NO					
Article 3.7 ter cancellation account	NO					
tCER cancellation account for expiry					NO	
lCER cancellation account for expiry						NO
lCER cancellation account for reversal of storage						NO
lCER cancellation account for non-submission of certification report						NO

Account type	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
tCER replacement account for expiry	NO	NO	NO	NO	NO	
lCER replacement account for expiry	NO	NO	NO	NO		
lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
Total	**NO**	**NO**	**NO**	**15,846,066**	**NO**	**NO**

Table 12.21 SEF Table 5(a), Summary information on additions and subtractions for the reported year 2018

	Additions						Subtractions					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Assigned amount units issued	NO											
Article 3 paragraph 7 ter cancellations							NO					
Cancellation following increase in ambition							NO					
Cancellation of remaining units after carry over							NO	NO	NO	NO	NO	NO
Non-compliance cancellation							NO	NO	NO	NO		
Carry-over		NO		NO				NO		NO		
Carry-over to PPSR	NO						NO					
Total	**NO**	**NO**		**NO**			**NO**	**NO**	**NO**	**NO**	**NO**	**NO**

Table 12.22 SEF Table 5(b), Summary information on annual transactions for the reported year 2018

	Additions						Subtractions					
	Unit type						Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 1 (2013)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2 (2014)	NO	NO	NO	130,870	NO	NO	NO	NO	NO	130,870	NO	NO
Year 3 (2015)	NO	NO	NO	3,605,224	NO	NO	NO	NO	NO	2,163,128	NO	NO

	Additions						Subtractions					
	Unit type						Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 4 (2016)	NO	NO	NO	7,239,334	NO	NO	NO	NO	NO	646,428	NO	NO
Year 5 (2017)	NO	NO	NO	6,492,374	NO	NO	NO	NO	NO	2,602,357	NO	NO
Year 6 (2018)	NO	NO	NO	4,906,968	NO	NO	NO	NO	NO	3,274,970	NO	NO
Year 7 (2019)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 8 (2020)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2021	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2022	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2023	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	**NO**	**NO**	**NO**	**22,374,770**	**NO**	**NO**	**NO**	**NO**	**NO**	**8,817,753**	**NO**	**NO**

Table 12.23 SEF Table 5(c), Summary information on annual transactions between PPSR accounts for the reported year 2018

	Additions						Subtractions					
	Unit type						Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 1 (2013)	NO						NO					
Year 2 (2014)	NO						NO					
Year 3 (2015)	NO						NO					
Year 4 (2016)	NO						NO					
Year 5 (2017)	NO						NO					
Year 6 (2018)	NO						NO					
Year 7 (2019)	NO						NO					
Year 8 (2020)	NO						NO					
Year 2021	NO						NO					
Year 2022	NO						NO					
Year 2023	NO						NO					

	Additions						Subtractions					
	Unit type						Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Total	**NO**						**NO**					

Table 12.24 SEF Table 5(d), Summary information on expiry, cancellation and replacement for the reported year 2018

	Requirement to replace or cancel		Replacement							Cancellation					
	Unit type		Unit type							Unit type					
	tCERs	lCERs	CERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 1 (2013)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2 (2014)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 3 (2015)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 4 (2016)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 5 (2017)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 6 (2018)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 7 (2019)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 8 (2020)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2021	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2022	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Year 2023	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**

Table 12.25 SEF Table 5(e), Summary information on retirement for the reported year 2018

	Retirement					
	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
Year 1 (2013)	NO	NO	NO	NO	NO	NO
Year 2 (2014)	NO	NO	NO	NO	NO	NO
Year 3 (2015)	NO	NO	NO	NO	NO	NO
Year 4 (2016)	NO	NO	NO	NO	NO	NO
Year 5 (2017)	NO	NO	NO	NO	NO	NO
Year 6 (2018)	NO	NO	NO	NO	NO	NO
Year 7 (2019)	NO	NO	NO	NO	NO	NO
Year 8 (2020)	NO	NO	NO	NO	NO	NO
Year 2021	NO	NO	NO	NO	NO	NO
Year 2022	NO	NO	NO	NO	NO	NO
Year 2023	NO	NO	NO	NO	NO	NO
Total	NO	NO	NO	NO	NO	NO

Table 12.26 SEF Table 6(a), Memo item: Corrective transactions relating to additions and subtractions for the reported year 2018

Additions						Subtractions					
Unit type						Unit type					
AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs

Table 12.27 SEF Table 6 (b), Memo item: corrective transactions relating to replacement for the reported year 2018

Requirement for replacement		Replacement					
Unit type		Unit type					
tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs

Table 12.28 SEF Table 6(c), Memo item: Corrective transactions relating to retirement for the reported year 2018

Retirement					
Unit type					
AAUs	ERUs	RMUs	CERs	tCERs	lCERs

12.2 Discrepancies and notifications

Decision 15/CMP.1 annex I.E paragraphs 12-17, decision 2/CMP.8 and decision 3/CMP.11, require Annex I Parties to report on various possible discrepancies and notifications. Australia's discrepancies and notifications are summarised in Table 12.29 for the reported year 2018.

Table 12.29 Accounting of Kyoto Protocol Units

Annual Submission Item	Report
Decision 15/CMP.1 annex I.E paragraph 11 and 19 as updated by decision 3/CMP.11: Standard electronic format (SEF)	See section 12.1. The SEF tables have been submitted to the UNFCCC.
Decision 15/CMP.1 annex I.E paragraph 12: List of discrepant transaction	Australia had no transaction with discrepancies for the reporting period.
Decision 15/CMP.1 annex I.E paragraph 13 & 14: List of CDM notifications	Australia did not receive any CDM notifications.
Decision 15/CMP.1 annex I.E paragraph 15: List of non-replacements	Australia had no non-replacements.
Decision 15/CMP.1 annex I.E paragraph 16: List of invalid units	Australia had no invalid units.
Decision 15/CMP.1 annex I.E paragraph 17: Actions and changes to address discrepancies	None required.
Decision 15/CMP.1 annex I.E paragraph 18: Commitment period reserve calculation	See section 12.4

12.3 Publically accessible information

In accordance with decision 13/CMP.1 paragraph 44, as amended by decision 3/CMP.11, and Regulation 50 of the *Australian National Registry of Emissions Units Regulations 2011,* public information is available at https://nationalregistry.cleanenergyregulator.gov.au/report/listPublicReports under the Public Reports facility. A full description of the information that is available is in Annex 7.

12.4 Calculation of the Commitment Period Reserve

For CP2, Australia's commitment period reserve (CPR) is 4,060,457,844 tonnes CO_2 equivalent, calculated as 90 per cent of its assigned amount in accordance with decisions 11/CMP.1, 1 and 2/CMP.8 and 2/CMP.11.

12.5 KP-LULUCF Accounting

Australia has elected to account for the KP Article 3.3 LULUCF activities on an annual basis and to account for the Article 3.4 activities at the end of the CP2 as set out in table 12.30 below.

Table 12.30 Information table on accounting for activities under Articles 3.3 and 3.4 of the Kyoto Protocol

	Base Year[2]	Net emissions/removals					Total 2013-17[3]	Accounting parameters		Accounting quantity [4]
		2013	2014	2015	2016	2017		Calibration period	FMRL	
						(kt CO_2 eq)				
A. Article 3.3 activities										
A.1. Afforestation/reforestation		-25,913	-25,932	-25,004	-28,289	-29,355	-134,493			-134,493
Excluded from ND		NA	NA	NA	NA	NA	NA			NA
Excluded removals associated		NA	NA	NA	NA	NA	NA			NA
A.2 Deforestation		35,226	36,914	26,735	29,110	26,076	154,062			154,062
B. Article 3.4 activities										
B.1 Forest management							-123,251			NA [12]
Net em/re excl ND		-22,951	-25,183	-23,044	-26,457	-25,616	-123,251			NA [12]
Note: Emissions from anthropogenic wildfire in the reporting period		3,397	3,397	3,397	3,397	3,397	16,983			NA [12]
Emissions from anthropogenic wildfire in FMRL [5][13]		3,397	3,397	3,397	3,397	3,397	16,983	40,759		
Note 2: Emissions from ND in the reporting period [5][13]		11,453	12,603	4,696	17,772	11,951	58,475			
Emissions from ND in FMRL [5][13]		10,756	10,756	10,756	10,756	10,756	53,781	129,073		
Note 3: Removals from ND in the reporting period [6][13]		NA [6]	NA [6]	NA [6]	NA [6]	NA [6]	NA [6]			
Removals from ND in FMRL [6][13]		NA [6]	NA [6]	NA [6]	NA [6]	NA [6]	NA [6]	NA [6]		
Debits from CEF-ne [7][8]		NA	NA	NA	NA	NA	NA			
FMRL [9]									4,700	
Technical corrections to FMRL [10]									-3,541	
FM cap [11]									-117,214	NA [12]
B.2. Cropland management	18,126	1,840	2,861	-333	-2,392	-2,246	-270			NA [12]
B.3. Grazing Land Management	13,577	19,169	18,442	14,477	11,186	7,845	71,118			NA [12]
B.4. Revegetation	277	34	40	50	3	10	137			NA [12]
B.5. Wetland drainage and rewetting	NA	NA	NA	NA	NA	NA	NA			NA

(1) All values are reported in table 4(KP) and tables 4(KP-I).A.1.1, 4(KP-I).B.1.1, 4(KP-I).B.1.2 and 4(KP-I).B.1.3 of the CRF for the relevant inventory year as reported in the current submission and are automatically entered in this table.

(2) Net emissions and removals from cropland management, grazing land management, revegetation and/or wetland drainage and rewetting, if elected, in the Party's base year, as established by decision 9/CP.2.

(3) Cumulative net emissions and removals for all years of the commitment period reported in the current submission.

(4) The accounting quantity is the total quantity of units to be added to or subtracted from a Party's assigned amount for a particular activity in accordance with the provisions of Article 7.4 of the Kyoto Protocol.

(5) A Party that has indicated their intent to apply the natural disturbance provisions may choose to exclude emissions from natural disturbances either annually or at the end of the commitment period.

(6) All subsequent CO_2 removals from post-wildfire recovery (including in years where the natural disturbances provision applies) are excluded from the calculation of FMRL (that is, the removals are excluded from the calculation of the background level and margin), and from reporting of forest management emissions during the commitment period, as outlined in the NIR Volume 3, Section 11.6.4.3 (consistent with guidance on exclusion of removals where projected reference levels are used – IPCC 2014, page 2.53; and ensuring consistency between the FMRL and the reporting of forest management – IPCC 2014, chapter 2.7.5.2). Because estimated natural disturbance emissions exceeded the background level plus margin in CP2 years, emissions from natural disturbances that exceed the background level in these years are excluded ('excluded natural disturbances emissions'). Therefore the accounting of natural disturbances in these years are equal to the background level of natural disturbance emissions (the same value as is in the FMRL) ensuring that the exclusion of natural disturbance emissions in these years generates zero net credits (in accordance with avoiding the expectation of net credits or net debits – IPCC 2014, pages 2.49-2.50). More information on the application of the natural disturbances provision is included in Chapter 11.6.4 of the NIR.

(7) A debit is generated in case the newly established forest does not reach at least the expected carbon stock at the end of the normal harvesting period. Total debits from carbon equivalent forests are subtracted from the accounting quantity forest management.

(8) In case of a projected forest management reference level, Parties should not fill in this row.

(9) Forest management reference level as inscribed in the appendix of the annex to decision 2/CMP.7, in kt CO_2 eq per year.

(10) Technical corrections in accordance with paragraphs 14 and 15 of the annex to decision 2/CMP.7 and reported in table 4(KP-I)B.1.1 in kt CO_2 eq per year.

(11) For the second commitment period, additions to the assigned amount of a Party resulting from forest management shall, in accordance with paragraph 13 of the annex to Decision 2/CMP.7, not exceed 3.5 per cent of the national total emissions excluding LULUCF in the base year times eight. Calculated in this way Australia's forest management cap is 117,214 Kt CO_2-e, and is shown here as a negative value to represent the issuance of RMU credits consistently with the accounting of other KP LULUCF activities within this table.

(12) Australia has opted for end of commitment period reporting for Article 3.4 activities.

(13) In accordance with footnote (5) in CRF table 4(KP) 'accounting' Australia has chosen to exclude emissions from natural disturbances annually, rather than at the end of the commitment period. To ensure that this is correctly reflected in the CRF table (does not allow annual exclusions) excluded emissions from natural disturbances are included in the reporting of net emissions/removals from forest management in 4(KP)B.1. More information on the application of the natural disturbances provision is included in Chapter 11.6.4 of the NIR.

13. Changes to the National System

Under the KP, decision 15/CMP.1 annex I.F paragraph 21, as amended by decisions 3/CMP.11, requires Parties to include in the Report information on any changes that have occurred in its national system compared with its last submission.

Changes in Australia's national systems implemented since the last submission are set out in Table 13.1.

Table 13.1 Change to the national system

Reporting Item	Annual Report
Decision 15/CMP.1 annex II.D paragraph 30 (a) Change of name or contact information	No change since last submission.
Decision 15/CMP.1 annex II.D paragraph 30 (b) Change of roles and responsibilities as well as change of the institutional, legal and procedural arrangements	No change since last submission.
Decision 15/CMP.1 annex II.D paragraph 30 (c) Changes in the process of inventory compilation	The process of inventory compilation continues to incorporate improvements in the collection of activity data, selection of emission factors and methods, and development of emission estimates. These improvements have been identified in the relevant chapters of the Report, with major inventory developments and related recalculations summarized in section ES.4.
Decision 15/CMP.1 annex II.E paragraph 30 (d) Change of process for key category identification and archiving	No change in this submission.
Decision 15/CMP.1 annex II.D paragraph 30 (e) Change of process for recalculations	No change in this submission.
Decision 15/CMP.1 annex II.D paragraph 30 (f) Changes with regard to QA/QC plan, QA/QC activities and procedures	Additional QA/QC activities and procedures have been implemented as identified in Chapter 1 and the relevant chapters of the Report.
Decision 15/CMP.1 annex II.D paragraph 30 (g) Change of procedures for the official consideration and approval of the inventory	No change in this submission.

14. Changes to the National Registry

Under the KP, Parties are required to put in place a national registry to report annually on acquisition, holding, transfer, cancellation, withdrawal and carryover of assigned amount units, removal units, emission reduction units and certified emission reductions during the previous year. A full description of Australia's national registry system is presented in Annex 7. Australia's national registry is referred to as the Australian National Registry of Emissions Units (ANREU).

Decision 15/CMP.1 annex I.G paragraph 22, as amended by decisions 3/CMP.11, requires Parties to include in the Report information on any changes that have occurred in its national registry compared with its last submission. Changes to Australia's National Registry since its last submission are included in Table 14.1 below.

Table 14.1 Change to the national registry – 2018

Reporting Item	Annual Report
Decision 15/CMP.1 annex II.E paragraph 32 Change of name or contact	Michelle Crosbie from the Clean Energy Regulator is no longer designated a Registry System Administrator of Australia's national registry. Steven Stolk has been designated as the Registry System Administrator. Full contact details contained in Annex 7.
Decision 15/CMP.1 annex II.E paragraph 32 (b) Change of cooperation arrangement	No change in this submission.
Decision 15/CMP.1 annex II.E paragraph 32 (c) Change to database or the capacity of National Registry	No change in this submission.
Decision 15/CMP.1 annex II.E paragraph 32 (d) Change of conformance to technical standards	No change in this submission.
Decision 15/CMP.1 annex II.E paragraph 32 (e) Change of discrepancies procedures	No change in this submission.
Decision 15/CMP.1 annex II.E paragraph 32 (f) Change of Security	No change in this submission.
Decision 15/CMP.1 annex II.E paragraph 32 (g) Change of list of publicly available information	No change in this submission.
Decision 15/CMP.1 annex II.E paragraph 32 (h) Change of Internet address	No change in this submission.
Decision 15/CMP.1 annex II.E paragraph 32 (i) Change of data integrity measure	No change in this submission.
Decision 15/CMP.1 annex II.E paragraph 32 (j) Change of test results	No change in this submission.
Response to previous Annual Review recommendations	Nil recommendations.

15. Minimisation of adverse impacts in accordance with Article 3.14

Australia is pleased to provide an update on how it is striving, under Article 3, paragraph 14, of the KP, to implement its greenhouse gas emission limitation and reduction commitments in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the UNFCCC.

Australia recognizes that the economic cost of reducing emissions is lower than the cost of inaction on climate change (Stern 2006; Garnaut 2008 and 2011). Curbing emissions in support of the global temperature goal will reduce the economic, social and environmental impacts of climate change, particularly for developing countries that are most vulnerable. This is why Australia is committed to reducing emissions and supporting other countries' efforts to mitigate and adapt to climate change.

Australia also recognizes that measures to address climate change can have social, environmental and economic impacts. In developing its climate change response measures, Australia seeks to identify possible impacts and minimise those that are negative.

How Australia addresses domestic impacts of response measures

Australia's is playing its role in global efforts to reduce emissions, while maintaining a strong economy and realising the benefits of the transition to a lower-emissions future. Central to this are the consultation processes that typically accompany policy development in Australia and that enable those potentially affected to raise concerns and present ideas.

For example, in conducting the 2017 review of Australia's climate change policies, Departmental officials consulted widely with businesses across all sectors of the economy and with the community. This included the release of a discussion paper which generated over 350 public submissions. The Department also met with more than 270 stakeholders and the Minister for the Environment and Energy hosted two roundtables attended by 42 business, community, environmental and Indigenous stakeholders.

Impact assessment is an integral part of Australia's policy development process. Legislation introduced to the Australian parliament must be accompanied by a Regulatory Impact Statement that assesses the economic and social impacts of a measure.

How Australia addresses the international impacts of response measures

Australia's bilateral consultations with other countries and engagement in international platforms such as the UNFCCC Forum on the Impact of the Implementation of Response Measures helps build understanding of positive and negative impacts and allows countries to raise concerns and suggest ways to minimise adverse impacts.

Australia participates actively in the UNFCCC Response Measures Forum and is committed to maximising its effectiveness. An Australian official was a nominated expert for the Ad-Hoc Technical Expert Group on Response Measures that met during the May 2017 UNFCCC session. This enabled Australia to share its experiences in preparing for and managing the economic and social impacts of climate action.

Australia helped develop the G20 Hamburg Climate and Energy Action Plan for Growth 2017, which highlighted the need to implement the UNFCCC, Paris Agreement and 2030 Agenda for Sustainable Development in a coherent and mutually supportive manner that takes advantage of significant opportunities for modernising economies, enhancing competitiveness and stimulating employment and growth.

Australia helps minimise the economic and social impacts of response measures on developing countries by supporting their economic diversification and transition towards less polluting forms of energy, employment and growth. Sustainable economic growth, poverty reduction and the promotion of prosperity are at the heart of Australia's aid program and the Australian Government is committed to integrating climate action throughout the program. For example, this means anticipating what future jobs might look like in a low emissions global economy when supporting education and livelihood programs. The Australian aid program includes targets for promoting prosperity, engaging the private sector and reducing poverty, and mandatory safeguards requirements on all Australian aid investments, including our bilateral climate finance programme, ensure potential adverse social and environmental impacts are identified and adequately addressed.

Australia provides a range of assistance to support the development and deployment of low emissions technologies in developing countries and to build countries' capacities to implement low emissions development strategies. For example, Australia is supporting:

- The Climate Technology Initiative Private Finance Advisory Network, which provides project development and investment advice, and facilitates the financing of clean energy projects;
- The NDC Partnership, which provides targeted and coordinated technical assistance so that countries can effectively develop and implement robust climate and development plans that enable scaling up of ambitions and impacts of climate actions. Australia is a member of the NDC Partnership's Steering Committee and has provided funding and assisted the establishment of the Regional Pacific NDC Hub, announced in Germany in November 2017 (new information since the last submission);
- The Clean Energy Solutions Centre, which builds capacity in clean energy policy, technology and finance;
- Multilateral Funds including the Green Climate Fund, World Bank and Asian Development Bank;
- Bilateral initiatives to deploy low carbon technologies and expertise in developing countries; and
- The Global Green Growth Institute, which supports developing countries with green growth planning and implementation.

ANNEX 1: Key category analysis

A1.1 Convention accounting

A *key category* has a significant influence on a country's total inventory of direct greenhouse gases in terms of absolute level of emissions, the trend in emissions, or both. Australia has identified the key sources for the UNFCCC inventory using the tier 1 level and trend assessments as recommended in the 2006 *IPCC Good Practice for National Greenhouse Gas Inventories* (IPCC 2006). This approach identifies sources that contribute to 95 per cent of the total emissions or 95 per cent of the trend of the inventory in absolute terms.

When the LULUCF sector is included in the analysis, Australia has identified *public electricity (solid fuel)*, *road transportation (liquid fuels) and land converted to forestland* as the most significant of the key categories (i.e. contributing more than 10 per cent of the level or trend) in 2017. The full results for the 2017 key source analysis are reported in Tables A.1.1 to A.1.3.

When the LULUCF sector is excluded from the analysis the most significant key categories in 2017 are *public electricity (solid fuel), road transportation (liquid fuels) and enteric fermentation (cattle).* The results of this latter analysis are presented in Tables A.1.4 to A.1.6. Table A.1.7 summarises the results of the key category analysis for LULUCF categories under KP accounting.

The Australian analysis has been undertaken using a relatively high degree of disaggregation of sources, as recommended in table 4.1 of the 2006 *IPCC Good Practice for National Greenhouse Gas Inventories* (IPCC 2006). This permits a greater degree of understanding of Australia's key categories. Past analyses by the UNFCCC secretariat of Australian data, using higher levels of aggregation common in the analyses undertaken by other countries, have not produced any important distinctions; however there are some cases where categories not identified as a key category in the key category analysis within the Common Reporting Format (CRF) tables have been identified as a key category in the Australian analysis. This is a consequence of the higher level of disaggregation.

In the trend key category analysis some categories that have been identified as trend key categories in the key category analysis within the CRF tables are not identified as trend key categories in the Australian analysis. This is because when the categories are disaggregated to a higher degree – more sectors are identified as key categories and this can move some categories further down the list where they do not make the 95 per cent cumulative total cut off.

Table A1.1 Key categories for Australia's 2017 inventory-level assessment including LULUCF

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Level Assesment	G Cumulative Total
1.A.1.A	Public Electricity and Heat Production \ Solid Fuels	CO_2	117,909	156,698	0.23	0.23
1.A.3.B	Road Transportation \ Liquid Fuels	CO_2	52,645	81,951	0.12	0.34
4.A.2	Land converted to Forest Land	CO_2	6,528	48,562	0.07	0.41
4.C.2	Land converted to Grassland	CO_2	149,593	43,642	0.06	0.48
3.A.1	Enteric Fermentation \ Cattle	CH_4	34,106	38,503	0.06	0.53
1.A.1.A	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8,281	27,849	0.04	0.57
4.A.1	Forest Land remaining Forest Land	CO_2	15,471	19,768	0.03	0.60
1.B.1.a.i	Underground Mines\Mining Activities	CH_4	16,605	16,097	0.02	0.63
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4,577	16,026	0.02	0.65
3.A.2	Enteric Fermentation \ Sheep	CH_4	30,128	12,732	0.02	0.67
2.F.1	Refrigeration and air-conditioning	HFC	-	11,973	0.02	0.68
1.A.3.A	Domestic Aviation	CO_2	2,615	8,736	0.01	0.70
1.A.4.B	Residential \ Gaseous Fuels	CO_2	4,646	8,521	0.01	0.71
5.A	Solid Waste Disposal	CH_4	15,240	8,256	0.01	0.72
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	968	8,217	0.01	0.73
1.A.4.C	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	3,406	7,512	0.01	0.74
2.C.1.d	Iron and steel production\ Coke	CO_2	9,203	7,440	0.01	0.75
1.A.2.F	Other (please specify) \ Mining \ Liquid Fuels	CO_2	1,759	7,369	0.01	0.77
1.B.2.c2.ii	Fugitives\Venting and Flaring\ Flaring\Gas	CO_2	2,426	6,543	0.01	0.77
1.A.2.B	Non-Ferrous Metals \ Gaseous Fuels	CO_2	4,170	6,486	0.01	0.78
1.A.2.B	Non-Ferrous Metals \ Solid Fuels	CO_2	4,132	6,048	0.01	0.79
1.B.1.a.ii	Fugitive Emissions From Fuels\ Solid Fuels\Mining Activities	CH_4	3,351	6,009	0.01	0.80
4.A.1	Forest Land remaining Forest Land	CH_4	4,524	5,782	0.01	0.81
1.B.2.c1	Fugitives\Venting and Flaring\ Venting	CO_2	2,104	5,376	0.01	0.82
4.C.1	Grassland remaining Grassland	CO_2	5,087	5,062	0.01	0.82
3.D.a.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N_2O	2,753	5,006	0.01	0.83
1.B.2.B.2	Fugitive Emissions From Fuels\ Oil and Natural Gas\ Natural Gas\ Production	CH_4	1,364	4,927	0.01	0.84
4.G	Harvested Wood Products	CO_2	7,417	4,649	0.01	0.85
1.A.1.A	Public Electricity and Heat Production \ Liquid Fuels	CO_2	2,907	3,864	0.01	0.85
1.A.2.C	Chemicals \ Liquid Fuels	CO_2	3,297	3,829	0.01	0.86
1.A.3.C	Railways \ Liquid Fuels	CO_2	1,734	3,486	0.01	0.86

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Level Assesment	G Cumulative Total
1.A.4.A	Commercial/Institutional \ Liquid Fuels	CO_2	1,246	3,203	0.00	0.87
3.D.a.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N_2O	4,278	3,117	0.00	0.87
4.B.1	Cropland remaining Cropland	CO_2	17,894	3,080	0.00	0.88
1.A.4.A	Commercial/Institutional \ Gaseous Fuels	CO_2	1,824	3,079	0.00	0.88
2.A.1	Cement Industry	CO_2	3,463	3,019	0.00	0.88
1.B.2.B.4	Transmission and Storage	CH_4	4,316	2,731	0.00	0.89
5.D	Wastewater treatment and discharge	CH_4	4,389	2,719	0.00	0.89
1.A.2.C	Chemicals \ Gaseous Fuels	CO_2	1,452	2,671	0.00	0.90
3.D.a.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	1,351	2,648	0.00	0.90
1.A.1.B	Petroleum Refining \ Liquid Fuels	CO_2	4,931	2,597	0.00	0.90
1.A.2.F	Other (please specify) \ Mineral industry \ Gaseous Fuels	CO_2	2,972	2,592	0.00	0.91
2.B.1	Ammonia Production	CO_2	544	2,271	0.00	0.91
3.D.b.2	Agricultural Soils \ Indirect Soil Emissions \ Nitrogen Leaching and Run-Off	N_2O	1,947	2,215	0.00	0.91
2.C.3	Aluminium Production	CO_2	2,058	2,197	0.00	0.92
4.C.1	Grassland remaining Grassland	N_2O	1,640	1,875	0.00	0.92
1.A.2.F	Other (please specify) \ Mineral industry \ Solid Fuels	CO_2	2,212	1,823	0.00	0.92
1.B.2.c1	Fugitives\Venting and Flaring\ Venting	CH_4	2,114	1,817	0.00	0.93
1.A.3.D	Domestic navigation \ Liquid Fuels	CO_2	2,208	1,804	0.00	0.93
1.A.2.E	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	1,255	1,716	0.00	0.93
1.B.2.c2.i	Fugitives\Venting and Flaring\ Flaring\Oil	CO_2	1,217	1,712	0.00	0.93
4.B.2	Land converted to Cropland	CO_2	18,506	1,574	0.00	0.93
2.A.3	Other process uses of carbonates	CO_2	1,251	1,550	0.00	0.94
3.H	Urea Application	CO_2	367	1,543	0.00	0.94
2.B.2	Nitric Acid Production	N_2O	995	1,519	0.00	0.94
3.B.3	Manure Management \ Swine	CH_4	1,546	1,447	0.00	0.94
1.A.2.F	Other (please specify) \ Construction \ Liquid Fuels	CO_2	2,838	1,430	0.00	0.95
3.G	Liming	CO_2	215	1,318	0.00	0.95
4.C.2	Land converted to Grassland	CH_4	5,400	1,241	0.00	0.95

Table A1. 2 Key categories for Australia's 2016 inventory—trend assessment including LULUCF

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Trend Assesment	% Contribution to Trend	G Cumulative Total
4.C.2	Land converted to Grassland	CO2	149,593	43,642	0.13	0.20	0.20
1.A.1.A	Public Electricity and Heat Production \ Solid Fuels	CO2	117,909	156,698	0.08	0.12	0.31
4.A.2	Land converted to Forest Land	CO2	6,528	48,562	0.06	0.09	0.40
1.A.3.B	Road Transportation \ Liquid Fuels	CO2	52,645	81,951	0.05	0.08	0.48
1.A.1.A	Public Electricity and Heat Production \ Gaseous Fuels	CO2	8,281	27,849	0.03	0.05	0.53
4.B.1	Cropland remaining Cropland	CO2	17,894	3,080	0.03	0.04	0.57
4.B.2	Land converted to Cropland	CO2	18,506	1,574	0.02	0.03	0.60
3.A.2	Enteric Fermentation \ Sheep	CH4	30,128	12,732	0.02	0.03	0.63
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO2	4,577	16,026	0.02	0.03	0.66
2.F.1	Refrigeration and air-conditioning	HFC	-	11,973	0.02	0.03	0.68
4.C.1	Grassland remaining Grassland	CO2	5,087	5,062	0.01	0.02	0.71
3.A.1	Enteric Fermentation \ Cattle	CH4	34,106	38,503	0.01	0.02	0.72
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO2	968	8,217	0.01	0.02	0.74
1.A.3.A	domestic Aviation	CO2	2,615	8,736	0.01	0.01	0.75
1.A.2.F	Other (please specify) \ Mining \ Liquid Fuels	CO2	1,759	7,369	0.01	0.01	0.77
5.A	Solid Waste Disposal	CH4	15,240	8,256	0.01	0.01	0.78
1.A.4.C	Agriculture/Forestry/ Fisheries \ Liquid Fuels	CO2	3,406	7,512	0.01	0.01	0.79
1.A.4.B	Residential \ Gaseous Fuels	CO2	4,646	8,521	0.01	0.01	0.80
1.B.2.c2.ii	Gas	CO2	2,426	6,543	0.01	0.01	0.81
1.B.2.B.2	Production	CH4	1,364	4,927	0.01	0.01	0.82
4.G	Harvested Wood Products	CO2	7,417	4,649	0.01	0.01	0.82
4.C.2	Land converted to Grassland	CH4	5,400	1,241	0.01	0.01	0.83
1.B.2.c1	Venting	CO2	2,104	5,376	0.01	0.01	0.84

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Trend Assesment	% Contribution to Trend	G Cumulative Total
2.C.3	Aluminium Production	CF4	3,794	135	0.00	0.01	0.85
1.B.1.a.ii	Mining Activities	CH4	3,351	6,009	0.00	0.01	0.85
1.A.2.B	Non-Ferrous Metals \ Gaseous Fuels	CO2	4,170	6,486	0.00	0.01	0.86
3.D.a.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N2O	2,753	5,006	0.00	0.01	0.87
4.A.1	Forest Land remaining Forest Land	CO2	15,471	19,768	0.00	0.01	0.87
1.A.2.B	Non-Ferrous Metals \ Solid Fuels	CO2	4,132	6,048	0.00	0.01	0.88
1.A.2.B	Non-Ferrous Metals \ Liquid Fuels	CO2	2,849	273	0.00	0.00	0.88
1.A.4.A	Commercial/ Institutional \ Liquid Fuels	CO2	1,246	3,203	0.00	0.00	0.89
4.E.2	Land converted to Settlements	CO2	3,011	602	0.00	0.00	0.89
1.A.3.C	Railways \ Liquid Fuels	CO2	1,734	3,486	0.00	0.00	0.89
2.B.1	Ammonia Production	CO2	544	2,271	0.00	0.00	0.90
4.A.1	Forest Land remaining Forest Land	CH4	4,524	5,782	0.00	0.00	0.90
1.A.1.B	Petroleum Refining \ Liquid Fuels	CO2	4,931	2,597	0.00	0.00	0.91
1.A.4.A	Commercial/ Institutional \ Gaseous Fuels	CO2	1,824	3,079	0.00	0.00	0.91
3.D.a.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N2O	1,351	2,648	0.00	0.00	0.91
1.B.1.a.i	Mining Activities	CH4	16,605	16,097	0.00	0.00	0.92
1.A.2.C	Chemicals \ Gaseous Fuels	CO2	1,452	2,671	0.00	0.00	0.92
1.A.1.A	Public Electricity and Heat Production \ Liquid Fuels	CO2	2,907	3,864	0.00	0.00	0.92
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO2	2,397	832	0.00	0.00	0.92
2.B.9	Chemical Industry \ Fluorochemical production	HFC-23	1,425	-	0.00	0.00	0.93
1.A.4.B	Residential \ Biomass	CH4	2,403	869	0.00	0.00	0.93
3.H	Urea Application	CO2	367	1,543	0.00	0.00	0.93

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Trend Assesment	% Contribution to Trend	G Cumulative Total
5.D	Wastewater treatment and discharge	CH4	4,389	2,719	0.00	0.00	0.94
3.G	Liming	CO2	215	1,318	0.00	0.00	0.94
1.B.2.B.4	Transmission and Storage	CH4	4,316	2,731	0.00	0.00	0.94
1.A.2.F	Other (please specify) \ Construction \ Liquid Fuels	CO2	2,838	1,430	0.00	0.00	0.94
1.A.2.C	Chemicals \ Liquid Fuels	CO2	3,297	3,829	0.00	0.00	0.94
1.B.1.c	Other	CO2	0	808	0.00	0.00	0.95
4.C.2	Land converted to Grassland	N2O	1,373	469	0.00	0.00	0.95
2.C.1.d	Coke	CO2	9,203	7,440	0.00	0.00	0.95

Table A1.3 Key categories for Australia's 2017 inventory—summary including LULUCF

A		B	C	D
IPCC Source Categories		Direct Greenhouse Gas	Key Source Category Flag	If Column C is Yes, Criteria for Identification
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	YES	Level, Trend
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	YES	Trend
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	YES	Level, Trend
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	YES	Trend
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.e	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	YES	Level
1.A.2.f	Other \ Mining \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other \ Mineral industry \ Gaseous Fuels	CO_2	YES	Level
1.A.2.f	Other \ Mineral industry \ Solid Fuels	CO_2	YES	Level
1.A.2.f	Other \ Construction \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.a	Domestic Aviation \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.c	Railways \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.d	Navigation \ Liquid Fuels	CO_2	YES	Level
1.A.4.a	Commercial/Institutional \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.4.a	Commercial/Institutional \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.4.b	Residential \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.4.b	Residential \ Biomass	CH_4	YES	Trend
1.A.4.c	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	YES	Level, Trend
1.B.1.A.1	Underground Mines\Mining Activities	CH_4	YES	Level, Trend
1.B.1.A.1	Underground Mines\Mining Activities	CO_2	YES	Level, Trend
1.B.1.C.	Fugitive Emissions From Fuels,\ Solid Fuels,\ Other	CO_2	YES	Trend
1.B.2.B.2	Fugitives\Natural Gas\Production	CH_4	YES	Level, Trend
1.B.2.B.4	Transmission and Storage	CH_4	YES	Level, Trend
1.B.2.C.1	Fugitives\Venting and Flaring\Venting\Gas	CO_2	YES	Level, Trend
1.B.2.C.1	Fugitives\Venting and Flaring\Venting\Gas	CH_4	YES	Level
1.B.2.c2.i	Fugitives\Venting and Flaring\Flaring\ Oil	CO_2	YES	Level
1.B.2.c2.ii	Fugitives\Venting and Flaring\Flaring\Gas	CO_2	YES	Level, Trend
2.A.1	Cement Production	CO_2	YES	Level
2.A.4	Other process uses of Carbonates	CO_2	YES	Level
2.B.1	Ammonia Production	CO_2	YES	Level, Trend

A		B	C	D
IPCC Source Categories		Direct Greenhouse Gas	Key Source Category Flag	If Column C is Yes, Criteria for Identification
2.B.2	Nitric Acid Production	N_2O	YES	Level
2.B.9	Chemical Industry \ Fluorochemical production	HFC-23	YES	Trend
2.C.3	Aluminium Production	CO_2	YES	Level
2.C.3	Aluminium Production	CF_4	YES	Trend
2.F.1	Refrigeration and Air Conditioning Equipment	HFC	YES	Level, Trend
3.A.1	Enteric Fermentation \ Cattle	CH_4	YES	Level, Trend
4.A.2	Enteric Fermentation \ Sheep	CH_4	YES	Level, Trend
3.B.3	Manure Management \ Swine	CH_4	YES	Level
3.D.a.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	YES	Level, Trend
3.D.a.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N_2O	YES	Level
3.D.a.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N_2O	YES	Level, Trend
3.D.b.2	Nitrogen Leaching and Run-off	N_2O	YES	Level
3.G	Liming	CO_2	YES	Level, Trend
3.H	Urea Application	CO_2	YES	Level, Trend
4.A.1	Forest Land remaining Forest Land	CO_2	YES	Level, Trend
4.A.1	Forest Land remaining Forest Land	CH_4	YES	Level, Trend
4.A.2	Land converted to Forest Land	CO_2	YES	Level, Trend
4.B.1	Cropland remaining Cropland	CO_2	YES	Level, Trend
4.B.2	Land converted to Cropland	CO_2	YES	Level, Trend
4.C.1	Grassland remaining Grassland	CO_2	YES	Level, Trend
4.C.1	Grassland remaining Grassland	N_2O	YES	Level
4.C.2	Land converted to Grassland	CO_2	YES	Level, Trend
4.C.2	Land converted to Grassland	N_2O	YES	Trend
4.C.2	Land converted to Grassland	CH_4	YES	Trend
4.C.2	Land converted to Settlements	CO_2	YES	Trend
4.G	Harvested Wood Products	CO_2	YES	Level, Trend
5.A.1	Solid Waste Disposal	CH_4	YES	Level, Trend
5.D.1	Wastewater treatment and discharge	CH_4	YES	Level, Trend

Table A1.4 Key categories for Australia's 2017 inventory-level assessment excluding LULUCF

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Level Assesment	G Cumulative Total
1.A.1.A	Public Electricity and Heat Production \ Solid Fuels	CO_2	117,909	156,698	0.28	0.28
1.A.3.B	Road Transportation \ Liquid Fuels	CO_2	52,645	81,951	0.15	0.43
3.A.1	Enteric Fermentation \ Cattle	CH_4	34,106	38,503	0.07	0.50
1.A.1.A	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8,281	27,849	0.05	0.55
1.B.1.a.i	Underground Mines\Mining Activities	CH_4	16,605	16,097	0.03	0.58
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4,577	16,026	0.03	0.61
3.A.2	Enteric Fermentation \ Sheep	CH_4	30,128	12,732	0.02	0.63
2.F.1	Refrigeration and air-conditioning	HFC	-	11,973	0.02	0.65
1.A.3.A	Domestic Aviation	CO_2	2,615	8,736	0.02	0.67
1.A.4.B	Residential \ Gaseous Fuels	CO_2	4,646	8,521	0.02	0.68
5.A	Solid Waste Disposal	CH_4	15,240	8,256	0.01	0.70
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	968	8,217	0.01	0.71
1.A.4.C	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	3,406	7,512	0.01	0.73
2.C.1.d	Iron and steel production\ Coke	CO_2	9,203	7,440	0.01	0.74
1.A.2.F	Other (please specify) \ Mining \ Liquid Fuels	CO_2	1,759	7,369	0.01	0.75
1.B.2.c2.ii	Fugitives\Venting and Flaring\ Flaring\Gas	CO_2	2,426	6,543	0.01	0.77
1.A.2.B	Non-Ferrous Metals \ Gaseous Fuels	CO_2	4,170	6,486	0.01	0.78
1.A.2.B	Non-Ferrous Metals \ Solid Fuels	CO_2	4,132	6,048	0.01	0.79
1.B.1.a.ii	Fugitive Emissions From Fuels \ Solid Fuels \ Coal Mining \ Surface Mining \ Mining Activities	CH_4	3,351	6,009	0.01	0.80
1.B.2.c1	Fugitives\Venting and Flaring\ Venting	CO_2	2,104	5,376	0.01	0.81
3.D.a.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N_2O	2,753	5,006	0.01	0.82
1.B.2.B.2	Fugitive Emissions From Fuels\ Oil and Natural Gas\ Natural Gas\ Production	CH_4	1,364	4,927	0.01	0.83
1.A.1.A	Public Electricity and Heat Production \ Liquid Fuels	CO_2	2,907	3,864	0.01	0.83
1.A.2.C	Chemicals \ Liquid Fuels	CO_2	3,297	3,829	0.01	0.84
1.A.3.C	Railways \ Liquid Fuels	CO_2	1,734	3,486	0.01	0.85
1.A.4.A	Commercial/Institutional \ Liquid Fuels	CO_2	1,246	3,203	0.01	0.85
3.D.a.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N_2O	4,278	3,117	0.01	0.86
1.A.4.A	Commercial/Institutional \ Gaseous Fuels	CO_2	1,824	3,079	0.01	0.86
2.A.1	Cement Industry	CO_2	3,463	3,019	0.01	0.87

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Level Assesment	G Cumulative Total
1.B.2.B.4	Transmission and Storage	CH_4	4,316	2,731	0.00	0.87
5.D	Wastewater treatment and discharge	CH_4	4,389	2,719	0.00	0.88
1.A.2.C	Chemicals \ Gaseous Fuels	CO_2	1,452	2,671	0.00	0.88
3.D.a.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	1,351	2,648	0.00	0.89
1.A.1.B	Petroleum Refining \ Liquid Fuels	CO_2	4,931	2,597	0.00	0.89
1.A.2.F	Other (please specify) \ Mineral industry \ Gaseous Fuels	CO_2	2,972	2,592	0.00	0.90
2.B.1	Ammonia Production	CO_2	544	2,271	0.00	0.90
3.D.b.2	Agricultural Soils \ Indirect Soil Emissions \ Nitrogen Leaching and Run-Off	N_2O	1,947	2,215	0.00	0.91
2.C.3	Aluminium Production	CO_2	2,058	2,197	0.00	0.91
1.A.2.F	Other (please specify) \ Mineral industry \ Solid Fuels	CO_2	2,212	1,823	0.00	0.91
1.B.2.c1	Fugitives\Venting and Flaring\ Venting	CH_4	2,114	1,817	0.00	0.92
1.A.3.D	Domestic Navigation \ Liquid Fuels	CO_2	2,208	1,804	0.00	0.92
1.A.2.E	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	1,255	1,716	0.00	0.92
1.B.2.c2.i	Fugitives\Venting and Flaring\ Flaring\Oil	CO_2	1,217	1,712	0.00	0.93
2.A.3	Other process uses of carbonates	CO_2	1,251	1,550	0.00	0.93
3.H	Urea Application	CO_2	367	1,543	0.00	0.93
2.B.2	Nitric Acid Production	N_2O	995	1,519	0.00	0.93
3.B.3	Manure Management \ Swine	CH_4	1,546	1,447	0.00	0.94
1.A.2.F	Other (please specify) \ Construction \ Liquid Fuels	CO_2	2,838	1,430	0.00	0.94
3.G	Liming	CO_2	215	1,318	0.00	0.94
1.A.4.B	Residential \ Liquid Fuels	CO_2	1,320	1,198	0.00	0.94
1.B.1.a.i	Solid Fuels\ Coal Mining\ Underground Mines \ Mining Activities	CO_2	1,122	1,174	0.00	0.95
3.B.1	Manure Management \ Cattle	CH_4	492	1,087	0.00	0.95
3.B.1	Manure Management \ Cattle	CH_4	492	1118	0.00	0.95

Table A1.5 Key categories for Australia's 2017 inventory—trend assessment excluding LULUCF

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Trend Assesment	% Contribution to Trend	G Cumulative Total
3.A.2	Enteric Fermentation \ Sheep	CH4	30,128	12,732	0.06	0.13	0.13
1.A.1.A	Public Electricity and Heat Production \ Gaseous Fuels	CO2	8,281	27,849	0.04	0.08	0.21
1.A.3.B	Road Transportation \ Liquid Fuels	CO2	52,645	81,951	0.03	0.06	0.27
2.F.1	Refrigeration and air-conditioning	HFC	-	11,973	0.03	0.06	0.32
5.A	Solid Waste Disposal	CH4	15,240	8,256	0.03	0.06	0.38
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO2	4,577	16,026	0.02	0.05	0.43
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO2	968	8,217	0.02	0.03	0.46
3.A.1	Enteric Fermentation \ Cattle	CH4	34,106	38,503	0.02	0.03	0.49
1.B.1.a.i	Mining Activities	CH4	16,605	16,097	0.01	0.03	0.52
1.A.3.A	domestic Aviation	CO2	2,615	8,736	0.01	0.02	0.54
1.A.2.F	Other (please specify) \ Mining \ Liquid Fuels	CO2	1,759	7,369	0.01	0.02	0.57
2.C.3	Aluminium Production	CF4	3,794	135	0.01	0.02	0.59
2.C.1.d	Coke	CO2	9,203	7,440	0.01	0.02	0.61
1.A.1.B	Petroleum Refining \ Liquid Fuels	CO2	4,931	2,597	0.01	0.02	0.63
1.A.2.B	Non-Ferrous Metals \ Liquid Fuels	CO2	2,849	273	0.01	0.02	0.65
1.B.2.c2.ii	Gas	CO2	2,426	6,543	0.01	0.02	0.66
1.B.2.B.2	Production	CH4	1,364	4,927	0.01	0.01	0.68
5.D	Wastewater treatment and discharge	CH4	4,389	2,719	0.01	0.01	0.69
1.A.4.C	Agriculture/Forestry/ Fisheries \ Liquid Fuels	CO2	3,406	7,512	0.01	0.01	0.70
1.B.2.B.4	Transmission and Storage	CH4	4,316	2,731	0.01	0.01	0.72
1.B.2.c1	Venting	CO2	2,104	5,376	0.01	0.01	0.73
3.D.a.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N2O	4,278	3,117	0.01	0.01	0.74
1.A.4.B	Residential \ Gaseous Fuels	CO2	4,646	8,521	0.01	0.01	0.75

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Trend Assesment	% Contribution to Trend	G Cumulative Total
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO2	2,397	832	0.01	0.01	0.76
1.A.2.F	Other (please specify) \ Construction \ Liquid Fuels	CO2	2,838	1,430	0.01	0.01	0.78
1.A.4.B	Residential \ Biomass	CH4	2,403	869	0.01	0.01	0.79
2.B.9	Chemical Industry \ Fluorochemical production	HFC-23	1,425	-	0.00	0.01	0.80
1.B.1.a.ii	Mining Activities	CH4	3,351	6,009	0.00	0.01	0.80
1.A.4.A	Commercial/ Institutional \ Liquid Fuels	CO2	1,246	3,203	0.00	0.01	0.81
2.B.1	Ammonia Production	CO2	544	2,271	0.00	0.01	0.82
2.A.1	Cement Industry	CO2	3,463	3,019	0.00	0.01	0.82
3.D.a.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N2O	2,753	5,006	0.00	0.01	0.83
1.A.2.F	Other (please specify) \ Mineral industry \ Gaseous Fuels	CO2	2,972	2,592	0.00	0.01	0.84
1.A.1.A	Public Electricity and Heat Production \ Solid Fuels	CO2	117,909	156,698	0.00	0.01	0.84
1.A.3.C	Railways \ Liquid Fuels	CO2	1,734	3,486	0.00	0.01	0.85
1.A.2.A	Iron and Steel \ Gaseous Fuels	CO2	1,393	664	0.00	0.01	0.85
1.A.3.D	domestic navigation \ Liquid Fuels	CO2	2,208	1,804	0.00	0.01	0.86
1.A.2.F	Other (please specify) \ Mineral industry \ Solid Fuels	CO2	2,212	1,823	0.00	0.01	0.87
3.H	Urea Application	CO2	367	1,543	0.00	0.00	0.87
3.G	Liming	CO2	215	1,318	0.00	0.00	0.87
2.C.3	Aluminium Production	C2F6	813	68	0.00	0.00	0.88
1.A.2.B	Non-Ferrous Metals \ Gaseous Fuels	CO2	4,170	6,486	0.00	0.00	0.88
1.B.2.c1	Venting	CH4	2,114	1,817	0.00	0.00	0.89
1.A.2.E	Food Processing, Beverages and Tobacco \ Solid Fuels	CO2	1,214	698	0.00	0.00	0.89
3.D.a.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N2O	1,351	2,648	0.00	0.00	0.90
1.A.2.C	Chemicals \ Solid Fuels	CO2	876	334	0.00	0.00	0.90
1.B.1.c	Other	CO2	0	808	0.00	0.00	0.90

A IPCC Source Abbreviation	B IPCC Source Category	C Direct G'house Gas	D Base Year Estimate	E Current Year Estimate	F Trend Assesment	% Contribution to Trend	G Cumulative Total
1.A.2.C	Chemicals \ Gaseous Fuels	CO2	1,452	2,671	0.00	0.00	0.91
1.A.4.A	Commercial/ Institutional \ Gaseous Fuels	CO2	1,824	3,079	0.00	0.00	0.91
1.A.4.A	Commercial/ Institutional \ Solid Fuels	CO2	523	45	0.00	0.00	0.91
1.A.2.B	Non-Ferrous Metals \ Solid Fuels	CO2	4,132	6,048	0.00	0.00	0.92
3.B.3	Manure Management \ Swine	CH4	1,546	1,447	0.00	0.00	0.92
1.A.2.A	Iron and Steel \ Solid Fuels	CO2	1,206	1,011	0.00	0.00	0.92
1.B.2.b.3	Natural Gas Processing	CH4	225	867	0.00	0.00	0.93
3.D.a.5	Mineralisation due to loss of soil carbon	N2O	459	45	0.00	0.00	0.93
1.A.4.B	Residential \ Liquid Fuels	CO2	1,320	1,198	0.00	0.00	0.93
1.A.3.B	Road Transportation \ Liquid Fuels	CH4	560	221	0.00	0.00	0.93
1.A.2.C	Chemicals \ Liquid Fuels	CO2	3,297	3,829	0.00	0.00	0.94
2.C.3	Aluminium Production	CO2	2,058	2,197	0.00	0.00	0.94
1.A.1.A	Public Electricity and Heat Production \ Gaseous Fuels	CH4	7	482	0.00	0.00	0.94
3.B.1	Manure Management \ Cattle	CH4	492	1,087	0.00	0.00	0.94
1.A.2.g.i	Other (please specify) \ Manufacturing of Machinery	CO2	422	123	0.00	0.00	0.94
1.A.3.D	domestic navigation \ Solid Fuels	CO2	313	-	0.00	0.00	0.95
1.A.2.F	Other (please specify) \ Mining \ Solid Fuels	CO2	671	494	0.00	0.00	0.95

Table A1. 6 Key categories for Australia's 2017 inventory—summary excluding LULUCF

A		B	C	D
IPCC Source Categories		Gas	Key Source Category Flag	If Colum C is Yes, Criteria for Identification
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	YES	Level, Trend
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	YES	Level
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CH_4	YES	Trend
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	YES	Trend
1.A.2.a	Iron and Steel \ Gaseous Fuels	CO_2	YES	Trend
1.A.2.a	Iron and Steel \ Solid Fuels	CO_2	YES	Trend
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	YES	Level, Trend
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	YES	Trend
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.c	Chemicals \ Solid Fuels	CO_2	YES	Trend
1.A.2.e	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	YES	Level
1.A.2.e	Food Processing, Beverages and Tobacco \ Solid Fuels	CO_2	YES	Trend
1.A.2.f	Other \ Mining \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other \ Mineral industry \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other \ Mineral industry \ Solid Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other \ Construction \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other \ Mining \ Solid Fuels	CO_2	YES	Trend
1.A.2.g.i	Other \ Mining \ manufacturing of machinery	CO_2	YES	Trend
1.A.3.a	Domestic Aviation \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.b	Road Transportation \ Liquid Fuels	CH_4	YES	Trend
1.A.3.c	Railways \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.d	Navigation \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.d	Navigation \ Solid Fuels	CO_2	YES	Trend
1.A.4.a	Commercial/Institutional \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.4.a	Commercial/Institutional \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.4.a	Commercial/Institutional \ Solid Fuels	CO_2	YES	Trend
1.A.4.b	Residential \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.4.b	Residential \ Biomass	CH_4	YES	Trend
1.A.4.b	Residential \ Liquid Fuels	CO_2	YES	Level. Trend
1.A.4.c	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	YES	Level, Trend
1.B.1.A.1	Fugitives \ Soild fuels \ Underground Mines	CH_4	YES	Level, Trend

A		B	C	D
IPCC Source Categories		**Gas**	**Key Source Category Flag**	**If Colum C is Yes, Criteria for Identification**
1.B.1.A.1	Fugitives \ Soild fuels \ Underground Mines	CO_2	YES	Level
1.B.1.A.2.1	Surface Mining\ Mining Activities	CH_4	YES	Level, Trend
1.B.1.c	Fugitive Emissions From Fuels, Solid Fuels, Other	CO_2	YES	Trend
1.B.2.B.2	Fugitive Emissions From Fuels, Oil and Natural Gas, Natural Gas, Production	CH_4	YES	Level, Trend
1.B.2.B.3	Fugitive Emissions From Fuels, Oil and Natural Gas, Natural Gas, Processing	CH_4	YES	Trend
1.B.2.B.4	Transmission and Storage	CH_4	YES	Level, Trend
1.B.2.C.1.2	Fugitives\Venting and Flaring\Venting\Gas	CO_2	YES	Level, Trend
1.B.2.C.1.2	Fugitives\Venting and Flaring\Venting\Gas	CH_4	YES	Level, Trend
1.B.2.C.2.1	Fugitives \ Venting and Flaring \ Flaring \ Oil	CO_2	YES	Level
1.B.2.C.2.2	Fugitives \ Venting and Flaring \ Flaring \ Gas	CO_2	YES	Level, Trend
2.A.1	Cement Production	CO_2	YES	Level, Trend
2.A.4	Other process uses of Carbonates	CO_2	YES	Level
2.B.1	Ammonia Production	CO_2	YES	Level, Trend
2.B.2	Nitric Acid Production	N_2O	YES	Level
2.B.9	Chemical Industry \ Fluorochemical production	HFC-23	YES	Trend
2.C.7	Iron and Steel \ Other	CO_2	YES	Level, Trend
2.C.3	Aluminium Production	CO_2	YES	Level, Trend
2.C.3	Aluminium Production	CF_4	YES	Trend
2.C.3	Aluminium Production	C_2F_6	YES	Trend
2.F.1	Refrigeration and Air Conditioning Equipment	HFC	YES	Level, Trend
3.A.1	Enteric Fermentation \ Cattle	CH_4	YES	Level, Trend
3.A.2	Enteric Fermentation \ Sheep	CH_4	YES	Level, Trend
3.B.1	Manure Management \ Cattle	CH_4	YES	Level, Trend
3.B.3	Manure Management \ Swine	CH_4	YES	Level, Trend
3.D.a.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	YES	Level, Trend
3.D.a.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N_2O	YES	Level, Trend
3.D.a.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N_2O	YES	Level, Trend
3.D.b.2	Agricultural Soils \ Indirect Soil Emissions \ Nitrogen Leaching and Run-Off	N_2O	YES	Level
3.G	Liming	CO_2	YES	Level, Trend
3.H	Urea Application	CO_2	YES	Level, Trend
5.A	Solid Waste Disposal	CH_4	YES	Level, Trend
5.D	Wastewater treatment and discharge	CH_4	Yes	Level, Trend

A1.2 Kyoto Protocol LULUCF Activities

The KP-LULUCF key categories have been identified using the method documented in section 2.3.6 of IPCC 2017. The results are presented in Table A.1.7.

Table A1.7 Summary overview for key categories for Land use, Land-use Change and Forestry activities under the Kyoto Protocol – 2017

		Criteria used for Key Category Identification			
Key Categories of Emissions and Removals	**Gas**	**Associated category in UNFCCC inventory is key**	**Category contribution is greater than the smallest category considered key in the UNFCCC inventory (including LULUCF)**	**Other**	**Comments**
Deforestation	CO_2	forest land converted to grassland	TRUE	NA	
Deforestation	CH_4	forest land converted to grassland	FALSE	NA	
Deforestation	N_2O	forest land converted to grassland	FALSE	NA	
Forest management	CO_2	forest land remaining forest land	TRUE	NA	Australia has applied the narrow approach to forest management. As a result the forest land remaining forest land classification does not directly correspond to the forest management activity.
Afforestation/ Reforestation	CO_2	grassland converted to forest land	TRUE	NA	
Grazing land management	CO_2	grassland remaining grassland, land converted to grassland (conversion prior to 1990)	TRUE	NA	
Grazing land management	CH_4	grassland remaining grassland, land converted to grassland (conversion prior to 1990)	TRUE	NA	
Grazing land management	N_2O	grassland remaining grassland, land converted to grassland (conversion prior to 1990)	TRUE	NA	
Cropland management	CO_2	cropland remaining cropland, land converted to cropland (conversion prior to 1990)	TRUE	NA	

Annexes

ANNEX 2: Uncertainty analysis

Uncertainty is inherent within any kind of estimation – be it an estimate of the national greenhouse gas emissions, or the national gross domestic product. While it is in some cases possible to continuously monitor emissions, it is not usually practical or economic to do so. This leads to estimations based on samples or studies being used which carry a degree of additional uncertainty attached to them. Uncertainty also arises from the limitations of the measuring instruments, and over the complexities of the modeling of key relationships between observed variables and emissions.

The purpose of estimating the uncertainty attached to emissions estimates is principally to provide information on where inventory resources should be allocated to maximise the future improvements to inventory quality.

Assessing uncertainty is a difficult exercise, especially in the absence of quantitative data. Australia has conducted an uncertainty analysis for the individual sectors in line with the IPCC 2006 *Guidelines for National Greenhouse Gas Inventories*. Monte Carlo and Latin Hypercube approaches were used to estimate emission uncertainty in some sectors, which is equivalent to the IPCC tier 2 methodology. Companies with large single sources of emissions must annually report through NGERS on the level of uncertainty associated with these emissions. Statistical uncertainty must be estimated and reported by NGER reporters with emissions of more than 25 Gg CO_2-e from the combustion of a fuel type, or an IPPU, fugitive or waste source other than fuel combustion. NGER reporters must follow the methods for assessing uncertainty published in the NGER (Measurement) Determination and report a combined estimate for activity data and emission factor uncertainty. Uncertainty estimates associated with single sources of emissions first became available under NGER in 2014.

NGER uncertainty estimates have been incorporated into the national uncertainty assessment in sectors where there are a limited number of large facilities such as electricity generation, cement production, aluminum production, petroleum refining and coal mining. Estimates for other sectors have been prepared using the judgement of the sectoral expert consultants. These estimates of uncertainty were reviewed in 2005 by independent experts under protocols developed by the Australian CSIRO Atmospheric Research Division. The CSIRO report confirmed, with one or two exceptions, the quantitative judgements made in relation to uncertainty of inventory estimates and provide a strong basis for confidence in the assessments reported in this chapter.

The uncertainties for individual sectors are reported in more detail below. The estimated uncertainties tend to be low for carbon dioxide from energy consumption as well as from some industrial process emissions. Uncertainty surrounding estimates from these sources are typically as low as ± 1–5 per cent. Uncertainty surrounding estimates of emissions are higher for agriculture, land use change and forestry, reflecting inherently high uncertainty due to the very nature of the processes involved (e.g. biological processes). A medium band of uncertainty applies to estimates from fugitive emissions, most industrial processes and non-CO_2 gases in the energy sector. The ranges presented are broadly consistent with the typical uncertainty ranges expected for each sector, as identified in IPCC 2006.

The estimates of uncertainty surrounding the emissions estimates for individual sectors may be combined to present an estimate of the overall uncertainty for the inventory as a whole. The results of the application of the IPCC tier 1 approach to estimating the uncertainty of the inventory as a whole, which identifies separately estimates of uncertainty for both activity and emission factors where available, and which does not account for correlations between variables (unlike some of the sectoral analyses), are presented in Table A2.1 to A2.4.

As indicated in IPCC 2006, the tier 1 approach is valid as long as a number of restrictive assumptions are met. An alternative, more flexible approach, which relies on Monte Carlo analysis and a more detailed specification of the sources of uncertainty, is currently under consideration for development by the DoEE for use in future national inventory reports. This analysis would be equivalent to the IPCC tier 2 approach and would take into consideration a number of refinements proposed by the CSIRO independent review.

In this inventory submission, DoEE has included the base year uncertainty assessment as well as the latest inventory year. The base year is 1990 and the latest inventory year is 2017.

The tier 1 results presented in Table A.2.1 show the estimated uncertainty surrounding the aggregate inventory estimate for base year 1990 to be ±9.2 per cent. The reported estimated uncertainty for the trend in emissions is ±4.5 per cent. This estimate has been calculated on the assumption that the total uncertainty for parts of agriculture, land use, land use change and forestry, and the waste sectors are uncorrelated through time.

Much of the uncertainty for the UNFCCC inventory derives from the LULUCF sector. The uncertainty for the aggregate inventory excluding LULUCF is estimated at ±8.6 per cent and the uncertainty in the trend is estimated ±2.6 per cent (Table A2.2).

The tier 1 results presented in Table A.2.3 show the estimated uncertainty surrounding the aggregate inventory estimate for 2017 to be ±6.5 per cent. The reported estimated uncertainty for the trend in emissions is ±4.8 per cent. This estimate has been calculated on the assumption that the total uncertainty for parts of agriculture, land use, land use change and forestry, and the waste sectors are uncorrelated through time.

Much of the uncertainty for the UNFCCC inventory derives from the LULUCF sector. The uncertainty for the aggregate inventory excluding LULUCF is estimated at ±5.5 per cent and the uncertainty in the trend is estimated ±5.2 per cent (Table A2.4).

Table A2.1 General reporting table for uncertainty including LULUCF for base year 1990

	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	1990 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.A.1.a Electricity generation - black coal	CO_2	72,725.26	72,725.26	1.57	1.57	2.22	0.27	-	0.12	-	0.27	0.27	1
1.A.1.a Electricity generation - black coal	CH_4	13.54	13.54	1.57	50.00	50.02	0.00	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - black coal	N_2O	189.54	189.54	1.57	50.00	50.02	0.02	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - brown coal	CO_2	45,183.47	45,183.47	0.50	0.50	0.71	0.05	-	0.07	-	0.05	0.05	1
1.A.1.a Electricity generation - brown coal	CH_4	7.50	7.50	0.50	50.00	50.00	0.00	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - brown coal	N_2O	189.77	189.77	0.50	50.00	50.00	0.02	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - natural gas	CO_2	8,280.60	8,280.60	1.70	1.70	2.41	0.03	-	0.01	-	0.03	0.03	1
1.A.1.a Electricity generation - natural gas	CH_4	7.20	7.20	1.70	50.00	50.03	0.00	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - natural gas	N_2O	43.68	43.68	1.70	50.00	50.03	0.00	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - liquid fuels	CO_2	2,907.27	2,907.27	2.83	2.83	4.00	0.02	-	0.00	-	0.02	0.02	2
1.A.1.a Electricity generation - liquid fuels	CH_4	2.71	2.71	35.36	35.36	50.00	0.00	-	0.00	-	0.00	0.00	2
1.A.1.a Electricity generation - liquid fuels	N_2O	4.13	4.13	35.36	35.36	50.00	0.00	-	0.00	-	0.00	0.00	2
1.A.1.b Petroleum refining - liquid fuels	CO_2	4,931.12	4,931.12	16.53	16.53	23.37	0.19	-	0.01	-	0.19	0.19	1
1.A.1.b Petroleum refining - liquid fuels	CH_4	1.26	1.26	16.53	50.00	52.66	0.00	-	0.00	-	0.00	0.00	1
1.A.1.b Petroleum refining - liquid fuels	N_2O	12.10	12.10	16.53	50.00	52.66	0.00	-	0.00	-	0.00	0.00	1
1.A.1.b Petroleum refining - gaseous fuels	CO_2	580.95	580.95	5.19	5.19	7.34	0.01	-	0.00	-	0.01	0.01	1
1.A.1.b Petroleum refining - gaseous fuels	CH_4	0.29	0.29	5.19	50.00	50.27	0.00	-	0.00	-	0.00	0.00	1
1.A.1.b Petroleum refining - gaseous fuels	N_2O	1.43	1.43	5.19	50.00	50.27	0.00	-	0.00	-	0.00	0.00	1
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	CO_2	7,942.01	7,942.01	3.97	3.97	5.62	0.07	-	0.01	-	0.07	0.07	1
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	CH_4	6.55	6.55	6.36	6.36	9.00	0.00	-	0.00	-	0.00	0.00	2
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	N_2O	43.68	43.68	8.49	8.49	12.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	CO_2	11,375.13	11,375.13	2.83	2.83	4.00	0.08	-	0.02	-	0.08	0.08	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	CH_4	3.40	3.40	6.36	6.36	9.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	N_2O	29.30	29.30	8.49	8.49	12.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	CO_2	19,643.69	19,643.69	2.83	2.83	4.00	0.13	-	0.03	-	0.13	0.13	2

	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	1990 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	CH_4	9.00	9.00	6.36	6.36	9.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	N_2O	74.21	74.21	8.49	8.49	12.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	CO_2	18,285.08	18,285.08	2.83	2.83	4.00	0.12	-	0.03	-	0.12	0.12	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	CH_4	43.07	43.07	6.36	6.36	9.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	N_2O	178.50	178.50	8.49	8.49	12.00	0.00	-	0.00	-	0.00	0.00	2
1.A.3 Transport fossil fuels	CO_2	59,821.60	59,821.60	2.83	2.83	4.00	0.40	-	0.10	-	0.40	0.40	3
1.A.3 Transport fossil fuels	CH_4	658.63	658.63	16.97	16.97	24.00	0.03	-	0.00	-	0.03	0.03	3
1.A.3 Transport fossil fuels	N_2O	914.33	914.33	29.70	29.70	42.00	0.06	-	0.00	-	0.06	0.06	3
1.A. Biomass fuels	CH_4	2,427.13	2,427.13	-	20.00	20.00	0.08	-	0.00	-	-	-	2
1.A. Biomass fuels	N_2O	240.60	240.60	-	50.00	50.00	0.02	-	0.00	-	-	-	2
1.B.1.a.i Solid Fuels - Underground Mines	CO_2	1,121.82	1,121.82	12.26	12.26	17.34	0.03	-	0.00	-	0.03	0.03	1
1.B.1.a.i Solid Fuels - Underground Mines	CH_4	17,640.76	17,640.76	12.26	50.00	51.48	1.50	-	0.03	-	0.51	0.51	1
1.B.1.a.i Solid Fuels - Underground Mines	N_2O	-	-	-	-	-	-	-	-	-	-	-	
1.B.1.a.ii Solid Fuels - Open Cut Mines	CO_2	61.78	61.78	23.45	23.45	33.16	0.00	-	0.00	-	0.00	0.00	1
1.B.1.a.ii Solid Fuels - Open Cut Mines	CH_4	3,350.71	3,350.71	23.45	50.00	55.22	0.31	-	0.01	-	0.18	0.18	1
1.B.1.a.ii Solid Fuels - Open Cut Mines	N_2O	-	-	-	-	-	-	-	-	-	-	-	
1.B.1.c Solid Fuels - Other	CO_2	0.28	0.28	5.00	20.00	20.62	0.00	-	0.00	-	0.00	0.00	3
1.B.1.c Solid Fuels - Other	CH_4	0.03	0.03	5.00	50.00	50.25	0.00	-	0.00	-	0.00	0.00	3
1.B.1.c Solid Fuels - Other	N_2O	0.00	0.00	5.00	50.00	50.25	0.00	-	0.00	-	0.00	0.00	3
1.B.2.a Oil and Natural Gas - Oil	CO_2	393.90	393.90	5.00	5.00	7.07	0.00	-	0.00	-	0.00	0.00	3
1.B.2.b Oil and Natural Gas - Natural Gas	CO_2	88.15	88.15	10.00	3.00	10.44	0.00	-	0.00	-	0.00	0.00	3
1.B.2.c Oil and Natural Gas - Venting and Flaring	CO_2	5,746.96	5,746.96	5.00	5.00	7.07	0.07	-	0.01	-	0.07	0.07	3
1.B.2.a Oil and Natural Gas - Oil	CH_4	77.04	77.04	5.00	5.00	7.07	0.00	-	0.00	-	0.00	0.00	3
1.B.2.b Oil and Natural Gas - Natural Gas	CH_4	6,122.27	6,122.27	5.00	50.00	50.25	0.51	-	0.01	-	0.07	0.07	3
1.B.2.c Oil and Natural Gas - Venting and Flaring	CH_4	2,588.52	2,588.52	5.00	5.00	7.07	0.03	-	0.00	-	0.03	0.03	3
1.B.2.a Oil and Natural Gas - Oil	N_2O	3.55	3.55	2.00	50.00	50.04	0.00	-	0.00	-	0.00	0.00	3
1.B.2.b Oil and Natural Gas - Natural Gas	N_2O	0.65	0.65	2.00	50.00	50.04	0.00	-	0.00	-	0.00	0.00	3

	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	1990 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.B.2 Oil and Natural Gas - Venting and Flaring	N_2O	36.04	36.04	2.00	50.00	50.04	0.00	-	0.00	-	0.00	0.00	3
2.A.1 Cement Production	CO_2	3,462.87	3,462.87	2.48	2.48	3.51	0.02	-	0.01	-	0.02	0.02	1
2.A.2 Lime Production	CO_2	775.37	775.37	2.48	2.48	3.51	0.00	-	0.00	-	0.00	0.00	1
2.A.4 Other Process Uses of Carbonates	CO_2	1,251.34	1,251.34	4.00	2.50	4.72	0.01	-	0.00	-	0.01	0.01	4
2.B Chemicals	CO_2	1,054.69	1,054.69	2.76	2.76	3.90	0.01	-	0.00	-	0.01	0.01	1
2.B Chemicals	CH_4	10.94	10.94	5.00	50.00	50.25	0.00	-	0.00	-	0.00	0.00	4
2.B Chemicals	N_2O	995.04	995.04	4.47	4.47	6.33	0.01	-	0.00	-	0.01	0.01	1
2.B Chemicals	HFCs	1,424.68	1,424.68	-	27.00	27.00	0.06	-	0.00	-	-	-	4
2.C.1 Iron and Steel Production	CO_2	9,203.23	9,203.23	1.63	1.63	2.30	0.03	-	0.02	-	0.03	0.03	1
2.C.1 Iron and Steel Production	CH_4	70.55	70.55	2.00	50.00	50.04	0.01	-	0.00	-	0.00	0.00	4
2.C.1 Iron and Steel Production	N_2O	21.48	21.48	2.00	50.00	50.04	0.00	-	0.00	-	0.00	0.00	4
2.C.3 Aluminium Production	CO_2	2,058.10	2,058.10	4.85	4.85	6.86	0.02	-	0.00	-	0.02	0.02	1
2.C.3 Aluminium Production	PFCs	4,607.01	4,607.01	-	27.00	27.00	0.21	-	0.01	-	-	-	4
2.C.2 Ferroalloys Production	CO_2	322.61	322.61	7.07	7.07	10.00	0.01	-	0.00	-	0.01	0.01	1
2.C.2 Ferroalloys Production	CH_4	0.07	0.07	7.07	50.00	50.50	0.00	-	0.00	-	0.00	0.00	1
2.C.2 Ferroalloys Production	N_2O	0.66	0.66	7.07	50.00	50.50	0.00	-	0.00	-	0.00	0.00	1
2.C.7 Other	CO_2	189.21	189.21	7.07	7.07	10.00	0.00	-	0.00	-	0.00	0.00	1
2.C.7 Other	CH_4	0.08	0.08	7.07	50.00	50.50	0.00	-	0.00	-	0.00	0.00	1
2.C.7 Other	N_2O	0.41	0.41	7.07	50.00	50.50	0.00	-	0.00	-	0.00	0.00	1
2.D Non-energy Products from Fuels and Solvent Use	CO_2	279.93	279.93	2.00	3.00	3.61	0.00	-	0.00	-	0.00	0.00	1
2.H.2 Food and Beverages Industry	CO_2	82.57	82.57	2.76	2.76	3.90	0.00	-	0.00	-	0.00	0.00	1
2.F Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	-	-	27.00	27.00	-	-	-	-	-	-	5
2.G Other Product Manufacture and Use	SF_6	220.56	220.56	-	27.00	27.00	0.01	-	0.00	-	-	-	5
3.A Enteric Fermentation	CH_4	64,625.62	64,625.62	10.00	50.00	50.99	5.45	-	0.11	-	1.51	1.51	6
3.B Manure Management	CH_4	2,084.72	2,084.72	22.36	50.00	54.77	0.19	-	0.00	-	0.11	0.11	6
3.B Manure Management	N_2O	405.19	405.19	22.36	50.00	54.77	0.04	-	0.00	-	0.02	0.02	7

	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	1990 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
3.C Rice Cultivation	CH_4	396.90	396.90	5.00	50.00	50.25	0.03	-	0.00	-	0.00	0.00	7
3.D Agricultural Soils	N_2O	11,722.41	11,722.41	25.00	50.00	55.90	1.08	-	0.02	-	0.69	0.69	7
3.F Agricultural Residue Burning	CH_4	291.96	291.96	32.40	50.00	59.58	0.03	-	0.00	-	0.02	0.02	7
3.F Agricultural Residue Burning	N_2O	138.90	138.90	32.40	50.00	59.58	0.01	-	0.00	-	0.01	0.01	7
3.G Liming	CO_2	215.35	215.35	20.00	50.00	53.85	0.02	-	0.00	-	0.01	0.01	7
3.H Urea application	CO_2	366.67	366.67	10.00	50.00	50.99	0.03	-	0.00	-	0.01	0.01	7
4.A.1 Forest Land remaining Forest Land	CO_2	-15,470.57	-15,470.57	15.00	30.00	33.54	-0.86	-	-0.03	-	-0.54	0.54	3
4.A.1 Forest Land remaining Forest Land	CH_4	4,523.58	4,523.58	15.00	50.00	52.20	0.39	-	0.01	-	0.16	0.16	3
4.A.1 Forest Land remaining Forest Land	N_2O	955.98	955.98	15.00	50.00	52.20	0.08	-	0.00	-	0.03	0.03	3
4.A.2 Land converted to Forest Land	CO_2	-6,528.10	-6,528.10	12.23	11.50	16.79	-0.18	-	-0.01	-	-0.19	0.19	3
4.A.2 Land converted to Forest Land	CH_4	14.02	14.02	11.00	50.00	51.20	0.00	-	0.00	-	0.00	0.00	3
4.A.2 Land converted to Forest Land	N_2O	92.91	92.91	11.00	50.00	51.20	0.01	-	0.00	-	0.00	0.00	3
4.B.1 Cropland remaining Cropland	CO_2	17,893.85	17,893.85	25.00	20.00	32.02	0.95	-	0.03	-	1.05	1.05	3
4.B.2 Land converted to Cropland	CO_2	18,505.99	18,505.99	11.20	25.50	27.85	0.85	-	0.03	-	0.48	0.48	3
4.B.2 Land converted to Cropland	CH_4	607.47	607.47	11.00	50.00	51.20	0.05	-	0.00	-	0.02	0.02	3
4.B.2 Land converted to Cropland	N_2O	170.76	170.76	11.00	50.00	51.20	0.01	-	0.00	-	0.00	0.00	3
4.C.1 Grassland remaining Grassland	CO_2	5,086.68	5,086.68	25.00	20.00	32.02	0.27	-	0.01	-	0.30	0.30	3
4.C.1 Grassland remaining Grassland	CH_4	3,912.64	3,912.64	25.00	50.00	55.90	0.36	-	0.01	-	0.23	0.23	3
4.C.1 Grassland remaining Grassland	N_2O	1,640.46	1,640.46	25.00	50.00	55.90	0.15	-	0.00	-	0.10	0.10	3
4.C.2 Land converted to Grassland	CO_2	149,593.37	149,593.37	11.00	25.00	27.31	6.75	-	0.25	-	3.85	3.85	3
4.C.2 Land converted to Grassland	CH_4	5,400.28	5,400.28	11.00	50.00	51.20	0.46	-	0.01	-	0.14	0.14	3
4.C.2 Land converted to Grassland	N_2O	1,373.24	1,373.24	11.00	50.00	51.20	0.12	-	0.00	-	0.04	0.04	3
4.D.1 Wetlands remaining Wetlands	CO_2	156.11	156.11	11.00	20.00	22.83	0.01	-	0.00	-	0.00	0.00	3
4.D.1 Wetlands remaining Wetlands	CH_4	195.11	195.11	10.00	100.00	100.50	0.03	-	0.00	-	0.00	0.00	3
4.D.1 Wetlands remaining Wetlands	N_2O	47.90	47.90	10.00	100.00	100.50	0.01	-	0.00	-	0.00	0.00	3
4.D.2 Land converted to Wetland	CO_2	711.35	711.35	11.00	25.00	27.31	0.03	-	0.00	-	0.02	0.02	3
4.E.1 Settlements remaining Settlements	CO_2	-19.84	-19.84	11.00	20.00	22.83	-0.00	-	-0.00	-	-0.00	0.00	3
4.E.2 Land converted to Settlements	CO_2	3,010.96	3,010.96	11.50	26.00	28.43	0.14	-	0.00	-	0.08	0.08	3

	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	1990 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
4.E.2 Land converted to Settlements	CH_4	104.07	104.07	11.50	50.00	51.31	0.01	-	0.00	-	0.00	0.00	3
4.E.2 Land converted to Settlements	N_2O	27.16	27.16	11.50	50.00	51.31	0.00	-	0.00	-	0.00	0.00	3
4.G Harvested Wood Products	CO_2	-7,416.93	-7,416.93	10.00	20.00	22.36	-0.27	-	-0.01	-	-0.17	0.17	8
5.A Solid Waste Disposal	CH_4	15,239.94	15,239.94	-	54.00	54.00	1.36	-	0.03	-	-	-	9
5.D Wastewater Treatment and Discharge	CH_4	4,389.40	4,389.40	-	50.00	50.00	0.36	-	0.01	-	-	-	9
5.D Wastewater Treatment and Discharge	N_2O	287.56	287.56	-	50.00	50.00	0.02	-	0.00	-	-	-	9
5.C Incineration and Open Burning of Waste	CO_2	73.36	73.36	-	40.00	40.00	0.00	-	0.00	-	-	-	9
5.C Incineration and Open Burning of Waste	CH_4	2.32	2.32	-	50.00	50.00	0.00	-	0.00	-	-	-	9
5.C Incineration and Open Burning of Waste	N_2O	11.32	11.32	-	50.00	50.00	0.00	-	0.00	-	-	-	9
5.B Biological treatment of solid waste	CH_4	8.76	8.76	-	100.00	100.00	0.00	-	0.00	-	-	-	9
5.B Biological treatment of solid waste	N_2O	13.36	13.36	-	100.00	100.00	0.00	-	0.00	-	-	-	9
Total Emissions		604,903.78	604,903.78										
Total Uncertainties							9.2					4.5	

Table A2.2 General reporting table for uncertainty excluding LULUCF for base year 1990

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	1990 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.A.1.a Electricity generation - black coal	CO_2	72,725.26	72,725.26	1.57	1.57	2.22	0.38	-	0.17	-	0.38	0.38	1
1.A.1.a Electricity generation - black coal	CH_4	13.54	13.54	1.57	50.00	50.02	0.00	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - black coal	N_2O	189.54	189.54	1.57	50.00	50.02	0.02	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - brown coal	CO_2	45,183.47	45,183.47	0.50	0.50	0.71	0.08	-	0.11	-	0.08	0.08	1
1.A.1.a Electricity generation - brown coal	CH_4	7.50	7.50	0.50	50.00	50.00	0.00	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - brown coal	N_2O	189.77	189.77	0.50	50.00	50.00	0.02	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - natural gas	CO_2	8,280.60	8,280.60	1.70	1.70	2.41	0.05	-	0.02	-	0.05	0.05	1
1.A.1.a Electricity generation - natural gas	CH_4	7.20	7.20	1.70	50.00	50.03	0.00	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - natural gas	N_2O	43.68	43.68	1.70	50.00	50.03	0.01	-	0.00	-	0.00	0.00	1
1.A.1.a Electricity generation - liquid fuels	CO_2	2,907.27	2,907.27	2.83	2.83	4.00	0.03	-	0.01	-	0.03	0.03	2
1.A.1.a Electricity generation - liquid fuels	CH_4	2.71	2.71	35.36	35.36	50.00	0.00	-	0.00	-	0.00	0.00	2
1.A.1.a Electricity generation - liquid fuels	N_2O	4.13	4.13	35.36	35.36	50.00	0.00	-	0.00	-	0.00	0.00	2
1.A.1.b Petroleum refining - liquid fuels	CO_2	4,931.12	4,931.12	16.53	16.53	23.37	0.27	-	0.01	-	0.27	0.27	1
1.A.1.b Petroleum refining - liquid fuels	CH_4	1.26	1.26	16.53	50.00	52.66	0.00	-	0.00	-	0.00	0.00	1
1.A.1.b Petroleum refining - liquid fuels	N_2O	12.10	12.10	16.53	50.00	52.66	0.00	-	0.00	-	0.00	0.00	1
1.A.1.b Petroleum refining - gaseous fuels	CO_2	580.95	580.95	5.19	5.19	7.34	0.01	-	0.00	-	0.01	0.01	1
1.A.1.b Petroleum refining - gaseous fuels	CH_4	0.29	0.29	5.19	50.00	50.27	0.00	-	0.00	-	0.00	0.00	1
1.A.1.b Petroleum refining - gaseous fuels	N_2O	1.43	1.43	5.19	50.00	50.27	0.00	-	0.00	-	0.00	0.00	1
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	CO_2	7,942.01	7,942.01	3.97	3.97	5.62	0.11	-	0.02	-	0.11	0.11	1
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	CH_4	6.55	6.55	6.36	6.36	9.00	0.00	-	0.00	-	0.00	0.00	2
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	N_2O	43.68	43.68	8.49	8.49	12.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	CO_2	11,375.13	11,375.13	2.83	2.83	4.00	0.11	-	0.03	-	0.11	0.11	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	CH_4	3.40	3.40	6.36	6.36	9.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	N_2O	29.30	29.30	8.49	8.49	12.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	CO_2	19,643.69	19,643.69	2.83	2.83	4.00	0.19	-	0.05	-	0.19	0.19	2

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	1990 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	CH_4	9.00	9.00	6.36	6.36	9.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	N_2O	74.21	74.21	8.49	8.49	12.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	CO_2	18,285.08	18,285.08	2.83	2.83	4.00	0.17	-	0.04	-	0.17	0.17	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	CH_4	43.07	43.07	6.36	6.36	9.00	0.00	-	0.00	-	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	N_2O	178.50	178.50	8.49	8.49	12.00	0.01	-	0.00	-	0.01	0.01	2
1.A.3 Transport fossil fuels	CO_2	59,821.60	59,821.60	2.83	2.83	4.00	0.57	-	0.14	-	0.57	0.57	3
1.A.3 Transport fossil fuels	CH_4	658.63	658.63	16.97	16.97	24.00	0.04	-	0.00	-	0.04	0.04	3
1.A.3 Transport fossil fuels	N_2O	914.33	914.33	29.70	29.70	42.00	0.09	-	0.00	-	0.09	0.09	3
1.A. Biomass fuels	CH_4	2,427.13	2,427.13	-	20.00	20.00	0.12	-	0.01	-	-	-	2
1.A. Biomass fuels	N_2O	240.60	240.60	-	50.00	50.00	0.03	-	0.00	-	-	-	2
1.B.1.a.i Solid Fuels - Underground Mines	CO_2	1,121.82	1,121.82	12.26	12.26	17.34	0.05	-	0.00	-	0.05	0.05	1
1.B.1.a.i Solid Fuels - Underground Mines	CH_4	17,640.76	17,640.76	12.26	50.00	51.48	2.16	-	0.04	-	0.73	0.73	1
1.B.1.a.i Solid Fuels - Underground Mines	N_2O	-	-	-	-	-	-	-	-	-	-	-	
1.B.1.a.ii Solid Fuels - Open Cut Mines	CO_2	61.78	61.78	23.45	23.45	33.16	0.00	-	0.00	-	0.00	0.00	1
1.B.1.a.ii Solid Fuels - Open Cut Mines	CH_4	3,350.71	3,350.71	23.45	50.00	55.22	0.44	-	0.01	-	0.26	0.26	1
1.B.1.a.ii Solid Fuels - Open Cut Mines	N_2O	-	-	-	-	-	-	-	-	-	-	-	
1.B.1.c Solid Fuels - Other	CO_2	0.28	0.28	5.00	20.00	20.62	0.00	-	0.00	-	0.00	0.00	3
1.B.1.c Solid Fuels - Other	CH_4	0.03	0.03	5.00	50.00	50.25	0.00	-	0.00	-	0.00	0.00	3
1.B.1.c Solid Fuels - Other	N_2O	0.00	0.00	5.00	50.00	50.25	0.00	-	0.00	-	0.00	0.00	3
1.B.2.a Oil and Natural Gas - Oil	CO_2	393.90	393.90	5.00	5.00	7.07	0.01	-	0.00	-	0.01	0.01	3
1.B.2.b Oil and Natural Gas - Natural Gas	CO_2	88.15	88.15	10.00	3.00	10.44	0.00	-	0.00	-	0.00	0.00	3
1.B.2.c Oil and Natural Gas - Venting and Flaring	CO_2	5,746.96	5,746.96	5.00	5.00	7.07	0.10	-	0.01	-	0.10	0.10	3
1.B.2.a Oil and Natural Gas - Oil	CH_4	77.04	77.04	5.00	5.00	7.07	0.00	-	0.00	-	0.00	0.00	3
1.B.2.b Oil and Natural Gas - Natural Gas	CH_4	6,122.27	6,122.27	5.00	50.00	50.25	0.73	-	0.01	-	0.10	0.10	3
1.B.2.c Oil and Natural Gas - Venting and Flaring	CH_4	2,588.52	2,588.52	5.00	5.00	7.07	0.04	-	0.01	-	0.04	0.04	3
1.B.2.a Oil and Natural Gas - Oil	N_2O	3.55	3.55	2.00	50.00	50.04	0.00	-	0.00	-	0.00	0.00	3
1.B.2.b Oil and Natural Gas - Natural Gas	N_2O	0.65	0.65	2.00	50.00	50.04	0.00	-	0.00	-	0.00	0.00	3

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	1990 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.B.2 Oil and Natural Gas - Venting and Flaring	N_2O	36.04	36.04	2.00	50.00	50.04	0.00	-	0.00	-	0.00	0.00	3
2.A.1 Cement Production	CO_2	3,462.87	3,462.87	2.48	2.48	3.51	0.03	-	0.01	-	0.03	0.03	1
2.A.2 Lime Production	CO_2	775.37	775.37	2.48	2.48	3.51	0.01	-	0.00	-	0.01	0.01	1
2.A.4 Other Process Uses of Carbonates	CO_2	1,251.34	1,251.34	4.00	2.50	4.72	0.01	-	0.00	-	0.02	0.02	4
2.B Chemicals	CO_2	1,054.69	1,054.69	2.76	2.76	3.90	0.01	-	0.00	-	0.01	0.01	1
2.B Chemicals	CH_4	10.94	10.94	5.00	50.00	50.25	0.00	-	0.00	-	0.00	0.00	4
2.B Chemicals	N_2O	995.04	995.04	4.47	4.47	6.33	0.01	-	0.00	-	0.01	0.01	1
2.B Chemicals	HFCs	1,424.68	1,424.68	-	27.00	27.00	0.09	-	0.00	-	-	-	4
2.C.1 Iron and Steel Production	CO_2	9,203.23	9,203.23	1.63	1.63	2.30	0.05	-	0.02	-	0.05	0.05	1
2.C.1 Iron and Steel Production	CH_4	70.55	70.55	2.00	50.00	50.04	0.01	-	0.00	-	0.00	0.00	4
2.C.1 Iron and Steel Production	N_2O	21.48	21.48	2.00	50.00	50.04	0.00	-	0.00	-	0.00	0.00	4
2.C.3 Aluminium Production	CO_2	2,058.10	2,058.10	4.85	4.85	6.86	0.03	-	0.00	-	0.03	0.03	1
2.C.3 Aluminium Production	PFCs	4,607.01	4,607.01	-	27.00	27.00	0.30	-	0.01	-	-	-	4
2.C.2 Ferroalloys Production	CO_2	322.61	322.61	7.07	7.07	10.00	0.01	-	0.00	-	0.01	0.01	1
2.C.2 Ferroalloys Production	CH_4	0.07	0.07	7.07	50.00	50.50	0.00	-	0.00	-	0.00	0.00	1
2.C.2 Ferroalloys Production	N_2O	0.66	0.66	7.07	50.00	50.50	0.00	-	0.00	-	0.00	0.00	1
2.C.7 Other	CO_2	189.21	189.21	7.07	7.07	10.00	0.00	-	0.00	-	0.00	0.00	1
2.C.7 Other	CH_4	0.08	0.08	7.07	50.00	50.50	0.00	-	0.00	-	0.00	0.00	1
2.C.7 Other	N_2O	0.41	0.41	7.07	50.00	50.50	0.00	-	0.00	-	0.00	0.00	1
2.D Non-energy Products from Fuels and Solvent Use	CO_2	279.93	279.93	2.00	3.00	3.61	0.00	-	0.00	-	0.00	0.00	1
2.H.2 Food and Beverages Industry	CO_2	82.57	82.57	2.76	2.76	3.90	0.00	-	0.00	-	0.00	0.00	1
2.F Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	-	-	27.00	27.00	-	-	-	-	-	-	5
2.G Other Product Manufacture and Use	SF_6	220.56	220.56	-	27.00	27.00	0.01	-	0.00	-	-	-	5
3.A Enteric Fermentation	CH_4	64,625.62	64,625.62	10.00	50.00	50.99	7.84	-	0.15	-	2.17	2.17	6
3.B Manure Management	CH_4	2,084.72	2,084.72	22.36	50.00	54.77	0.27	-	0.00	-	0.16	0.16	6
3.B Manure Management	N_2O	405.19	405.19	22.36	50.00	54.77	0.05	-	0.00	-	0.03	0.03	7

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	1990 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
3.C Rice Cultivation	CH_4	396.90	396.90	5.00	50.00	50.25	0.05	-	0.00	-	0.01	0.01	7
3.D Agricultural Soils	N_2O	11,722.41	11,722.41	25.00	50.00	55.90	1.56	-	0.03	-	0.99	0.99	7
3.F Agricultural Residue Burning	CH_4	291.96	291.96	32.40	50.00	59.58	0.04	-	0.00	-	0.03	0.03	7
3.F Agricultural Residue Burning	N_2O	138.90	138.90	32.40	50.00	59.58	0.02	-	0.00	-	0.02	0.02	7
3.G Liming	CO_2	215.35	215.35	20.00	50.00	53.85	0.03	-	0.00	-	0.01	0.01	7
3.H Urea application	CO_2	366.67	366.67	10.00	50.00	50.99	0.04	-	0.00	-	0.01	0.01	7
5.A Solid Waste Disposal	CH_4	15,239.94	15,239.94	-	54.00	54.00	1.96	-	0.04	-	-	-	9
5.D Wastewater Treatment and Discharge	CH_4	4,389.40	4,389.40	-	50.00	50.00	0.52	-	0.01	-	-	-	9
5.D Wastewater Treatment and Discharge	N_2O	287.56	287.56	-	50.00	50.00	0.03	-	0.00	-	-	-	9
5.C Incineration and Open Burning of Waste	CO_2	73.36	73.36	-	40.00	40.00	0.01	-	0.00	-	-	-	9
5.C Incineration and Open Burning of Waste	CH_4	2.32	2.32	-	50.00	50.00	0.00	-	0.00	-	-	-	9
5.C Incineration and Open Burning of Waste	N_2O	11.32	11.32	-	50.00	50.00	0.00	-	0.00	-	-	-	9
5.B Biological treatment of solid waste	CH_4	8.76	8.76	-	100.00	100.00	0.00	-	0.00	-	-	-	9
5.B Biological treatment of solid waste	N_2O	13.36	13.36	-	100.00	100.00	0.00	-	0.00	-	-	-	9
Total Emissions		420,315.32	420,315.32										
Total Uncertainties							8.6					2.6	

Table A2.3 General reporting table for uncertainty including LULUCF for latest inventory year 2017

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	2017 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.A.1.a Electricity generation - black coal	CO_2	72,725.26	103,085.98	1.57	1.57	2.22	0.43	0.06	0.17	0.10	0.38	0.39	1
1.A.1.a Electricity generation - black coal	CH_4	13.54	19.51	1.57	50.00	50.02	0.00	0.00	0.00	0.00	0.00	0.00	1
1.A.1.a Electricity generation - black coal	N_2O	189.54	225.29	1.57	50.00	50.02	0.02	0.00	0.00	0.00	0.00	0.00	1
1.A.1.a Electricity generation - brown coal	CO_2	45,183.47	53,612.01	0.50	0.50	0.71	0.07	0.02	0.09	0.01	0.06	0.06	1
1.A.1.a Electricity generation - brown coal	CH_4	7.50	9.11	0.50	50.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	1
1.A.1.a Electricity generation - brown coal	N_2O	189.77	254.53	0.50	50.00	50.00	0.02	0.00	0.00	0.01	0.00	0.01	1
1.A.1.a Electricity generation - natural gas	CO_2	8,280.60	27,849.46	1.70	1.70	2.41	0.13	0.03	0.05	0.06	0.11	0.12	1
1.A.1.a Electricity generation - natural gas	CH_4	7.20	481.64	1.70	50.00	50.03	0.05	0.00	0.00	0.04	0.00	0.04	1
1.A.1.a Electricity generation - natural gas	N_2O	43.68	192.69	1.70	50.00	50.03	0.02	0.00	0.00	0.01	0.00	0.01	1
1.A.1.a Electricity generation - liquid fuels	CO_2	2,907.27	3,863.71	2.83	2.83	4.00	0.03	0.00	0.01	0.01	0.03	0.03	2
1.A.1.a Electricity generation - liquid fuels	CH_4	2.71	4.79	35.36	35.36	50.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.1.a Electricity generation - liquid fuels	N_2O	4.13	6.07	35.36	35.36	50.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.1.b Petroleum refining - liquid fuels	CO_2	4,931.12	2,596.93	16.53	16.53	23.37	0.11	-0.00	0.00	-0.05	0.10	0.11	1
1.A.1.b Petroleum refining - liquid fuels	CH_4	1.26	1.08	16.53	50.00	52.66	0.00	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.b Petroleum refining - liquid fuels	N_2O	12.10	1.34	16.53	50.00	52.66	0.00	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.b Petroleum refining - gaseous fuels	CO_2	580.95	385.39	5.19	5.19	7.34	0.01	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.b Petroleum refining - gaseous fuels	CH_4	0.29	0.20	5.19	50.00	50.27	0.00	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.b Petroleum refining - gaseous fuels	N_2O	1.43	0.98	5.19	50.00	50.27	0.00	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	CO_2	7,942.01	25,074.76	3.97	3.97	5.62	0.26	0.03	0.04	0.12	0.23	0.26	1
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	CH_4	6.55	26.18	6.36	6.36	9.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	N_2O	43.68	206.66	8.49	8.49	12.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	CO_2	11,375.13	10,823.56	2.83	2.83	4.00	0.08	0.00	0.02	0.00	0.07	0.07	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	CH_4	3.40	3.09	6.36	6.36	9.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	N_2O	29.30	27.26	8.49	8.49	12.00	0.00	0.00	0.00	0.00	0.00	0.00	2

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	2017 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	CO_2	19,643.69	27,595.26	2.83	2.83	4.00	0.21	0.02	0.05	0.05	0.18	0.19	2
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	CH_4	9.00	12.70	6.36	6.36	9.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	N_2O	74.21	112.28	8.49	8.49	12.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	CO_2	18,285.08	26,930.55	2.83	2.83	4.00	0.20	0.02	0.04	0.05	0.18	0.19	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	CH_4	43.07	61.76	6.36	6.36	9.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	N_2O	178.50	304.39	8.49	8.49	12.00	0.01	0.00	0.00	0.00	0.01	0.01	2
1.A.3 Transport fossil fuels	CO_2	59,821.60	96,840.98	2.83	2.83	4.00	0.72	0.07	0.16	0.21	0.64	0.67	3
1.A.3 Transport fossil fuels	CH_4	658.63	360.20	16.97	16.97	24.00	0.02	-0.00	0.00	-0.01	0.01	0.02	3
1.A.3 Transport fossil fuels	N_2O	914.33	1,517.03	29.70	29.70	42.00	0.12	0.00	0.00	0.03	0.11	0.11	3
1.A. Biomass fuels	CH_4	2,427.13	991.41	-	20.00	20.00	0.04	-0.00	0.00	-0.04	-	0.04	2
1.A. Biomass fuels	N_2O	240.60	329.02	-	50.00	50.00	0.03	0.00	0.00	0.01	-	0.01	2
1.B.1.a.i Solid Fuels - Underground Mines	CO_2	1,121.82	1,173.80	12.26	12.26	17.34	0.04	0.00	0.00	0.00	0.03	0.03	1
1.B.1.a.i Solid Fuels - Underground Mines	CH_4	17,640.76	17,551.31	12.26	50.00	51.48	1.69	0.00	0.03	0.16	0.50	0.53	1
1.B.1.a.i Solid Fuels - Underground Mines	N_2O	-	-	-	-	-	-	-	-	-	-	-	
1.B.1.a.ii Solid Fuels - Open Cut Mines	CO_2	61.78	161.49	23.45	23.45	33.16	0.01	0.00	0.00	0.00	0.01	0.01	1
1.B.1.a.ii Solid Fuels - Open Cut Mines	CH_4	3,350.71	6,008.78	23.45	50.00	55.22	0.62	0.01	0.01	0.25	0.33	0.41	1
1.B.1.a.ii Solid Fuels - Open Cut Mines	N_2O	-	-	-	-	-	-	-	-	-	-	-	
1.B.1.c Solid Fuels - Other	CO_2	0.28	808.32	5.00	20.00	20.62	0.03	0.00	0.00	0.03	0.01	0.03	3
1.B.1.c Solid Fuels - Other	CH_4	0.03	97.21	5.00	50.00	50.25	0.01	0.00	0.00	0.01	0.00	0.01	3
1.B.1.c Solid Fuels - Other	N_2O	0.00	0.47	5.00	50.00	50.25	0.00	0.00	0.00	0.00	0.00	0.00	3
1.B.2.a Oil and Natural Gas - Oil	CO_2	393.90	199.14	5.00	5.00	7.07	0.00	-0.00	0.00	-0.00	0.00	0.00	3
1.B.2.b Oil and Natural Gas - Natural Gas	CO_2	88.15	70.43	10.00	3.00	10.44	0.00	-0.00	0.00	-0.00	0.00	0.00	3
1.B.2.c Oil and Natural Gas - Venting and Flaring	CO_2	5,746.96	13,631.44	5.00	5.00	7.07	0.18	0.01	0.02	0.07	0.16	0.17	3
1.B.2.a Oil and Natural Gas - Oil	CH_4	77.04	57.58	5.00	5.00	7.07	0.00	-0.00	0.00	-0.00	0.00	0.00	3

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	2017 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.B.2.b Oil and Natural Gas - Natural Gas	CH_4	6,122.27	9,384.42	5.00	50.00	50.25	0.88	0.01	0.02	0.33	0.11	0.35	3
1.B.2.c Oil and Natural Gas - Venting and Flaring	CH_4	2,588.52	2,608.59	5.00	5.00	7.07	0.03	0.00	0.00	0.00	0.03	0.03	3
1.B.2.a Oil and Natural Gas - Oil	N_2O	3.55	2.44	2.00	50.00	50.04	0.00	-0.00	0.00	-0.00	0.00	0.00	3
1.B.2.b Oil and Natural Gas - Natural Gas	N_2O	0.65	0.43	2.00	50.00	50.04	0.00	-0.00	0.00	-0.00	0.00	0.00	3
1.B.2 Oil and Natural Gas - Venting and Flaring	N_2O	36.04	84.96	2.00	50.00	50.04	0.01	0.00	0.00	0.00	0.00	0.00	3
2.A.1 Cement Production	CO_2	3,462.87	3,019.06	2.48	2.48	3.51	0.02	-0.00	0.00	-0.00	0.02	0.02	1
2.A.2 Lime Production	CO_2	775.37	1,031.10	2.48	2.48	3.51	0.01	0.00	0.00	0.00	0.01	0.01	1
2.A.4 Other Process Uses of Carbonates	CO_2	1,251.34	1,550.02	4.00	2.50	4.72	0.01	0.00	0.00	0.00	0.01	0.01	4
2.B Chemicals	CO_2	1,054.69	3,073.58	2.76	2.76	3.90	0.02	0.00	0.01	0.01	0.02	0.02	1
2.B Chemicals	CH_4	10.94	14.44	5.00	50.00	50.25	0.00	0.00	0.00	0.00	0.00	0.00	4
2.B Chemicals	N_2O	995.04	1,518.93	4.47	4.47	6.33	0.02	0.00	0.00	0.00	0.02	0.02	1
2.B Chemicals	HFCs	1,424.68	-	-	27.00	27.00	-	-0.00	-	-0.06	-	0.06	4
2.C.1 Iron and Steel Production	CO_2	9,203.23	7,439.73	1.63	1.63	2.30	0.03	-0.00	0.01	-0.00	0.03	0.03	1
2.C.1 Iron and Steel Production	CH_4	70.55	58.85	2.00	50.00	50.04	0.01	-0.00	0.00	-0.00	0.00	0.00	4
2.C.1 Iron and Steel Production	N_2O	21.48	15.16	2.00	50.00	50.04	0.00	-0.00	0.00	-0.00	0.00	0.00	4
2.C.3 Aluminium Production	CO_2	2,058.10	2,197.08	4.85	4.85	6.86	0.03	0.00	0.00	0.00	0.02	0.03	1
2.C.3 Aluminium Production	PFCs	4,607.01	202.63	-	27.00	27.00	0.01	-0.01	0.00	-0.17	-	0.17	4
2.C.2 Ferroalloys Production	CO_2	322.61	451.59	7.07	7.07	10.00	0.01	0.00	0.00	0.00	0.01	0.01	1
2.C.2 Ferroalloys Production	CH_4	0.07	0.10	7.07	50.00	50.50	0.00	0.00	0.00	0.00	0.00	0.00	1
2.C.2 Ferroalloys Production	N_2O	0.66	0.90	7.07	50.00	50.50	0.00	0.00	0.00	0.00	0.00	0.00	1
2.C.7 Other	CO_2	189.21	286.07	7.07	7.07	10.00	0.01	0.00	0.00	0.00	0.00	0.00	1
2.C.7 Other	CH_4	0.08	0.09	7.07	50.00	50.50	0.00	0.00	0.00	0.00	0.00	0.00	1
2.C.7 Other	N_2O	0.41	0.63	7.07	50.00	50.50	0.00	0.00	0.00	0.00	0.00	0.00	1
2.D Non-energy Products from Fuels and Solvent Use	CO_2	279.93	184.05	2.00	3.00	3.61	0.00	-0.00	0.00	-0.00	0.00	0.00	1
2.H.2 Food and Beverages Industry	CO_2	82.57	213.30	2.76	2.76	3.90	0.00	0.00	0.00	0.00	0.00	0.00	1

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	2017 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
2.F Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	12,252.94	-	27.00	27.00	0.62	0.02	0.02	0.55	-	0.55	5
2.G Other Product Manufacture and Use	SF_6	220.56	176.22	-	27.00	27.00	0.01	-0.00	0.00	-0.00	-	0.00	5
3.A Enteric Fermentation	CH_4	64,625.62	51,543.56	10.00	50.00	50.99	4.92	-0.01	0.09	-0.46	1.21	1.29	6
3.B Manure Management	CH_4	2,084.72	2,626.43	22.36	50.00	54.77	0.27	0.00	0.00	0.06	0.14	0.15	6
3.B Manure Management	N_2O	405.19	1,048.76	22.36	50.00	54.77	0.11	0.00	0.00	0.06	0.05	0.08	7
3.C Rice Cultivation	CH_4	396.90	285.17	5.00	50.00	50.25	0.03	-0.00	0.00	-0.01	0.00	0.01	7
3.D Agricultural Soils	N_2O	11,722.41	14,170.43	25.00	50.00	55.90	1.48	0.01	0.02	0.31	0.83	0.89	7
3.F Agricultural Residue Burning	CH_4	291.96	310.02	32.40	50.00	59.58	0.03	0.00	0.00	0.00	0.02	0.02	7
3.F Agricultural Residue Burning	N_2O	138.90	157.85	32.40	50.00	59.58	0.02	0.00	0.00	0.00	0.01	0.01	7
3.G Liming	CO_2	215.35	1,318.39	20.00	50.00	53.85	0.13	0.00	0.00	0.09	0.06	0.11	7
3.H Urea application	CO_2	366.67	1,543.35	10.00	50.00	50.99	0.15	0.00	0.00	0.10	0.04	0.11	7
4.A.1 Forest Land remaining Forest Land	CO_2	-15,470.57	-19,768.34	15.00	30.00	33.54	-1.24	-0.01	-0.03	-0.30	-0.69	0.76	3
4.A.1 Forest Land remaining Forest Land	CH_4	4,523.58	5,781.56	15.00	50.00	52.20	0.56	0.00	0.01	0.15	0.20	0.25	3
4.A.1 Forest Land remaining Forest Land	N_2O	955.98	1,135.14	15.00	50.00	52.20	0.11	0.00	0.00	0.02	0.04	0.05	3
4.A.2 Land converted to Forest Land	CO_2	-6,528.10	-48,562.43	12.23	11.50	16.79	-1.52	-0.07	-0.08	-0.81	-1.39	1.61	3
4.A.2 Land converted to Forest Land	CH_4	14.02	72.82	11.00	50.00	51.20	0.01	0.00	0.00	0.00	0.00	0.01	3
4.A.2 Land converted to Forest Land	N_2O	92.91	324.67	11.00	50.00	51.20	0.03	0.00	0.00	0.02	0.01	0.02	3
4.B.1 Cropland remaining Cropland	CO_2	17,893.85	-3,080.44	25.00	20.00	32.02	-0.18	-0.03	-0.01	-0.62	-0.18	0.65	3
4.B.2 Land converted to Cropland	CO_2	18,505.99	1,574.26	11.20	25.50	27.85	0.08	-0.02	0.00	-0.62	0.04	0.62	3
4.B.2 Land converted to Cropland	CH_4	607.47	42.39	11.00	50.00	51.20	0.00	-0.00	0.00	-0.04	0.00	0.04	3
4.B.2 Land converted to Cropland	N_2O	170.76	22.34	11.00	50.00	51.20	0.00	-0.00	0.00	-0.01	0.00	0.01	3
4.C.1 Grassland remaining Grassland	CO_2	5,086.68	-5,062.20	25.00	20.00	32.02	-0.30	-0.02	-0.01	-0.32	-0.30	0.43	3
4.C.1 Grassland remaining Grassland	CH_4	3,912.64	4,539.13	25.00	50.00	55.90	0.47	0.00	0.01	0.09	0.27	0.28	3
4.C.1 Grassland remaining Grassland	N_2O	1,640.46	1,874.66	25.00	50.00	55.90	0.20	0.00	0.00	0.04	0.11	0.12	3
4.C.2 Land converted to Grassland	CO_2	149,593.37	43,641.89	11.00	25.00	27.31	2.23	-0.15	0.07	-3.65	1.12	3.82	3
4.C.2 Land converted to Grassland	CH_4	5,400.28	1,241.14	11.00	50.00	51.20	0.12	-0.01	0.00	-0.29	0.03	0.29	3
4.C.2 Land converted to Grassland	N_2O	1,373.24	468.88	11.00	50.00	51.20	0.04	-0.00	0.00	-0.06	0.01	0.06	3

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	2017 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
4.D.1 Wetlands remaining Wetlands	CO_2	156.11	42.53	11.00	20.00	22.83	0.00	-0.00	0.00	-0.00	0.00	0.00	3
4.D.1 Wetlands remaining Wetlands	CH_4	195.11	233.81	10.00	100.00	100.50	0.04	0.00	0.00	0.01	0.01	0.01	3
4.D.1 Wetlands remaining Wetlands	N_2O	47.90	91.50	10.00	100.00	100.50	0.02	0.00	0.00	0.01	0.00	0.01	3
4.D.2 Land converted to Wetland	CO_2	711.35	-0.44	11.00	25.00	27.31	-0.00	-0.00	-0.00	-0.03	-0.00	0.03	3
4.E.1 Settlements remaining Settlements	CO_2	-19.84	-24.33	11.00	20.00	22.83	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	3
4.E.2 Land converted to Settlements	CO_2	3,010.96	602.05	11.50	26.00	28.43	0.03	-0.00	0.00	-0.09	0.02	0.09	3
4.E.2 Land converted to Settlements	CH_4	104.07	19.49	11.50	50.00	51.31	0.00	-0.00	0.00	-0.01	0.00	0.01	3
4.E.2 Land converted to Settlements	N_2O	27.16	8.21	11.50	50.00	51.31	0.00	-0.00	0.00	-0.00	0.00	0.00	3
4.G Harvested Wood Products	CO_2	-7,416.93	-4,649.40	10.00	20.00	22.36	-0.19	0.00	-0.01	0.06	-0.11	0.13	8
5.A Solid Waste Disposal	CH_4	15,239.94	8,255.80	-	54.00	54.00	0.83	-0.01	0.01	-0.47	-	0.47	9
5.D Wastewater Treatment and Discharge	CH_4	4,389.40	2,718.64	-	50.00	50.00	0.25	-0.00	0.00	-0.10	-	0.10	9
5.D Wastewater Treatment and Discharge	N_2O	287.56	505.39	-	50.00	50.00	0.05	0.00	0.00	0.02	-	0.02	9
5.C Incineration and Open Burning of Waste	CO_2	73.36	30.75	-	40.00	40.00	0.00	-0.00	0.00	-0.00	-	0.00	9
5.C Incineration and Open Burning of Waste	CH_4	2.32	-	-	50.00	50.00	-	-0.00	-	-0.00	-	0.00	9
5.C Incineration and Open Burning of Waste	N_2O	11.32	-	-	50.00	50.00	-	-0.00	-	-0.00	-	0.00	9
5.B Biological treatment of solid waste	CH_4	8.76	109.65	-	100.00	100.00	0.02	0.00	0.00	0.02	-	0.02	9
5.B Biological treatment of solid waste	N_2O	13.36	167.30	-	100.00	100.00	0.03	0.00	0.00	0.03	-	0.03	9
Total Emissions		604,903.78	534,695.45										
Total Uncertainties							6.5					4.8	

1. NGER, 2. Energy Strategies 2003, 3. DoEE/expert judgement, 4. Burnbank Consulting 2006, 5. IPCC 2006, 6. Dr Mark Howden, CSIRO, 7. Dr Carl Meyer, CSIRO, 8. Dr Gary Richards, Department of Climate Change and Energy Efficiency, 9. Blue Environment 2016.

Table A2.4 General reporting table for uncertainty excluding LULUCF for latest inventory year 2017

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	2017Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.A.1.a Electricity generation - black coal	CO_2	72,725.26	103,085.98	1.57	1.57	2.22	0.41	0.02	0.25	0.03	0.55	0.55	1
1.A.1.a Electricity generation - black coal	CH_4	13.54	19.51	1.57	50.00	50.02	0.00	0.00	0.00	0.00	0.00	0.00	1
1.A.1.a Electricity generation - black coal	N_2O	189.54	225.29	1.57	50.00	50.02	0.02	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.a Electricity generation - brown coal	CO_2	45,183.47	53,612.01	0.50	0.50	0.71	0.07	-0.01	0.13	-0.01	0.09	0.09	1
1.A.1.a Electricity generation - brown coal	CH_4	7.50	9.11	0.50	50.00	50.00	0.00	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.a Electricity generation - brown coal	N_2O	189.77	254.53	0.50	50.00	50.00	0.02	0.00	0.00	0.00	0.00	0.00	1
1.A.1.a Electricity generation - natural gas	CO_2	8,280.60	27,849.46	1.70	1.70	2.41	0.12	0.04	0.07	0.07	0.16	0.17	1
1.A.1.a Electricity generation - natural gas	CH_4	7.20	481.64	1.70	50.00	50.03	0.04	0.00	0.00	0.06	0.00	0.06	1
1.A.1.a Electricity generation - natural gas	N_2O	43.68	192.69	1.70	50.00	50.03	0.02	0.00	0.00	0.02	0.00	0.02	1
1.A.1.a Electricity generation - liquid fuels	CO_2	2,907.27	3,863.71	2.83	2.83	4.00	0.03	0.00	0.01	0.00	0.04	0.04	2
1.A.1.a Electricity generation - liquid fuels	CH_4	2.71	4.79	35.36	35.36	50.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.1.a Electricity generation - liquid fuels	N_2O	4.13	6.07	35.36	35.36	50.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.1.b Petroleum refining - liquid fuels	CO_2	4,931.12	2,596.93	16.53	16.53	23.37	0.11	-0.01	0.01	-0.15	0.14	0.21	1
1.A.1.b Petroleum refining - liquid fuels	CH_4	1.26	1.08	16.53	50.00	52.66	0.00	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.b Petroleum refining - liquid fuels	N_2O	12.10	1.34	16.53	50.00	52.66	0.00	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.b Petroleum refining - gaseous fuels	CO_2	580.95	385.39	5.19	5.19	7.34	0.01	-0.00	0.00	-0.00	0.01	0.01	1
1.A.1.b Petroleum refining - gaseous fuels	CH_4	0.29	0.20	5.19	50.00	50.27	0.00	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.b Petroleum refining - gaseous fuels	N_2O	1.43	0.98	5.19	50.00	50.27	0.00	-0.00	0.00	-0.00	0.00	0.00	1
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	CO_2	7,942.01	25,074.76	3.97	3.97	5.62	0.25	0.03	0.06	0.14	0.34	0.36	1
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	CH_4	6.55	26.18	6.36	6.36	9.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.1.c Manufacture of solid fuels and other energy industries - fossil fuels	N_2O	43.68	206.66	8.49	8.49	12.00	0.00	0.00	0.00	0.00	0.01	0.01	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	CO_2	11,375.13	10,823.56	2.83	2.83	4.00	0.08	-0.01	0.03	-0.03	0.10	0.11	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	CH_4	3.40	3.09	6.36	6.36	9.00	0.00	-0.00	0.00	-0.00	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Solid fossil fuels	N_2O	29.30	27.26	8.49	8.49	12.00	0.00	-0.00	0.00	-0.00	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	CO_2	19,643.69	27,595.26	2.83	2.83	4.00	0.20	0.00	0.07	0.01	0.26	0.26	2
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	CH_4	9.00	12.70	6.36	6.36	9.00	0.00	0.00	0.00	0.00	0.00	0.00	2

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	2017Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.A.2, 1.A.4, 1.A.5 Gaseous fossil fuels	N_2O	74.21	112.28	8.49	8.49	12.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	CO_2	18,285.08	26,930.55	2.83	2.83	4.00	0.19	0.01	0.06	0.02	0.26	0.26	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	CH_4	43.07	61.76	6.36	6.36	9.00	0.00	0.00	0.00	0.00	0.00	0.00	2
1.A.2, 1.A.4, 1.A.5 Liquid fossil fuels	N_2O	178.50	304.39	8.49	8.49	12.00	0.01	0.00	0.00	0.00	0.01	0.01	2
1.A.3 Transport fossil fuels	CO_2	59,821.60	96,840.98	2.83	2.83	4.00	0.70	0.04	0.23	0.12	0.92	0.93	3
1.A.3 Transport fossil fuels	CH_4	658.63	360.20	16.97	16.97	24.00	0.02	-0.00	0.00	-0.02	0.02	0.03	3
1.A.3 Transport fossil fuels	N_2O	914.33	1,517.03	29.70	29.70	42.00	0.11	0.00	0.00	0.02	0.15	0.15	3
1.A. Biomass fuels	CH_4	2,427.13	991.41	-	20.00	20.00	0.04	-0.01	0.00	-0.11	-	0.11	2
1.A. Biomass fuels	N_2O	240.60	329.02	-	50.00	50.00	0.03	0.00	0.00	0.00	-	0.00	2
1.B.1.a.i Solid Fuels - Underground Mines	CO_2	1,121.82	1,173.80	12.26	12.26	17.34	0.04	-0.00	0.00	-0.01	0.05	0.05	1
1.B.1.a.i Solid Fuels - Underground Mines	CH_4	17,640.76	17,551.31	12.26	50.00	51.48	1.63	-0.01	0.04	-0.68	0.72	0.99	1
1.B.1.a.i Solid Fuels - Underground Mines	N_2O	-	-	-	-	-	-	-	-	-	-	-	0
1.B.1.a.ii Solid Fuels - Open Cut Mines	CO_2	61.78	161.49	23.45	23.45	33.16	0.01	0.00	0.00	0.00	0.01	0.01	1
1.B.1.a.ii Solid Fuels - Open Cut Mines	CH_4	3,350.71	6,008.78	23.45	50.00	55.22	0.60	0.00	0.01	0.19	0.47	0.51	1
1.B.1.a.ii Solid Fuels - Open Cut Mines	N_2O	-	-	-	-	-	-	-	-	-	-	-	0
1.B.1.c Solid Fuels - Other	CO_2	0.28	808.32	5.00	20.00	20.62	0.03	0.00	0.00	0.04	0.01	0.04	3
1.B.1.c Solid Fuels - Other	CH_4	0.03	97.21	5.00	50.00	50.25	0.01	0.00	0.00	0.01	0.00	0.01	3
1.B.1.c Solid Fuels - Other	N_2O	0.00	0.47	5.00	50.00	50.25	0.00	0.00	0.00	0.00	0.00	0.00	3
1.B.2.a Oil and Natural Gas - Oil	CO_2	393.90	199.14	5.00	5.00	7.07	0.00	-0.00	0.00	-0.00	0.00	0.01	3
1.B.2.b Oil and Natural Gas - Natural Gas	CO_2	88.15	70.43	10.00	3.00	10.44	0.00	-0.00	0.00	-0.00	0.00	0.00	3
1.B.2.c Oil and Natural Gas - Venting and Flaring	CO_2	5,746.96	13,631.44	5.00	5.00	7.07	0.17	0.01	0.03	0.07	0.23	0.24	3
1.B.2.a Oil and Natural Gas - Oil	CH_4	77.04	57.58	5.00	5.00	7.07	0.00	-0.00	0.00	-0.00	0.00	0.00	3
1.B.2.b Oil and Natural Gas - Natural Gas	CH_4	6,122.27	9,384.42	5.00	50.00	50.25	0.85	0.00	0.02	0.16	0.16	0.22	3
1.B.2.c Oil and Natural Gas - Venting and Flaring	CH_4	2,588.52	2,608.59	5.00	5.00	7.07	0.03	-0.00	0.01	-0.01	0.04	0.04	3
1.B.2.a Oil and Natural Gas - Oil	N_2O	3.55	2.44	2.00	50.00	50.04	0.00	-0.00	0.00	-0.00	0.00	0.00	3
1.B.2.b Oil and Natural Gas - Natural Gas	N_2O	0.65	0.43	2.00	50.00	50.04	0.00	-0.00	0.00	-0.00	0.00	0.00	3

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of ef	Uncert'y in activity data	Uncert'y in trend of total emissions	footnote ref no.
		1990 Gg CO_2 e	2017Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.B.2 Oil and Natural Gas - Venting and Flaring	N_2O	36.04	84.96	2.00	50.00	50.04	0.01	0.00	0.00	0.00	0.00	0.00	3
2.A.1 Cement Production	CO_2	3,462.87	3,019.06	2.48	2.48	3.51	0.02	-0.00	0.01	-0.01	0.03	0.03	1
2.A.2 Lime Production	CO_2	775.37	1,031.10	2.48	2.48	3.51	0.01	0.00	0.00	0.00	0.01	0.01	1
2.A.4 Other Process Uses of Carbonates	CO_2	1,251.34	1,550.02	4.00	2.50	4.72	0.01	-0.00	0.00	-0.00	0.02	0.02	4
2.B Chemicals	CO_2	1,054.69	3,073.58	2.76	2.76	3.90	0.02	0.00	0.01	0.01	0.03	0.03	1
2.B Chemicals	CH_4	10.94	14.44	5.00	50.00	50.25	0.00	0.00	0.00	0.00	0.00	0.00	4
2.B Chemicals	N_2O	995.04	1,518.93	4.47	4.47	6.33	0.02	0.00	0.00	0.00	0.02	0.02	1
2.B Chemicals	HFCs	1,424.68	-	-	27.00	27.00	-	-0.00	-	-0.12	-	0.12	4
2.C.1 Iron and Steel Production	CO_2	9,203.23	7,439.73	1.63	1.63	2.30	0.03	-0.01	0.02	-0.02	0.04	0.04	1
2.C.1 Iron and Steel Production	CH_4	70.55	58.85	2.00	50.00	50.04	0.01	-0.00	0.00	-0.00	0.00	0.00	4
2.C.1 Iron and Steel Production	N_2O	21.48	15.16	2.00	50.00	50.04	0.00	-0.00	0.00	-0.00	0.00	0.00	4
2.C.3 Aluminium Production	CO_2	2,058.10	2,197.08	4.85	4.85	6.86	0.03	-0.00	0.01	-0.01	0.04	0.04	1
2.C.3 Aluminium Production	PFCs	4,607.01	202.63	-	27.00	27.00	0.01	-0.01	0.00	-0.38	-	0.38	4
2.C.2 Ferroalloys Production	CO_2	322.61	451.59	7.07	7.07	10.00	0.01	0.00	0.00	0.00	0.01	0.01	1
2.C.2 Ferroalloys Production	CH_4	0.07	0.10	7.07	50.00	50.50	0.00	0.00	0.00	0.00	0.00	0.00	1
2.C.2 Ferroalloys Production	N_2O	0.66	0.90	7.07	50.00	50.50	0.00	0.00	0.00	0.00	0.00	0.00	1
2.C.7 Other	CO_2	189.21	286.07	7.07	7.07	10.00	0.01	0.00	0.00	0.00	0.01	0.01	1
2.C.7 Other	CH_4	0.08	0.09	7.07	50.00	50.50	0.00	-0.00	0.00	-0.00	0.00	0.00	1
2.C.7 Other	N_2O	0.41	0.63	7.07	50.00	50.50	0.00	0.00	0.00	0.00	0.00	0.00	1
2.D Non-energy Products from Fuels and Solvent Use	CO_2	279.93	184.05	2.00	3.00	3.61	0.00	-0.00	0.00	-0.00	0.00	0.00	1
2.H.2 Food and Beverages Industry	CO_2	82.57	213.30	2.76	2.76	3.90	0.00	0.00	0.00	0.00	0.00	0.00	1
2.F Product Uses as Substitutes for Ozone Depleting Substances	HFCs	-	12,252.94	-	27.00	27.00	0.60	0.03	0.03	0.79	-	0.79	5
2.G Other Product Manufacture and Use	SF_6	220.56	176.22	-	27.00	27.00	0.01	-0.00	0.00	-0.01	-	0.01	5
3.A Enteric Fermentation	CH_4	64,625.62	51,543.56	10.00	50.00	50.99	4.74	-0.08	0.12	-4.00	1.73	4.36	6
3.B Manure Management	CH_4	2,084.72	2,626.43	22.36	50.00	54.77	0.26	-0.00	0.01	-0.01	0.20	0.20	6
3.B Manure Management	N_2O	405.19	1,048.76	22.36	50.00	54.77	0.10	0.00	0.00	0.06	0.08	0.10	7

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	**Gas**	**Base year emissions**	**Year t emissions**	**Activity data Uncert'y**	**Emission factor uncert'y**	**Combined uncert'y**	**Uncert'y in total inventory**	**Type A Sensit'y**	**Type B Sensit'y**	**Uncert'y in trend of ef**	**Uncert'y in activity data**	**Uncert'y in trend of total emissions**	**footnote ref no.**
		1990 Gg CO_2 e	**2017Gg CO_2 e**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	
3.C Rice Cultivation	CH_4	396.90	285.17	5.00	50.00	50.25	0.03	-0.00	0.00	-0.03	0.00	0.03	7
3.D Agricultural Soils	N_2O	11,722.41	14,170.43	25.00	50.00	55.90	1.43	-0.00	0.03	-0.15	1.19	1.20	7
3.F Agricultural Residue Burning	CH_4	291.96	310.02	32.40	50.00	59.58	0.03	-0.00	0.00	-0.01	0.03	0.03	7
3.F Agricultural Residue Burning	N_2O	138.90	157.85	32.40	50.00	59.58	0.02	-0.00	0.00	-0.00	0.02	0.02	7
3.G Liming	CO_2	215.35	1,318.39	20.00	50.00	53.85	0.13	0.00	0.00	0.12	0.09	0.15	7
3.H Urea application	CO_2	366.67	1,543.35	10.00	50.00	50.99	0.14	0.00	0.00	0.13	0.05	0.14	7
5.A Solid Waste Disposal	CH_4	15,239.94	8,255.80	-	54.00	54.00	0.80	-0.03	0.02	-1.52	-	1.52	9
5.D Wastewater Treatment and Discharge	CH_4	4,389.40	2,718.64	-	50.00	50.00	0.25	-0.01	0.01	-0.36	-	0.36	9
5.D Wastewater Treatment and Discharge	N_2O	287.56	505.39	-	50.00	50.00	0.05	0.00	0.00	0.02	-	0.02	9
5.C Incineration and Open Burning of Waste	CO_2	73.36	30.75	-	40.00	40.00	0.00	-0.00	0.00	-0.01	-	0.01	9
5.C Incineration and Open Burning of Waste	CH_4	2.32	-	-	50.00	50.00	-	-0.00	-	-0.00	-	0.00	9
5.C Incineration and Open Burning of Waste	N_2O	11.32	-	-	50.00	50.00	-	-0.00	-	-0.00	-	0.00	9
5.B Biological treatment of solid waste	CH_4	8.76	109.65	-	100.00	100.00	0.02	0.00	0.00	0.02	-	0.02	9
5.B Biological treatment of solid waste	N_2O	13.36	167.30	-	100.00	100.00	0.03	0.00	0.00	0.04	-	0.04	9
Total Emissions		420,315.32	554,126.56										
Total Uncertainties							5.5					5.2	

1. NGER, 2. Energy Strategies 2003, 3. DoEE/expert judgement, 4. Burnbank Consulting 2006, 5. IPCC 2006, 6. Dr Mark Howden, CSIRO, 7. Dr Carl Meyer, CSIRO, 8. Dr Gary Richards, Department of Climate Change and Energy Efficiency, 9. Blue Environment 2016

A2.1 Energy

A2.1.1 Stationary energy

Uncertainty analyses were conducted for emissions from three sectors: 1.A.1.a. *Electricity*, 1.A.1.b. *Petroleum refining* and 1.A.1.c. *Manufacture of solid fuels and other energy industries* (Table A2.5).

In the electricity generation sector (black coal, brown coal, natural gas and liquid fuels) and petroleum refining sector (liquid fuels and gaseous fuels) the uncertainty associated with most of Australia's emissions in these sectors are reported under NGERS as source specific uncertainty estimates. The reported CO_2-e uncertainties for NGER facilities were combined to derive an overall estimate that has been applied against the sector and fuel.

In the electricity generation sector, CO_2 emissions from the combustion of coal or gas for electricity generation must be estimated using facility specific measurements. The use of facility specific measurements based on sampling and analysis of fuels results in relatively low uncertainty estimates as published in Table A2.5.

Table A2.5 Quantified uncertainty values for key stationary energy subcategories

Greenhouse gas source and sink category	Uncertainty (%)[a]			
	CO_2	CH_4	N_2O	Total CO_2-e
1.A.1.a Electricity				
Black coal [b]	±2.2	±50	±50	±2.2
Brown coal [b]	±0.8	±50	±50	±0.8
Petroleum	±±4	±50	±50	±4
Natural gas [b]	±2	±50	±50	±2
1.A.1.b Petroleum refining				
Petroleum [b]	±21.7	±52.3	±52.3	±21.7
Gas [b]	±12.1	±50.7	±50.7	±12.1
1.A.1.c Manufacture of solid fuels and other energy industries				
Fossil Fuels	±4	±50	±50	±4

(a) Uncertainty reported at 95 per cent confidence limits estimated using Latin Hypercube (a type of Monte Carlo) analysis and preliminary estimates for electricity incorporating NGER uncertainty estimates.
(b) Derived from NGER

In the fuel combustion sector the uncertainty associated with emissions of N_2O and CH_4 has negligible impact on overall uncertainty.

A2.1.2 Transport

Monte Carlo analyses were conducted for all subsectors and fuel types. The uncertainty distributions for emission factors and activity data were developed on the basis of expert judgement.

The total estimated uncertainties in the *transport* subsector were ±4 per cent for CO_2, ±24 per cent for CH_4, and ±42 per cent for N_2O. Uncertainties in the emissions from individual source categories ranged from ±1 per cent to ±24 per cent for CO_2, ±23 per cent to ±59 per cent for CH_4, and ±32 per cent to ±63 per cent for N_2O. The largest source of uncertainty is in the emission factors.

The estimates also reflect the relatively higher uncertainty attached to the emission estimates for particular vehicle types, which are drawn from ABS data and its survey of motor vehicle use, than for the sector as a whole. This outcome reflects the dependency between activity variables; and because overall transport fuel consumption is more accurately known than the individual segments.

Table A2.6 Emissions and quantified uncertainty values for key transport subcategories

Greenhouse gas source and sink category	Uncertainty (%)[(a)]		
	CO_2	CH_4	N_2O
1.A.3. Transport	±4	±24	±42
a. Civil aviation	±9	±52	±52
b. Road transport	±4	±25	±42
i. Passenger cars	±6	±31	±44
ii. Light trucks	±7	±38	±41
iii. Medium trucks	±9	±41	±60
iv. Heavy trucks	±10	±44	±61
v. Buses	±8	±36	±53
vi. Motorcycles	±10	±43	±61
c. Railways	±5	±39	±39
d. Navigation	±8	±59	±32
e. Other transportation	±24	±46	±63
International bunkers			
Aviation	±10	±58	±59
Marine	±4	±47	±52

(a) Uncertainty reported at 95 per cent confidence limits.

A2.1.3 Fugitives

In the coal fugitives sector uncertainty associated with most of Australia's emissions in this sector are reported under NGERS. The reported CO_2-e uncertainties for each large underground and open cut coal mine have been combined to derive a sector estimate which is reported in Table A2.7.

In the coal fugitives sector underground coal mines must directly monitor their CH_4 emissions while open cut coal mines either undertake analysis and measurements or use state based default emission factors. The uncertainty estimates reported in Table A2.7 reflect the uncertainty associated with these measurement approaches.

Uncertainties in oil and natural gas emissions were estimated to be ±7.1 per cent for CO_2, ±50.3 per cent for CH_4 and ±50 per cent for N_2O, and will be updated in future submissions.

Uncertainties in natural gas emissions were estimated to be ±10.4 per cent for CO_2, ±51 per cent for CH_4 and ±50 per cent for N_2O, and will be updated in future submissions.

Table A2.7 Quantified uncertainty values for key fugitive emissions subcategories

Greenhouse gas source and sink category	Uncertainty (%)[a]			
	CO_2	CH_4	N_2O	CO_2-e
1.B.1. Solid fuels				
1B1ai Underground mines	±15.3	±51.2		±15.3
1.B.1.a.ii. Surface mining	±36	±56.1		±36
1.B.2.a. Oil	±7.1	±50.3	±50	±7.1
1.B.2.b. Natural gas	±10.4	±50.3	±50	±10.4
1.B.2.c. Venting and flaring	±7.1	±50.3	±50	±7.1

(a) Uncertainty reported at 95 per cent confidence limits estimated using Latin Hypercube analysis.

A2.2 Industrial Processes and Product Use

An analysis of uncertainty was conducted using the methods and random sampling techniques described in IPCC 2006. Uncertainty estimates from CO_2 emissions from cement production and CO_2 from aluminum production are derived from NGER. Uncertainty estimates of the other sectors (activity levels and emission factors) are based on expert judgement.

As the IPCC tier 1 approach is not suitable for assessing uncertainty where approximately normal distribution assumptions cannot be sustained, an analysis was undertaken using Latin Hypercube techniques. These techniques can take into account asymmetric probability distributions associated with emission factors. For example, as the average emission factor for PFCs tends to the minimum limit that is understood to be technically feasible, the probability of the emission factor being lower than estimated is less than the probability of it being higher than estimated.

The uncertainty in the *industrial processes* subsectors ranged from ±2.5 per cent to ±50.1 per cent.

Table A2.8 Quantified uncertainty values for key industrial processes subsectors using different techniques

Greenhouse gas source and sink category	Uncertainty (%)[a,b]					
	CO2	CH4	N2O	HFC	PFC	SF6
2.A.1 Cement Production	± 3.51					
2.A.2 Lime Production	± 3.51					
2.A.4 Other Process Uses of Carbonates	± 4.72					
2.B Chemicals	± 3.90	± 50.25	± 6.33	± 27.00		
2.C.1 Iron and Steel Production	± 2.30	± 50.04	± 50.04			
2.C.3 Aluminium Production	± 6.86				± 27.00	
2.C.2 Ferroalloys Production	± 10.00	± 50.50	± 50.50			
2.C.7 Other	± 10.00	± 50.50	± 50.50			
2.D Non-energy Products from Fuels and Solvent Use	± 3.61					
2.H.2 Food and Beverages Industry	± 3.90					
2.F Product Uses as Substitutes for Ozone Depleting Substances				± 27.00		
2.G Other Product Manufacture and Use						± 27.00

(a) Uncertainty reported at 95% confidence limits assuming approximately normal distributions. (b) Uncertainty derived from NGER data. Source: NGER, Burnbank Consulting 2007, IPCC 2006.

A2.3 Agriculture

An uncertainty analysis was undertaken for the *agriculture* subsectors using the approach 1 propagation of error method. The uncertainties applied to activity data and emission factors were based on IPCC (2006) uncertainty estimates and expert judgement (see Table A2.9). It is planned in the future to develop approach 2 uncertainty estimates to better reflect data correlations and the complex tier 2 functions used to estimate emissions.

Table A.2.9 Uncertainty in emission estimates for agriculture sectors

Greenhouse gas source and sink categories	Uncertainty (%)		
	CH_4	N_2O	CO_2
A. Enteric fermentation	±51		
B. Manure management	±55	±55	
C. Rice cultivation	±50		
D. Agricultural soils		±56	
E. Agricultural residue burning	±60	±60	
F. Liming			±54
G. Urea application			±51

A2.4 Land Use, Land Use Change and Forestry

Uncertainty analysis for the LULUCF sector was undertaken using the IPCC Approach 1, propagation of error method as described in IPCC 2006.

Forest land

In the sub-sector *forest land remaining forest land* activity data is derived from national statistics of forest harvesting (ABARES 2014). The uncertainty of these activity data has not been published and so is estimated to be +/-15 per cent. The uncertainties regarding the emission factor used are also unpublished and are estimated to be +/-30 per cent.

The sub-sector *land converted to forest land* includes *grassland converted to forest* and *wetlands converted to forest*. The uncertainty associated with the detection of forest cover gains is reported to be +/3.5 per cent (see Appendix 6.A). Field sampling results presented by Paul *et al.*. 2014 indicate an uncertainty of +/-11.5 per cent for the estimation of standing biomass. As explained in Volume 2, Section 6.5.3, the higher uncertainty around *wetlands converted forest land* contributes only a small increment to the overall uncertainty for the sub-sector.

Cropland

Cropland remaining cropland activity data are derived from ABS reporting of agricultural management practices as a regional level. The uncertainty associated with these reported activity data is estimated to be +/-25 per cent and the uncertainty associated with model results is estimated to be +/-20 per cent.

The sub-sector *land converted to cropland* includes *forest land converted to cropland* and *wetlands converted to cropland*. For *forest land converted to cropland*, remote sensing-based data are used and the uncertainty in these data is reported to be +/-3.5 per cent. The key input variable to the estimation of biomass at the time of forest conversion to other land uses is the initial assumed above ground biomass. Based on data presented by Richards and Brack (2004) uncertainty in this parameter is estimated to be +/-25 per cent.

For *wetlands converted to cropland*, as explained in Volume 2, Section 6.7.3, the higher uncertainty around *wetlands converted cropland* contributes only a small increment to the overall uncertainty for the sub-sector.

Grassland

Grassland remaining grassland activity data are derived from ABS reporting of agricultural management practices as a regional level, and from remote-sensed area changes in sparse woody vegetation.. The uncertainty associated with these reported activity data is estimated to be +/-25 per cent and the uncertainty associated with model results is estimated to be +/-20 per cent.

The sub-sector *land converted to grassland* includes *forest land converted to grassland* and *wetlands converted to grassland*. The remote-sensing-based activity data and FullCAM modelling of carbon stock changes for *forest converted to grassland* are similar to *forest converted to cropland,* and the activity data and estimation method for *wetlands converted to grassland* is similar to that for *wetlands converted to cropland*. As such, overall uncertainty is also similar to *land converted to cropland*.

Wetlands

Wetlands remaining wetlands data includes sparse woody vegetation cover changes based on satellite imagery and ABARES aquaculture production statistics with similar levels of uncertainty. Estimation of net emissions from sparse woody vegetation is via a Tier 2 spreadsheet model. The higher overall uncertainty around aquaculture emissions (Table A2.10 below) is driven by that of the simple Tier 1 model used to estimate N_2O emissions from aquaculture.

The sub-sector *land converted to wetlands* comprises forest land converted to flooded land (e.g. reservoirs). Activity data collection and emissions estimates, and thus uncertainty, are similar to that for forest converted to grassland.

Settlements

Settlements remaining settlements data comprises sparse woody vegetation cover changes based on satellite imagery with net emissions estimated via a Tier 2 spreadsheet model. As such, the level of uncertainty is similar to the CO_2 component of *wetlands remaining wetlands* (Table A2.10 below).

The sub-sector land *converted to settlements* includes *forest land* (both terrestrial and coastal mangrove) *converted to settlements* and *wetlands converted to settlements*. Terrestrial forest conversions exert the dominant influence on overall uncertainty. As such, although the uncertainties around emissions from mangrove forest and tidal marsh conversions are greater than for terrestrial forest conversions, their impact is relatively small.

Harvested wood products

The harvested wood products model uses the same source of activity data as the *forest land remaining forest land* model. Uncertainties associated with these activity data are estimated to be +/-10 per cent. Estimated uncertainty associated with the harvested wood products carbon stock change were derived as reduced form outputs of monte carlo analyses (see chapter 6.13) providing an uncertainty of +/-20 per cent.

Table A2.10 Estimation of uncertainties in components of the land use change and forestry subsectors

Greenhouse gas source and sink categories	Uncertainty (%)		
	CO_2	CH_4	N_2O
A.1 Forest land remaining forest land	±33.5	±52.2	±52.2
A.2 Land converted to forest land	±17.3	±51.2	±51.2
B.1/C.1 Cropland/Grassland remaining	±32.0	±32.0	±32.0
B. 2/C.2 Forest land converted to Cropland/Grassland	±27.3	±51.2	±51.2
D.1 Wetlands remaining Wetlands	±22.8		±100.5
D.2 Land converted to Wetlands	±27.3		
E.1 Settlements remaining Settlements	±22.8		
E.2 Land converted to Settlements	±28.4		
G Harvested wood products	±100		

A2.5 Waste

Estimates for uncertainty for emissions from solid waste disposal and wastewater treatment were estimated by Blue Environment. Estimates of uncertainty for biological treatment and incineration are based on expert judgement.

Table A2.11 Relative uncertainty in emission estimates for key waste subsectors

Greenhouse gas source and sink categories	Uncertainty (%)		
	CO_2	CH_4	N_2O
Waste			
A. Solid waste disposal on land[(a)]	NA	±54	NA
D. Biological treatment of solid waste	NA	±100	±100
C. Incineration and open burning of waste	±40	±50	±50
D. Wastewater treatment and discharge[(a)]	NA	±50	±50

(a) Source Blue Environment 2016

ANNEX 3: Other Detailed Methodological Descriptions

The Australian methodology for the estimation of this inventory is documented in the relevant chapters.

A3.1 Sector-specific Black Carbon Emissions

Black carbon (BC) is a short-lived, small aerosol (or airborne) particle linked to both climate warming and adverse health effects. Black carbon emissions have recently become a focus of attention because their effects on the near-term warming of the atmosphere and on human health. Reducing black carbon emissions is of particular interest in Polar Regions, such as the Arctic, which are especially sensitive to the effects of black carbon. (Canada BC 2018)

Black carbon is an aerosol (airborne particle) emitted from combustion processes. Black carbon is not emitted on its own, but as a component of particulate matter less than or equal to 2.5 micrometres in diameter (PM2.5), along with other components, such as organic carbon (OC) and inorganic compounds such as sulphates.

Two important assumptions underlie the methodologies used to develop the BC inventory:

1. Black carbon is predominantly emitted in PM2.5; and only PM2.5 emissions resulting from combustion contain significant amounts of black carbon. Therefore, the basis for the black carbon inventory is the PM2.5 emitted from combustion processes, multiplied by black carbon ratios specific to each type of inventory sector and fuel source.
2. Although important in some cases, PM2.5 emissions from non-combustion sources, such as dust raised by traffic on paved and unpaved roads or by wind and machinery on open fields or mine sites, are not considered sources of black carbon in this inventory.

The dataset that breaks down the PM2.5 emitted from a particular source (e.g. diesel engine emissions) into its different components, including black carbon and organic carbon, is known as a speciation profile. Most speciation profiles contain a fraction for elemental carbon; these fractions are commonly used as a surrogate to quantify black carbon emissions. The current inventory primarily relies on the United States Environmental Protection Agency's (U.S. EPA) SPECIATE 4.5 database (EPA 2014a) for speciation factors to calculate black carbon emissions from compiled combustion PM2.5 emissions. Several BC/PM2.5 ratios are specific to the combustion processes or technologies (e.g. appliance types for residential wood combustion), to the fuel type (e.g. diesel, gasoline, natural gas) or to the application (e.g. natural gas use for electrical power generation).

Appendix __ lists all ratios used in this inventory. Industrial PM2.5 emissions originate from both combustion and non-combustion sources; however, only PM2.5 emissions resulting from combustion contain significant amounts of black carbon. Where readily available, the PM2.5 emissions data from combustion were used in conjunction with BC/ PM2.5 fractions to estimate black carbon emissions.

Separating combustion from noncombustion sources of PM2.5 remains a challenge in some cases due to a lack of data on activities (i.e. quantity of fuel burned) and on non-combustion sources (e.g. rock dust at a mine). In those cases, combustion and non-combustion PM2.5 are separated based on the judgement of experts with knowledge of industrial processes. (Canada BC 2018)

Generally, black carbon emissions are calculated using PM2.5 emissions from combustion processes and the fraction of black carbon in the PM2.5. For example, diesel engines have relatively high emission rates of PM2.5 per unit energy, and the fraction of black carbon in these PM2.5 emissions is also relatively high.

Other combustion sources with high PM2.5 emissions include solid fuel combustion units, such as coal- and wood-fired boilers. Industrial sources are generally equipped with highly effective PM2.5 controls on boiler emissions, with PM-control efficiencies often in the 90 per cent range. This is reflected in the lower PM2.5 emissions compared to other sources.

However, the smaller and distinctly different equipment used for residential wood combustion (fireplaces, wood stoves or furnaces) have poorer PM2.5 control efficiencies than larger units, despite the different types of fuel and firing practices used for burning firewood. Due to the lower efficiency combined with the limited treatment of stack gases for many existing residential wood-burning devices, they are the largest source of combustion-related PM2.5 emissions. Black carbon emissions from residential wood burning are only one third that of mobile sources due to a lower BC/PM2.5 fraction for wood devices than for diesel engines. (Canada BC 2018)

A3.2 Scope

For Australia's first Black Carbon Inventory, data from the National Pollutant Inventory (NPI) is used to complement the activity data found in our annual inventory. The PM2.5 emissions data from the NPI have been measured and therefore used in a Tier 3 methodology, covering a range of inventory sectors. Sectors that are not covered by NPI dataset have used activity data calculated in our inventory analysis as the input to the Tier 2 methodology. These methodologies are explained in detail in section ________.

A3.3 Tier Framework and Limitations

Understanding Limitations in Black Carbon Emissions Estimations

Before embarking on the production of a BC inventory, it is important for the developers to understand the limitations of the current state of practice in estimating BC emissions. A foremost limitation is that air pollutant inventories are focused on mass emissions, while BC is defined based on optical properties, and measurements that form the basis of underlying emission, and speciation factors do not provide a complete accounting for these optical properties. Another limitation is that post-hoc speciation factors do not match the level of detail of PM emission factors in many sectors, introducing additional error to the process. These issues are discussed in the following sections.

Black carbon definition

What is referred to as “black carbon” varies in the literature, and in measurement practice; the definition also depends on whether a BC analysis is focused on climate-forcing or health-based outcomes. From a climate-forcing perspective, the term black carbon may be used for the broader metric of “light absorbing carbon” (LAC), comprising both light-absorbing elemental carbon (EC) and light-absorbing organic carbon (OC) (i.e., brown carbon). From a health perspective, BC has typically been defined only as the mass of EC (i.e., the graphitic component of PM). So, BC may refer to the mass of EC only, or to the broader, optically-defined LAC.

A3.4 Sector-specific Black Carbon Emission Estimation Methods

Black carbon emissions can be calculated using either a Tier 3 or Tier 2 method.

Tier 3 Method

For the Tier 3 method, NPI PM2.5 emissions data is used to calculate Black Carbon (BC) emissions. This method involves multiplying the PM2.5 emissions with a speciation factor (BC fraction) that converts PM2.5 to BC emissions. Because the NPI PM2.5 emissions are considered measured, this is Tier 3.

PM2.5 emissions x Speciation Factor = BC emissions by sector

The Speciation Factors by sector and by fuel type. The fractions are sourced from US EPA Speciate 4.5 database and the PM2.5 emissions are from the NPI database.

The NPI emissions are broken down into fuel types with a breakdown of tonnes of fuel used by fuel type and using this information, a calculation is done to breakdown the total emissions by facility into each fuel type.

Black carbon emissions are calculated by inventory sector, by State and aggregated to the National level. The NPI datasets includes data for Energy, Industrial Processes and Waste.

Tier 2 method

For the Tier 2 method, inventory analysis data is used to calculate BC emissions. In this method, the amount of fuel combusted is used and multiplied by a PM2.5 emission factor (by fuel type) and a speciation factor.

Quantity of fuel combusted x PM2.5 emission factor x BC Fractions = BC emissions by sector

For sectors that are not covered by the NPI, the Tier 2 method is used.

Energy, Industrial Processes and Waste

For these sectors, Tier 3 method was used with PMN2.5 emissions from the NPI dataset and Speciation Factors.

Transport

For the Transport sector, the methods are sub-sector specific using the Tier 2 approach.

Onroad Sources

Tier 2 for On-road sources

Total Black Carbon emissions from on-road vehicles (EBC)

i	Type of fuel
j	vehicle class
Qi,j	quantity of fuel type I for vehicle class j
EFi,j,EC	fuel based EC (elemental carbon) emission factor for fuel type i and vehicle class j
Eni	energy content of fuel type I

$$EBC = S_{i,j} \left(Q_{i,j} * EF_{i,j,EC} * 1/En_i \right)$$

Nonroad Sources

Total Black Carbon emissions from non-road vehicles (EBC)

c	equipment use category
i	fuel type
t	technology level (year it was made)
Qc,i,t	fuel consumption for a given equipment use category c, fuel type i, and technology level t
EFc,i,t,PM2.5	PM2.5 emission factor for a given equipment use category c, fuel type i, and technology level t
SFi,t,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for fuel type i, and technology level t (if available)

$$EBC = S_{c,i,t} \left(Q_{c,i,t} * EF_{c,i,t,PM2.5} * SF_{i,t,BC/PM2.5} \right)$$

Railway

Total Black Carbon emissions from locomotives (EBC)

i	rail operation type
Qi	amount of locomotive fuel combusted, by rail operation type i
EFi,PM2.5	PM2.5 emission factor for rail operation type i
SFBC/PM2.5	speciation factor to convert PM2.5 to black carbon for locomotives

$$EBC = S_{i} \left(Q_{i} * EF_{i,PM2.5} \right) * SF_{BC/PM2.5})$$

Marine

Tier 1 Method for Marine Sources

Total Black Carbon emissions from marine sources (EBC)

i	fuel type
Qi	fuel consumption for a given equipment use category c, fuel type i, and technology level t
EFi,PM2.5	PM2.5 emission factor for a given equipment use category c, fuel type i, and technology level t
SFi,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for fuel type i, and technology level t (if available)

$$EBC = S_{i} \left(Q_{i} * EF_{i,PM2.5} * SF_{i,BC/PM2.5} \right)$$

Aviation

Method for Aviation: Tier 2 – Tier 1 = cruising emissions

Tier 2: Total Black Carbon emissions from aviation sources (EBC)

LTOi,j	activity annual airport LTOs for aircraft type i using fuel type j (land and takeoff cycles)
i	aircraft type (i.e. commercial air carriers, air taxis, general aviation, military)
j	aircraft fuel type (i.e. aviation gasoline, or jet fuel)
EFi,j,PM2.5	PM2.5 emission factor for aircraft type i and fuel type j
SFi,j,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for fuel type j

$$EBC = S_{i,j} \left(LTO_{i,j} * EF_{i,j,PM2.5} * SF_{i,j,BC/PM2.5} \right)$$

Tier 1: Total Black Carbon emissions from aviation sources (EBC)

i	type of fuel (i.e. aviation gasoline or jet fuel). Note that piston engines associated with smaller aircraft and helicopters use aviation gasoline while jet fuel is used by larger helicopters and aircraft equipped with turboprops, turbofans and jets
Qi	quantity of aviation fuel used by fuel type, i
EFi,PM2.5	PM2.5 emission factor for aircraft type i and fuel type i
SFi,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for fuel type i

$$EBC = Si,j\ (Qi * EFi,PM2.5 * SFi,BC/PM2.5)$$

Residential Combustion

For this sector, the Tier 2 method was used for wood heaters.

Other Sources

Biomass Burning

Open Burning

A Tier 3 FullCAM method was used for Biomass Burning.

Variable	Description
0.45	Fraction of carbon in fuel
Ak	area burned of biome 'k'
Bk	fuel load (mass of fuel per area for biome 'k')
ak	Fraction of above-ground biomass for biome 'k'
bk	Combustion efficiency (fraction of fuel burned for biome 'k')
EFk,PM2.5	PM2.5 emission factor for biome 'k' (i.e. emissions per mass of C in the fuel [kg/kg-C in fuel])
SFk,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for biome 'k'

$$EBC,k = (0.45 * Ak * Bk * ak * bk) * EFk,PM2.5 * SFk,BC/PM2.5)$$

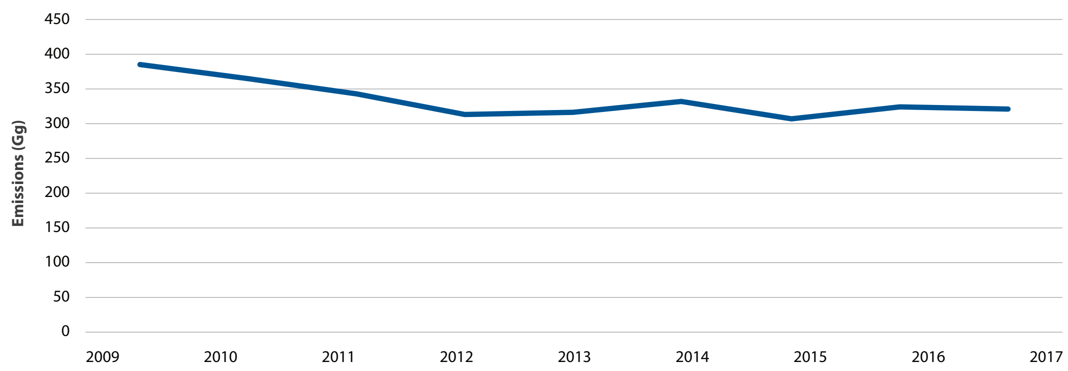
Agricultural Burning

For this sector, the Tier 2 method is used.

A3.5 Black Carbon Emissions by Sector

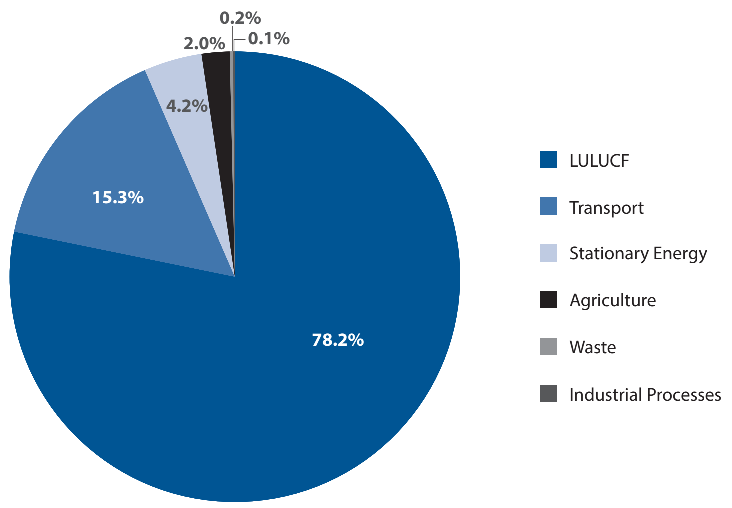
Black carbon emissions by sector is displayed below from 2009-10 to 2016-17. There is a downward trend of black carbon emissions across all sectors in this period.

Figure A3.01 Black carbon emissions including Land Use, Land-Use Change and Forestry (LULUCF)



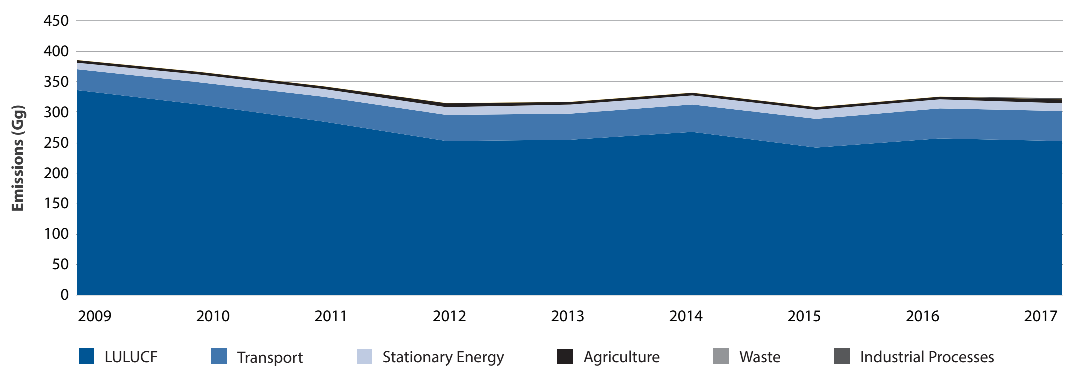
The distribution of black carbon by sector for year 2017 is displayed below. LULUCF sector (including biomass burning) is the highest emitter of black carbon followed by Transport sector (including diesel consumption in heavy vehicle and Kerosene consumption in aviation).

Figure A3.02 Black Carbon distribution by sector for year 2017



The figure below displays the trend of black carbon distribution by sector. Over this time period, LULUCF and Tranport sectors were the largest emitters.

Figure A3.03 Black carbon distribution by sector, trend



ANNEX 4: Carbon dioxide reference approach for the energy sector

A4.1 Estimation of CO_2 using the IPCC reference approach

The reference approach estimates CO_2 emissions from *fuel combustion activities* (covering both *stationary energy* and *transport*). It is calculated using a top-down approach based on Australia's energy balance statistics for production, imports, exports and stock change. Data are obtained from the *Australian Energy Statistics* published by the Department of Industry, Innovation and Science (DIIS) with supplementary sectoral-specific data where available. The *Australian Petroleum Statistics* are used as a basis for the liquid fossil fuel data.

A4.2 Comparison of Australian methodology with IPCC reference approach

For 2017, the total CO_2 emissions estimated using Australia's sectoral approach methodology are 378.3 Mt. Total CO_2 emissions estimated using the reference approach are 373.1 Mt – this is a 1.89 per cent difference between the two methods.

The sectoral approach has been recalculated for the period from 2009 to 2016. This was made in response to improvements made in the *Australian Energy Statistics* (AES) by DIIS. The reference approach has also been recalculated for the period from 2009 to 2016 due to improved data from AES. The recalculations are presented in Table A4.1.

Table A4.1 Reference approach and sectoral approach comparison for 1990 to 2016

Year	IPCC Reference (CO_2 (Mt))	Sectoral (CO_2 Mt)	Difference in %
1990	254	252	1.12 %
1991	258	254	1.46 %
1992	259	258	0.19 %
1993	266	262	1.32 %
1994	269	265	1.30 %
1995	277	276	0.33 %
1996	287	283	1.47 %
1997	291	291	0.03 %
1998	306	304	0.52 %
1999	314	313	0.28 %
2000	319	318	0.25 %
2001	324	326	-0.59 %
2002	331	331	0.02 %
2003	338	337	0.14 %
2004	346	350	-1.12 %
2005	351	355	-1.17 %
2006	358	360	-0.55 %
2007	366	366	-0.14 %

Year	IPCC Reference (CO_2 (Mt)	Sectoral (CO_2 Mt)	Difference in %
2008	377	372	1.52 %
2009	379	375	1.19 %
2010	367	370	-0.91 %
2011	367	368	-0.08 %
2012	376	373	0.83 %
2013	370	365	1.35 %
2014	363	362	0.31 %
2015	366	368	-0.42 %
2016	377	377	0.16 %

The overall difference between the reference approach and the sectoral approach is within 2 per cent for all years. In the case of petroleum fuels, the difference between the reference approach and the sectoral approach exceeds 2 per cent for some years (up to 3.78 per cent in 1996). The main reason for the differences in petroleum fuels relates to the sensitivity of final apparent consumption and emissions to the average density and energy content values used to convert production, exports, imports and stock changes from volume/mass units into energy units.

ANNEX 5: Assessment of Completeness

The UNFCCC guidelines require inventory compilers to assess inventories for the level of completeness of national inventories. The sources of greenhouse gas emissions are many and diverse and, in general, are not directly observable without considerable cost. Many emission sources are minor and resource intensive to estimate. Consequently, all national inventories have minor omissions which, for transparency, need to be identified. This section addresses the completeness of key activity datasets, such as the consumption of fossil fuels, and the completeness of the coverage of emissions and removals sources for the Australian inventory.

A5.1 Completeness of activity data

The emission estimates were reviewed for internal consistency and completeness through the application of mass balance approaches to ensure the reconciliation of carbon supplies and carbon uses within the economy for fossil fuels, carbonates and biomass entering the economy. Details have been provided in the respective sectoral chapters. An overview of the mitigation strategies and control measures adopted, monitoring mechanisms employed and quality objectives or targets results specified is provided in Annex 6.

A5.2 Omitted emission sources

The UNFCCC reporting guidelines provide standard reporting templates that are designed to accommodate the circumstances of as many countries as possible. The reporting templates are not always closely aligned with Australia's circumstances. Consequently, in Australia's reporting tables there are a number of categories where the term "not occurring" has been reported for certain cells because of an absence of a certain economic activity. An example is *adipic acid* production, which does not occur in Australia.

Nonetheless, there are a small number of emission sources which are believed to be minor and which are reported as "not estimated" either because of a lack of data or because the emission processes are not well enough understood to permit the development of reliable methodologies. In these instances, default methodologies are not specified by the IPCC due to limited understanding internationally of these processes. One example is CO_2 from Burning of Coal Deposits and Waste Piles (1.B.1). The spontaneous combustion of waste piles is a known source of CO_2 emissions. Research undertaken on the measurement of this emission source has not yet been able to develop any reliable approach to the estimation of this emission source. The *2006 IPCC Guidelines* do not include a default methodology that could be applied in the absence of information on this source.

The UNFCCC reporting guidelines (FCCC/CP/2013/10/Add.3) also allow minor emission sources to be reported as "not estimated" where a disproportionate amount of effort would be required to collect data for a category that would be insignificant in terms of the overall level and trend in national emissions (i.e. <0.05 per cent of national emissions excluding *LULUCF* and not exceeding 500 kt CO_2-e). Sources reported as "not estimated" under this provision include: *2.G.3 N_2O from product uses (imports), 3.D.1.d other organic fertilisers*, and *5.C.1 Incineration and open burning of waste – clinical waste* (CH_4 and N_2O).

Australia's emissions of N_2O from product uses (imports) (2.G.3) are not estimated since no data is available on imports. Australia will investigate the availability of import data with the aim to include this source of emissions in future inventory submissions.

The organic fertilisers used in Australia are principally derived from animal wastes (3.D.1.d). Emissions from this organic N source are covered elsewhere. Data on the application of other organic N fertiliser is not available through either ABS or industry data collections, nor is a comprehensive list of organic fertiliser producers available. To assess the significance of the category, data was sourced from one of the largest commercial producers. They reported production of meat and fish meal containing 117.8 tonnes of Nitrogen. Applying the IPCC default EF of 1 per cent this equates to 0.55kt CO_2-e of emissions. Even allowing for the complete estimate to be over 900 times greater, this category can be considered insignificant (<500 kt CO_2-e.) and as such, emissions are "not estimated".

The use of urea based additives (diesel emissions fluid DEF) in catalytic converters is occurring in Australia. A certain proportion of heavy vehicles and passenger vehicles designed to meet Euro 5 emission standards are equipped with engine emission control systems using selective catalyst reduction (SCR) technology. The vast majority of DEF consumption will be in the heavy vehicle fleet. In Australia, around 4 million kL of diesel fuel is consumed by heavy vehicles. Manufacturers of heavy diesel engines cite around 2 per cent consumption of DEF to diesel. Assuming every Euro 5 compliant heavy vehicle used SCR technology, this consumption equates to around 3000 tonnes of CO_2 attributed to urea based catalysts. Therefore, this category can be considered insignificant (<500 kt CO_2-e.) and as such, emissions are "not estimated".

For the incineration of clinical waste and solvents (5.C.1), the *2006 IPCC guidelines* do not provide default CH_4 and N_2O emission factors. Furthermore, when the highest 2006 IPCC default EFs for CH_4 and N_2O listed for municipal solid and general industrial waste incineration are applied to the AD for clinical waste and solvents incineration, emissions estimates contribute around 0.0001 per cent (0.7 Gg CO_2-e) of total emissions from all sectors. Accordingly, emissions of CH_4 and N_2O from this source can be considered insignificant (<500 kt CO_2-e.) and as such, emissions are "not estimated".

In *LULUCF*, Australia uses a combination of Approach 3 (for conversions to and from forest land) and Approach 1 (for other land uses) for land representation, as described by the *IPCC 2006 Guidelines* Vol. 4, chapter 3. As such, some conversion categories cannot be separately reported, but in accordance with the *IPCC 2006 Guidelines*, this does not represent a lack of completeness. Some conversions to croplands, grasslands, wetlands or settlements are included in lands remaining in that category. For conversions where separate estimates and activity data are not provided, table A.5.1 identifies where these conversion categories are included elsewhere. Planned improvements are underway to develop a fully spatially explicit time series of land-use maps to apply Approach 3, land representation, to all land-uses. Such improvements will enable reporting of separate activity data and emissions estimates for all conversion categories.

Table A.5.1 *LULUCF* reporting matrix

Final land use		Initial land-use					
	from / to	Forest land (a)	Cropland (a)	Grassland (a)	Wetlands (a)	Settlements (a)	Other land
	Forest land (a)	R	R	R	R	R	NO
	Cropland (a)	R	R	Included in *Cropland remaining Cropland* (crop-pasture rotations)	R	NO	NO
	Grassland (a)	R	Included in *Cropland remaining Cropland* (crop-pasture rotations)	R	R	NO	NO
	Wetlands (a)	R	Included in Wetlands remaining wetlands (b)	Included in Wetlands remaining wetlands (b)	R	NO	NO
	Settlements (a)	R	Included in Settlements remaining settlements (b)	Included in Settlements remaining settlements (b)	R	R	NO
	Other land	NO	NO	NO	NO	NO	R

(a) Australia considers all land to be managed, except for *other land*, therefore there is no land in unmanaged land sub-categories and there are no transitions from managed to unmanaged land or vice-versa.

(b) Australia applies Approach 3 spatially explicit tracking of annual conversions to and from forest lands and Approach 1 for areas under grasslands, wetlands and settlements. As a result, only total areas are known for the areas under the latter conversion categories, not the prior land-use. In accordance with the *IPCC 2006 Guidelines*, emissions and removals are estimated using the methods for land remaining in a land category where the prior land-use is not known.

In this submission, building on the previous years' submission, Australia has prepared additional estimates for the voluntary reporting category of wetlands based on the 2013 *Wetlands Supplement*. This submission captures activities relating to coastal wetlands, with a focus on mangrove forest and tidal marsh habitats, along with aquaculture production. Emissions estimates resulting from the impacts of capital dredging on seagrass meadows have been reported for the first time in this submission. Further additional estimates are to be included in future submissions, as per planned improvements described in Chapter 6, including extending coverage to inland wetlands as well as expanding the scope of activity data relating to coastal wetland habitats.

ANNEX 6: Additional information: quality controls including Australia's National Carbon Balance

A6.1 Additional information on the QA/QC Plan

The management of the QA/QC activities relating to the inventory are undertaken by the National Inventory Team within the Department of the Environment and Energy (DoEE) and detailed in the *National Greenhouse Accounts: Quality Assurance-Quality Control Plan.* An overview of the quality control system is provided in Chapter 1 while sector-specific information on quality control activities has been included in the QA/QC sections of each chapter. This Annex provides additional information and, in particular, provides information in relation to three aspects of the quality control system: i) a detailed description of the quality control measures in place; ii) results of the carbon balance for the economy; and iii) a description of Australia's responses to the recommendations contained in the previous UNFCCC ERT report.

The objectives of the national inventory quality system are to support the provision of emission estimates that meet the UNFCCC criteria of accuracy; time series consistency; transparency, completeness and comparability of estimates with those of other parties.

Key risks to the attainment of the defined quality objectives are identified at each level of inventory preparation including the measurement of data at the facility level; the collation of activity and other input data by DE and other agencies; and the process of emissions estimation.

Specified mitigation strategies, measures and routine actions are deployed to control the identified risks.

These strategies range from utilisation of data measurements governed by existing national measurement systems such as the *National Measurement Act* or various taxation acts to the use of automated quality control tools embedded in the Australian Greenhouse Emissions Information System (AGEIS). Principal mitigation strategies and control measures are set out in Table A6.1.

Monitoring of the quality measures and evaluation of the results are critical to the goal of maintaining the system's effectiveness. In particular, control measures include the use of mass balance checks for all years to assess completeness and accuracy. All carbon entering the market economy is accounted for – either as emissions or stored in products or stored in wastes. Carbon balances for fuels, biomass, carbonates, synthetic gases and wastewater consumption have been constructed and the results presented as Australia's National Carbon Balance in Table A6.2.

In response to a recommendation by the previous UNFCCC ERT reports, models have been developed to demonstrate the flows of fugitive methane and carbon dioxide associated with underground and surface coal mines. The underground coal mine model shown in Figure A6.2 also demonstrates the effectiveness of methane capture for electricity generation and flaring in reducing the net fugitive emissions – capturing 40 per cent of the gross methane generated from underground coal mining.

External review of the inventory is a critical part of the process of ensuring the quality of the estimates. In principle, the Australian inventory is subject to audit by the Australian National Audit Office (ANAO), and a performance audit was conducted by the ANAO in 2009–10. In addition, each year the inventory is reviewed by international experts organised as part of the UNFCCC expert review team process. In Tables A6.6a to A6.6e, the recommendations of previous UNFCCC ERT reports have been included for increased transparency and a summary of Australia's responses included. These tables provide a tool for tracking the management of the ERT recommendations and suggestions.

Table A6.1 Summary of principal mitigation strategies and quality control measures

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
1.A.1 (i)	Accuracy, completeness and time series consistency	Facility-level data for Energy, IP and Waste subject to national measurement system and Australian regulations and international standards as specified in the NGER Measurement Determination 2008	Compliance	Department of the Environment and Energy	6.7.2.2, page 6.16
1.A.1 (ii)	Accuracy, completeness and time series consistency	Agriculture and transport data subject to measurement standards of the Australian Bureau of Statistics (ABS).	Compliance	Monitoring through evaluation of NGER (Measurement) Determination 2008.	6.7.2.2, page 6.16
1.A.1 (iii)	Accuracy, completeness and time series consistency	Geospatial data.	<10% of SLATS forest clearing.	Department of the Environment and Energy	6.7.2.2, page 6.16
1.A.1 (iv)	Accuracy, completeness and time series consistency	Climate data received by the Department subjected to rigorous visual and quantitative checks based on ensuring 1) no null values 2) coverage of entirety of Australia 3) free of errors while ingesting into FullCAM.	Compliance	Department of the Environment and Energy	6.7.2.2, page 6.16
1.A.2	Accuracy	Data submitted under NGERs subject to Clean Energy Regulator Scheme Audit and Assurance unit.	Compliance	Clean Energy Regulator Scheme Audit and Assurance unit	6.7.2.2, page 6.16
1.B.1	Comp-arability	Integration of national and facility estimation method within National Greenhouse Accounts Framework	Compliance	National Inventory Team	6.7.1.2 page 6.12
1.D.1	Transparency	Company level data published by the Clean Energy Regulator under the NGER Act 2007.	Compliance	Company level data published by the Clean Energy Regulator under the NGER Act 2007.	6.5, page 6.8

Annexes

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
2.A.1	Accuracy	Comparison of energy data with independent sources of activity data.	Reconciliation within <2%.	Excel spreadsheet comparison using dataset from AES, NEM review, Coal Services Pty Ltd, Queensland Department of Mines and Energy	6.7.2.1, page 6.15
2.A.2	Accuracy	External consultants operate QC protocol	Compliance	National Inventory Team	6.4, page 6.16
2.A.3	Accuracy	Quality control systems for external data providers.	Compliance	Agency Governance Board	6.4, page 6.16
2.B.1	Completeness	Application of standardised rules for use of facility level data in national inventory.	Compliance	See Chapter 1 of the National Inventory Report (NIR)	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (i)	Completeness	Reconciliation of estimates of energy in fuel supplies to the Australian economy and energy contained in data inputs used in the estimation of carbon in emissions; or stored in products; or non-oxidised; or in permanent storage.	Compliance with target objective of <0.1%	AGEIS Automated Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (ii)	Completeness	Reconciliation of estimates of carbonate supplies to the Australian economy and estimates of carbonates in data inputs used in estimation of emissions; or stored in products; or waste residues or in permanent storage	Compliance with target objective of <1%	AGEIS Automated Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (iii)	Completeness	Reconciliation of estimates of carbon in biomass supplies to the Australian economy and carbon contained in data inputs used for estimation of emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <1%	Excel spreadsheet using data from ABARES forestry publication	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (iv)	Completeness	Reconciliation of estimates of carbon in wastewater to the Australian economy and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <1%	AGEIS Automated Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
2.B.2 (v)	Completeness	Reconciliation of estimates of nitrogen in wastewater to the Australian economy and nitrogen contained in emissions or stored in products or other by-products	Compliance with target objective of <1%	AGEIS Automated Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (vi)	Completeness	Reconciliation of estimates of carbon in synthetic gases supplied to the Australian economy and synthetic gases contained in emissions or stored in products or destroyed	Compliance with target objective of <0.1%	AGEIS Automated Report.	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (vii)	Completeness	Reconciliation of estimates of natural gas consumption in the Australian economy as reported by various data sources.	Compliance with target objective of <3%	NGER data	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (viii)	Completeness	Reconciliation of estimates of land allocated to land use and land use change classifications and aggregated total land supply.	Compliance with target objective of <0.1%	National Inventory Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
3.A.1 (i)	Accuracy	Selection of emission estimation methodologies should be consistent with IPCC Good Practice and comparable with international practice.	Compliance	NGGI Committee.	IPCC Good Practice Guidance
3.A.1 (ii)	Accuracy	Tier 2 (3) model parameters should not be significantly different to the mean of NGER facility-specific data.	Compliance	National Inventory Team.	6.7.1.2, page 6.13
3.A.1 (iii)	Accuracy	Tier 2 (3) model parameters should not be significantly different to results from the public empirical research program that meet specified conditions for quality.	Compliance	National Inventory Team.	6.7.1.2, page 6.13
3.A.1 (iv)	Accuracy	Tier 2 (3) model parameters should not be significantly different to results from privately measured datasets that meet specified conditions for quality.	Compliance	National Inventory Team.	6.7.1.2, page 6.13
3.A.2 (i)	Accuracy	AGEIS development in accordance with COBIT	Compliance	AGEIS and FullCAM Advisory Board	AGEIS Strategic Plan
3.A.2 (ii)	Accuracy	AGEIS operation in accordance with COBIT	Compliance	AGEIS and FullCAM Advisory Board	AGEIS Strategic Plan
3.A.2 (iii)	Accuracy	Allocation of separate staff roles and responsibilities	Compliance	AGEIS and FullCAM Advisory Board	6.4, page 6.7

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
3.A.2 (iv)	Accuracy	FullCAM development in accordance with COBIT	Compliance	AGEIS and FullCAM Advisory Board	FullCAM Strategic Plan
3.A.2 (v)	Accuracy	FullCAM operation in accordance with COBIT	Compliance	AGEIS and FullCAM Advisory Board	FullCAM Strategic Plan
3.A.3	Accuracy	Verification of selected AGEIS estimates by sectoral experts.	Difference between AGEIS inventory estimates and verification estimates should be less than 0.1%	Data comparison with sector-specific calculation sheets using Excel spreadsheet.	6.7.3, page 6.16
3.A.4	Accuracy	The estimated uncertainty of the overall inventory should decline over time	Compliance	Annex 2 of the NIR 2016	6.9, page 6.18
3.A.5	Accuracy	Number of significant accuracy issues raised by the UNFCCC ERT 2016, and agreed by the Department, should reduce over time.	Compliance	UNFCCC Expert Review Team Report	6.8, page 6.18
3.B.1 (i)	Completeness	Reconciliation of fuel data submitted into the AGEIS and carbon contained in emissions or stored in products or non-oxidised or permanent storage	Compliance with target objective of <0.01%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3 page 6.16
3.B.1 (ii)	Completeness	Reconciliation of carbonate data submitted into the AGEIS and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.001 %	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3 page 6.16
3.B.1 (iii)	Completeness	Reconciliation of biomass data submitted into the AGEIS and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.001%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3 page 6.16
3.B.1 (iv)	Completeness	Reconciliation of carbon in wastewater data submitted into the AGEIS and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.001%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3 page 6.16
3.B.1 (v)	Completeness	Reconciliation of nitrogen in wastewater data submitted into the AGEIS and nitrogen contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.001%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3 page 6.16

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
3.B.1 (vi)	Completeness	Reconciliation of HFCs in data submitted into the AGEIS and carbon contained in emissions or stored in products or waste residues or in permanent storage.	Compliance with target objective of <0.001%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3 page 6.16
3.B.1 (vii)	Completeness	Reconciliation of CO2 emissions in the LULUCF sector with the results of carbon stock accounting models.	Compliance with target objective of <0.001%	ABARES Australia's State of Forests Report	Table 6.1, page 6.10; 6.7.3 page 6.16
3.B.1 (viii)	Completeness	Reconciliation of carbon in fossil fuels, carbonates, biomass, synthetic gases and wastewater in data submitted into the AGEIS and carbon contained in emissions or stored in products or destroyed.	Compliance with target objective of <0.001%	AGEIS Automated Report.	Table 6.1, page 6.10; 6.7.3 page 6.16
3.B.2 (i)	Completeness	Reconciliation of National Inventory with aggregate of State and Territory inventories	Compliance with target objective of <0.1%	AGEIS Automated Report	6.7.2.1, page 6.14
3.B.2 (ii)	Completeness	Reconciliation of the National Greenhouse Gas Inventory with the National Inventory by Economic Sector	Compliance with target objective of <0.1%	AGEIS Automated Report	6.7.2.1, page 6.14
3.B.2 (iii)	Completeness	Reconciliation of the National Greenhouse Gas Inventory with OLAP output from the Australian Greenhouse Emissions Information System.	Compliance with target objective of <0.1%	AGEIS Automated Report	6.7.2.1, page 6.14
3.B.3	Completeness	Number of emission sources not estimated, for which IPCC methods exist, comparable with international practice	Consistent with international practice	UNFCCC Expert Review Team Report	6.8, page 6.18
3.B.4	Completeness	Number of significant completeness issues raised by the UNFCCC ERT 2016, and agreed by the Department, should reduce over time	Compliance	UNFCCC Expert Review Team Report	6.8, page 6.18
3.C.1	Comparability	Implied emission factors for key variables should not be significantly different to those of other UNFCCC reporting parties	Compliance	AGEIS Automated Report	6.7.1.2, page 6.13
3.C.2	Comparability	Number of significant comparability issues raised by the UNFCCC ERT 2016, and agreed by the Department, should reduce over time	Compliance	UNFCCC Expert Review Team Report	6.8, page 6.18
3.C.3	Comparability	Recalculation percentages for the national inventory Annex A sectors should not be significantly different to those of other UNFCCC reporting parties over time	Compliance	UNFCCC National Inventory submissions 2016	6.8, page 6.18

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
3.D.1	Time series	Analysis by category for time series consistency	Compliance	UNFCCC Expert Review Team Report	Table 6.1, page 6.11
3.D.2	Time series	Number of significant time series consistency issues raised by the UNFCCC ERT 2016, and agreed by the Department, should reduce over time	Compliance	UNFCCC Expert Review Team Report	Table 6.1, page 6.11
3.E.1	Transparency	Publication of assumptions, methodologies, data sources and emission estimates in the National Inventory Report and related products	Compliance	National Inventory Report 2014	6.5, page 6.8
3.E.2	Transparency	Publication of the AGEIS emissions database on the Department website and related products	Compliance	http://ageis.climatechange.gov.au/	6.5, page 6.
3.E.3	Transparency	Number of significant transparency issues raised by the UNFCCC ERT 2016, and agreed by the Department, should reduce over time	Compliance	UNFCCC Expert Review Team Report	6.5, page 6.

* Planned for AGEIS implementation 2016-17.

Annexes

A6.2 Australia's National Carbon Balance

Table A6.2 Australia's National Carbon Balance 2016

Supply	Kt C	Uses	Kt C
Fossil fuel consumption* (a)	113,012	*Emissions*	
Carbonate consumption (a)	1,878	1.A Combustion emissions (fossil fuels)	103,185
Hydrofluorocarbon consumption (d)	4,326	1.B Fugitive emissions	43
		2.A Industrial process fossil fuel emissions	3,769
		Memo: International bunker fuels	3,855
		2.A Mineral product carbonate emissions	1,858
Biomass consumption		2.F Hydrofluorocarbon emissions (d)	3,594
Wood and paper products (a)	5,843	Memo: Combustion emissions (wood products and waste)	350
Bagasse, ethanol, biogas (b)	3,004	Memo: Combustion emissions (bagasse, ethanol, biogas)	3,004
Firewood (b)	1,048	Memo: Combustion emissions (all wood)	2,213
		5.A Landfill emissions from HWP	301
Waste disposal (food, garden, textiles, rubber – landfill)(c)	1,175	5.A Landfill emissions from non-HWP	753
		Aerobic treatment processes (paper, wood and wood waste)	1,080
		Increment to product stocks	
		Petrochemical and steel products	102
		Carbonate products	1
		Hydrofluorocarbon products (d)	540
		Increment to HWP stocks	2,413
		Biomass fibre recycled	1,427
		Increment to waste stocks and residues	
		Carbon dioxide captured for permanent storage	
		Non-oxidised carbon*	892
		Carbonate wastes	20
		Increment to HWP waste in landfill	271
		Increment to non-HWP waste in landfill	510
		Miscellaneous	
		Hydrofluorocarbons destroyed	192
		Residual	-88
Total supply	**130,286**	**Total uses**	**130,286**

Notes: (a) entering market; (b) final consumption; (c) entering waste stream; (d) based on carbon dioxide equivalents.
* Coal fuelled electricity generation assumes the NGERS oxidation factor of less than 100 per cent oxidation.

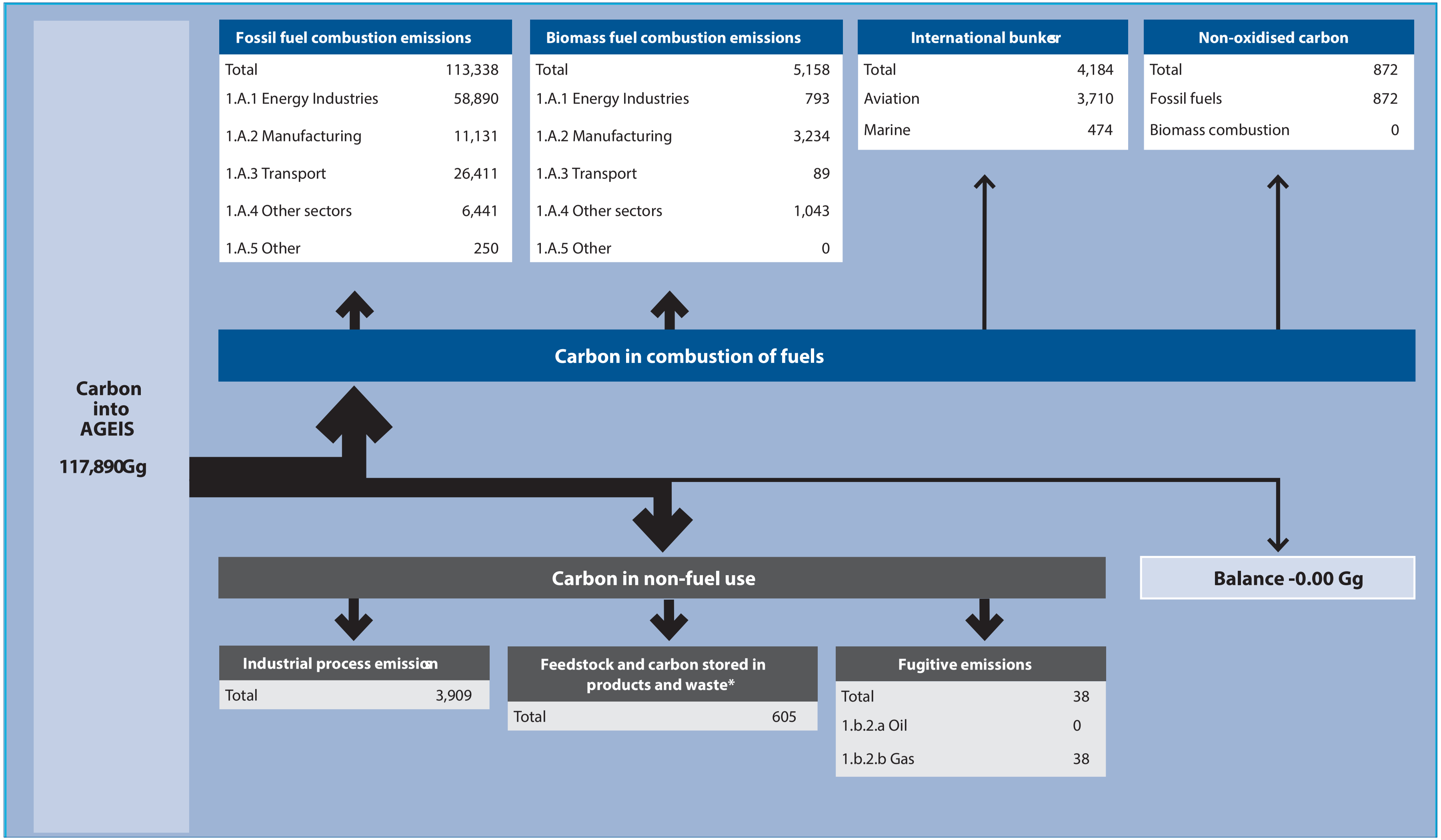
Australia's National Carbon Balance records the supply of carbon entering the market economy through the most important channels and tracks the uses or fates of that carbon allocated amongst greenhouse emissions, increments to the stock of carbon in products and increments to the stock of carbon in waste residues. Of the 130,286 kt C of carbon entering the market economy, 130,374 kt C is estimated to result in greenhouse gas emissions; 4,483 kt C is estimated to result in increments of the carbon stock in products and 1,693 kt C is estimated to result in increments to carbon stored in waste product and residues.

Assessments of the total amount of carbon in stock are more difficult to assess and depend critically on starting assumptions. Bearing this in mind, it is estimated that there is approximately 94 Mt of carbon stored in harvested wood products in Australia and about 50 Mt of carbon stored in landfills. The latter estimate relies on the relatively strong assumption that all landfills have been maintained in order to fulfil anaerobic conditions. If the alternative assumption was adopted, such that it was assumed that all landfills were eventually exposed to aerobic conditions, then the amount of carbon stored in landfills would tend to zero over very long time periods.

The National Carbon Balance is also used as a quality control tool. The Australian inventory utilises a very large number of disaggregated data inputs for energy-related emission calculations (~15 000 per year). Consequently, a carbon balance is undertaken to compare carbon input to carbon output for all years. The carbon input represents the carbon embodied within the total quantity of energy and non-energy fuels which have been consumed in a year, and are entered into the AGEIS for calculation. The carbon output represents the distribution of the carbon utilised throughout the economy, as determined by the output of the calculations within the AGEIS. The carbon output is distributed as either emissions from fuel combustion, emissions from the use of fossil fuels as reductants, non-energy uses (e.g. feedstocks, bitumen, coal oils and tar), use of biomass sources of energy and international bunkers. While the predominant outcome of carbon entering the economy is emissions, a small portion of the carbon is stored in carbon-containing products or non-oxidised as ash. A flow chart detailing the results of the carbon balance for 2016 is at Figure A6.1.

For 2016, all carbon was within 0.001 per cent, which is the tolerance level prescribed in the Quality Assurance/ Quality Control Plan. The carbonate balance is one of the components that make up the overall carbon balance. Assumptions on the molecular weight of the mix of 'other' carbonates, which contents are unknown causes a difference of 0.053 per cent. Due to this, the carbonate balance is accounted for at an acceptable level. Due to the influence of the carbonate balance, the carbon balance has reached a difference of 0.067 per cent. As a result, the carbon balance is accounted for at an acceptable level with a 0.067 per cent difference.

Figure A6.1 Balance flow chart showing carbon inputs and distribution of outputs for 2016



* Include CO_2 captured for temporary storage and transfer offsite

Figure A6.2 Fugitive gas balance flow chart for underground mines, 2016

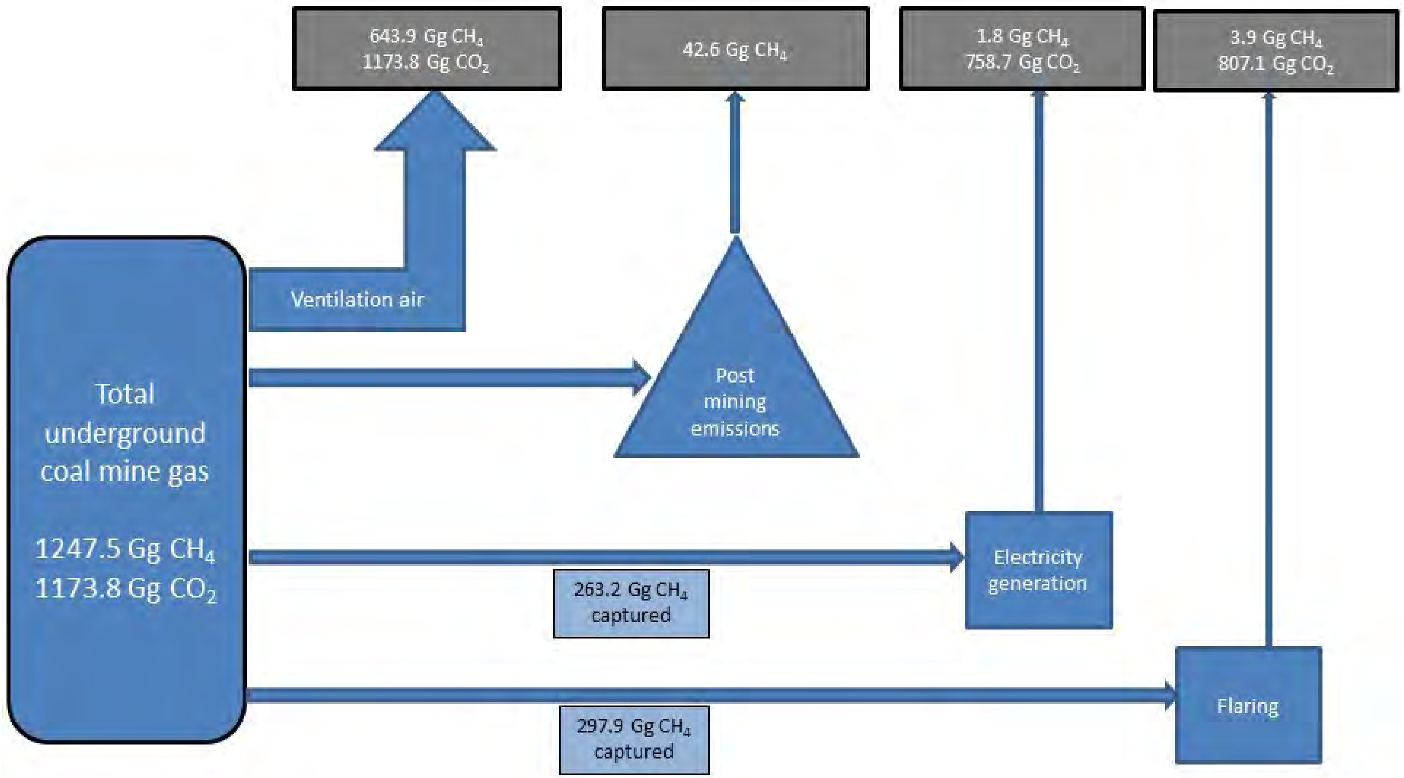


Figure A6.3 Fugitive gas balance flow chart for open cut mines, 2016

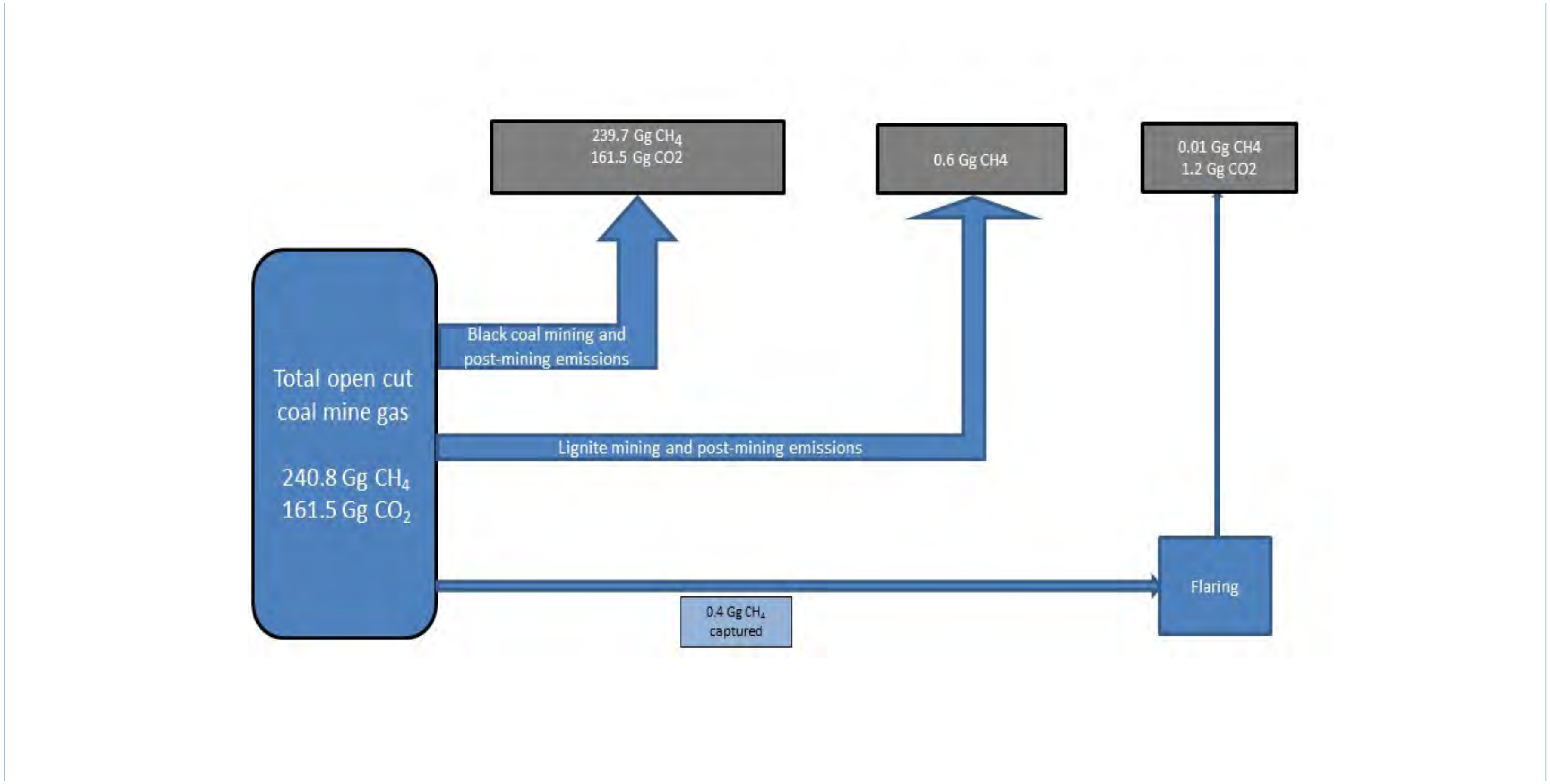


Table A6.3 Underground mining raw coal production, by coal field

Year	Coal Production by Basin (tonnes of production)							
	HUNTER	SOUTHERN	WESTERN	NEWCASTLE	BOWEN NORTHERN CENTRAL	BOWEN CENTRAL	BOWEN SOUTHERN	QLD SOUTHERN
1990	4,344,800	17,771,200	8,685,300	18,971,900	684,542	5,173,984	591808	523410
1991	4,848,129	18,134,150	9,433,269	18,435,910	659,348	6,549,461	635513	779744
1992	5,197,075	18,071,525	7,806,943	18,423,863	508,221	8,175,110	548438	595156
1993	4,622,113	17,566,298	9,947,807	17,705,992	589,456	8,782,642	632108	692298
1994	3,371,283	16,217,123	10,377,687	16,824,755	1,159,564	10,711,371	629277	618883
1995	6,364,090	14,663,729	11,613,380	16,061,104	2,564,908	13,172,078		687236
1996	9,192,400	15,314,900	13,002,300	16,804,600	1,612,780	10,992,009		597411
1997	10,813,245	15,784,757	12,697,898	15,346,470	3,846,835	13,756,322		558769
1998	14,144,563	15,360,353	12,010,638	16,783,447	4,543,003	19,158,765		
1999	13,680,481	13,112,341	10,860,591	13,664,985	7,398,073	20,290,940		
2000	15,252,463	11,805,638	10,447,917	15,257,326	13,169,231	25,006,028		
2001	14,589,035	12,602,477	12,775,399	13,751,733	11,214,891	27,105,717		
2002	13,081,548	12,693,281	12,984,571	13,831,303	12,196,246	26,580,624		
2003	12,257,057	11,174,159	12,683,711	10,842,531	11,661,140	23,111,145		
2004	16,582,600	10,434,890	10,924,964	11,412,069	9,618,348	22,058,438		
2005	15,207,383	12,142,786	13,655,101	10,901,574	11,953,481	22,731,234		
2006	15,674,644	13,340,369	12,676,749	10,540,319	11,754,358	22,534,011		
2007	16,875,285	13,412,166	12,929,478	14,023,563	14,351,067	21,268,729		
2008	17,311,462	11,507,490	12,741,554	13,917,235	16,842,856	25,972,448		
2009	19,245,169	12,707,969	16,562,805	14,552,747	16,778,503	24,262,219		
2010	19,580,571	12,985,314	15,082,379	15,156,042	21,775,029	30,182,038		
2011	16,028,421	14,261,975	16,146,188	15,697,532	17,056,976	28,099,846		
2012	11,579,449	16,559,350	16,262,355	16,060,680	10,634,861	24,734,441		
2013	18,719,469	16,059,422	17,306,310	16,907,142	19,811,148	26,869,534		
2014	21,502,396	15,008,927	21,269,733	16,311,233	18,420,997	28,550,873		
2015	15,011,591	17,257,917	28,540,355	16,935,960	22,856,422	30,662,361		
2016	13,349,675	15,094,766	25,236,372	11,778,374	22,564,967	32,219,885		
2017	12,390,066	12,825,284	27,860,425	11,228,860	24,624,784	26,738,958		

Source: Queensland Department of Energy and Water, Coal Services Pty Ltd

Table A6.4 Australian Petroleum refining activity data

Year	Fuel type (PJ)		
	Solid	Liquid	Gas
1990	-	76.0	11.3
2000	-	80.1	18.6
2001	-	80.6	20.0
2002	-	78.9	20.7
2003	-	75.4	22.3
2004	-	67.0	22.7
2005	-	65.1	24.1
2006	-	56.1	24.6
2007	-	63.3	23.6
2008	-	60.7	22.8
2009	-	68.2	14.1
2010	-	72.4	12.5
2011	-	75.6	14.5
2012	-	69.5	17.6
2013	-	69.2	14.1
2014	-	66.1	10.9
2015	-	55.6	10.3
2016	-	44.2	4.2

Source: Australian Energy Statistics and NGER

A6.3 Summary of Responses to UNFCCC ERT Recommendations and Comments

As at the time of submission of this Report, the review of Australia's previous report, *National Inventory Report 2016*, had not been completed. The recommendations contained in this section are those that were not the subject of discussion between Australia and the review team at the time of submission of this Report.

Table A6.6(a) Status of Issues raised in the previous report

Sector	Report and paragraph reference	ERT Recommendation	Response	Implementation
I.6	2.B.1 Ammonia production – CO_2 (I.8, 2016) (I.10, 2015) Transparency	Ensure consistency between the emission levels reported in the IPPU chapter of the NIR and in the key category analysis.	Not resolved. As provided in the rationale in ID# I.3 above, disaggregation of emission data for ammonia production is very limited owing to confidentiality requirements under the NGER system. However, in the key category analysis (NIR vol. 3, annex 1, p. 105) CO_2 emissions for ammonia production are estimated disaggregated for the base year (603 kt CO_2) and the current year (i.e. 2,606 kt CO_2 eq in 2015). The ERT noted that disaggregated data for ammonia production in the KCA have been provided since the 2015 submission and no explanation was provided by the Party on why it was possible to disaggregate in the KCA and not in the CRF table (see ID# I.3 above). During the review the Party informed the ERT that consistency will be ensured and the KCA will adhere to the current status of the CRF table.	Further disaggregation of chemical industry emissions is provided in this submission – see section 4.4.
I.8	2.C.1 Iron and steel production – CH_4 (I.15, 2016) (I.17, 2015) Transparency	Correct the AD for steel production in the CRF tables and improve the QA/QC tests for the reporting in the NIR and the CRF tables in order to avoid data entry errors.	Not resolved. The data for steel production (kt) reported in NIR table 4.16 are not consistent with the data reported in CRF table 2(I)A-Hs2 for 2014 and 2015.	Resolved.
I.10	2.F.5 Solvents – HFCs (I.28, 2016) (I.30, 2015) Accuracy	Align the calculation method with the definition provided in the NIR, and apply an operational loss of 25%, 50% and 25%, respectively, for use of F-gases as solvents.	Not resolved. Australia informed the ERT that the recommendation will be implemented in the next submission. In NIR section 4.8.6 (p. 254) the Party also explained that an operational loss rate of 25%, 50% and 25%, respectively, is to be applied to the vintage stock model for the use of F-gases as solvents.	The description of the method has been updated in NIR section 4.8.2.
L.5	4.A.2 Land converted to forest land – CO_2, CH_4 and N_2O (L.7, 2016) (L.28, 2015) Consistency	Implement the planned improvement to allocate the AD and emissions/removals from forest conversion events that occurred before 1990 and that are followed by natural regeneration in a consistent manner and in accordance with the 2006 IPCC Guidelines.	Not resolved. The Party has reported in the NIR (vol. 2, section 6.5.6) that the improvement of FullCAM regarding the revised allocation inputs will be completed and implemented in the next NIR.	This recommendation has been implemented for this NIR.

Sector	Report and paragraph reference	ERT Recommendation	Response	Implementation
L.6	4.A.2 Land converted to forest land – CO_2, CH_4 and N_2O (L.8, 2016) (L.28, 2015) Consistency	In the specific case of subsequent land-use changes within a period shorter than 50 years, base the rule for the allocation of AD and estimates in each reporting year on the end-use category of the land in that year.	Not resolved. The Party has reported in the NIR (vol. 2, section 6.5.6) that the improvement of FullCAM regarding the revised allocation inputs will be completed and implemented in the next NIR.	This recommendation has been implemented for this NIR.
L.7	4.A.2 Land converted to forest land – CO_2, CH_4 and N_2O (L.9, 2016) (L.29, 2015) Completeness	Report emissions/removals occurring throughout the reporting period owing to natural forest regeneration before 1990.	Not resolved. The Party has reported in the NIR (vol. 2, section 6.5.6) that the improvement of FullCAM regarding the revised allocation inputs will be completed and implemented in the next NIR.	This recommendation has been implemented for this NIR.
KL.3	Forest management – CO_2 (KL.5, 2016) Accuracy	Consider a longer time series (including the years 1990–2009) for determining the calibration period for applying the natural disturbance provision (e.g. using (part of) the information presented on wildfires for 1850–2009) and avoid restricting the calibration period to 2000–2012.	Not resolved. The use of a longer time series including the years 1990–2009, and possibly part of the information on the long-term fire history, is under consideration. This is part of the planned improvements described in NIR vol.3, section 11.6.4 (p.30–31).	Consideration has now been made and Australia has discerned that it is not possible to implement a longer time series due to a lack of reliable and consistent source data prior to 1988.

Table A6.6(b) Issues identified in three or more successive reviews and not addressed by the Party

Sector	Report and paragraph reference	ERT Recommendation	Response	Implementation
I.2	(2015-17)	Confirm or update the CaO and MgO content ratios in order to ensure the accuracy of the values for more recent years and the consistency of the time series	Agreed	From 2016 onwards, 2 cement facilities have report facility-specific EFs based on the CaO and MgO contents of their cement. The remaining facilities continue to use the CS factor as described in NIR section 4.3.1 as this best represents their particular product specifications.
I.5	(2015-17)	Improve the level of transparency used to report disaggregated subcategory emission data for ammonia production, while preserving the legally required confidentiality in the overall reporting of emissions	Agreed	Further disaggregation of chemical industry emissions is provided in this submission – see section 4.4.
I.6	(2015-17)	Ensure consistency between the emission levels reported in the IPPU chapter of the NIR and in the key category analysis	Agreed	Consistency is ensured in the current submission
I.7	(2015-17)	Investigate whether other drivers could be applied to estimate emissions from lead production, zinc production and other (metal production) for the period 1990–2008, such as production volumes	Agreed	An alternative data source has been obtained from the Resources and Energy Quarterly (DIIS 2007). These data will be assessed for use in the 2019 submission.
I.8	(2015-17)	Correct the AD for steel production in the CRF tables and improve the QA/QC tests for the reporting in the NIR and the CRF tables in order to avoid data entry errors	Agreed	Resolved.
I.9	(2015-17)	Include in the methodological description in the NIR a more accurate description of the methodology used, in particular the use of the vintage stock model	Agreed	The description of the method has been updated in NIR section 4.8.2.
I.10	(2015-17)	Align the calculation method with the definition provided in the NIR, and apply an operational loss of 25%, 50% and 25%, respectively, for use of F-gases as solvents	Agreed	The description of the method has been updated in NIR section 4.8.2.
L.5	(2015-17)	Implement the planned improvement to allocate the AD and emissions/removals from forest conversion events that occurred before 1990 and that are followed by natural regeneration in a consistent manner and in accordance with the 2006 IPCC Guidelines	Agreed	This recommendation has been implemented for this NIR.
L.6	(2015-17)	In the specific case of subsequent land-use changes within a period shorter than 50 years, base the rule for the allocation of AD and estimates in each reporting year on the end-use category of the land in that year	Agreed	This recommendation has been implemented for this NIR.

Sector	Report and paragraph reference	ERT Recommendation	Response	Implementation
L.7	(2015-17)	Report emissions/removals occurring throughout the reporting period owing to natural forest regeneration before 1990	Agreed	This recommendation has been implemented for this NIR.

Table A6.6(c) General

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
G.7 Uncertainty	NIR	Australia reported the uncertainty assessment in NIR tables 2A.1 and 2A.2, (vol 3 annex 2, p. 119). The ERT noted that the information on GHGs in column B of tables 2A.1 and 2A.2 was provided either as CO_2 eq, or as a specific gas (e.g. CO_2, CH_4 etc). For example in NIR table A2.1, the CO_2 eq instead of the specifc gases was reported for category 1.A.1.a (electricity generation) for black coal, brown coal and natural gas); while for category 1.A.1.a (electricity generation – liquid fuels) the mass of particular gases (CO_2 ,CH_4 and N_2O) are reported. The ERT further noted that in accordance with the 2006 IPCC Guidelines (Vol. 1, chapter 3) the uncertainty analysis has to be performed by category and by gas and not the CO_2-eq as indicated in column B of tables 3.2 and 3.3, chapter 3, Vol.1 of the 2006 IPCC Guidelines. The ERT is of the view that the combination of CO_2-eq and specific GHGs in the uncertainty analysis may affect the comparability of the uncertainty values included in the estimates, lead to additional ambuguity and finally result in incorrect estimate of the overall uncertainty. **The ERT recommends** that, Australia undertake the inventory uncertainty analysis on gas-by-gas basis using the particular GHGs as recommended by the 2006 IPCC Guidelines, or provide transparent information that the procedures used are in accordance with the 2006 IPCC Guidelines. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Comparability	Agreed	This recommendation has been implement for this NIR.

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
G.8 Uncertainty analysis	NIR	Australia reported in NIR tables A2.1 and A2.2 (vol 3, annex 2) the inventory uncertainty analysis. The ERT noted that in accordance with the UNFCCC Annex I inventory reporting guidelines, paragraph 15, Parties are required to report "the uncertainties for at least the base year and the latest inventory year and the trend uncertainty between these two years." In response to the question raised by the ERT, Australia clarified that the uncertainty for the base year was not included in the NIR and provided the uncertainty estimate for the base-year as ±7.9% (including LULUCF) and ±4.0% (excluding LULUCF). **The ERT recommends** that Australia include information on the base year uncertainty assessment in next inventory submissions *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Adherence to the UNFCCC Annex I inventory reporting guidelines	Agreed	This recommendation has been implement for this NIR.

Table A6.6(d) Industrial processes and product use

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
I.14 2.D.1 Lubricant use – CO_2	NIR	The ERT noted that CRF table 2(I)A-Hs2 shows a CO_2 IEF of 0.00053 t CO_2/t for lubricant use in 2015. During the review, the Party confirmed that a wrong unit was used when the value was entered into the CRF table and that the correct value of the CO_2 IEF should be 0.53 t CO_2/t. **The ERT recommends** that the Party correct the CO_2 IEF in CRF table 2(I)A-Hs2 and verify whether CO_2 emission estimates are accurated and inform about the results in the next submission *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Accuracy	Agreed	This issue has been addressed in this submission
I.15 2.A.4 Other process uses of carbonates – CO_2	NIR	The ERT noted that CRF table2(I)A-Hs1 shows a CO_2 IEF of 0.00048 t CO_2/t of carbonate use (category 2.A.4.d (other)). During the review, the Party confirmed that a wrong unit was used when the value was entered into the CRF table and that the correct value should be 0.48 t CO_2/t of carbonate use. **The ERT recommends** that the Party correct the CO_2 IEF in CRF table 2(I)A-Hs1 and verify whether CO_2 emission estimates are accurated and inform about the results in the next submission. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Accuracy	Agreed	This issue has been addressed in this submission

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
I.16 2.B.1 Ammonia production – CO 2	NIR	Australia reported in NIR section 4.4.1 (p. 190) that "a portion of CO_2 emissions arising from ammonia production are recovered for use in the production of urea" and that "emissions from the production and use of urea are included with the emissions from ammonia (category 2.B.1) in accordance with good practices". The ERT noted that, at the same time Australia also reported CO_2 emissions from urea use under the agriculture sector, in category 3.H (urea application) using a tier 3 method for AD (i.e. plant-level natural gas consumption). The ERT noted that potential double counting might be occurring. During the review the Party indicated that CO_2 emissions from the use of urea are subject to a small double counting, with emissions being included in both the production and the use of urea produced in Australia and that this will be corrected in the next submission. The Party also explained that the reporting of CO_2 emissions from urea consumption in agriculture (category 3.H) was introduced in 2015 and a correction to the reporting of CO_2 from ammonia was not made. Data on urea consumption is provided annually by Fertilizer Australia and includes domestic and imported urea. The vast majority of urea consumed in Australia is from imported sources (over 88% in 2015). The consumption of domestically produced urea in the agriculture sector amounted to 6.4 Gg CO_2 in 2015, which represents an overestimation of national GHG emissions (without LULUCF) of 0.0012%. **The ERT recommends** that the Party correct the double counting of CO_2 emissions in urea production and use by excluding from ammonia production (category 2.B.1) the CO_2 emissions recovered for use in the production of urea and reporting such emissions in accordance with the 2006 IPCC Guidelines (Vol 3, Chapter 3, Box 3.2). *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Accuracy	Agreed	This issue has been addressed in this submission. See section 4.4.1 of the NIR.
I.17 2.B.1 Ammonia production – CO_2	NIR	Section 4.4.10 of the NIR "Source specific QA/QC" (for chemical production) indicates that the quantity of CO_2 generated per tonne of ammonia produced has been compared with that of Annex I Parties reporting emissions from ammonia production (t CO_2/t ammonia produced). The majority of Parties fall into a range of 0.44–0.52 t CO_2/t ammonia produced according to figure 4.4 of the NIR. Below figure 4.4. it is stated in the text that "The IEF for ammonia production for Australia ranges between 1.181 t CO_2 and 1.544 t CO_2 per tonne of ammonia produced." On the same page it is stated that "Statistical analysis indicates that the IEF for ammonia production for Australia is not significantly different to the factors reported by other Annex I parties." However, the ERT noted that the IEF range indicated by the Party for ammonia production is 2–3 times higher than the factors reported by other Annex I Parties as presented in figure 4.4. During the review the Party indicated that this was an editorial error during the graphic design process and that figure 4.4 was generated with data from figure 4.3 (carbonate consumed) and provided to the ERT the correct figures. **The ERT recommends** that the Party correct figure 4.4 in the NIR to reflect the correct CO_2 generated per tonne of ammonia produced. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Adherence to the UNFCCC Annex I inventory reporting guidelines	Agreed	This issue has been addressed in this submission. See section 4.4.10 of the NIR.

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
I.18 2.G.3 N_2O from product uses –N2O	NIR	Australia indicated in NIR section 4.4.2 (p.192), in response to a previous recommendation, that N_2O emissions from product uses are estimated based on imports in addition to domestic production (see ID# I.11 in table 3). However, during the review the ERT noted that in NIR table 4.3 (p. 176), the consumption of N_2O from product use is estimated based on company surveys, but there is no indication of whether this covers imports as well. In response, the Party clarified that prior to 2003, it is assumed that all consumption of N_2O was derived from domestic production. From 2003 onwards, one of the two N_2O producing plants in Australia ceased production and imports of N_2O commenced and N_2O emissions from product uses are estimated based on imports in addition to domestic production. In addition, Australia clarified that while it is known that imports are occurring, actual import data are not available and therefore emissions are estimated using a per capita usage factor assumed to include imports and domestic production throughout the time series. The ERT noted that the Party has not explained in the NIR the fact that a per capita usage factor is used to include imports and also does not provide a justification as to how it has been ensured that the usage factor includes imports. **The ERT recommends** that the Party include an explanation in the NIR that no AD information on N_2O imports is available and emissions are estimated using a per capita usage factor assumed to include imports and domestic production throughout the time series. The ERT also recommends that the Party explain in the NIR the methodology used for estimating N_2O imports based on the per capita usage factor and verify if no underestimation/ overestimation of emissions occurs and report the results in the NIR. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Accuracy	Agreed	This issue has been addressed in this submission. See section 4.9 of the NIR

Table A6.6(e) Agriculture

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
A.14 3. General (Agriculture) – CH_4 and N_2O	NIR	In response to a previous recommendation (see A.1 in table 3) Australia provided in NIR section 5.3.2.2 (p. 265) an explanation of the approach and assumptions used to derive the average annual livestock populations. However, during the review the ERT noted that Australia derived annual livestock population of cattle (taken from the Australian Bureau of Statistics) by adjusting the numbers of cattle for an annual equivalent number of animals held on feedlots (NIR, vol.1, p. 262). Further details of the annual equivalent derivation methods are provided on p. 266 of the NIR. However, the reasons for adjustments have not been provided in the NIR. During the review, Australia explained that the feedlot cattle, on average, spend between 70 and 250 days on feedlots prior to slaughtering. With this, the annual equivalent population number is derived using an approach consistent with equation 10.1 in the 2006 IPCC Guidelines (vol. 4, chapter 10) and subtracted from beef cattle numbers. For example, feedlot cattle processed for domestic purposes spend 75 days on average in the feedlot. An annual equivalent population is derived by applying a multiplier of 0.21 (75/365). **The ERT recommends** that Australia explain in the NIR the reasons for adjusting the numbers of cattle and the assumptions considered per animal species in order to obtain the annual equivalent number of animals held on feedlots. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Transparency.	Agreed	The approach to deriving annual equivalent feedlot populations is clearly explained in section 5.3.2.2 as well as table 5.7 of the NIR.
A.15 3.A Enteric fermentation – CH_4	NIR	Australia reports in section 5.3.7.5 (p. 273) of the NIR on the external review conducted by agricultural experts from industry, government and academia on the agriculture sector; however, the ERT noted that NIR table 1.4 (p. 16) lists additional expert reviews carried out for methodologies and data in the agriculture sector in 2015 (e.g. the review of agriculture, cropland and grassland methods in 2015). The ERT asked for clarification on the documentation and main recommendations derived from this review and the status of implementation of those recommendations. In response, Australia provided information on the FullCAM (used to ensure consistent use of methods across the time series) and the Agriculture Inventory Expert Advisory Panel. Australia mentioned that an important outcome from the work of this panel was to consider and endorse for use in the inventory the research on enteric fermentation from cattle published in Charmley *et al.*. (2015). Australia also shared some further documents, including a non-public document *Dairy Technical Working Group 2015*, which includes a list of recommendations. The ERT also noted that most recommendations have been implemented, for example, on animal characteristics as can be seen in NIR appendix 5A. The ERT commends Australia for its efforts in continuously improving estimations. However, **the ERT recommends** that Australia include in the NIR information on the conduct and results of the quality assurance reviews of FullCAM (related to the review of agriculture, cropland and grassland) and on the Agriculture Inventory Expert Advisory Panel , in particular, providing information on: (1) the review recommendations outcomes, (2) status of implementation of those recommendations; and (3) reference. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Transparency.	Agreed	Further information has been provided in Table 5.4 of the NIR.

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
A.16 3.A.4 Other livestock – CH_4	NIR	Australia reported in table 5.10 of the NIR (p. 270) that a country specific EFs (tier 2) for emus/ostriches were derived based on the assumption that the size and anatomy of these animals was equal to half of that of a goat. The ERT noted that emus/ostriches and goats have different digestive systems and the 2006 IPCC Guidelines provide in table 10.10 (volume 4, chapter 10) a note on an approach for deriving approximated EFs using a tier 1 EF for an animal with similar digestive system and based on a weight ratio. During the review, Australia clarified that enteric fermentation EFs for emus/ostriches were determined by an expert working group. This determination was based on the enteric fermentation EFs for goats in the 2006 IPCC Guidelines based on size and anatomy. The body weight of an emu and an ostrich was determined to be comparable to that of a goat. The EF was then halved to take into account that emus and ostriches are not ruminants like goats, and therefore, their digestive process functions differently, but no justification for this calculation was provided. The ERT noted that in accordance with the 2006 IPCC Guidelines (Vol 4, chapter 10.2.4) data and methods used to characterize the animals should be well documented when developing a country specific EFs. **The ERT recommends** that Australia describe in the NIR a justification of the methodology used to identify the country specific EF for emus/ostriches in accordance with the 2006 IPCC Guidelines (vol. 1, chapter 2, table 2A.1) for example, by providing a summary or references in the NIR to the available information on the expert judgment (reports or peer review); or revise the methodology in accordance with the 2006 IPCC Guidelines (vol. 3, chapter 10.2.4). *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Accuracy.	Agreed	The EF for ostriches and emus is currently under review. An update will be provided in the next inventory submission.
A.20 3.C Rice cultivation – CH_4	NIR	The ERT noted that in NIR section 5.5.2 the Party uses a default EF (1.30 kg CH_4 ha-1 day-1) which, multiplied by an average of the 150 days of a growing season, gives an emission rate for Australia (195 kg CH_4/ha). The ERT noted that the 2006 IPCC Guidelines (vol. 4, section 5.5.1, p.5.48) recommends that the tier 1 method also use scaling factors to adjust the EF to account for various conditions such as the water regimes and the type and amount of organic amendments. During the review, Australia provided the ERT with the scaling factors applied (SFw=1, SFp=1, SFo=1) and explained that the original source for the 150-day continuously flooded growing season is provided by expert advice and obtained from the National Greenhouse Gas Inventory Committee of Australia. These operational characteristics are also supported by information from the Ricegrowers Association of Australia, including information that rice is planted in October and harvested in March and is grown using flood irrigation. **The ERT recommends** that Australia include in the NIR the scaling factors used, including a justification for the scaling factors used for the average growing season. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Transparency.	Agreed	Australia has updated the adjustment factors for rice cultivation to account for a non-flooded pre-season of > 180 days. See section 5.5.2 of the NIR.

Table A6.6(f) Land Use Land Use Change and Forestry

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
L.17 4. General (LULUCF) – Gen	NIR	Australia reported areas and changes in areas in CRF table 4.1 for the entire time series. However, the ERT noted that such data do not represent the annual changes in areas of land-use categories between the previous and the current inventory year. For instance, for 2015 the Party reported in CRF table 4.1 the area of 3,826.84 kha for grassland converted to forest land (category 4.A.2.2), and 2,200.65 kha for forest land converted to cropland (category 4.B.2.1). However, the ERT noted that these values are cumulative as can be seen in CRF tables 4.A and 4.B; and in CRF table 4.1 the annual change and not the cumulative value should be presented. **The ERT recommends** that the Party correct the annual changes data for land-use categories between the previous and the current inventory year in CRF table 4.1 for all categories. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Comparability.	Agreed	This recommendation has been implemented for this NIR.
W.3 5.B.1 Composting – N2O	NIR	The ERT noted that the CH_4 and N_2O EFs used for composting are referenced to Amlinger *et al*. (2008) and are presented as CO_2 eq (NIR table 7.16, p. 253). During the review, the ERT noted that while the CH_4 IEF in CRF table 5.B (0.75 g CH_4/kg waste) matched the reference provided by Australia in NIR table 7.16 (0.019 t CO_2 eq/t waste), the N2O IEF did not match (0.0065 g N_2O/kg waste in CRF table 5.B and 0.002 t CO_2 eq/t waste). During the review, Australia informed the ERT that an inconsistency had been discovered in the calculation and provided the ERT with a revised calculation spreadsheet with the corrected EF (0.029 t CO_2 e/t waste). The ERT agreed with the explanation and noted that the impact of the change was below 0.05% of the national total. **The ERT recommends** that Australia recalculate the N_2O emissions from composting in the next submission using the correct EF and ensure that the recalculations are adequately described in the NIR. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Accuracy.	Agreed	Emissions of N2O from composting have been recalculated in this submission. See section 7.4 of the NIR for further information.

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
W.5 5.B.2 Anaerobic digestion at biogas facilities – CH_4	NIR	In the 2017 submission, AD and emissions from anaerobic digestion are reported as "NO" in CRF table 5.B for the entire time series. The NIR (section 7.4, p. 252) states that it is an emerging technology in Australia. The ERT notes that online resources (e.g. http://www.worldbiogasassociation.org/wp-content/uploads/2017/07/WBA-australia-4ppa4_v1.pdf) report that digesters based on agricultural waste, industrial waste and biowaste are operating in Australia. During the review, Australia stated that it continues to monitor progress in this area of waste treatment. The Party further stated that the majority of these facilities occur at landfills and wastewater treatment plants; the red meat industry is covered under industrial wastewater; and manure treatment from livestock is covered under agriculture. Of the biological solid waste treatment facilities reporting under the NGER system, none report AD for anaerobic digestion. **The ERT recommends** that Australia provide more information in the NIR regarding anaerobic digesters, including the number of anaerobic digesters, where anaerobic digestion takes place, and on where this activity is already included in other categories and estimate emissions in case AD for anaerobic digestion in solid waste treatment facilities exist. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Transparency.	Agreed	Further information has been provided in section 7.4 of the NIR.
W.6 5.D.1 Domestic wastewater – N_2O	NIR	The NIR (section 7.6.2.1, p. 262) states that EFs from the IPCC good practice guidance are used rather than default values from the 2006 IPCC Guidelines. During the review, Australia explained that a country-specific approach is used to estimate N_2O emissions from wastewater treatment and discharge, which takes account of separate processes of nitrification and denitrification taking place in rivers and estuaries; and that the IPCC good practice guidance provides disaggregated factors to enable this CS approach to be taken; and that the factors are taken from the agriculture chapter of the IPCC good practice guidance (p 4.73). The ERT notes that the 2006 IPCC Guidelines contain revised information compared with the data from the IPCC good practice guidance; for example, the 2006 IPCC Guidelines (vol. 4, chapter 11, p. 11.24, footnote 23) provide a revised EF for rivers. The ERT therefore considers that Australia might overestimate N2O emissions from wastewater treatment. **The ERT recommends** that Australia apply the EFs from the 2006 IPCC Guidelines or provide justification in the NIR that the EFs contained in the IPCC good practice guidance better reflect Australian conditions. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Accuracy.	Agreed	Australia has updated the N2O factors used for the calculation of emissions from wastewater discharge as recommended by the ERT. See section 7.6.2.3 of the NIR for further information.

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
W.7 5.D.1 Domestic wastewater – CH_4	NIR	Based on the description in the NIR (section 7.6.2.2, p. 265), the calculation of emissions from on-site treatment of wastewater is unclear. The MCF is reported in the NIR as 0.15; however, septic tanks are mentioned and this technology has an MCF of 0.5 in the 2006 IPCC Guidelines. The NIR also does not contain information on the share of the population not connected to the sewer system. During the review, Australia provided information on the share of the population not connected to the sewer system. Australia also stated that the MCF of 0.15 was considered appropriate for Australian conditions by experts on the National Greenhouse Gas Inventory Committee and that this factor has been in use since the inception of the inventory and there has been no information to suggest that these systems have changed since the original factor was adopted. The ERT notes that changing the MCF to the IPCC default will not result in a change greater than 0.05% of the national total. **The ERT recommends** that Australia provide documentation showing that an MCF for septic tanks of 0.15 is appropriate for Australian conditions. In the absence of such documentation, **the ERT recommends** that Australia apply the 2006 IPCC Guidelines default MCF factor of 0.5 for the waste treated in septic tanks. **The ERT further recommends** that the Party provide in the NIR the share of the population not connected to the sewer system. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Accuracy	Agreed	Australia has updated the MCF for septic systems to align with the default value published in the 2006 IPCC Guidelines. See section 7.6.2.2 of the NIR for further information.
W.8 5.D.1 Domestic wastewater – CH_4	NIR	The NIR (section 7.6.2.1, p. 262) states that for wastewater treatment plants, where specific data are available, the COD per person is t 0.677. Furthermore, it is stated that for the remaining wastewater a country-specific value of t 0.0585 per person is used. This value is referenced to a study by the National Greenhouse Gas Inventory Committee (1995). The ERT noted the large difference between the two values and raised a question on this.Australia responded that a transcription error had occurred in the NIR and that the correct value for COD per person should be 0.069 rather than 0.677. Australia explained that there is a proportion of the wastewater treatment sector where no facility-specific data are available under the NGER system and the choice of parameters applicable to the residual portion of the sector was made in accordance with the decision tree described in section 1.4.1 of the NIR. Each of these facilities will have a unique set of operational circumstances and COD sources and are therefore not considered representative of those facilities not captured under the NGER system. **The ERT recommends** that Australia correct the value for COD per person in the NIR and explain how Australia determines the COD per person for the portion of AD obtained from the NGER system as well as from facilites not captured under NGER. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Transparency.	Agreed	The per capita COD value has been updated in the NIR as recommended. See section 7.6.2.1 of the NIR.

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
W.9 5.D.2 Industrial wastewater – CH_4 and N_2O	NIR	Australia reported in NIR section 7.6.3 (p. 268) that the quantity of organic waste in wastewater is obtained under the NGER system for 2009 onwards and, where available, the quantity of COD treated at each facility has been taken from direct measurements reported under the NGER system. NGER data are used where industry coverage is considered sufficient to provide a representative picture of wastewater treatment practices in a given industry (i.e. the pulp and paper, beer and sugar, dairy, meat and poultry, wine, fruit and vegetables and organic chemicals industries). Where facility-specific data under the NGER system are unavailable, estimates are based on CS wastewater and COD generation rates as shown in NIR table 7.24. Australia also states in the NIR that no on-site wastewater treatment occurs outside NGER reporting for pulp and paper production, sugar production and beer production. Based on the description in the NIR, it is not clear to the ERT how the Party ensured that CH_4 and N_2O emission estimates are complete, more specifically how measured COD data obtained under the NGER system are used in conjunction with the country-specific COD generation rates for industrial wastewater as presented in NIR table 7.24. In addition, it was not clear to the ERT how the production amount (tonnes or litres) of a certain commodity (e.g. pulp and paper, beer, sugar, etc.) matched the wastewater amount reported in NGER to allow for the calculation of a residual commodity production (tonne or litres) that is not covered by the NGER system. During the review, Australia explained that the wastewater amounts reported in NGER are tied to a commodity production amount and therefore it is possible to subtract this production from the total national production statistics. Australia also provided the ERT with a spreadsheet showing the total commodity production and the production covered by NGER and the COD concentration under the NGER system. **The ERT recommends** that Australia include in the NIR information on how measured COD data obtained under the NGER system are used in conjunction with the country-specific COD generation rates for industrial wastewater and clarify how the commodity production amount matched the wastewater amount reported in NGER for the calculation of a residual commodity production (tonnes or litres) that is not covered by NGER. Additionally, **the ERT recommends** that Australia explain in the NIR the background for the assumption that no on-site wastewater treatment occurs outside NGER reporting for pulp and paper production, sugar production and beer production. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Transparency.	Agreed	Further information has been provided in section 7.6.3 of the NIR.

Sector	Report and paragraph reference	ERT Recommendation	Response	Rationale
KL.11 Revegetation – activity data	NIR	The Party reported in the NIR, vol. 3, chapter 11.9.3.4, that currently available data only support modelling of estimations of aggregated carbon stock changes from RV. These represent changes across all five carbon pools; however, they are reported under above-ground biomass, as this reflects the most significant pool for this activity. During the review, the Party indicated that it has not excluded any pools from accounting, and therefore the NIR remains consistent with chapter 2.3.1 of the Kyoto Protocol Supplement. Australia has elected end of commitment period accounting for this activity. Planned improvements are under way to bring this activity into alignment with Australia's FullCAM tier 3 spatial modelling approach used for most KP-LULUCF activities. **The ERT recommends** that the Party provide in the annual submission information on progress made in the planned improvements to report carbon stock changes from individual pools and align the calculations for revegeation with Australia's FullCAM tier 3 spatial modelling approach used for most KP-LULUCF activities. *Is finding an issue and/or a problem? If yes, classify by type:* Yes. Transparency.	Agreed	The following will appear in chapter 11.9.3.4.: "Scoping work to facilitate disaggregation by carbon pool through use of tier 3 FullCAM approaches has been completed, and the implementation of the planned improvements for this disaggregation has begun."

ANNEX 7: Description of Australia's National Registry

The description of Australia's national registry follows the reporting guidance set down in decision 15/CMP.1, part II (Reporting of supplementary information under Article 7, paragraph 1, E. National registries), as amended by decision 3/CMP.11, under the KP.

A7.1 Name and contact information of the registry administrator designated by the Party to maintain the national registry

Steven Stolk
Registry System Administrator
Clean Energy Regulator
GPO Box 621
CANBERRA ACT 2601
Tel: +61 2 6159 3593
Email: steven.stolk@cleanenergyregulator.gov.au

A7.2 Names of any other party with which the party cooperates by maintaining their respective registries in a consolidated system

The ANREU is not operated in a consolidated system with any other party's registry.

A7.3 A description of the database structure and capacity of the national registry

The following is an extract from the Software Specifications for the ANREU.

Front end server

The ANREU runs Microsoft Internet Information Services 8 (IIS) for its front-end web servers. All incoming requests will enter and outgoing responses will exit though the IIS server. The IIS server rewrites URLs, then either passing it to the application server or back to the client. SSL termination happens on this tier. Secure Socket Layer (SSL) provides a secure connection between the ANREU and a client's web browser or the ITL. SSL uses a certificate which has been issued by a security authority to encrypt data moving over the unsecured internet. Beyond this point data will travel unencrypted between this IIS web front-end server and the application server. This is considered internal to the application. The IIS server converts all inbound and outbound HTTP communication to HTTPS secure communications.

Requests from the ITL and responses from the ANREU follow the same pattern. However, the front end server is not used for outgoing connections to the ITL initiated by the ANREU.

Application server

The middle tier serves the ANREU web application and uses Apache Tomcat 9.0. Apache Tomcat is an open source implementation of the Java Servlet and JavaServer Pages specifications that originally started as Sun Microsystems' original reference implementation. Tomcat runs the compiled Java Bytecode and allows for external access to application. Tomcat also provides externalized configuration for the application such as database connection details.

For outgoing requests to the ITL initiated by the ANREU web application, SSL origination occurs in the ANREU web application itself. Encrypted responses from the ITL return directly to the web application.

Database

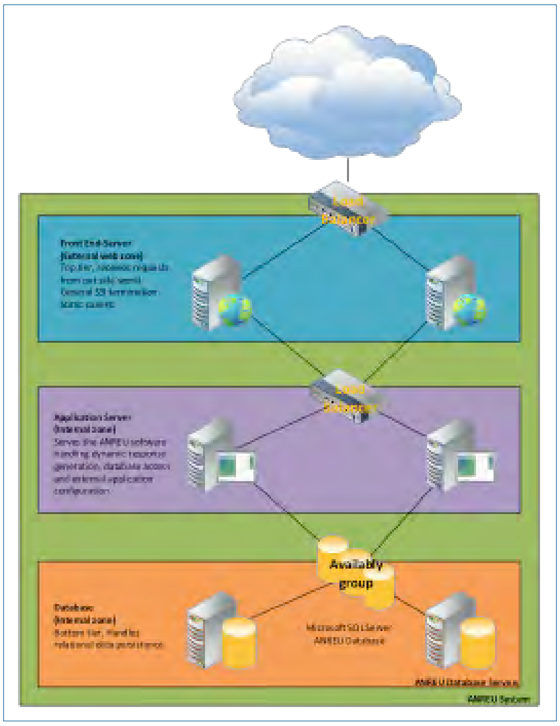
Microsoft SQL Server 2016 provides a relational database back-end for persistent storage of data for the application.

International Transaction Log Services

Transactions performed between the ANREU and the ITL take place through web service interfaces, following the Data Exchange Standards for Registry Systems under the Kyoto Protocol (DES). These web service interfaces are implemented using Apache Axis1 (Axis) which is an open source implementation of the Simple Object Access Protocol (SOAP). Axis supports generation of Java stub code based on the RPC/Encoded Web Service Definition Language (WSDL) specified by the DES. SOAP web services map to an internal service layer, isolating the web service code from the application code so that chances to the application can be made without affecting the ITL web service contract.

There are two web service interfaces that run, the client interface which allows the sending of messages to the ITL, and the server interface which allows the ANREU to receive messages from the ITL. Both of these interfaces are defined as WSDLs in the DES.

Figure A7.1 ANREU Logical Network Topology (Production Environment)



A7.4 A description of how the national registry conforms to the technical standards for the purpose of ensuring the accurate, transparent and efficient exchange of data between national registries, the clean development registry and the independent transaction log, including (i) to (vi) below

The ANREU contains the functionality to perform issuance, conversion, external transfer, (voluntary) cancellation, retirement and Reconciliation processes using XML messages and web-services as specified in the latest version of the Data Exchange Standards for Registry Systems under the Kyoto Protocol (DES).

In addition, the ANREU also contains: 24 Hour Clean-up, Transaction Status enquiry, Time Synchronisation, Data Logging requirements (including, Transaction Log, Reconciliation Log, Internal Audit Log and Message Archive) and the different identifier formats as specified in the UNFCCC DES document.

(i) A description of the formats used in the national registry for account numbers, serial numbers for ERUs, CERs, AAUs, and RMUs, including project identifiers and transaction numbers

The formats used in the ANREU are as specified in Data Exchange Standards for Registry Systems under the Kyoto Protocol (DES). Annex F – Definition of identifiers.

(ii) A list, and the electronic format, of the information transmitted electronically when transferring ERUs, CERs, AAUs, and/or RMUs to other registries

The formats used in the ANREU to transmit information to other registries are specified in the Data Exchange Standards for Registry Systems under the Kyoto Protocol (DES).

(iii) A list, and the electronic format, of the information transmitted electronically when acquiring ERUs, CERs, AAUs, and/or RMUs from other national registries or the CDM registry

The formats used in the ANREU to acknowledge the messages transmitted to other registries are specified in the Data Exchange Standards for Registry Systems under the Kyoto Protocol (DES).

(iv) A list, and the electronic format, of the information transmitted electronically from the national registry to the independent transaction log when issuing, transferring, acquiring, cancelling and retiring ERUs, CERs, AAUs, and/or RMUs

Information will be transmitted to the ITL in the message formats specified in the Data Exchange Standards for Registry Systems under the Kyoto Protocol (DES).

(v) An explanation of the procedures employed in the national registry to prevent discrepancies in the issuance, transfer, acquisition, cancellation and retirement of ERUs, CERs, AAUs, and/or RMUs

In order to minimise discrepancies between the ANREU and the ITL, the following approach has been adopted:

- Communications between the registry and the ITL are via web-services using XML messages – as specified in the Data Exchange Standards for Registry Systems under the Kyoto Protocol (DES). These web services, XML message format and the processing sequence are checked by the registry to ensure the compliance with the DES;
- The registry validates data entries against the formats of information as specified in Annex F of the DES;

- The registry implements internal controls in accordance with the checks performed by the ITL – as documented in Annex E of the DES.
- All units that are involved in a transaction are earmarked internally within the registry; thereby preventing the units from being involved in another transaction until a response has been received from the ITL and the current transaction has been completed;
- The web service that sends the message to the ITL for processing will ensure that a message received acknowledgement is received from the ITL before completing the submission of the message. Where no acknowledgement message has been received following a number of retries, the web-service would terminate the submission and roll back any changes made to the unit blocks that were involved;
- Where a 24 hour clean-up message is received from the ITL, the existing web service would roll back any pending transactions for the units that were involved, thereby preventing any discrepancies in the unit blocks between the registry and the ITL;
- Finally, if an unforeseen failure were to occur, the data discrepancies between our registry and the ITL can be corrected via a manual intervention function. Following this, reconciliation will be performed to validate that the data is in sync between the registry and the ITL. If a discrepancy reoccurs in the registry, the following measures will be applied:
  - Identification, and registration of the discrepancy;
  - Identification of the source of the discrepancy (DES, registry specifications, erroneous programming code);
  - Elaboration of a resolution plan and testing plan;
  - Correction and testing of the software;
  - Release and deployment of the corrected software.

(vi) An overview of the security measures employed in the national registry to deter unauthorised manipulations and minimize operator error

Below is a brief description of security measures implemented by the ANREU. For more detailed information, please refer to the formal readiness documentation which has been submitted as required to the ITL.

A7.5 Identification and Authentication

All applicants looking to open an account in the ANREU are required to provide specified proof of identity documentation, along with completing a “fit and proper” person test. These identity requirements are defined in the *Australian National Registry of Emissions Unit Act 2011* and the *Australian National Registry of Emissions Unit Regulations 2011.*

Access to the registry is allowed via a personal username and password – allocated as a part of a Registration process performed by the Clean Energy Regulator. Passwords have an expiry date and any reset requires revalidation of the user’s identity. Password configuration is as per Australian Government guidelines.

A7.6 Access control

Users of the ANREU are divided into five security groups. These groups control the access and security at the application level. A user's login information is assigned to a user group, which determines what the user can and cannot do within the system.

The Registry supports the following user groups.

System Administrator

The System Administrator group has global authority throughout the Registry. This user is responsible not only for the day-to-day functionality of the system, but also for administrative support. This may include user management, managing and setting batch jobs, and reviewing audit and transaction logs. The system administrator is only available to personnel employed by the Clean Energy Regulator and is IP restricted.

IT Administrator

The IT Administrator group has authority to update system settings. These users are responsible for the day to day operation of the ANREU. An IT Administrator is unable to perform any transaction or administer accounts.

Business Administrator

This role is limited to users within the Clean Energy Regulator and possesses all the abilities of the account administrator, but also has the ability to initiate issuance transactions (domestic Australian units) and to approve issuance transactions initiated by a separate individual. In certain restricted instances, business administrators may initiate transfer transactions on behalf of the Clean Energy Regulator.

Account Administrator

This role is limited to selected users within the Clean Energy Regulator and allows access to account administration functions within the ANREU (creation/editing/deletion of account holders, accounts and users). An Account Administrator is unable to perform any transactions (e.g. unit transfers) in the ANREU.

Approval Officer

This role is limited to users within the Clean Energy Regulator. The approval officer user group has permissions to view all data related to accounts, account holders (organisations), and registered users (people). The approval officer user group may not alter any data related to accounts, account holders (organisations), and registered users (people), with the exception of their own personal data. The approval officer user group is permitted to approve (but not initiate) issuance transactions. They may not edit or delete any other transactional data.

Systems Auditor

A Systems Auditor has read only access to ANREU Account and Transaction information. A Systems Auditor is unable to update any information on an Account, nor is able to perform any transactions. Systems Auditor access is only available to personnel employed by the Clean Energy Regulator.

Industry User/Account Holders

Industry Users are external persons who require access to specific accounts within the ANREU. Users at this level are established when an ANREU account is initially created. All Industry Users must pass required Proof of Identity and Fit and Proper person validations prior to being associated with an account. Additional security permissions are maintained for each Industry User associated with each account e.g. the ability to initiate or approve transactions for that account. These permissions are set by the Clean Energy Regulator upon advice from the account holder.

A7.7 Access protection

In order to prevent operator errors, the ANREU incorporates validations on all user inputs to ensure that only valid details are submitted for processing; The ANREU displays confirmation of user input to help the user to spot any errors that had been made and implements an internal approval process (input of relevant password details) for secondary approval for relevant operations before submitting the details to the ITL for processing.

Additional Security measures

In addition to the above, the ANREU incorporates an initiator / approver design to assist in mitigating the risks associated with high risk unit transfer functions. The initiator / approver function requires a transaction to be initiated by one identity (authorised representative) and be approved by another (authorised representative). The approval step includes validating the transaction by entering a single use PIN issued to the approver when the "initiate" transaction component is completed.

This measure supports the recommendations as outlined by the ITL Change Advisory Board.

A7.8 A list of the information publicly accessible through the user interface to the national registry

Non-confidential information has been made accessible to the public in line with the requirements of decision 13/CMP.1 annex II.E, as amended by decision 3/CMP.11, on the National Registry website under the Public Reports menu.

Up to date information on accounts as required by paragraph 45 of decision 13/CMP.1, as amended by decision 3/CMP.11, has been included under Public Reports > Accounts. No ERUs have been issued to date so no information is available.

Information available to the public includes:

- Account name: the holder of the account;
- Account type: the type of account;
- Commitment period;
- Representative identifier;

Information relating to projects as required by paragraph 46 has been included under Public Reports > Joint Implementation Project Information Report.

Holding and transaction information as required by paragraph 47 is published as described below:

(a) The total quantity of ERUs, CERs, AAUs and RMUs in each account at the beginning of the year is available under Public Reports > Account Information Report, with Unit Block Holdings for each account.

(b) The total quantity of AAUs issued on the basis of the assigned amount pursuant to Article 3, paragraphs 7 and 8 is available at Public Reports > Annual Holding and Transaction Summary Report.

(c) The total quantity of ERUs issued on the basis of Article 6 projects is available at Public Reports > Annual Holding and Transaction Summary Report.

(d) The total quantity of ERUs, CERs, AAUs, and RMUs acquired from other registries and the identity of the transferring accounts and registries is available at Public Reports > Annual Holding and Transaction Summary Report.

(e) The total quantity of RMUs issued on the basis of each activity under Article 3 paragraphs 3 and 4 is available at Public Reports > Annual Holding and Transaction Summary Report.

(f) The total quantity of ERUs, CERs, AAUs, and RMUs transferred to other registries and the identity of the acquiring accounts and registries is available at Public Reports > Annual Holding and Transaction Summary Report.

(g) The total quantity of ERUs, CERs, AAUs, and RMUs cancelled on the basis of activities under Article 3, paragraphs 3 and 4 is available at Public Reports > Annual Holding and Transaction Summary Report.

(h) The total quantity of ERUs, CERs, AAUs, and RMUs cancelled following determination by the Compliance Committee that the party is not in compliance with its commitment under Article 3, paragraph 1 is available at Public Reports > Annual Holding and Transaction Summary Report.

(i) The total quantity of other ERUs, CERs, AAUs and RMUs cancelled is available at Public Reports > Annual Holding and Transaction Summary Report.

(j) The total quantity of ERUs, CERs, AAUs and RMUs retired is available at Public Reports > Annual Holding and Transaction Summary Report.

(k) The total quantity of ERUs, CERs and AAUs carried over from the previous commitment period is available at Public Reports > Annual Holding and Transaction Summary Report.

(l) Current holdings of ERUs, CERs, AAUs and RMUs in each account is available at Public Reports > Annual Holding and Transaction Summary Report.

Public reports pertaining to the total quantity of AAUs in the previous period surplus reserve account at the beginning of the year will be made available in accordance with decision 3/CMP.11 when such transactions take place.

A7.9 An explanation of how to access information through the user interface of the national registry

Access to the ANREU is available through the internet at http://nationalregistry.cleanenergyregulator.gov.au/

A7.10 Measures to safeguard, maintain and recover data in the event of a disaster

The servers (main and backup sites) that host the ANREU are in physically secure data centres fitted with secure access control systems. All data centres are fitted with smoke detection and automatic fire suppression systems. Anti-virus software upgrades are downloaded and installed autonomously on to the servers as soon as they are released.

A full backup of each database and an hourly transaction log backup during business hours take place every day with the back-up media being held at an offsite third party secure storage facility. The database content will also be replicated at a minimum of 30 minute intervals to a secondary data centre location when the clustering environment is implemented. This will serve as the hosting platform for Disaster Recovery.

In the event of a disaster a decision will be taken (between the Clean Energy Regulator and the IT contract supplier) to invoke disaster recovery. This will involve:

- Stopping all transactions to the main platform.
- Ensuring that the committed transactions are replicated to the DR site.
- Switching all external interaction with the main site over to the secondary location.

The IT contract supplier is committed to resuming the service for the Regulator operators within 8 hours of the decision being made.

A7.11 Results of previous test procedures

Comprehensive testing information has been submitted as part of the ITL readiness documentation in December 2013. Please refer to this documentation for details.

Australia's independent assessment reports are available from the UNFCCC website https://unfccc.int/kyoto_protocol/registry_systems/independent_assessment_reports/items/4061.php

ANNEX 8: General notes, glossary and abbreviations

A8.1 General notes

Units

The units mainly used in this inventory are joules (J), grams (g), tonnes (t), metres (m) and litres (L), together with their multiples. Standard metric prefixes used in this inventory are:

kilo (k) = 10^3 (thousand)

mega (M) = 10^6 (million)

giga (G) = 10^9

tera (T) = 10^{12}

peta (P) = 10^{15}

Emissions are generally expressed in gigagrams (Gg) in the inventory tables, as called for under international guidelines, and in megatonnes (Mt) in the text of the inventory report:

gigagram (Gg) = 1,000 tonnes = 1 kilotonne (kt)

megatonne (Mt) = 1,000,000 tonnes = 1,000 Gg

Gases

CF_4	perfluoromethane (a perfluorocarbon)
C_2F_6	perfluoroethane (a perfluorocarbon)
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
HFCs	hydrofluorocarbons
NF_3	nitrogen trifluoride
N_2O	nitrous oxide
NMVOC	non-methane volatile organic compounds
NO_x	oxides of nitrogen
PFCs	perfluorocarbons
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide

Global warming potentials

CO_2 = 1 HFC-23 = 14,800

CH_4 = 25 HFC-125 = 3,500

N_2O = 298 HFC-134a = 1,430

CF_4 = 7,390 HFC-143a = 4,470

C_2F_6 = 12,200 SF_6 = 17,700

Conversion factors

From element basis to molecular mass	From molecular mass to element basis
C CO_2: x 44/12 = 3.67	CO_2 C: x 12/44 = 0.27
C CH_4: x 16/12 = 1.33	CH_4 C: x 12/16 = 0.75
N N_2O: x 44/28 = 1.57	N_2O N: x 28/44 = 0.64

Indicators

In the tables, the following standard indicators are used:

NO (not occurring) when the activity or process does not occur in Australia

NA (not applicable) when the activity occurs in Australia but the nature of the process does not result in emissions or removals

NE (not estimated) where it is known that the activity occurs in Australia but there are no data or methodology available to derive an estimate of emissions

IE (included elsewhere) where emissions or removals are estimated but included elsewhere in the inventory

C (confidential) where reporting at a disaggregated level could lead to the disclosure of confidential information

A8.2 Glossary

Term	Description
Accounting quantity	The accounting quantity for the Kyoto Protocol *land use, land use change and forestry* activities represents RMU credits issued or assigned amount units (AAUs) cancelled for a given year of the commitment period. A net removal will result in the issuance of RMU credits while a net source will result in the deletion of AAUs.
Activity	A process that generates greenhouse gas emissions or uptake. In some sectors it refers to the level of production or manufacture for a given process or category.
Automotive Diesel Oil (ADO)	A middle distillate petroleum product used as a fuel in high-speed diesel engines. It is mostly consumed in the road and rail transport sectors and agriculture, mining and construction sectors.
Anaerobic	A process relying on bacteria that can live without oxygen.
Anthropogenic	Resulting from human activities. In the inventory, anthropogenic emissions are distinguished from natural emissions.
Bagasse	The fibrous residue of the sugar cane milling process which is used as a fuel in sugar mills.
Briquettes	A composition fuel manufactured from brown coal, which is crushed, dried and moulded under high pressure without the addition of binders.
Calibration	Model calibration is the estimation and adjustment of model parameters and constants to improve the agreement between model outputs and a data set. Calibration requires high quality data that represent the range of conditions under which the model is required to perform so as to avoid possible bias in emission estimates.
Clinker	An intermediate product from which cement is made.
Coke	The solid product obtained from the carbonisation of suitable types of coal at high temperature. It is low in moisture and volatile matter and is mainly used in the iron and steel industry as an energy source and chemical agent. Semi-coke or coke obtained by carbonisation at low temperatures is included in this category.
Dolomite	A naturally occurring mineral ($CaCO_3$.mg CO_3) which can be used to produce lime, iron and steel.
Emission Factor	The quantity of greenhouse gases emitted per unit of some specified activity.
Emission Intensity	The total emissions divided by the total energy content of the fuels or the total energy used in a sector. The overall emissions intensity of coal used in Australia, for example, is determined by the quantity and emission factors for each of the many types and grades of coal used.
Enteric Fermentation	The process in animals by which gases, including methane, are produced as a by-product of microbial fermentation associated with digestion of feed.
Feedlot	A confined yard area with watering and feeding facilities where livestock (mainly beef cattle) are completely handfed for the purpose of production. It does not include the feeding or penning of cattle for weaning, dipping or similar husbandry purposes or for drought or other emergency feeding, or at a slaughtering place or in recognised saleyards.
Feedstocks	Products derived from crude oil and destined for further processing in the refining industry, other than blending. Products include those imported for refinery intake and those returned from the petrochemical industry to the refining industry, such as naphtha.
Flaring	The process of combusting unwanted or excess gases and/or oil at a crude oil or gas production site, a gas processing plant or an oil refinery.
Forest	Parties are required to select single minimum values for land area, tree crown cover and tree height. Australia uses a criteria of 20% tree crown cover, 2 metre minimum tree height, and a minimum of 0.2 hectares in land area for inclusion. These minimum criteria are within the ranges outlined in the Marrakech Accords.

Term	Description
Fuel Oil	Covers all residual (heavy) fuel oils including those obtained by blending.
Fugitive Emissions	Generally deliberate but not fully controlled emissions that typically result from leaks, including those from pump seals, pipe flanges and valve stems. Fugitive emissions also include methane emitted from coal mine seams. During petroleum storage tank filling, venting loss of vapour is a fugitive emission.
Global Warming Potential (GWP)	Represents the relative warming effect of a unit mass of a gas compared with the same mass of CO_2 over a specific period. Multiplying the actual amount of gas emitted by the GWP gives the CO_2-equivalent emissions.
Greenhouse Gases	Gases that contribute to global warming, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). In addition, the photochemically important gases – NMVOCs, oxides of nitrogen (NO_x) and carbon monoxide (CO) – are also considered. NMVOC, NO_x and CO are not direct greenhouse gases. However, they contribute indirectly to the greenhouse effect by influencing the rate at which ozone and other greenhouse gases are produced and destroyed in the atmosphere.
Hydrofluorocarbons (HFCs)	Used as substitutes for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).
Initial Assigned Amount	Represents Australia's emissions target for the first commitment period of the Kyoto Protocol. The initial assigned amount for the first commitment period was calculated as 108% of the base year emissions and is established as 591.5 Mt CO_2-e a year for each year of the first commitment period 2008-2012. At such time as the government ratifies the Doha Amendment to the KP, Australia's assigned amount for the second commitment period will be calculated based on its target of 99.5% of base year emissions.
Intergovernmental Panel on Climate Change (IPCC)	The international body responsible for assessing the state of knowledge about climate change. The IPCC increases international awareness of climate change science and provides guidance to the international community on issues related to climate change response.
Key Category	The IPCC Good Practice report (IPCC 2000) introduces the concept of key categories for prioritising the inventory development process. A key category has a significant influence on a country's total inventory of direct greenhouse gases in terms of absolute level of emissions, the trend in emissions, or both. The tier 1 key category analysis identifies categories that contribute to 95% of the total emissions or 95% of the trend of the inventory in absolute terms. Tier 2 analysis identified categories that contribute to 90% of total uncertainty in the inventory.
Kyoto Protocol	The Kyoto Protocol to the convention on climate change was developed through the UNFCCC negotiating process. The protocol was negotiated in Kyoto, Japan, in 1997. It sets binding greenhouse gas emissions targets for UNFCCC developed country Parties that ratify the agreement. The first commitment period of the KP ran from 2008-2012. In 2012 Parties to the KP agreed to the Doha Amendment, establishing a second commitment period (CP2) to run from 2013 – 2020. The CP2 is yet to enter into force.
Liquefied Petroleum Gas (LPG)	A light hydrocarbon fraction of the paraffin series. It occurs naturally, associated with crude oil and natural gas in many oil and gas deposits, and is also produced in the course of petroleum refinery processes. LPG consists of propane (C_3H_8) and butane (C_4H_{10}), or a mixture of the two. In Australia, LPG as marketed contains more propane than butane.
Lubricants	Hydrocarbons that are rich in paraffin and not used as fuels. They are obtained by vacuum distillation of oil residues.
Military Transport	Includes all activity by military land vehicles, aircraft and ships.
Natural Gas	Consists primarily of methane (around 90%, with traces of other gaseous hydrocarbons, as well as nitrogen and carbon dioxide) occurring naturally in underground deposits. As a transport fuel it is generally used in compressed or liquefied form.

Term	Description
Navigation	All civilian (non-military) marine transport of passengers and freight. Domestic marine transport consists of coastal shipping (freight and cruises), interstate and urban ferry services, commercial fishing, and small pleasure craft movements. International shipping using marine bunker fuel purchased in Australia is reported but not included in the national inventory emissions total.
NMVOC	Non-methane volatile organic compounds such as alkanes, alkenes and alkynes, aromatic compounds and carbonyls that are gases at standard temperature and pressure (i.e. Boiling points below 200°C) and normally 10 or less carbon atoms per molecule; excludes chlorofluorocarbons (CFCs).
PFC	Perfluorocarbons, chemical compounds containing carbon and fluorine atoms only (e.g. CF_4 and C_2F_6).
Prescribed Burning	The intentional burning of forests to reduce the amount of combustible material present and thereby reduce the risk of wildfires. In Australia this is known as 'fuel reduction burning'.
Process Emission	The gas released as a result of chemical or physical transformation of materials from one form to another.
Reference approach	A 'top–down' tier 1 IPCC methodology for estimating CO_2 emissions from fuel combustion activities (1.a).
Sink	Any process, mechanism, or activity that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.
Solid Waste	Waste from various activities; includes municipal solid *waste* (waste from domestic premises and council activities largely associated with servicing residential areas; such as street sweepings, street tree lopping, parks and gardens and litter bins), commercial and industrial waste, and building and demolition waste.
Solvent	An organic liquid used for cleaning or to dissolve materials.
Source	Any process or activity that releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere.
Tier	The IPCC methods for estimating emissions and removals are divided into 'tiers' encompassing different levels of activity and technology detail. Tier 1 methods are generally very simple (activity multiplied by default emissions factor) and require less data and expertise than the most complicated tier 3 methods. Tier 2 and 3 methods generally require more detailed country-specific information on things such as technology type or livestock characteristics. The concept of tiers is also used to describe different levels of key source analysis, uncertainty analysis, and quality assurance and quality control activities.
Town Gas	Includes all manufactured gases that are typically reticulated to consumers, including synthetic natural gas, reformed natural gas, tempered LPG, and tempered natural gas.
Uncertainty	Uncertainty is a parameter associated with the result of measurement that characterises the dispersion of values that could be reasonably attributed to the measured quantity (e.g. The sample variance or coefficient of variation). In general inventory terms, uncertainty refers to the lack of certainty (in inventory components) resulting from any causal factor such as unidentified sources and sinks, lack of transparency etc.
United Nations Framework Convention on Climate Change (UNFCCC)	An international environmental treaty which entered into force in 1994. Parties to the convention have agreed to work towards achieving the ultimate aim of stabilising 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.

Term	Description
Validation	Model validation is a demonstration that a model, within its domain of applicability, possesses a satisfactory range of accuracy consistent with the intended application of the model. Validation compares simulated system output with real system observations using data not used in model development. It is used to test the model performance and that the calibration of the model has not produced biased emission estimates.
Verification	In terms of the inventory verification refers to the collection of activities and procedures that can be followed during the planning and development, or after completion of an inventory that can help establish its reliability for the intended application of that inventory. Typically methods external to the inventory are used to verify the truth of the inventory, including comparisons with estimates made by other bodes. Verification as it pertains to modelling is a demonstration that the modelling formalism is correct. It is a check that calculations, inputs, and computer code is correct.
Venting	The process of releasing gas into the atmosphere without combustion. This may be done either at the production site or at the refinery or stripping plants. It is done to dispose of non-commercial gas or to relieve system pressure.

A8.3 Abbreviations

AAA	Aerosol Association of Australia
AAC	Australian Aluminium Council
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABARE	Australian Bureau of Agricultural and Resource Economics
ABR	Australian Business Register
ABS	Australia Bureau of Statistics
ACARP	Australian Coal Association Research Program
ACT	Australian Capital Territory
AD	Activity Data
ADB	Asian Development Bank
ADC	Aluminium Development Council
ADO	Automotive Diesel Oil
ADR	Australian Design Rule
AEC	Australian Energy Council
AELC	Australian Egg Corporation Ltd.
AEMO	Australian Energy Market Operator
AES	Australian Energy Statistics
AEZ	Agro Ecological Zones
AFIC	Australian Feeds Information Centre
AFRC	Agriculture and Food Research Council
AGA	Australian Gas Association
AGEIS	Australia Greenhouse Emissions Information System
AGO	Australian Greenhouse Office
AIHW	Australian Institute of Health and Welfare
ALFA	Australian Lot Feeders Association
ANAO	Australian National Audit Office
ANREU	Australian National Registry of Emissions Units
ANU	Australian National University
ANZSIC	Australia New Zealand Standard Industrial Classification
APEC	Asia Pacific Economic Corporation
API	American Petroleum Institute
APPEA	Australian Petroleum Production and Exploration Association
APS	Australian Petroleum Statistics

ARC	Agricultural Research Council
ARRBTR	Australian Road Research Board Transport Research
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.
ASRIS	Australian Soil Resource Information System
ASS	Acid Sulphate Soils
AUASB	Auditing and Assurance Standards Board
AUSLIG	Australian Surveying and Land Information Group
AVHRR	Advanced Very High Resolution Radiometer
Avtur	Aviation turbine fuel
AWTA	Australian Wool Testing Authority
BEF	Burning Efficiency
BITRE	Bureau of Infrastructure, Transport and Regional Economics
BoM	Bureau of Meteorology
BTX	Benzene, Toluene, Xylene
BREE	Bureau of Resources and Energy Economics
BRS	Bureau of Rural Science
C&D	Construction and Demolition waste
C&I	Commercial and Industrial waste
CAAANZ	Conservation Agriculture Alliance of Australia and New Zealand
CAB	Change Advisory Board
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Use and Storage
CEF	Clean Energy Future package
CEM	Clean Energy Ministerial
CER	Clean Energy Regulator
CERI	Clean Energy Research Institute
CFTT	Centre for Forest Tree Technology
COBIT	Control Objectives for Information and related Technology
COD	Chemical Oxygen Demand
CP2	Kyoto Protocol/ Second Commitment Period
CPN	Conditional Probability Network
CRC SI	Cooperative Research Centre for Spatial Information
CRES	Centre for Resource and Environmental Studies
CRF	Common Reporting Format

CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUEDC	Composite Urban Emissions Drive Cycle
DAFF	Department of Agriculture, Fisheries and Forestry
DAWR	Department of Agriculture and Water Resources
DCC	Department of Climate Change
DCCEE	Department of Climate Change and Energy Efficiency
DE	Department of the Environment
DEDJTR	Department of Economic Development, Jobs, Transport and Resources
DoEE	Department of the Environment and Energy
DEEDI	Department of Employment, Economic Development and Innovation
DEM	Digital Elevation Model
DES	Data Exchange Standards
DEWHA	Department of Environment, Water, Heritage and the Arts
DIS	Department of Industry and Science
DIT	Department of Infrastructure and Transport
DM	Dry Matter
DMD	Dry Matter Digestibility
DMITRE	Department of Manufacturing, Innovation, Trade, Resources and Energy
DMIRS	Department of Mines and Petroleum Industry, Regulation and Safety
DNRM	Department of Natural Resources and Mines
DOC	Degradable Organic Carbon
DOC_f	fraction of Degradable Organic Carbon dissimilated
DOM	Database Operations Manager
DRET	Department of Resources, Energy and Tourism
DSDBI	Department of State Development, Business and Innovation
DSITI	Queensland Department of Science, Information Technology and Innovation
E&P Forum	Exploration and Production Forum
EAC	Electricity
EDC	Emission Decay Curve
EDS	Early Dry Season
EF	Emission Factor
EGCFE	Expert Group on Clean Fossil Energy
EIS	Environmental Impact Statements
EITEI	Emissions Intensive Trade Exposed Industries

EPA	Environmental Protection Agency
ERIC	Environmental Research and Information Consortium Pty Ltd
ERT	Expert Review Team
ESAA	Energy Supply Association of Australia
ESAS	Electricity Sector Adjustment Scheme
EU ETS	European Union Emissions Trading Scheme
EVAO	Estimated Value of Agricultural Operations
FAO	Food and Agriculture Organisation
FITR	Fourier Transform Infrared Spectroscopy
FtRF	Filling the Research
FOD	First Order Decay
FORS	Federal Office of Road Safety
FPA	Forest Practices Authority
FullCAM	Full Carbon Accounting Model
GA	Geoscience Australia
G8	The Group of Eight
GCL	Geosynthetic Clay Liner
GCV	Gross Calorific Equivalents
GE	Gross Energy
GEDO	Greenhouse and Energy Data Officer
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GRDC	Grains Research and Development Corporation
GWA	George Wilkenfeld and Associates
GWP	Global Warming Potential
HDPE	High Density Polyethylene
IBRA	Interim Biogeographic Regionalisation for Australia
IDF	Industrial Diesel Fuel
IEA	International Energy Agency
IEF	Implied Emission Factor
IPCC	Intergovernmental Panel on Climate Change
IAR	Initial Assessment Report
ISC	Interspecies correlation
ISO	International Organization for Standardization

IUFRO	International Union of Forest Research Organizations
JCP	Jobs and Competitiveness Program
JCPAA	Joint Committee of Public Accounts and Audit
KP	Kyoto Protocol
LDS	Late Dry Season
LKD	Lime Kiln Dust
LNG	Liquefied Natural Gas
LPG	Liquid Petroleum Gas
LTO	Landing/Takeoff
LULUCF	Land use, land use change and forestry
M2M	Methane to Markets
MCF	Methane Correction Factor
MDI	Metered Dose Inhaler
MDP	Metropolitan Development Program
MLA	Meat and Livestock Australia
ME	Metabolizable Energy
MEF	Manure Emission Factor
MMS	Manure Management Systems
MRT	Mineral Resources Tasmania
MSW	Municipal Solid Waste
MVG	Major Vegetation Groups
MWTP	Municipal Wastewater Treatment Plants
NAILSMA	North Australian Indigenous Land & Sea Management Alliance
NATA	National Association of Testing Authorities
NCAS	National Carbon Accounting System
NEA	National Energy Administration
NFI	National Forest Inventory
NG	Natural Gas
NGERS	National Greenhouse and Energy Reporting Scheme
NGGI	National Greenhouse Gas Inventory
NGGIC	National Greenhouse Gas Inventory Committee
NIAES	National Institute for Agro-Environmental Sciences
NIR	National Inventory Report
NLWRA	National Land and Water Resources Audit

NORP	Nitrous Oxide Research Program
NRC	National Research Council
NSW	New South Wales
NT	Northern Territory
OECD	Organisation for Economic and Co-operation Development
OSCAR	Online System for Comprehensive Activity Reporting
PCC	Post Combustion Capture
PVC	Polyvinyl Chloride
QA/QC	Quality assurance/Quality control
QDME	Queensland Department of Mines and Energy
QDNRME	Queensland Department of Natural Resources, Mines and Energy
QLD	Queensland
RET	Department of Resources, Energy and Tourism
RIRDC	Rural Industries Research and Development Corporation
ROU	Recycled Organics Unit
RMSE	Root Mean Square Error
RRA	Refrigerant Reclaim Australia
RSA	Registry System Administrators
SA	South Australia
SCA	Standing Committee on Agriculture
SCaRP	Soil Carbon Research Program
SECV	State Electricity Commission of Victoria
SEEA	System of Environmental-Economic Accounting
SEF	Standard Electronic Format
SEWPaC	Department of Sustainability, Environment, Water, Population and Communities
SIAR	Standard Independent Annual Review
SUV	Sports Utility Vehicle
SWDS	Solid Waste Disposal Site
TAS	Tasmania
TOC	Total Organic Carbon
UAG	Unaccounted for Gas
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
VIC	Victoria

VKT	Vehicle Kilometres Travelled
VOC	Volatile Organic Compounds
WA	Western Australia
WALFA	Western Arnhem Land Fire Abatement
WBCSD	World Business Council for Sustainable Development
WMAA	Waste Management Association of Australia
WRI	World Resource Institute
WSAA	Water Services Association of Australia
YSLB	Years Since Last Burnt

ANNEX 9: References

Volume 1

1. Introduction and Inventory Context

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DEPARTMENT OF THE ENVIRONMENT AND ENERGY

PDR: MS19-000340

To: Minister for Energy and Emissions Reduction (For Decision)

Cc: Minister for the Environment (For Information)

RELEASE OF THE DECEMBER 2018 QUARTERLY UPDATE OF THE NATIONAL GREENHOUSE GAS INVENTORY AND THE 2017 NATIONAL INVENTORY REPORT

Timing: 31 May 2019 - to meet the deadline for the Order of the Production of Documents

Recommendations:

s22

4. That you note:

   a. the Department submitted the 2017 *National Inventory Report* to the United Nations Framework Convention on Climate Change (UNFCCC) on 24 May 2019 (**Attachments E to G**); and

   b. that the Department intends to publish the 2017 *National Inventory Report*, the *State and Territory Greenhouse Gas Inventories* (**Attachment H**) and *National Inventories by Economic Sector* (**Attachment I**) together with the *Quarterly Update,* in consultation with your Office, prior to 31 May 2019.

Noted / Please discuss

Minister: Date:

Comments:

Clearing Officer: Sent 28/05/2019	Rob Sturgiss	Assistant Secretary, NISIR / ICCEID	s22
Contact Officer:	s22	Director, NIS ICCEI Division	s22

s22

s22

2017 National Inventory Report: Submission to the UNFCCC

14. Submission of the *2017 National Inventory Report* (**Attachments E to G**) to the UNFCCC meets Australia's reporting obligations under the UNFCCC and the Kyoto Protocol.

    a. In order to meet the UNFCCC deadline for reporting, the Department submitted the *2017 National Inventory Report* to the UNFCCC on 24 May 2019 and intends to publish on the Department's website with the other National Greenhouse Accounts.

15. The Department intends to publish the additional accounts (*State and Territory Greenhouse Gas Inventories* (**Attachment H**) and *National Inventories by Economic Sector* (**Attachment I**) on the Department's website together with the *Quarterly Update.*

16. Emissions estimates in the National Inventory Report relate to the 2016-17 year, with some preliminary estimates for 2017-18. The data in this report is old news and is also contained in the latest *Quarterly Update*, which has more recent data up to December 2018.

17. The *2017 National Inventory Report* uses the latest scientific methods and data. All new methods and data must be applied to the entire time series from 1990. We expect these revisions will lead to a small increase in the amount of carry over into the Paris Agreement period, when finalised for the next Emissions Projections report, by around 20 Million tonnes.

Consultation:

18. The methods, data and estimates in the 2017 National Inventory Report and State and Territory Greenhouse Gas Inventories have been shared with the States and the User Reference Group (NFF, AFPA, AIGN, CSIRO, Andrew MacIntosh, and Hugh Saddler).

ATTACHMENTS

A: *Quarterly Update of the National Greenhouse Gas Inventory: December 2018*
B: Comparison of the estimates for the new publication and previous publication
C: Key Points
D: Web landing page
E: *National Inventory Report Vol 1*
F: *National Inventory Report Vol 2*
G: *National Inventory Report Vol 3*
H: *State and Territory Greenhouse Gas Inventories*
I: *National Inventories by Economic Sector*