Australian Government
Department of Industry, Science, Energy and Resources

National Inventory Report

2019

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

Australian National Greenhouse Accounts

April 2021

VOLUME 1

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Executive Summary

ES.1 Background information on greenhouse gas inventories

This is Australia's *National Inventory Report 2019,* 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 1990–2019, and preliminary estimates for 2020. 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. In that context, the national method improvements in this Report include improvements informed by the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019), prepared by the IPCC and adopted at its 49th Session in May 2019. The IPCC 2019 and the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2013 Wetlands Supplement) also informed the voluntary reporting of additional sources of *fugitive* emissions and certain sources in *wetlands* in this Report. The impact on greenhouse gas emission estimates of refinements to methodologies adopted for this inventory has been summarised in section 4 of the Executive Summary.

The Report contains net emissions for 2019 compiled using reporting rules applicable to the KP second commitment period (CP2). 2019 is the seventh year of the KP CP2, which entered into force on 31 December 2020. Australia implemented its CP2 commitments prior to the Doha Amendment's entry into force, consistent with Decision 1/CMP.8. 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 Industry, Science, Energy and Resources (the Department). 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.

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

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 https://www.industry.gov.au/policies-and-initiatives/australias-climate-change-strategies/tracking-and-reporting-greenhouse-gas-emissions. They provide additional information with respect to Australia's emissions on both a regional and industry basis.

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 518.9 million tonnes (Mt) of carbon dioxide equivalent (CO_2-e) in 2019. Total emissions have decreased by 96.6 Mt CO_2-e, or 15.7 per cent, on net emissions recorded in 1990. In 2020, preliminary estimates indicate emissions at 500.8 Mt CO_2-e.

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 biennial report submission to the UNFCCC[2], the Australian Government indicated that the target is to be developed into an emissions budget covering the period 2021–2030, and that it will report progress towards the commitment using estimates of net emissions according to UNFCCC classifications. The Government has also indicated that the national inventory used to track progress towards the commitment would apply the natural disturbances provision in reporting net emissions from infrequent, extreme wildfires in temperate forests, which are beyond control despite the extensive efforts of emergency management organisations.[3]

To support Australia's Paris Agreement NDC, this Report contains greenhouse gas emissions estimates for 1990, 2005, 2010, 2015, 2018, 2019 and preliminary 2020 estimates 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 518.9 Mt CO_2-e in 2019, which was 15.2 per cent lower than in 2005 (Table ES.01).

These estimates are presented using GWP AR5 values adopted under the Paris Agreement in Annex 3, Volume 3 of this Report.

2 https://unfccc.int/sites/default/files/resource/Australia%20Fourth%20Biennial%20Report.pdf

3 https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Australia%20First/Australia%20NDC%20recommunication%20FINAL.PDF

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

UNFCCC classification sector and subsector	Emissions Mt CO_2-e 1990	2005	2010	2015	2018	2019	2020 (preliminary)	Per cent change 2005–2019
1 Energy (combustion + fugitive)	292.9	398.3	417.0	417.1	430.6	430.4	417.1	8.1
Stationary energy	195.5	278.9	288.2	278.7	281.0	278.9	274.4	0.0
Transport	61.4	82.2	88.8	95.4	100.1	100.5	93.8	22.2
Fugitive emissions from fuel	36.0	37.1	40.0	42.9	49.5	51.0	48.9	37.4
2 Industrial processes and product use	25.9	31.8	33.5	30.4	31.4	32.6	31.3	2.4
3 Agriculture	84.9	79.8	69.8	73.6	75.2	69.8	66.2	-12.5
4 Land use, land use change and forestry	191.8	87.8	64.8	0.5	-22.5	-26.3	-25.8	-129.9
6 Waste	20.0	14.4	15.2	12.1	12.6	12.4	12.0	-13.6
Total net emissions	**615.5**	**612.0**	**600.3**	**533.6**	**527.2**	**518.9**	**500.8**	**-15.2**

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 fourth Biennial Report[4], the Australian Government indicated that it will report progress towards that commitment based on an emissions 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, 2013–2019 and preliminary 2020 estimates 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 522.1 Mt CO_2-e in 2019, which was 3.6 per cent lower than in 2000.

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

KP Classification sector and subsector	Emissions Mt CO_2-e 2000	2013	2014	2015	2016	2017	2018	2019	Preliminary (2020)	Per cent change 2000–2019
Energy	363.3	412.8	406.8	417.1	426.9	429.5	430.6	430.4	417.1	18.5
Industrial Processes and Product Use	26.5	29.1	29.0	30.4	30.2	30.6	31.4	32.6	31.3	22.8
Agriculture	82.3	76.0	76.4	73.6	72.6	76.6	75.2	69.8	66.2	- 15.2
LULUCF activities	53.7	16.6	8.4	- 5.4	- 25.2	- 35.2	- 17.3	- 23.1	-20.0	- 143.0
Waste	15.7	12.5	12.6	12.1	12.6	12.7	12.6	12.4	12.0	- 20.6
Total	**541.5**	**546.9**	**533.1**	**527.7**	**517.1**	**514.2**	**532.5**	**522.1**	**506.6**	**- 3.6**

4 https://publications.industry.gov.au/publications/climate-change/dimate-change/publications/australias-fourth-biennial-report.html

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

This Report contains net emissions estimates for 2019 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 567.4 Mt CO_2-e in 2019. When Removal Units (RMU) from *LULUCF* activities are added, net liabilities in 2019 were 500.4 Mt CO_2-e. Over CP2 to date (2013–19), Australia's net position stands at an estimated net surplus of 1,136,812,188 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 2019–20, is provided in Chapter 12 of Volume 3.

Table ES.03 Emissions and removals associated with Articles 3.1, 3.3 and 3.4 of the Kyoto Protocol, Australia, 2013–2019 (Mt CO_2-e)

Sector and subsector	Emissions Mt CO_2-e						
	2013	2014	2015	2016	2017	2018	2019
Energy	412.8	406.8	417.1	426.9	429.5	430.6	430.4
IPPU	29.1	29.0	30.4	30.2	30.6	31.4	32.6
Agriculture	76.0	76.4	73.6	72.6	76.6	75.2	69.8
Waste	12.5	12.6	12.1	12.6	12.7	12.6	12.4
Deforestation [(a)]	36.0	38.3	30.1	27.7	26.9	29.3	22.3
National inventory emissions (1)	**566.3**	**563.0**	**563.1**	**569.9**	**576.2**	**579.1**	**567.4**
RMU credits generated by Article 3.3 and 3.4 activities							
Afforestation/reforestation [(a)]	-30.1	-30.7	-29.2	-31.8	-32.9	-23.6	-17.7
Article 3.4 activities	-20.4	-30.2	-37.3	-52.0	-60.2	-32.2	-32.6
Total RMU credits (2) [(b)]	**-50.5**	**-60.9**	**-66.5**	**-83.9**	**-93.1**	**-55.7**	**-50.3**
Kyoto Protocol Total (1 – 2)	**515.8**	**502.1**	**496.6**	**486.1**	**483.1**	**523.3**	**517.1**

(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 2019 (t CO_2-e)

Kyoto units	t CO_2-e
CP2 Assigned Amount	4,511,619,826
AAUs	127,650,775
CERs	21,768,290
CP2 RMUs (2013–2019)	460,889,166
Total Kyoto units (1)	**5,121,928,057**
National inventory emissions	
2013–2019 (2)	3,985,115,869
Net position (1) – (2)	**1,136,812,188**

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 2019 comprising 82.9 per cent (430.4 Mt CO_2-e) of total net emissions. *Energy* emissions increased by 46.9 per cent between 1990 and 2019 and decreased by 0.04 per cent between 2018 and 2019.

For the *energy* subsectors in 2019:

- *stationary energy* was the main contributor to total net emissions (53.8 per cent of total net emissions), and decreased by 0.8 per cent between 2018 and 2019;
- *transport* emissions (19.4 per cent of total net emissions) increased by 0.4 per cent between 2018 and 2019; and
- *fugitive emissions from fossil fuels* (9.8 per cent of total net emissions) increased by 3.1 per cent between 2018 and 2019.

Industrial processes and product use made up 6.3 per cent (32.6 Mt CO_2-e) of the total net emissions for 2019 and increased by 3.7 per cent between 2018 and 2019.

Agriculture emissions made up 13.4 per cent (69.8 Mt CO_2-e) of total net emissions in 2019 and decreased by 7.2 per cent between 2018 and 2019.

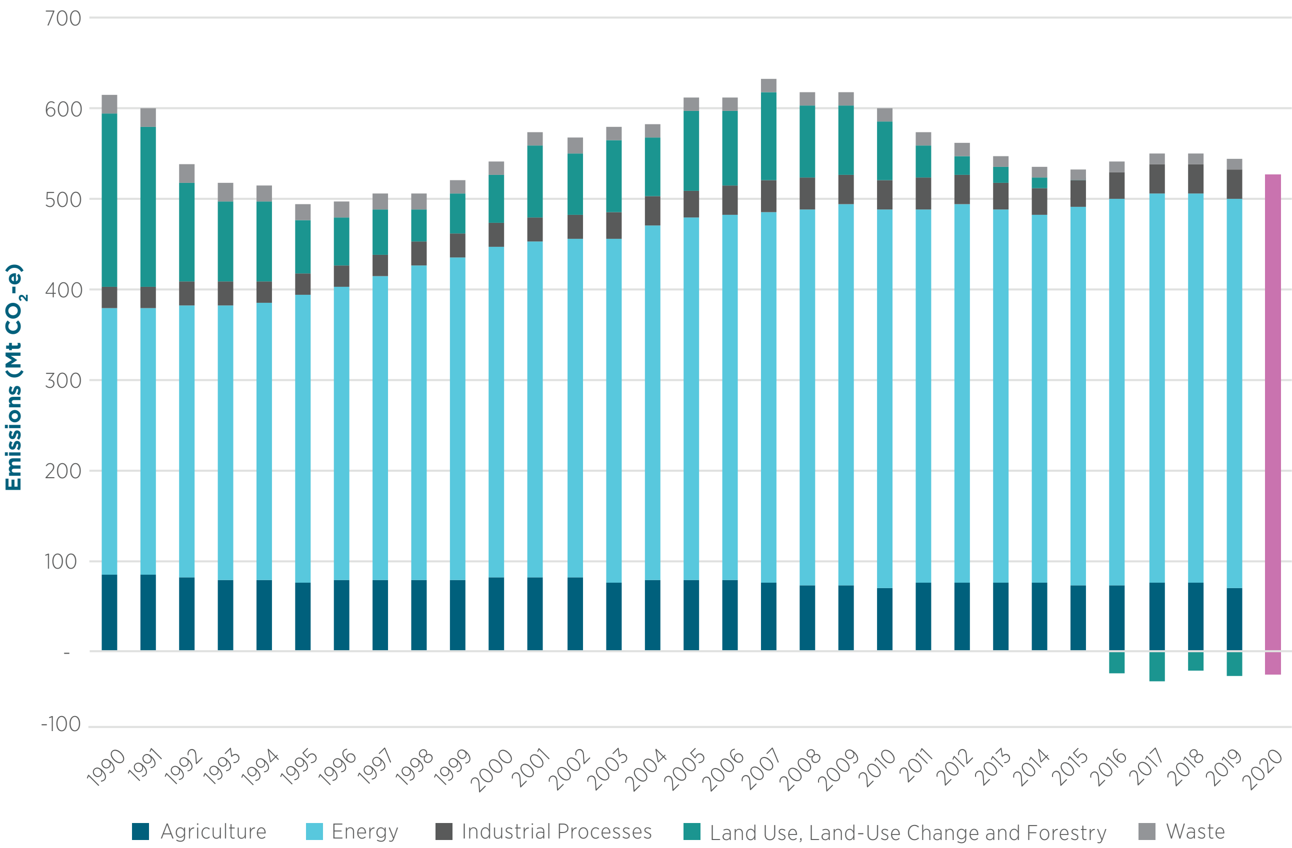
The *waste* sector contributed 2.4 per cent (12.0 Mt CO_2-e) of the total net emissions in 2019 and decreased by 1.2 per cent between 2018 and 2019.

The UNFCCC *LULUCF sector* was a net sink of 26.3 Mt CO_2-e in 2019, equivalent to -5.1 per cent of total net emissions (excluding LULUCF). Net emissions for this sector decreased by 3.8 Mt CO_2-e between 2018 and 2019.

The full time series of the national inventory, including for major sectors and preliminary estimates for 2020, is presented in Figure ES.01. Preliminary estimates for 2020 indicate total net emissions of 500.8 Mt CO_2-e with increases in all sectors from the combined impacts of the COVID-19 pandemic and structural declines in *agriculture* and *public electricity and heat production*.

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, 1990–2019 (preliminary 2020) (Mt CO_2-e)



Focus on land sector estimates

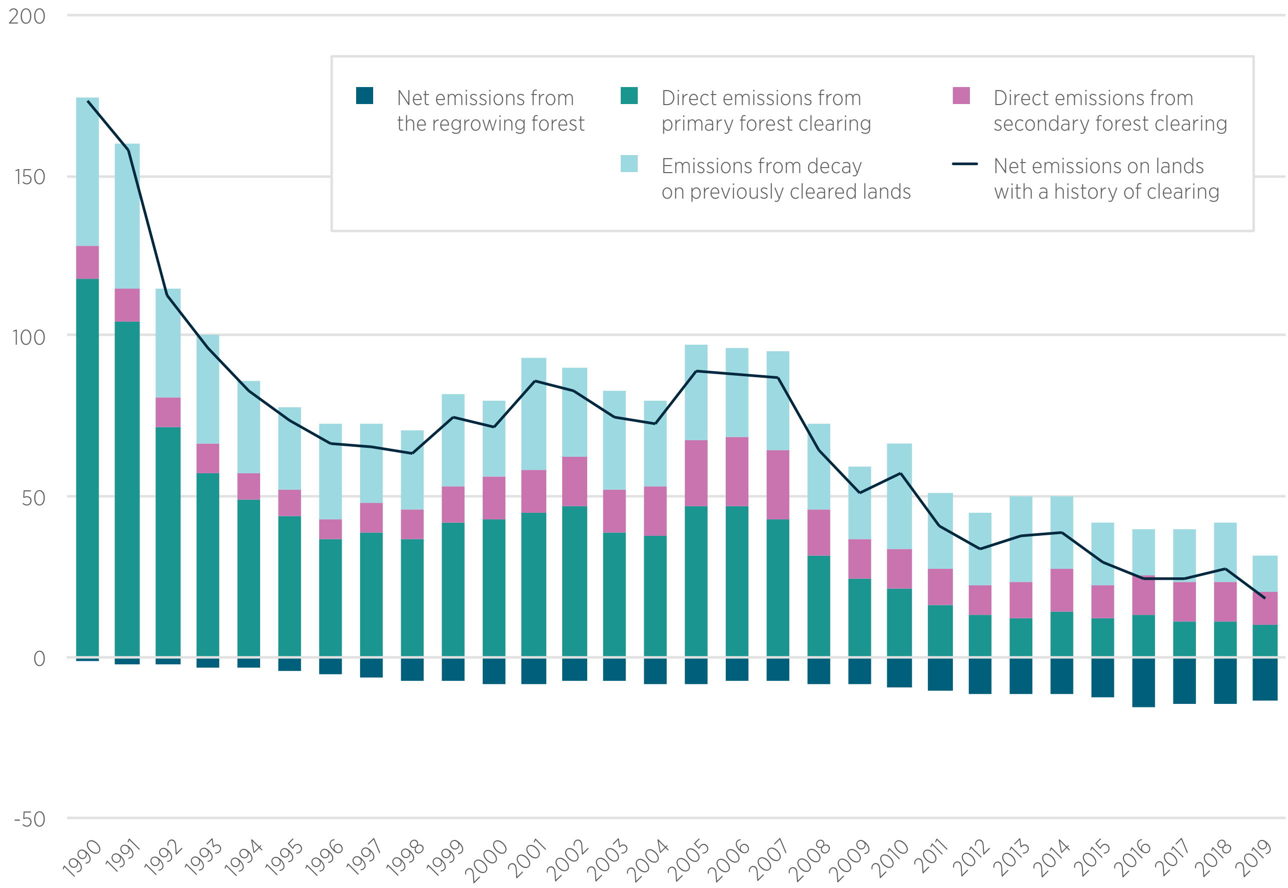
In Australia, the forest area increased by an estimated 114 thousand hectares in 2019 and, cumulatively, has now increased by 2.9 million hectares since 2005 (Figure ES.02).

The most important driver of net emissions from the land sector in 2019 has been the conversion of *forest to other land uses*[5] including for agriculture, mining and settlements. The emissions from *forest converted to other land uses* totalled 31.5 Mt CO_2-e in 2019.

Direct emissions from primary forest clearing (from combustion of forest debris following a clearing event) fell in 2019 to 10.5 Mt CO_2-e, down 8 per cent from 2018 levels (11.4 Mt CO_2-e) (see Figure ES.02). Direct emissions from re-clearing contribute far fewer net emissions per hectare than the clearing of mature forests on average due to the lower biomass of younger regrowth forests. Sequestration from secondary regrowth on areas where previous land clearing has been observed has been classified under *land converted to forest*.

5 *Forest converted to other land uses* includes the conversion of terrestrial native forests to grasslands, croplands, settlements and flooded lands as the elements of land clearing. The impacts of mangrove excavation, plantation removal and fire management in Northern Australia are calculated separately.

Figure ES.02 Emissions from *forest converted to other land uses*, Australia, 1990–2019 (Mt CO_2-e)



In Australia, millions of hectares of bushland are burnt by wildfire each year (Figure ES.03). Most significantly, areas of tropical woodland – in Australia also known as savannas – are the largest areas of fire. Fires are frequent, of relatively low intensity, and the bush regrows relatively quickly.

The 2019–20 wildfires in Australia were unusual for the extent to which areas of temperate forests were burnt. Fires in these forests are relatively infrequent, are of greater intensity, and generate large spikes in emissions followed by long periods of sequestration as the forests recover.

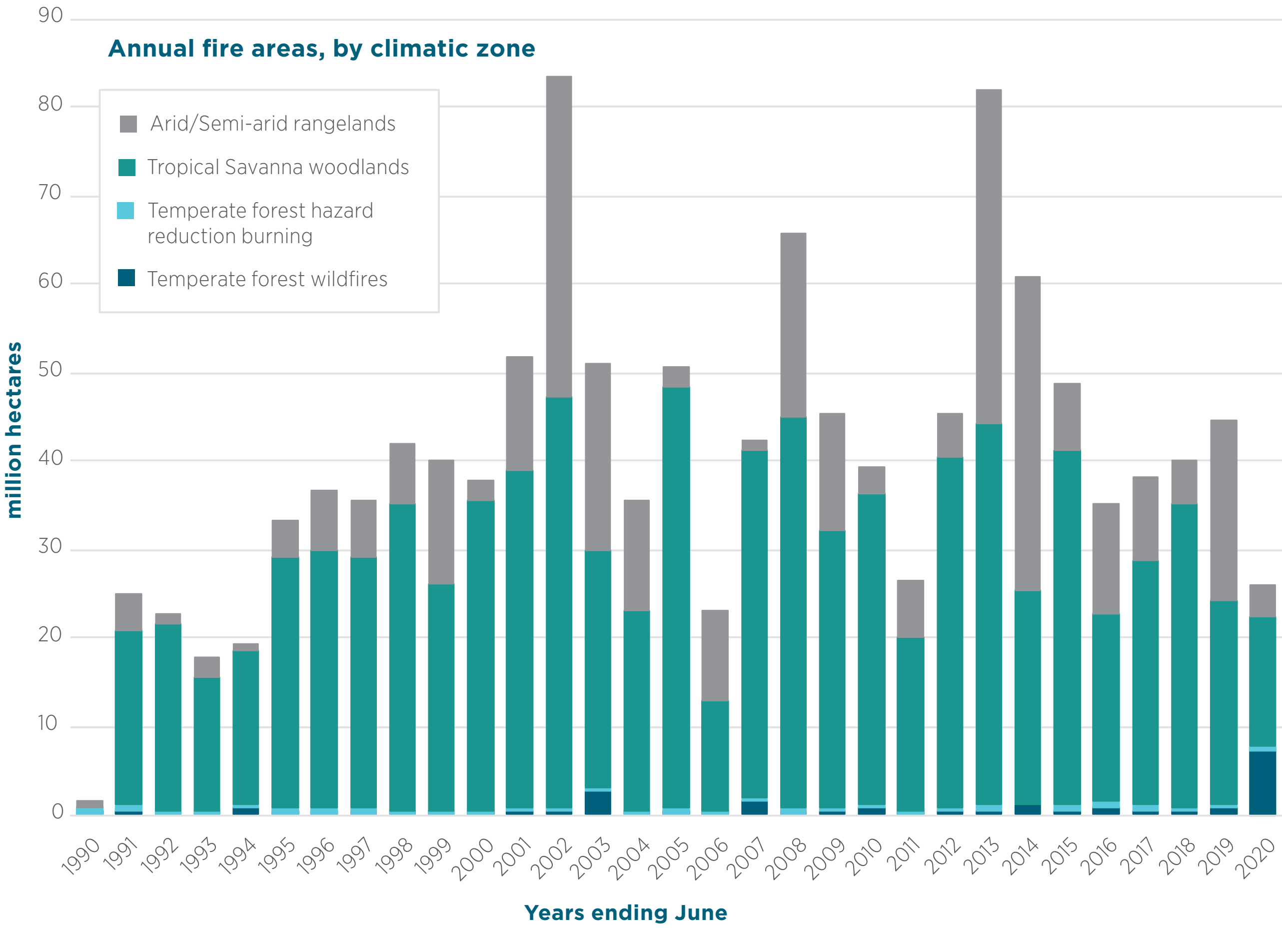
Australia's National Greenhouse Accounts include carbon emissions and post-fire sequestration associated with wildfires, based on satellite monitoring of fires across Australia and advanced carbon modelling of fire-prone ecosystems.

Consistent with international rules and international practice, this national inventory applies the concept of natural disturbances in reporting net emissions from infrequent, extreme wildfires in temperate forests, which are beyond control despite the extensive efforts of emergency management organisations.

In effect, consistent with the Managed Land Proxy, the national inventory includes the long-run trend in carbon stock change in the forests, reflecting the balance of the carbon lost in the fire and that re-absorbed by regrowth. To ensure transparency, and consistent with Paris Agreement decision 18/CMA.1, national net emissions data – both with and without the natural disturbances provision – are reported in Table 2.1.

The Department will actively monitor forest recovery from wildfires to ensure that future human disturbances, such as salvage logging, future fire disturbance and the impacts of changes in climate are taken into account.

Figure ES.03 Areas of wildfire in Australia, by forest and climate type, 1990–2020 (Mha)



ES.3.2 *KP-LULUCF* Activities

This Report contains estimates for 2019 from KP *LULUCF* activities (Table ES.03) compiled using reporting rules applicable to the KP CP2.

The *deforestation* activity contributed net emissions of 22.3 Mt CO_2-e in 2019. 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 17.7 Mt CO_2-e in 2019.

Forest management, cropland management, grazing land management and *revegetation* activities are estimated to generate RMU credits of 49.4 Mt CO_2-e in 2019.

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 Quality Assurance through inverse modelling of emissions

Inverse modelling has been deployed in Australia to better understand the characterisation of point and dispersed emission sources with the aim of improving the national inventory methods over time.

One example concerns analysis by the Commonwealth Scientific and Industrial Research Organisation (CSIRO, Luhar et al 2020) of methane plumes in the Surat Basin – a region in Queensland rich in economic activity that is also methane intensive including coal seam gas extraction, coal mining, beef and feedlot production, abattoirs, sewerage and water management activities.

Results presented in DISER 2021 showed that there was strong alignment between the CSIRO 'top-down' analysis and an estimate for a regional inventory for the Basin using national inventory methods. The estimate for methane emissions for the Surat Basin for 2016 for this regional inventory was within 10 per cent of the CSIRO's independent, top-down analysis.

The close fit is partly the result of recent improvements to estimation methods introduced into the national inventory since 2016 which have raised the estimate of methane emissions in the Surat Basin by around 24 per cent for 2016.

More 'top-down' empirical work is underway in Australia and all methods will be kept under review as new empirical studies on methane fluxes emerge.

Monitoring of atmospheric hydrofluorocarbon (HFC) concentrations has been undertaken by the CSIRO at the Cape Grim Baseline Air Pollution Station in Tasmania since the mid 1990s. Each year, the Department commissions CSIRO to also make an independent, 'top-down[6]' estimate of annual emissions of HFCs from Australia and then compares this information with estimates of HFC emissions using the national inventory 'bottom-up' methods as part of its routine quality assurance program.

The comparison undertaken in DISER 2020 showed strong alignment between the two sets of estimates in the early years of the time series, but a growing gap between the two sets of estimates in recent years. This gap has been recognised and addressed to some extent in this report – but a significant gap persists in which the national inventory estimates remain higher for the most recent years. Further work will be undertaken in upcoming inventory cycles to improve the bottom-up inventory estimates for HFC emissions.

ES.4.2 Australian National Audit Office (ANAO) Performance Audit

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).

6 'Top-down' estimates are derived from measurements of HFC concentrations in the atmosphere to deduce an estimate of emissions from all sources for a region. 'Bottom up' estimates are derived from equations that relate emissions to observed activity data for specific point-sources - such as the number of air-conditioners in the economy.

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 the Full Carbon Accounting Model (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.[7]

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

7 Further detail on the rounding policy can be found in Volume 1, section ES.4.1 of the *National Inventory Report 2016 Volume 1*, Commonwealth of Australia 2018: https://publications.industry.gov.au/publications/climate-change/system/files/resources/gas-group/national-inventory-report-2016-volume-1.pdf

ES.4.3 Implementation of IPCC 2013 Wetlands Supplement

Aspects of the IPCC 2013 Wetlands Supplement are being progressively implemented into the national inventory. Activity-based net emissions are provided for seagrass, tidal marsh removal, as well as for aquaculture and emergence/loss of mangrove forest (reported under forest categories). Estimates relating to wetlands categories are reported in Chapter 6 of Volume 2.

ES.4.4 Recalculations

The impact of the recalculations on emission levels for the sectors including *LULUCF* was a decrease in the estimate of total emissions for the year 1990 of 2.2 Mt CO_2-e and a decrease of 10.2 Mt CO_2-e in 2018 compared with last year's submission.

A new Tier 3 spatial method for *harvested native forests* has been adopted for public multiple use forest in the states of Victoria and New South Wales. This spatial method models timber harvesting using specific locations, dates and types of harvesting as provided by state government agencies. It enables a far more accurate modelling by relating forest growth and harvesting emissions to data for each location on forest biomass stock, climate information and disturbances including prescribed burns and wildfire.

These improvements are the result of a collaborative process with the state government agencies, including in the provision of data, and review of model parameters and assumptions, as well as on the final estimates for their respective jurisdiction.

Other significant recalculations resulted from the introduction of estimation improvements for oil and gas *fugitives* and *product uses as substitutes for Ozone Depleting Substances*.

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, 2005, 2009–18

Sector	Mt CO_2-e											
	1990	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1.A Fuel Combustion	0.1	0.1	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.0	-0.0
1.A.1, 2, 4, 5 Stationary Energy	0.1	0.1	0.2	0.2	0.2	0.2	0.5	0.5	0.5	0.5	0.0	0.7
1.A.3 Transport	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	-	0.0	0.0	-0.7
1.B Fugitives	-1.4	-1.8	-2.3	-2.7	-3.1	-2.7	-2.4	-3.0	-2.9	-3.7	-4.4	-5.0
2 Industrial Processes	-0.1	-0.1	-1.5	-2.2	-2.0	-2.3	-2.4	-2.7	-2.7	-2.8	-2.5	-2.8
4 Agriculture	0.1	-0.3	-0.3	-0.4	-0.4	-0.4	-0.4	-0.4	-0.5	-0.5	-0.5	-0.4
5 LULUCF	-0.8	-3.2	6.5	11.8	5.1	10.3	11.5	1.8	0.3	-0.7	-6.7	-1.9
6 Waste	-	-	-	-0.0	-	-	0.0	-0.0	-0.0	0.0	0.0	-0.1
Total Recalculation	**-2.2**	**-5.2**	**2.6**	**6.8**	**-0.3**	**5.1**	**6.8**	**-3.9**	**-5.2**	**-7.2**	**-14.0**	**-10.2**

Acknowledgements

The Department of Industry, Science, Energy and Resources 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 Agriculture, Water and the Environment

Department of Infrastructure, Transport, Regional Development and Communications

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 2019* (the Report) provides estimates of Australia's net greenhouse gas emissions for the period 1990–2019, and preliminary estimates for 2020. This Report and associated common reporting format (CRF) tables are submitted to the UNFCCC to fulfil 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[8] and the supplementary reporting requirements under Article 7 of the Kyoto Protocol (decisions 6/CMP.9, 2/CMP.8, 2 and 4/CMP.7, 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 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. In that context, the national method improvements in this Report include improvements informed by the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019), prepared by the IPCC and adopted at its 49th Session in May 2019. The IPCC 2019 and the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2013 Wetlands Supplement) also informed the voluntary reporting of additional sources of *fugitive* emissions and certain sources in *wetlands* in this Report. 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. This Report fulfils Australia's reporting obligations under the KP; containing net emissions for 2019 compiled using reporting rules applicable to the KP second commitment period (CP2).

The Report contains net emissions for 2019 compiled using reporting rules applicable to the KP second commitment period (CP2). 2019 is the seventh year of the KP CP2, which entered into force on 31 December 2020. Australia implemented its CP2 commitments prior to the Doha Amendment's entry into force, consistent with Decision 1/CMP.8. The Australian Government submitted its instrument of acceptance to the Doha Amendment on 9 November 2016.

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

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 (NF3). Also covered in ancillary fashion for reporting under the UNFCCC are the indirect greenhouse gases; carbon monoxide (CO), oxides of nitrogen (NOX), and non-methane volatile organic compounds (NMVOCs). Sulphur dioxide (SO2), an aerosol precursor, is also included because emissions of this gas influence global warming.

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)[9]. 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). Australia 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 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, Science, Energy and Resources (DISER), and the Australian Bureau of Statistics (ABS), are published on this basis. The year 2019 refers to the Australian fiscal year from 1 July 2018 to 30 June 2019, 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.

9 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 SF_6 and 17,200 for nitrogen trifluoride (NF3). The full list of GWPs can be found in Annex III to decision 24/CP19 (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.

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).

The Report provides estimates of Australia's total net emissions in 2019, and preliminary estimates for 2020, and identifies trends in emissions 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.

1.1.6 Supplementary Kyoto Protocol reporting requirements

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.

1.1.7 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/CMP11) 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 11
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

Paragraph number (decision 19/CMP.1)	Description of national inventory system characteristic	Section cross reference
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.

1.1.8 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: https://www.industry.gov.au/policies-and-initiatives/australias-climate-change-strategies/tracking-and-reporting-greenhouse-gas-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. Following Machinery of Government changes announced by the Australian Government on 5 December 2019, responsibility for the national inventory was assigned to the Department of Industry, Science, Energy and Resources (the Department) effective 1 February 2020.

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:

General Manager
National Inventory Systems and International Reporting Branch
Department of Industry, Science, Energy and Resources
Australian Government
GPO Box 2013
Canberra ACT 2601
AUSTRALIA

nationalgreenhouseaccounts@industrygov.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: https://ageis.climatechange.gov.au/.

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 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 modelling 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 modelling 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 Industry, Science, Energy and Resources inventory asset structures and relationship

Acronym Key

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

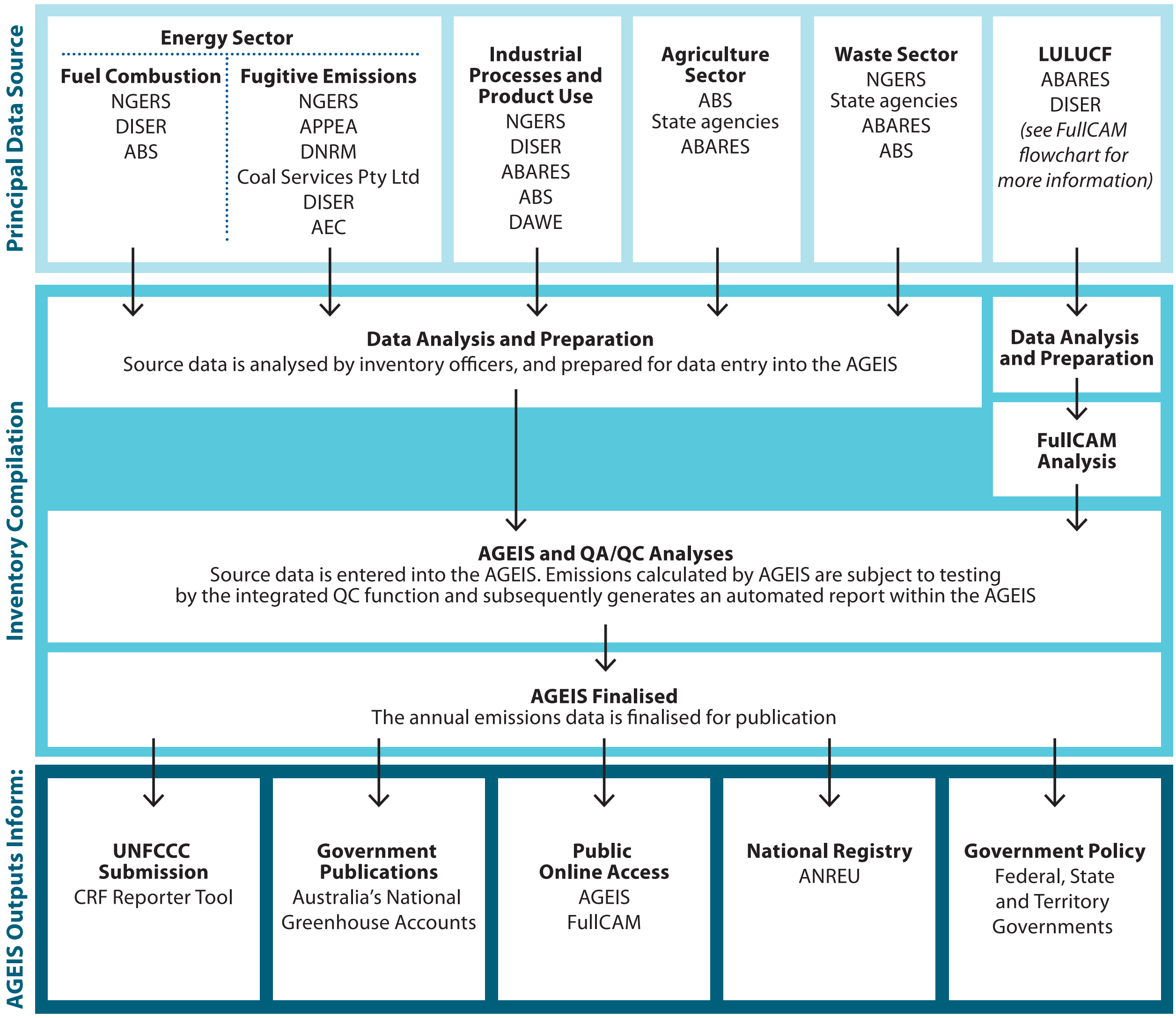
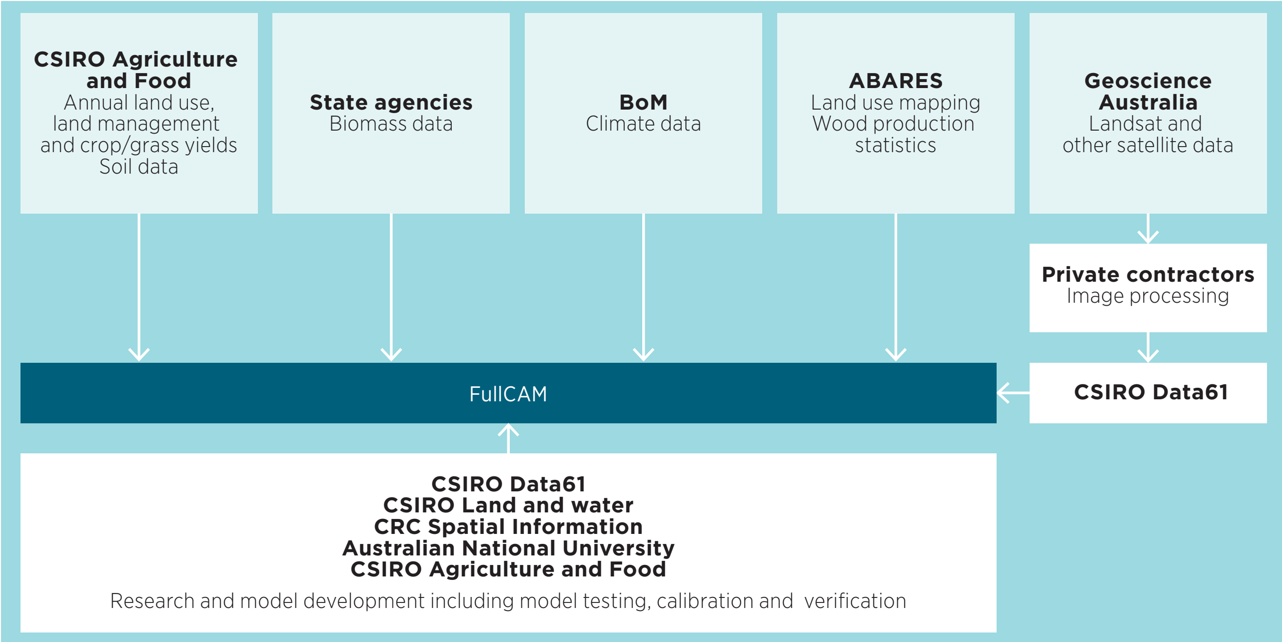


Figure 1.2 FullCAM institutional arrangements



Technical competence of staff

Department of Industry, Science, Energy and Resources 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.

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

The Australian Government's response to the review is available at https://www.environment.gov.au/about-us/accountability-reporting/tabled/response-cca-review-nger. The Government accepted the majority of the review recommendations, and the Department and the Clean Energy Regulator are progressing their implementation, including action aimed at:

- better meeting data users' needs by publishing more detailed analyses of key findings and trends, increasing the volume of data reported publicly and improving the presentation of website data;
- improving reporter awareness of options to reduce the costs of reporting small sources of emissions and energy; and
- better targeting compliance audits to ensure data integrity and reduced costs to business.

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 voluntarily use external auditors to audit their reports prior to submission to the CER.

In 2019–20, the CER adapted quickly to the COVID-19 pandemic, providing guidance and support to auditors and regulated entities, through alternative assurance mechanisms, where feasible. As a result, its audit program was not materially impacted. During the period 1 July 2019 to 30 June 2020, in which reporters submitted data for the financial year 2018–19, 301 audits were completed with 94 per cent indicating the participant was compliant with scheme requirements. Over the same period, 99.2 per cent of entities submitted their reports on time.[10]

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.

10 http://www.cleanenergyregulator.gov.au/About/Accountability-and-reporting/Annual-Reports

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 through its annual *Australian Energy Statistics* (AES, DISER 2020). 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 Environment and Science and the New South Wales Department of Planning, Industry and Environment. 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 4.8 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.

Tier 1 QC activity: Checks(a)	Control Measure(b)	Implementation / Comment
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.
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	B.1-2, 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 fugitive emissions.	< 2	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	Achieved
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
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.	< 0.01	Achieved
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.

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@industry.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 review report on the submission in 2020 have been implemented, or will be addressed in the future.

Inverse modelling of emissions

Inverse modelling has been deployed in Australia to better understand the characterisation of point and dispersed emission sources with the aim of improving the national inventory methods over time.

In 2019, the CSIRO undertook analysis of methane plumes in the Surat Basin – a region in Queensland rich in economic activity that is also methane intensive including coal seam gas extraction, coal mining, beef and feedlot production, abattoirs, sewerage and water management activities.

The CSIRO operated two flux towers at either end of the Basin and obtained continuous measurements over 2016 to obtain a 'top-down' estimate of methane emissions in the Basin for the year (Luhar et al 2020).

A regional inventory for the Basin using national inventory methods was also constructed to provide a test and quality assurance for national inventory methods. The estimate for methane emissions for the Surat Basin for 2016 for this regional inventory was within 10 per cent of the CSIRO's independent, top-down analysis (DISER, 2021).

For the CSG zone within the Surat Basin, where CSG operations are concentrated and account for around 60 per cent of all emissions, there was also good agreement between the top-down estimates of Luhar et al 2020 and the bottom-up inventory using national inventory methods for methane reported in DISER 2021, with the estimates based on inventory methods being 18 per cent higher.

The good fit between the regional inventory using national inventory methods and the CSIRO 'top-down' data provides strong assurance of the quality of national inventory methods for methane.

The close fit is partly the result of recent improvements to estimation methods introduced into the national inventory since 2016. These include updated methods for fugitive emissions from CSG production, methane emissions from combustion slip at CSG operations, manure management, water bodies and abandoned coal seam gas wells which are estimated to have raised the estimate of methane emissions in the Surat Basin by around 24 per cent in 2016.

More 'top-down' empirical work is underway in Australia and all methods will be kept under review as new empirical studies on methane fluxes emerge.

Monitoring of atmospheric hydrofluorocarbon (HFC) concentrations has been undertaken by the CSIRO at the Cape Grim Baseline Air Pollution Station in Tasmania since the mid 1990's.

Each year, the Department commissions CSIRO to also make an independent, 'top-down[11]' estimate of annual emissions of HFCs from Australia and then compares this information with estimates of HFC emissions using the national inventory 'bottom-up' methods as part of its routine quality assurance program.

11 'Top-down' estimates are derived from measurements of HFC concentrations in the atmosphere to deduce an estimate of emissions from all sources for a region. 'Bottom up' estimates are derived from equations that relate emissions to observed activity data for specific point-sources – such as the number of air-conditioners in the economy.

The CSIRO analysis (Dunse et al 2020) is especially valuable in this case for a number of reasons:

1. All emissions of HFCs are anthropogenic, and must be counted within the national inventory (unlike methane, for example, where some sources are considered to be non-anthropogenic), which simplifies the comparison estimates generated by 'top-down' and 'bottom-up' approaches; and
2. The national inventory 'bottom-up' methods are recognised to produce estimates with considerable uncertainties (given the absence of direct observations of leakages of HFCs from equipment, like air-conditioning, in many millions of pieces of equipment across the country).

In the inventory, the long run losses of HFCs are likely to be very well-known, since all HFC gases are supplied through imports into Australia, under license under the *Ozone Protection and Synthetic Gas Management Act 1989* and because all of these gases, used in equipment such as air-conditioning or refrigeration, will eventually leak out into the atmosphere unless they are captured and destroyed through a single facility managed by Refrigerant Reclaim Australia.

The time profile of these HFC losses are less well-known, however, largely because the time profile depends on a lot of factors including the fugitive leakages from a wide variety of equipment and the rate of recycling of gas at the point of equipment disposal in the economy.

The comparison undertaken in DISER 2020 of national inventory 'bottom-up' estimates with the 'top-down' estimates based on the CSIRO Cape Grim measurements showed strong alignment between the two sets of estimates in the early years of the time series, but a growing gap between the two sets of estimates in recent years.

This gap has been recognised and addressed to some extent in this report, in which assumed leakage rates for equipment types were comprehensively aligned with recommendations in Expert Group 2018 rather than being aligned with IPCC default leakage rates, as was previously done.

The new methods show a closing of the gap between the 'bottom-up' and 'top-down' estimates for the period since 2014, with a recalculation down of around 23 per cent for recent years – but a significant gap persists in which the national inventory estimates remain higher.

Further work will be undertaken in upcoming inventory cycles to improve the bottom-up inventory estimates. The major avenues for further updates will include an assessment of the extent of refrigerant stockpiling and recycling within the Australian economy and a review of equipment retirement profiles for different classes of equipment.

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 DOCf values (S. Guendehou, international expert from UNFCCC reviewer roster)
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.

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

The Australian Government's response to the review is available at https://www.environment.gov.au/about-us/accountability-reporting/tabled/response-cca-review-nger. The Government accepted the majority of the review recommendations, and the Department and the Clean Energy Regulator are progressing their implementation, including action aimed at:

- better meeting data users' needs by publishing more detailed analyses of key findings and trends, increasing the volume of data reported publicly and improving the presentation of website data;
- improving reporter awareness of options to reduce the costs of reporting small sources of emissions and energy; and
- better targeting compliance audits to ensure data integrity and reduced costs to business.

Verification activities

In addition to supporting the above mentioned inverse modelling of HFC emissions, the CSIRO Baseline Air Pollution Station at Cape Grim in Tasmania collects and analyses data on the concentrations of other synthetic gases – PFCs and SF_6 – 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 Industry, Science, Energy and Resources 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 (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 https://www.industry.gov.au/policies-and-initiatives/australias-climate-change-strategies/tracking-and-reporting-greenhouse-gas-emissions (April).

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

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 Resources and Energy Insights Branch. The Department's Resources and Energy Insights Branch 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 of Agriculture, Water and the Environment (DAWE). 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.

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:

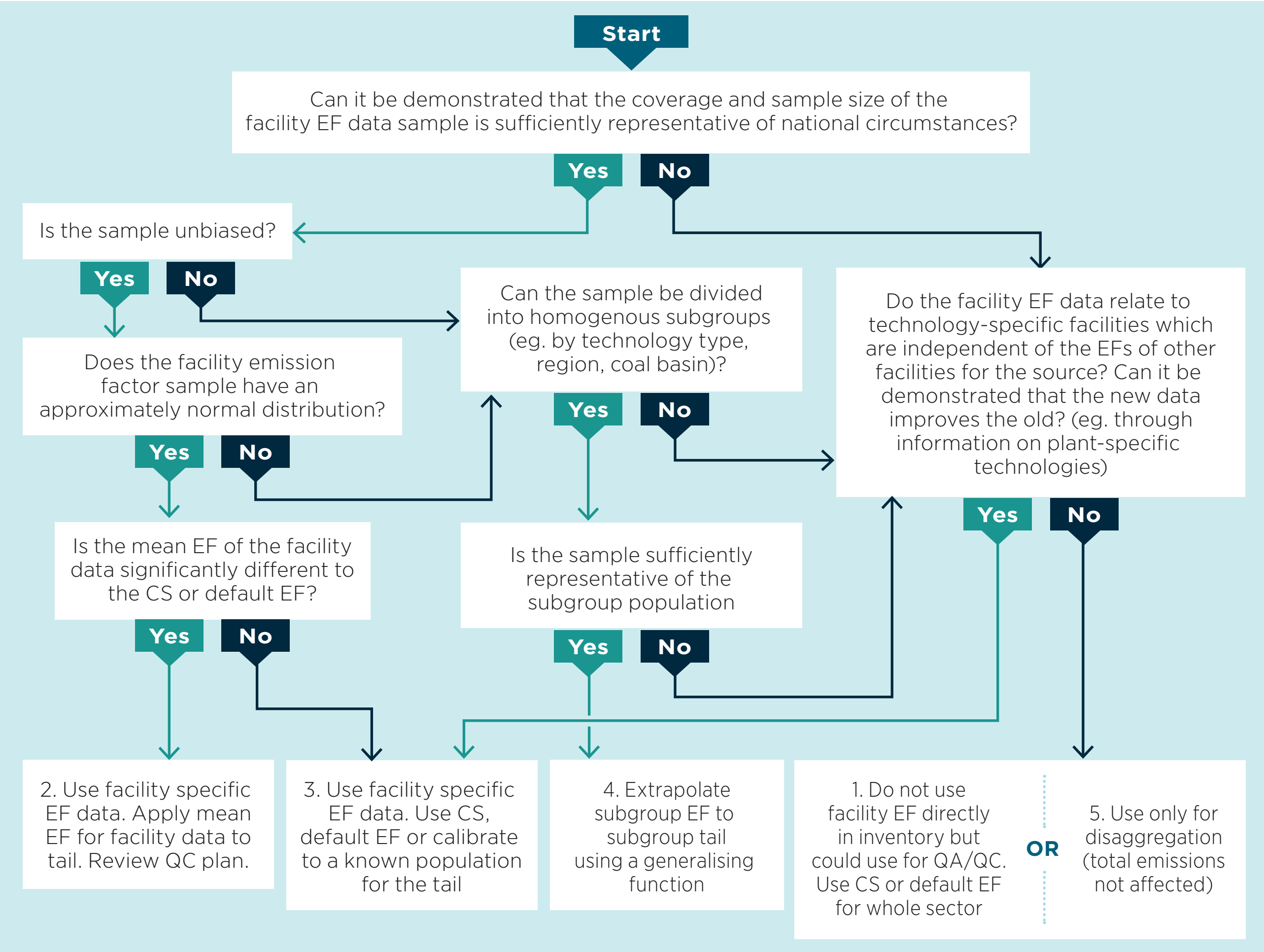
- facility-specific emission estimation processes;
- characterisations of the capital and technology types at the point of emission;
- dynamic relationships that link current emissions outcomes with the activity levels of previous years; and
- spatial differences in emissions processes across Australia.

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 Industry, Science, Energy and Resources, NGER	Published, Mandatory data reporting system
Energy sector (1A3)	Department of Industry, Science, Energy and Resources, ABS	Published
Energy sector (1B)	NGER, Coal Services Pty Ltd, QLD DNRM, WA DMP, SA DSD, APPEA, ESAA, DIIS, NSW DIRE, Department of Industry, Science, Energy and Resources	Mandatory data reporting system, published
Industrial processes and product use (2)	NGER	Mandatory data reporting system
	Department of Agriculture, Water and the Environment	Mandatory reporting of HFCs under import licensing arrangements
Agriculture (3)	ABS	Published
	ABARES	Published
Land use, land use change and forestry (4)	Geosciences Australia, ABARES, CSIRO	Memorandum of Understanding Published
	Western Australian Land Information Authority (Landgate)	Data Supply Licence Agreement,published
Waste (5)	NGER Department of Agriculture, Water and the Environment	Mandatory data reporting system 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.

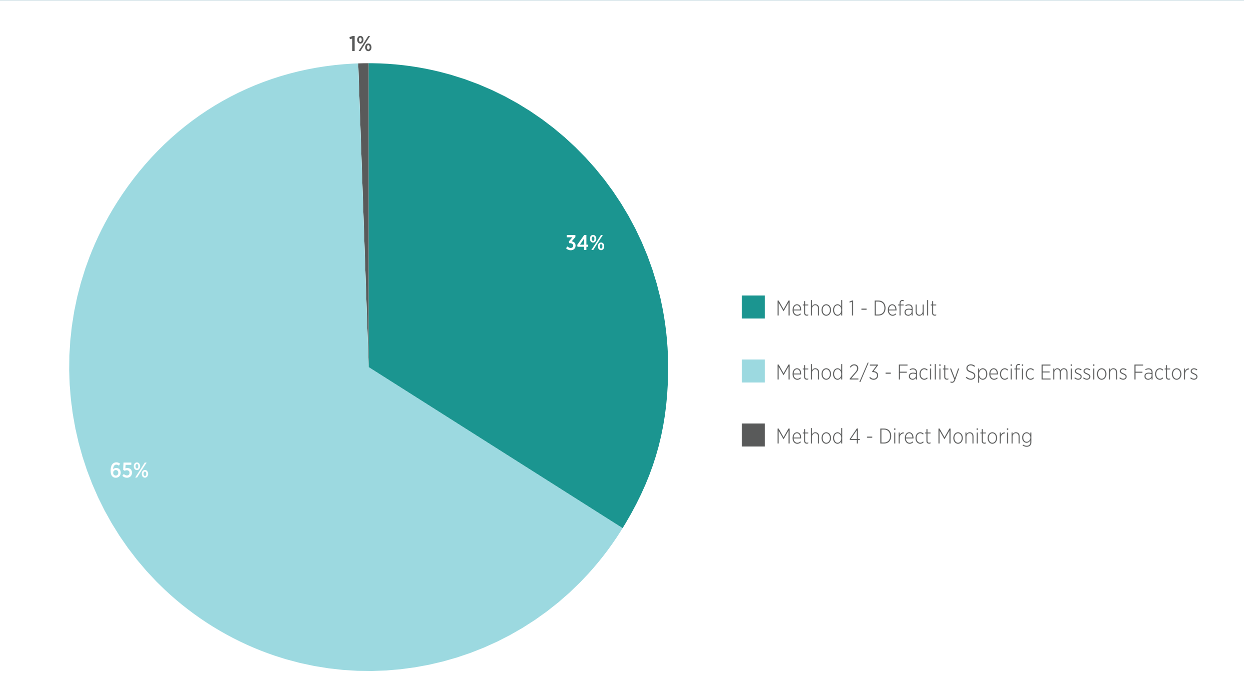
The national inventory may use emissions data generated using NGER method 4 depending on the analysis of the quality of the data and in accordance with the decision tree set out in section 1.4.1.

Implementation of the NGER (Measurement) Determination

In the eleventh year of implementation of the NGER system (2018–19), 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, 34 per cent of CO_2 emissions were estimated using method 1. 1 per cent of CO_2 emissions were estimated using method 4 (Figure 1.4). These outcomes reflect choices 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, a large majority 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 for which the payoff from additional measurement effort is often limited. Choices made by companies for gas lay somewhere between coal and petroleum products.

Figure 1.4 2019–20 NGERs CO_2 emissions: method selected by NGER reporters

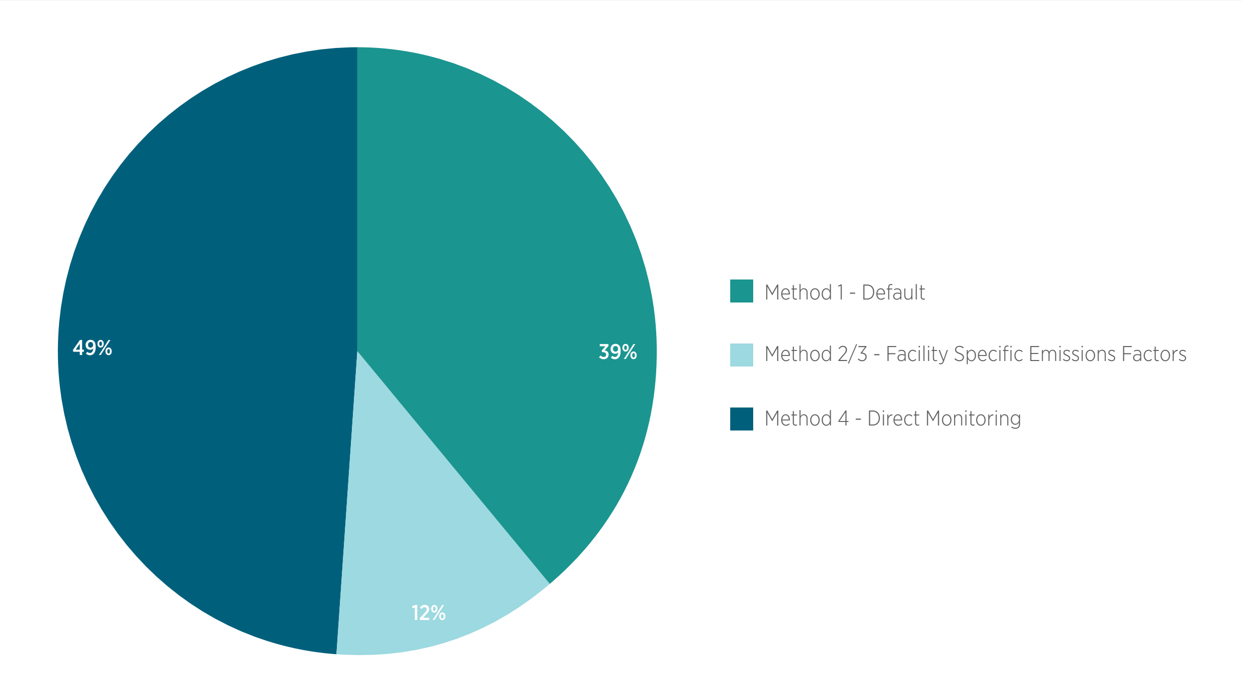


There is a similar story when choices made about estimation methods used for methane are considered (Figure 1.5). Around 49 per cent of CH_4 emissions were estimated using direct monitoring of emissions while 39 per cent of CH_4 emissions were estimated using method 1.

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 2019–20 NGERs 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.

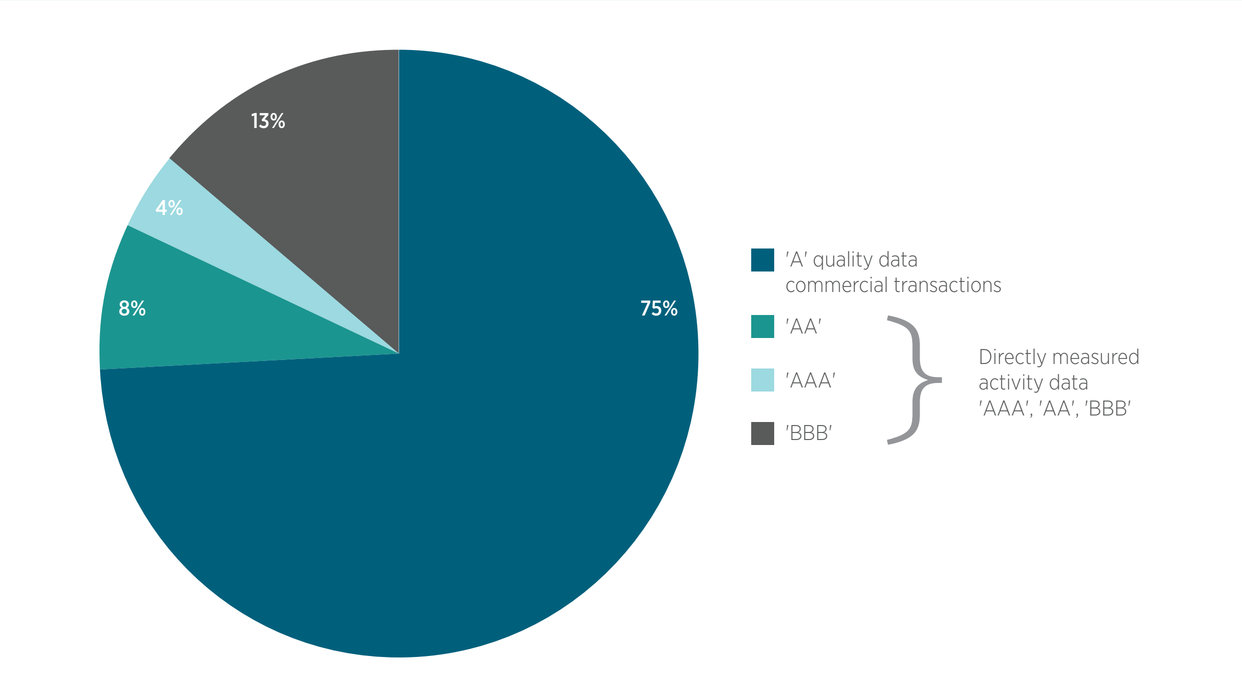
Activity data

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.

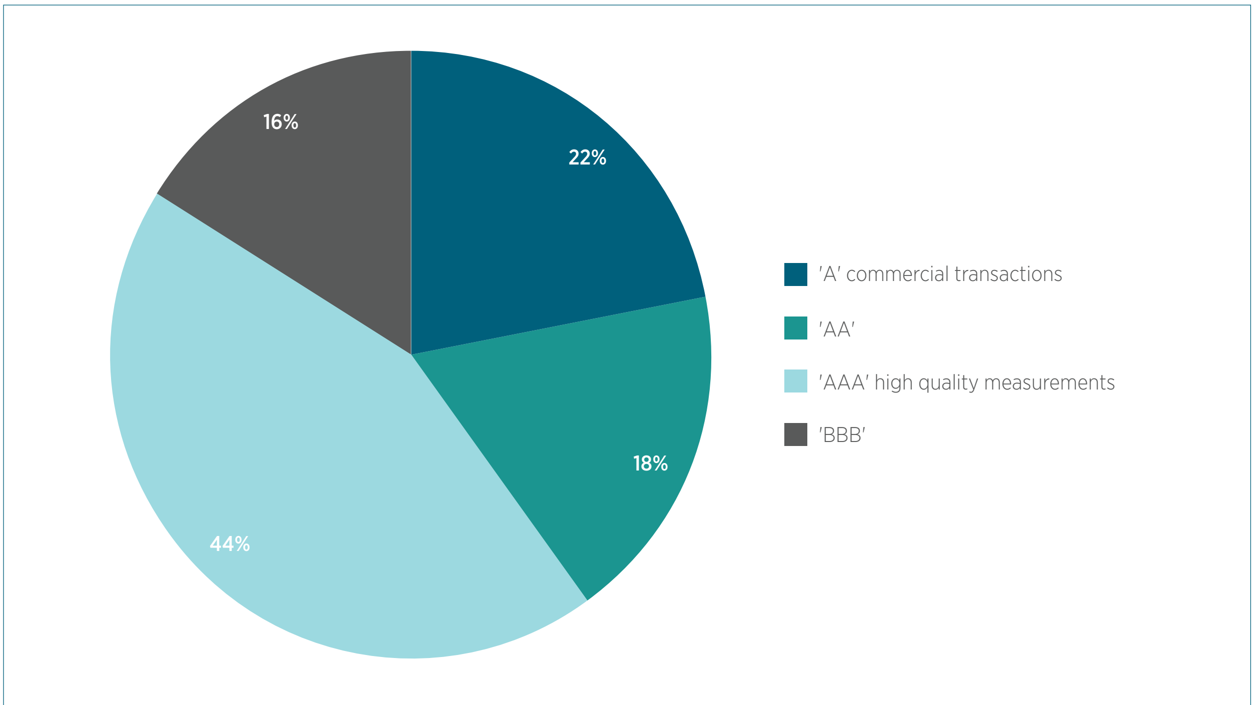
A recent analysis of the choices made by companies with respect to the quality of their activity data inputs is presented in Figure 1.6. Of reported activity data points under the NGER system, 75 per cent is derived from commercial transactions and requires no new measurements to be undertaken by the 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 emissions, companies have tended to choose to use actual measurements of activity to underpin emissions estimates (Figure 1.7). 44 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 75 per cent of the data points used in emission estimation processes, these data points only related to 22 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 DAWE 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/CP19. 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 *enteric fermentation (cattle)* as the most significant of the key categories (i.e. contributing more than 10 per cent of the level and/or trend) in 2019. When the *LULUCF* sector is excluded from the analysis the most significant key categories in 2019 are *public electricity (solid fuel), road transportation (liquid fuels)* and *enteric fermentation (cattle).* 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 2019 is estimated at ± 4.2 per cent. The reported uncertainty for the trend in emissions is estimated to be ± 4.7 per cent. When the *LULUCF* sector is excluded from the analysis the uncertainty is estimated at ± 3.1 per cent for the 2019 inventory estimate and ± 4.7 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 including emissions for reservoirs and other constructed water bodies, certain ponded pastures, seagrass, tidal marsh removal, as well as for aquaculture and emergence/loss of mangrove forest (reported under forest categories). More information on the coverage of *wetland* categories for this submission is available in Annex 5 of Volume 3 of this Report.

This Report also includes voluntary reporting of additional sources in *fugitive emissions* from post-meter gas appliances and abandoned gas wells, with national methodologies informed by IPCC 2019.

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.

Category	Source
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.
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 of Agriculture, Water and the Environment, 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.

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

Table 2.1 National greenhouse gas emissions, Mt CO_2e

Australia's total greenhouse gas emissions in 2019 were 518.9 Mt CO_2-e (Table 2.1 and Figure 2.1). This represents a decrease of 96.6 Mt CO_2-e (15.7 per cent) on net emissions recorded in 1990.

UNFCCC classification sector and subsector	Emissions Mt CO_2-e							Per cent change
	1990	2005	2010	2015	2018	2019	2020 (preliminary)	2005–2019
1 Energy (combustion + fugitive)	292.9	398.3	417.0	417.1	430.6	430.4	417.1	8.1
Stationary energy	195.5	278.9	288.2	278.7	281.0	278.9	274.4	0.0
Transport	61.4	82.2	88.8	95.4	100.1	100.5	93.8	22.2
Fugitive emissions from fuel	36.0	37.1	40.0	42.9	49.5	51.0	48.9	37.4
2 Industrial processes and product use	25.9	31.8	33.5	30.4	31.4	32.6	31.3	2.4
3 Agriculture	84.9	79.8	69.8	73.6	75.2	69.8	66.2	-12.5
4 Land use, land use change and forestry *incl. natural disturbances provision*	191.8	87.8	64.8	0.5	-22.5	-26.3	-25.8	-129.9
6 Waste	20.0	14.4	15.2	12.1	12.6	12.4	12.0	-13.6
Total net emissions	**615.5**	**612.0**	**600.3**	**533.6**	**527.2**	**518.9**	**500.8**	**-15.2**
Memo: *Total net emissions without natural disturbances provision*	612.2	581.5	586.6	522.2	525.4	549.0	1,324.5	-5.6

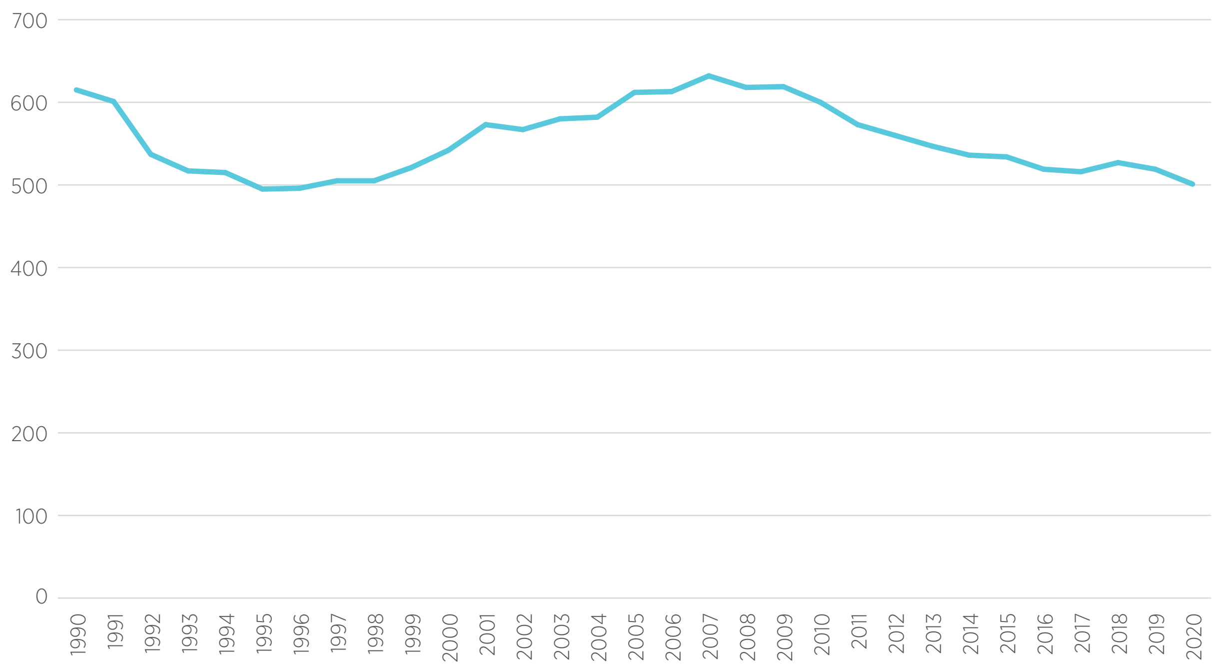
The preliminary estimate for Australia's total greenhouse gas emissions in 2020 is 500.8 Mt CO_2-e, a decrease of 3.5 per cent on 2019 levels.

To ensure transparency, and consistent with Paris Agreement decision 18/CMA.1, Table 2.1 also presents total net emissions without the application of the natural disturbance provision, while Australia's approach to addressing emissions and subsequent removals from natural disturbances is detailed in Chapter 6, Volume 2, and summarised in section ES.3.1, Volume 1, of this Report.

The preliminary 2020 emissions above includes a preliminary estimate of net emissions from natural disturbances during the 2019–2020 fire season of nearly 830 million tonnes of carbon dioxide equivalent (Mt CO_2-e), noting that affected forests are expected to recover over time, generating a significant carbon sink in the coming years.[12] The future recovery of the forest is expected to be complete, so the 2019–20 bushfires are expected to have a negligible impact on the long-run trend in carbon stock change in the affected forests and therefore on progress towards Australia's 2020 and 2030 targets. The department will actively monitor the forest recovery from the bushfires to ensure that any future human disturbances, such as salvage logging, future fire disturbance and the impacts of changes in climate are taken into account.

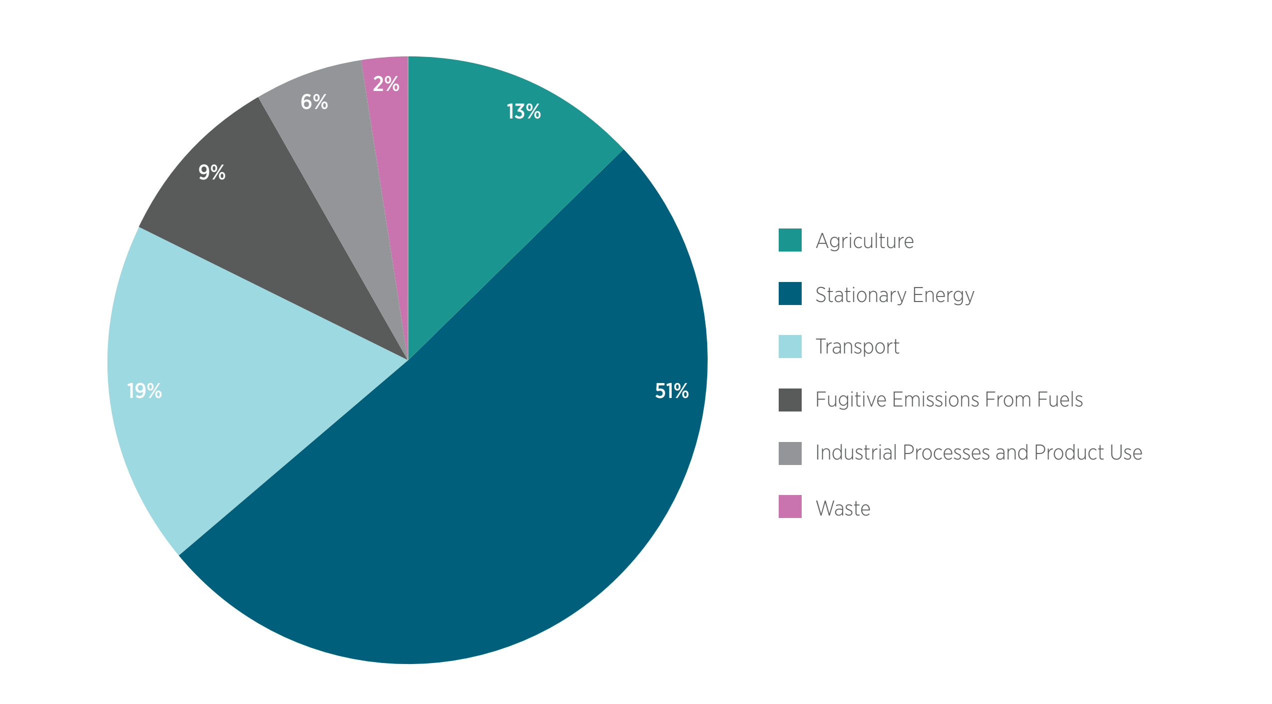
12 https://www.industry.gov.au/bushfirereport

Figure 2.1 National Inventory trend for aggregated greenhouse gas emissions (including LULUCF), Australia, 1990–2019 (preliminary 2020)



The combined *energy* subsectors (including *stationary energy, transport* and *fugitive* emissions) were the largest source of greenhouse gas emissions in 2019 comprising 78.9 per cent of emissions excluding *LULUCF* (Figure 2.2) followed by the *agriculture* sector (12.8 per cent).

Figure 2.2 Contribution to total net CO_2-e emissions (excluding LULUCF) by sector, Australia, 2019

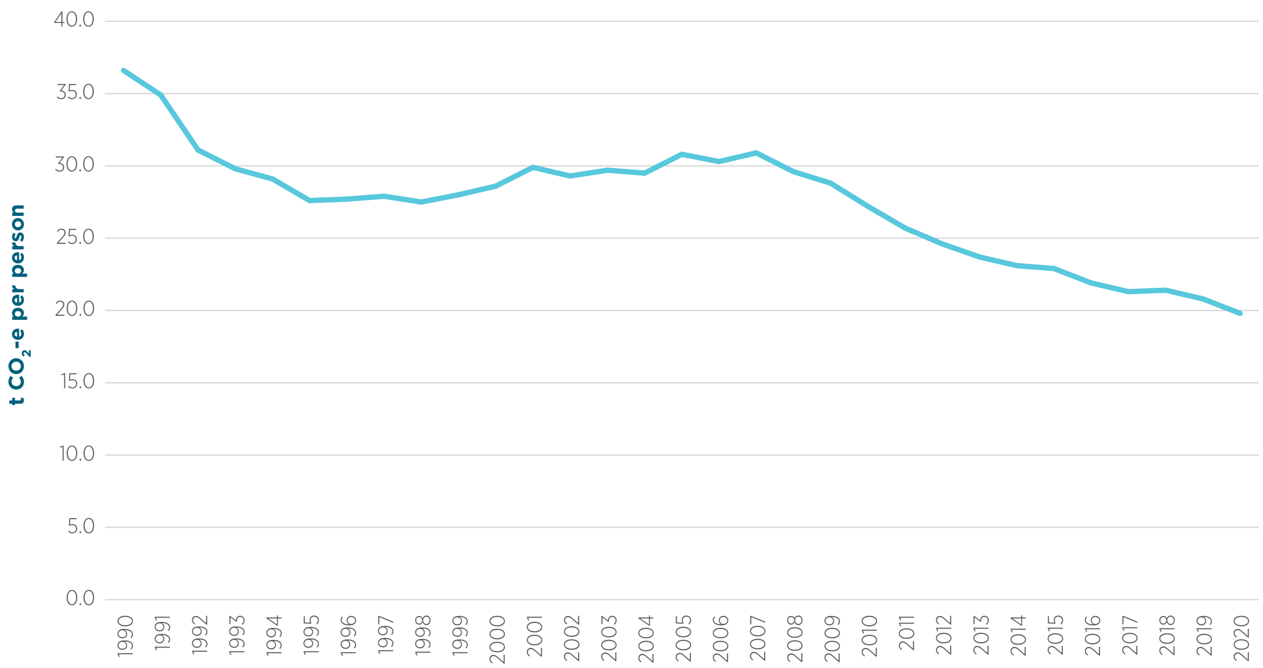


2.2 Emission trends per capita and per GDP

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.

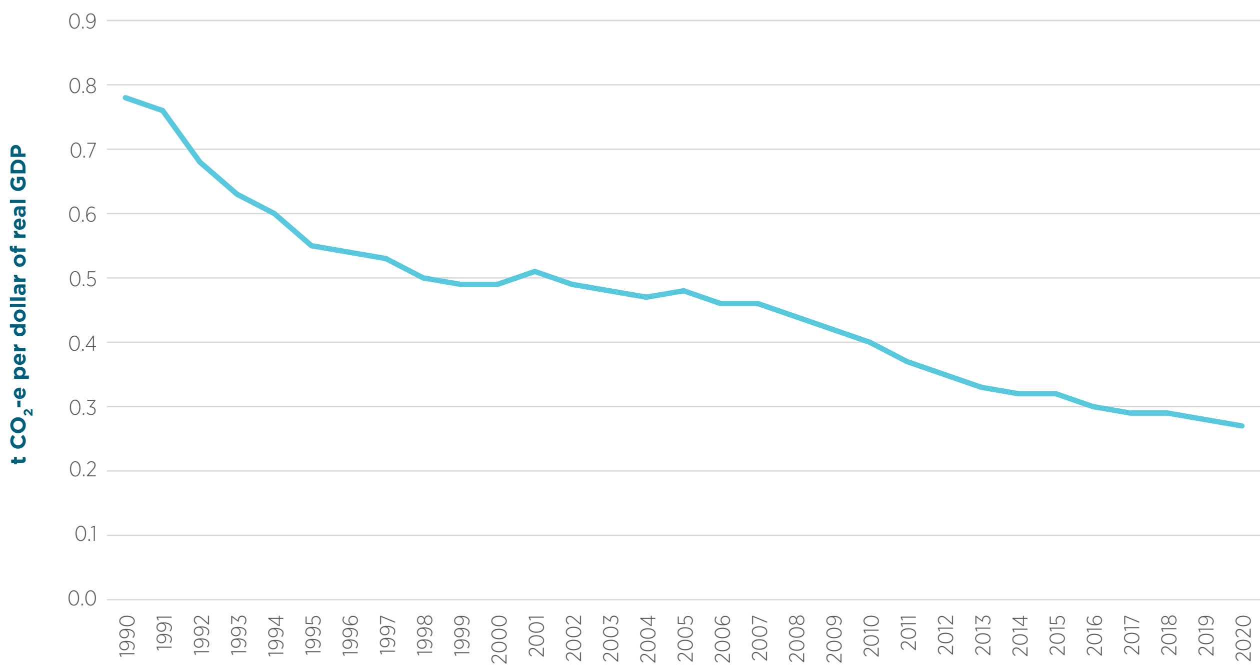
Australia's population grew strongly between 1990 and 2020, from 17.1 million in 1990 to around 25.7 million in 2020 (growth of 50.5 per cent). For the national inventory total (including emissions from the land sector), the 2020 estimate is 19.8 t CO_2-e per person, compared to 36.6 t CO_2-e in 1990, representing a 45.8 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 798 billion Australian dollars (AUD) in 1990 to over AUD 1,882 billion in 2020 (growth of 135.9 per cent). For the national inventory total (including emissions from *LULUCF),* the 2020 estimate is 0.27 kg CO_2-e per dollar, compared to 0.78 kg CO_2-e per dollar in 1990, which is a decline of 65.4 per cent.

Figure 2.4 Emissions per GDP, Australia (t CO_2-e per dollar of real GDP 2019–20 prices)



2.3 Emission trends by sector

Sectors with increasing emissions over the 1990 to 2019 period included *stationary energy* (42.7 per cent), *transport* (63.6 per cent), *fugitive emissions from fossil fuels* (41.8 per cent) and *industrial processes and product use* (25.7 per cent). Decreased emissions were recorded for *waste* (37.9 per cent), *agriculture* (17.8 per cent) and *LULUCF* (113.7 per cent).

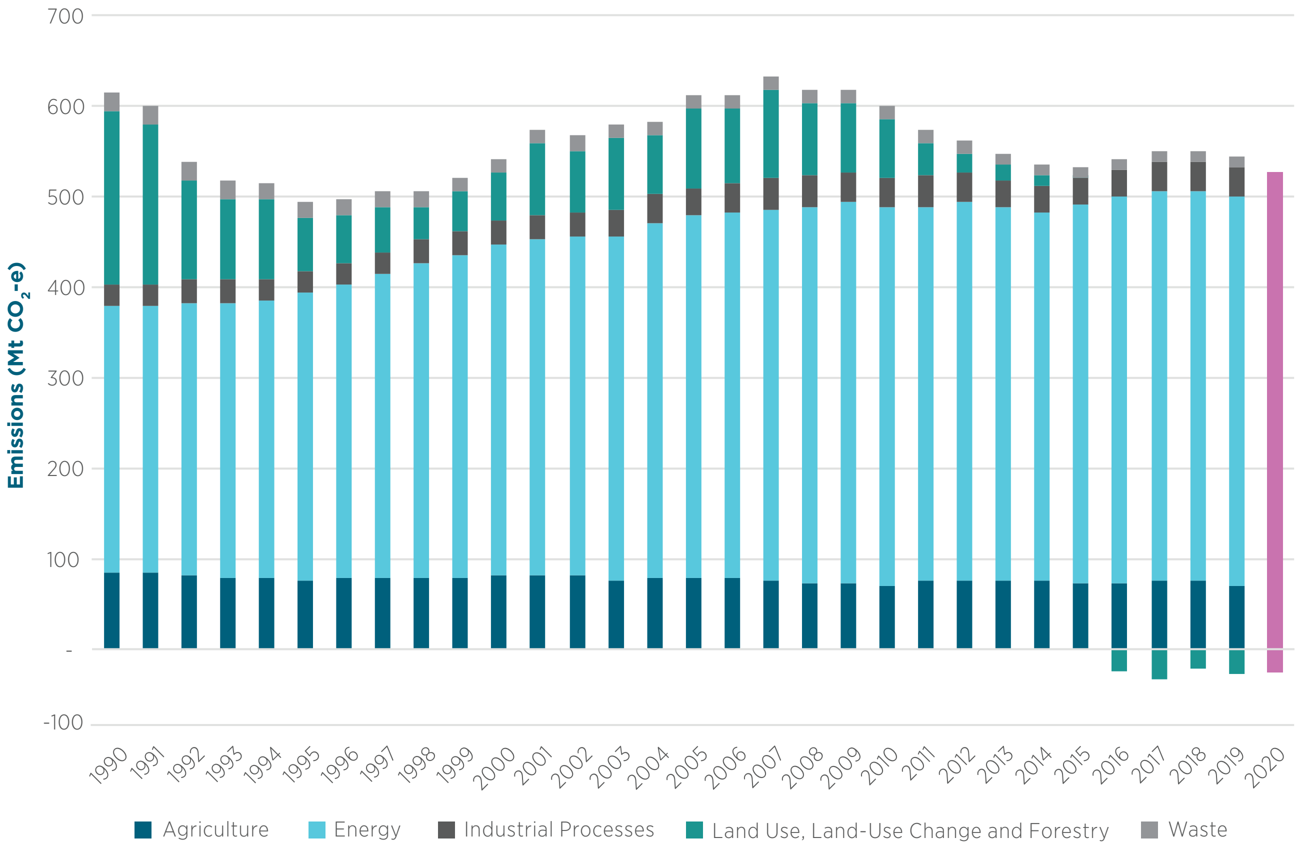
Figure 2.5 shows the emissions for each sector from 1990–2019 (preliminary estimates are also included for 2020). The principal drivers of these emission trends are as follows:

- *Energy:* The largest sectoral increase in greenhouse gas emissions over the 1990 to 2019 period, of 83.4 Mt CO_2-e (42.7 per cent), occurred in the stationary energy sector, driven in part by increasing population, household incomes and export increases from the resource sector. Emissions from the public electricity and heat production sub-sector in 2019 decreased by 32.2 Mt CO_2-e (15.2 per cent) from the peak in 2009, despite continuing population and economic growth. This was primarily driven by a 12.2 per cent decrease in the share of generation from coal, along with a 7.4 per cent increase in the share of generation of renewable energy in the National Electricity Market, with the largest increases coming from wind and solar. 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 21 per cent in 2019;

- *Industrial processes and product use:* The emissions in the industrial processes and product use sector have increased by 25.7 per cent since 1990. The increase is primarily driven by the growth in hydrofluorocarbons (HFCs) used in refrigeration and air-conditioning equipment, as they replace ozone depleting chemicals phased out by the Montreal Protocol. Increased HFC emissions over the period from refrigeration and air conditioning were partly offset by declining emissions in other activities, in particular, in metals production. Declines in emissions from iron and steel production have been observed due to plant closures while declines in emissions from aluminium production are largely due to improvements in process control and plant upgrades and closures.
- *Agriculture:* Agricultural emissions have decreased by 17.8 per cent since 1990. Climate (droughts, recovery from droughts, large seasonal differences, rainfall and floods) as well as economic forces (national and international markets and produce demand) directly impact emissions from the agricultural sector. The 17.8 per cent decline is primarily associated with a decline in sheep numbers as a result of the wool crisis and the collapse of the wool reserve price scheme. From 1995 to 2002 emissions increased due to increased beef cattle numbers and crop production, which resulted most markedly in increased enteric fermentation emissions and increased emissions from agricultural soils. From 2002 until 2010, prolonged and widespread drought conditions over southern and eastern Australia contributed to reductions in livestock populations, crop production, and fertiliser use. In turn, emissions declined over this period. As Australia saw relief from the Millennium Drought, emissions rose between 2011 and 2017, as farmers were able to increase herds and flocks and crop production. Drought conditions in more recent years have resulted in a lack of feed and elevated levels of turn-off of cattle and sheep and a contraction in the livestock population. In addition, crop production and fertiliser consumption has decreased. Decreases in emissions have followed.
- *Waste:* Emissions from the waste sector have decreased by 37.9 per cent, as increases in waste generation associated with growing populations and industrial production have been offset by increased methane recovery. The majority of emissions were from solid waste disposal (73.6 per cent), which has experienced a substantial improvement in methane recovery rates over the period (from a negligible amount in 1990 to 7.5 Mt CO_2-e in 2019).
- *LULUCF:* The decrease in emissions from LULUCF since 1990 (-113.7 per cent) has been mainly driven by the decline in emissions from land clearing (forest land converted to other land uses), forest cover expansion (including post-1990 plantation establishment), and declines in the harvesting of native forests

Trends in emissions from each sector are discussed further in Chapters 3–7.

Figure 2.5 Net CO_2-e emissions by sector, Australia, 1990–2019 (preliminary 2020)



2.4 Analysis of emission trend drivers

Kaya analysis

The following kaya analysis demonstrates that growth in population and gross domestic product have placed upward pressure on national carbon dioxide emissions, offset by decreases in energy intensity and, to a lesser extent, emissions intensity.

An equation based on the Kaya identity (Equation 2.1) expresses CO_2 emissions from fuel combustion and industrial processes and product use (IPPU) 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 2019, CO_2 emissions from fuel combustion and IPPU increased by 49 per cent (Figure 2.6). Underlying growth factors were a 49 per cent increase in population (light blue bar) and a 59 per cent increase in GDP per capita (green bar). Declining factors were a 34 per cent decline in the energy intensity of the economy (dark blue bar) and a 5 per cent decline in the emissions intensity of energy consumption (dark grey bar). Over the time series, Australia's CO_2 emissions trended upwards until 2009 before declining over the period to 2018 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, 1990–2019

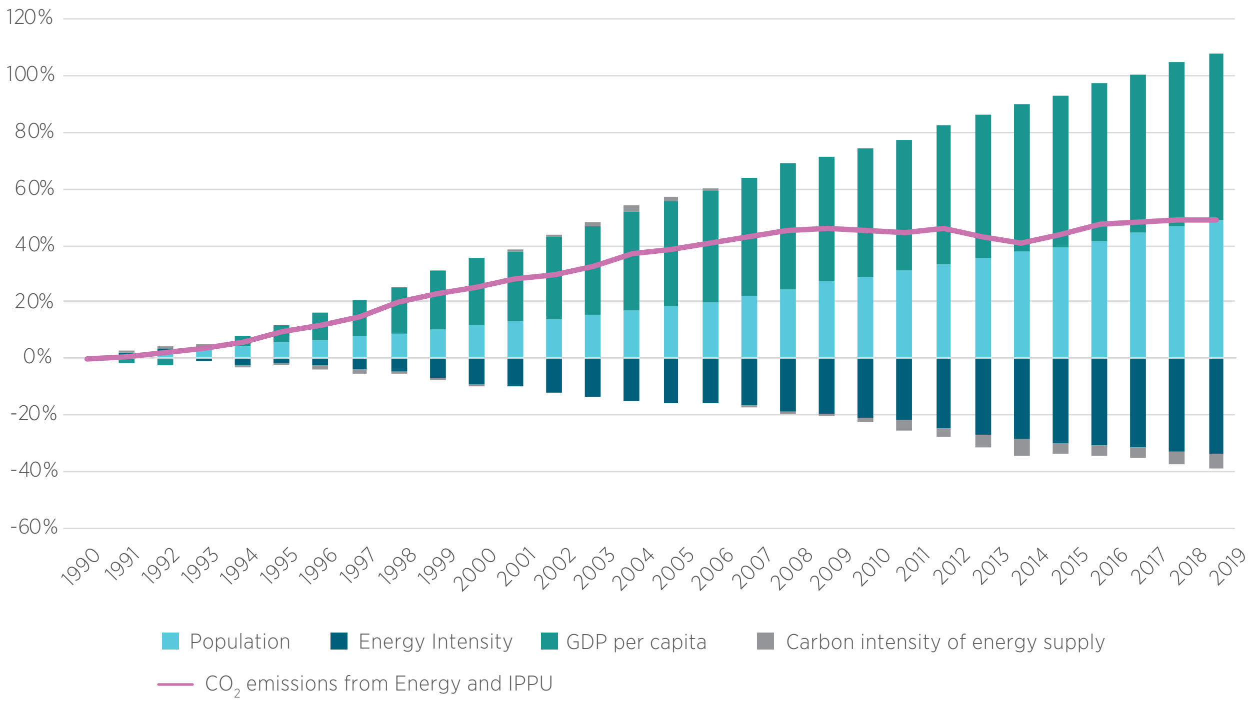
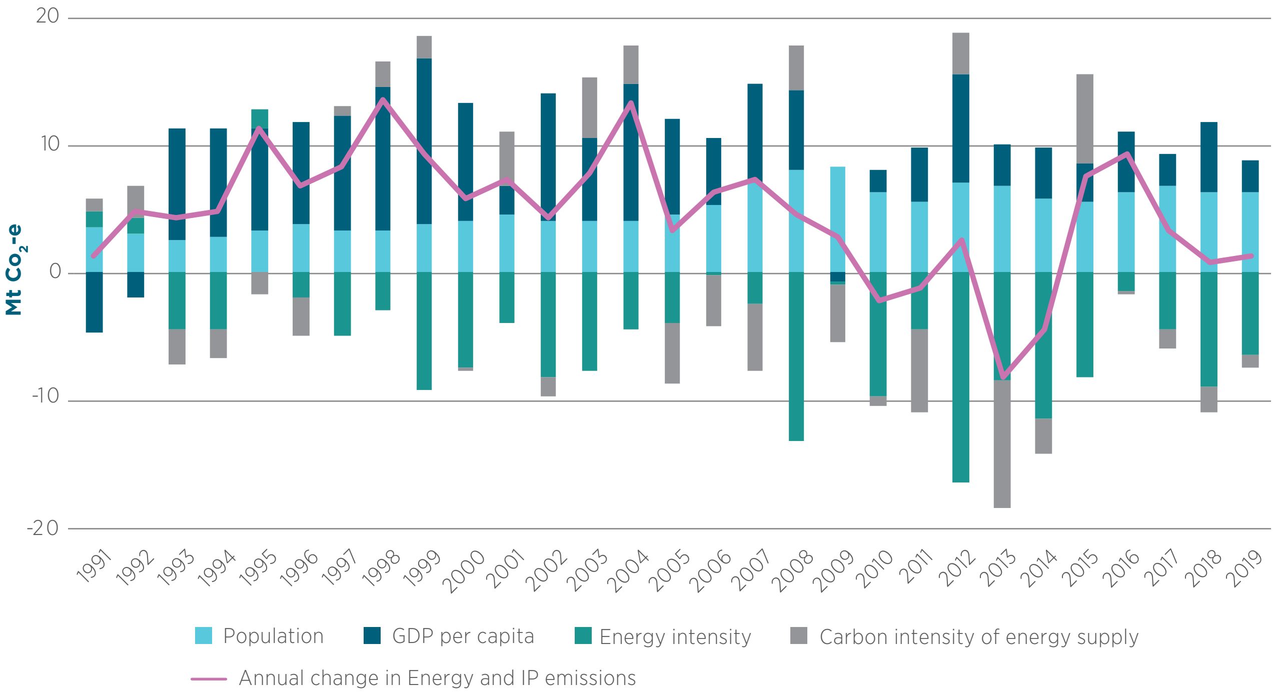


Figure 2.7 attributes annual emission changes (purple line) to the four underlying factors. The combined impact of increases in population (light blue bar) and GDP per capita (dark blue bar) have contributed to increasing emissions in all years.

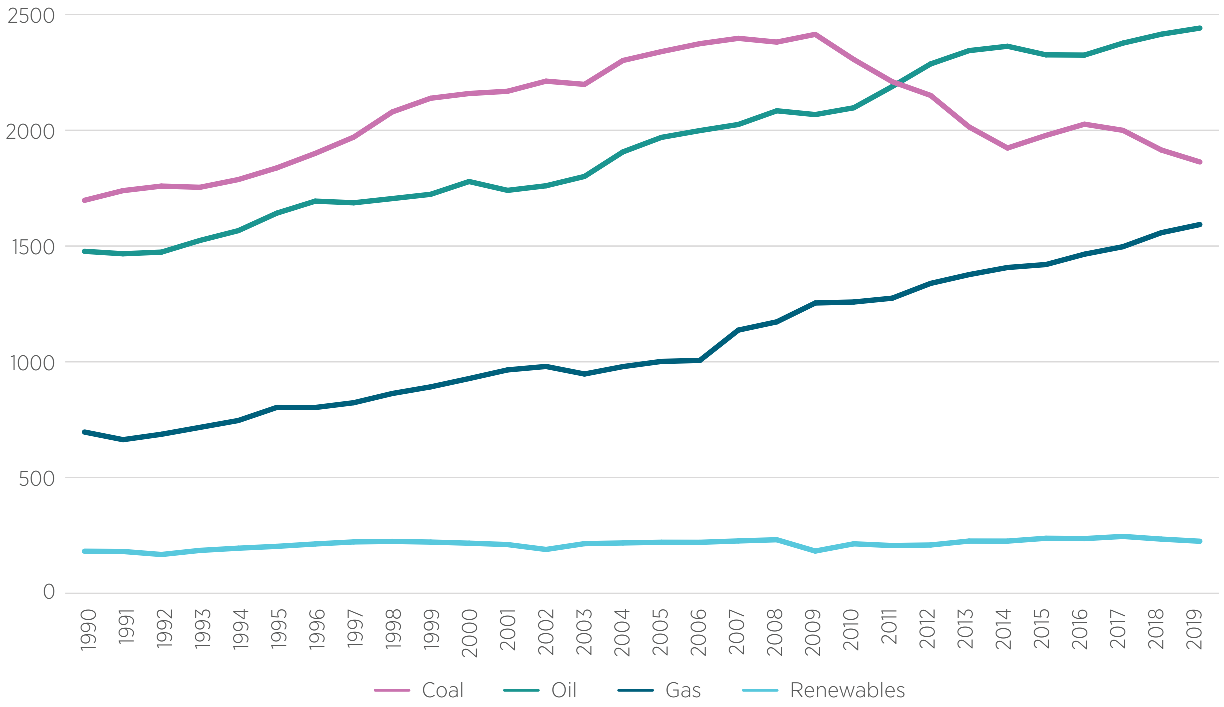
The energy intensity of the economy (green bar) decreased in 26 of the 29 years at varying annual rates reflecting energy efficiency improvements and structural change in the economy towards less energy intensive service sectors. The emissions intensity of energy (grey bar) has fluctuated over the time 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: Australia 1991–2019 (Mt CO_2-e)



This trend is reflected in the fuel switching evident in the observed 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 since that time. In 2019, coal consumption was 23 per cent below its 2009 peak level of 2,350 petajoules.

Figure 2.8 Energy consumption by fuel type 1990–2019 (PJ)



Source: Australian Energy Statistics 2020 Update, Table D

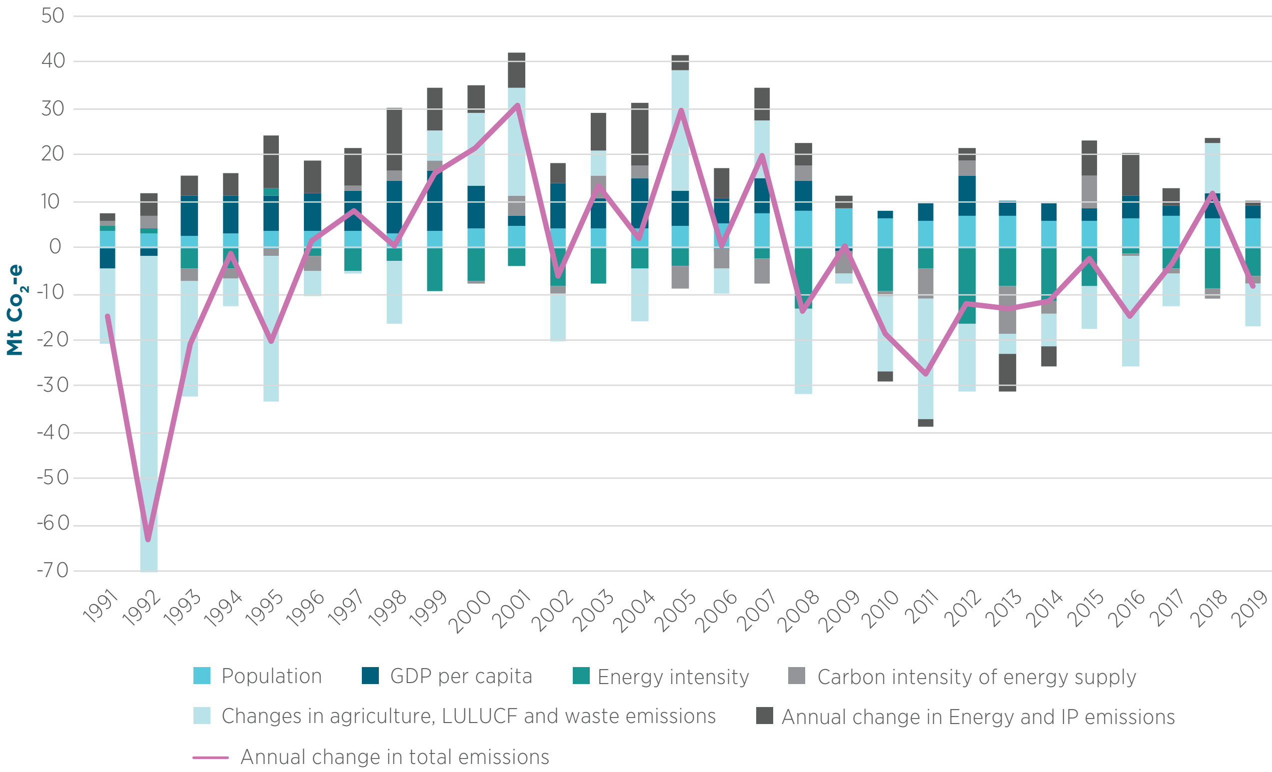
The Kaya analysis considers a subset of Australia's total emissions. At the national level increases in CO_2 emissions from fuel combustion and IPPU have been offset by declines in other emission sources. Figure 2.9 expands the decomposition to include other emission sources as a fifth driver of total 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: $$\text{Total emissions} = P \times \frac{GDP}{P} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy} + \text{other emission sources}$$

CO_2-e emissions from fuel combustion and IPPU remained steady in 2019, falling by 2 per cent compared to 2018, or by 1.2 per cent on a per capita basis. Similarly, carbon intensity improved by 2 per cent.

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 Annual change in total emissions from underlying drivers: Australia 1991–2019 (Mt CO_2-e)



2.5 Consumption based inventory

Structural changes in the economy have also contributed to the observed trend in Australia's emissions profile. This can be illustrated through presentation of a consumption-based account, which estimates the impacts on emissions in Australia and in other countries due to Australian consumption or demand.

Household consumption was the most significant contributor to Australia' national consumption-based emissions inventory, at 302.4 Mt CO_2-e (or 71.7 per cent of total consumption emissions), followed by government final consumption emissions of 43.4 Mt CO_2-e (or 10.3 per cent of total consumption emissions). When combined with gross fixed capital formation from government and public corporations, the Government sector was responsible for emissions of 66.7 Mt CO_2-e (or 15.8 per cent of consumption-based emissions across the economy) (Table 2.2).

The analysis also shows that the emissions generated to support Australia's consumption are less than those reported as the (production-based) national greenhouse gas inventory by 78.6 Mt CO_2-e or 15.7 per cent in the year to September 2020. Consumption-based emissions are approximately 16.5 tonnes per person, which is around 3.1 tonnes per person less than the per capita emission calculation using the national greenhouse gas inventory. The gap reflects the effects of trade on Australia's emissions profile.

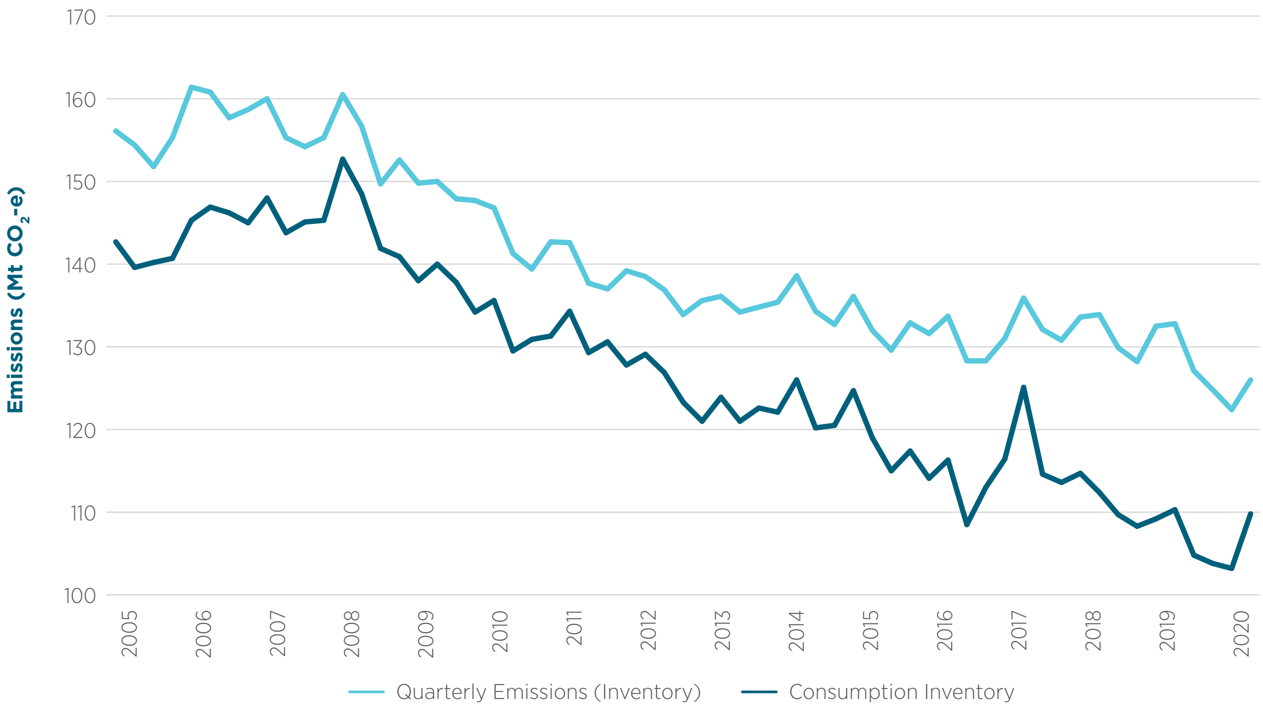
Table 2.2 Consumption-based national greenhouse gas inventory, Australia, year to September 2020, by sector, Mt CO_2e

Household consumption	302.4
Government consumption	43.4
Fixed capital – Govt & Public corporations	23.2
Private fixed capital	85.6
Change in inventories [(a)]	-33.0
Total consumption-based inventory	421.6

(a) Includes carbon sequestered in forests and plantations available to be utilised in wood and paper production in the future.

Emissions generated by Australian consumption were 139.9 Mt CO_2-e or 24.9 per cent lower than emissions to the year to September 2005 (Figure 2.9). The gap between this trend, and that observed for the national greenhouse gas inventory, reflects the effects of trade on Australia's emissions profile, with an increasing trend towards emissions intensive exports relative to the emissions intensity of imports.

Figure 2.10 National Greenhouse Gas and Consumption-based inventories, Australia, by quarter, September 2005 to September 2020, Mt CO_2e



2.6 Emission trends for Kyoto Protocol – LULUCF inventory

This section contains emissions and removals associated with Articles 3.1, and 3.4 of the KP for the first seven 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 2.3 Emissions and removals associated with Articles 3.1, 3.3 and 3.4 of the Kyoto Protocol, 2013–2019

Sector and subsector	Emissions Mt CO_2-e						
	2013	2014	2015	2016	2017	2018	2019
Energy	412.8	406.8	417.1	426.9	429.5	430.6	430.4
IPPU	29.1	29.0	30.4	30.2	30.6	31.4	32.6
Agriculture	76.0	76.4	73.6	72.6	76.6	75.2	69.8
Waste	12.5	12.6	12.1	12.6	12.7	12.6	12.4
Deforestation [(a)]	36.0	38.3	30.1	27.7	26.9	29.3	22.3
National inventory emissions (1)	**566.3**	**563.0**	**563.1**	**569.9**	**576.2**	**579.1**	**567.4**
RMU credits generated by Article 3.3 and 3.4 activities							
Afforestation/reforestation [(a)]	-30.1	-30.7	-29.2	-31.8	-32.9	-23.6	-17.7
Article 3.4 activities	-25.7	-25.5	-29.8	-43.7	-49.5	-41.4	-49.4
Total RMU credits (2) (b)	**-55.8**	**-56.1**	**-59.0**	**-75.5**	**-82.4**	**-65.0**	**-67.0**
Kyoto Protocol Total (1 – 2)	**510.5**	**506.8**	**504.1**	**494.5**	**493.9**	**514.1**	**500.4**

(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. Accounting quantity in accordance with decisions 2/CMP.7 and 3/CMP.11.

Trends in emissions

3. Energy

3.1 Overview

Total emissions from the *energy* sector for 2019 were estimated to be 430.4 Mt CO_2-e (Table 3.1). *Energy industries* were the main contributor, accounting for 49.7 per cent of emissions from the *energy* sector. Other significant contributors to total *energy* emissions were *transport* (23.3 per cent), and *manufacturing industries and construction* (9.5 per cent).

Energy sector emissions increased by 46.9 per cent between 1990 and 2019. Annual emissions from 2018 to 2019 decreased by 0.2 Mt (0.04 per cent).

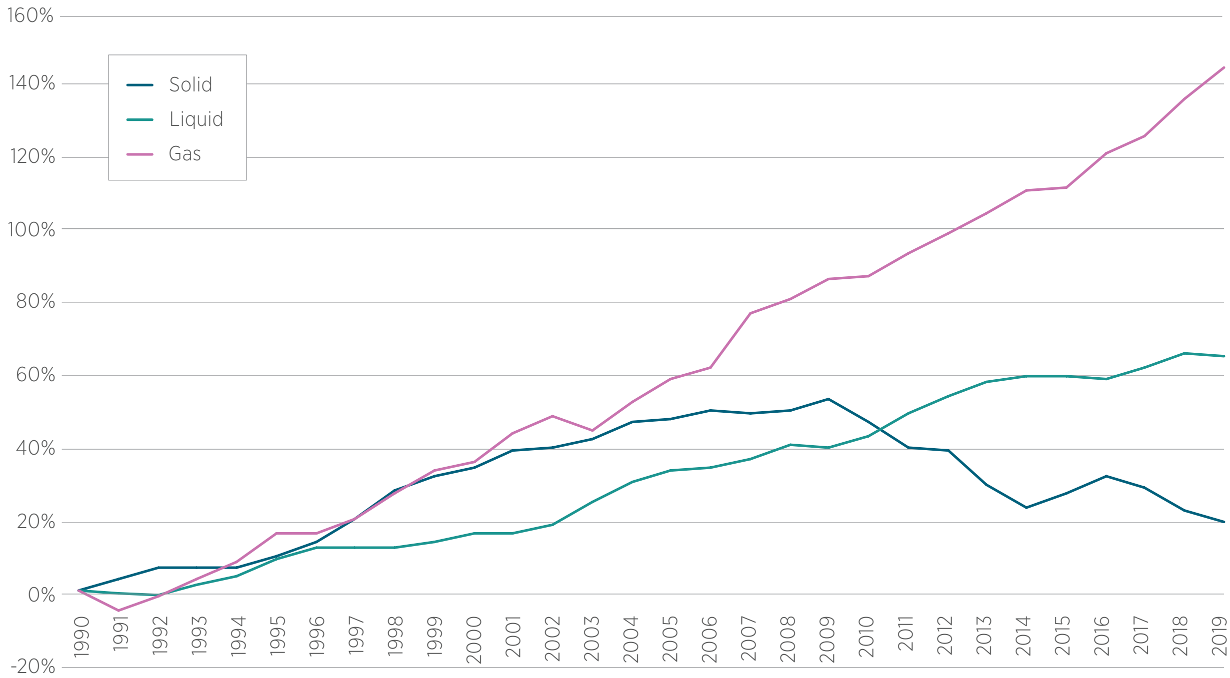
Preliminary estimates for 2020 show energy sector emissions increasing by 42.4 per cent between 1990 and 2020, and decreasing by 3.1 per cent from 2019 to 2020.

Table 3.1 Energy sector CO_2-e emissions, 2019, 2020

	CO_2-e emissions (Gg)				
Greenhouse Gas Source and Sink Categories	**CO_2**	**CH_4**	**N_2O**	**Total 2019 CO_2-e**	**Preliminary 2020 estimate CO_2-e**
1. ENERGY	**394,500**	**32,898**	**2,994**	**430,393**	**418,125**
A. Fuel combustion activities	**374,299**	**2,156**	**2,903**	**379,358**	**368,054**
1 Energy industries	212,031	887	896	213,814	207,768
a Electricity and heat production	178,257	551	643	179,451	171,600
b Petroleum refining	3,002	1	2	3,005	2,655
c Manufacture of solid fuels	30,772	335	252	31,358	33,513
2 Manufacturing industries and construction	40,309	58	426	40,793	41,203
3 Transport	98,770	323	1,366	100,458	93,941
a Domestic aviation	8,453	1	19	8,472	6,803
b Road transportation	83,540	203	867	84,610	79,748
c Railways	3,641	5	465	4,110	4,140
d Navigation (domestic)	2,202	110	15	2,326	2,209
e Other transportation	935	4	1	939	1,041
4 Other sectors	22,404	888	209	23,500	24,225
5 Other Mobile (military)	785	1	7	792	916
B. Fugitive emissions from fuels	**20,201**	**30,742**	**91**	**51,034**	**48,920**
1 Solid fuels	2,062	22,511	0	24,574	26,001
2 Oil and natural gas	18,139	8,231	90	26,461	22,919

Trends in fuel consumption use within the *Energy* sector are shown in Figure 3.1. A slowdown in the consumption of solid fuels is accompanied by continuing increases in gaseous and liquid fuel use.

Figure 3.1 Energy sector CO_2-e emissions by fuel type, percentage change since 1990



3.1.1 Stationary energy

Stationary energy principally comprises fossil fuel combustion in *energy industries* and *manufacturing industries and construction.* Total estimated emissions from stationary energy combustion were 278.9 Mt CO_2-e in 2019, equal to 51.2 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 179.5 Mt CO_2e or 64.3 per cent of *stationary energy* emissions in 2019. 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 34.4 Mt CO_2-e in 2019.

The *manufacturing industries and construction* subsector (1.A.2) emissions were 40.8 Mt CO_2-e in 2019. 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).

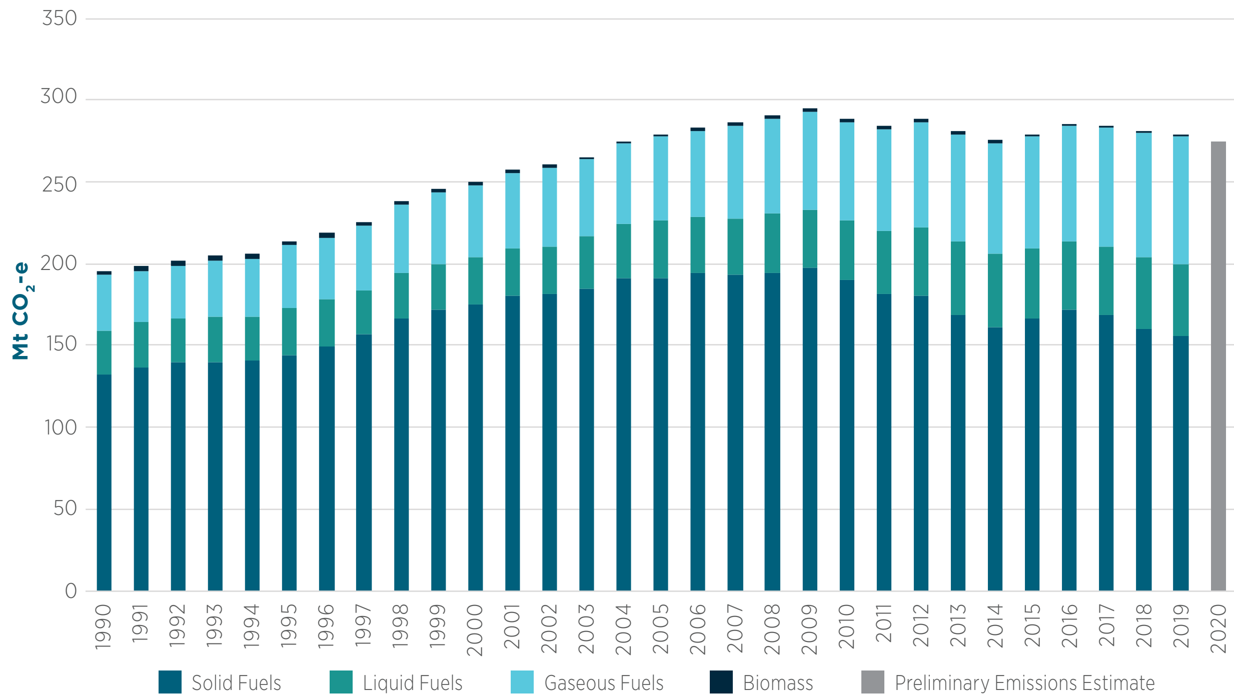
Estimated emissions from *other sectors* (1.A.4) were 23.5 Mt CO_2-e in 2019. This subsector comprises direct fuel combustion in the residential, commercial and institutional sectors, including energy used in mobile equipment in *agriculture, forestry* and *fishing* industries. However, as with *manufacturing,* 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* (0.8 Mt CO_2-e).

Trends

Emissions from *stationary energy* increased by 42.7 per cent (83.4 Mt CO_2-e) between 1990 and 2019, including an increase in emissions from the combustion of solid fossil fuels of 18.3 per cent (24.2 Mt CO_2e) in the same period (Figure 3.2). Emissions related to gaseous fossil fuels have shown the largest relative and absolute growth, increasing by 135.1 per cent (45.1 Mt CO_2-e) between 1990 and 2019. Emissions from liquid fossil fuels increased by 57.3 per cent (15.7 Mt CO_2-e) in the same period. Biomass emissions decreased by 56.1 per cent (1.5 Mt CO_2-e) between 1990 and 2019. Between 2018 and 2019, emissions from *stationary energy* decreased by 0.8 per cent (2.1 Mt CO_2-e).

The preliminary estimate for Australia's *stationary energy* (excluding electricity) sector in 2020 is 102.8 Mt CO_2-e, an increase of 3.4 per cent on 2019 levels.

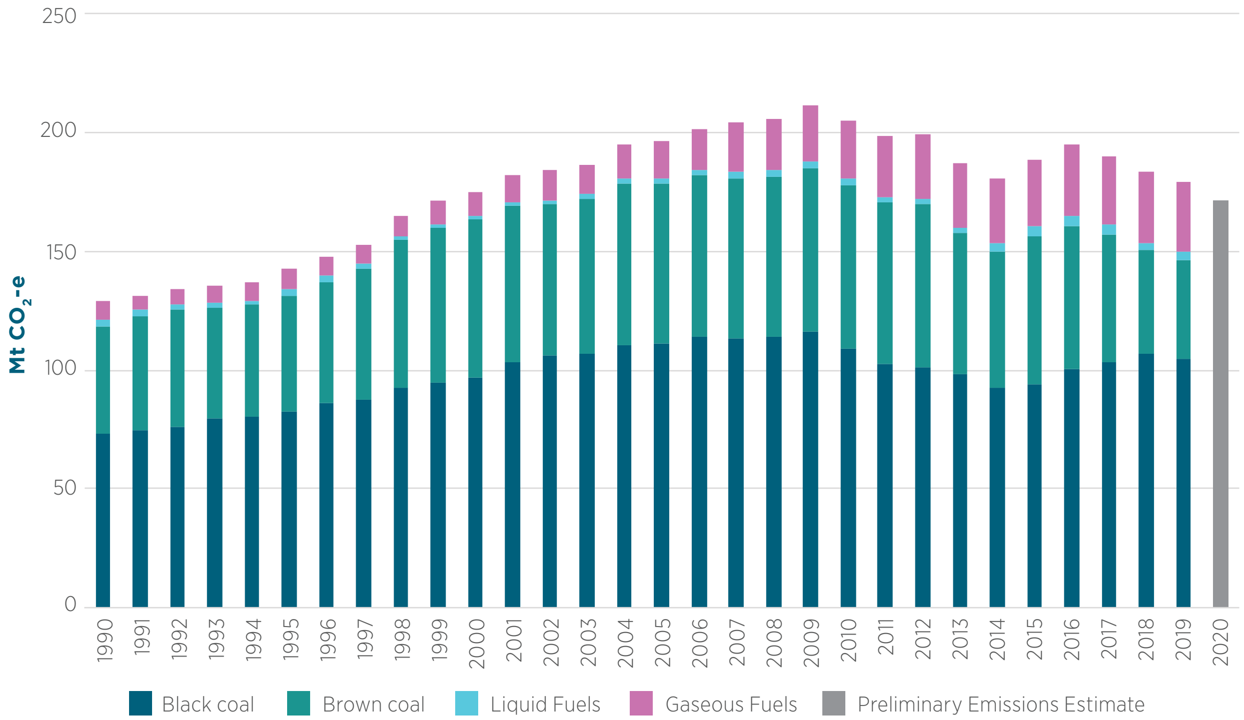
Figure 3.2 Total CO_2-e emissions from stationary energy combustion by fuel, 1990–2019 (preliminary estimates 2020)



Electricity generation emissions decreased by 4.2 Mt (2.3 per cent) from 2018 to 2019, and increased by 49.9 Mt (38.5 per cent) from 1990 to 2019 (Figure 3.3). From 2018 to 2019 there were decreases in emissions from black coal of 1.6 per cent, gas of 0.5 per cent and brown coal of 5.2 per cent.

The preliminary estimate for 2020 is 171.6 Mt, a decrease of 4.3 per cent on 2019 levels.

Figure 3.3 CO_2-e emissions from electricity generation by fossil fuels, 1990–2019 (preliminary estimates 2020)



Emissions from *stationary energy* subsectors, other than *electricity generation,* increased by 2.1 Mt CO_2-e (2.1 per cent) between 2018 and 2019, and increased overall by 33.5 Mt (50.9 per cent) from 1990 to 2019. Emissions from the *manufacturing industries and construction* subsector decreased by 0.2 per cent (0.4 Mt CO_2-e) between 2018 and 2019 and increased by 1.5 per cent (4.5 Mt CO_2-e) from 1990 to 2019.

3.1.2 Transport

In 2019, the *transport* sector contributed 100.5 Mt CO_2-e or 19.4 per cent of Australia's net emissions (excluding *LULUCF).*

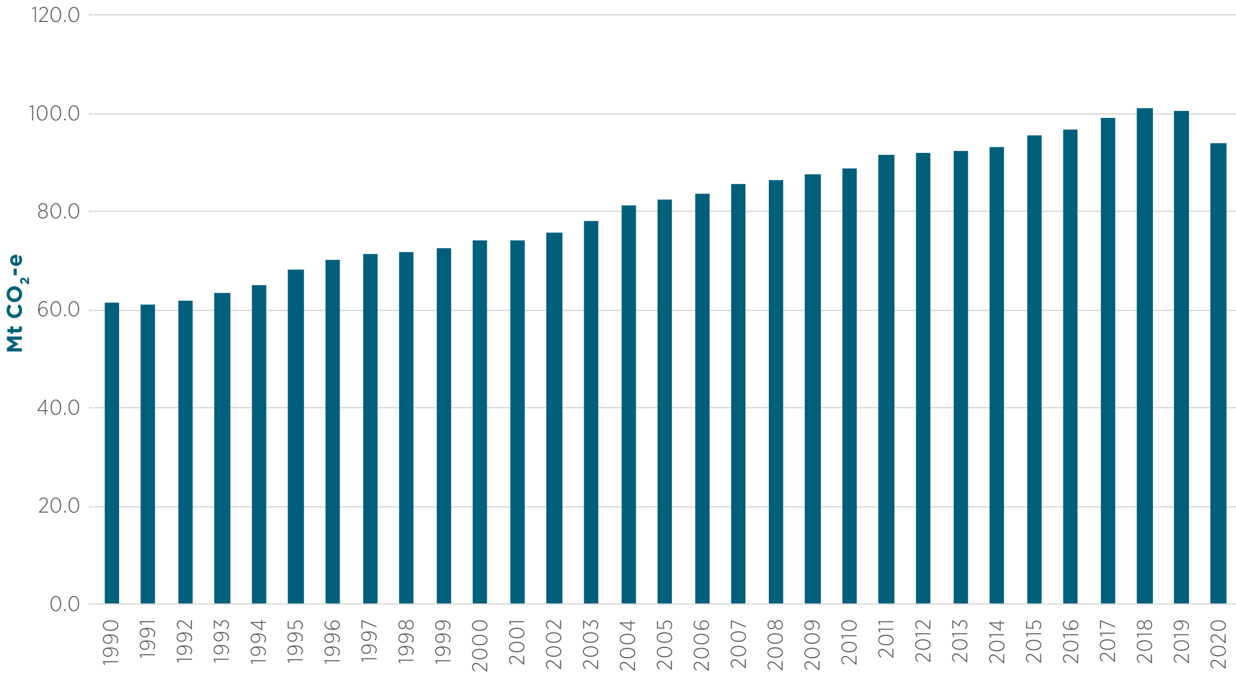
The major source of *transport* emissions in Australia is road transportation, which accounts for 84.2 per cent (84.6 Mt CO_2-e) of *transport* emissions. This outcome is principally driven by the importance of motor vehicles as modes of transportation of passengers and freight in Australia. Passenger cars account for 45.0 Mt CO_2-e and trucks (light and heavy) and buses 22.2 Mt CO_2-e. Other sources are far smaller: domestic aviation contributed 8.4 per cent (8.5 Mt CO_2-e), domestic navigation 2.3 per cent (2.3 Mt CO_2e), railways 4.1 per cent (4.1 Mt CO_2-e) and pipeline transport 0.9 per cent (0.9 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 2019, international bunker fuels generated 17.7 Mt CO_2-e of emissions.

Trends

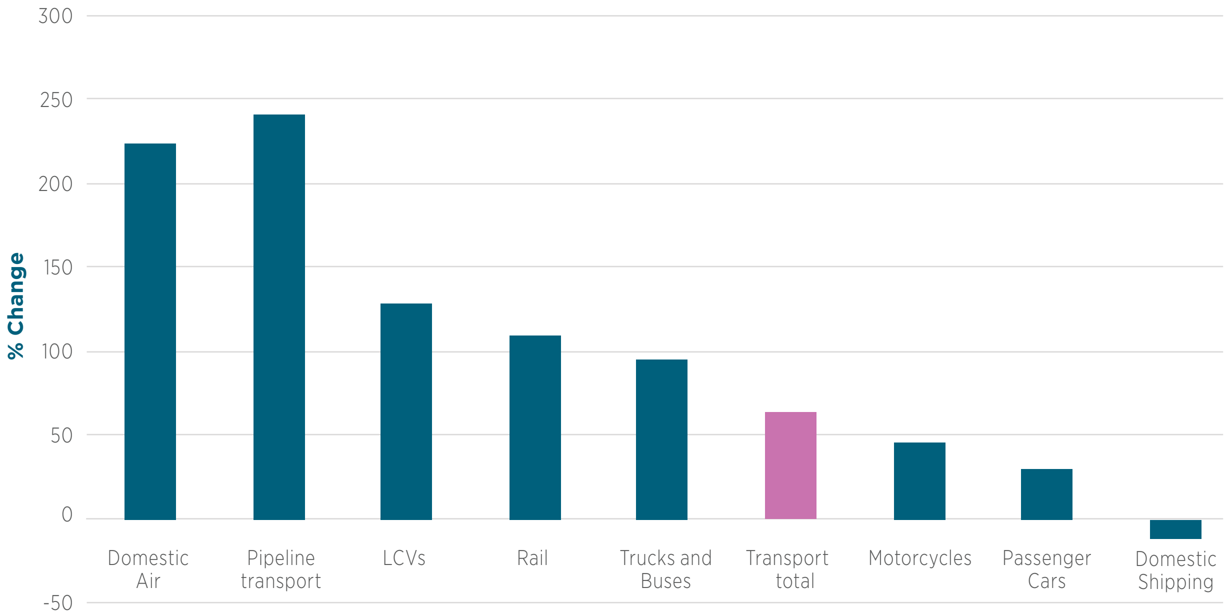
Transport emissions are one of the strongest source of emissions growth in Australia. Emissions from this sector were 63.6 per cent higher in 2019 than in 1990, and on average have increased by around 1.7 per cent annually (Figure 3.4). The preliminary estimate for 2020 is 93.8 Mt CO_2-e, a decrease of 6.7 per cent on 2019 levels. Liquid fuel consumption in the last quarter of 2020 decreased dramatically (petrol consumption down by 24.4 per cent and Jet fuel down by 73.6 per cent) as Australian's movement was restricted at the height of the pandemic.

Figure 3.4 Total transport emissions, 1990–2019 (preliminary estimates 2020)



Emissions from road transportation increased by 57.1 per cent (30.7 Mt CO_2-e) between 1990 and 2019 (Figure 3.5). 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 (128.3 per cent and 95.4 per cent respectively) over the same period. Emissions from pipeline transport grew very strongly between 1990 and 2019, increasing 240.8 per cent (0.6 Mt CO_2-e).

Figure 3.5 Comparison of growth in transport emissions by subcategory, 1990–2019



Since 1990, domestic air travel grew by 178 per cent (367,425.15 Km). This reflects an increase in domestic flight departures of 53 per cent. This shift in trend is due to population growth and cheaper airfares (as low as 8¢ per km) offered by budget airlines.

Emissions from pipeline transport increased by 12.8 per cent between 2005 and 2019. This is due to increased throughput associated with the expansion of gas production, especially offshore production.

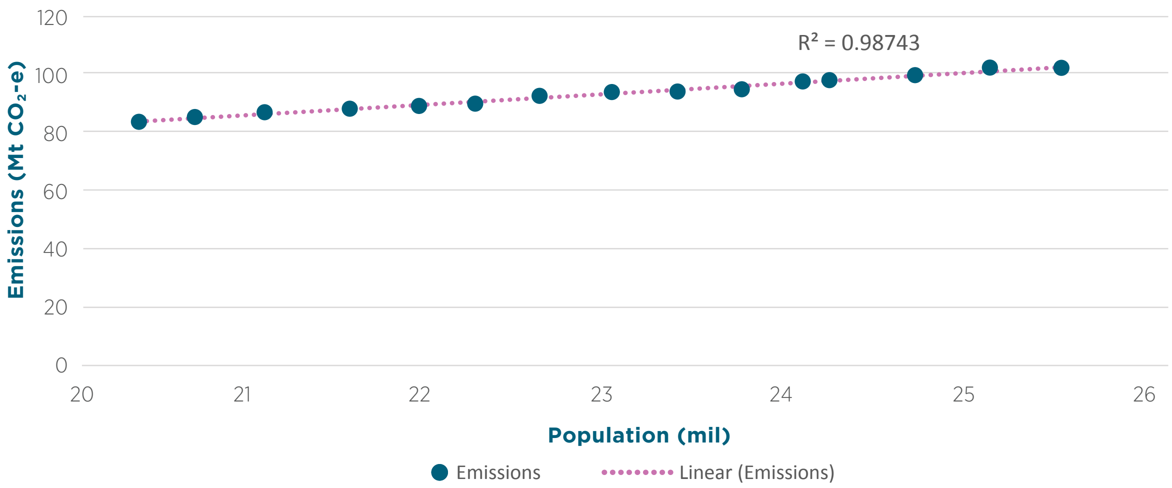
Road Transport Trends 2005–2019

Trends in Australia's emissions from the road transport sector are primarily driven by:

Population and economic growth

Since 2005, according to the Australian Bureau of Statistics, Australia's population and Gross Domestic Product per capita went up by 46.5 per cent 25.1 per cent respectively. The regression analysis below shows strong correlation between population growth and emissions from Australia's transport sector, over the same period.

Figure 3.6 Population and emissions regression model

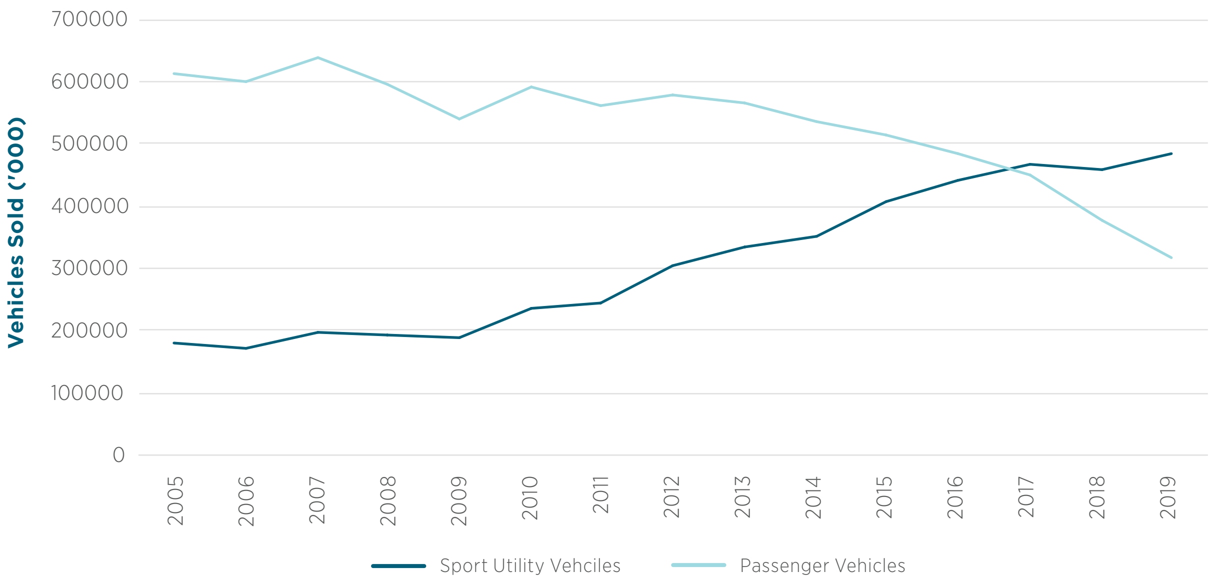


New passenger vehicles and Light Commercial Vehicles (LCV) registration during this time also grew by 34.7 and 67.8 per cent respectively (ABS Motor Vehicle Census, Australia 2020)[13].

Increase in market share of diesel-powered Sport Utility Vehicles (SUV)

Since 2005, SUV sales are up by 167.0 per cent while traditional passenger vehicle (PV) sales dropped by 48.3 per cent.

Figure 3.7 SUV and passenger vehicles sales trend in Australia, 2005–2019



13 https://www.abs.gov.au/ausstats/abs@.nsf/mediareleasesbytitle/28861A19CCDB9441CA25753D001B59DA?OpenDocument

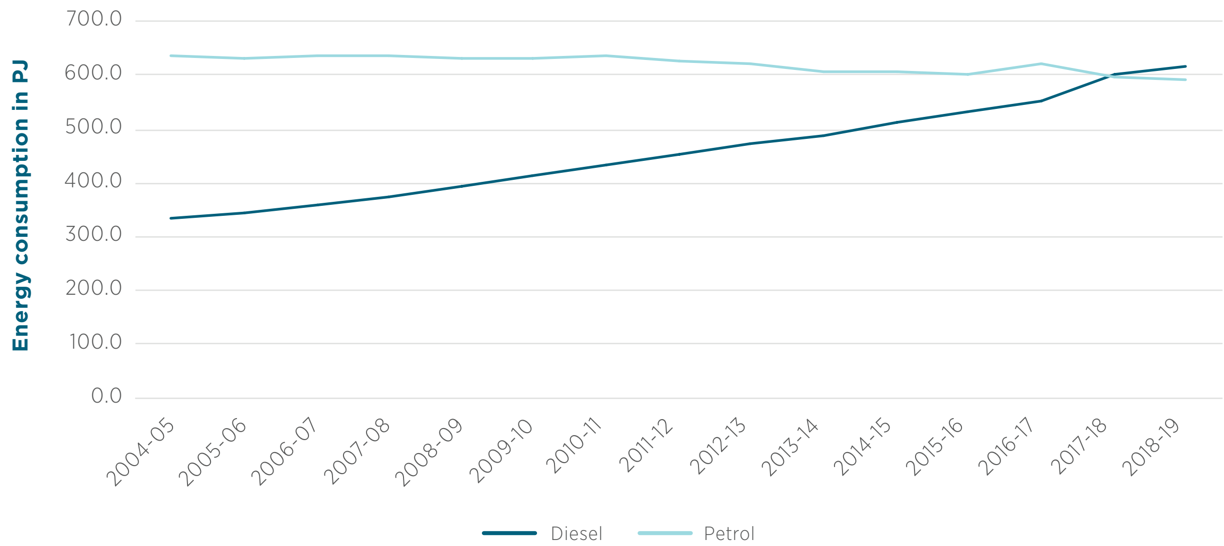
Energy

Increase in diesel consumption in road transport and passenger vehicles

The Australian Energy Statistics data shows that between 2004–05 and 2018–19, diesel consumption in road transport grew by 85.4 per cent while energy consumption by petrol declined by 7.1 per cent.

In the same period, diesel consumption by passenger vehicles grew by 231.0 per cent while petrol consumption fell by 18.7 per cent (Pekol Consulting Report 2020).

Figure 3.8 Energy consumption in road transport by fuel type (2004–05 to 2018–19)



Increase in motor vehicle kilometres travelled by passenger vehicles, LCVs and Trucks

With growing population, more Australians are driving further. Since 2005, passenger vehicle kilometres travelled grew by 6.8 per cent (Pekol Consulting Report 2020).

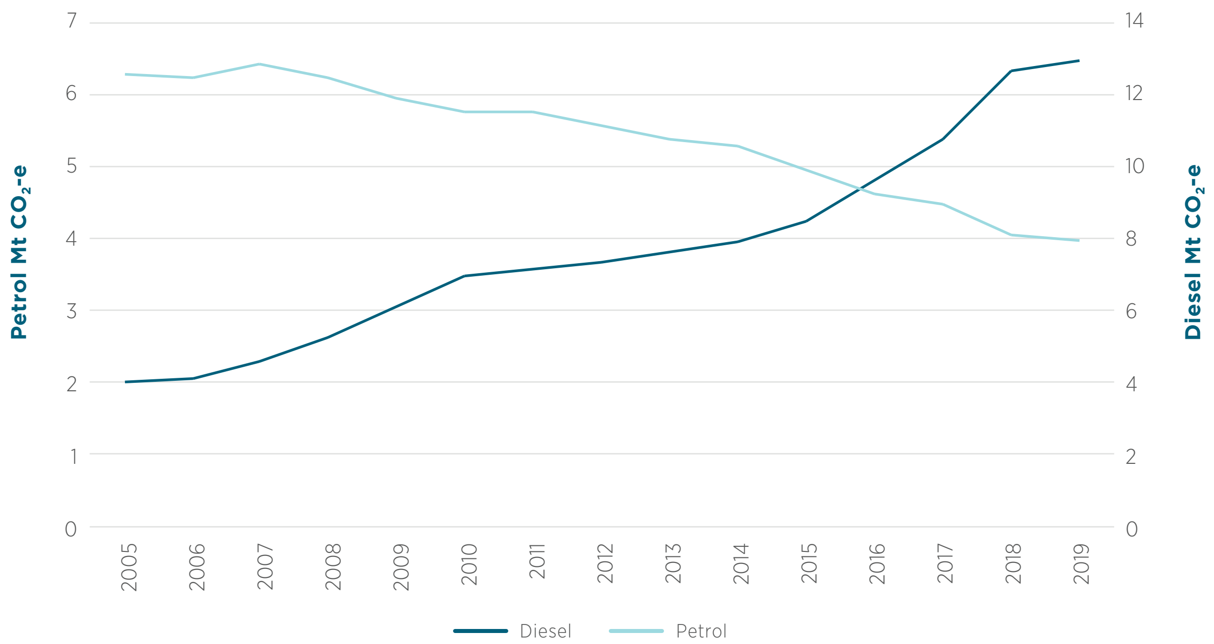
For the same period, kilometres travelled by diesel powered LCVs and articulated trucks increased by 47.3 per cent and 26.6 per cent respectively (Pekol Consulting Report 2020).

Increase in market share of diesel-powered LCVs

LCV sales climbed from 3.9 per cent of the market in 2002 to 9.3 per cent as of May 2019.

Emissions from diesel-powered LCVs grew by 223.7 per cent while emissions from petrol powered LCVs declined by 36.0 per cent, since 2005. This trend is driven by growth in number of Australian workers employed in trades that required features exclusive to this class of vehicle.

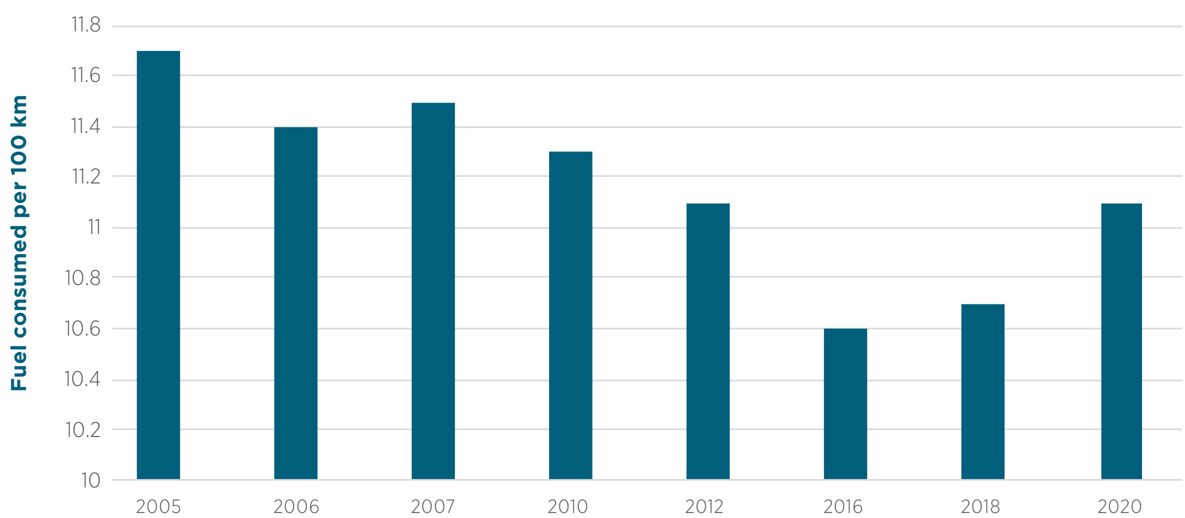
Figure 3.9 Total CO_{2}-e emissions from light commercial vehicles by fuel type, 2005–2020



Less fuel efficient vehicles sold in Australia

Australia's passenger vehicle fleet's yearly fuel consumption rate is around 11.1 /100 km (on average). The fuel efficiency of Australia's passenger vehicles improved by around 8.5 per cent between 2005 and 2018. However, vehicle fuel consumption rate increased by 3.7 per cent in 2019. This recent increase can be attributed, in part, to general shift towards larger vehicles in the passenger fleet.

Figure 3.10 Rate of Fuel consumption in litres per 100 km



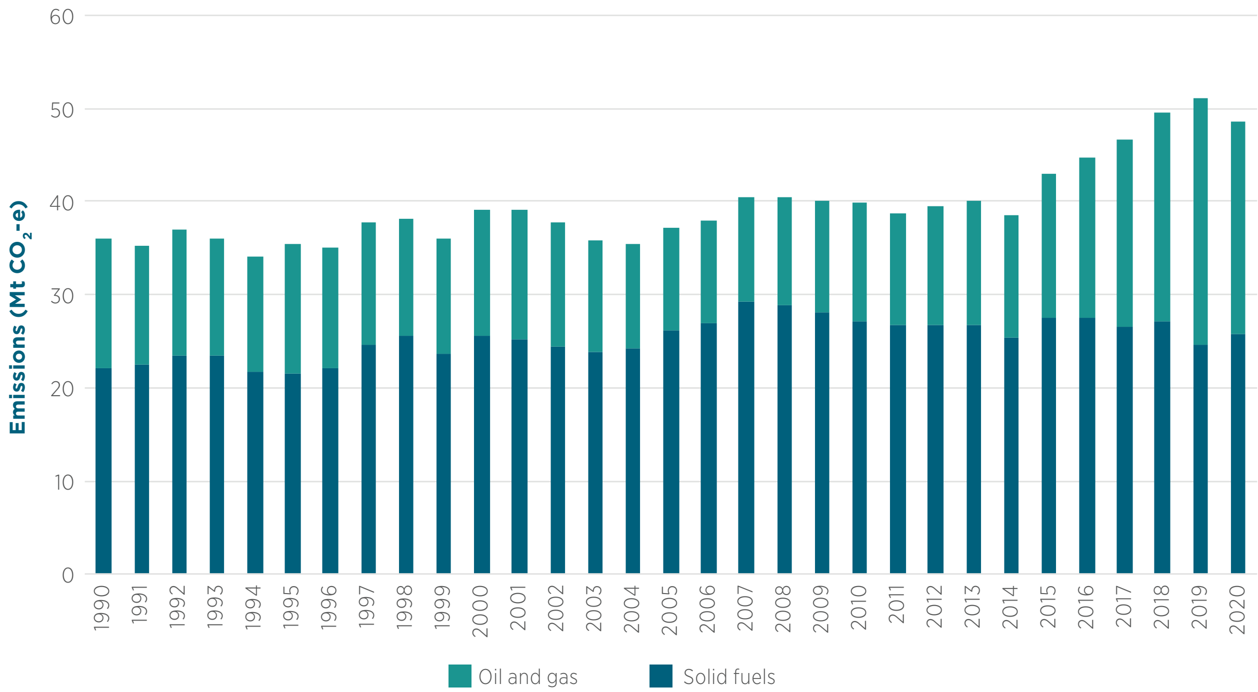
3.1.3 Fugitive emissions

Total estimated *fugitive emissions* for 2019 were 51.0 Mt CO_2-e, representing 9.8 per cent of net national emissions (excluding LULUCF). Net *solid fuel* emissions contributed 48.2 per cent (24.6 Mt CO_2-e) of fugitive *emissions. Oil and natural gas production, processing and distribution* account for the remaining 51.8 per cent (26.5 Mt CO_2-e) of fugitive *emissions.* The preliminary *fugitive* emissions estimate for 2020 is 48.9 Mt CO_2-e, a decrease of 4.2 per cent on 2019 levels.

Trends

Overall *fugitive emissions* increased 41.8 per cent (15.0 Mt CO_2-e) between 1990 and 2019, and increased by 3.0 per cent (1.5 Mt CO_2-e) from 2018 to 2019 (Figure 3.11). From 1990 to 2019, *fugitive emissions* from *solid fuels* increased by 10.8 per cent (2.4 Mt CO_2-e) and *oil and natural gas* emissions increased by 91.4 per cent (12.6 Mt CO_2-e).

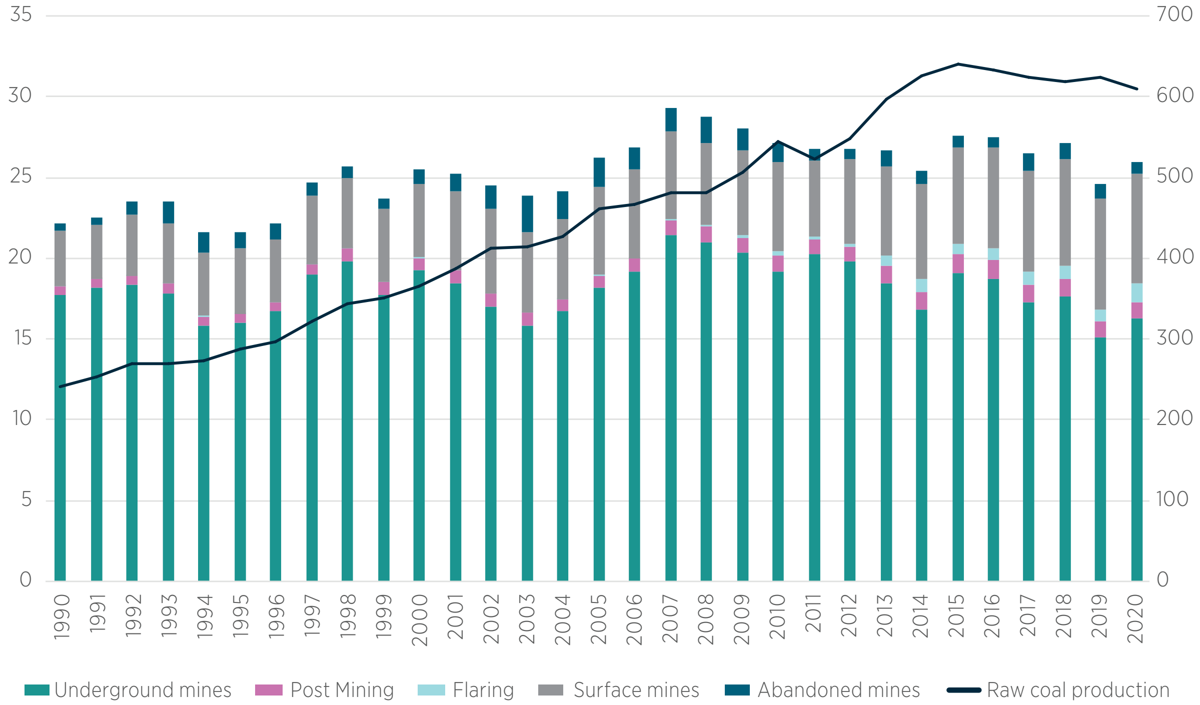
Figure 3.11 CO_2-e fugitive emissions by category, 1990–2019 (preliminary estimates 2020)



Fugitive emissions from solid fuels decreased by 9.6 per cent (-2.6 Mt CO_2-e) between 2018 and 2019. Underground mine emissions decreased by 13.8 per cent (-2.7 Mt CO_2-e). Emissions from surface mines increased by 4.0 per cent (0.3 Mt CO_2-e) between 2018 and 2019. Emissions from decommissioned mines have decreased by 14.7 per cent (-0.2 Mt CO_2-e) between 2018 and 2019, and emissions from flaring decreased by 15.4 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 324.2 Mt in 2019, 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 3.12) 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 3.12 Fugitive CO_2-e emissions from coal mining activities, 1990–2019 (preliminary estimates 2020)

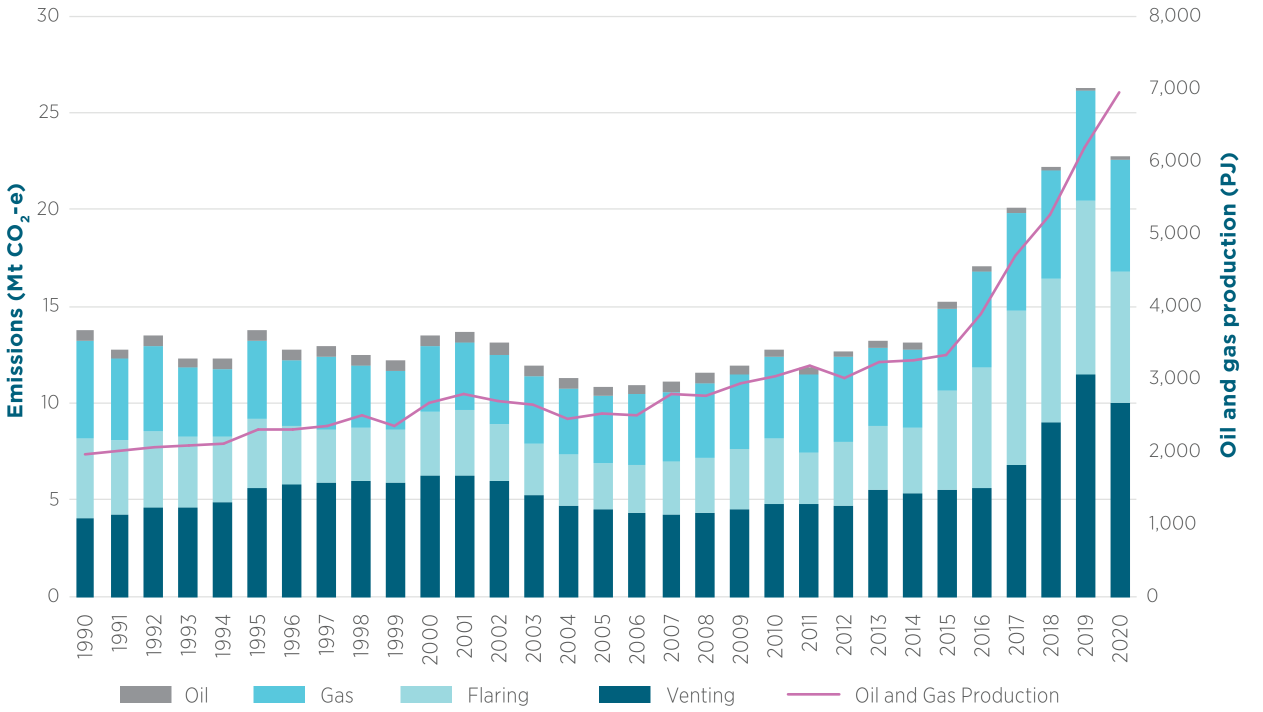


Oil and natural gas fugitive emissions increased 91.4 per cent (12.6 Mt CO_2-e) between 1990 and 2019 (Figure 3.13) while production increased 167.7 per cent during the same time period. The reduction in emissions intensity for this sector is the result of improvements in gas distribution (a reduction of 58.3 per cent in emissions since 1990) and large and efficient production, processing, and export facilities coming online (LNG).

Between 1990 and 2019, fugitive emissions from oil-related activities decreased 63.8 per cent (0.3 Mt CO_2-e) whereas emissions from gas-related activities have increased 10.9 per cent (0.6 Mt CO_2-e). In 2019, emissions from oil-related activities decreased 12.9 per cent (0.03 Mt CO_2-e) whereas emissions from gas-related activities have increased 2.0 per cent (0.1 Mt CO_2-e). Much of the emissions increase has occurred since 2000, with gas-related emissions increasing 66.0 per cent (2.3 Mt CO_2-e) in 2019 when compared with 2000 levels.

Emissions from venting increased 26.8 per cent (2.4 Mt CO_2-e) in 2019 when compared with 2018, and increased 182.9 per cent (7.5 Mt CO_2-e) compared with 1990. Flaring emissions increased 21.8 per cent (1.6 Mt CO_2-e) in 2019 when compared with 2018, and increased 118.3 per cent (4.9 Mt CO_2-e) since 1990.

Figure 3.13 Fugitive CO_2-e emissions from oil and gas production, 1990–2018 (preliminary estimates 2019)



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 Industry, Science, Energy and Resources compiled the *Australian Energy Statistics* (AES DISER 2020) 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 historical energy statistics were based on the voluntary *Fuel and Electricity Survey* (FES). With the introduction of the NGER system, 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

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 NGERS 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 3.14. 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 NGERS 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 NGERS. The CO_2 EF of 95.0 Gg/PJ for brown coal briquette has also been derived from NGER data.

In the case of coal used for non-electricity generation, the coal CO_2 EF's are statistically tested each year against the mean of the population of newly measured EF's to determine whether there is any significant difference to the mean of the population of new measurements. This test ensures that the EF applied to coal consumers in non-electricity sectors is consistent with the population of measurements undertaken annually under NGERS.

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 103.8 and 109.4 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

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 NGERS 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 3.14. For small electricity generators who do not meet the reporting thresholds of NGERS, 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

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 [(ka)]	91.8
	Black coal used by other industry [(a)]	90.0
	Brown coal used by industry [(a)]	93.5
	Coke [(l)]	109.4
	Coal by-products (coke oven gas) [(b)]	37.0
	Coal by-products (coal tar) [(b)]	81.8
	Coal by-products (liquefied aromatic hydrocarbons [(d)]	69.7
	LPG [(c)]	60.2
Petroleum fuels	Naphtha [(d)]	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 [(d)]	69.8
	Refinery gas and liquids [(d)]	54.7
	Refinery coke [(d)]	92.6
	Fuel oil [(m)]	73.6
	Tyres [(j)]	81.6
	Solvents [(d)]	69.7
	Bitumen [(d)]	80.7
Gases	Natural gas (including coal seam gas) [(e)]	51.4
	Natural gas (Basic chemicals sector) [(e)]	51.4
	Ethane [(f)]	56.5
	Town gas [(c)]	60.2
Biomass fuels	Wood and wood waste [(g)]	94.0
	Wood (For Residential subsector) [(h)]	77.5
	Ethanol [(d)]	67.3
	Bagasse [(d)]	95.0

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

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

Energy

Oxidation Factors for CO_2

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 recommend 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 system. 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 1.2.1.

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:

$$E_{hki} = F_{hk} \cdot E_{fhki} \qquad (3.2)$$

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 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.I. 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 the absence of evidence to differentiate gas variations in measured gas concentrations between boilers, differences cannot be attributed 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 default emission factors was obtained from the following sources:

- Petroleum products: Australian Institute of Petroleum and the National Pollutant Inventory;
- Natural gas and LPG: Australian Gas Association;
- Coal: the former Australian Government Department of Primary Industries and Energy.

Data for SO_2 emissions are available directly from reporting by facilities under the National Pollutant Inventory.

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).

3.2.4 Activity data

The Australian Energy Statistics (AES, DISER 2020) of energy use by economic sector and fuel has been compiled since the 1970s. The Department of Industry, Science, Energy and Resources compiled the 2020 Australian Energy Statistics.

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 Australian Energy Statistics utilises data collected under NGERS 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 available from the previous voluntary Fuel and Electricity Survey.

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 NGERS 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 is reconciled with 'top-down' statistics on the supply and use of all major fuels in Australia collected from the suppliers of those fuels.

The data is presented in common energy units (PJ) on an individual State basis. Historically, the Australian Energy Statistics 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 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.

Revisions are made to the AES to update the data in previous years of the series. These revisions are made to ensure that the AES presents an accurate picture of Australian energy production and use, including in historical periods. Often a revision will reflect changes in source data, such as the NGERS or Australian Petroleum Statistics. The AES can also be revised to correct errors or to account for changes in estimation techniques. Additional information regarding revisions is available in the Guide to the Australian Energy Statistics, available at the following web link: https://www.energy.gov.au/sites/default/files/Guide%20to%20the%20Australian%20Energy%20Statistics%202020.pdf.

These recalculations are incorporated into the inventory as they become available.

Activity data for the time series 1990 to 2019, reported by category level and fuel type, are available on the AGEIS website: https://ageis.climatechange.gov.au/

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 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 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.I.

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

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 as the basis for 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 the data published by the IEA.

A project has previously been undertaken to reconcile the data provided to the IEA with the published Australian Energy Statistics data used in the inventory. The Department found that the data reported to the IEA by the DIIS, the Australian Government department previously responsible for 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, with the data provided to the IEA being processed by methods outside of the control of Australia (including the use of default energy content values as compared to facility specific NGERs data); and
- Coal production data reported in the CRF tables 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 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 the AES which represent Australia's fiscal year (i.e. 1 July 2019 to 30 June 2020). Therefore differences will exist due to accounting period inconsistencies and revisions to data published annually in the AES.

- In addition, recent investigations has revealed that only the most recent year of data is appended and published by the IEA. This results in time series discrepancies when compared to later AES publications.

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	Subdivision	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).

Summary of methods and emission factors: Energy Industries

Categories	CO_2 Method applied	CO_2 Emission factor	CH_4 Method applied	CH_4 Emission factor	N_2O Method applied	N_2O 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) (I.A.I.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 system. Under the NGERS, 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.

Prior to the establishment of NGERs, methods for estimation were provided by the Generator Efficiency Standards program – as detailed in the *Generator Efficiency Standards Technical Guidelines* (AGO 2006a). The adoption of consistent methods in the NGERS 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. This data is currently available for around 140 fossil fuel based power stations in Australia. The energy use of small power stations that do not meet the NGERS reporting thresholds, are estimated as the difference between the total of reported values under NGERS 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 NGERS 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.

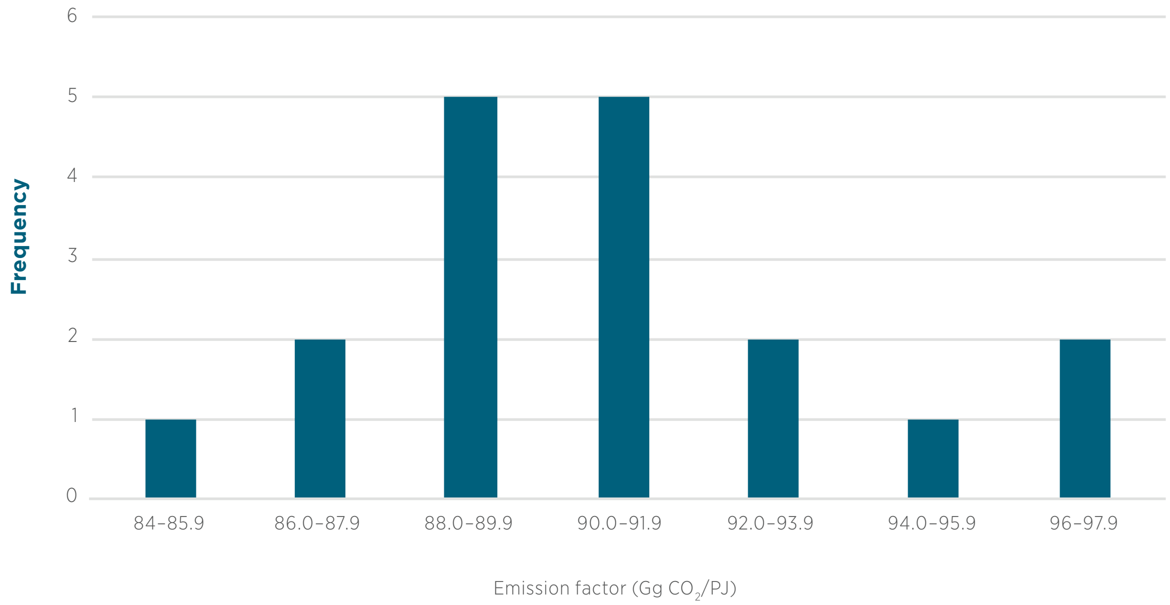
Research conducted by BREE on regional and remote electricity generation in Australia (BREE 2013b) was used in 2013 to validate or update the fuel consumption totals estimated in the *Australian Energy Statistics.* This research surveyed off-grid electricity generated and consumed outside of the major 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 system, oxidation factors and the emission 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 the *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 3.14 shows the distribution of emission factors reported by electricity generators for major fuel types.

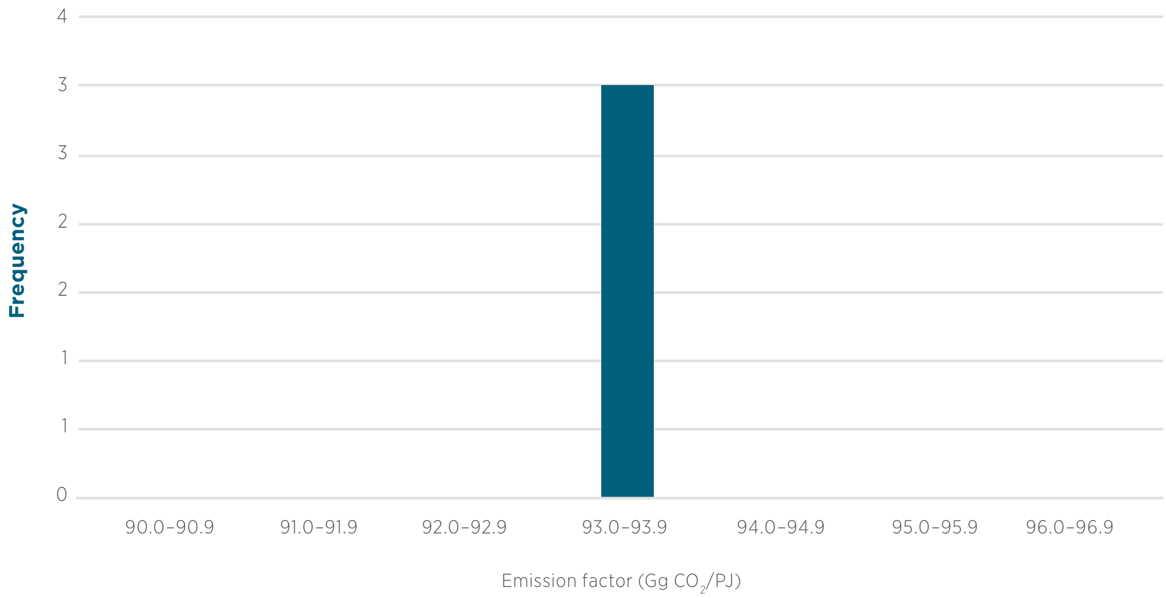
CH_4 and N_2O emissions from landfill gas captured for combustion for electricity generation are reported in this subsector and CO_2 emissions are reported as a memo item.

Figure 3.14 Emission factors for CO_2 in electricity generation, Australia, 2019

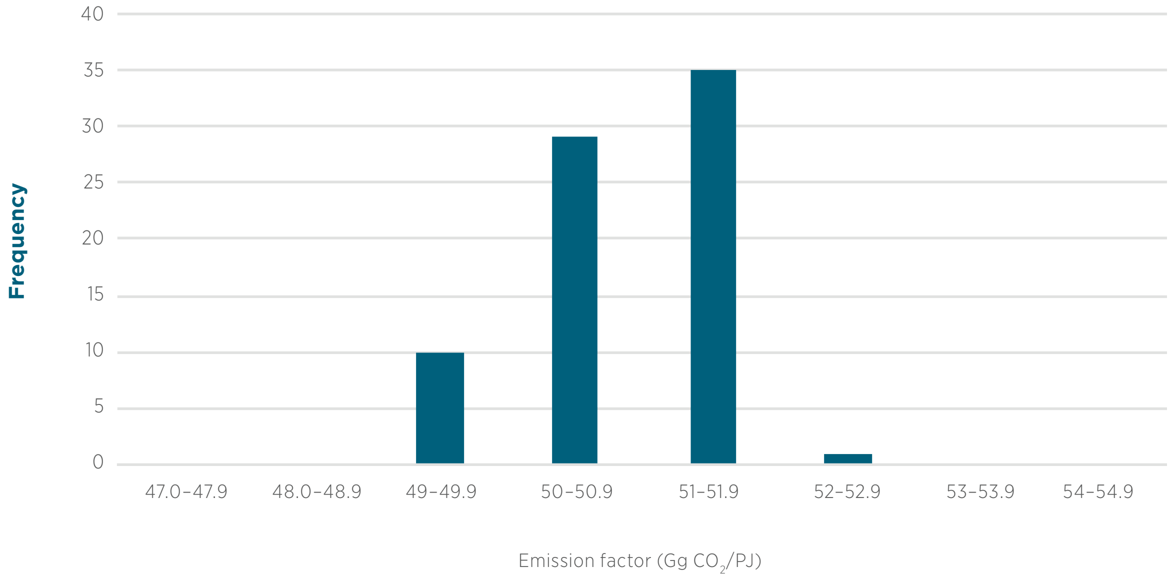
(a) Black Coal power stations



(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) (I.A.I.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 NGERS for all Australian oil refineries from 2009 to 2018. 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.

Implied Emission Factor

It is noted that the gaseous fuel IEF for petroleum refining fluctuates through the time series and is sometimes significantly lower than the default IPCC Guidelines value of 56.1 t CO_2/TJ. This is due to the direct reporting under NGERS of more accurate plant specific data while time series changes reflect the closures of facilities and the impact their plant and fuel specific emission factors have on the sector IEF.

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. Additional information is 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 3.5 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
2018	59	41
2019	59	41

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.

Oil and Gas Extraction (1.A.1.c.ii)

Methane emission factors for four-stroke rich burn/lean burn engines were taken from EPA AP-42 and weighted in the proportions observed by Zimmerle et al 2020 in the US industry to derive a single methane emission factor for reciprocating engines of 404.61 t CH_4/PJ for use in the Australian inventory.

Additional information regarding the fugitive emissions associated with gathering and boosting stations is available in *Natural gas (1.B.2.b).*

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 system. 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 2019). 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. Activity and emission input data is fully reconciled against the emission outputs 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 2018 Inventory

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

A revision has been made to the calculations for electricity generation to include specific LNG plants using data sourced from NGERS. This change was made in response to the increasing production of LNG in Australia in recent years and to better capture the self-use generation at these plants.

A time series recalculation has been made to 1.A.1.c.ii Oil and gas extraction as part of the natural gas gathering and boosting methodology improvements made within 1.B.2 Oil and gas. The combustion methane emission factors for combustion at gas plants were revised from 1.98 t CH_4/PJ, based on gas turbine equipment, to 404.61 t CH_4/PJ, based on four-stroke rich burn/lean burn engines taken from EPA AP-42 and weighted in the proportions observed by Zimmerle et al 2020 in the US industry to derive a single methane emission factor for reciprocating engines for use in the Australian inventory.

This new value is considerably higher than the previous value applied and reflects, essentially, a reallocation of methane emissions previously allocated as a source of fugitive leakages (which has been recalculated down in response in this inventory).

Table 3.6 1.A.1 Energy Industries: recalculation of total CO_2-e emissions, 1990–2018

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
I.A.I.a Electricity and heat production				
1990	129,580	129,580	0	0.0%
2000	175,413	175,413	0	0.0%
2001	182,686	182,686	0	0.0%
2002	183,990	183,990	0	0.0%
2003	186,561	186,561	0	0.0%
2004	194,933	194,933	0	0.0%
2005	196,762	196,762	0	0.0%
2006	201,313	201,313	0	0.0%
2007	204,125	204,125	0	0.0%
2008	205,961	205,961	0	0.0%
2009	211,695	211,695	0	0.0%
2010	205,095	205,095	0	0.0%
2011	198,498	198,498	0	0.0%
2012	199,117	199,117	0	0.0%
2013	187,049	187,049	0	0.0%
2014	180,789	180,789	0	0.0%
2015	188,989	188,989	0	0.0%
2016	194,743	194,743	0	0.0%
2017	189,771	189,771	0	0.0%
2018	183,170	183,638	467	0.3%
I.A.I.b Petroleum refining				
1990	5,527	5,527	0	0.0%
2000	6,169	6,169	0	0.0%
2001	6,282	6,282	0	0.0%
2002	6,208	6,208	0	0.0%
2003	6,062	6,062	0	0.0%
2004	5,537	5,537	0	0.0%
2005	5,479	5,479	0	0.0%
2006	4,921	4,921	0	0.0%
2007	5,335	5,335	0	0.0%
2008	5,125	5,125	0	0.0%
2010	5,292	5,292	0	0.0%
2011	5,691	5,691	0	0.0%
2012	5,148	5,148	0	0.0%
2013	4,905	4,905	0	0.0%

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2014	4,588	4,588	0	0.0%
2015	3,858	3,858	0	0.0%
2016	2,955	2,955	0	0.0%
2017	2,986	2,986	0	0.0%
2018	3,079	3,079	0	0.0%
1.A.1.C Manufacturing of solid fuels and other energy industries				
1990	7,992	8,103	111	1.4%
2000	10,578	10,662	84	0.8%
2001	10,468	10,540	72	0.7%
2002	11,454	11,468	13	0.1%
2003	12,393	12,531	137	1.1%
2004	13,648	13,782	134	1.0%
2005	14,221	14,370	149	1.0%
2006	14,730	14,875	145	1.0%
2007	14,566	14,714	147	1.0%
2008	14,709	14,881	172	1.2%
2009	15,477	15,634	158	1.0%
2010	16,065	16,272	208	1.3%
2011	16,334	16,523	190	1.2%
2012	18,011	18,206	195	1.1%
2013	19,022	19,519	497	2.6%
2014	19,422	19,291	498	2.6%
2015	18,716	19,195	479	2.6%
2016	21,251	21,725	474	2.2%
2017	25,448	25,672	223	0.9%
2018	27,586	27,885	299	1.1%

3.3.6 Planned improvements

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.

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.

Action the ERT recommendation to allocate any known refinery gas used in petroleum refining to liquid fuels and if the amounts and type of other gaseous fossil fuels from NGERS reporting are not known with sufficient certainty, to allocate them to other fossil fuels in the CRF category 1.A.1.b and only report natural gas under gaseous fuels.

NGERs data collection processes will be examined to explore the possibility of collecting facility specific data on technology types used for gas combustion on site at gas plants.

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 3.7 Relationship between IPCC source categories and ANZSIC sectors: Manufacturing and Construction

IPCC Source Category	Division	ANZSIC Subdivision/Group/Class Subdivision	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
	C Manufacturing	20	202	Ceramics
F Other (part)	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 (Table 3.9). Emissions estimated from activity data are based on the energy consumption by industry sector and fuel type compiled by the DISER. 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 3.8 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.

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:

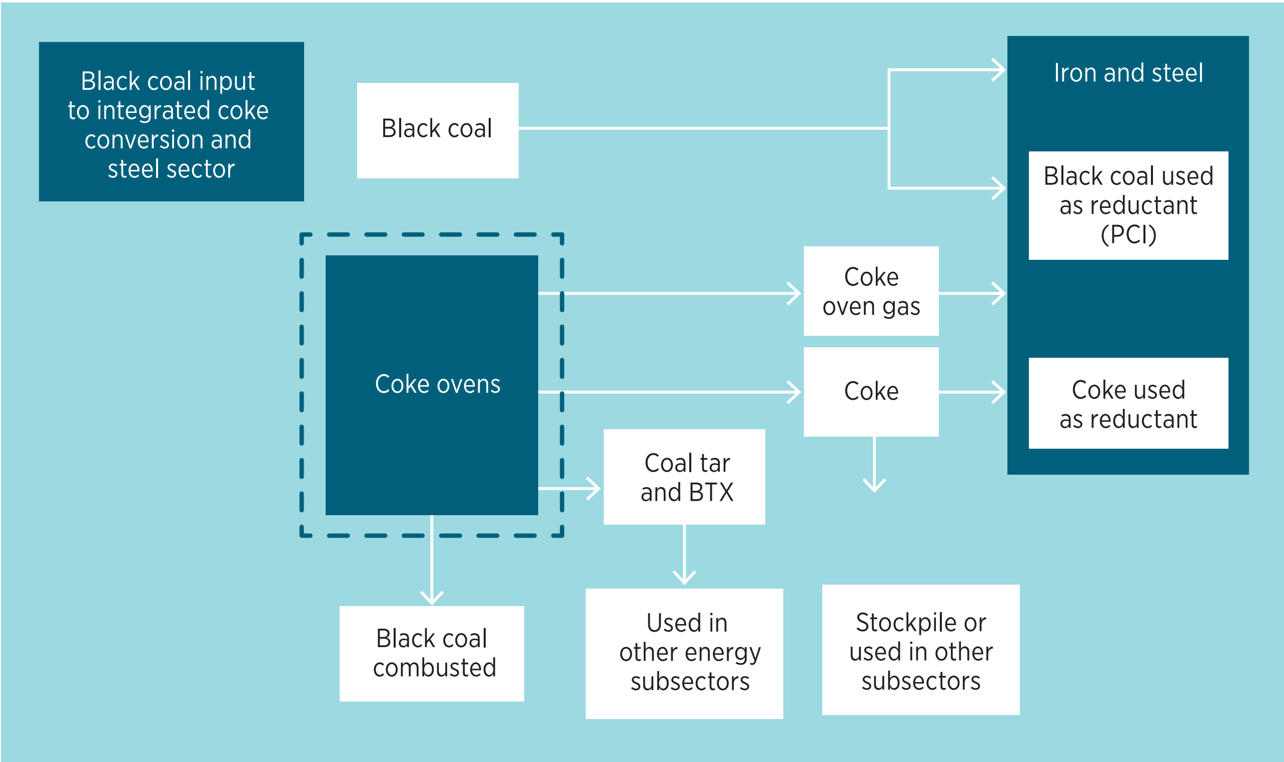
- The operation of Coke Ovens is considered to be an energy transformation industry, and hence must be reported separately to the rest of the iron and steel emissions;
- The production of coke yields a variety of by-products, including coke oven gas, coal and tar;
- Liquefied aromatic hydrocarbons and 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;

Energy

- 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 3.15. 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 3.15, 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 3.15 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.

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 3.11 and Table 3.12.

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. The majority of emissions of ethane and naphtha combusted as fuels are reported in the national inventory under *1.A.2c Chemicals.*

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 3.9 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.

Table 3.10 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.

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 3.12 shows the percentage of black coal/coke oven gas fuel mix within solid fuels.

Table 3.11 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	4	96
2016	4	96
2017	16	84
2018	2	98
2019	1	99

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 2018 Inventory

Recalculations to *1.A.2 manufacturing and construction* are detailed at the sub-category level in Table 3.14.

Revisions to the Australian Energy Statistics

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

Recalculations were made in response to revisions in fuel consumption for natural gas and various liquid fuels reported in the Australian Energy Statistics. These are reflected in minor adjustments within the time series of 1.A.2.g Other and in 2018 for 1.A.2.c Chemicals.

Table 3.12 1.A.2 Manufacturing and Construction: recalculation of total CO_2-e emissions, 1990–2018

	2020 submission	2021 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%
2000	2,521	2,521	0	0.0%
2001	2,547	2,547	0	0.0%
2002	2,769	2,769	0	0.0%
2003	2,466	2,466	0	0.0%
2004	2,684	2,684	0	0.0%
2005	2,916	2,916	0	0.0%
2006	2,584	2,584	0	0.0%
2007	2,479	2,479	0	0.0%
2008	2,819	2,819	0	0.0%
2009	2,014	2,014	0	0.0%
2010	1,740	1,740	0	0.0%
2011	1,618	1,618	0	0.0%
2012	1,582	1,582	0	0.0%
2013	1,712	1,712	0	0.0%
2014	1,536	1,536	0	0.0%
2015	1,541	1,541	0	0.0%
2016	1,557	1,557	0	0.0%
2017	1,442	1,442	0	0.0%
2018	1,555	1,555	0	0.0%
1.A.2.b Non-ferrous metals				
1990	11,193	11,193	0	0.0%
2000	13,310	13,310	0	0.0%
2001	12,537	12,537	0	0.0%
2002	12,741	12,741	0	0.0%
2003	12,472	12,472	0	0.0%
2004	12,783	12,783	0	0.0%
2005	13,775	13,775	0	0.0%
2006	13,920	13,920	0	0.0%
2007	14,197	14,197	0	0.0%
2008	14,808	14,808	0	0.0%
2009	13,431	13,431	0	0.0%
2010	12,863	12,863	0	0.0%
2011	12,297	12,297	0	0.0%
2012	13,010	13,010	0	0.0%
2013	14,583	14,583	0	0.0%
2014	15,278	15,278	0	0.0%
2015	12,747	12,747	0	0.0%
2016	12,652	12,652	0	0.0%
2017	12,481	12,481	0	0.0%
2018	12,304	12,304	0	0.0%

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1.A.2.c Chemicals				
1990	5,661	5,661	0	0.0%
2000	6,064	6,064	0	0.0%
2001	6,674	6,674	0	0.0%
2002	6,160	6,160	0	0.0%
2004	7,535	7,535	0	0.0%
2005	6,867	6,867	0	0.0%
2006	6,597	6,597	0	0.0%
2007	6,222	6,222	0	0.0%
2008	6,949	6,949	0	0.0%
2009	6,796	6,796	0	0.0%
2010	7,024	7,024	0	0.0%
2011	8,025	8,025	0	0.0%
2012	8,715	8,715	0	0.0%
2013	9,065	9,065	0	0.0%
2014	9,185	9,185	0	0.0%
2015	8,541	8,541	0	0.0%
2016	7,427	7,427	0	0.0%
2017	6,842	6,842	0	0.0%
2018	6,872	7,103	231	3.4%
1.A.2.d Pulp paper and print				
1990	1,327	1,327	0	0.0%
2000	1,494	1,494	0	0.0%
2001	1,505	1,505	0	0.0%
2002	1,506	1,506	0	0.0%
2003	1,553	1,553	0	0.0%
2004	1,669	1,669	0	0.0%
2005	1,819	1,819	0	0.0%
2006	1,825	1,825	0	0.0%
2007	1,766	1,766	0	0.0%
2008	1,713	1,713	0	0.0%
2009	1,370	1,370	0	0.0%
2010	1,336	1,336	0	0.0%
2011	1,178	1,178	0	0.0%
2012	1,067	1,067	0	0.0%
2013	1,132	1,132	0	0.0%
2014	1,001	1,001	0	0.0%
2015	1,003	1,003	0	0.0%
2016	984	984	0	0.0%
2017	999	999	0	0.0%
2018	1,045	1,045	0	0.0%

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1.A.2.e Food, beverages and tobacco				
1990	3,054	3,054	0	0.0%
2000	3,283	3,283	0	0.0%
2001	2,668	2,668	0	0.0%
2002	2,666	2,666	0	0.0%
2003	3,438	3,438	0	0.0%
2004	3,155	3,155	0	0.0%
2005	3,597	3,597	0	0.0%
2006	3,513	3,513	0	0.0%
2007	3,206	3,206	0	0.0%
2008	3,270	3,270	0	0.0%
2009	3,197	3,197	0	0.0%
2011	3,319	3,319	0	0.0%
2012	3,171	3,171	0	0.0%
2013	3,065	3,065	0	0.0%
2014	3,010	3,010	0	0.0%
2015	2,962	2,962	0	0.0%
2016	2,916	2,916	0	0.0%
2017	2,753	2,753	0	0.0%
2018	2,706	2,706	0	0.0%
1.A.2.f Non-metallic minerals				
1990	5,517	5,517	0	0.0%
2000	5,046	5,046	0	0.0%
2001	5,411	5,411	0	0.0%
2002	5,495	5,495	0	0.0%
2003	6,478	6,478	0	0.0%
2004	6,508	6,508	0	0.0%
2005	6,268	6,268	0	0.0%
2006	6,141	6,141	0	0.0%
2007	6,797	6,797	0	0.0%
2008	6,852	6,852	0	0.0%
2009	6,174	6,174	0	0.0%
2010	6,339	6,339	0	0.0%
2011	6,405	6,405	0	0.0%
2012	5,841	5,841	0	0.0%
2013	5,581	5,581	0	0.0%
2014	5,304	5,304	0	0.0%
2015	5,272	5,272	0	0.0%
2016	5,194	5,194	0	0.0%
2017	4,916	4,916	0	0.0%
2018	4,951	4,950	0	0.0%

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1.A.2.g Other				
1990	6,769	6,769	0	0.0%
2000	7,235	7,235	0	0.0%
2001	7,110	7,110	0	0.0%
2002	7,792	7,792	0	0.0%
2003	6,365	6,365	0	0.0%
2004	6,170	6,170	0	0.0%
2005	6,342	6,342	0	0.0%
2006	6,066	6,066	0	0.0%
2007	6,260	6,260	0	0.0%
2008	6,626	6,626	0	0.0%
2009	7,563	7,563	0	0.0%
2010	7,271	7,271	0	0.0%
2011	8,076	8,076	0	0.0%
2012	9,527	9,527	0	0.0%
2013	10,879	10,874	-4	0.0%
2014	11,073	11,068	-6	-0.1%
2015	10,427	10,422	-5	0.0%
2016	10,243	10,238	-5	0.0%
2017	10,644	10,638	-5	0.0%
2018	11,288	11,288	0	0.0%

3.4.6 Planned improvements

The Department will continue to look at applying revisions to the earlier part of the time series in response to future Australian Energy Statistics releases.

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 2020* (DISER 2020). 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 I.A.4. 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 3.13 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
1A2g	Other	T2	CS	T2	CS	T2	CS

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)

$F_{(l)}u_{ijk}$ 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 (DISER 2020).* The main adjustments applied to energy consumption data allocates some fuels to off-road, residential and military fuel uses (reported in Table 3.14).

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 from 2008 onwards 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/take-off 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 take-off 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 2019) within the Department of Infrastructure, Transport, Regional Development and Communications.

The Australian aviation fleet profile is developed using the Australian Aircraft Register which is available from the Civil Aviation Safety Authority (Table 3.15). 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 3.17). 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 DISER 2020. Cruise EFs are taken from IPCC (2006) (Table 3.15), 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 3.19).

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* (DISER 2019) 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 Department of Infrastructure and Regional Development (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 (now the The Department of Infrastructure, Transport, Regional Development and Communications) no longer undertakes modelling 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 3.14 The Australian aircraft fleet, 2019, and emission factors by type of aircraft

Type of aircraft	Number	Emission Factors				
		CH_4 kg/LTO	N_2O kg/LTO	NO_x kg/LTO	CO kg/LTO	NMVOC 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	72	0.06	0.10	9.01	6.19	0.51
A330-200/300	34	0.13	0.20	35.57	16.20	1.15
BAE146	14	0.14	0.00	4.07	11.18	1.27
B717	20	0.01	0.10	10.96	6.78	0.05
B727-200	1	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	158	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	51	0.00	0.02	1.51	2.24	0.00
SA227	48	0.00	0.02	1.51	2.24	0.00
SA226	10	0.00	0.02	1.51	2.24	0.00
Gulfstream IV	77	0.14	0.10	5.63	8.88	1.23
EMB 110	6	0.06	0.01	0.30	2.97	0.58
EMB 120	14	0.00	0.02	1.51	2.24	0.00
Beech 200	132	0.06	0.01	0.30	2.97	0.58
F27	121	0.03	0.02	1.82	2.33	0.26
International						
747-400	7	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	19	0.40	0.30	69.31	22.00	2.02

Source: CASA Civil Aircraft Register (2019), International Civil Aviation Organisation, Aircraft Engine Emissions Databank (EASA 2018).

Table 3.15 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	6.0	10.0	0.9
International Fleet	0.2	0.2	46.0	19.8	1.4

Source: DISER estimates.

Energy

Table 3.16 Aviation cruise emission factors (grams per tonne of fuel consumed)

Fleet	CH_4 (g/t) [(a)]	N_2O (g/t) [(a)]	NOx(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 3.17 Aviation Tier 1 Non-CO_2 Emission Factors

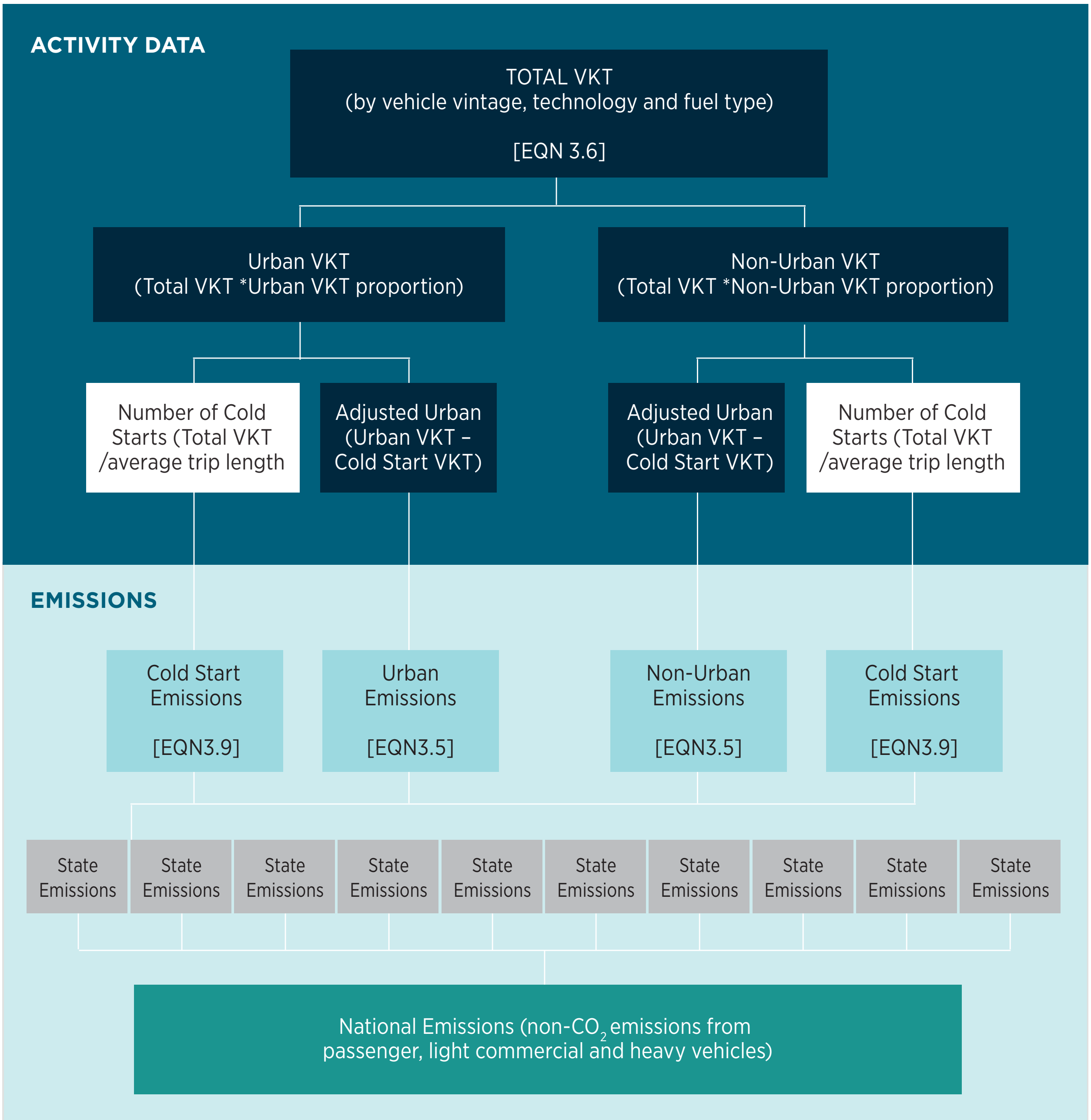
Tier 1 Non-CO_2	CH_4 (kg/TJ)	N_2O (kg/TJ)	NO_x(kg/TJ)	CO (kg/TJ)	NMVOC (kg/TJ
All Fuels	0.5	2	250	0.024	0.00054

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 3.16).

Figure 3.16 Methodology for the estimation of non-CO_2 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} = $Au^{=1}ijk$ x ($F_{(l)k}$ x Pk) (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

Au_{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, non-CO_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 2020). 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 Table 3.A.21. 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 2020).

Vehicles using automotive gasoline, ethanol, diesel and LPG are further classified by age of vehicle using data contained in ABS 2020. 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:

$$E_{(l)ijk} = A^{u=2}{}_{ijk} \times EF_{(l)ijk} \tag{3.5}$$

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:

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

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

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

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

and where

$$EF_{(l)ijk} = (ZKL_{ijk} + DR_{ijk} \times C_umVKT_{ijk}) \tag{3.7}$$

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

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

and where

$$C_umVKT_{ijk} = \Sigma_{t=1-n} A^{u=2}{}_{ijk} \tag{3.8}$$

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:

$$Ecs_{ijk} = CS_{ijk} \times EF_cs_{ijk} \tag{3.9}$$

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

EF_cs_{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 DISER 2019 and ABS (2018 a). The data on fuel consumption rates are taken from ABS (2018). The profile and age of the passenger vehicle stock in each State and Territory required for equation 3.7 is taken from ABS (2019). 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.16 to 3.A.18.

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.10). 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.6) and deterioration rates (Table 3.A.12) 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 3.20. 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 3.18 Australian petrol passenger car exhaust emission standards, Australian heavy duty diesel exhaust emission standards

Australian Standard	Year introduced	Source standard
Petrol passenger vehicles		
ADR 79/00	2004	Euro 2
ADR 79/01	2006	Euro 3
ADR 79/02	2010	Euro 4
ADR 79/03	2011	Euro 5
ADR 79/04	2016	Euro 5
Heavy duty diesel exhaust		
ADR 70/00	1996	Euro 1
ADR 80/00	2003	Euro 3
ADR 80/01	2005	Euro 4
ADR 80/02	2008	Euro 4
ADR 80/03	2010	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 Table 3.A.8. 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 Table 3.A.7.

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.

The inventory model is regularly 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 Table 3.A.12. 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 Table 3.A.9.

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.10.

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.

Diesel oil implied emission factors, notably for N_2O, tend to fluctuate due to the emission factors for N_2O being highly different for medium and heavy trucks and buses, resulting in implied emission factor fluctuations according to their proportional contributions.

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 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 Table 3.A.13.

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 Table 3.A.20.

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 do 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 36,000 diesel heavy vehicles operating in 2018 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 36,000 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 l4kt 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 3.19 Non-CO_2 emission factors for non-road sources

Source Category	CH_4	N_2O	NO_x (g/MJ)	CO	NMVOC
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, DISER 2020) 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. Emissions are estimated using Tier 2 methods described by equations 3.1 and 3.2. CO_2 EFs are reported in Table 3.2. Data on fuel consumption is taken from the Australian Energy Statistics.

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 Industry, Science, Energy and Resources (DISER) 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.

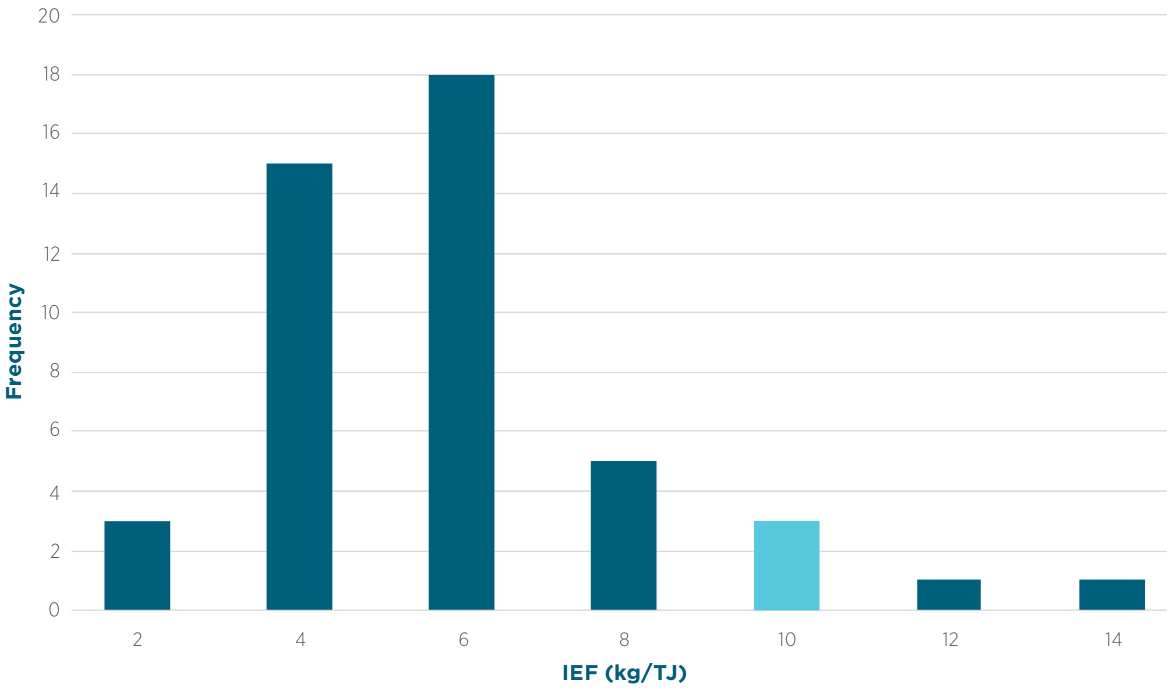
Comparisons of IEFs and with international data sources are conducted systematically for the Australian inventory. In the 2008 inventory submission it was found that the IEF for CH_4 from the combustion of liquid fuels in Australia (18.1 kg CH_4/TJ) was significantly higher than those of other Annex 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 3.17 2018 methane implied emission factor (IEF) from liquid fuel combustion (kg/TJ) for Annex I countries and 2019 IEF for Australia



Independent emissions modelling

Independent assessments of emissions from air and road transport are undertaken in Australia, providing 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 modelling 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 2018 Inventory

- Recalculations for 2018 have resulted from a revision of data from the AES for fuel consumption.
- Minor adjustment to 2016 and 2017 in road transport resulted from revisions to the allocated fuels between vehicle types within road transport.

Table 3.20 1.A.3 Transport: recalculation of total CO_2-e emissions, 1990–2018

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1.A.3.a Domestic aviation				
1990	2,624	2,624	0	0.0%
2000	4,951	4,951	0	0.0%
2001	5,498	5,498	0	0.0%
2002	4,943	4,943	0	0.0%
2003	4,722	4,722	0	0.0%
2004	4,944	4,944	0	0.0%
2005	5,375	5,375	0	0.0%
2006	5,653	5,653	0	0.0%
2007	6,128	6,128	0	0.0%
2008	6,637	6,637	0	0.0%
2009	6,669	6,669	0	0.0%
2010	6,783	6,783	0	0.0%
2011	7,609	7,609	0	0.0%
2012	7,945	7,945	0	0.0%
2013	8,430	8,430	0	0.0%
2014	8,525	8,525	0	0.0%
2015	8,553	8,553	0	0.0%
2016	8,754	8,754	0	0.0%
2017	8,799	8,799	0	0.0%
2018	9,020	9,099	79	0.9%
1.A.3.b Road Transportation				
1990	53,873	53,873	0	0.0%
2000	64,775	64,775	0	0.0%
2001	64,263	64,263	0	0.0%
2002	66,173	66,173	0	0.0%
2003	68,755	68,755	0	0.0%
2004	71,271	71,271	0	0.0%
2005	71,563	71,563	0	0.0%
2006	72,683	72,683	0	0.0%
2007	73,689	73,689	0	0.0%
2008	74,521	74,521	0	0.0%
2009	75,059	75,059	0	0.0%
2010	76,269	76,269	0	0.0%
2011	78,168	78,168	0	0.0%
2012	78,573	78,573	0	0.0%
2013	78,270	78,270	0	0.0%
2014	79,308	79,308	0	0.0%

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2015	80,902	80,902	0	0.0%
2016	81,730	81,730	0.1	0.0001%
2017	83,680	83,680	0.5	0.001%
2018	85,189	84,445	-744	-1%
1.A.3.c Railways (a)				
1990	1,962	1,962	0	0.0%
2000	1,769	1,769	0	0.0%
2002	1,770	1,770	0	0.0%
2003	1,851	1,851	0	0.0%
2004	2,054	2,054	0	0.0%
2005	2,139	2,139	0	0.0%
2006	2,147	2,147	0	0.0%
2007	2,194	2,194	0	0.0%
2008	2,617	2,617	0	0.0%
2009	2,719	2,719	0	0.0%
2010	2,688	2,688	0	0.0%
2011	2,772	2,772	0	0.0%
2012	3,069	3,069	0	0.0%
2013	3,301	3,301	0	0.0%
2014	3,386	3,386	0	0.0%
2015	3,659	3,659	0	0.0%
2016	3,772	3,772	0	0.0%
2017	3,939	3,939	0	0.0%
2018	4,026	4,034	9	0.2%
1.A.3.d Navigation				
1990	2,633	2,633	0	0.0%
2000	2,058	2,058	0	0.0%
2001	1,959	1,959	0	0.0%
2002	1,963	1,963	0	0.0%
2003	1,941	1,941	0	0.0%
2004	2,115	2,115	0	0.0%
2005	2,292	2,292	0	0.0%
2006	2,131	2,131	0	0.0%
2007	2,524	2,524	0	0.0%
2008	1,807	1,807	0	0.0%
2009	2,251	2,251	0	0.0%
2010	2,426	2,426	0	0.0%
2011	2,278	2,278	0	0.0%
2012	1,800	1,800	0	0.0%
2013	1,551	1,551	0	0.0%
2014	1,451	1,451	0	0.0%
2015	1,687	1,687	0	0.0%

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2016	1,610	1,610	0	0.0%
2017	1,701	1,701	0	0.0%
2018	1,723	1,695	-28	-1.7%
1.A.3.e Other Transportation				
1990	303	303	0	0.0%
2000	574	574	0	0.0%
2001	687	687	0	0.0%
2002	776	776	0	0.0%
2003	835	835	0	0.0%
2004	791	791	0	0.0%
2005	841	841	0	0.0%
2006	888	888	0	0.0%
2007	921	921	0	0.0%
2008	935	935	0	0.0%
2009	659	659	0	0.0%
2010	645	645	0	0.0%
2011	600	600	0	0.0%
2012	574	574	0	0.0%
2013	617	617	0	0.0%
2014	587	587	0	0.0%
2015	585	585	0	0.0%
2016	679	679	0	0.0%
2017	729	729	0	0.0%
2018	838	813	-25.2	-3.0%

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 continues to investigate EFs for new petrol passenger vehicles to take account of the latest exhaust emission standards adopted in Australia.

The Department will investigate sources with the aim to update non-CO_2 emission factors for domestic navigation. Current factors come from Lloyd's Register of Shipping which has been noted by the latest ERT as being possibly out of date. Noting that it is minor source of emissions this analysis will be prioritised accordingly.

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 3.22. Only the petroleum from ANZSIC Subdivision 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 I.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 are reported in Table 3.1. Activity data are taken from the AES published by the Department (DISER 2020). Non-CO_2 EFs for this sector, by ANZSIC Division, are reported in Appendix Table 3.A.3.

Table 3.21 Relationship between IPCC source categories and ANZSIC sectors: Other Sectors

IPCC Source Category	Division	ANZSIC Category Subdivision	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
	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 3.22 Summary of methods and emission factors: 1.A.4 Other Sectors

Source Category	CO_2 Method applied	 Emission factor	CH_4 Method applied	 Emission factor	N_2O 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 households 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 3.18, and is also summarised in the algorithm below:

$$E_{k,n} = F_n \times S \times W \times f_{nk}\{\Sigma\ PEF_n\} \tag{3.10}$$

Where E_{kn} = 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

f_{nk} = 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.

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

s) '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).

t) '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

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

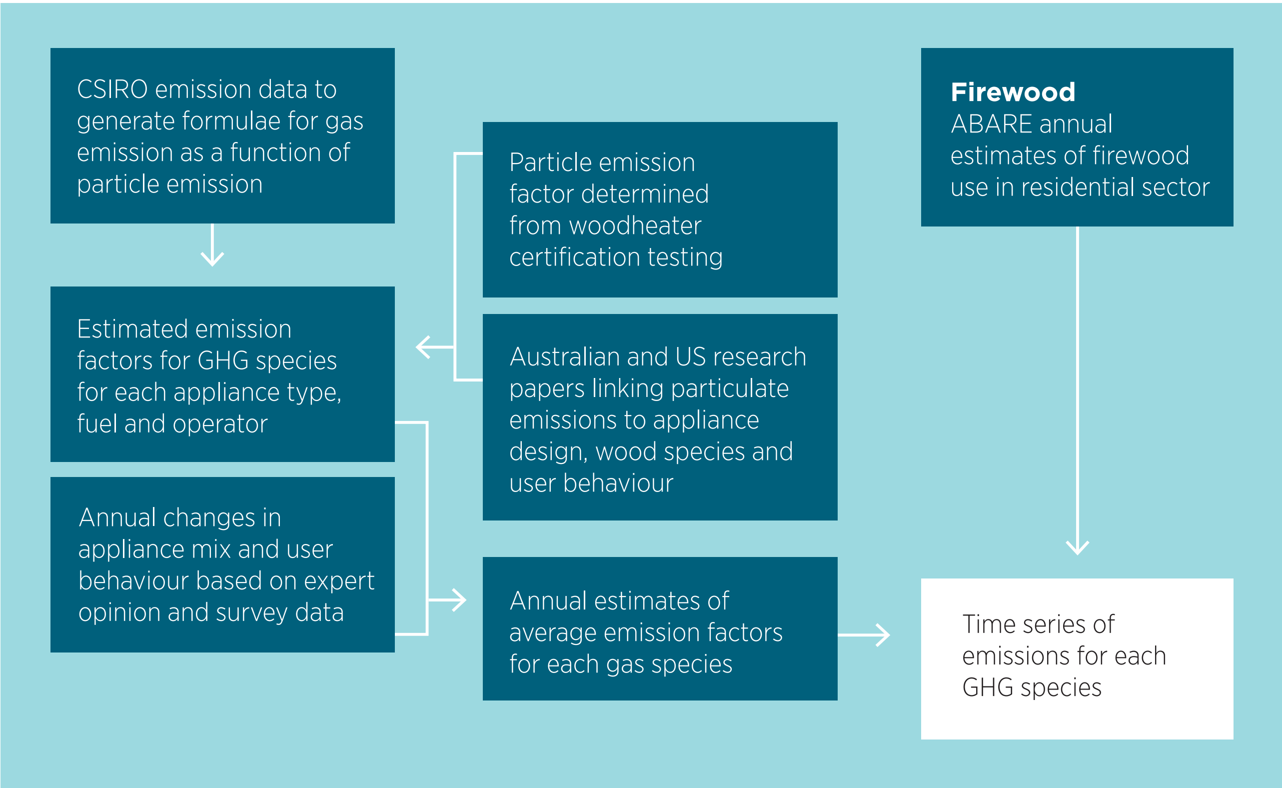
The use of wet firewood is often cited as one of the main reasons for high emissions from wood heaters. However, the CSIRO study, and other Australian studies (e.g. Todd *et al.* 1989a) have consistently shown that only very wet wood (i.e. unseasoned) influences emissions. High burn-rate tests carried 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 3.18 Schematic diagram of the methodology process for estimation of emissions from wood heaters



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The resulting emissions factor trends are shown below in Table 3.24. 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 3.23 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
2005	76.1	791.3	1.9	9,487.4	21.0	1,002.4	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
2018	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1
2019	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*, the AES 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 3.26).

Table 3.24 Non-CO_2 emission factors for non-road mobile sources

	CH_4	N_2O	NO_x (g/MJ)	CO	NMVOC
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.

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 2018 Inventory

Revisions to the Australian Energy Statistics:

Recalculations to 1.A.4 other are detailed at the sub-category level in Table 3.27. Recalculations were made in response to revisions to AES. These revisions were made to 1.A.4.a and 1.A.4.b.

Table 3.25 1.A.4 Other sectors: recalculation of total CO_2-e emissions, 1990–2018

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1.A.4.a Commercial/institutional				
1990	3,614	3,614	0	0.0%
2000	4,544	4,544	0	0.0%
2001	4,262	4,262	0	0.0%
2002	4,401	4,401	0	0.0%
2003	4,341	4,341	0	0.0%
2004	4,389	4,389	0	0.0%
2005	4,456	4,456	0	0.0%
2006	4,653	4,653	0	0.0%
2007	4,687	4,687	0	0.0%
2008	4,804	4,804	0	0.0%
2009	4,866	4,866	0	0.0%
2010	4,978	4,978	0	0.0%
2011	5,162	5,162	0	0.0%
2012	5,382	5,382	0	0.0%
2013	5,481	5,481	0	0.0%
2014	5,787	5,787	0	0.0%
2015	5,931	5,931	0	0.0%
2016	6,127	6,127	0	0.0%
2017	6,275	6,105	-170	-2.7%
2018	6,508	6,201	-306	-4.7%
1.A.4.b Residential				
1990	8,526	8,526	0	0.0%
2000	9,194	9,194	0	0.0%
2001	9,291	9,291	0	0.0%
2002	9,144	9,144	0	0.0%
2003	9,172	9,172	0	0.0%
2004	9,041	9,041	0	0.0%
2005	9,048	9,048	0	0.0%
2006	9,360	9,360	0	0.0%
2007	9,377	9,377	0	0.0%
2008	9,541	9,541	0	0.0%
2009	9,675	9,675	0	0.0%
2010	9,748	9,748	0	0.0%
2011	9,950	9,950	0	0.0%
2012	10,064	10,064	0	0.0%
2013	10,289	10,289	0	0.0%
2014	10,456	10,456	0	0.0%
2015	10,570	10,570	0	0.0%
2016	10,818	10,818	0	0.0%
2017	10,689	10,689	0	0.0%
2018	10,676	10,667	-8	-0.1%

	2020 submission	2021 submission	Change	
	(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%
2000	4,484	4,484	0	0.0%
2001	5,502	5,502	0	0.0%
2002	5,586	5,586	0	0.0%
2003	6,222	6,222	0	0.0%
2004	6,233	6,233	0	0.0%
2005	6,573	6,573	0	0.0%
2006	6,221	6,221	0	0.0%
2007	6,008	6,008	0	0.0%
2008	6,076	6,076	0	0.0%
2009	6,056	6,056	0	0.0%
2010	6,205	6,205	0	0.0%
2011	6,234	6,234	0	0.0%
2012	6,346	6,346	0	0.0%
2013	6,444	6,444	0	0.0%
2014	6,398	6,398	0	0.0%
2015	6,772	6,772	0	0.0%
2016	7,174	7,174	0	0.0%
2017	7,705	7,705	0	0.0%
2018	7,759	7,759	0	0.0%

3.6.6 Planned improvements

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.

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 3.27.

Table 3.26 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.

3.7.2 Methodology

Emissions from military vehicles are estimated using tier 1 methods described by equations 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 2018 Inventory

Recalculations made to *1.A.5 other* are detailed at the sub-category level in Table 3.28.

Table 3.27 1.A.5 Other: recalculation of total CO_2-e emissions (Gg), 1990–2018

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(per cent)
1.A.5.b Mobile – Military transport				
1990	423	423	0	0.0%
2000	635	635	0	0.0%
2001	639	639	0	0.0%
2002	591	591	0	0.0%
2003	561	561	0	0.0%
2004	583	583	0	0.0%
2005	623	623	0	0.0%
2006	655	655	0	0.0%
2007	828	828	0	0.0%
2008	847	847	0	0.0%
2009	834	834	0	0.0%
2010	889	889	0	0.0%
2011	899	899	0	0.0%
2012	872	872	0	0.0%
2013	912	912	0	0.0%
2014	1,026	1,026	0	0.0%
2015	946	946	0	0.0%
2016	1,124	1,124	0	0.0%
2017	928	928	0	0.0%
2018	828	828	0	0.0%

Military Transport has had minor recalculations for the period with the inclusion of updated data provided by the Department of Defence.

3.7.6 Planned improvements

All relevant data are kept under constant review.

3.8 Source Category I.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 the NGERS. Carbon dioxide, methane and nitrous oxide emissions are also reported from flaring.

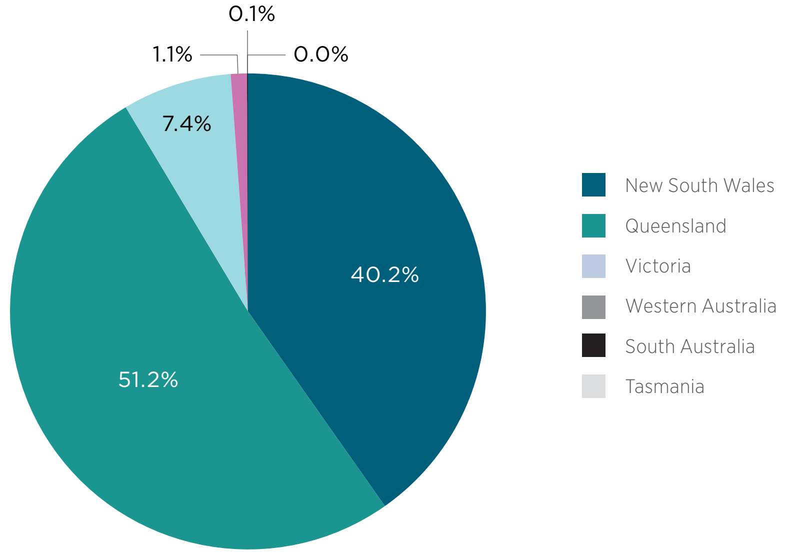
In 2019, there were 41 underground mines and 77 open cut mines operating nationally, while emissions are estimated for 121 decommissioned mines.

Table 3.28 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

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. The share of coal production from Australian states for 2019 is shown in Figure 3.19.

Figure 3.19 Share of coal production from Australian states – 2019



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 Central Queensland, Northern Bowen Basin, the Central Bowen Basin and the Southern Basin. From 2010 to 2019, there has been strong growth in production from the Western New South Wales, Hunter and Central Queensland and declines from the Central Bowen and Newcastle Basins.

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 the 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 3.20. 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.

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Figure 3.20 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 NGERS. For the 2019 year, data on measured CH_4 and CO_2 emissions is available for all 41 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 (m^3 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 3.29 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 (2018) (formerly the Joint Coal Board) and NGER data
- Queensland – Department of Natural Resources, Mines and Energy (DNRME 2020) and NGER data
- Western Australia – Department of Mines, Industry, Regulation and Safety (DMIRS 2020) and NGER data
- Victoria – NGER data

Underground mining (I.B.Iai)

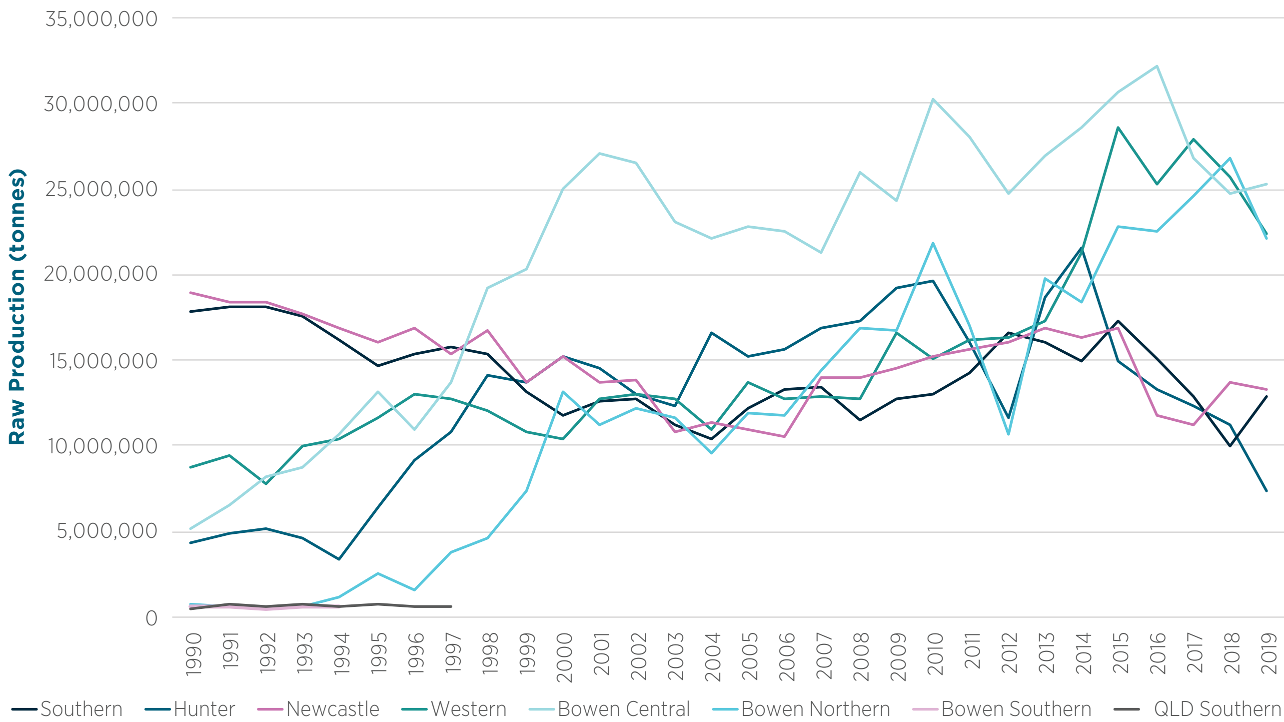
Mining activities

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 NGERS are also required to measure and report CO_2 emissions. This is significant as, prior to NGERS reporting, there was little data available on fugitive CO_2 emissions from Australian coal mining.

The NGERS 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 3.21, 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).

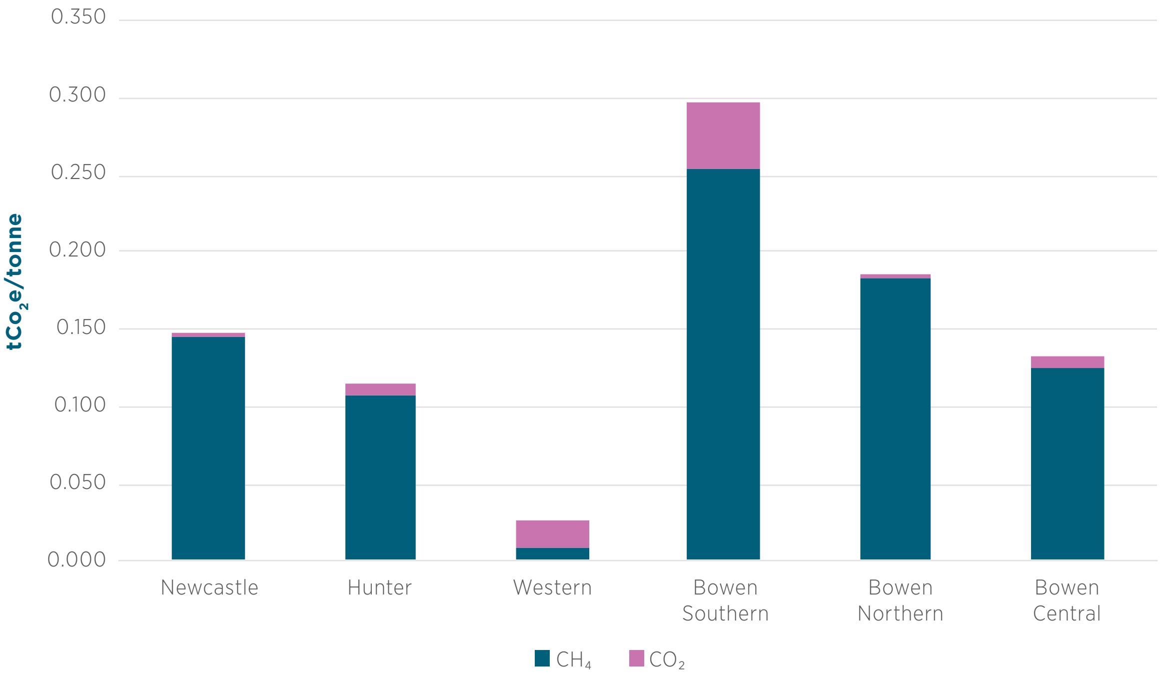
Figure 3.21 Underground black coal production by coal field



Source: NGER data (2020)

Energy

Figure 3.22 The gas content profile of Australian underground production by coal field



Source: NGER data (2020).

Choice of emission factor

Estimates based on direct measurements were reported for all underground mines under NGERS in 2019. Emissions for underground coal mines, which were closed prior to the introduction of NGERS, 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:

$$E_{pm} = QTY_a \cdot EF_{pm} \cdot C_{pm} \quad (1B_1\ 5)$$

The emission factor, E , 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 (I.B.Iaii)

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 3.30 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

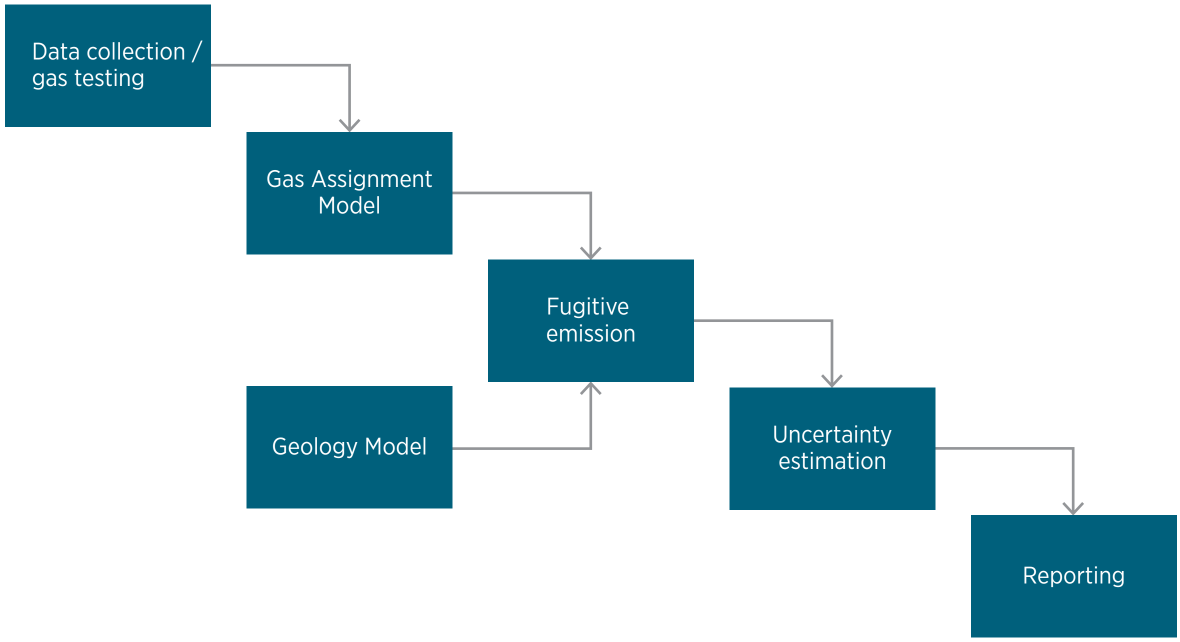
Notes: T2 = tier 2, T3 = tier 3, CS = Country-specific, PS = Plant-specific.

Higher tier, facility-specific, NGER method

The Department of Industry, Science, Energy and Resources has invested in a comprehensive program of measurement technique research and development since 2007 in order to underpin emissions estimation processes under NGERS. An important outcome of the program has been the development of guidelines for the application of the existing NGERS 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 NGERS. As indicated elsewhere, mine estimates are subject to the full audit and compliance processes that apply for other NGER reports.

Figure 3.23 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 3.23) 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[14] 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 NGERS method is detailed below.

14 The Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves developed by the Joint Ore Reserves Committee (JORC).

A. For estimating total surface mine fugitive emissions in a year:

$E_j = \Upsilon_j \Sigma_z (S_{j,z})$

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)

Υ_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:

$S_{jz} = M_z \times \gamma_z \times GC_{jz} - \Sigma_t Q_{ij, cap, z} - \Sigma_t Q_{ij,flared,z} - \Sigma_t Q_{ijtr} - \Sigma_t E_{j,vented,z}$

Where M_z is the mass of the gas bearing strata 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 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

ΣQ_{iJcapz} is the total quantity of gas type $_{(j)}$ in coal mine waste gas $_{(i)}$ captured for combustion from the gas bearing strata at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres

$\Sigma Q_{iJflaredz}$ 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

Energy

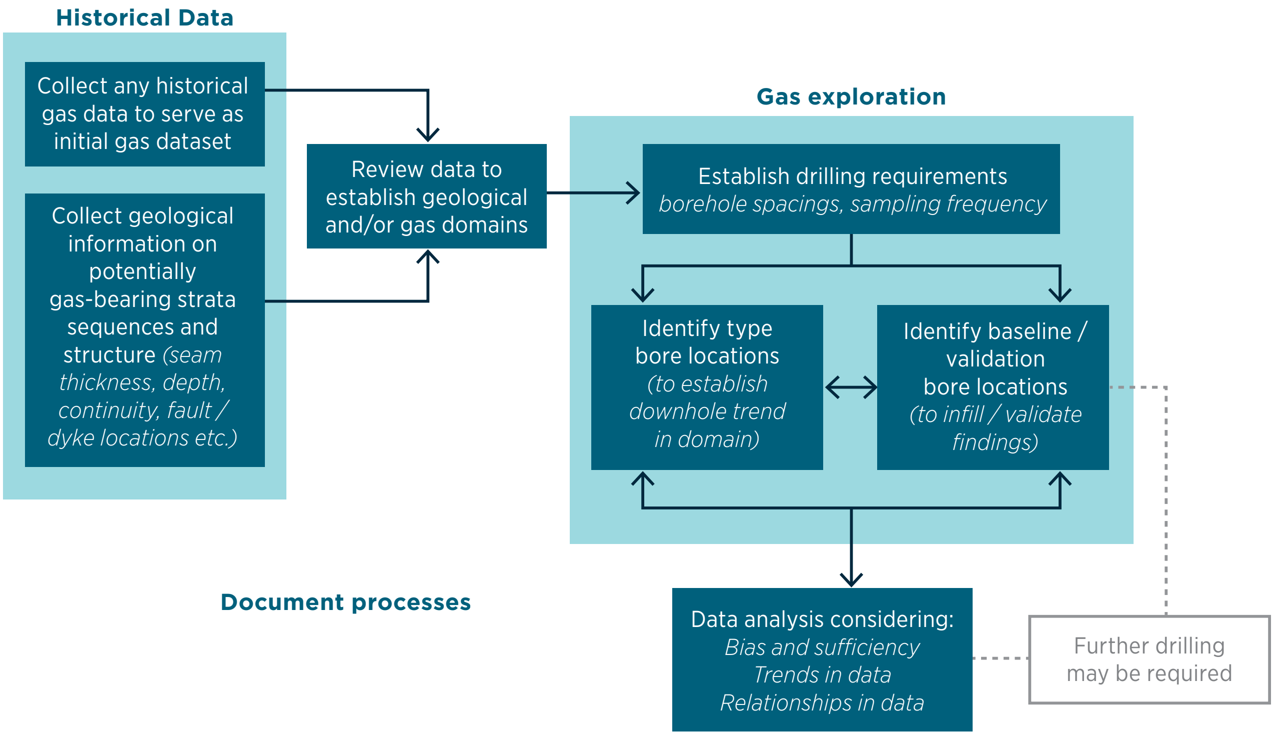
C. For estimating the content of gas type (j) contained by the gas bearing strata (z) total gas contained by gas bearing strata for (B) above:

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 3.24).

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 3.24 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 the default value, obtained from half the measurable quantities of both components observed in this zone: i.e. 0.25 m^3/t at 50 per cent CO_2 gas composition.

Process used for inclusion of NGER surface mine emission data into the national inventory

NGERS 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 NGERS 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 NGERS. 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 NGERS 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 NGERS 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 NGERS 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 3.31 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.

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:

$$E_{dm} = (E_{tdm} \cdot EF_{dm} \cdot (1 - F_{dm})) - E_{rec} \qquad (1B_1\_7)$$

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 1 B1_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

Energy

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 3.25, and are described in the following formulae:

Gassy mines

$$EF_{dm} = (1 + A * T)^{b} - C \qquad (1B_1\_8)$$

Non-gassy mines

$$EF_{dm} = (1 + A * T)^{b} - C \qquad (1B_1\_9)$$

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)

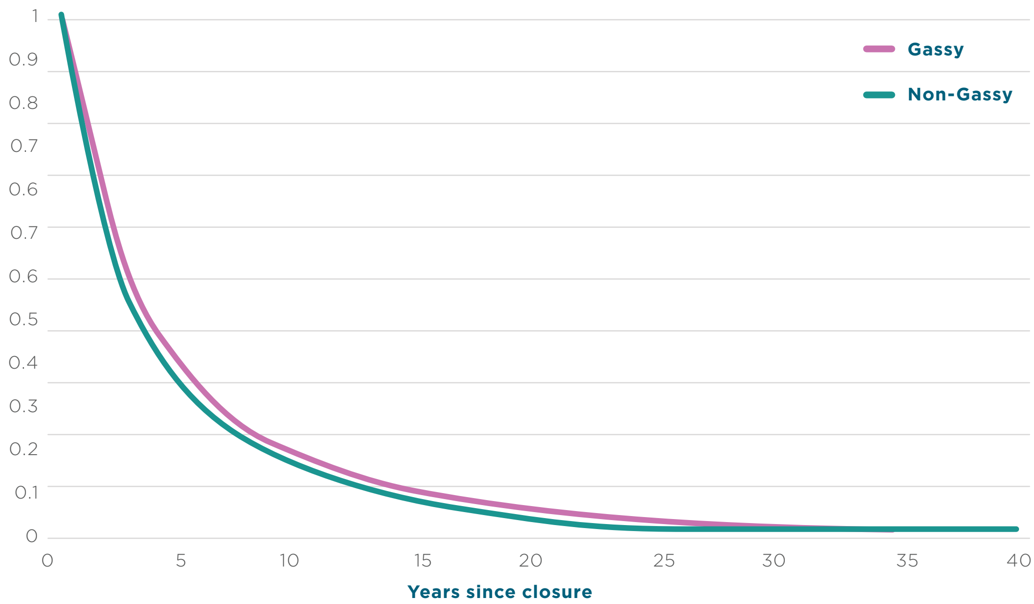
T is the time (years) elapsed since decommissioning of mine

A, b and C are coefficients unique to the decline curves (see Table 3.33)

Table 3.32 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

Figure 3.25 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:

- NGERS for mines from 2009 to 2019
- Coal Services Pty Ltd (2020), for New South Wales mines from 1972 to 2019; and
- Department of Natural Resources, Mines and Energy (DNRME 2020) for Queensland mines from 1979 to 2019.

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 (I.B.I.c. Other)

Data for 2009 to 2019 on the recovery and flaring of CH_4 from coal mines is available from mines reporting under NGERS. 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 *I.B.I.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/m^3 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-NGERS 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 3.19). 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 3.33 and Figure 3.34).

Table 3.33 Time series consistency method for determining underground coal mine emission factors – methane

Methane	1990–2004	2005 Industry survey	2006–2008	2009–18 NGER	2019 NGER
"Actual" data reported EFs held by companies represents constant 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	Actual data	Actual data	Interpolated EFs	Actual data	NGER data backcast only until an actual emissions data year is available using interpolation to fill intervening years.

Energy

Table 3.34 Time series consistency method for determining underground coal mine emission factors – CO_2

Carbon dioxide	1990–2008	2009–18 NGER	2019 NGER
Basin specific factors (based on NGER data) used for mines for which NGER data was not available.	EFs held constant	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 NGERS facility-specific EF has been applied through the entire time series. Where the new data improves on the old EF because comprehensive NGERS measurement provides updated and improved data of the original study area measured in 1993 (Hunter and Newcastle) then, for methane, the earliest NGERS 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 NGERS derived factor is applied to the entire time series.

For carbon dioxide, where no measurements previously exist, then the earliest NGERS 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 Industry, Science, Energy and Resources 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 2018 IEFs of all other reporting parties. The 2018 data from other reporting parties was used for comparison purposes because 2019 data from key coal producing parties were not available at the time.

Figure 3.26 Implied emission factor (IEF) for methane from solid fuel underground mine (kg/t) for Annex I countries (2018) and IEF for Australia (2019)

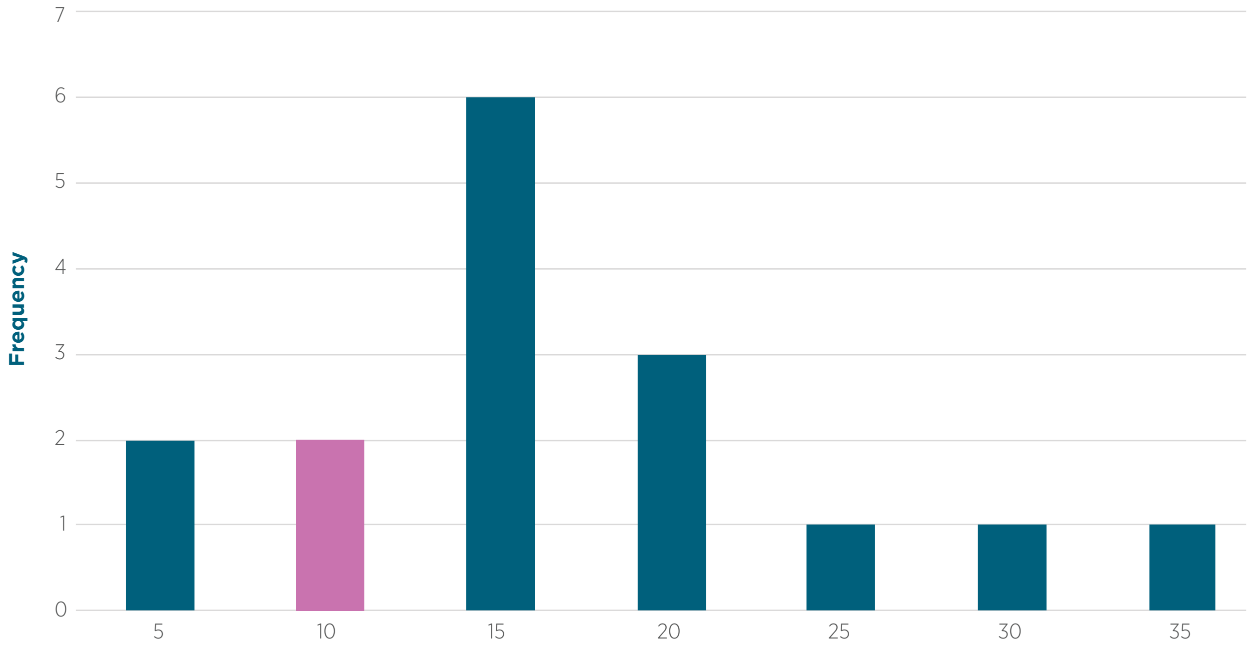
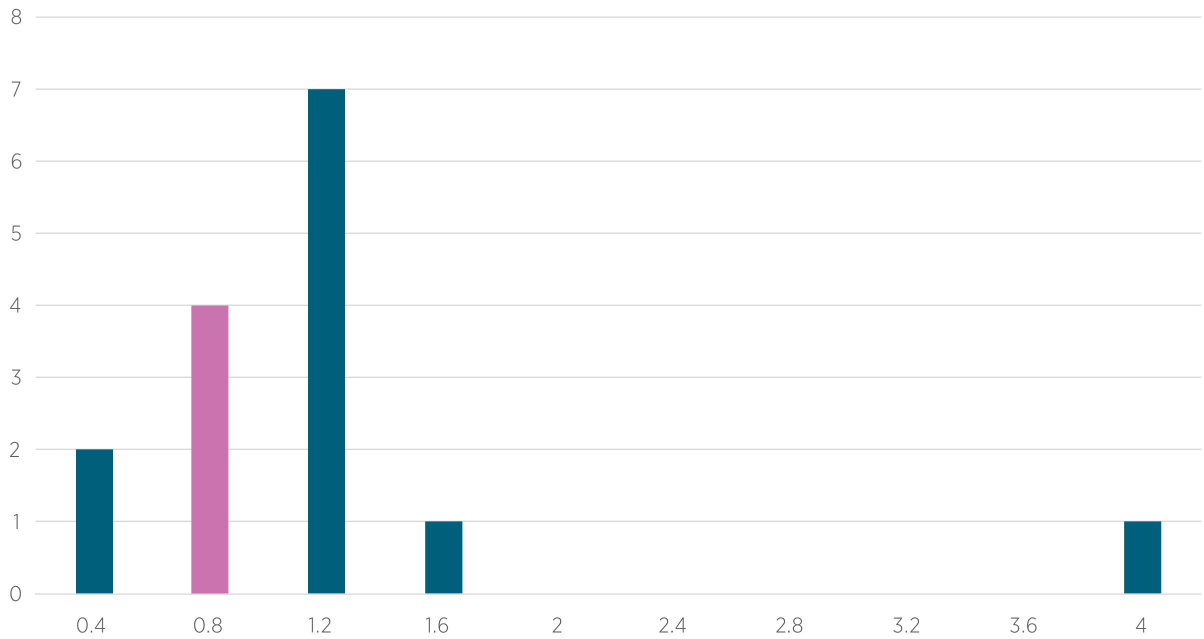


Figure 3.27 Implied emission factor (IEF) for methane from solid fuel surface mine (kg/t) for Annex I countries (2018) and IEF for Australia (2019)



Energy

In 2019, Australia's IEF for methane from underground mines was 5.35 kg CH_4/t compared to 30.5 kg CH_4/t (n =18) for the 2018 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 2019 was 0.51 kg CH_4/t compared to 0.91 CH_4/t (n = 15) for the 2018 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.

The IEF for carbon dioxide emissions from underground mining in 2019 was 11.93 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 3.28 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 2019.

Measurement audits

The NGERS 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 NGERS legislation sets out minimum qualifications of the estimator of surface mine emissions using the NGERS 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 NGERS 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 NGERS 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 NGERS 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).

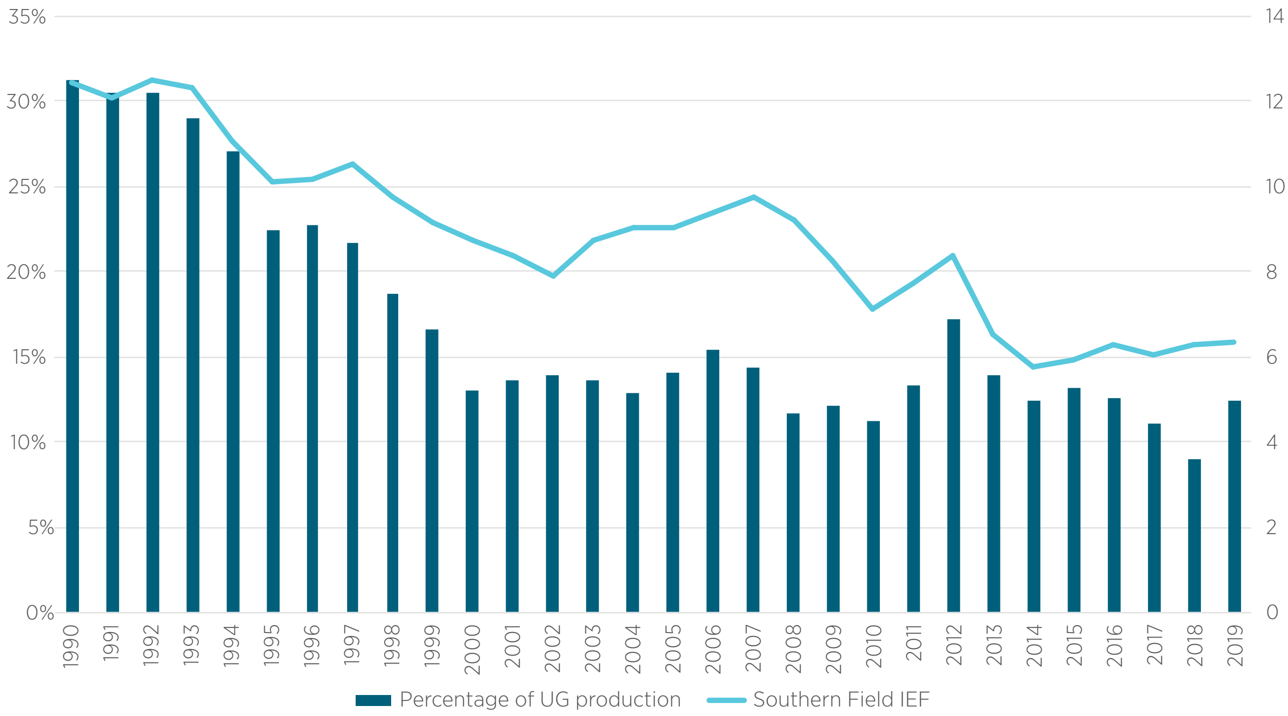
In the case of surface mines, not all facilities have undertaken facility specific measurements. In Queensland, apart from the Surat Basin, insufficient facility-specific estimates have been obtained and, in the absence of a sufficient sample of data, the national inventory continues to apply default 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 m^3/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 3.28 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 1990–2019 and NGER data.

3.8.5 Recalculations since the 2018 Inventory

Since the submission of the 2018 inventory, there were minor revisions to activity data from NGER for 2017 and 2018 inventory years for underground and open cut mines.

In late 2020 the Department was also made aware of partial mine closures impacting three underground mines, which has driven minor increases to the abandoned mine category.

Table 3.35 1.B.1 Solid Fuels: recalculation of total CO_2-e emissions (Gg), 1990–2018

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
I.B.I.a.i Underground Mines				
1990	18,763	18,763	-	0%
2000	20,999	20,999	-	0%
2001	20,420	20,420	-	0%
2002	19,237	19,237	-	0%
2003	18,898	18,898	-	0%
2004	19,159	19,159	-	0%
2005	20,644	20,644	-	0%
2006	21,358	21,358	-	0%
2007	23,770	23,770	-	0%
2008	23,619	23,619	-	0%
2009	22,598	22,723	125	1%
2010	21,370	21,387	18	0%
2011	21,912	21,912	-	0%
2012	21,326	21,325	- 0.4	0%
2013	20,057	20,562	505	3%
2014	18,413	18,811	397	2%
2015	20,646	20,930	284	1%
2016	20,236	20,471	235	1%
2017	18,725	19,442	717	4%
2018	19,175	19,729	554	3%
I.B.I.a.ii Surface Mines				
1990	3,412	3,412	-	0%
2000	4,535	4,535	-	0%
2001	4,808	4,808	-	0%
2002	5,246	5,246	-	0%
2003	4,955	4,955	-	0%
2004	4,954	4,954	-	0%
2005	5,477	5,477	-	0%
2006	5,472	5,472	-	0%
2007	5,416	5,416	-	0%
2008	5,094	5,094	-	0%
2009	5,241	5,241	-	0%
2010	5,462	5,462	-	0%
2011	4,716	4,716	-	0%
2012	5,212	5,212	-	0%
2013	5,518	5,518	-	0%
2014	5,916	5,916	-	0%
2015	6,012	6,012	-	0%

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2016	6,297	6,297	-	0%
2017	6,170	6,171	1	0%
2018	6,596	6,573	- 22	0%
1.B.1.C Other (Flaring)				
1990	0.3	0.3	-	0%
2000	12	12	-	0%
2001	10	10	-	0%
2002	9	9	-	0%
2003	19	19	-	0%
2004	60	60	-	0%
2005	67	67	-	0%
2006	75	75	-	0%
2007	76	76	-	0%
2008	92	92	-	0%
2009	202	202	-	0%
2010	274	274	-	0%
2011	186	186	-	0%
2012	210	210	-	0%
2013	646	646	-	0%
2014	820	820	-	0%
2015	691	691	-	0%
2016	773	773	-	0%
2017	906	906	-	0%
2018	903	903	-	0%

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.

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.

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/storage* and *1.B.2.b.5 natural gas distribution*.

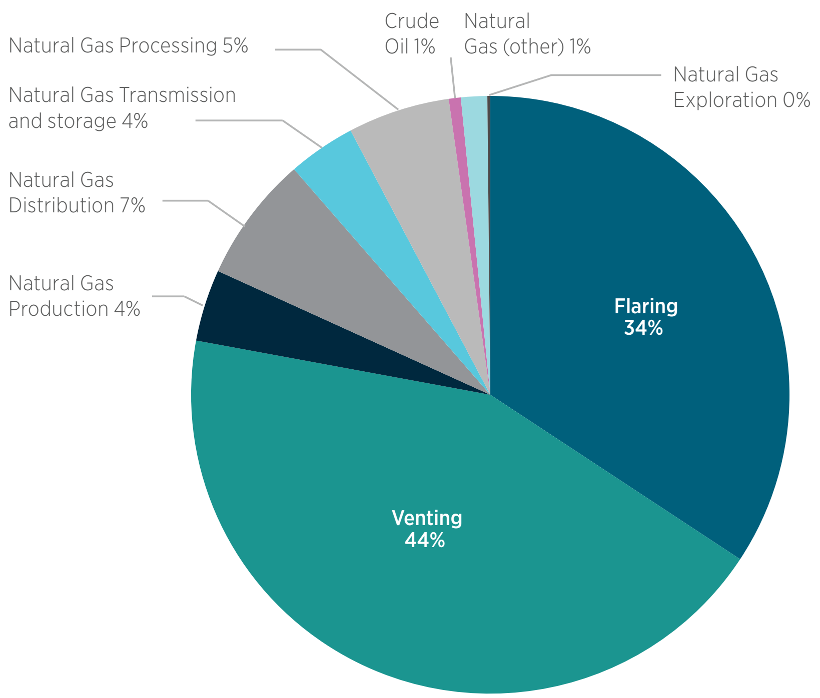
Post meter fugitive emissions from appliances, industrial and power plants and natural gas vehicles are reported under *1.B.2.b.6 Other*.

Fugitive emissions from abandoned oil and gas wells are reported under 1.*B.2.a.6 Other* and *1.B.2.b.6 Other* respectively.

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.ii Oil and Gas Extraction*.

As demonstrated in Figure 3.29, the majority (89 per cent) of fugitive emissions from oil and natural gas extraction occur in four source categories: flaring (34 per cent), venting (44 per cent), natural gas production (4 per cent) and natural gas distribution (7 per cent).

Figure 3.29 Fugitive emissions contribution by oil and natural gas sub-sectors, 2019



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 3.37.

Table 3.36 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, 2009–2019) and APPEA data (1990–2008)
		Liquids flared	Tonnes of liquid flared	NGERs facility reports (CER, 2009–2019) and APPEA data (1990–2008)
1.B.2.a.2	Oil production	Leakage	Tonnes of crude oil produced	NGERs facility reports (CER, 2009–2019) 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* (DISER) (1990–2019)
1.B.2.a.4	Refining / Storage	Refining leakage	Tonnes of crude oil refined	NGERs facility reports (CER, 2009–2019) and APPEA data (1990–2008)
		Storage leakage	Tonnes of crude oil stored	NGERs facility reports (CER, 2009–2019) and APPEA data (1990–2008)
		Gas flared	Tonnes of gas flared	NGERs facility reports (CER, 2009–2019) and AES data (1990–2008)

Inventory Category		Operation/source	Activity Data – Type	Activity Data – Source
1.B.2.a.5	Distribution of oil products	Leakage	Petroleum sales	*Australian Petroleum Statistics* (DISER) (1990–2019)
1.B.2.a.6.i	Abandoned oil wells	Leakage	Number of abandoned wells	State and Territory drill hole datasets
1.B.2.c	Venting and flaring	Gas vented and flared during oil and gas production.	See Table 3.44	See Table 3.44

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 and workovers. Emission factors are reported in Table 3.38.

Table 3.37 Oil and gas exploration flaring, venting, and leakage emission factors

Inventory category	Unit	Factor			Source
		CO_2	CH_4	N_2O	
Offshore/ Onshore testing	tonnes of emissions / tonne of unprocessed gas flared	2.75	0.035	0.000081	NGERs facility reports (CER, 2009–2019) APPEA (1998–2008)
	tonnes of emissions / tonne of crude oil flared	3.2	0.00033	0.00022	NGERs facility reports (CER, 2009–2018) APPEA (1998–2008)
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		Day et al. 2017
	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 3.39.

Table 3.38 Oil production fugitive emission factors

Inventory Category	Operation/source	Emissions (t) / throughput (kt)					
		CO_2	CH_4	NMVOC	N_2O	NO_2	CO
Crude oil production	Production leaks		0.057	810			
	Internal floating tank		0.00084				
	Fixed roof tank		0.0042				
	Floating tank		0.003				

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. 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 (DISER 2019), or
- Production of crude oil in Victoria (DISER 2019).

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 NGERS 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 petroleum refinery fuel combustion 1.A.1.b. 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 H2 (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 NGERS. 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 NGERS activity data back through the time series.

The EFs for flaring are country-specific factors used are consistently throughout the time series (Table 3.40).

Table 3.39 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: DISER estimates, following methodology of E & P Forum (1994).

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 3.41 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 3.40 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.

Abandoned oil wells (1.B.2.a.6.i)

Abandoned wells are defined as wells that are no longer producing petroleum or exploration activities have ceased.

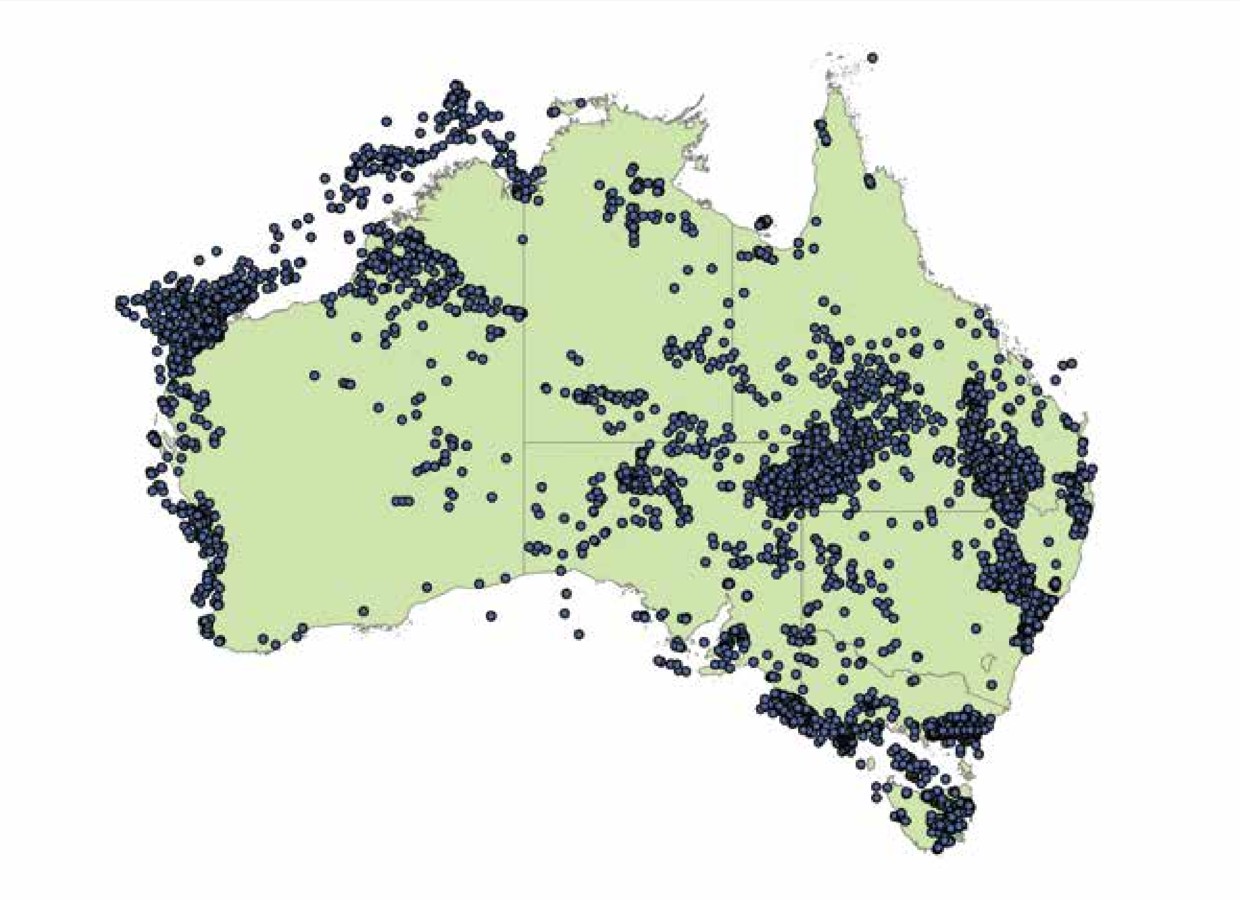
In 2019, Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) undertook analysis of methane flows in the Surat Basin – a region of Queensland and northern New South Wales rich in economic activity that is also methane intensive. The CSIRO's findings were a key driver for Australia's review of its methane estimation approaches, further information on this review can be found in section 3.9.4.

The review analysed domestic and international scientific literature, including the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019 Refinement). The review found the emissions factors for abandoned oil wells, published in Table 4.2.4E of the IPCC 2019 Refinement, represented the best available science relevant to Australia's national situation.

Activity data on the number of abandoned oil wells and the plugging status of those wells were obtained from State and Territories governments, who manage data reported by the petroleum wells' responsible entities. Entities are generally obligated to report data through State and Territory regulations. The State and Territories datasets contain historical well data, often dating back to the early 1900s. Well locations are shown in Figure 3.30 and comprise the following sources:

- NSW Drillholes Petroleum (NSW Department of Planning, Industry and Environment)
- VIC Drillhole Database (Geological Survey of Victoria)
- WA Petroleum & Geothermal Information Management System (Department of Mines, Industry Regulation and Safety)
- QLD Borehole Series (QLD Department of Natural Resources, Mines and Energy)
- SA Resources Information Gateway (SA Department for Energy and Mining)
- NT Petroleum Wells dataset (NT Department of Primary Industry and Resources)
- TAS Drillhole dataset (TAS Department of State Growth)

Figure 3.30 Map of abandoned oil and gas wells



Activity data for the estimation model is counts of the abandoned wells for each year from 1990 to 2019. As the rig release date was not available in many cases, the rig spud date was used to identify the number of abandoned wells for the year estimated. The abandoned wells count was then further categorised into plugging status (plugged, unplugged, unknown), production type (oil, gas) and location (onshore, offshore), .

The identification of plugging status between the State and Territory datasets is inconsistent, there are some commonalities which were used to allocate the well to an appropriate sub-category. Examples of the coding for the wells status are given in Table 3.42 below:

Table 3.41 Classification of various well status

State coding	Method coding
Plugged and Abandoned	Plugged
Capped/cased/ cemented/ shut-in	Plugged
Suspended/Abandoned	Unplugged
Dry	Unplugged
Unknown	Unknown
Suspended/Capped/Shut-in	Unknown
Null	Unknown

Where the well was identified as having oil and gas shows, or where the production type is unknown, the abandoned well is allocated to gas.

Table 3.42 Number of 2019 abandoned oil and gas wells

		Gas	Oil
Onshore	Plugged	14,070	605
	Not plugged	2,313	793
	Unknown	2,977	669
Offshore	Plugged	1,165	489
	Not plugged	190	123
	Unknown	336	154
Total		**21,051**	**2,833**

The estimates for abandoned wells are calculated using the emissions factors published in the IPCC 2019 Refinement Table 4.2.4E.

Table 3.43 Abandoned oil and gas wells emission factors

Category	Sub-category	Emissions factors (t CH_4/ abandoned well)
Onshore	Plugged	2.0E-05
	Unplugged	8.8E-02
	Unknown	1.2E-02
Offshore	Plugged	3.5E-07
	Unplugged	1.8E-03
	Unknown	2.4E-04

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, Queensland 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,Pluto and Gorgon liquefied natural gas (LNG) plants near Dampier in Western Australia, Darwin in the Northern Territory,Gladstone in Queensland and offshore Broome Western Australia in a floating liquefied natural gas facility.

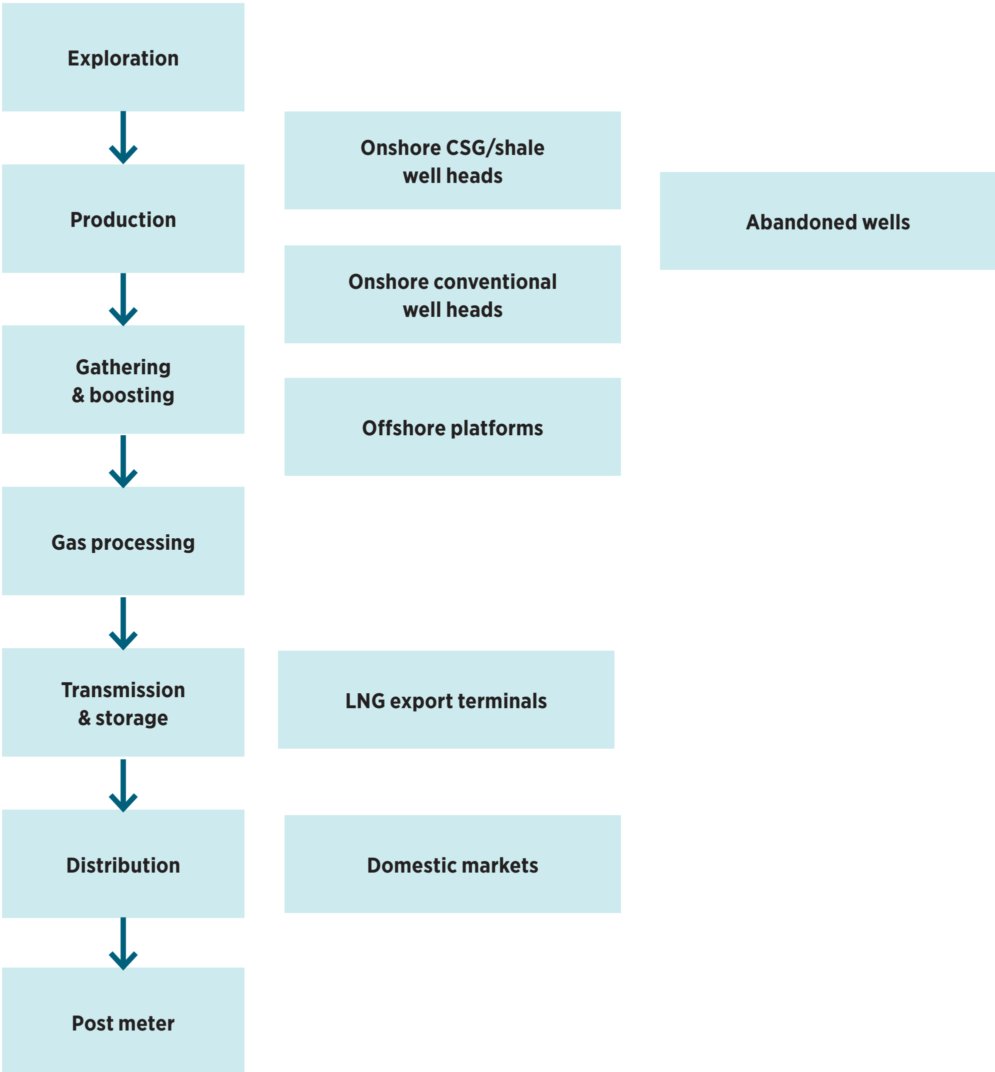
The major sub-categories of fugitive emissions of methane and carbon dioxide associated with gas supply relate to:

- 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, water production, including compressors, dehydrators, pipelines and treatment plants; offshore gas platforms leakages;
- 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.
- Natural gas Post-meter emissions (1.B.2.b.6) including leakage emissions from appliances, industrial plants and power stations and natural gas vehicles;
- Abandoned gas wells (1.B.2.b.8) leakage from onshore and offshore abandoned wells.

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 3.31 Emission estimation segments for the gas supply chain



Source: Department of Industry, Science, Energy and Resources.

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, including those 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 (Zimmerle *et al.* 20);
   d) Gas processing plants (Mitchell *et al.* 2015);
   e) Storage and export terminal infrastructure (US EPA 2016); and
   f) Appliance leakage in the commercial and residential sector (Merrin and Francesco 2019).
4. Factors derived from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories:
   a) Abandoned oil and gas wells; and
   b) Industrial plants and power stations and natural gas vehicles.

The activity data used to calculate emissions from 1.B.2.b natural gas is documented in Table 3.45.

Table 3.44 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, 2009–2019) and APPEA data (1990–2008)
	Drilling leakage	Number of drilling days	Derived from NOPTA, state resource agencies, and APPEA data (1990–2018)
	Well completions leakage	Number of wells drilled	NOPTA, state resource agencies, QLD petroleum production statistics 2020 and APPEA data (1990–2018)
	Well workovers leakage	Number of well workovers	Derived from QLD petroleum statistics 2020 and APPEA data (1990–2018)
1.B.2.b.2 Gas production	Wells and well pads leakage	Tonnes of crude oil produced	NGERs facility reports (CER, 2009–2019) and APPEA data (1990–2008)
	Produced water leakage	Megalitres of water produced	APPEA data (1990–2018) QLD petroleum production statistics 2020
	Offshore gas platforms leakage	Number of platforms operating in a year	Geoscience Australia (1990–2019)
	Gathering and boosting compressor stations leakage	Tonnes of gas throughput	NGERs facility reports (CER, 2009–2019), APPEA data (1990–2008), South Australia Department for Energy and Mining Monthly field production, Energy Quest – 2020 and Queensland Government CSG production data (1990–2020)
	Gathering and boosting pipeline leakage	Kilometres of pipeline	Derived using the *Australian Energy Statistics* (DISER, Petajoules of Production, 1990–2018), 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)

Inventory Category	Operation/source	Activity Data – Type	Activity Data – Source
1.B.2.b.3 Gas processing	Leakage	Tonnes of gas throughput	NGERs facility reports (CER, 2009–2019) and AES production data (1990–2019)
1.B.2.b.4 Transmission and storage	Transmission leakage	Length of high pressure pipeline	*Electricity Gas Australia* (AEC 2018) Australian Pipeline and Gas Association 2020
	Gas storage leakage	Number of gas storage stations operating in a year	Various facility data sources and Australian Energy Market Operator (1990–2019)
	LNG storage leakage	Number of LNG storage stations operating in a year	Various facility data sources and Australian Energy Market Operator (1990–2019)
	LNG terminals leakage	Number of LNG terminals operating in a year	Various facility data sources and Australian Energy Market Operator (1990–2019)
1.B.2.b.5 Distribution	Leakage	Terajoules of gas sales	NGERs facility reports (CER, 2009–2019) and AES production data (1990–2019)
1.B.2.b.6.i Abandoned gas wells	Leakage	Number of abandoned wells	State and Territory drillhole datasets.
1.B.2.b.6.ii Post-meter	Leakage	Number of appliance types	Residential Baseline Study for 2000 to 2030 (DIS 2015)
		Industrial and power plant gas throughput	AES production data (1990–2019
		Number of gas vehicles	NSW State motor vehicle registration statistics
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

Energy

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 and venting;
- 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 3.46. 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 3.45 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
2012	814
2013	1708
2014	1123
2015	906
2016	709
2017	697
2018	802
2019	347

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 3.45.

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 4.7 x 10^{-5} 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 2019, there were 51,474 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 4.7 x 10^{-5} 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 2018, there were 42 shallow platforms and 8 deep water platforms in Australian waters.

Table 3.46 Fugitive emission factors for natural gas

Inventory category	Unit	Factor CO_2	Factor CH_4	Source
Onshore Natural Gas wells	tonnes of emissions / tonne of gas throughput	0.00013 (a)	0.000047	Day *et al.* 2014
Offshore natural gas platforms (shallow water)	tonnes of emissions / platform	171.8 (a)	62.6	US EPA NIR Table A-134 (2016)
Offshore natural gas platforms (deep water)	tonnes of emissions / platform	1,813.9 (a)	661.1	US EPA NIR Table A-134 (2016)
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	Modelled	Modelled	Zimmerle *et al.* 2020
	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
LNG storage	tonnes of emission / LNG storage station		921	US EPA NIR Table A-134 (2016)
LNG terminals	tonnes of emission / LNG terminal		1,109	US EPA NIR Table A-134 (2016)
Abandoned gas wells	tonnes of emissions / well		Various	See Table 3.42
Post-meter leakage	Various	Various	Various	See Table 3.47

Onshore Gathering and boosting stations and pipelines

Onshore gas gathering and boosting fields (particularly coal seam gas) generally consist of gas gathering pipeline systems transporting gas directly to processing facilities or via field compressor boosting stations. Leakage emissions from gas processing facilities are reported under 1.B.2.b.3 Gas processing. The leakage from gas boosting stations are reported under 1.B.2.b.2 Gas production using the method detailed below. Leakage emissions from the gathering pipeline system are estimated based on km of pipeline length and an emission factor from API 2009, 6.1.2, Table 6.4 and as cited in NGERS method '2'.

The emission factor for gathering and boosting stations is derived from Zimmerle *et al.* 2020, who collected measurements from 180 gathering and boosting stations across the United States.

The Department has estimated a non-linear relationship between the fugitive leakage emission rate emitted to the atmosphere and gathering and boosting station throughput (the quantity of natural gas passing through the station) (DISER 2020). The leakage emission rate declines quickly at low throughput levels and tends to a low rate of emission for higher levels of throughput. While stations with low throughput tend to have higher leakage rates, the low throughput of these stations means that their total emissions are nonetheless close to negligible.

The new equation adopted for the Australian inventory is:

$$E_{ij} = 1.8301 \times Q_{ij}^{-0.708}$$

where E_{ij} is the estimated fugitive leakage emissions of methane from gas gathering and boosting stations; and
Q_{ij} is the quantity of coal seam gas throughput at the gas gathering and boosting station.

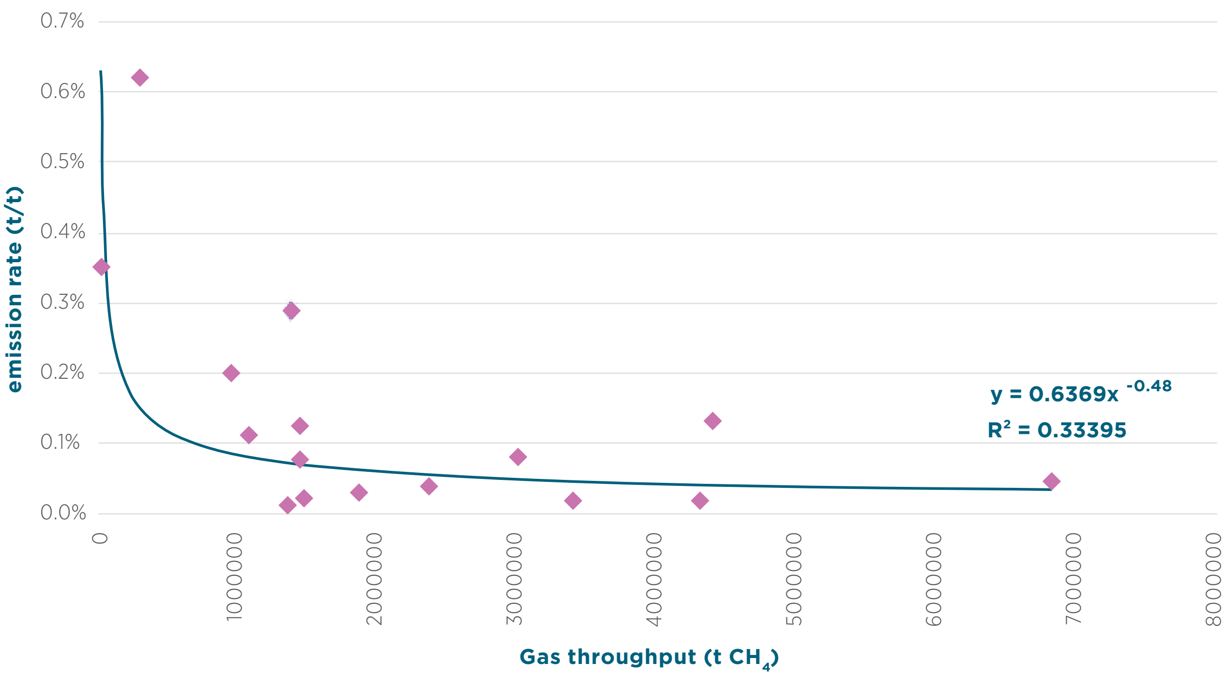
Gas Processing (1.B.2.b.3)

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 3.32).

$$Y = 0.6369 . X ^\wedge -0.48$$

Where Y = emission rate in tonnes of emissions per tonne of gas throughput
X = gas throughput in tonnes

Figure 3.32 Gas processing plants 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.

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 NGERS (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 2019, there were 8 gas storage facilities in operation in Australia.

Energy

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 2019, there were 10 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 2019, there were an estimated 12 LNG storage stations in operation in Australia.

Natural Gas Distribution (1.B.2.b.5)

There is currently a 10 year data overlap between the total annual gas utility sales (AES, DISER 2020) and the quantity of natural gas distribution reported under NGERs (CER, 2018). 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 10 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.

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 was 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. In 2006, 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 was more realistic for circumstances of the time (Energy Strategies 2005), and the leakage share of UAG was estimated at 55 per cent. In 2020, a review of literature and public submissions by distribution companies concluded that a figure in the range of 35–40 per cent would be more accurate after further improvements to distribution networks in all states. As such, the estimate for leakage under UAG is set to 37.3 per cent from 2018 onwards. A linear refinement of historic data for the 2006 to 2018 period was also be applied.

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 2018);
- 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 3.48).

Table 3.47 Natural gas composition and emission factors

Pipeline	Longford, Melbourne (Victoria)	Moomba, Sydney (NSW, SA)	Roma, Brisbane (Qld)	Denison, Gladstone (Qld)	Dampier, Perth (WA)	Dongarra, Perth (WA)	Amadeus, Darwin (NT)	Australia (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			

Other (1.B.2.b.6)

The category includes voluntarily reported emissions from abandoned gas well and post-meter emissions. Emissions from each source is in Table 3.49a.

Table 3.49a Other (1.B.2.b.6) emissions

Year	Abandoned gas wells (kt CO_2-e)	Post meter emissions (kt CO_2-e)	Total (kt CO_2-e)
1990	2.8	146.9	149.7
1991	2.9	139.7	142.6
1992	3.0	144.6	147.6
1993	3.1	149.8	152.8
1994	3.2	159.0	162.1
1995	3.2	168.5	171.8
1996	3.3	165.1	168.4
1997	3.4	170.6	174.0
1998	3.5	180.9	184.5
1999	3.6	194.5	198.1
2000	3.7	201.7	205.3
2001	3.8	214.1	218.0
2002	3.9	219.7	223.6
2003	4.0	227.7	231.7
2004	4.1	243.7	247.8
2005	4.2	255.5	259.7
2006	4.3	262.2	266.5
2007	4.4	291.5	295.9
2008	4.5	302.2	306.7
2009	4.6	312.6	317.2

Year	Abandoned gas wells ($kt\ CO_2$-e)	Post meter emissions ($kt\ CO_2$-e)	Total ($kt\ CO_2$-e)
2010	4.7	322.1	326.8
2011	4.8	333.9	338.7
2012	5.0	343.3	348.2
2013	5.1	351.3	356.4
2014	5.3	362.8	368.1
2015	5.5	366.4	371.9
2016	5.6	368.9	374.4
2017	5.7	360.8	366.4
2018	6.0	370.0	376.0
2019	6.0	368.5	374.5
2020	6.1	368.7	374.8

Abandoned gas wells (1.B.2.b.6.i)

Abandoned gas wells are defined as wells that are no longer producing gas or exploration activities have ceased.

In 2019, Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) undertook analysis of methane flows in the Surat Basin – a region of Queensland and northern New South Wales rich in economic activity that is also methane intensive. The CSIRO's findings were a key driver for Australia's review of its methane estimation approaches, further information on this review can be found in section 3.9.4.

The review analysed domestic and international scientific literature, including the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019 Refinement). The review found the emissions factors for abandoned oil wells, published in Table 4.2.4E of the IPCC 2019 Refinement, represented the best available science relevant to Australia's national situation.

Activity data on the number of abandoned gas wells and the plugging status of those wells were obtained from State and Territories governments, who manage data reported by the petroleum wells' responsible entities. The data sources and description of processing methods used to compile the activity data for both abandoned gas and oil wells are provided under *Abandoned oil wells (1.B.2.a.6.i).*

Post-meter emissions (1.B.2.b.6.ii)

This segment includes fugitive emissions beyond gas meters and from natural gas-fuelled vehicles.

Appliance leakage

Fugitive methane and carbon dioxide leakage emissions that occur downstream from the meter are estimated for natural gas appliances used in the residential and commercial sectors, such as cooktops, water heaters and space heating.

A nationally specific method was applied using emissions factors by appliance type derived from a measurement study by Merrin and Francesco (2019) which looked at non-combustion emissions from residential natural gas appliances (Table 3.49).

Table 3.49b Methane emission factors by natural gas appliance type for residential and commercial sectors

Appliance type	EF (t CH_4/appliance/year)	Derivation (see Merrin & Francesco 2019)
Residential		
Cooking		
Upright – NG	9.30E-05	average of "stove" and "oven" factors
Cooktop – NG	5.60E-05	"stove" factor
Oven – NG	1.30E-04	"oven" factor
Space conditioning		
Gas Space: Flued-NG	2.20E-04	"furnace" factor
Gas Space: Unflued-NG	2.20E-04	"furnace" factor
Gas Ducted-NG	2.20E-04	"furnace" factor
Water heating		
GSWH – NG	7.70E-05	"water heater" factor
GIWH – NG	1.20E-03	"tankless W.H." factor
SGWH Z1 – NG	1.20E-03	"tankless W.H." factor
SGWH Z2 – NG	1.20E-03	"tankless W.H." factor
SGWH Z3 – NG	1.20E-03	"tankless W.H." factor
SGWH Z4 – NG	1.20E-03	"tankless W.H." factor
Other equipment		
Pool Heating-Gas	1.20E-03	"tankless W.H." factor
Spa-Gas	1.20E-03	"tankless W.H." factor
Commercial		
Space heating	2.20E-04	"furnace" factor
Hot water	6.39E-04	Average of "water heater" and "tankless W.H." factors
Kitchen/catering	9.30E-05	Average of "stove" and "oven" factors
Other	3.17E-04	Average of factors above

Activity data for appliances in the residential sector was sourced from the Residential Baseline Study for Australia 2000–2030 (October 2015) commissioned by the Department of Industry and Science. Activity data for appliances in the commercial sector was inferred from residential data in conjunction with relative natural gas consumption in both sectors.

Industrial and power plants

A review of international scientific literature including the IPCC 2019 Refinement found the emission factors for leakages at industrial plants and power stations published in Table 4.2.4K of the IPCC 2019 Refinement represented the best available science relevant to Australia's national situation. Emission factors of 0.4 tonnes of methane and 0.0033 tonnes of carbon dioxide per million cubic metres of natural gas are applied to activity data comprising the natural gas consumption of electricity and industrial plants. Industrial sectors for which fugitive leakage is already calculated under the Oil and Gas sector such as Oil and Gas extraction, Gas transmission and Distribution are excluded to avoid double-counting.

Natural gas vehicles

The review found the emissions factors for leakage from natural gas fuelled vehicles, published in Table 4.2.4K of the IPCC 2019 Refinement, represented the best available science relevant to Australia's national situation. Emission factors of 3.0 x 10^{-4} tonnes of methane and 2.3 x 10^{-6} tonnes of carbon dioxide per natural gas fuelled vehicle are used. The emission factor includes releases from dead volumes during fuelling, emptying of gas cylinders of high-pressure interim storage units, for execution of pressure tests and relaxation of residual pressure from vehicles' gas tanks, for pressure tests or decommissioning.

Activity data were obtained from New South Wales State motor vehicle registration statistics (NSW Roads and Maritime Service 2018). A national time series of natural gas vehicles was then inferred by using the consumption of natural gas in the transport sector to ensure time series consistency and completeness.

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 3.50.

Table 3.48 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, 2009–2018) 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 (DoEE 2016 to 2018)
1.B.2.c.2.i Oil flaring	Crude oil flared during oil production	Tonnes of liquid flared	NGERs facility reports (CER, 2009–2018) and APPEA data (1990–2008)
	Gas flared during oil refining	Tonnes of gas flared	NGERs facility reports (CER, 2009–2018) and APPEA data (1990–2008)
	Gas flared during oil refining	Tonnes of gas flared	NGERs facility reports (CER, 2009–2018) 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, 2009–2018) 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 NGERS 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

Emission factors can be found in Table 3.51 and are country-specific, sourced from the APPEA industry inventory. The NGER emission factors are consistent with those used for the APPEA inventory, thus ensuring time series consistency between the time series.

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 NGERS 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 3.49 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	0.0014	0.00022	APPEA 2000
Gas flared during oil production	Tonnes of emission / tonne of gas flared	2.9	0.035	0.000081	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.

- Inverse modelling has been deployed in Australia to better understand the characterisation of point and dispersed emission sources with the aim of improving the national inventory methods over time.
- In 2019, the CSIRO undertook analysis of methane plumes in the Surat Basin – a region in Queensland rich in economic activity that is also methane intensive including coal seam gas extraction, coal mining, beef and feedlot production, abattoirs, sewerage and water management activities.
- The CSIRO operated two flux towers at either end of the Basin and obtained continuous measurements over 2016 to obtain a 'top-down' estimate of methane emissions in the Basin for the year (Luhar et al 2020).
- A regional inventory for the Basin using national inventory methods was also constructed to provide a test and quality assurance for national inventory methods. The estimate for methane emissions for the Surat Basin for 2016 for this regional inventory was within 10% of the CSIRO's independent, top-down analysis (DISER, 2021).
- For the CSG zone within the Surat Basin, where CSG operations are concentrated and account for around 60% of all emissions, there was also an excellent agreement between the top-down estimates of Luhar et al 2020 and the bottom-up inventory using national inventory methods for methane reported in DISER 2021, with the estimates based on inventory methods being 17% higher.
- The good fit between the regional inventory using national inventory methods and the CSIRO 'top-down' data provides strong assurance of the quality of national inventory methods for methane, including for coal seam gas production.
- The close fit is partly the result of recent improvements to estimation methods introduced into the national inventory since 2016, which have more than doubled the estimate of methane emissions from CSG production in Australia (DISER 2021).

3.9.5 Recalculations since the 2020 submission

Table 3.50 Summary of recalculations

UNFCCC category	Years recalculated	Recalc summary (Gg CO_2-e) 1990	2000	2010	2018	NIR section reference	Reason for recalculation
1.B.2.b.5 Distribution	2007 to 2018	-	-		- 846	Page 161: Natural Gas Distribution (1.B.2.b.5)	Revision of UAG fraction and update of AD based on AES
1.B.2.b.1 Exploration	2018	-	-		20	Page 156: Gas Exploration (1.B.2.b.1)	Updated CSG well data from QLD Petroleum Production Statistics
1.B.2.b.3 Processing	2017 to 2018				-15	Page 160: Gas Processing (1.B.2.b.3)	Removed double counting of throughput for three processing plants
1.B.2.b.2 Production – Offshore platforms	1990 to 2018	0	3		18	Page 158: Offshore platforms	Updated 2018 activity data and improved allocation of platforms to geological basin locations to better reflect basin gas characteristics
1.B.2.b.2 –Production – Onshore Gathering and Boosting Stations						Page 159: Gathering and boosting stations and pipelines	
Conventional gas	1990 to 2018	- 1,246	- 929	- 1,906	- 2,841		Improved emission factor methodology to reflect latest published research. Correct activity data now used – applied to onshore activity only. Previously submission activity data had also included offshore gas production in error.
Unconventional gas	1990 to 2018	- 2	- 5	- 133	- 1,835		Improved emission factor methodology to reflect latest published research.
Pipelines	1990 to 2018	1	1	1	3		Improved allocation of gathering pipe to geological basin locations to better reflect basin gas characteristics
1.B.2.b.2 – Onshore wells leakage	1990 to 2018	3	2	3	5	Page 158: Onshore natural gas wells	Improved allocation of wells to geological basin locations to better reflect basin gas characteristics
1.B.2.b.c – Venting	1990 to 2018	- 137	- 322	- 389	- 320	Page 166: Venting – gas	Amended error in calculation of CO_2 fraction in Condensate venting – previously CO_2 was incorrectly reported as being around 70 times the volume of the methane venting. CO_2 is now estimated to reflect the appropriate gas composition of the respective geological basins

A detailed explanation and quantification of recalculations are provided in Table 3.53.

Energy

In summary, the recalculations since the 2020 submission were undertaken to incorporate:

- Updated activity data
  - 1.B.2.b.1 Exploration
  - 1.B.2.b.2 Offshore platforms
  - 1.B.2.b.3 Processing
  - 1.B.2.b.5 Natural Gas Distribution
- Improved emission factor methodology to reflect latest published research
  - 1. B.2.b.2 Onshore Gathering and Boosting Stations.
- Improved gas composition based on location
  - 1.B.2.b.2 Pipelines
  - 1.B.2.b.2 Onshore wells leakage
  - 1.B.2.b.2 Offshore platforms
  - 1.B.2.b.c Venting – condensates
- Rectify calculation error
  - 1.B.2.b.c Venting – condensates
- Revised methodology parameters
  - 1.B.2.b.5 Natural Gas Distribution

Revised natural gas sales figures relating to natural gas distribution was provided in the *Australian Energy Update 2018* (DoEE 2019), which resulted in recalculations for estimates of emissions for *1B2biii5 Distribution.*

Revised apportionment of the leakage share of unaccounted for gas was provided in December 2020, which resulted in recalculations for estimates of emissions for *1.B.2.b.iii.5 Distribution.*

Table 3.51 1.B.2 Oil and gas: recalculation of total CO_2-e emissions (Gg), 1990–2018

	2020 submission	2021 submission	Change	
	($Gg\ CO_2$-e)		($Gg\ CO_2$-e)	(per cent)
1.B.2.a Oil – Total				
1990	475	475	-0.1	0.0%
2000	560	560	-0.1	0.0%
2001	584	584	-0.1	0.0%
2002	592	592	-0.1	0.0%
2003	565	565	-0.1	0.0%
2004	527	527	-0.1	0.0%
2005	508	508	-0.1	0.0%
2006	477	477	-0.1	0.0%
2007	513	512	-0.1	0.0%
2008	497	497	-0.1	0.0%
2009	390	390	-0.1	0.0%
2010	381	381	-0.1	0.0%
2011	388	388	-0.1	0.0%
2012	356	356	-0.1	0.0%
2013	359	359	-0.1	0.0%
2014	296	296	-0.1	0.0%
2015	306	306	-0.1	0.0%
2016	238	238	-0.1	0.0%
2017	261	261	-0.1	0.0%
2018	197	197	0.0	0.0%
1.B.2.b Natural gas – Total				
1990	6,361	5,116	-1,244.3	-19.6%
2000	4,342	3,418	-924.1	-21.3%
2001	4,186	3,528	-657.5	-15.7%
2002	4,217	3,583	-634.1	-15.0%
2003	4,513	3,464	-1,048.8	-23.2%
2004	5,307	3,447	-1,859.8	-35.0%
2005	4,946	3,491	-1,454.9	-29.4%
2006	5,524	3,654	-1,869.9	-33.8%
2007	5,032	3,615	-1,416.5	-28.2%
2008	5,658	3,945	-1,712.9	-30.3%
2009	5,947	3,947	-2,000.2	-33.6%
2010	6,525	4,209	-2,316.0	-35.5%
2011	6,796	4,039	-2,757.0	-40.6%
2012	6,702	4,342	-2,360.2	-35.2%
2013	6,586	4,077	-2,509.0	-38.1%
2014	6,650	4,097	-2,553.2	-38.4%

Energy

	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
2015	7,153	4,311	-2,841.2	-39.7%
2016	8,709	5,048	-3,660.3	-42.0%
2017	9,821	5,045	-4,776.7	-48.6%
2018	10,707	5,566	-5,141.1	-48.0%
1.B.2.C Venting and Flaring – Total				
1990	8,372	8,235	-136.6	-1.6%
2000	9,949	9,628	-321.5	-3.2%
2001	10,012	9,690	-321.2	-3.2%
2002	9,392	9,030	-361.6	-3.9%
2003	8,308	7,968	-340.7	-4.1%
2004	7,698	7,396	-301.8	-3.9%
2005	7,288	6,960	-327.9	-4.5%
2006	7,204	6,893	-311.0	-4.3%
2007	7,397	7,074	-323.0	-4.4%
2008	7,529	7,204	-324.5	-4.3%
2009	8,049	7,660	-389.7	-4.8%
2010	8,665	8,276	-389.3	-4.5%
2011	7,849	7,500	-348.9	-4.4%
2012	8,454	8,109	-345.6	-4.1%
2013	9,217	8,889	-327.4	-3.6%
2014	9,097	8,801	-296.5	-3.3%
2015	10,985	10,703	-282.0	-2.6%
2016	12,196	11,901	-295.5	-2.4%
2017	15,197	14,887	-310.3	-2.0%
2018	16,872	16,552	-320.2	-1.9%

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;
- Further refinement of the leakage method for gas gathering and boosting.

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 CCS projects operating within the time period covered in this 2021 National Inventory Report. However Chevron Australia's Gorgon LNG project has started the carbon dioxide underground injection system at the Gorgon natural gas facility in August 2019. Once fully operational, it is expected that the Gorgon system will inject between 3.4 and 4 million tonnes of greenhouse gas emissions each year. Australia will include reporting of CCS from the Gorgon project in the 2022 inventory submission.

CCS projects

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.

Chevron Australia's Gorgon LNG project CCS operations at Barrow Island in Western Australia are developed in accordance with approvals under the project specific legislative instrument the *Barrow Island Act 2003* (WA). Carbon dioxide is separated from the natural gas and 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 Industry, Science, Energy and Resources 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.1.c 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
1.A.1.c.ii 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
Unprocessed Natural Gas	404.6	0.9	107.1	19.3	1.6	2.3
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
1.A.2.a 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
1.A.2.c Chemicals (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
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

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
1.A.2.e Food Processing, Beverages and 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
1.A.2.f Non-metallic Minerals (ANZSIC Subdivision 20)						
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.g.vi 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
1.A.2.g.i 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.g.v 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 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

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
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
1.A.2.g.iii Mining excluding fuels (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

Fuel Type	Emission Factors (Mg/PJ)					
	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Residential						
Wood and Wood Waste (a)						
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	0.6	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)				
			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) 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 1.6-11 Uncontrolled 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 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 NOx 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

Fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	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	
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	

Fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
ADO												
Post-2008	0.002		0.008		0.000		0.003		0.021		0.000	
2006–2007	0.003	COPERT IV	0.021	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)
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	
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						0.049			
1998–2003	0.037		0.025		0.037				0.048			
1985–1997 (3-way cat)	0.206	Post-97 EF x earlier petrol age class – relativity	0.158		0.053				0.159			
1985–1997 (2-way cat)	0.592		0.331		0.211 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 Urban Non-urban				Heavy Duty Truck Urban Non-urban				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		0.110		0.140		0.110		0.140		0.110	
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		0.096		0.220		0.096		0.120		0.053	
Pre-1996	0.220		0.096		0.220		0.096		0.120		0.053	
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		0.157	COPERT IV	0.07		0.157	COPERT IV	0.0628	
Pre-1996	0.157		0.037		0.157		0.063		0.157		0.0628	

(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

Fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	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	Orbital Australia 2010	0.020	Orbital Australia 2010	0.001	Orbital Australia 2010	0.003	Orbital Australia 2010	0.144	Orbital Australia 2010	0.001	Orbital Australia 2010
2006–2007	0.004		0.037		0.001		0.003		0.144		0.001	
2004–2005	0.008		0.121		0.009		0.006		0.087		0.009	
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	Weeks *et al.* 1993	0.041	USEPA (as cited in IPCC 2006)	0.005	Hot urban EF x COPERT IV (IPCC 2006) non-urban to urban ratio	0.005	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.047	USEPA (as cited in IPCC 2006)	0.005	Hot urban EF x COPERT IV (IPCC 2006) non-urban to urban ratio
Pre-76	0.003		0.036		0.002		0.003		0.041		0.002	
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	

Fuel type	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
ADO												
Post-2008	0.003		0.023		0.002		0.009		0.045	COPERT IV (converted to a per – start EF)	0.004	COPERT IV – (Highway)
2006–2007	0.009	COPERT IV	0.045	COPERT IV (converted to a per start EF)	0.004	COPERT IV (Highway)	0.009	COPERT IV	0.045		0.004	
2004–2005	0.004		0.045		0.006		0.004		0.045		0.006	
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	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			
1998–2003	0.030		0.025		0.059				0.082			
1985–1997 (3-way cat)	0.030	Post-97 EF x earlier petrol age class relativity	0.029		0.082 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			

(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.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 Urban Non-urban				Heavy Duty Truck Urban Non-urban				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	0.006	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		0.139	0.047										
2004–2005	0.075	0.399	0.077	0.275	0.669	0.236									
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	2.52	10.87	1.04	2.52	10.87	1.04	3.91	48.61	3.47
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
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

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 Australian Energy Statistics fuel consumption to unlisted categories 2019

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	99.995 per cent	0.005 per cent			
Water transport ADO	68.9 per cent	31.1 per cent			
Water transport fuel oil	100 per cent				
Air transport aviation gasoline	99.7 per cent	0.3 per cent			
Air transport aviation turbine fuel	94.0 per cent	6.0 per cent			

Source: Derived from Farrington 1988, ABS 2018 and Department of Defence 2019.

Table 3.A.15 Shares used to allocate Australian Energy Statistics fuel consumption to unlisted categories 2019

	Fuel Type			
Vehicle Type	Automotive Gasoline	ADO	LPG	NG [(a)]
Passenger cars	89.1 per cent	19.8 per cent	78.8 per cent	1.9 per cent
Light commercial vehicles	9.8 per cent	29.8 per cent	14.6 per cent	2.9 per cent
Medium duty trucks	0.1 per cent	19.1 per cent	0.3 per cent	1.7 per cent
Heavy duty trucks	-	27.9 per cent	-	2.7 per cent
Buses	0.2 per cent	3.5 per cent	6.3 per cent	90.8 per cent
Motor cycles	0.7 per cent	-	-	-

Source: (a) ABS 2018. (b) Pekol Traffic and Transport 2020.

Table 3.A.16 Australian petrol-fuelled vehicle stock age distribution and fuel consumption rates: 2019

Passenger cars: year of manufacture	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
	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)
2019	291,296	0.104	7,395	0.129	136	0.162	4	0.280	87	0.184
2018[b]	631,316	0.104	14,600	0.129	149	0.162	17	0.280	611	0.184
2017	674,633	0.104	15,196	0.129	140	0.162	46	0.202	500	0.184
2016	750,685	0.104	20,540	0.129	163	0.162	25	0.202	524	0.184
2015	747,437	0.104	18,606	0.129	124	0.162	27	0.202	696	0.184
2014	691,524	0.104	20,131	0.129	125	0.162	26	0.202	648	0.184
2013	727,143	0.104	26,983	0.129	183	0.162	42	0.202	560	0.184
2012	685,488	0.106	31,738	0.130	182	0.180	36	0.205	646	0.209
2011	625,608	0.106	34,296	0.130	176	0.180	15	0.205	958	0.209
2010	663,906	0.106	43,789	0.130	247	0.180	21	0.205	860	0.209
2009	584,647	0.106	45,834	0.130	180	0.180	21	0.205	802	0.209
2008	624,979	0.106	56,124	0.130	258	0.180	41	0.205	1,137	0.209
2007	662,753	0.106	58,304	0.130	476	0.180	110	0.205	1,016	0.209
2006	611,888	0.106	54,355	0.130	536	0.180	49	0.205	1,049	0.209
2005	614,953	0.106	79,818	0.130	434	0.180	39	0.205	745	0.209
2004	556,399	0.106	73,420	0.130	470	0.180	41	0.205	418	0.209
2003	515,685	0.106	66,317	0.130	332	0.180	33	0.205	780	0.209
2002	417,065	0.118	50,829	0.122	413	0.284	20	0.304	661	0.197
2001	362,830	0.118	43,871	0.122	318	0.284	14	0.304	479	0.197
2000	330,324	0.118	39,797	0.122	216	0.284	12	0.304	750	0.197
1999	269,681	0.118	39,742	0.122	197	0.284	12	0.304	536	0.197
1998	240,514	0.118	34,140	0.122	260	0.284	24	0.304	552	0.197
1997	171,299	0.118	25,984	0.122	213	0.284	11	0.304	495	0.197
1996	119,230	0.118	22,651	0.122	177	0.284	11	0.304	387	0.197
1995	98,706	0.118	19,946	0.122	160	0.284	11	0.304	345	0.197
1994	80,141	0.118	18,560	0.122	163	0.284	34	0.304	273	0.197
1993	60,851	0.118	13,919	0.122	151	0.284	15	0.304	223	0.197
1992	47,675	0.118	13,462	0.122	196	0.284	3	0.304	195	0.197
1991	38,655	0.118	10,573	0.122	157	0.284	3	0.304	151	0.197
1990	38,190	0.118	11,510	0.122	213	0.284	6	0.304	156	0.197
1980–1989[a]	116,162	0.118	47,149	0.122	2,604	0.284	80	0.304	503	0.197
1979 and earlier	155,140	0.118	38,494	0.122	12,549	0.284	159	0.304	160	0.197

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 Industry, Science, Energy and Resources estimates derived from ABS 2013, ABS 2014a.

Energy

Table 3.A.17 Australian diesel-fuelled vehicle stock age distribution and fuel consumption rates: 2019

Passenger cars: year of manufacture	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
	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)
2019	53,88	0.114	76,772	0.121	11,135	0.283	2,587	0.727	2,206	0.257
2018[b]	125,925	0.114	183,517	0.121	26,040	0.283	6,429	0.727	3,962	0.257
2017	142,425	0.114	176,920	0.121	23,071	0.283	5,700	0.554	3,837	0.257
2016	171,362	0.114	186,525	0.121	23,290	0.283	4,883	0.554	3,854	0.257
2015	162,317	0.114	173,783	0.121	22,237	0.283	4,965	0.554	4,064	0.257
2014	153,773	0.114	159,492	0.121	20,591	0.283	5,810	0.554	4,233	0.257
2013	162,481	0.114	165,189	0.121	19,649	0.283	6,093	0.554	3,888	0.257
2012	159,553	0.113	160,444	0.125	21,054	0.289	5,572	0.555	4,607	0.299
2011	126,613	0.113	117,866	0.125	15,502	0.289	3,223	0.555	4,674	0.299
2010	120,907	0.113	118,032	0.125	23,765	0.289	5,409	0.555	4,296	0.299
2009	86,804	0.113	96,913	0.125	18,384	0.289	2,987	0.555	3,579	0.299
2008	86,481	0.113	105,551	0.125	22,171	0.289	3,818	0.555	4,623	0.299
2007	64,742	0.113	80,849	0.125	27,852	0.289	7,621	0.555	3,371	0.299
2006	50,199	0.113	70,486	0.125	20,868	0.289	4,316	0.555	3,002	0.299
2005	36,106	0.113	54,173	0.125	20,901	0.289	4,435	0.555	2,949	0.299
2004	30,593	0.113	47,227	0.125	19,561	0.289	4,134	0.555	2,106	0.299
2003	25,640	0.113	38,096	0.125	14,280	0.289	3,419	0.555	1,938	0.299
2002	21,081	0.148	33,902	0.121	16,090	0.289	2,575	0.527	1,880	0.350
2001	17,209	0.148	23,770	0.121	11,052	0.289	1,816	0.527	1,825	0.350
2000	15,583	0.148	27,280	0.121	10,774	0.289	1,865	0.527	2,360	0.350
1999	12,392	0.148	24,776	0.121	10,666	0.289	1,997	0.527	1,971	0.350
1998	11,552	0.148	21,951	0.121	10,293	0.289	2,185	0.527	1,989	0.350
1997	10,179	0.148	18,074	0.121	8,046	0.289	1,723	0.527	1,571	0.350
1996	8,730	0.148	15,559	0.121	6,959	0.289	1,388	0.527	1,437	0.350
1995	8,623	0.148	13,898	0.121	7,438	0.289	1,581	0.527	1,567	0.350
1994	8,786	0.148	13,743	0.121	7,948	0.289	1,642	0.527	1,534	0.350
1993	7,910	0.148	11,461	0.121	6,060	0.289	1,028	0.527	1,185	0.350
1992	9,348	0.148	10,044	0.121	5,854	0.289	540	0.527	1,091	0.350
1991	8,008	0.148	7,151	0.121	4,803	0.289	369	0.527	802	0.350
1990	7,323	0.148	8,497	0.121	7,220	0.289	838	0.527	741	0.350
1980–1989[a]	24,813	0.148	25,138	0.121	47,397	0.289	5,668	0.527	2,295	0.350
1979 and earlier	697	0.148	1,294	0.121	9,201	0.289	1,806	0.527	212	0.350

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 Industry, Science, Energy and Resources estimates derived from ABS 2013, ABS 2014a.

Table 3.A.18 Australian LPG-fuelled vehicle stock age distribution and fuel consumption rates: 2019

Passenger cars: year of manufacture	Passenger cars		Light commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
	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)
2019	865	0.092	315	0.13	37	0.157	2	0.432	41	0.246
2018[b]	2,996	0.092	2,384	0.13	183	0.157	3	0.432	180	0.246
2017	546	0.092	105	0.130	95	0.157	39	0.530	20	0.246
2016	867	0.092	479	0.130	60	0.157	6	0.530	35	0.246
2015	1,813	0.092	809	0.130	24	0.157	0	0.530	66	0.246
2014	3,290	0.092	1,186	0.130	30	0.157	6	0.530	69	0.246
2013	4,117	0.092	1,665	0.130	36	0.157	3	0.530	43	0.246
2012	4,780	0.125	2,592	0.167	70	0.173	5	0.640	42	0.247
2011	3,902	0.125	1,253	0.167	53	0.173	8	0.640	192	0.247
2010	7,561	0.125	4,083	0.167	73	0.173	16	0.640	264	0.247
2009	8,835	0.125	4,795	0.167	44	0.173	8	0.640	377	0.247
2008	10,480	0.125	7,000	0.167	45	0.173	3	0.640	481	0.247
2007	10,193	0.125	5,968	0.167	55	0.173	15	0.640	319	0.247
2006	11,362	0.125	7,240	0.167	73	0.173	3	0.640	285	0.247
2005	11,785	0.125	6,241	0.167	70	0.173	9	0.640	196	0.247
2004	12,724	0.125	5,668	0.167	67	0.173	0	0.640	121	0.247
2003	14,350	0.125	5,712	0.167	56	0.173	3	0.640	65	0.247
2002	12,078	0.119	5,122	0.169	67	0.255	6	0.432	94	0.515
2001	10,920	0.119	5,102	0.169	38	0.255	0	0.432	261	0.515
2000	11,433	0.119	5,078	0.169	26	0.255	0	0.432	155	0.515
1999	11,957	0.119	4,241	0.169	21	0.255	0	0.432	121	0.515
1998	9,994	0.119	3,382	0.169	16	0.255	0	0.432	43	0.515
1997	10,914	0.119	2,690	0.169	23	0.255	0	0.432	38	0.515
1996	8,845	0.119	2,385	0.169	20	0.255	0	0.432	19	0.515
1995	5,896	0.119	2,071	0.169	20	0.255	0	0.432	63	0.515
1994	4,764	0.119	1,879	0.169	17	0.255	3	0.432	112	0.515
1993	4,269	0.119	1,384	0.169	15	0.255	0	0.432	58	0.515
1992	3,965	0.119	1,199	0.169	32	0.255	0	0.432	28	0.515
1991	3,323	0.119	970	0.169	30	0.255	0	0.432	23	0.515
1990	2,164	0.119	1,205	0.169	28	0.255	0	0.432	35	0.515
1980–1989[a]	7,751	0.119	5,356	0.169	548	0.255	3	0.432	69	0.515
1979 and earlier	6,096	0.119	4,350	0.169	1,154	0.255	111	0.432	17	0.515

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 Industry, Science, Energy and Resources 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	0.058	NA	NA

Source: ABS 2018. (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, 2019

	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Passenger Cars	12.09	11.47	17.15	13.55	10.47	11.39	11.52	11.53
Light Commercial Vehicles	15.55	15.28	32.27	16.60	15.77	12.37	15.60	17.33
Medium Trucks	15.79	16.54	29.33	20.69	18.44	12.23	14.21	19.98
Heavy Trucks	88.46	79.17	135.02	85463	79.32	71.87	64.13	70.29
Buses	38.09	24.06	48.89	24.83	22.31	21.07	21.50	23.02

Source: Pekol Traffic and Transport 2020.

Table 3.A.22 Carbon dioxide emission factor for coke

Year	Emission Factor (CO_2 Gg/ PJ)
1990	103.79
1995	103.84
2000	103.83
2005	106.41
2010	106.65
2011	106.50
2012	106.76
2013	106.15
2014	106.91
2015	108.20
2016	108.19
2017	108.63
2018	109.40
2019	109.40

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 1991 b). (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 1991 b). (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 32.6 Mt CO_2-e in 2019, or 6.3 per cent of net national emissions (excluding *LULUCF)* (Table 4.1).

Table 4.1 Industrial processes and product use sector CO_2-e emissions, 2019, 2020

Greenhouse Gas Source and Sink Categories	Greenhouse gas source CO_2-e emissions (Gg)					
	CO_2	CH_4	N_2O	HFC/ PFC/ SF_6	Total 2019 CO_2-e	Preliminary 2020 estimates CO_2-e
2. Industrial Processes And Product Use	**19,368**	**72**	**2,244**	**10,885**	**32,569**	**31,281**
A. Mineral Industry	5,589	NA	NA	NA	5,589	5,379
B. Chemical Industry	2,821	11	2,228	NA	5,059	4,918
C. Metal Industry	10,559	61	17	303	10,940	10,509
D. Non-energy products from fuels and solvent use	180	NA	NA	NA	180	180
E. Electronics Industry	NA	NA	NA	NE	NE	NE
F. Product uses as substitutes for Ozone Depleting Substances	NA	NA	NA	10,445	10,445	9,944
G. Other product manufacture and use	NA	NA	NA	137	137	137
H. Other	219	NA	NA	NA	219	214

The *metal industry* contributed 33.6 per cent (10.9 Mt CO_2-e) of the sector's emissions, The *mineral industry* contributed 17.2per cent (5.6 Mt CO_2-e), *chemical industries* contributed 15.5 per cent (5.1 Mt CO_2-e), the *product uses as substitutes for ozone depleting substances* contributed 32.1 cent (10.4 Mt CO_2-e), *Other (food and drink)* contributed 0.4 per cent (0.1 Mt CO_2-e) and *other product manufacture and use* contributed 0.7 per cent (0.2 Mt CO_2-e).

The main gas emitted by *industrial processes and product use* is CO_2, contributing 59.5 per cent (19.4 Mt CO_2-e) of the sector's emissions in 2019. PFCs contributed 0.9 per cent (0.3 Mt CO_2-e), HFCs contributed 32.1 per cent (10.4 Mt CO_2-e), SF_6 contributed 0.4 per cent (0.1 Mt CO_2-e), N_2O contributed 6.9per cent (2.2 Mt CO_2-e), and CH_4 0.2 per cent (0.1 Mt CO_2-e).

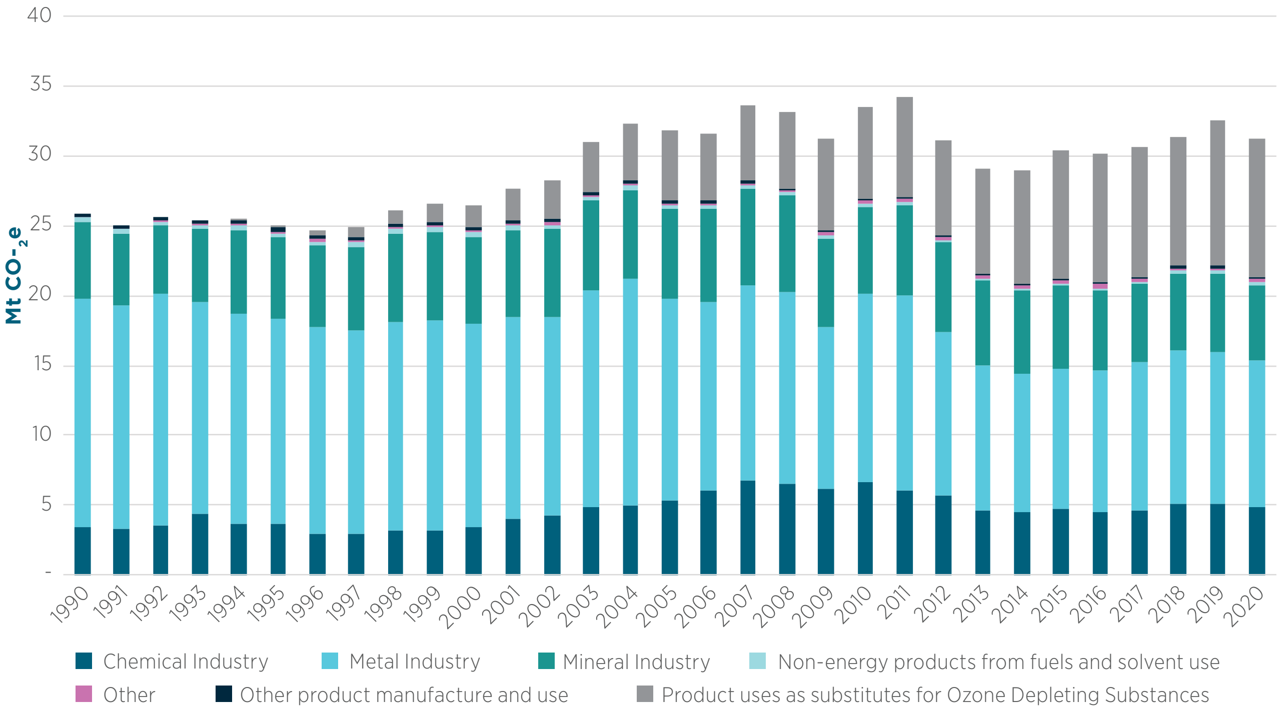
Trends

Net emissions from *industrial processes and product use* increased by 25.7 per cent (6.7 Mt CO_2-e) from 1990 to 2019, and increased by 3.7 per cent (1.2 Mt CO_2-e) between 2018 and 2019. The preliminary estimate for 2020 is 31.3 Mt CO_2-e, a decrease of 4.0 per cent on 2019 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 2020 is shown in Figure 4.1.

Figure 4.1 Emissions from industrial processes and product use by subsector, 1990–2019 (preliminary 2020)



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 2019 were 3.0 Mt CO_2-e, a 12.2 per cent decrease from 1990, while production has decreased by 9.3 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 2019 was 1,489 kt compared with 1,509 kt in 2018 representing a decrease in production of 1.3 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 2019, total carbonate consumption had increased by 5.3 per cent from 1990. The year on year growth in carbonate consumption, however, has varied from positive to negative throughout the time series.

Soda ash production and use

Soda ash is produced in Australia by only one company, Alcoa. A second producer, Penrice Soda Products, 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.

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. Emissions from the chemical industry peaked in 2007 and have since undergone a decline as a result of improvements in nitric acid emissions control and declining levels of synthetic rutile production due to plant closures.

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 2019 were 1.4 per cent lower than in 2018.

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 4.5 per cent higher in 2019 than 2018 owing to an increase in production levels and the associated consumption of coal tar, petroleum coke and other inputs to the anode production process.

The 61.0 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 have increased steadily over time 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. A phase-down of bulk imports of HFCs commenced on 1 January 2018.

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). CO_2 *emissions from carbide production* (2.B.5) and *soda ash production* (2.B.7) under 2.B.10 – *confidential chemical industry emissions.* Emissions of N_2O from the *use of N_2O 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 aggregated 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 Method applied	CO_2 EF	CH_4 Method applied	CH_4 EF	N_2O Method applied	N_2O EF	HFCs Method applied	HFCs EF	PFCs Method applied	PFCs EF	SF_6 Method applied	SF_6 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	T2/3	CS,D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2. Nitric Acid Production	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	
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										

Greenhouse Gas Source and Sink Categories	CO_2 Method applied	CO_2 EF	CH_4 Method applied	CH_4 EF	N_2O Method applied	N_2O EF	HFCs Method applied	HFCs EF	PFCs Method applied	PFCs EF	SF_6 Method applied	SF_6 EF
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. Pleat Transfer Fluid								NA	NA	NA	NA	
5. Other												
F. Product Uses as Substitutes for Ozone Depleting Substances							M	D/CS	NA	NA	NA	NA
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	NA	NA
8. Other Applications (b)							NA	NA	NA	NA	NA	NA
G. Other Product Manufacture and Use					T2	CS	NA	NA	NA	NA	T2	CS
1. Electrical Equipment					NA	NA	NA	NA	NA	NA	T2	CS
2. SF, and PFCs from Other Product Uses					NA	NA	NA	NA	NA	NA	T2	CS
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, M = model, NE = not estimated, NA= not available, NO = not occurring, IE = included elsewhere
(a) Emissions reported under 2.A.3 *limestone and dolomite use;* (b) 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 2019

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, Millennium 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 – SR 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 Agriculture, Water and the Environment under the regulations applying under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 2003*
2.G.1 2.G.2	Electrical equipment SF_6 and PFCs from other product uses	NGERS	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.

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

Under the provisions of the National Greenhouse and Energy Reporting (Measurement) Determination, facilities are able to determine facility-specific EFs based on the CaO and MgO contents of their cement clinker according to the following equation:

$$F_{CaO} \times 0.785 + F_{Mgo} \times 1.092$$

Where F_{CaO} is the estimated fraction of cement clinker that is calcium oxide derived from carbonate sources and produced from the operation of the facility

F_{MgO} is the estimated fraction of cement clinker that is magnesium oxide derived from carbonate sources and produced from the operation of the facility

From 2016, two cement production facilities have reported facility-specific EFs based on facility-specific measurement of the CaO and MgO contents of their produced clinker.

The National Greenhouse and Energy Reporting (Measurement) Determination also sets out the sampling requirements for cement clinker:

1) A sample of cement clinker must be derived from a composite of amounts of the cement clinker produced.
2) The samples must be collected on enough occasions to produce a representative sample.
3) The samples must also be free of bias so that any estimates are neither over nor under estimates of the true value.
4) Bias must be tested in accordance with an appropriate standard.

The minimum frequency of analysis of samples of cement clinker must be in accordance with the Tier 3 method for cement clinker in section 2.2.1.1 in Chapter 2 of Volume 3 of the 2006 IPCC Guidelines.

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, 2000–2019

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
2018	5,443	24	2,942
2019	5,625	26	3040

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. This is the sole facility that undertakes in-house lime 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 Eq associated with lime production Aq 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 x (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:

	1990	2006	2007	2019
Commercial lime	Weighted average EF 0.751 t CO_2/ t lime		Facility specific Efs	
			Default CS EF-0.675 t CO_2/t lime	
In-house lime	Default CS EF-0.675 t CO_2/t lime			

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.

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, 2000–2019

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
2018	1,509	1,026
2019	1,489	1,025

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:

$$E = A_{ls} . F_{ls} . EF_{ls} + A_d . F_d . EF_d + A_o . F_o . EF_O$$

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.

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, 2000–2019

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	1,680
2015	1,638	1,768	1,630
2016	1,788	1,784	1,705
2017	1,727	1,539	1,550
2018	1,572	1,623	1,555
2019	1,623	1,487	1,524

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 may be estimated from a consideration of the consumption data Asau 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
2018	320	133
2019	332	138

Source: EnerGreen Consulting 2009, NGER System 2009 to date.

4.3.5 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.

4.3.6 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, 2019

		Raw material (d) (kt)	Emissions (Gg CO_2)	Carbon (kt)
Use				
2.A.1	Cement production	6,884	3,040	829
2.A.2	Lime production	2,282	1,025	280
2.A.3	Glass Production	180	80	22
2.A.4	Other process uses of carbonates	2,923	1,269	346
2.B.7	Soda Ash Production	-	-	-
3.C.2	Agricultural Liming	3,312	1,318	360
Total Use (a)				
Supply				
Implied production		17,221		
Imports		997		
Exports		5		
Total supply (b)		**18,213**		

Source:

(a) DISER.

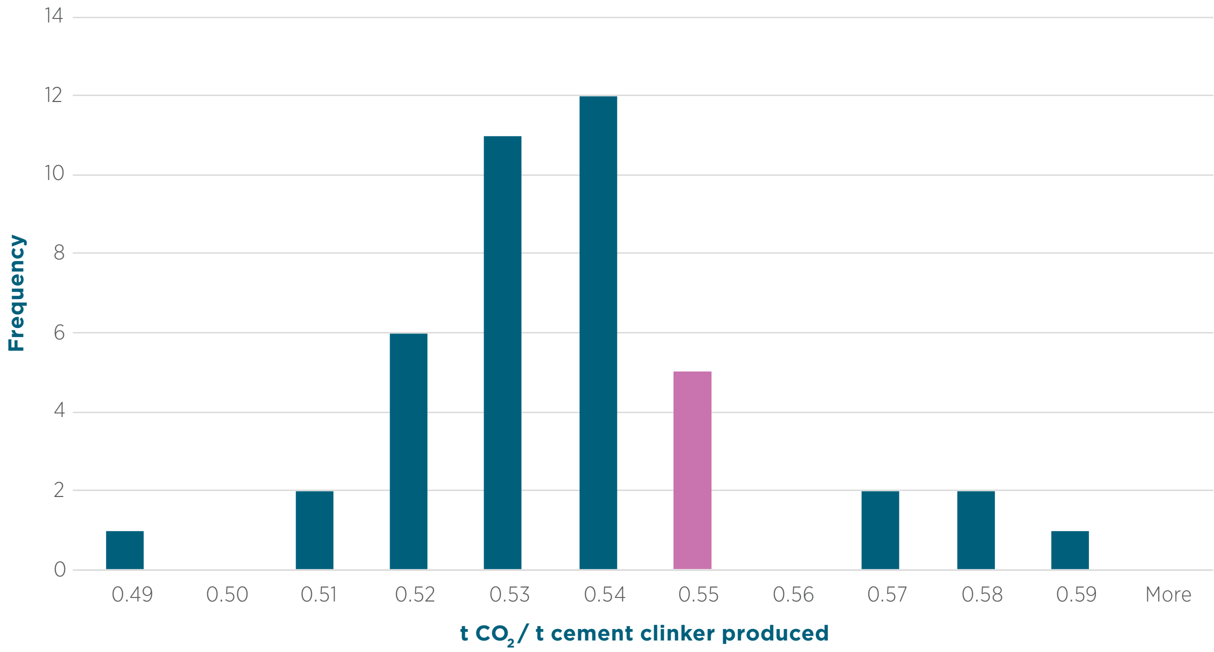
(b) ABS 2020.

(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 (2018 Inventory) and Australia (2019 Inventory)

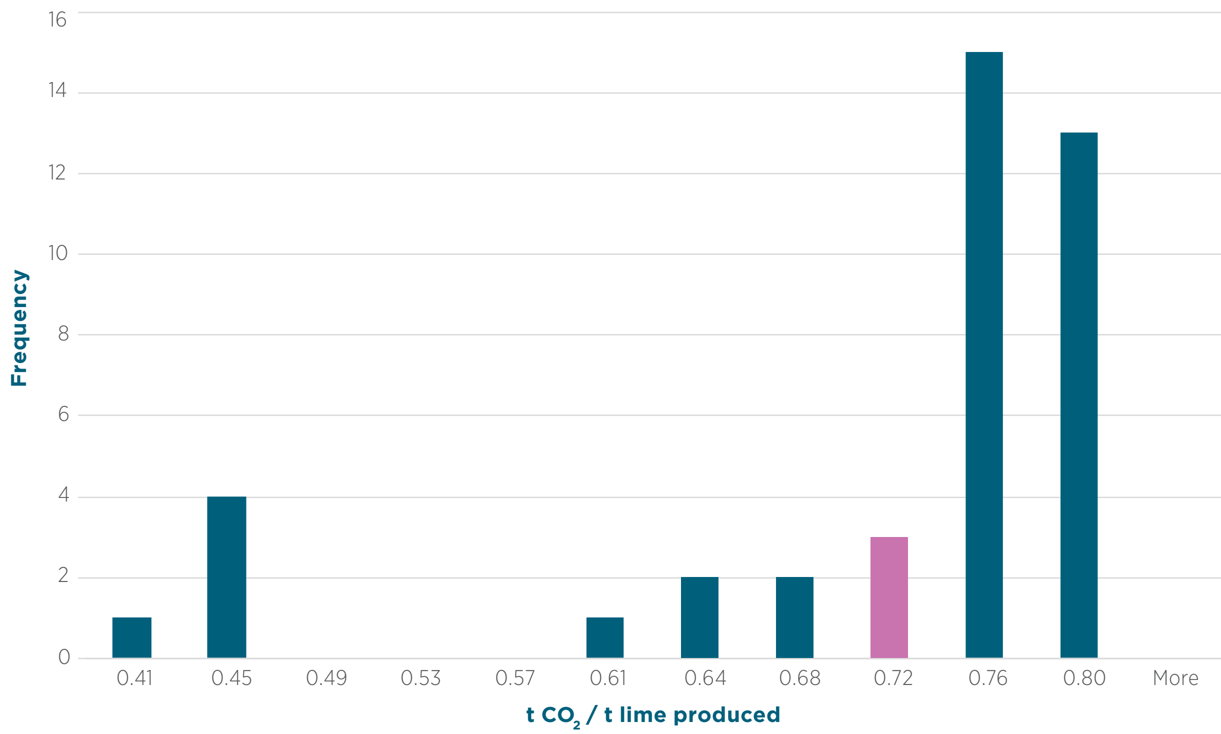


Note: In the figure above, Australia's IEF is located within the marked range.

Australia's IEF for cement clinker production at the national level ranges between 0.535 t CO_2/tonne of cement clinker produced and 0.560 t 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 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 (2018 Inventory) and Australia (2019 Inventory)



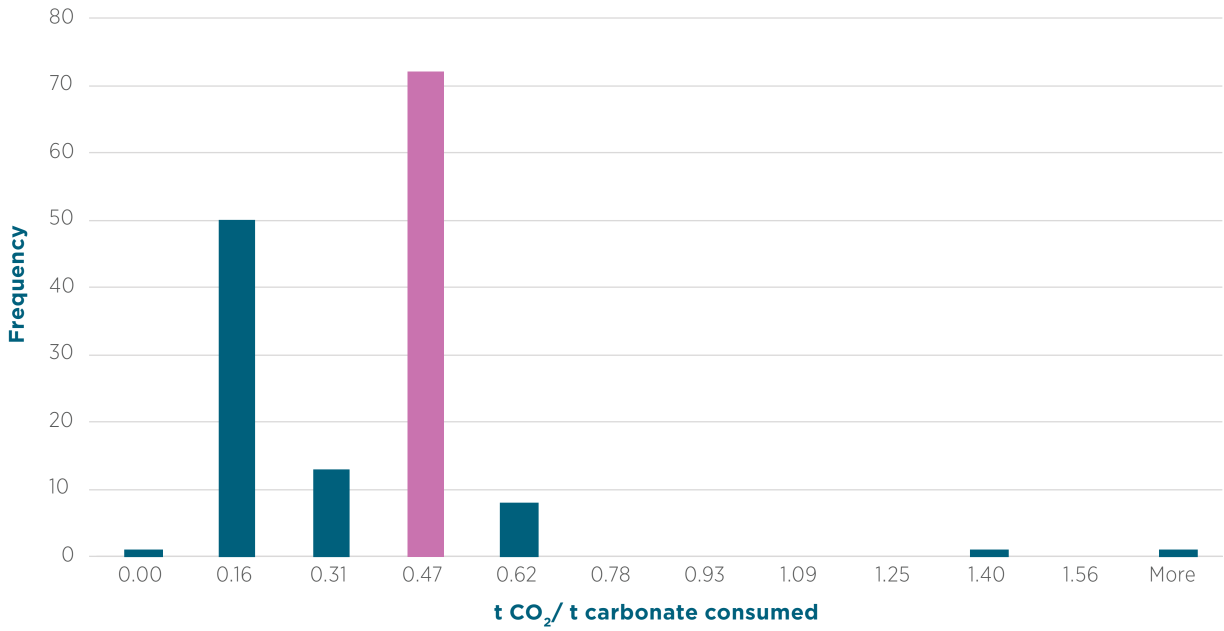
Note: In the figure above, Australia's IEF is located within the marked range.

Australia's IEF for lime production at the national level ranges between 0.68 t CO_2/tonne of lime produced and 0.82 t 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 2018 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 (2018 Inventory) and Australia (2019 Inventory)



Note: In the figure above, Australia's IEF is located within the marked range.

Australia's carbonates IEF ranges between 0.410 t CO_2/t carbonate consumed and 0.435 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.

4.3.7 Recalculations since the 2018 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.*

Recalculations we undertaken in the mineral products sector due to the updates to construction industry indexes from 2011–2018 published by the Australian Bureau of Statistics which is used to estimate emissions from brick manufacturing.

Table 4.9 2.A.1 Cement production: recalculation of CO_2-e emissions (Gg), 1990–2018

	2020 Submission Gg CO_2-e	2021 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
2.A.1 Cement Production				
1990	3,463	3,463	-	0%
2000	3,621	3,621	-	0%
2001	3,541	3,541	-	0%
2002	3,488	3,488	-	0%
2003	3,584	3,584	-	0%
2004	3,555	3,555	-	0%
2005	3,664	3,664	-	0%
2006	3,888	3,888	-	0%
2007	3,972	3,972	-	0%
2008	3,863	3,863	-	0%
2009	3,829	3,829	-	0%
2010	3,549	3,549	-	0%
2011	3,496	3,496	-	0%
2012	3,518	3,518	-	0%
2013	3,294	3,294	-	0%
2014	3,138	3,138	-	0%
2015	3,076	3,076	-	0%
2016	2,931	2,931	-	0%
2017	3,019	3,019	-	0%
2018	2,942	2,942	-	0%

Table 4.10 2.A.2 Lime production: recalculation of CO_2-e emissions (Gg), 1990–2018

	2020 Submission Gg CO_2-e	2021 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
2.A.2 Lime Production				
1990	775	775	-	0%
2000	957	957	-	0%
2001	1,149	1,149	-	0%
2002	1,176	1,176	-	0%
2003	1,194	1,194	-	0%
2004	1,217	1,217	-	0%
2005	1,213	1,213	-	0%
2006	1,102	1,102	-	0%
2007	1,225	1,225	-	0%
2008	1,320	1,320	-	0%
2009	1,152	1,152	-	0%
2010	1,231	1,231	-	0%
2011	1,244	1,244	-	0%
2012	1,305	1,305	-	0%
2013	1,256	1,256	-	0%
2014	1,186	1,186	-	0%
2015	1,169	1,169	-	0%
2016	1,051	1,051	-	0%
2017	1,031	1,031	-	0%
2018	1,026	1,026	-	0%

Table 4.11 2.A.3&4 Other process uses of carbonates: recalculation of CO_2-e emissions (Gg), 1990–2018

	2020 Submission Gg CO_2-e	2021 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
2.A.3 & 4 Other process uses of carbonates				
1990	1,251	1,251	-	0%
2000	1,654	1,654	-	0%
2001	1,548	1,548	-	0%
2002	1,628	1,628	-	0%
2003	1,651	1,651	-	0%
2004	1,617	1,617	-	0%
2005	1,601	1,601	-	0%
2006	1,679	1,679	-	0%
2007	1,789	1,789	-	0%
2008	1,715	1,715	-	0%
2009	1,427	1,427	-	0%
2010	1,525	1,525	-	0%
2011	1714	1699	15	0.9%
2012	1588	1590	-1	-0.1%
2013	1554	1555	-1	-0.1%
2014	1681	1680	1	0.0%
2015	1633	1630	3	0.2%
2016	1710	1705	6	0.3%
2017	1550	1550	-0.5	-0.04%
2018	1555	1555	-0.6	-0.04%

(a) Includes 2.B.7 soda ash production

4.3.8 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 Application.* 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.*

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.

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:

$$3H_2 + N_2 \ 2NH_3$$

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, (reported in Table 3.2) to plant specific natural gas consumption data A_i:

$Ea = \Sigma Ai \,.\, EF_i. - R$

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 five facilities reported under the NGER System were used for 2009 onwards where available. In 2019, one facility reported a facility specific emissions factor.

For the remaining three 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 directly through NGERS. However, these can be inferred from reported data and the average implied emission factor for CO_2 from generated Australian ammonia production plants was 1.43tonnes CO_2/ tonnes NH_3 in 2019. This IEF is 2.2% higher than for 2018. However, throughout the time series there is some greater volatility in inter annual IEF variations caused by some facilities not reporting facility specific EF in conjunction with natural gas consumption and ammonia production.

Ammonia production data for 2012–2018 has been updated since the last submission, with one facility having previously reported incorrect production values. This corrects previous high inter annual variations in the IEF.

This value is lower than the 2.1 tonnes CO_2/tonnes NH_3 IPCC default European average 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.

In response to an ERT recommendation, it was identified that one facility had reported production combined with imports for the years 2012–2017, rendering actual production data for the facility uncertain. Australia will continue to source accurate data, however in the meantime Australia has indexed production data for these years based accurate production and IEF for 2018.

Production and emissions from *ammonia production* are shown in Table 4.12.

Table 4.12 Production and emissions from the production of ammonia 1990, 2000–2019

	Production (kt)	Emissions (Gg CO_2-e)
1990	448	544
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	1,684	1,992
2013	1,877	2,139
2014	2,129	2,573
2015	2,020	2,433
2016	1,905	2,370
2017	1,924	2,271
2018	1,939	2,417
2019	1,576	1,953

Source: Energreen 2009, NGERS 2009 Onwards. DISER 2020.

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:

$4 NH_3 + 5O_2$ $4NO + 6H_2O$
$2NO + O_2$ $2NO_2$
$3NO_2 + H_2O$ $2HNO_3 + NO$

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 constraints.

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
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
2018	1,709	1,821
2019	1,699	2,228

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.2018):

$$2TiO_2 + 4Cl_2 + 3C\ 2TiCl_4 + 2CO + CO_2$$
$$TiCl_4 + O_2\ TiO_2 + 2Cl_2$$

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:

$$CO_2\ \text{Emissions} = \Sigma EF_{i} \cdot . A_i$$

Where EFi is the EF for fuel type i and A_i is the quantity of fuel type i consumed as a reductant

Industrial Processes and Product Use

Choice of emission factor

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 TiO_2

Year	Emissions (Gg CO_2)
1990	415
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
2018	832
2019	848

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:

$$CaCO_3 + 2NaCl \; Na_2CO_3 + CaCl_2$$

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.

$Es = [\ \Sigma f\ CC_f \cdot A_f + CC_l \cdot A_l - \Sigma_p\ CC_p \cdot A_p \cdot - \Sigma_w\ CC_w \cdot A_w\ ] \cdot 3.664$

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_f is the carbon content of the limestone consumed

A_f is the mass of limestone consumed

CC_l 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 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:

$Na_2CO_3 + Ca(OH)_2\ 2\ NaOH + CaCO_3$

Sodium hydroxide is manufactured using soda ash (also diverted from the product stream) and slaked lime with calcium carbonate as a waste by-product:

$MgSO_4 + 2\ NaOH\ Mg(OH)_2 + Na_2SO_4$

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.

$MgSO_4 + 2\ NaOH\ Mg(OH)_2 + Na_2SO_4$

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:

$$2\ NaHCO_3\ Na_2CO_3 + H_2O + CO_2$$

The mass of CO_2 emitted from the use of sodium bicarbonate Esbu is estimated using consumption data Asbu, 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 was 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). Due to the inability to secure competitively priced natural gas in Victoria with prices exceeding AUD$10/GJ, the plant was placed in care & maintenance mode in March 2016.

Methanol production was undertaken by one plant in Australia, which has since suspended operation. 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. (https://vinyl.org.au/about-vinyl/manufacturing-process). Dichloroethylene production does not occur in Australia.

CO_2 emissions from ethylene oxide production are reported in 2.H Food and Drink, where by product CO_2 is used and emitted.

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)

Industrial Processes and Product Use

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.

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.

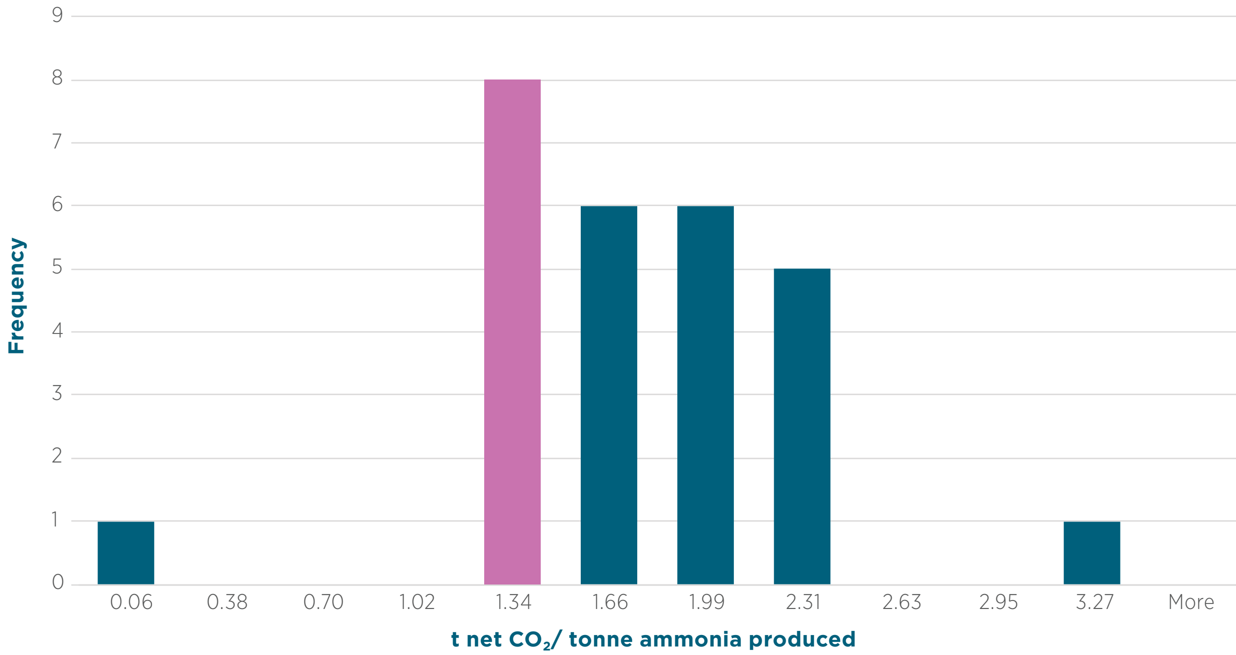
4.4.10 Source specific QA/QC

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 (2018 Inventory) and Australia (2019 Inventory)



Note: In the figure above, Australia's IEF is located within the marked range.

The IEF for ammonia production for Australia ranges between 1.060 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.

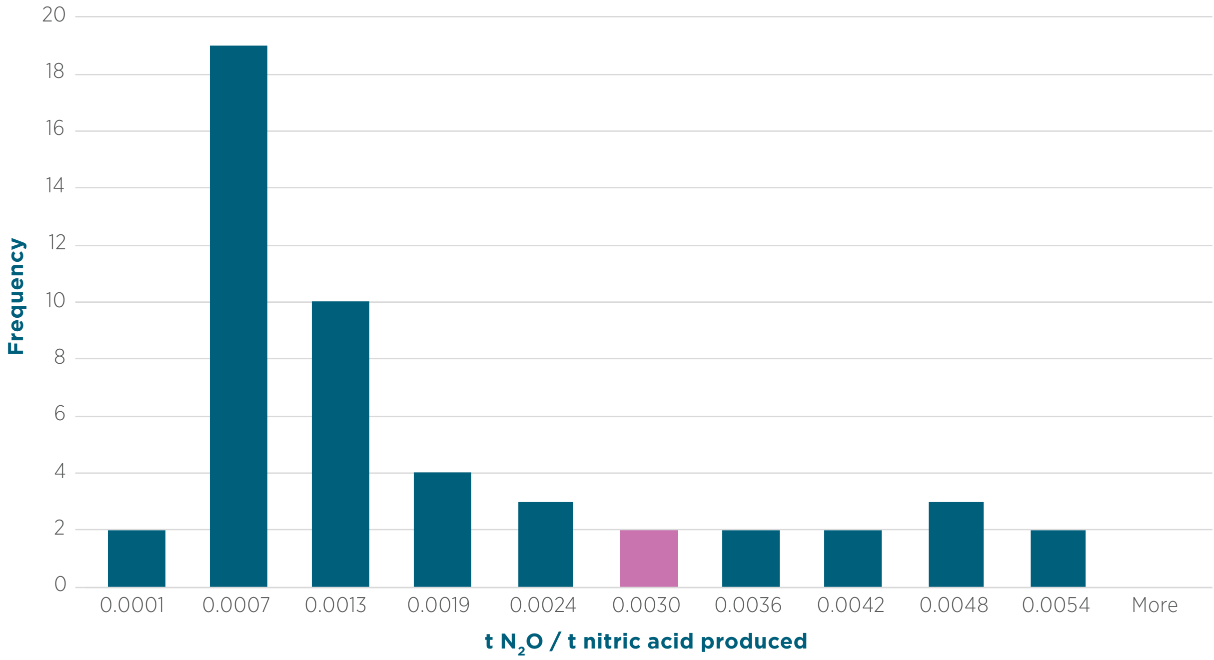
In general, Australia's IEF is generally lower than the default values listed in the *2006 IPCC Guidelines* of 1.666– 3.273 t CO_2/t ammonia. The *2006 IPCC Guidelines* lists a range of default "total fuel requirements" (including natural gas consumed for energy purposes as well as chemical feedstock) by production process ranging between 29.7 GJ fuel/t NH_3 and 42.5 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 21.04 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 (2018 Inventory) and Australia (2019 Inventory)



Note: In the figure above, Australia's IEF is located within the marked range.

The IEF for nitric acid production for Australia ranges between 0.002 t N_2O per tonne of nitric acid produced and 0.01 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 trialling 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 2018 Inventory

A revision to natural gas consumption in the production of ammonia occurred in the 2014 inventory year, resulting in the recalculations presented in Table 4.16.

Minor revisions to N_2O use due to revised population statistics from 2016 - 2017.

Corrected production data to one facility in Australia for Ammonia Production was made for 2014.

Revisions to Petrochemicals and Carbon Black were made due to the inclusion of new CO_2 estimates for Methanol Production.

Table 4.16 2.B Chemicals: recalculation of total CO_2-e emissions (Gg), 1990–2018

Year	2020 Submission Gg CO_2-e	2021 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
2.B Chemicals				
1990	3,485	3,485	-	0%
2000	3,445	3,492	47	1.4%
2001	4,053	4,100	47	1.2%
2002	4,216	4,263	47	1.1%
2003	4,851	4,898	47	1.0%
2004	5,002	5,049	47	0.9%
2005	5,355	5,402	47	0.9%
2006	6,033	6,080	47	0.8%
2007	6,723	6,770	47	0.7%
2008	6,518	6,566	48	0.7%
2009	6,153	6,202	48	0.8%
2010	6,690	6,739	48	0.7%
2011	6,057	6,105	48	0.8%
2012	5,606	5,654	48	0.9%
2013	4,576	4,625	48	1.1%
2014	4,522	4,541	18	0.4%
2015	4,730	4,779	48	1.0%
2016	4,493	4,529	35	0.8%
2017	4,607	4,603	-4	-0.1%
2018	5,098	5,100	2	0.03%

4.4.12 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.

For Petrochemical and carbon black production (2.B.8) Australia was not able to identify a CO_2 EF unique to the technology type previously used in Australia, and does not have feedstock consumption data available to support a mass balance equation. As an alternative, it was identified the CH_4 IEF for Methanol production in the USA is similar to Australia (2.3 vs 2.0 for Australia) – as this implies a comparable production technology in used, Australia has can derive CO_2 emissions using the USA CO_2 IEF of 670 kg/t. This will be included in the next submission.

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, 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. Carbonate 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. An assessment of NGERS energy data confirms there is currently no consumption of blast furnace gas by any facilities external to the iron and steel facilities. Accordingly, no re-allocation of CO_2 emissions associated with that activity to the Energy sector is required. This is kept under review for changes in practice.

There are two major producers of iron and steel in Australia; Liberty 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.* In addition to the production of iron and steel from integrated iron and steel facilities, there are also three iron and steel producing facilities where electric arc furnaces are in operation.

Emissions associated with the consumption of fuels as reductants or anode ingredients are also estimated under *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 2 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:

$2C \text{ (coke)} + O_2 \rightarrow 2CO$

$C + H_2O \rightarrow CO + H_2$

$FeyOz + zCO \rightarrow yFe + zCO_2$

$FeyOz + zH_2 \rightarrow yFe + zH_2O$

$CaCO_3 \text{ (limestone)} \rightarrow CaO + CO_2$

$CaCO_3.MgCO_3 \text{ (dolomite)} \rightarrow CaO.MgO + 2CO_2$

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* (DISER 2020).

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)	109.4 (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

	F: Emission Factors (Mg/PJ)					
Fuel Type	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.

Fugitive emissions of CO_2 from blast furnace gas and other process gases are included in totals reported in the energy sector, with fugitive emissions reported for Iron and Steel production being from the distribution of natural gas (containing trace amounts of CO_2) within facilities.

Activity data

Activity data for coke consumption in the production of iron and steel are obtained from DISER *Australian Energy Statistics* (DISER 2020) 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) [lb)]	Natural Gas consumption (PJ) [1 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 CO_2-e)
1990	6,223	NO	NO	200	44	295	0.4	265	NA	9,811
2000	6,345	558	6	233	97	405	0.5	477	NA	10,651
2001	6,027	1,223	22	215	113	534	0.5	517	NA	9,893
2002	5,933	1,142	23	275	124	572	0.6	561	NA	9,668
2003	6,282	1,670	34	267	129	571	0.7	537	NA	10,844
2004	6,312	1,592	32	247	124	499	0.6	458	NA	11,453
2005	5,977	NO	NO	234	126	464	0.7	486	NA	9,532
2006	6,560	NO	NO	234	115	446	0.7	461	NA	9,721
2007	6,600	NO	NO	191	118	496	0.6	435	NA	10,107
2008	6,597	NO	NO	203	121	507	0.6	444	NA	9,964
2009	5,529	NO	NO	213	111	506	0.8	499	NA	8,075
2010	6,867	NO	NO	189	120	515	0.7	395	NA	9,999
2011	7,333	NO	NO	190	101	499	0.7	485	NA	10,465
2012	5,357	NO	NO	174	123	505	0.8	486	NA	8,289
2013	4,749	NO	NO	159	131	496	1.1	454	NA	7,410
2014	4,446	NO	NO	183	137	492	1.1	500	387	6,975
2015	4,776	NO	NO	169	145	501	1.0	450	413	7,462
2016	4,945	NO	NO	191	142	459	1.3	514	224	7,674
2017	5,198	NO	NO	172	112	466	1.0	448	220	8,257
2018	5,554	NO	NO	154	111	474	0.9	369	221	8,484
2019	5,393	NO	NO	136	114	480	0.9	407	222	8,340

Sources: (a) Resources and Energy Quarterly (DISER 2020). (b) Energreen 2009. (c) South32 Annual Reports.

Industrial Processes and Product Use

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 derived using historical production volumes.

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:

$$2Al_2O_3 + 3C\ 4Al + 3CO_2$$

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 (Na3AlF6) 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), tetrafluromethane (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:

$$Eal = A_i \,.\, ECi.\, EF_i$$

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 Protocol,* 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, 2000–2019

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
2018	1,435	0.017	0.002
2019	1,457	0.016	0.006

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, 2000–2019

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
2018	1,570	2,488
2019	1,576	2,600

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.

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 derived using metal production data from the Department of Industry, Science, Energy and Resources (DISER 2020).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* (DISER 2020). 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 Department of Industry and Science (DIS), it was determined that NGER data were best to use for this particular source.

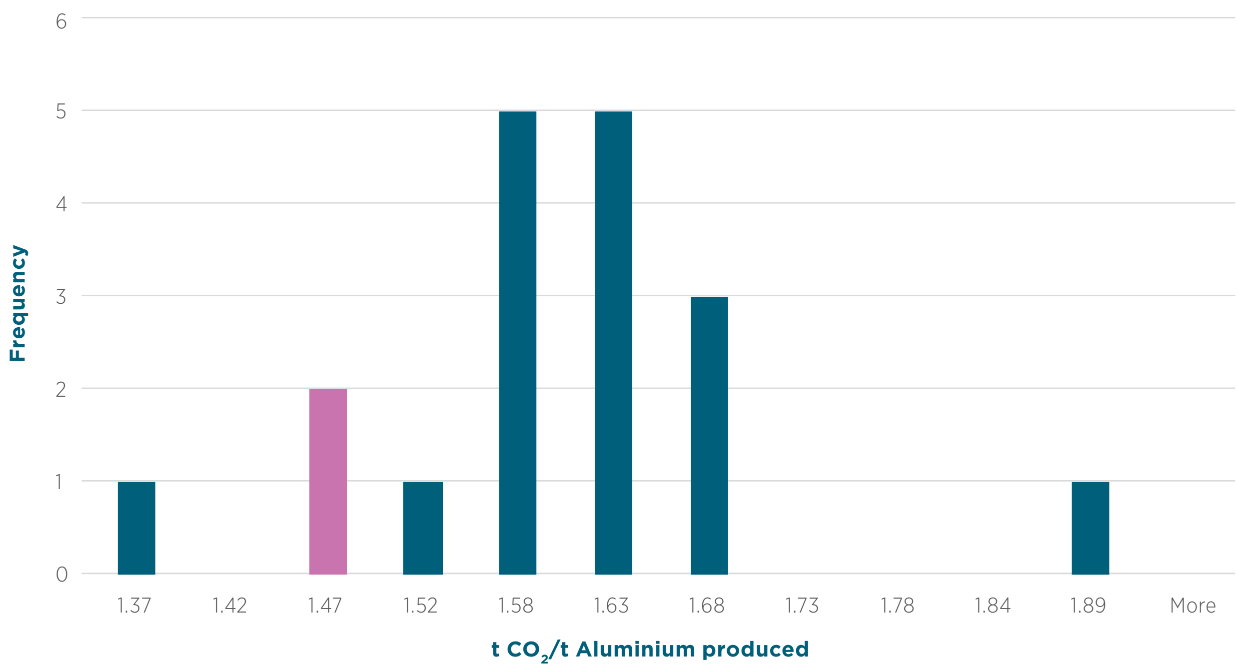
Aluminium

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 (96 per cent), whereas the International Aluminium Institute (2019) reports a decline of 90 per cent between 1990 and 2018 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 (2018 Inventory) and Australia (2019 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 1.40 t CO_2/t aluminium produced and 1.78 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 2018 Inventory

Recalculations for 1990–2008 were made by deriving historical reductant use in Ferroalloys and other metals from production data.

Table 4.23 2.C Metal Industry: recalculation of total CO_2-e emissions (Gg), 1990–2018

Year	2020 Submission Gg CO_2-e	2021 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
2.C Metals				
1990	16,473	16,344	-129	-0.8%
2000	14,753	14,560	-193	-1.3%
2001	14,612	14,454	-158	-1.1%
2002	14,456	14,298	-158	-1.1%
2003	15,620	15,517	-103	-0.7%
2004	16,234	16,171	-63	-0.4%
2005	14,421	14,395	-26	-0.2%
2006	13,492	13,515	23	0.2%
2007	13,885	13,997	112	0.8%
2008	13,588	13,734	146	1.1%
2009	11,566	11,566	-	0%
2010	13,419	13,419	-	0%
2011	13,972	13,972	-	0%
2012	11,774	11,774	-	0%
2013	10,386	10,386	-	0%
2014	9,866	9,866	-	0%
2015	10,104	10,104	-	0%
2016	10,202	10,202	-	0%
2017	10,653	10,653	-	0%
2018	10,976	10,976	-	0%

4.5.9 Planned improvements

All activity 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 171.2 Gg CO_2 and 191.8 Gg NMVOC in 2018 (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 2019

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	180.0			
2.D.2 Paraffin Wax Use	NE			
2.D.3 Solvent Use				111.4
2.D.4 Other				80.4

Emissions from Lubricant Use declined by 35.7 per cent or 0.1 Mt CO_2-e on 1990.

Emissions from *Solvent Use* decreased by 1.8 per cent or 2.0 Gg NMVOC between 1990 and 2019. 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 DISER 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 DISER. 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 DISER 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. AD are currently not available to determine the quantity of lubricants consumed in 2-stroke engines. Accordingly, all emissions from lubricant use are accounted for in the *Industrial Processes* 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* (DISER 2020)

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 2018 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), 1990–2018

	2020 Submission Gg CO_2-e	2021 Submission Gg CO_2-e	Change (Gg CO_2-e)	Change (per cent)
2D Non-Energy Products from Fuels and Solvent Use				
1990	280	280	-	0 %
2000	284	284	-	0 %
2001	294	294	-	0 %
2002	299	299	-	0 %
2003	308	308	-	0 %
2004	334	334	-	0 %
2005	254	254	-	0 %
2006	244	244	-	0 %
2007	227	227	-	0 %
2008	235	235	-	0 %
2009	237	237	-	0 %
2010	247	247	-	0 %
2011	232	232	-	0 %
2012	188	188	-	0 %
2013	185	185	-	0 %
2014	181	181	-	0 %
2015	175	175	-	0 %
2016	173	173	-	0 %
2017	184	184	-	0 %
2018	171	171	-	0 %

4.6.4 Planned improvements

All activity data, methodologies and EFs are kept under review. Particular focus will be on the investigation of AD to enable the re-allocation of emission from lubricant use in 2-stroke engines to the *Energy* sector.

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 and solvents.

The methodology used for compiling emissions estimates for this source category relates emissions to the stock and vintage of hydrofluorocarbon (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 local production of HFCs in Australia) reported to the Department of Agriculture, Water and the Environment, 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 Agriculture, Water and the Environment 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 (M_{bijkt}) 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) 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, $D_{ijk}t$.

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

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

Mpc_{ijkt} is the quantity of gas i in imports of pre-charged equipment type j for vintage k if k= year t

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

$I_{t-z\ t}$, 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 annual leakage rates (EF_{ijkt}) are based on a mix of IPCC 2006 and country-specific factors adjusted for annual fluctuations in atmospheric observations measured at the CSIRO monitoring station in Cape Grim Tasmania.

Calibration of annual leakage rate with atmospheric observations

Annual loss emission factors for refrigeration and air conditioning applications from 2006 onwards have been adjusted in line with changes in atmospheric concentrations measured at the Cape Grim monitoring station in Tasmania (CSIRO 2019). 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 an implied leakage rate calculated based on the national estimate developed by CSIRO (averaged over a period of 3 years).

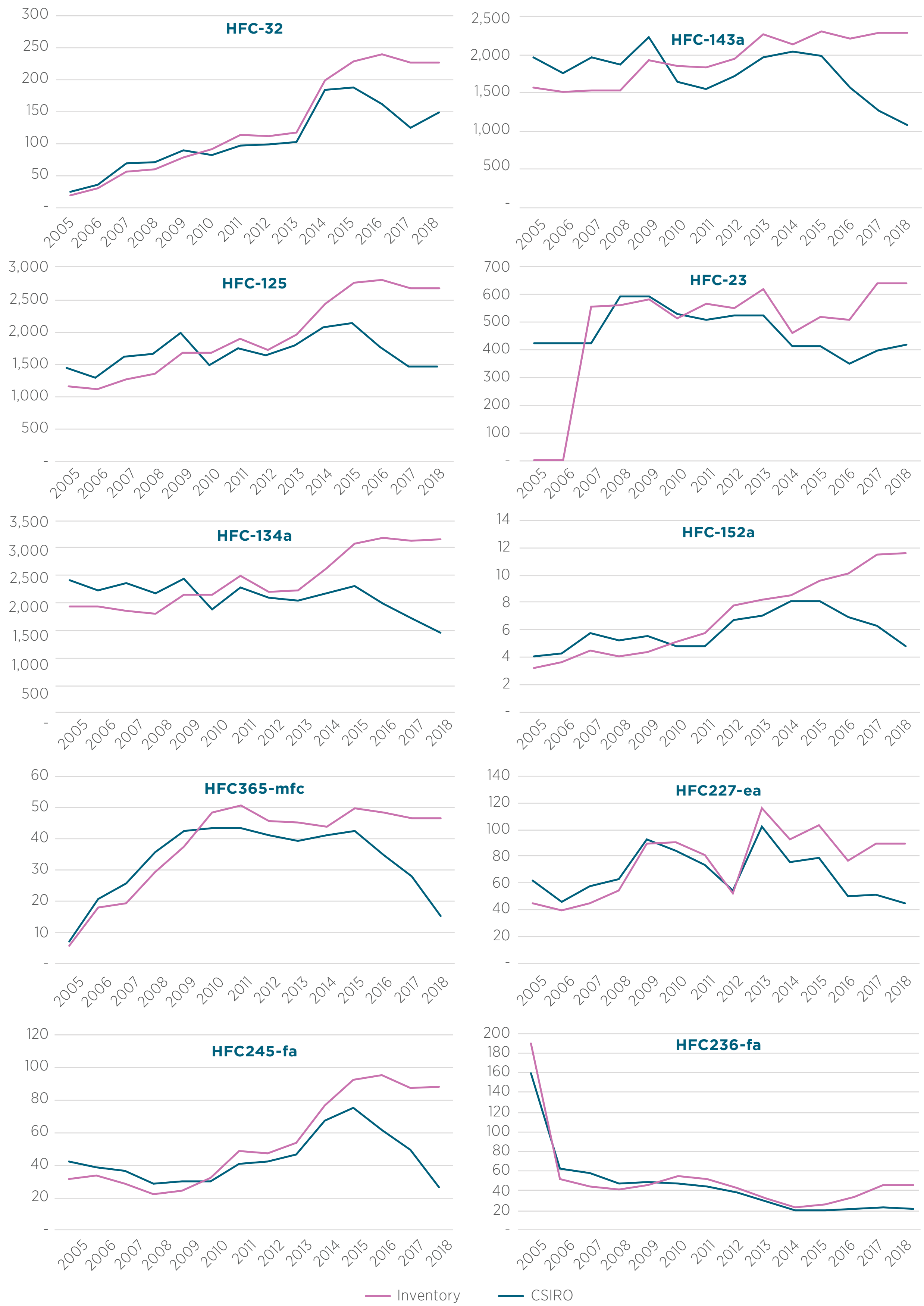
F-gases are considered to be ideal to use inverse modelling techniques to derive national estimates. The 2006 IPCC Guidelines identify fluorinated gases as being among the most suitable for which inverse modelling could provide verification of emissions estimates (p 6.21). As inverse modelling can be 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 do not provide any advice on the direct use of inverse modelled emissions estimates, Australia has opted to use the fluctuations in the implied emission factor given by the CSIRO modelled estimates, divided by an estimate of the national HFC bank, to adjust annual leakage rates. Country-specific leakage rates have been used for the current inventory year based on industry expert assessment commissioned by the Department of Environment and Energy in in 2018 (Expert Group 2018); these leakage rates are then back-calibrated to the start of atmospheric observations in 2006. The strength of this approach is that the trend in atmospheric observations is replicated in the inventory and inventory estimates 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 Volume 1 of the 2006 IPCC Guidelines.

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 DISER speciation from 2005 to 2018.

Figure 4.8 Post-calibration comparison of HFC emissions by species (kt CO_2-e)



Source: DISER 2020

Replenishment and disposal

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 operator of the sole product stewardship scheme for refrigerants in Australia. The total amount of HFC gas recovered for destruction by RRA data is allocated between different end use categories in assumed proportions informed by IPCC default recovery factors.

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 Hydrofluorocarbons: key assumptions concerning average equipment life, initial and annual losses and replenishment rates, by equipment type 2019

End Use Category	Average equipment life (a,b) Years	Loss on initial charge (a) per cent	Annual loss per cent	Replenishment (c)	Emissions Estimation Method
Commercial refrigeration					
Stand-alone commercial applications	12.5	1.75	7.2 (d)(e)	Full replenishment every 2 years	Method 3
Medium and large commercial applications	11	1.75	11.8 (d)(e)	Full replenishment every 2 years	Method 3
Industrial commercial applications	22.5	1.75	15.7 (d)(e)	Full replenishment every 2 years	Method 3
Domestic refrigeration	15	0.6	1.7 (d)(e)	No replenishment	Method 2
Transport refrigeration	7.5	5.1	15.7 (d)(e)	Full replenishment every 2 years	Method 3
Light vehicle air conditioning	12	0.4	6.7 (d)(e)	Full replenishment at 6 years	Method 1
Heavy vehicle air conditioning	12.5	0.4	10.8 (d)(e)	Full replenishment every 2 years	Method 3
Domestic stationary air conditioning					
Refrigerated portable air conditioners	15	0.6	2.5 (d)(e)	No replenishment	Method 2
Split system air conditioners	15	0.6	3.5 (d)(e)	No replenishment	Method 2
Packaged air conditioners	15	0.6	2.5 (d)(e)	No replenishment	Method 2
Commercial air conditioners	22.5	5.1	4.5 (d)(e)	Full replenishment every 2 years	Method 3
Foams (open and closed cell)	20	60.0	2.3 (a)	No replenishment	Method 4
Aerosols	2	0.0	50.0 (a)	No replenishment	Method 4
Fire	10	0.4	5.0 (a)	Full replenishment every 2 years	Method 4
Metered Dose Inhalers	2	0.0	50.0 (a)	No replenishment	Method 3

Source: (a) IPCC 2006. (b) Burnbank 2002. (c) DISER. (d) Expert Group 2018 (e) Annual leakage rates for refrigeration and air conditioning are back-calibrated using Cape Grim atmospheric observations- see atmospheric calibration discussion above.

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:

$$G_{demmv} = G_{dpmv} + G_{drmv}$$

$$G_{dpmv} = (New_{mv} - Imp_{mv}) \times Chg_{mv}$$

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_{dpmv} 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 = Imppcedrac x 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 DAWE

The amount of bulk gas estimated to be used in filling of newly manufactured products in method 3 and 4 may vary substantially between years, as it depends on the quantity of bulk imports remaining after demand for filling method 1 and 2 products and replenishments across all product categories is satisfied

Activity data: HFC gas imported into Australia

Data on imports of HFC gases are reported to DAWE 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 below.

Table 4.28 End-use allocation of imports of bulk and pre-charged HFC gas 2019 (Mt CO_2-e)

End Use Breakdown	Bulk Imports (Mt CO_2-e)	Pre-charged imports (Mt CO_2-e)	Total (Mt CO_2-e)
Refrigeration	**8.17**	**0.33**	**8.50**
Transport refrigeration	0.60	0.13	0.73
Commercial refrigeration	7.57	0.19	7.75
Domestic refrigeration and freezers	-	0.02	0.02
Stationary air-conditioning	**0.35**	**4.05**	**4.39**
Chillers	0.34	0.86	1.21
Refrigerated portable	-	0.10	0.10
Split systems	-	2.93	2.93
Packaged systems	0.01	0.16	0.16
Mobile air-conditioning	**0.72**	**0.79**	**1.51**
Cars	0.28	0.71	0.99
Trucks	0.44	0.08	0.52
Foam	0.17	-	0.17
Aerosols/solvents	0.20	0.23	0.43
Fire equipment	0.19	0.00	0.19
Metered dose inhalers	**-**	**0.13**	**0.13**
TOTAL	**9.79**	**5.54**	**15.33**

Source: DISER.

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 imports

Gas imported in pre-charged equipment is disaggregated into the following equipment types:

- Commercial or domestic use heat pumps
- Commercial use air-conditioning
- Commercial use refrigeration
- Components and parts for use in ODS equipment or SGG equipment
- Consumer goods
- Domestic use air-conditioning
- Domestic use refrigeration
- Electrical switchgear
- Expanding polyurethane foam aerosols
- Fixed fire systems and components
- Food, household and personal use aerosols
- Industrial, safety or technical use aerosols
- Motor vehicle, watercraft or aircraft air-conditioning
- Motor vehicle, watercraft or aircraft refrigeration
- Novelty use and other aerosols
- Other
- Scientific or electrical equipment

The pre-charged equipment data are also disaggregated by the refrigerant they contain. The following substances were reported in 2019 pre-charged imports:

- HFC-125
- HFC-134A
- HFC-143A
- HFC-152A
- HFC-227EA
- HFC-23
- HFC-236FA
- HFC-245CA
- HFC-245FA
- HFC-32
- HFC-404A
- HFC-407A

- HFC-407C
- HFC-407D
- HFC-407F
- HFC-410A
- HFC-413A
- HFC-417A
- HFC-425A
- HFC-43-10MEE
- HFC-449A
- HFC-450A
- HFC-451A
- HFC-452A
- HFC-453A
- HFC-454A
- HFC-507A
- HFC-508A
- HFC-508B
- HFC-513A
- HFC-515A

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 HF gas in operating equipment (Mt CO_2-e)

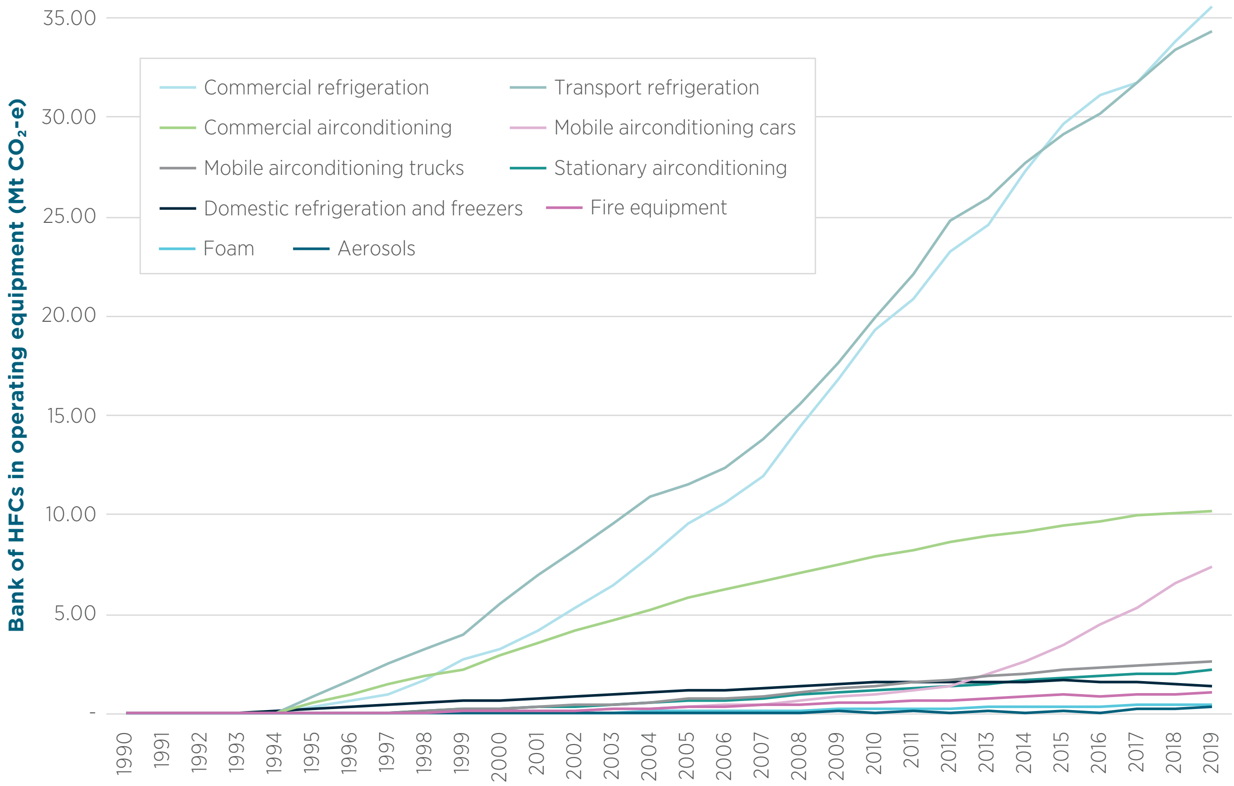


Table 4.29 Halocarbons: estimated stock and emissions: all equipment types

Year	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1990	-	-
1991	-	-
1992	-	-
1993	-	-
1994	0.11	0.00
1995	2.05	0.16
1996	3.82	0.39
1997	5.63	0.66
1998	7.86	0.93
1999	10.32	1.40
2000	13.34	1.65
2001	16.52	2.30
2002	19.97	2.76
2003	23.43	3.53
2004	27.16	4.05
2005	30.55	4.97
2006	33.05	4.76
2007	36.77	5.44

Year	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
2008	42.22	5.47
2009	47.80	6.63
2010	53.60	6.52
2011	58.28	7.15
2012	64.09	6.74
2013	67.89	7.46
2014	73.57	8.12
2015	79.06	9.17
2016	82.85	9.22
2017	86.48	9.25
2018	91.82	9.27
2019	95.91	10.44

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*. Stock estimates in recent years are based on Expert Group projections and reflect a transition to the use of hydrocarbon refrigerants in place of HFCs.

Average charges per unit for domestic refrigerators are based on the pre-charged equipment data collected under the *Act* and were 0.157 kg in 2019. Service life emissions are derived using Expert Group 2018 leakage rates calibrated to observed atmospheric concentration fluctuations observed at the Cape Grim monitoring station.

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[15].

The number of newly manufactured products filled with HFC gas is inferred as the balance of opening and closing stock numbers, imports/exports and retirements. The estimated amount of gas filled may vary substantially between years; where the above balance is negative, this amount is assumed to be zero.

It is assumed that no replenishment of gas losses from domestic refrigerators takes place as the units contain small well-sealed charges of gas.

15 http://www.fisherpaykel.com/global/investors/Investors-DFs/Annualpercent20Reports/Annualpercent20Reviewpercent20Yearpercent20Endedpercent2031percent20Marchpercent202010.pdf

Unit disposals are based on an average lifetime of 15 years with the first units in each vintage retiring after 5 years (Burnbank 2002). Approximately 30% of potential emissions from disposal were estimated to have been recovered for destruction in 2019.

Table 4.30 shows the capital stocks, HFC stock and emissions from domestic refrigeration.

Table 4.30 Halocarbons: estimated stock/ and emissions: domestic refrigerator/freezers

Year	Domestic refrigerator stock using HFCs [(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	0.01
1996	8,774,688	0.32	0.01
1997	8,970,905	0.42	0.01
1998	9,167,123	0.53	0.02
1999	9,363,340	0.62	0.02
2000	9,538,827	0.71	0.03
2001	9,714,313	0.79	0.02
2002	9,937,512	0.87	0.04
2003	10,226,951	0.97	0.04
2004	10,518,356	1.06	0.05
2005	10,811,949	1.15	0.05
2006	11,045,172	1.19	0.05
2007	11,514,381	1.30	0.06
2008	11,850,689	1.40	0.06
2009	12,182,534	1.49	0.07
2010	12,283,818	1.55	0.07
2011	12,322,307	1.59	0.07
2012	12,372,914	1.62	0.07
2013	12,423,522	1.64	0.06
2014	12,474,129	1.64	0.08
2015	12,474,129	1.66	0.08
2016	11,850,423	1.60	0.08
2017	11,151,546	1.56	0.08
2018	10,410,801	1.49	0.07
2019	9,625,030	1.43	0.07

Source: (a) ABS 2008b; ABS 2014; Expert Group projections

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.

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. Approximately 20% of potential emissions from disposal were estimated to have been recovered for destruction in 2019.

Table 4.31 Halocarbons: estimated stock and emissions: split system stationary air-conditioners

Year	Split system air conditioner stock (a)	Stock of gas (Mt CO_2-e)	Emissions (Mt CO_2-e)
1995	664,300	0.34	0.01
1996	709,650	0.65	0.04
1997	755,000	0.94	0.06
1998	800,350	1.22	0.08
1999	845,700	1.47	0.10
2000	1,146,548	2.87	0.17
2001	1,447,395	4.17	0.27
2002	1,748,243	5.38	0.38
2003	2,075,944	6.62	0.48
2004	2,403,645	7.78	0.58
2005	2,731,346	8.59	0.65
2006	3,062,064	9.54	0.69
2007	3,549,559	10.86	0.77
2008	3,723,500	12.54	0.83
2009	4,106,477	14.19	0.95
2010	4,437,195	16.27	1.00
2011	4,767,913	18.30	1.08
2012	5,098,631	20.77	1.12
2013	5,429,349	21.85	1.21
2014	5,760,067	23.44	1.39
2015	6,090,785	24.74	1.48
2016	6,713,882	25.87	1.61
2017	7,257,270	27.41	1.61
2018	7,715,016	29.07	1.72
2019	8,085,303	30.03	1.82

Source: (a) ABS 2008b; Expert Group projections.

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	1.07	0.05
1997	1,704,215	1.57	0.07
1998	1,764,251	2.06	0.10
1999	1,823,714	2.51	0.12
2000	1,807,716	2.63	0.14
2001	1,791,754	2.72	0.14
2002	1,775,404	2.81	0.18
2003	1,767,740	2.91	0.20
2004	1,759,693	3.01	0.22
2005	1,746,587	2.86	0.23
2006	1,703,566	2.73	0.20
2007	1,660,699	2.73	0.21
2008	1,618,530	2.77	0.20
2009	1,674,441	3.07	0.21
2010	1,730,352	3.19	0.21
2011	1,786,263	3.25	0.20
2012	1,842,174	3.34	0.19
2013	1,898,085	3.43	0.18
2014	1,953,995	3.51	0.20
2015	2,009,906	3.56	0.21
2016	2,009,906	3.48	0.22
2017	2,009,906	3.43	0.21
2018	2,009,906	3.39	0.20
2019	2,009,906	3.32	0.21

Source: (a) ABS 2008b.

Table 4.33 Halocarbons: estimated stock and emissions: refrigerated portable air conditioners

Year	Refrigerated portable system stock [a]	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
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	0.28	0.01
2009	270,000	0.38	0.02
2010	358,200	0.52	0.02
2011	446,400	0.62	0.03
2012	446,400	0.66	0.03
2013	446,400	0.71	0.03
2014	446,400	0.79	0.04
2015	446,400	0.84	0.04
2016	446,400	0.89	0.05
2017	446,400	0.95	0.05
2018	446,400	1.00	0.05
2019	446,400	1.04	0.06

Source: (a) ABS 2008.

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 2019) have been used to construct a capital stock model. The stock of light vehicles, the stock of HFC gas contained in motor vehicle air-conditioners and the associated emissions are reported below. 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	0.04
1996	10,106,055	1.01	0.13
1997	10,249,706	1.44	0.21
1998	10,438,519	1.94	0.26
1999	10,735,002	2.25	0.32
2000	11,103,805	2.99	0.28
2001	11,441,871	3.58	0.54
2002	11,722,502	4.13	0.55
2003	12,017,165	4.75	0.63
2004	12,329,726	5.25	0.71
2005	12,701,059	5.84	0.80
2006	13,168,195	6.28	0.79
2007	13,453,049	6.68	0.79
2008	13,803,497	7.13	0.76
2009	14,121,275	7.49	0.80
2010	14,563,421	7.91	0.76
2011	14,828,578	8.27	0.74
2012	15,194,051	8.69	0.71
2013	15,596,290	9.00	0.71
2014	15,947,248	9.21	0.79
2015	16,248,000	9.45	0.80
2016	16,589,084	9.67	0.83
2017	16,937,865	9.95	0.76
2018	17,251,336	10.12	0.75
2019	17,541,397	10.23	0.77

Source: (a) ABS 2019a; Includes stocks not containing HFC refrigerants.

The stock of gas has been compiled using the ABS data on light vehicle stocks, import data on number of units imported and average charge, and assumptions about proportions of each vintage with air-conditioning for early years in the time series. Assumptions needed on the percentage of pre-1995 vehicles retrofitted with HFC-134a units to estimate an addition to the stock of gas were taken from Burnbank 2002.

The number of newly manufactured vehicles filled with HFC gas is estimated as the balance of increases in vehicle stocks, less the the number of vehicles imported in that year. When the number of imported vehicles exceeds the increase in new vehicle stocks, it is assumed that no domestic filling of gas into newly manufactured vehicles occurs.

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.

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. Approximately 20% of potential emissions from disposal were estimated to have been recovered for destruction in 2019.

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	0.02	0.02	0.00
1996	0.03	0.04	0.01
1997	0.04	0.07	0.01
1998	0.07	0.12	0.02
1999	0.11	0.20	0.04
2000	0.10	0.25	0.05
2001	0.14	0.32	0.06
2002	0.17	0.41	0.08
2003	0.20	0.50	0.11
2004	0.24	0.61	0.13
2005	0.29	0.73	0.16
2006	0.23	0.79	0.16
2007	0.30	0.91	0.18
2008	0.37	1.09	0.18
2009	0.39	1.25	0.22
2010	0.40	1.42	0.22
2011	0.39	1.56	0.25
2012	0.41	1.73	0.23
2013	0.41	1.86	0.26
2014	0.47	2.03	0.29
2015	0.52	2.21	0.32
2016	0.44	2.32	0.33
2017	0.43	2.40	0.33
2018	0.49	2.54	0.33
2019	0.52	2.68	0.36

Source: DISER/ DAWE – 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. Approximately 30% of potential emissions from disposal were estimated to have been recovered for destruction in 2019.

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	0.03	0.02	0.01
1996	0.04	0.05	0.01
1997	0.05	0.07	0.02
1998	0.09	0.13	0.04
1999	0.15	0.21	0.07
2000	0.12	0.25	0.08
2001	0.17	0.30	0.10
2002	0.22	0.39	0.12
2003	0.23	0.45	0.17
2004	0.30	0.54	0.19
2005	0.36	0.65	0.24
2006	0.30	0.70	0.22
2007	0.35	0.77	0.27
2008	0.45	0.94	0.26
2009	0.48	1.06	0.33
2010	0.49	1.20	0.32
2011	0.47	1.29	0.36
2012	0.48	1.41	0.33
2013	0.51	1.49	0.37
2014	0.61	1.66	0.42
2015	0.68	1.82	0.48
2016	0.59	1.91	0.47
2017	0.60	1.99	0.48
2018	0.55	2.03	0.46
2019	0.73	2.17	0.53

Source: DISER/ DAWE – 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. Approximately 30% of potential emissions from disposal were estimated to have been recovered for destruction in 2019.

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	0.37	0.32	0.06
1996	0.43	0.62	0.13
1997	0.61	0.99	0.24
1998	1.06	1.68	0.37
1999	1.71	2.75	0.64
2000	1.34	3.29	0.80
2001	1.93	4.14	1.05
2002	2.51	5.37	1.26
2003	2.79	6.43	1.71
2004	3.52	7.97	1.95
2005	4.19	9.52	2.55
2006	3.54	10.57	2.39
2007	4.32	11.98	2.83
2008	5.40	14.48	2.81
2009	6.04	16.83	3.57
2010	6.11	19.35	3.45
2011	5.70	20.92	3.94
2012	6.08	23.23	3.61
2013	5.81	24.55	4.16
2014	7.28	27.28	4.40
2015	7.86	29.71	5.14
2016	6.65	31.14	5.04
2017	5.97	31.75	5.08
2018	7.35	33.81	4.92
2019	7.75	35.56	5.64

Source: DISER/ DAWE – 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. Approximately 20% of potential emissions from disposal were estimated to have been recovered for destruction in 2019.

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	0.01	0.01	0.00
1996	0.01	0.02	0.00
1997	0.02	0.03	0.00
1998	0.03	0.06	0.00
1999	0.04	0.09	0.01
2000	0.04	0.11	0.01
2001	0.05	0.15	0.01
2002	0.06	0.19	0.02
2003	0.07	0.24	0.02
2004	0.08	0.29	0.03
2005	0.12	0.37	0.03
2006	0.08	0.42	0.04
2007	0.11	0.48	0.04
2008	0.22	0.66	0.05
2009	0.28	0.88	0.06
2010	0.21	1.01	0.07
2011	0.23	1.17	0.07
2012	0.29	1.38	0.08
2013	0.70	1.98	0.10
2014	0.78	2.61	0.14
2015	1.01	3.44	0.18
2016	1.26	4.47	0.22
2017	1.06	5.28	0.25
2018	1.63	6.61	0.30
2019	1.21	7.44	0.36

Source: DISER/ DAWE – 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. 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. 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	0.01	0.00	0.01
1996	0.01	0.01	0.01
1997	0.02	0.01	0.01
1998	0.02	0.02	0.01
1999	0.04	0.04	0.03
2000	0.01	0.04	0.01
2001	0.04	0.06	0.03
2002	0.03	0.07	0.02
2003	0.06	0.09	0.04
2004	0.04	0.11	0.03
2005	0.09	0.14	0.06
2006	0.02	0.14	0.02
2007	0.09	0.17	0.06
2008	0.06	0.19	0.05
2009	0.13	0.23	0.09
2010	0.06	0.25	0.05
2011	0.12	0.28	0.08
2012	0.05	0.29	0.04
2013	0.12	0.33	0.08
2014	0.08	0.34	0.06
2015	0.17	0.39	0.12
2016	0.03	0.39	0.03
2017	0.11	0.41	0.08
2018	0.05	0.42	0.05
2019	0.17	0.46	0.12

Source: DISER/ DAWE – 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. 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.

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	0.01	0.01	0.00
1996	0.01	0.02	0.00
1997	0.02	0.04	0.00
1998	0.03	0.06	0.00
1999	0.05	0.10	0.00
2000	0.02	0.11	0.01
2001	0.05	0.15	- 0.01
2002	0.04	0.18	0.01
2003	0.06	0.23	0.01
2004	0.06	0.26	0.01
2005	0.10	0.34	0.01
2006	0.04	0.35	0.01
2007	0.10	0.41	0.02
2008	0.09	0.46	0.02
2009	0.15	0.56	0.03
2010	0.10	0.60	0.03
2011	0.13	0.68	0.03
2012	0.10	0.71	0.04
2013	0.14	0.78	0.03
2014	0.13	0.82	0.06
2015	0.20	0.93	0.05
2016	0.09	0.92	0.07
2017	0.13	0.95	0.07
2018	0.11	0.96	0.06
2019	0.19	1.04	0.07

Source: DISER/ DAWE – 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 (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. 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.

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 the Department of Sustainability, Environment, Water, Population and Communities (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.

Emissions from MDIs are estimated according to the same assumptions used for aerosols and solvents.

The growth in imports and the bank of HFC in metered dose inhalers along with the associated emissions from this bank is shown below.

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	0.16	0.13
2007	0.17	0.18	0.15
2008	0.19	0.20	0.17
2009	0.21	0.23	0.19
2010	0.21	0.24	0.20
2011	0.21	0.24	0.21
2012	0.15	0.19	0.20
2013	0.14	0.16	0.17

Year	Imports of gas ($Mt\ CO_2$-e)	Stock of gas in operating equipment ($Mt\ CO_2$-e)	Emissions ($Mt\ CO_2$-e)
2014	0.13	0.15	0.14
2015	0.12	0.14	0.13
2016	0.12	0.14	0.13
2017	0.13	0.14	0.12
2018	0.13	0.14	0.13
2019	0.13	0.15	0.13

Source: DISER 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	0.03	0.02	0.02
1999	0.05	0.04	0.03
2000	0.02	0.02	0.04
2001	0.05	0.04	0.03
2002	0.04	0.04	0.04
2003	0.07	0.06	0.05
2004	0.05	0.05	0.06
2005	0.10	0.09	0.07
2006	0.02	0.03	0.07
2007	0.10	0.08	0.06
2008	0.07	0.08	0.08
2009	0.16	0.13	0.10
2010	0.07	0.08	0.12
2011	0.14	0.11	0.10
2012	0.06	0.07	0.10
2013	0.14	0.11	0.09
2014	0.09	0.09	0.11
2015	0.20	0.17	0.13
2016	0.03	0.06	0.14
2017	0.33	0.25	0.14
2018	0.23	0.24	0.25
2019	0.43	0.37	0.30

Source: DISER Estimates.

4.8.3 Source specific QA/QC

Data are obtained by DAWE 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 were 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 were 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 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 4.43.

Checks are undertaken to ensure that the sum of bulk gas demand for domestic production and replenishment of leaked gas equals total bulk imports. Table 4.45 shows this gas balance check.

Table 4.43 Halocarbons: balance sheet – allocations of imported gas (Mt CO_2-e)

	Backcast import data											Import data reported by DAWE														
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**	**2018**	**2019**
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	7.59	8.84	9.79
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	6.64	5.54
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**	**15.49**	**15.33**
Allocations to end use																										
Transport refrigeration	-	0.03	0.04	0.05	0.09	0.15	0.12	0.17	0.22	0.23	0.30	0.36	0.30	0.35	0.45	0.48	0.49	0.47	0.48	0.51	0.61	0.68	0.59	0.60	0.55	0.73
Commercial refrigeration	-	0.37	0.43	0.61	1.06	1.71	1.34	1.93	2.51	2.79	3.52	4.19	3.54	4.32	5.40	6.04	6.11	5.70	6.08	5.81	7.28	7.86	6.65	5.97	7.35	7.75
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	0.02	0.02
Chillers	-	0.01	0.01	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.08	0.12	0.08	0.11	0.22	0.28	0.21	0.23	0.29	0.70	0.78	1.01	1.26	1.06	1.63	1.21
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	0.12	0.10
Split systems	-	0.35	0.35	0.35	0.36	0.36	1.57	1.59	1.60	1.74	1.75	1.48	1.68	2.11	2.55	2.66	3.14	3.17	3.67	2.41	3.04	2.89	2.82	3.26	3.55	2.93
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	0.19	0.16
Cars	-	0.61	0.58	0.64	0.76	0.63	1.03	1.03	1.10	1.25	1.22	1.36	1.19	1.23	1.25	1.21	1.27	1.13	1.19	1.12	1.05	1.14	1.12	1.13	1.05	0.99
Trucks	-	0.02	0.03	0.04	0.07	0.11	0.10	0.14	0.17	0.20	0.24	0.29	0.23	0.30	0.37	0.39	0.40	0.39	0.41	0.41	0.47	0.52	0.44	0.43	0.49	0.52
Foam	-	0.01	0.01	0.02	0.02	0.04	0.01	0.04	0.03	0.06	0.04	0.09	0.02	0.09	0.06	0.13	0.06	0.12	0.05	0.12	0.08	0.17	0.03	0.11	0.05	0.17
Aerosols/ Solvents	-	0.01	0.01	0.02	0.04	0.08	0.06	0.11	0.12	0.16	0.16	0.23	0.17	0.27	0.26	0.37	0.28	0.35	0.21	0.28	0.22	0.32	0.15	0.45	0.36	0.56
Fire equipment	-	0.01	0.01	0.02	0.03	0.05	0.02	0.05	0.04	0.06	0.06	0.10	0.04	0.10	0.09	0.15	0.10	0.13	0.10	0.14	0.13	0.20	0.09	0.13	0.11	0.19
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**	**15.49**	**15.33**
Balance against total gas imported	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.44 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	2018	2019
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**	**15.49**	**15.33**
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	6.64	5.54
Bulk gas used in production & retrofit	0.07	1.93	1.80	2.05	2.37	2.93	2.67	3.55	3.18	4.17	3.53	4.75	2.44	3.68	2.66	5.56	2.50	4.33	2.01	4.48	2.96	6.53	0.97	4.03	1.83	6.13
Bulk gas used in replenishment	-	-	0.16	0.13	0.41	0.46	1.32	1.06	2.03	1.65	2.89	2.28	3.87	2.33	4.44	2.72	5.34	2.94	5.51	3.04	6.05	3.58	7.06	3.56	7.01	3.66
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**	**15.49**	**15.33**
Emissions	0.00	0.16	0.39	0.66	0.93	1.40	1.65	2.30	2.76	3.53	4.05	4.97	4.76	5.44	5.47	6.63	6.52	7.15	6.74	7.46	8.12	9.17	9.22	9.25	9.27	10.45
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	0.24	0.32	0.39	0.40	0.41	0.73	0.36	0.65	0.45	0.61	0.87	0.81
Stock change	0.11	1.94	1.78	1.80	2.24	2.46	3.02	3.18	3.45	3.46	3.73	3.39	2.50	3.72	5.45	5.58	5.80	4.67	5.82	3.80	5.68	5.49	3.79	3.63	5.35	4.08
Balance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.45 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	2018	2019
Total bulk imports	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	7.59	8.84	9.79
Bulk gas demand for production	0.07	1.93	1.80	2.05	2.37	2.93	2.67	3.55	3.18	4.17	3.53	4.75	2.44	3.68	2.66	5.56	2.50	4.33	2.01	4.48	2.96	6.53	0.97	4.03	1.83	6.13
Bulk gas demand for replenishment	-	-	0.16	0.13	0.41	0.46	1.32	1.06	2.03	1.65	2.89	2.28	3.87	2.33	4.44	2.72	5.34	2.94	5.51	3.04	6.05	3.58	7.06	3.56	7.01	3.66
Bulk gas in stocks																										
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 4.46 Halocarbons: results of sensitivity testing of allocation assumptions (Mt CO_2-e)

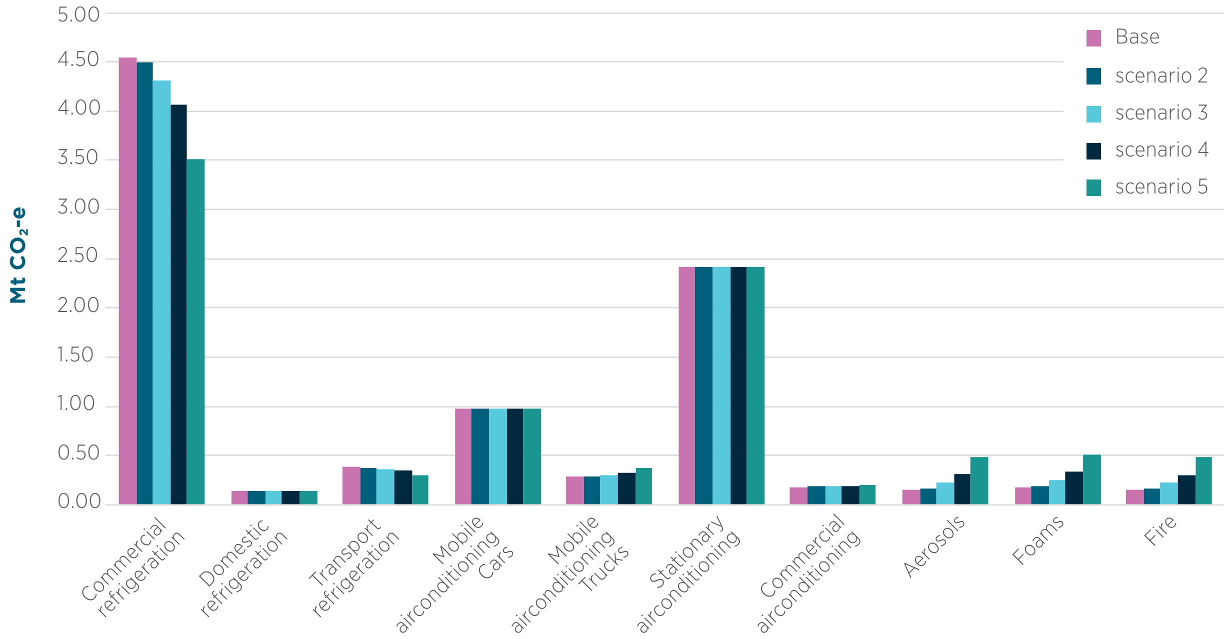
	Allocation assumptions (per cent of total bulk imports)				
End use allocation	**Base**	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Aerosols/solvents	2 per cent	2 per cent	3 per cent	4 per cent	5 per cent
Domestic/Commercial/ Transport refrigeration	60 per cent	59 per cent	55 per cent	50 per cent	40 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 4.10 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.

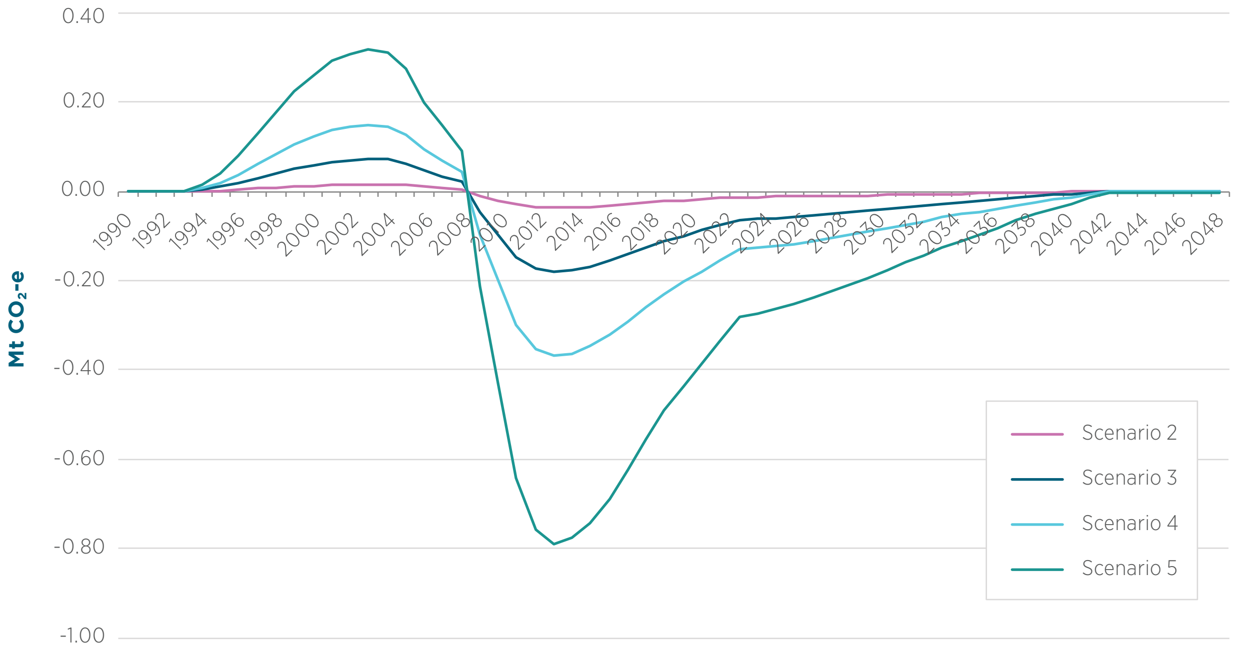
Under scenario 5 (a 33 per cent re-allocation from domestic, commercial and transport refrigeration), approximately 1 million tonnes is re-directed in equal proportions towards aerosols, foam and fire protection. This results in a reduction in emissions of 0.79 million tonnes CO_2-e in domestic, commercial 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 4.10 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 4.11. 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 4.11 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 the 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.

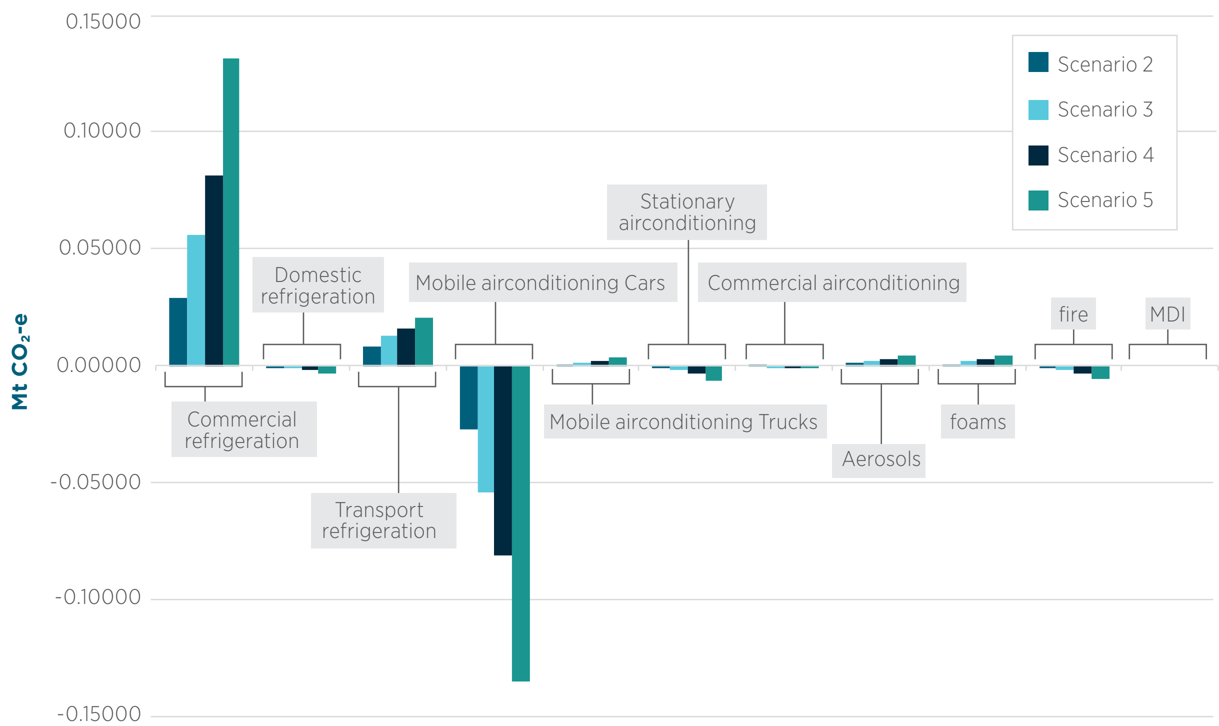
As with bulk gas allocation, the total emissions estimate was found to be insensitive to changes in assumed replenishment rates with a 50 per cent reduction in replenishment resulting in only a 0.25 per cent change in total emissions in 2008. The effects of changes to the replenishment assumptions on 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 4.12 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 4.47 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
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 4.12 Halocarbons: results of sensitivity testing of replenishment assumptions – change in emissions 2008 (Mt CO_2-e)



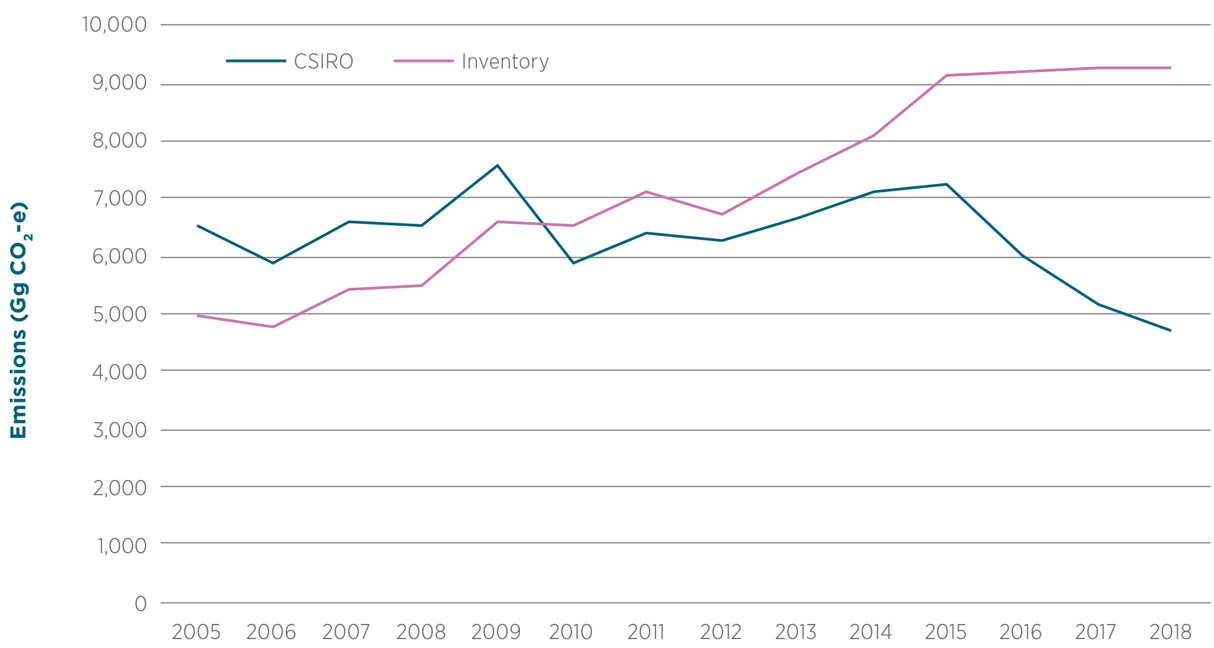
External verification through atmospheric testing

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.

Recalculations made in this inventory (see *Recalculations* below below) have improved agreement between the CSIRO and inventory estimates with an average difference of approximately 16% from 2005 to 2015. Further work will be conducted to investigate reasons for the fall in the CSIRO estimate in recent years; agreement may further be improved by planned upcoming inventory improvements (see *Planned improvements* below).

Figure 4.13 shows the comparisons of estimates based on Cape Grim measurements with inventory estimates for the time-series up to 2018.

Figure 4.13 Comparison of Inventory HFC emission estimates with estimates derived from Cape Grim measurement data



4.8.4 Recalculations

The following recalculations have occurred since the last inventory submission:

- Annual leakage rates and atmospheric calibration

  Estimates of HFC emissions in previous submissions applied base leakage rates based on consideration of IPCC 2006 guidelines and Expert Group 2013, and calibrated those base rates for years 2006 onwards in proportion with fluctuations in the 3-year average of estimates from CSIRO atmospheric observations.

  In this inventory submission, two changes were made to this methodology:

  - First, revised base leakage rates for refrigeration and air conditioning were adopted based on latest available country-specific expert assessment (Expert Group 2018). CSIRO emission estimates were then used to calibrate backwards through the time series to 2005

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- Second, indexing leak rates according to a 3-year average of CSIRO estimates failed to take into account growth in the national bank of HFCs. Indexing in this inventory submission was therefore done in proportion with an implied atmospheric national emission factor given by the CSIRO 3-year average emissions estimate, *divided by* an estimate of the national HFC bank.

CSIRO's estimates this year were also themselves revised based on latest modelling.

- Revisions were made to HFC destruction data based on revised inputs provided by Refrigerant Reclaim Australia
- A revision was made to retirement parameters for split system air conditioning systems to align with default lifetime guidance provided by the 2006 IPCC guidelines.

Table 4.48 2.F Product Uses as Substitutes for Ozone Depleting Substances: recalculation of total CO_2-e emissions (Gg), 1990–2018

	2020 Submission Gg CO_2-e	2021 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
1990	-	-	-	-
1991	-	-	-	-
1992	-	-	-	-
1993	-	-	-	-
1994	1	2	2	305.2%
1995	95	158	63	66.9%
1996	414	393	-22	-5.2%
1997	705	662	-44	-6.2%
1998	998	928	-70	-7.0%
1999	1,375	1,397	22	1.6%
2000	1,614	1,648	34	2.1%
2001	2,307	2,297	-10	-0.5%
2002	2,926	2,764	-162	-5.5%
2003	3,579	3,531	-48	-1.3%
2004	4,267	4,050	-217	-5.1%
2005	5,003	4,969	-34	-0.7%
2006	5,167	4,757	-410	-7.9%
2007	6,066	5,438	-628	-10.4%
2008	6,859	5,473	-1,386	-20.2%
2009	8,109	6,626	-1,483	-18.3%
2010	8,672	6,516	-2,156	-24.9%
2011	9,140	7,150	-1,990	-21.8%
2012	9,056	6,740	-2,315	-25.6%
2013	9,860	7,464	-2,396	-24.3%
2014	10,779	8,118	-2,661	-24.7%
2015	11,795	9,167	-2,629	-22.3%
2016	11,979	9,219	-2,761	-23.0%
2017	11,686	9,251	-2,435	-20.8%
2018	11,982	9,273	-2,709	-22.6%

4.8.5 Planned improvements

Updates in this inventory to annual leakage rates, the atmospheric calibration method and retirement profile for split system air conditioning units have increased the agreement between the inventory bottom-up estimate of HFC emissions and the top-down atmospheric estimate from CSIRO.

Further work will be undertaken in upcoming inventory cycles to improve inventory estimates by:

- Better assessing the extent of refrigerant stockpiling and recycling within the Australian economy;
- Reviewing equipment retirement profiles for different classes of equipment.

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 was 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 SF_6 concentrations measured at the CSIRO Cape Grim monitoring station.

For the 2009 reporting year amendments were made to the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*, which requires utilities and other entities to estimate their emissions from their own data using mass-balance and 'top-up' approaches.

Under these approaches, surveyed entities 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.

In 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 was 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) was 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 NGERS 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, annual loss rates of SF_6 from 2010 onwards are adjusted in line with changes in atmospheric concentrations measured at the Cape Grim monitoring station in Tasmania (CSIRO 2019). CSIRO uses inverse modelling techniques to derive an estimate of national SF_6 emissions based on atmospheric measurements of SF_6 concentrations. The base annual leakage factor is indexed to the changes in a national implied emission factor given by the CSIRO national estimate divided by the national stock of SF_6.

SF_6 is 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 allows the trend in atmospheric observations to be replicated in the inventory. 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.

Annual leakage rates applied for each inventory year from 2010 onwards are shown below. 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.

Table 4.49 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	24	0.0075
2011	23	0.0066
2012	22	0.0062
2013	22	0.0056
2014	18	0.0054
2015	20	0.0049
2016	18	0.0048
2017	20	0.0042
2018	15	0.0040
2019 (a)	15	0.0040

Source: CSIRO 2019.

(a) 2019 values not yet available – have been held constant on 2018 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 Scheme.

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 was obtained from data published by Transgrid, the major network in the largest State of New South Wales, in the Transgrid, Network Management Plan 2011 (February 2011). The characteristics of Trangrid's operations were considered likely to be similar to those of other large utilities in Australia and mainly reflect the operation of high voltage transmission lines.

Figure 4.14 Illustration of Transgrid's network

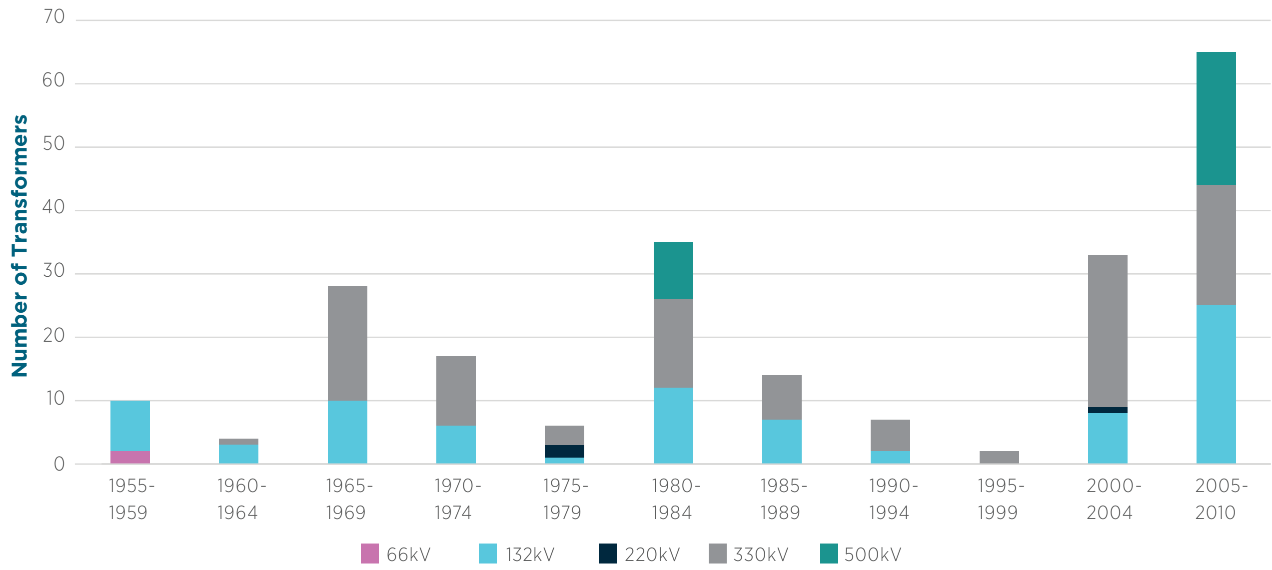
Source: Transgrid Network Management Plan 2011–2016.

Confirmation of the general age profile of Transgrid's circuit breaker assets was 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 identified 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 was expected to increase to around 1 per cent of stock by 2019.

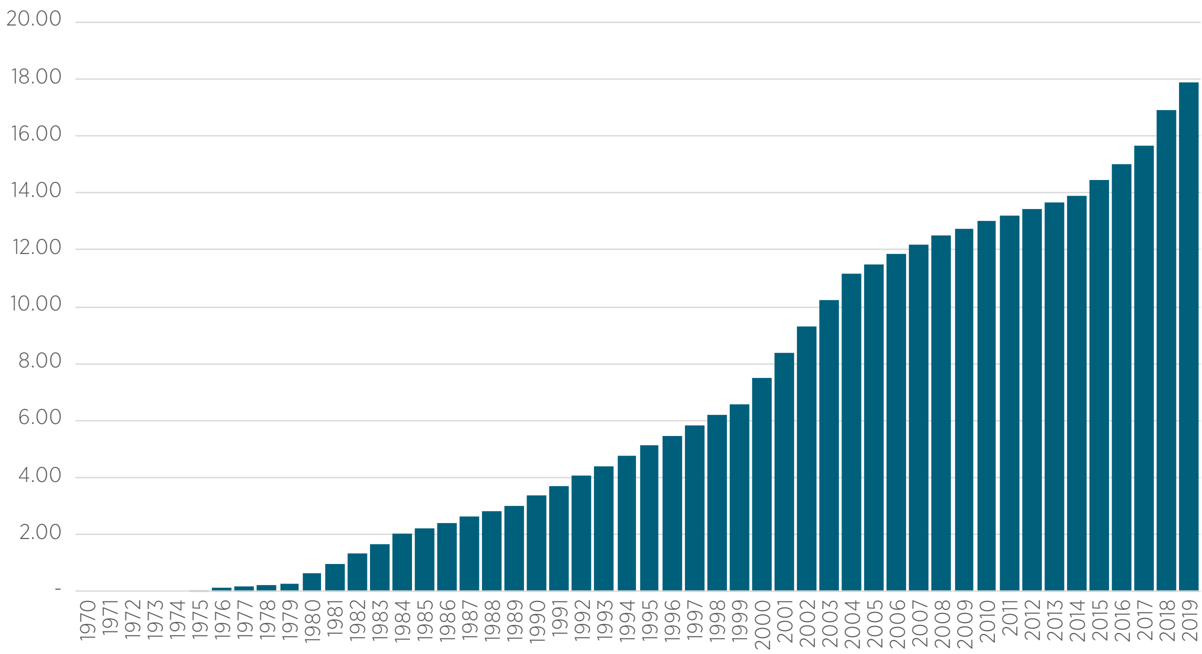
Figure 4.15 Age profile of Transgrid's circuit breaker assets, by type of equipment



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 was expected to be 40 years old.

Figure 4.16 Estimated stock of SF_6 in Australia 1970–2019 (Mt CO_2-e)



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Estimation of emissions of SF_6 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 NGERS 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 527,762 tonnes of SF_6 in CO_2-e filled in new electrical equipment in 2019.

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 reported 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 527,762 tonnes of SF_6 in CO_2-e filled into new equipment results in emissions of 44,860 tonnes of CO_2-e in 2016.

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 1972–2019

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 of New South Wales (*Transgrid, Network Management Plan 2011,* February 2011). Information was 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 were 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 1972–2019

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 2019;
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:

a. application of the IPCC GPG global default factor for 1990–1995 of 15 per cent (IPCC GPG 3.58);

b. 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 1972–2019

The stock of SF_6 and SF_6 emissions between 1972 and 2019 are presented below.

Table 4.50 Stocks and emissions of SF_6: Australia: 1972–2019

	Stock of SF_6 in electrical equipment				Manufacturing of electrical equipment			Total
Year	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	-	-	-	0.1500				
1973	-	-	-	0.1500				
1974	-	-	-	0.1500				
1975	57,675	-	0.0500	2,884	30,279	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
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

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
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	0.0075	98,055	169,465	0.0850	14,404	112,459
2011	13,223,778	2.1	0.0066	87,362	154,888	0.0850	13,166	100,528
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	14,989,553	3.7	0.0048	72,501	300,496	0.0850	25,542	98,044
2017	15,643,090	4.4	0.0042	65,419	359,478	0.0850	30,556	95,974
2018	16,921,439	8.2	0.0040	68,337	673,343	0.0850	57,234	125,571
2019	17,904,656	5.8	0.0040	72,308	527,762	0.0850	44,860	117,167

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 0.0008 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 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 newer 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.

4.9.2.2 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.

Table 4.51 2006 IPCC Guidelines default factors for Europe and Japan:

	Default Tonnes of SF_6 emissions per tonne (nameplate)	Uncertainty per cent	Range (higher) Tonnes of SF_6 emissions per tonne (nameplate)	Range (lower) 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 base 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.

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.

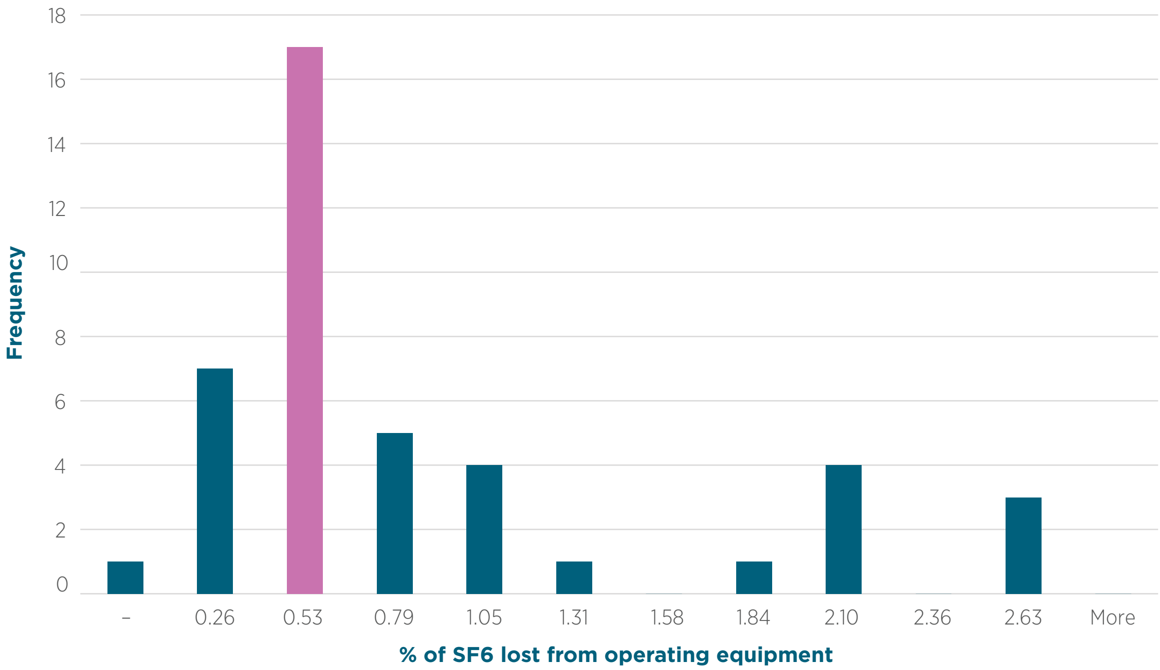
Consequently, Australia's assessment is that the country specific base EF, 0.0089 tonnes of SF_6 emission per tonne of SF_6 stock, is consistent with the information presented by the IPCC.

2) Comparison of the country specific emission factor with the factors of similar countries.

The estimated country specific EF for Australia was compared with factors applied in other Annex-1 parties. Australia's EF is consistent with the factors used in most Annex I parties. Sixteen other countries shared a factor in the range 0.26–0.53 reported in the histogram plot and 18 other parties had higher EFs in the group. Only 8 parties had EFs below Australia's country specific factor.

Consequently, Australia's national EF was considered to be consistent with those applied by other countries.

Figure 4.17 Histogram of reported product life emission factors (per cent) by Annex I parties (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.

4.9.3 Recalculations since the 2019 Inventory

Recalculations have occurred from 2010 onwards as a result of revised atmospheric calibrations:

- Previous submissions calibrated annual leakage rates from electrical equipment in proportion with the changes in the 3-year average of CSIRO estimates of national SF_6 emissions based on atmospheric observations. As for atmospheric calibration of HFC emission estimates, indexing leak rates in this way failed to take into account growth in the national bank of SF_6. Calibration in this inventory submission was therefore done in proportion with an implied atmospheric national emission factor given by the CSIRO 3-year average SF_6 emissions estimate, *divided by* the national SF_6 bank.

The impact of these recalculations is shown below.

Table 4.52 2.F Consumption of halocarbons and SF_6: recalculation of total CO_2-e emissions (Gg), 1990–2018

	2020 Submission Gg CO_2-e	2021 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
2010	143	130	-13	-9.1%
2011	141	118	-23	-16.1%
2012	148	115	-33	-22.0%
2013	142	108	-34	-23.7%
2014	155	106	-50	-31.9%
2015	171	116	-55	-32.0%
2016	186	117	-69	-37.1%
2017	190	115	-75	-39.3%
2018	229	145	-83	-36.4%

4.9.4 Planned improvements

Areas of further refinement include:

- Consultation with CSIRO and other industry experts to better understand the specific causes for fluctuations in atmospheric observations.

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 2018 Inventory

No recalculations were undertaken in the Other sector in this submission as shown in Table 4.53.

Table 4.53 2.D Food and Drink: recalculation of total CO_2-e emissions (Gg), 1990–2018

Year	2020 Submission Gg CO_2-e	2021 Submission Gg CO_2-e	Change Gg CO_2-e	Change per cent
2.D Other Production				
1990	83	83	-	0%
2000	145	145	-	0%
2001	147	147	-	0%
2002	150	150	-	0%
2003	152	152	-	0%
2004	165	165	-	0%
2005	167	167	-	0%
2006	160	160	-	0%
2007	148	148	-	0%
2008	163	163	-	0%
2009	161	161	-	0%
2010	231	231	-	0%
2011	262	262	-	0%
2012	218	218	-	0%
2013	240	240	-	0%
2014	202	202	-	0%
2015	216	216	-	0%
2016	273	273	-	0%
2017	213	213	-	0%
2018	219	219	-	0%

4.10.5 Planned improvements

Activity data and EFs will be kept under review.

5. Agriculture

5.1 Overview

Agriculture produced an estimated 69.8 Mt CO_2-e emissions or 12.8 per cent of net national emissions (excluding *LULUCF)* in 2019 (Table 5.1).

Enteric fermentation was the main source of *Agriculture* emissions, contributing 69.1 per cent (48.2 Mt CO_2-e) of the sector's emissions. The next largest source was *agricultural soils* (17.5 per cent), followed by *manure management* (9.2 per cent). *Liming* and *urea application* contribute 3.8 per cent of the sector's emissions with *rice cultivation* and *field burning of agricultural residues* contributing the remainder (0.3 per cent).

Table 5.1 Agriculture sector CO_2-e emissions, 2019, 2020

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)				
	CO_2	CH_4	N_2O	Total 2019 CO_2-e	Preliminary 2020 estimates CO_2-e
3. Agriculture	**2,665**	**54,179**	**12,908**	**69,753**	**66,247**
A. Enteric fermentation	NA	48,209	NA	48,209	46,011
B. Manure management	NA	5,802	631	6,433	6,298
C. Rice cultivation	NA	32	NA	32	23
D. Agricultural soils	NA	NA	12,210	12,210	11,039
E. Prescribed burning of savannas	NA	IE	IE	IE	IE
F. Field burning of agricultural residues	NA	136	68	204	212
G. Liming	1,318	NA	NA	1,318	1,318
H. Urea application	1,347	NA	NA	1,347	1,347

Trends

Emissions from *Agriculture* decreased by 17.8 per cent (15.1 Mt CO_2-e) between 1990 and 2019 and decreased by 7.2 per cent (5.4 Mt CO_2-e) between 2018 and 2019 (Figure 5.1).

Preliminary estimates of *Agriculture* sector emissions for 2020 are 66.3 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 2022.

Enteric fermentation emissions are driven by livestock population numbers, in particular, pasture-raised beef cattle. Between 1990 and 2019 enteric fermentation emissions declined by 25.4 per cent (16.4 Mt CO_2-e). The decline in emissions in the early 1990s was principally driven by a steep fall in sheep numbers due, in large part, to the collapse of the wool reserve price scheme. The changes in flock and herd numbers reflect changing relative returns to the beef and sheep meat/wool industry and climatic conditions such as drought.

Between 2018 and 2019, emissions from *enteric fermentation* decreased by 6.7 per cent (3.5 Mt CO_2-e). Drought conditions in recent years have resulted in a decline in Australian livestock numbers. The national beef cattle herd peaked in 2013 at 25.7 million, although the declines in the number of pasture-raised cattle (22.6 million in 2019) have been somewhat offset by the upward trend in the number of cattle finished in feedlots. Dry conditions also impacted the sheep industry, with sheep numbers in 2019 (69 million) approaching the 2010 low of 68.1 million.

Figure 5.1 CO_2-e emissions from agriculture, 1990–2019 (preliminary 2020)

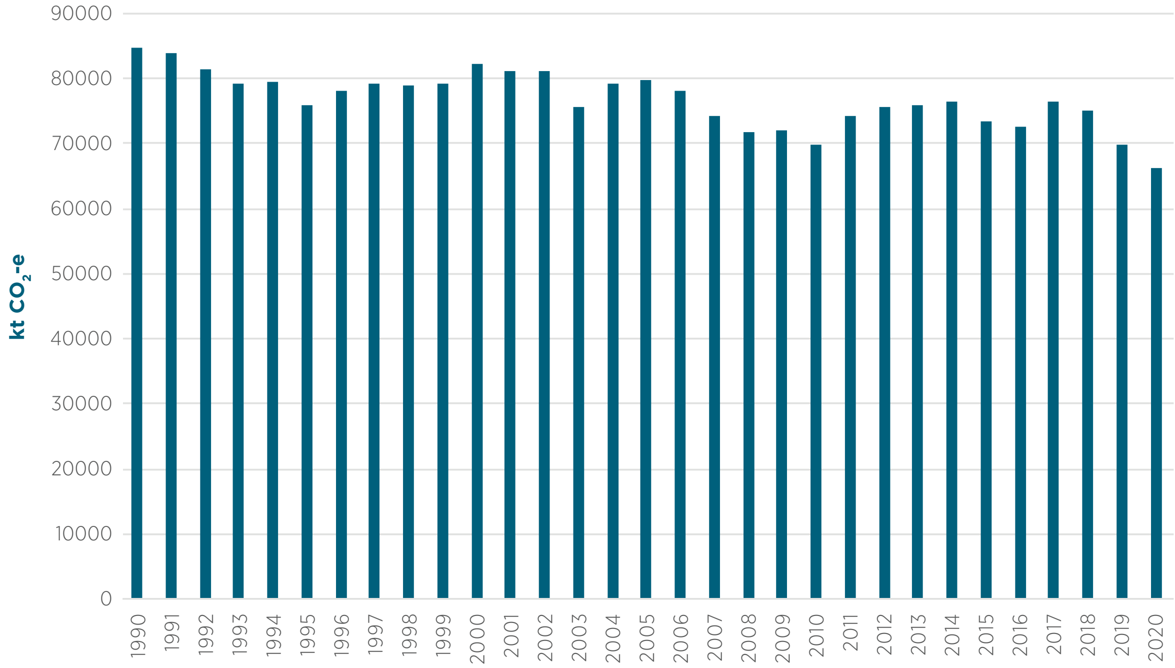
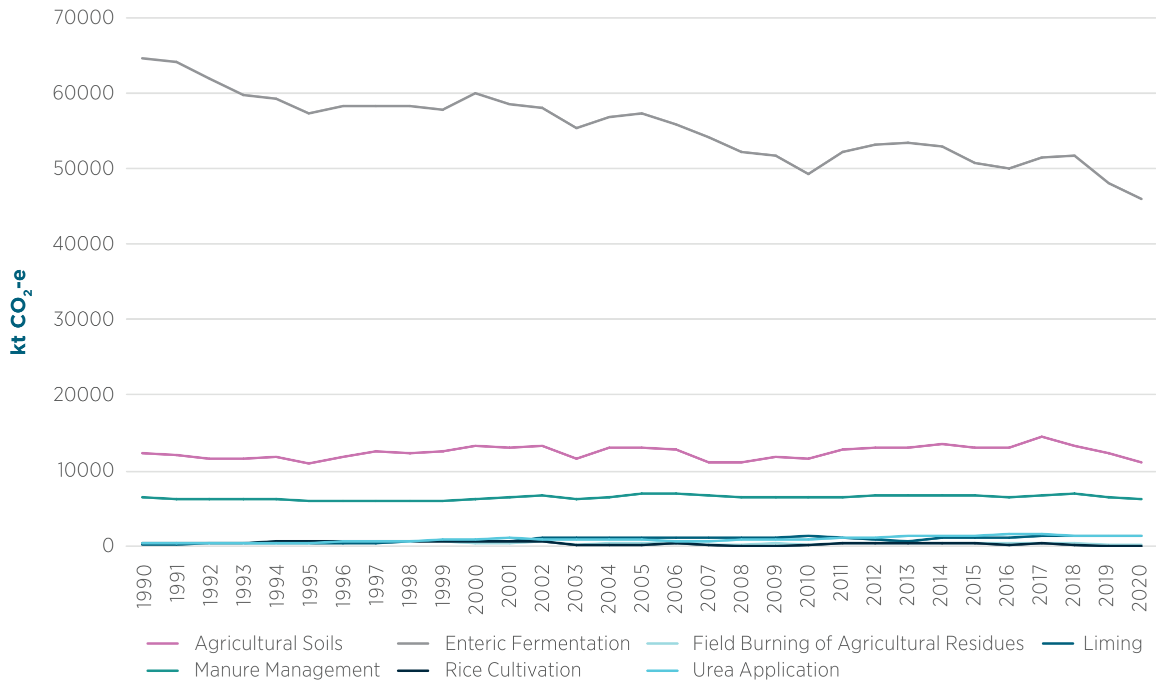


Figure 5.2 CO_2-e emissions from agriculture, by sub-sector, 1990–2019 (preliminary 2020)



Agricultural soils emissions decreased by 1.1 per cent (0.13 Mt CO_2-e) between 1990 and 2019. The long term gradual upward trend is the result of increasing agricultural fertiliser use and increase in retention of crop residues. However, emissions decreased by 8.7 per cent (1.2 Mt CO_2-e) between 2018 and 2019, as recent drought conditions have seen a decrease in crop yields and fertiliser consumption. The trend is similar to the emissions decline between 2001 and 2009 due to drought conditions. The decline is even more marked given the above average to exceptional yields of 2016–17.

Manure management emissions increased by 0.7 per cent (0.04 Mt CO_2-e) between 1990 and 2019 due mainly to growth in the intensive feedlot cattle industry. Emissions in this sector decreased by 6.3 per cent (0.4 Mt CO_2-e) between 2018 and 2019. The decrease in *manure management* emissions during this time is mainly attributable to a decrease in cattle on feed due to prolonged drought conditions across cattle producing areas, resulting in higher feed costs and accelerated destocking rates.

Emissions from *liming* and *urea application* have increased by 1.1 Mt CO_2-e and 0.1 Mt CO_2-e respectively since 1990. Between 2018 and 2019 liming emissions remained unchanged, while urea application emissions decreased by 0.01 Mt CO_2-e.

Emissions from *rice cultivation* in 2019 were 93.4 per cent (0.4 Mt CO_2-e) lower than in 1990 and 87.6 per cent (0.2 Mt CO_2-e) lower than in 2018. As rice cultivation in Australia is highly responsive to water availability, the trend in rice area under cultivation, and the resultant emissions, can be highly variable from year to year. The recent drought has seen a steep decline in area under rice production and subsequently yield, due to high water prices and low availability of irrigation water.

From around 2001, 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. 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 the prolonged drought and water policy reform.

Emissions from *field burning of agricultural residues* decreased by 52.6 per cent (0.2 Mt CO_2-e) between 1990 and 2019 and by 37.3 per cent (0.1 Mt CO_2-e) between 2018 and 2019. This decrease is due to a decline in stubble burning practices in Australia as the practice of stubble retention became more widespread. Another contributing factor to decreasing emissions is the decline of sugar cane burning as the industry has shifted to green cane harvesting and use of trash blankets.

5.2 Overview of source category description and methodology – Agriculture

The *Agriculture* sector includes emissions from seven sub-sectors, listed in Table 5.1.

Livestock industries produce CH_4 and N_2O emissions during feed consumption (enteric fermentation (3A)) and from animal waste products (manure management (3B)). In Australia, the principal livestock species are cattle and sheep, with breeds chosen for pasture and paddock management systems and, in many cases, in semi-arid or tropical and sub-tropical climatic conditions. As a consequence, typical animal performance tends to vary significantly from those of other Annex I countries. Intensive livestock industries also play an increasing role in Australia, specifically for dairy and beef cattle, poultry and swine.

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 emissions from the application of lime (3G) and urea (3H) to agricultural soils.

Emissions from burning of tropical forests and tropical and semi-arid grasslands in Northern and Central Australia (previously reported as prescribed burning of savannas prior to the expansion of the scope of *Land Use, Land Use Change and Forestry* under the 2006 IPCC Guidelines) are reported under *Land Use, Land Use Change and Forestry*.

The Australian agriculture methodology consists of both country specific (CS) and IPCC default methodologies and emission factors (EFs) (Table 5.2).

Table 5.2 Summary of methods and EFs: Agriculture (CH_4 and N_2O)

Greenhouse gas source and sink categories		CH_4 Method applied	CH_4 Emission factor	N_2O Method applied	N_2O 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		
3. Swine		CS, T2	CS		
4. Other	a. Poultry [(a)]	NE	NE		
	b. Alpacas, buffalo, deer, goats, horses, camels, mules/asses, ostriches and emus	T1	IPCC		
B	**Manure management**				
1. Cattle	a. Dairy cattle	CS, T2	CS	CS, T2	CS
	b. Beef cattle – pasture	CS, T2	CS	NA	NA
	c. Beef cattle – feedlot	CS, T3	CS	CS, T3	CS
2. Sheep		CS, T2	CS	NA	NA
3. Swine		CS, T3	CS	CS, T3	CS
4. Other	a. Poultry	CS, T3	IPCC, CS	CS, T3	CS
	b. Alpacas, buffalo, deer, goats, horses, camels, mules/asses, ostriches and emus	CS, T2	IPCC, 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, CS
	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	CS
	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	CS
E	**Prescribed burning of savannas**	**IE**	**IE**	**IE**	**IE**
F	**Field burning of agricultural residues**	**CS**	**CS**	**CS**	**CS**
		CO_2			
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, NE = not estimated, NA = not applicable, IE = included elsewhere.

The *Agriculture* inventory is compiled on a State basis with State emissions totals aggregated into the national account. The inventory is compiled in this way to reduce errors associated with averaging input data across areas with large physical, climatic 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 variability 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 tropical to cool, methane conversion factors for manure management systems (MMS) 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 Australian Bureau of Statistics (ABS) (census/survey data collected on 30 June in the relevant year) and data provided by industry associations (Table 5.3). There is limited activity data for the livestock categories horses, camels, buffalo, deer, goat, mules and asses, alpacas, and emus and ostriches. As such, population data is only updated every five years, when more detailed census data is provided to the ABS. Activity data used to estimate emissions are published on the AGEIS (https://ageis.climatechange.gov.au/).

Other primary data used in equations (liveweight, liveweight gain, pasture digestibility, allocation to MMS etc) are based on reviews of published data and expert assessments. Additional data sources are documented in Appendix 5.

Table 5.3 Summary of principal data sources for Agriculture

Agriculture sector	Activity data
3A Enteric fermentation 3B Manure management	**Animal Numbers** ABS Agricultural Commodities 2020a (annual); Australian Lot Feeders Association (ALFA 2020) (quarterly); ABS meat chicken production (2020b) & slaughter statistics (2020c) (annual); Meat & Livestock Australia farm survey data (ABARES 2020c) (annual) **Other Production Statistics** Dairy Australia (annual); ABARES Agricultural Commodities (2020a) (quarterly); Australian Wool Testing Authority (monthly)
3C Rice cultivation	ABS Agricultural Commodities (2020a) (annual)
3D Agricultural soils	
Inorganic fertiliser	Fertilizer Australia (annual); ABS Water use in Australia (2020d)
Sewage sludge	NGER System; DCC (2009)
Crop residues	ABS Agricultural Commodities (2020a) (crops); ABARES Australian crop report (2020b); FullCAM (pasture)
N mineralised due to loss of soil C	FullCAM; Soil C changes from *cropland remaining cropland* (see Section 6.6)
Cultivation of histosols	CSIRO – derived from areas of organosols (https://www.clw.csiro.au/aclep/asc_re_on_line/or/orgasols.htm)
3E Savanna burning	NA – reported under 4A *Forest lands* and 4C *Grasslands*
3F Field burning of agricultural residues	ABS Agricultural Commodities (2020a), sugar industry associations (annual), Hops Products Australia (annual)
3G Liming	ABS Land Management and Farming in Australia survey (2018) (annual)
3H Urea application	Fertilizer Australia (annual)

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 CS information (Table 5.4). The pasture based beef cattle and sheep categories contain a number of expert assessments, with the CS values 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 consultants elicited expert assessments either through round table meetings or through surveys. Assessments were then compiled and agreed revised values circulated to the Expert Advisory Panels for final comment.

The consultants also undertook a number of reality checks on the assessments to ensure that correlated values such as seasonal liveweight, daily liveweight gain, pasture digestibility and crude protein content were internally consistent (White 2002). Expert assessments were 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 documented in Wiedemann *et al.* (2014) and Dairy Technical Working Group (2015).

Comparison with international data

The ABS reports agricultural data to the United Nations Food and Agriculture Organization (FAO) annually. Some divergence occurs between the activity data in the inventory CRF tables and those published by the FAO. The reasons for these differences include:

a) Beef cattle numbers reported in the CRF differ from those reported to the FAO as the CRF tables contain ABS data adjusted for annual equivalent number of animals held in feedlots (this applies to all years). Poultry numbers differ as meat chicken data used in the inventory are annual equivalents derived from slaughter statistics rather than the static populations reported to FAO.

b) Over the time frame of the inventory, the ABS changed the threshold of the Estimated Value of Agricultural Operations (EVAO) used to determine which agricultural operations are included in their census/survey. From 1989 to 1993 ABS used EVAO's of $20–25,000, in comparison to $5000 used from 1994 until 2015. From 2016, the EVAO was revised to $40,000. To ensure time series consistency in the data, a multiplier is applied to adjust animal numbers to reflect the sub-threshold farms of the 1989–1993 and 2016 censuses. This approach has been reviewed by the ABS who deemed it to be appropriate to ensure time-series consistency in activity data.

c) For the 2005–06 census (ABS 2007), 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 swine from 2002 to 2005.

Table 5.4 Documentation of expert judgements

Category	Activity data CH_4 EF for enteric fermentation – cattle	Revisions of methods and data – feedlot cattle, poultry and swine	Methods and EFs used to estimate emissions from inorganic fertiliser	Implementation of a mass flow approach to MMS
Submission year	**2016**	**2015**	**2015**	**2015**
Name(s) of experts involved	Author: Dr Ed Charmley *et al.* Expert Advisory Panel (EAP).	Authors: Wiedemann, SG, Sullivan, T & McGahan, EJ. Expert Advisory Panel.	Authors: I. Scherbak & P. Grace. Expert Advisory Panel.	Authors: Wiedemann, SG, Sullivan, T & McGahan, EJ. 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. EAP: Various backgrounds related to agricultural science.	Authors: Agricultural scientist; greenhouse gas emission research. EAP: 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. EAP: Various backgrounds related to agricultural science.	Authors: Agricultural scientist; greenhouse gas emission research. EAP: Various backgrounds related to agricultural science.
Quantity being judged	Calculation of enteric fermentation emissions from cattle.	Revision of methods and data for feedlot cattle, swine and poultry.	Methods and EFs used to estimate emissions from inorganic fertiliser.	Manure management emissions – implementing a mass flow approach.
Logical basis for judgement	The methods for estimating methane emissions from enteric fermentation in cattle as used in the Australian national inventory were based on older data that was 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 CS methods and EFs that better 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.
Results (activity value, EF etc.)	There is a close relationship between dry matter intake (DMI) and methane (CH_4) production and Charmley recommended using a unified relationship (20.7g CH_4/kg DMI) for dairy and beef cattle.	Several revisions to feedlot cattle, swine and poultry data and methods. For specific data please refer to document 'GHG Prediction methods for feedlots, poultry and swine'.	There is a correlation between the EFs and nitrogen use. EFs in some production systems increased with nitrogen application rates. A two component model was 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 was implemented which estimates the inputs (volatile solids and N) and losses (CH_4, N_2O, NH_3) at each treatment stage. Inputs into the secondary stage take into account losses from the primary stage. This was advocated for based on research in Wiedemann *et al.* (2014).

Category	Activity data CH_4 EF for enteric fermentation – cattle	Revisions of methods and data – feedlot cattle, poultry and swine	Methods and EFs used to estimate emissions from inorganic fertiliser	Implementation of a mass flow approach to MMS
Submission year	**2016**	**2015**	**2015**	**2015**
Results of any external review	Charmley *et al.'s* work was reviewed by the EAP and approved for use in the Australian inventory – see NIR Section 5.2.1. 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 the Australian inventory.	Scherbak and Grace's work was reviewed by the EAP and approved for use in the Australian inventory.	Mass flow approach was reviewed by the EAP and approved for use in the Australian inventory.
Approved by inventory compiler, in submission year	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 by 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 2006 IPCC Guidelines. 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 reported 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) 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 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), who related 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):

$$I_{ij} = (1.185 + 0.00454W_{ij} - 0.0000026W_{ij}^2 + 0.315LWG_{ij})^2 \times MR_{Iij} + MI_{ij} \quad \text{(3A.1a\_1)}$$

Where W_{ij} = liveweight (kg) (Appendix 5.A.1)

LWG_{ij} = liveweight gain (kg/day) (Appendix 5.A.2)

MR_i = increase in metabolic rate when producing milk (SCA 1990) 1.1 for milking and house cows and 1 for all other classes

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The additional intake required for milk production (MI_{ij} kg DM/head/day) is calculated by:

$$MI_{ij} = MP_{ij} \times NE / k_l / q_{m,ij} / 18.4 \quad (3A.1a\_2)$$

Where MP_{ij} = milk production (kg/head/day) from Dairy Australia State[16] 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:

$$M_{ij} = 20.7 \times I_{ij} / 1000 \quad (3A.1a\_3)$$

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:

$$E = \Sigma_i \Sigma_j ((N_{ij=1,2,4} \times M_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times M_{ij=3,5} \times 281) + (N_{ij=3,5} \times MPW_{ij=3,5} \times 84)) \times 10^{-6} \quad (3A.1a\ 4)$$

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 = 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 years	4 = Cows 1–2 years
3 = NSW			5 = Cows > 2 years	5a = Cows 2–3 years
4 = Queensland	4a = High		6 = Steers < 1 year	5b = Cows > 3 years
	4b = High/moderate		7 = Steers > 1 year	6 = Steers < 1 year
	4c = Moderate/low			7a = Steers 1–2 years
	4d = Low			7b = Steers 2–3 years
5 = Tasmania				7c = Steers >3 years
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.

16 Litres of milk is multiplied by 1.03 to convert to kg of milk.

The equation presented by Minson and McDonald (1987) calculates feed intake (I_{ijkln} kg dry matter/head/day) from liveweight and liveweight gain:

$$I_{ijkln} = (1.185 + 0.00454W_{ijkln} - 0.0000026\ W_{ijkln} + 0.315\ LWG_{ijkln})^2 \times MA_{ijkl=5} \quad (3A.1b\_1)$$

Where W_{ijkln} = liveweight (kg) (Appendix 5.B.1)

LWG_{ijkln} = live weight gain (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:

$$M_{ijkl} = 20.7 \times I_{ijkln}/1000 \quad (3A.1b\_3)$$

To calculate 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. As feedlot cattle spend on average between 70–250 days in 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. Emissions from feedlot cattle are calculated in Section 5.3.2.3.

The approach is represented in the following equation:

$$N_{ijkl} = N_{ijk(\ l=1,\ l=2,\ l=3,\ l=6,\ [(l=7)\ -\ \text{total feedlot numbers}]\ )} \quad (3A.1b\_4)$$

Where N_{ijkl} = numbers of non-feedlot beef cattle in each State, region, season and class

$N_{ijk(\ l=1,\ l=2,\ l=3,\ l=6}$ = 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:

$$E = \Sigma_i\Sigma_j\Sigma_k\Sigma_l\Sigma_n\ (91.25 \times N_{ijkln} \times M_{ijkln}) \times 10^{-6} \quad (3A.1b\_5)$$

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

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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 (2019) simplified tier 2 method.

$$I_j = W_j^{\,0.75} [(0.2444 \times NE_{ma,j} - 0.0111 \times NE_{ma,j}^{\,2} - 0.472) / NE_{ma,j}] \qquad (3A.1c\_1)$$

Where W_j = liveweight (kg) (Appendix 5.C.1)

$NE_{ma,j}$ = Dietary net energy concentration (MJ/kg) (Appendix 5.C.2)

The equation developed by Moe and Tyrrell (1979) to predict daily methane yields (Y_j MJ CH_4/head/day) is:

$$Y_j = 3.406 + 0.510SR_j + 1.736H_j + 2.648C_j \qquad (3A.1c\_2)$$

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 feed intake of the animal and the proportion of intake that is soluble residue, hemicellulose and cellulose, for each animal class (Appendix 5.C.2).

The total daily production of methane (M_j kg CH_4/head/day) is thus:

$$M_j = Y_j / F \qquad (3A.1c\_3)$$

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:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_j) \times 10^{-6} \qquad (3A.1c\_4)$$

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 reported 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, growth and grazing over large areas.

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		
8 = Western Australia		

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 expressed as a per cent)

The potential or maximum intake of feed by sheep occurs when feed is abundant and of high quality. However, the actual feed intake of animals is often less than the potential intake. This can be caused by many factors, including through low feed availability. Relative intake is defined as the proportion of potential intake that the animal will consume. The relative intake (RI_{ijk}) related 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 (t/ha) (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

Agriculture

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:

$$MA_{ijk=4} = (LE_{ijk=4} \times FA_{ijk=4}) + ((1-LE_{ijk=4}) \times 1) \quad (3A.2\_4)$$

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):

$$M_{ijk} = I_{ijk} \times 0.0188 + 0.00158 \quad (3A.2\_5)$$

Annual methane production (Gg) of Australian sheep is calculated as:

$$E = \Sigma_i \Sigma_j \Sigma_k (91.25 \times N_{ijk} \times M_{ijk}) \times 10^{-6} \quad (3A.2\_6)$$

Where N_{ijk} = numbers of sheep in each class for each season and State

M_{ijk} = methane production (kg/head/day)

5.3.4 Swine (3.A.3)

Swine are non-ruminant animals, and convert a smaller proportion of feed energy intake into methane than ruminants. Whittemore (1993) suggested the output of methane by a 60 kg swine is about 0.2 MJ/day.

Assuming that on average, a 60 kg swine consumes 1.95 kg DM/day of a diet containing 18.6 MJ GE/kg, the gross energy (GE) intake was 36.3 MJ GE. Thus swine 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 GE (Christensen and Thorbek 1987), 0.6 to 0.8 per cent of GE (Moss 1993) and 0.4 per cent of GE (Kirchgessner *et al.* 1991). A methane conversion of 0.7 per cent of GE intake is used for Australia.

Agriculture

Table 5.9 Symbols used in algorithms for swine

State (i)	Swine 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 swine gives the total daily production of methane (M_{ij} kg CH_4/head/day) as:

$$M_{ij} = I_{ij} \times 18.6 \times 0.007 / F \quad (3A.3\_1)$$

Where I_{ij} = feed 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 swine is calculated as:

$$E = \Sigma_i \Sigma_j (N_{ij} \times M_{ij} \times 365) \times 10^{-6} \quad (3A.3\_2)$$

Where N_{ij} = the number of swine 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. A simplified methodology based on the IPCC (2006) tier 1 method is followed, using aggregated numbers of the various livestock types and an annual methane emissions factor. The annual EFs are mostly based on IPCC 2006 defaults (Table 5.11).

The methane EFs for buffalo and emus/ostriches follow IPCC (2019), which is based on the latest internationally-assessed science. The Asian buffalo factor was adopted as most buffalo in Australia originated from Asia and are found in the Northern Territory, which experiences similar monsoonal climates to parts of Asia. No default value was provided in IPCC (2006) for emus/ostriches, therefore the IPCC (2019) factor is the best available data.

Consistent with decision 24/CP.19 (Annex I.E, para 10), this country-specific approach draws on IPCC 2019 to the extent it is better able to reflect Australia's situation than IPCC 2006. The introduction of the new estimation approaches has improved the accuracy and completeness of Australia's inventory. EFs for other livestock species were not revised in IPCC 2019.

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 = Mules/asses	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:

$$E = \Sigma_i (N_{ij} \times M_j \times 10^{-6}) \quad (3A.4\_1)$$

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 EFs (kg CH_4/head/year)

Livestock type	EF	Source
Buffalo	76	IPCC (2019)
Goats	5	IPCC (2006)
Deer	20	IPCC (2006)
Camels	46	IPCC (2006)
Alpacas	8	IPCC (2006)
Horses	18	IPCC (2006)
Mules/asses	10	IPCC (2006)
Emus/ostriches	5	IPCC (2019)
Poultry	NE	not estimated by IPCC

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 2.

Time series consistency is ensured by using consistent methods and full recalculations in the event of any refinement to methodology. See Section 5.2.1 regarding how changes to data collection methods by the Australian Bureau of Statistics have been addressed to ensure time series consistency of livestock numbers, and reasons for differences in beef cattle and poultry populations with published FAO data.

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.

Changes in the trends of activity data are also monitored in the inventory, to ensure the drivers of change can be explained by factors such as economic or climatic variability. This source category is also covered by the general QA/QC procedures detailed in Chapter 1.

Inverse modelling of cattle and sheep populations were undertaken to ensure consistency with reported populations. These studies showed 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 EFs

As CS tier 2 methods are used to estimate emissions from cattle, sheep and swine, the IEFs have been compared with values in the 2006 IPCC Guidelines and the IPCC 2019 Refinement (Table 5.12). The IEFs for pasture based beef cattle and swine are generally consistent with the IPCC values.

The dairy cattle IEF is similar to the IPCC 2019 value for Oceania (93 kg CH_4/head/year). Differences with IPCC EFs are due to the use of a more detailed age and animal class structure for Australia's dairy and beef cattle herds. The feedlot cattle IEF differs due to CS feed intakes (Section 5.3.7.3).

The lower IEFs for sheep primarily reflect the inclusion of an age structure in the Australian method (Table 5.8), and the use of actual intake as a proportion of potential intake to incorporate the likelihood of low feed quality and/or availability (Section 5.3.3), which impacts upon the methane conversion rate (Section 5.3.7.4).

Table 5.12 Implied EFs – enteric fermentation (kg CH_4/head/year)

Livestock type	Australia	IPCC 2006	IPCC 2019
Dairy cattle	93	90	93
Beef cattle – pasture	51	60	63
Beef cattle – feedlot	67	60	63
Sheep	6.8	8	5 or 9
Swine	1.6	1.5	1 or 1.5

Sources: IPCC 2006 and IPCC 2019. EFs shown are for developed countries and/or Oceania. 2019 EFs for sheep and swine vary due to disaggregation by low or high productivity systems.

5.3.7.3 Feed intake

As Australia uses CS tier 2 methods for estimating feed intakes, these values 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 to 3.16 per cent) as recommended by the IPCC (2006).

Comparison of intakes for beef cattle between Parties is complicated as animals kept under feedlot conditions have not been reported separately from pasture based animals, as is undertaken in the Australian inventory. The average herd intake for pasture based animals is within the range 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)	206–249	231	192–404	311
Non-dairy cattle			112–194	139
Beef cattle – pasture	116–136	124		
Beef cattle – feedlot	200	200		
Sheep	13–20	17	14–51	23

Source: Other Parties herd intake from UNFCCC locator tool

Sheep

The CS method used to estimate intake from Australian sheep produces lower average intakes than those 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 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 generally 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 CS methods for estimating methane emissions, methane conversion rates (Ym) have been compared against IPCC values.

Cattle

The IPCC (2006) indicates that animals fed diets containing 90 per cent concentrates should use Ym 3.0 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. This results in estimated 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.

The conversion rates for dairy and beef cattle on pastures (6.1–6.2 per cent) are also consistent with IPCC (2019) values (Dairy cattle: 5.7–6.5 per cent, beef cattle on pasture: 6.3–7.0 per cent).

Sheep

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 experimental livestock characterisation was used with 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).

The herd average Ym for Australian sheep is 6.2 per cent which is within the range of the IPCC (2019) value (6.7 per cent).

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, swine 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 2018 Inventory

There were no recalculations affecting this subsector in the 2021 submission.

Table 5.14 Enteric fermentation (3A): recalculation of total CO_2-e emissions, 1990–2018

Year	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	64,633	64,633	-	0
2000	59,905	59,905	-	0
2005	57,367	57,367	-	0
2010	49,341	49,341	-	0
2011	52,270	52,270	-	0
2012	53,108	53,108	-	0
2013	53,488	53,488	-	0
2014	52,958	52,958	-	0
2015	50,800	50,800	-	0
2016	49,982	49,982	-	0
2017	51,543	51,543	-	0
2018	51,668	51,668	-	0

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 few years. Areas for improvement are identified through the UNFCCC expert reviews, domestic QA/QC processes 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. *Beef cattle pasture and feedlot methods and parameters* – review methods, parameters and activity data used to estimate enteric fermentation emissions from beef cattle to support Livestock Emission Reduction Roadmap implementation of potential emission reductions associated with feed supplements. These activities are being led by the Australian red meat industry as part of its ambition to be carbon neutral by 2030.

2. *Sheep methods and parameters* – review methods and parameters used to estimate enteric fermentation emissions from sheep, using recent published data such as from the Reducing Emissions from Livestock Research Program.

3. *Feed and animal characteristics* – As these characteristics can change as industry practices change over time, the current values need to be reviewed periodically.

5.4 Source Category 3.B Manure Management

5.4.1 Source category description and methodology

Methane is produced from the decomposition of organic matter remaining in 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 MMS can occur via combined nitrification and denitrification of ammoniacal nitrogen contained in the wastes. The amount released depends on the systems and duration of waste management. Indirect N_2O emissions occur via runoff and leaching, and the atmospheric deposition of N volatilised from the MMS.

As manure from intensive livestock industries may pass through multiple treatment stages, Australia applies a tier 3 mass flow approach to estimating emissions whereby the volatile solid and nitrogen inputs and losses are estimated at each treatment state. Inputs into the secondary treatment stage take into account losses from the primary stage (see Figure 5.3).

Subscripts for the algorithms are the same as used for calculating enteric fermentation (Tables 5.5–5.10) with an additional MMS component (Table 5.15).

Figure 5.3 Mass flow method of estimating manure management emissions – feedlot cattle example

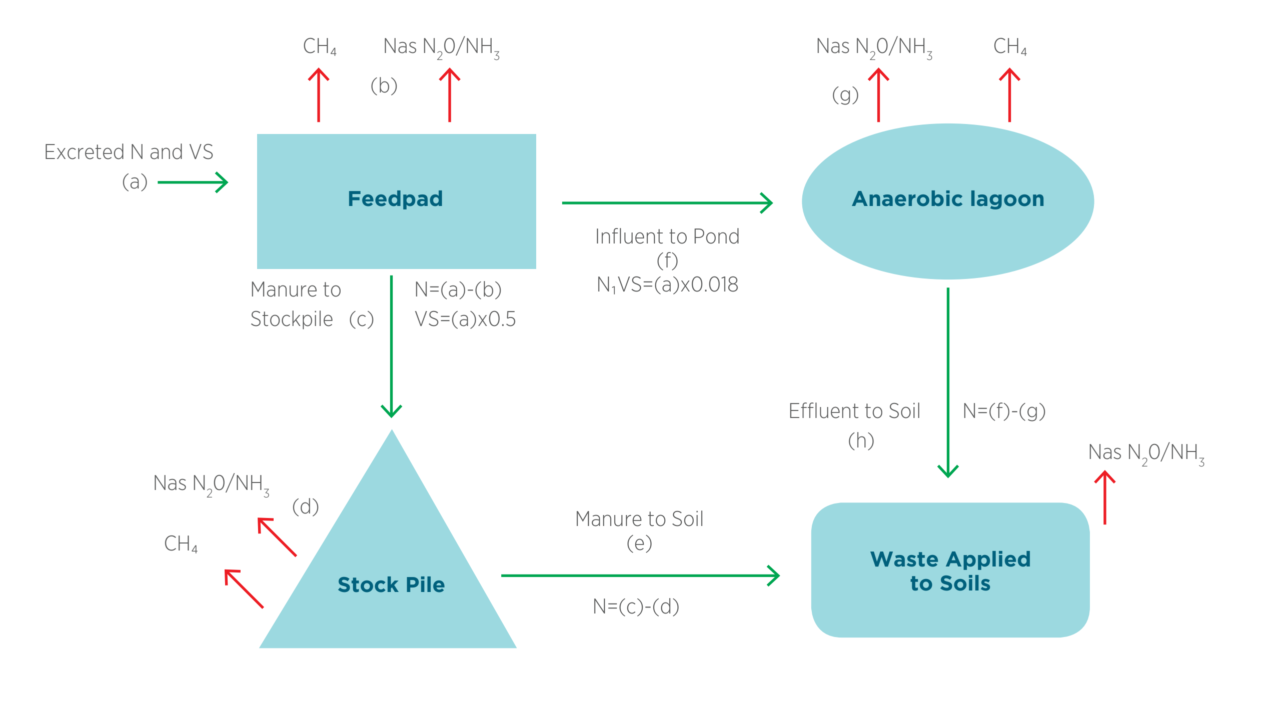


Table 5.15 Additional symbols used in algorithms for manure related emissions

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 (feed pad)	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 emissions from livestock into MMS

Methane production from the manure of dairy cattle, feedlot cattle, swine and poultry is 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.

Manure management emissions for swine and poultry exceed 100 per cent in the allocation of MMS, as manure from intensive livestock industries may pass through multiple treatment stages. The same manure is allocated to multiple manure management system categories in these cases. For example, 100 per cent of the volatile solids will first pass through a primary system, such as a feed pad. The same manure will then pass through a secondary treatment, e.g. composting, and then through to a tertiary treatment such as an effluent pond.

Methane emissions from livestock onto pasture, range and paddock (PRP)

There are two components to methane emission estimates from range-kept livestock (e.g. pasture based beef cattle, sheep, goats etc.):

- Emissions from dung deposited onto PRP
- Emissions from dung deposited into constructed ponds/anaerobic lagoons

The proportion of manure allocated to anaerobic lagoons is five per cent of total PRP manure. This fraction is calibrated to the estimated difference between methane emissions from constructed ponds servicing livestock and those servicing crop production, as reported in Grinham *et al.* (2018) and Ollivier *et al.* (2019), and assuming that this difference is wholly attributable to manure from livestock. Details of these calculations and total emissions for the source (farm dams) are given in *Wetlands* (Section 6.10 – Volume 2 of the NIR).

Country specific factors used to calculate methane emissions from pasture-based livestock are shown in Table 5.16, primarily from IPCC (2019). A default VS excretion rate for Oceania was not provided in IPCC (2006) so the update has been used, as it is based on the latest internationally-assessed science as reported in IPCC (2019). Methane EFs have been further disaggregated in 2019 to enable different factors to be used for the different MMS. The *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019) informed improvements to Australia's country-specific emission estimation approaches consistent with decision 24/CP.19 (Annex I.E, para 10, *Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention*).

Table 5.16 Factors used to calculate CH_4 emissions from pasture-based livestock

Factor type and units	Factor	Source
VS excretion rate for other cattle – Oceania (1000 kg animal mass/day)	8.7	CS, IPCC 2019
TAM for cattle (Typical Animal Mass – kg)	352.4268	derived from average Australian pasture-based cattle liveweights across all cattle classes
CH_4 EF for PRP (g CH_4 kg VS^{-1} for all animals, high and low productivity systems)	0.6	CS, IPCC 2019
CH_4 EF for uncovered anaerobic lagoons (g CH_4 kg VS^{-1} for non-dairy cattle in low productivity systems, in warm climate zones)	69.7	CS, IPCC 2019

Annual volatile solid excretion (kg VS/animal/year) is calculated as:

VS = (VS excretion rate x TAM/1000) x 365 .... **(3B_a)**

To calculate weighted EFs for PRP and lagoons, the CH_4 EFs in Table 5.16 are multiplied by the annual VS excretion rate. Resulting factors are:

- EF (PRP) = 0.67 kg CH_4 /head/year
- EF (lagoon) = 78.00 kg CH_4 /head/year

A combined weighted IEF (kg CH_4/head/year) is calculated as:

Weighted IEF = (EF (PRP) x PRP share (95%)) + (EF (lagoon) x lagoon share (5%)) .... **(3B_b)**

The revised factor (4.54 kg CH_4 /head/year) now places Australia's IEF within the range of other Annex 1 IEFs (see Figure 5.4).

The weighted IEF is then converted from kg CH_4/head/year to kg CH_4/kg DM manure for temperate and warm climatic conditions, using the proportion change between the new combined weighted IEF (4.54) and the CH_4 IEF reported for beef cattle pasture in NIR 2017 Volume 1, Table 5.17 (0.02 kg CH_4 /head/year). The revised EFs are:

EFW = 0.012 kg CH_4/kg DM manure
EFT = 0.003 kg CH_4/kg DM manure

Where EFW = the EF for methane from manure in warm climates

EFT = the EF for methane from manure in temperate climates

EFW and EFT are then used to calculate daily CH_4 emissions (kg) per cattle class and state, using Equation 3B.1b_1 in Section 5.4.3.1.

5.4.1.2 Nitrous oxide

Nitrogen excretion from cattle, sheep, swine, and poultry are estimated using CS tier 2 mass balance approaches where N excretion = N input – N retention. For other livestock, CS excretion rates are applied. The N_2O EF and volatilisation factors are based on a combination of IPCC (2006) default and CS values.

Where multiple manure treatment stages occur, an integrated nitrous oxide EF (iNOF) and an integrated volatilisation factor (iFracGASM$_{MMS}$) have 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, CS 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).

A CS FracLEACH value is used to calculate N that is lost through leaching and runoff associated with manure management, which is based on the latest internationally-assessed science, as reported in IPCC (2019). The *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019) informed improvements to Australia's country-specific emission estimation approaches consistent with decision 24/CP.19 (Annex I.E, para 10, *Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention*).

Consistent with decision 24/CP.19 (Annex I.E, para 10), this country-specific approach draws on IPCC 2019 to the extent the revised factor incorporates results from recent studies in Australia and New Zealand, that are better able to reflect Australia's situation than the IPCC 2006. The introduction of the new estimation approaches has improved the accuracy and completeness of Australia's inventory.

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 appear 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. This is higher than the IPCC (2019) value of 0.47 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:

$$VS_{ij} = (I_{ij} \times (1 - DMD_{ij}) + (0.04 \times I_{ij})) \times (1 - A) \qquad (3B.1a\_1)$$

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:

$$M_{ij} = VS_{ij} \times B_o \times iMCF_i \times \rho \qquad (3B.1a\_2)$$

Where B_o = emissions potential – 0.24m³ CH_4/kg VS (IPCC 2019)

$iMCF_i$ = integrated methane conversion factor (Appendix 5.A.6)

ρ = density of methane (0.6784 kg/m³) – From *National Greenhouse and Energy Reporting (Measurement) Determination 2008*

Methane produced by pre-weaned calves (MPW) is given in Appendix 5.A.5. The annual methane production (Gg) from manure of dairy cattle is calculated as:

$$Total = \Sigma_i\Sigma_j ((N_{ij=1,2,4} \times M_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times M_{ij=3,5} \times 281) + (N_{ij=3,5} \times MPW_{ij=3,5} \times 84)) \times 10^{-6} \quad (3B.1a\_3)$$

Where N_{ij} = numbers of dairy cattle in each State, class and season

M_{ij} = 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 faeces and urine.

The crude protein intake CPI_{ij} (kg/head/day) of dairy cattle is calculated thus:

$$CPI_{ij} = I_{ij} \times CP_{ij} \quad (3B.1a\_4)$$

Where I_{ij} = dry matter intake (kg/day), 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 retained by the body (NR_{ij} kg/head/day) is calculated as the amount of nitrogen retained in milk and body tissue such that:

$$NR_{ij} = (0.032 \times MP_{ij}/6.38) + \{\{0.212–0.008(L_{ij} – 2) – [(0.140-0.008(L_{ij} – 2))/(1+\exp(–6(Z_{ij} – 0.4)))]\} \times (LWGij \times 0.92)\}/6.25 \quad (3B.1a\_5)$$

Where MP_{ij} = milk production (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 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:

$$F_{ij} = \{0.3(CPI_{ij} \times (1-[(DMD_{ij}+10)/100])) + 0.105(ME_{ij} \times I_{ij} \times 0.008) + (0.0152 \times I_{ij})\}/6.25 \quad (3B.1a\_6)$$

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 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 faeces (FPW) and urine (UPW) of pre-weaned calves is given in Appendix 5.A.5.

The total annual faecal (AF_{ij} Gg) and urinary (AU_{ij} Gg) nitrogen excreted is calculated as:

$$AF_{ij} = \Sigma_j((N_{ij=1,2,4} \times F_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times F_{ij=3,5} \times 281) + (N_{ij=3,5} \times FPW_{ij=3,5} \times 84)) \times 10^{-6} \quad \text{(3B.1a\_8a)}$$

$$AU_{ij} = \Sigma_j((N_{ij=1,2,4} \times U_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times U_{ij=3,5} \times 281) + (N_{ij=3,5} \times UPW_{ij=3,5} \times 84)) \times 10^{-6} \quad \text{(3B.1a\_8b)}$$

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 MMS can then be calculated as follows:

$$FN_{ijMMS} = (AF_{ij} \times MMS) \quad \text{(3B.1a\_9a)}$$

$$UN_{ijMMS} = (AU_{ij} \times MMS) \quad \text{(3B.1a\_9b)}$$

Where MMS = the fraction of nitrogen that is managed in the different MMS (Appendix 5.A.8)

The total emissions of nitrous oxide from the different MMS can then be calculated as follows:

$$Faecal_{ijMMS} = (FN_{ijMMS} \times EF_{MMS} \times C_g) \quad \text{(3B.1a\_10a)}$$

$$Urine_{ijMMS} = (FN_{ijMMS} \times EF_{MMS} \times C_g) \quad \text{(3B.1a\_10b)}$$

$$Total_{MMS} = \Sigma_i\Sigma_j (Faecal_{ijMMS} + Urine_{ijMMS}) \quad \text{(3B.1a\_10c)}$$

Where EF_{MMS} = emission factor (N_2O-N kg/ N excreted) for the different MMS (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 (Gg N) from the MMS is calculated as:

$$MN_{atmosi} = \Sigma_j\Sigma_{MMS} ((FN_{ijMMS} + UN_{ijMMS}) \times FracGASM_{MMS}) \quad \text{(3B.5a\_1)}$$

Where $FracGASM_{MMS}$ = the fraction of N volatilised for dairy MMS (Appendix 5.A.9)

Atmospheric deposition emissions from dairy MMS are calculated as:

$$E = \Sigma i (MN_{atmosi} \times EF \times C_g) \quad \text{(3B.5a\_2)}$$

Where E = annual emissions from atmospheric deposition (Gg N_2O)

EF = 0.0039 (Gg N_2O-N/Gg N) (Inorganic fertiliser EF for irrigated pasture – Table 5.25)

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 MMS. 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.

A CS N_2O EF for leaching and runoff is used, which is based on a synthesis of the latest internationally-assessed science, as reported in IPCC (2019). The *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019) informed improvements to Australia's country-specific emission estimation approaches consistent with decision 24/CP.19 (Annex I.E, para 10, *Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention*).

Consistent with decision 24/CP.19 (Annex I.E, para 10), this country-specific approach draws on IPCC 2019 to the extent it is better able to reflect Australia's situation than IPCC 2006. The introduction of the new estimation approaches has improved the accuracy and completeness of Australia's inventory.

The amount of N available for leaching and runoff (MN_{LEACH}) is calculated as:

$$MN_{LEACH} = \Sigma_i \Sigma_j ((FN_{ijMMS=4} + UN_{ijMMS=4}) \times FracWET_{MMSi} \times Frac_{LEACH\_MS}) \quad (3B.5a\_3)$$

Where $FN_{ijMMS=4}$ and $UN_{ijMMS=4}$ = mass of N in solid storage

$FracWET_{MMSi}$ = fraction of N available for leaching and runoff (Appendix 5.J.2)

$Frac_{LEACH\_MS}$ = 0.24 (Gg N/Gg applied) (CS EF, source IPCC (2019)) fraction of N lost through leaching and runoff

Annual leaching and runoff emissions from dairy MMS (Gg N_2O) are calculated as:

$$E = MN_{LEACH} \times EF \times C_g \quad (3B.5a\_4)$$

Where MN_{LEACH} = mass of N lost through leaching and runoff (Gg N)

EF = 0.011 (Gg N_2O-N/Gg N) (CS EF, source IPCC (2019))

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 manure (M_{ijkl} kg/head/day) of pasture based beef cattle is calculated as:

$$M_{ijkl} = I_{jkln} \times (1- DMD_{ijk}) \times ((PW_j \times EFW) + (PT_j \times EFT)) \quad (3B.1b\_1)$$

Where I_{jkln} = 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), calculated in Section 5.4.1.1

EFT = temperate emission factor (kg CH_4 / kg DM Manure), calculated in Section 5.4.1.1

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 pasture based 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 (PRP), there are no direct or indirect manure management N_2O emissions. The nitrogen voided in dung and urine of grazing livestock, as calculated in this section, provides the basis for calculating nitrous oxide emissions from agricultural soils in source category 3D.

The amount of nitrogen retained by the body (NR_{ijkln} kg/head/day) is calculated as the amount of nitrogen retained as milk and body tissue such that:

$$NR_{ijkln} = (0.032 \times MP_{ijkln}/6.38) + \{\{0.212-0.008(L_{ijkln} - 2) - [(0.140-0.008(L_{ijkln} - 2))/ (1+\exp(-6(Z_{ijkln} - 0.4)))]\} \times (LWG_{ijkln} \times 0.92)\}/6.25 \quad (3B.1b\_3)$$

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 Kimberley 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), milk production is considered to be 6 and 4 kg/day respectively (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 using Equation 3A.1b_1)

Z_{ijkln} = relative size – liveweight/standard reference weight (Appendix 5.B.1 and 5.B.6)

LWG_{ijkln} = liveweight gain (kg/day) (Appendix 5.B.2)

Nitrogen excreted in faeces (F_{ijkln} kg/head/day) is calculated, using equations developed by SCA (1990) and Freer *et al.* (1997), as the indigestible fraction of the un-degraded protein from solid feed, microbial crude protein and milk protein plus the endogenous faecal protein, such that:

$$F_{ijkln} = (\{0.3((I_{ijkln} \times CP_{ijkl}) \times (1-[(DMD_{ijkl} +10)/100])) + 0.105(ME_{ijkl} \times I_{ijkln} \times 0.008) + (0.0152 \times I_{ijkln})\}/6.25) + (0.08(0.032 \times MC_{ijkl})/6.38) \quad (3B.1\ b\_4)$$

Where I_{ijkln} = dry matter intake (kg/head/day), 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:
$ME = 0.1604\ DMD_{ijkl} - 1.037$ (DMD expressed as a per cent)

MC_{ijkl} = milk intake (kg/head/day). In areas where Brahman cross breeds are dominant (NT, Qld and Kimberley 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), milk intake is 6 and 4 kg/day respectively (Appendix 5.B.5)

Nitrogen excreted in urine (U_{ijkln} kg/head/day) is calculated by subtracting NR_{ijkl}, F_{ijkl} and dermal protein loss from nitrogen intake such that:

$$U_{ijkln} = (I_{ijkln} \times CP_{ijkl}/6.25) + (0.032 \times MC_{ijkl}/ 6.38) - NR_{ijkl} - F_{ijkl} - [(1.1 \times 10\text{-}4 \times W_{ijkl}^{0.75}) / 6.25] \quad (3B.1b\_5)$$

Where W_{ijkl} = liveweight (kg) (Appendix 5.B.1)

Agriculture

The total annual faecal ($AF_{ijkln\ MMS=14}$ Gg) and urinary ($AU_{ijkln\ MMS=14}$ Gg) nitrogen excreted to PRP 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} = 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, as most manure is handled in drylot and solid storage, only a small fraction of the potential methane emissions are generated.

Volatile solid production for beef cattle in feedlots (VS_j kg/head/day) was estimated using a 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, calculated in Section 5.3.2.3

DMD_j = DM digestibility expressed as a fraction (Appendix 5.C.2)

A = ash content expressed as a fraction (16 per cent) – The ash content fraction is used in BeefBal, and is based on measured data from Australia. Data presented in Gopalan *et al.* (2013) confirmed 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 manure management (M_j kg/head/day) is then calculated as:

$$M_j = VS_j \times B_o \times iMCF_i \times \rho \quad (3B.1c\_2)$$

Where B_o = emission potential (0.19m³ CH_4/kg VS (IPCC 2019))

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 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 CS value.

$iMCF_i$ = integrated MCF for feedlot cattle in each state (Appendix 5.C.3)

ρ = density of methane (0.6784 kg/m³) – From the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*

Annual methane production (Gg) from the manure of beef cattle in feedlots is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_j \times 10^{-6}) \quad (3B.1c\_3)$$

Where N_{ij} = Annual equivalent numbers of beef cattle in feedlots

M_j = methane production (kg/head/day)

Agriculture

5.4.4.2 Direct nitrous oxide emissions

The excretion of nitrogen from feedlot cattle is estimated from nitrogen intake (NI_j) and the fraction retained (NR_j).

Nitrogen intake NI_j (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, 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)

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

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)

Cg = 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 FracGASMMMS values (Appendix 5.C.3) based on the IPCC (2006) default and Australian research (Appendix 5.C.7) are used to estimate N volatilisation.

The mass of feedlot waste volatilised (Gg) is calculated as:

$$MNatmos_{ij} = \Sigma_i \Sigma_j (N_{ij} \times AE_{ij} \times iFracGASM_{MMS}) \qquad (3B.5c\_1)$$

Where AE_{ij} = mass of nitrogen excreted, calculated in Equation 3B.1c_6

$iFracGASM_{MMS}$ = integrated fraction of N volatilised from feedlot cattle (Appendix 5.C.3)

Annual atmospheric deposition emissions (Gg N_2O) from MMS are calculated as:

$$E = MN_{ATMOS} \times EF \times Cg \qquad (3B.5c\_2)$$

Where MN_{ATMOS} = mass of N volatilised (Gg N)

EF = 0.002 (Gg N_2O-N/Gg N) (Inorganic fertiliser EF for non-irrigated cropping – Table 5.25)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Agriculture

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, while runoff from feedlots is captured in effluent ponds. Emissions associated with 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 manure (M_{ijk} kg/head/day) of sheep is calculated as:

$$M_{ijk} = I_{ijk} \times (1 - DMD_{ijk}) \times EFT \quad \text{(3B.2\_1)}$$

Where I_{ijk} = dry matter intake calculated in Section 5.3.3

DMD_{ijk} = digestibility expressed as a percentage (Appendix 5.D.2)

EFT = temperate emission factor (kg CH_4 / kg DM Manure)

The annual methane production (Gg) from sheep manure is calculated as:

$$Total = \Sigma_i\Sigma_j\Sigma_k (N_{ijk} \times M_{ijk} \times 91.25) \times 10^{-6} \quad \text{(3B.2\_2)}$$

Where N_{ijk} = numbers of sheep in each State, class and season

M_{ijk} = methane production (kg/head/day)

5.4.5.2 Nitrous oxide emissions

As sheep manure is deposited direct to PRP, there are no direct or indirect manure management N_2O emissions. The nitrogen voided in dung and urine of grazing 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 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 faeces and urine.

Crude protein intake CPI_{ijk} (kg/head/day) of sheep is calculated as:

$$CPI_{ijk} = I_{ijk} \times CP_{ijk} + (0.045 \times MC_{ijk}) \quad \text{(3B.2\_3)}$$

Where I_{ijk} = feed intake (kg DM/head/day), 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, 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) (Appendix 5.D.1 and 5.D.7)

Nitrogen excreted in faeces (F_{ijk} kg/head/day) is calculated using functions developed by SCA (1990) and Freer *et al.* (1997), as the indigestible fraction of the un-degraded 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 faeces (F_{ijk}) from nitrogen intake such that:

$$U_{ijk} = (CPI_{ijk} / 6.25) - NR_{ijk} - F_{ijk} \quad (3B.2\_6)$$

The annual faecal (AF_{ijk} Gg) and urinary (AU_{ijk} Gg) nitrogen excreted to PRP is calculated as:

$$AF_{ijk\ MMS=14} = (N_{ijk} \times F_{ijk} \times 91.25) \times 10^{-6} \quad (3B.2\_7a)$$

$$AU_{ijk\ MMS=14} = (N_{ijk} \times U_{ijk} \times 91.25) \times 10^{-6} \quad (3B.2\_7b)$$

Where N_{ijk} = the number of sheep in each State, season and class

5.4.6 Swine (3.B.3)

5.4.6.1 Methane

In Australia, swine are generally housed and the liquid waste slurry produced during cleaning is often channelled 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 swine can be wasted (ranging from 5–20 per cent). This waste feed also contributes volatile solids to the MMS and will result in methane emissions. For completeness, emissions are estimated from all waste entering the MMS.

PIGBAL (Skerman *et al.* 2013) is a nutrient balance model for intensive piggeries in Australia. By entering typical animal characteristics, feed intakes, diet compositions and wastage rates, the model calculates the volatile solids (VS_{ij} kg/head/day) in the animal manure (including urine) and waste feed (Appendix 5.E).

Using this information, CH_4 production from wastes (M_{ij} kg/head/day) can be calculated as:

$$M_{ij} = VS_{ij} \times B_o \times iMCF_i \times \rho \qquad (3B.3\_1)$$

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 2019)

$iMCF_j$ = integrated methane conversion factor based on the proportion of different manure management regimes (Appendix 5.E.4)

ρ = density of methane (0.6784kg/m³) – From the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*

The annual methane production (Gg) from wastes of Australian swine is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_{ij} \times 10^{-6}) \qquad (3B.3\_2)$$

Where N_{ij} = numbers of swine in each class for each State

M_{ij} = methane production (kg/head/day)

5.4.6.2 Direct nitrous oxide emissions

Swine are fed high quality diets with high levels of crude protein. The rapid growth rates of most swine results in a relatively high proportion of this nitrogen being retained in the body. Swine 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 MMS 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, feed intakes, feed types and wastage rates (Appendix 5.E).

Allocations to the different MMS have changed over time (Table 5.E.5), with an increase in swine being housed on deep litter resulting in a decrease of allocations to effluent ponds (Wiedemann *et al.* 2014). Intensification of the industry has also occurred, with typical animal mass increasing across every State throughout the timeseries, while N excretion rates have decreased. This has resulted in a continual increase to the N_2O IEF, from 0.0245 kg N_2O/ head/year in 1990 to 0.0787 in 2018.

Annual nitrogen (AE_{ij} Gg/year) from swine manure and waste feed is calculated as:

$$AE_{ij} = N_{ij} \times E_{ij} \times 10^{-6} \quad (3B.3\_3)$$

Where N_{ij} = numbers of swine in each class in each State

E_{ij} = nitrogen in waste (kg/head/year) as calculated by PIGBAL (Appendix 5.E.3)

Total emissions of nitrous oxide from the different MMS (Gg) can then be calculated as follows:

$$Total_{MMS} = \Sigma_i \Sigma_j (AE_{ij} \times iNOF \times Cg) \quad (3B.3\_4)$$

Where iNOF = the integrated nitrous oxide emission factor for swine 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 swine based on default IPCC (2006) and CS values (Appendix 5.E.8).

The mass of piggery waste volatilised is calculated as:

$$M_{atmos} = \Sigma_i \Sigma_k (N_{ij} \times AE_{ij} \times iFracGASM_{MMS}) \quad (3B.5c\_1)$$

Where AE_{ij} = mass of nitrogen excreted, calculated in Equation 3B.3_3

$iFracGASM_{MMS}$ = the integrated fraction of N volatilised for the swine industry (Appendix 5.E.4)

Annual indirect nitrous oxide production (Gg N_2O) from swine MMS is calculated as:

$$E = MN_{atmos} \times EF_{ij} \times C_g \quad (3B.5c\_2)$$

Where 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 5.25)

C = 44/28 factor to convert elemental mass of N_2O to molecular mass

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 MMS.

$$MN_{LEACH_{ij}} = \Sigma_i \Sigma_k (N_{ij} \times AE_{ij} \times MS_{iMMS=5} \times FracWET_{MMSi} \times Frac_{LEACH\_MS}) \quad (3B.5c\_3)$$

Where $MN_{LEACH_{ij}}$ = mass of N lost through leaching and runoff (Gg N)

AE_{ij} = mass of nitrogen in waste, calculated in equation 3B.3_3

$MS_{iMMs=5}$ = fraction of waste handled through drylot (Appendix 5.E.5)

$FracWET_{MMSi}$ = fraction of N available for leaching and runoff (Appendix 5.J.2)

$Frac_{LEACH\_MS}$ = 0.24 (Gg N/Gg applied) (CS EF, source IPCC (2019)) fraction of N lost through leaching and runoff

Annual leaching and runoff emissions (Gg N_2O) from swine MMS are calculated as:

$$E = MN\text{LEACH}_{ij} \times EF \times C_g \qquad \text{(3B.5c\_4)}$$

Where EF = 0.011 (Gg N_2O-N/Gg N) (CS EF, IPCC (2019))

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.4.7 Poultry (3.B.4.G)

Table 5.17 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 feed intakes and dry matter digestibility:

$$VS_{ij} = I_{ij}\,(1 - DMD_{ij}) \times (1 - A) \qquad \text{(3B.4g\_1)}$$

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 poultry manure (M_{ij} kg/head/day) can then be calculated as:

$$M_{ij} = VS_{ij} \times B_o \times iMCF_{ij} \times \rho \qquad \text{(3B.4g\_2)}$$

Where B_o = emission potential (0.36 m^3 CH_4/kg VS for meat chickens and 0.39 m^3 CH_4 / kg VS for layers (IPCC 2019))

$iMCF_{ij}$ = Integrated methane conversion factor (Appendix 5.F.2)

ρ = density of methane (0.6784 kg/m^3) – From the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*

Annual methane production (Gg) for poultry is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_{ij} \times 10^{-6}) \qquad \text{(3B.4g\_3)}$$

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 excretion of nitrogen from meat chickens and layers makes use of the following algorithms to calculate nitrogen intake (NI_{ij}) and retention (NR_{ij}) and from these, the output of nitrogen in manure.

The nitrogen intake NI_j (kg/head/day) of poultry is calculated by:

$$NI_j = I_j \times CP_j / 6.25 \qquad (3B.4g\_4)$$

Where I_j = dry matter intake (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:

$$NE_{ij} = NI_j (1 - NR_j) \times 365 \times 10^{-6} \qquad (3B.4g\_5)$$

Where NR_j = nitrogen retention as a proportion of intake (Appendix 5.F.1)

Total emissions of nitrous oxide from the different MMS (Gg) can then be calculated as follows:

$$Total_{MMS} = \Sigma_2\Sigma_j (N_{ij} \times NE_{ij} \times iNOF_j \times C_g) \qquad (3B.4g\_6)$$

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 5.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 (3.B.5)

Atmospheric deposition

Integrated FracGASM values (Appendix 5.F.2) based on default IPCC (2006) and CS values (Appendix 5.F.7) are used to estimate N volatilisation from poultry.

Mass of poultry waste volatilised (Gg N) is calculated as:

$$M_{atmos} = \Sigma_i\Sigma_j (N_{ij} \times NE_{ij} \times iFracGASM_{MMSj}) \qquad (3B.5d\_1)$$

Where NE_{ij} = mass of nitrogen excreted (Gg/head/year), calculated in Equation 3B.4g_5

$iFracGASM_{MMSj}$ = the integrated fraction of N volatilised for the meat and layer industries (Appendix 5.F.2)

Annual atmospheric deposition emissions (Gg N_2O) from poultry MMS are calculated as:

$$E = MN_{atmos} \times EF_{ij} \times C_g \qquad (3B.5d\_2)$$

Where EF_{ij} = 0.0021 (Gg N_2O-N/Gg N) (Meat = inorganic fertiliser EF for non-irrigated pastures)

EF_{ij} = 0.002 (Layers = inorganic fertiliser EF for non-irrigated cropping – Table 5.25)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Agriculture

Leaching and runoff

Leaching and runoff from poultry facilities (with the exception of free range operations and manure stockpiles) is considered negligible. Therefore the emissions associated with waste leaching and runoff are only estimated for manure stockpiles. Emissions from free range operations are estimated in the agricultural soils category 3D.

$$MN_{LEACH} = \Sigma_i \Sigma_j (N_{ij} \times NE_{ij} \times MS_{iMMS=4-5} \times FracWET_{MMSi} \times Frac_{LEACH\_MS}) \quad (3B.5d\_3)$$

Where $MN_{LEACH_{ij}}$ = mass of N lost through leaching and runoff (Gg N)

NE_{ij} = mass of nitrogen excreted (Gg/head/year), calculated in Equation 3B.4g_5

$MS_{iMMs=4-5}$ = fraction of waste handled through drylot and solid storage (Appendix 5.F.3)

$FracWET_{MMSi}$ = Fraction of N available for leaching and runoff (Appendix 5.J.2)

$Frac_{LEACH\_MS}$ = 0.24 (Gg N/Gg applied) (CS EF, source IPCC (2019)) fraction of N lost through leaching and runoff

Annual leaching and runoff emissions (Gg N_2O) from poultry MMS are calculated as:

$$E = \Sigma_i \Sigma_j (MN_{LEACH_{ij}} \times EF \times C_g) \quad (3B.5d\_4)$$

Where EF = 0.011 (Gg N_2O-N/Gg N) (CS EF, source IPCC (2019))

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, mules and asses, 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 is 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 mules/asses (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 of other livestock (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), calculated in Section 5.4.1.1

EFT = temperate emission factor (kg CH_4 / kg DM Manure), calculated in Section 5.4.1.1

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)

Annual methane production (Gg) from 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 other livestock is deposited direct to PRP, there are no direct or indirect manure management N_2O emissions. The nitrogen voided in dung and urine of grazing 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 is 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 PRP 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)

The annual nitrogen excreted in faeces (AF_{ij}) and Urine (AU_{ij}) to PRP 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 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. See Section 5.2.1 regarding how changes to data collection methods by the Australian Bureau of Statistics have been addressed to ensure time series consistency of livestock numbers, and reasons for differences in beef cattle and poultry populations with published FAO data..

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 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 EFs

Comparison with IPCC values

As CS tier 2 methods are used to estimate emissions from cattle, sheep, pigs and poultry, the IEFs have been compared with IPCC defaults (Table 5.18).

Table 5.18 Implied EFs – Methane manure management (kg/head/year)

Livestock type	Australia	IPCC default (Oceania)
Dairy cattle	15	23–31
Beef cattle		
Pasture	4.86	1–2
Feedlot	3.5	1–2
Sheep	0.34	0.19–0.37
Swine	23.19	11–24
Poultry	0.04	0.02–1.4

Source: IPCC (2006).

Dairy cattle

The IEFs for dairy cattle differ from the IPCC defaults due to the allocation of waste to different MMS. Australia assumes that 80–88 per cent of waste is voided at pasture compared with 76 per cent in the IPCC (2006) default.

Pasture beef cattle

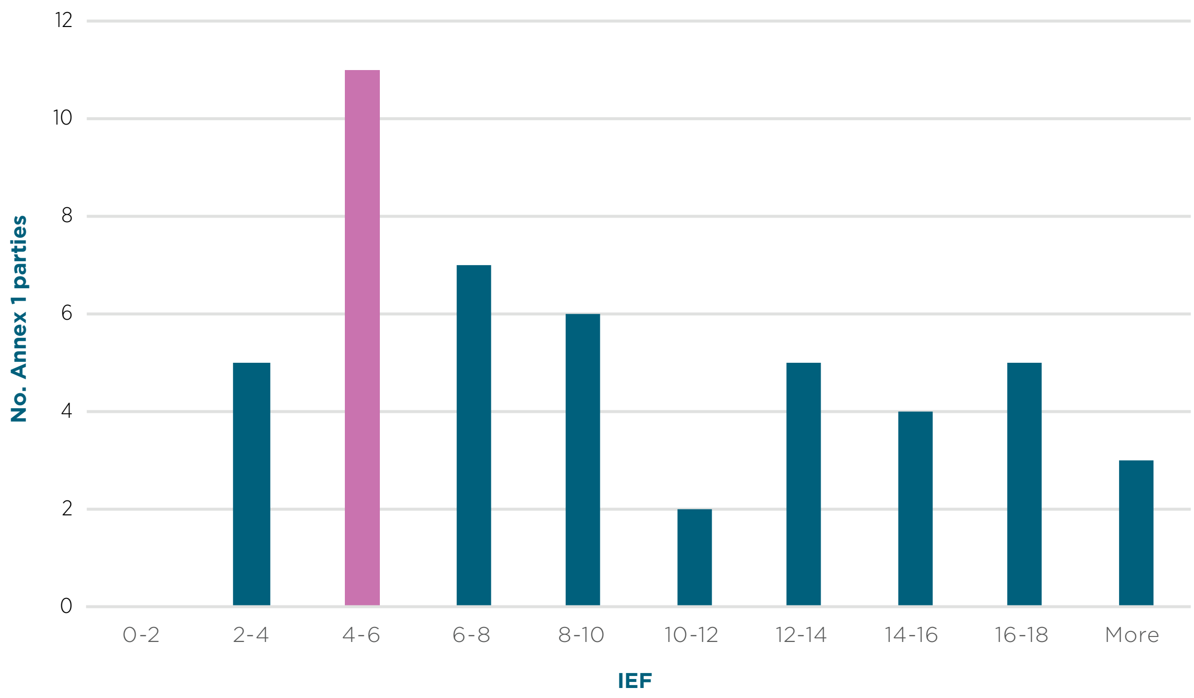
The IEF for range-kept beef cattle is higher than the IPCC default EF range. Reasons for this difference include:

- Australia assumes that 5 per cent of pasture beef cattle manure is deposited into constructed ponds, which is included in manure management CH_4 emissions. The anaerobic lagoon EF applied to constructed ponds is significantly higher than the PRP EF, therefore, raising Australia's overall IEF.
- The default factors for Oceania include a number of developing nations in the region, which have different production systems for livestock compared to those in Australia.

Comparison with Annex-1 IEFs

Australia's approach to the estimation of emissions from manure deposited by cattle places Australia's IEF within the range of Annex-1 IEFs (Figure 5.4). The Australian value falls within the 4_6 IEF group.

Figure 5.4 Pasture beef cattle IEF comparisons



Australia's manure management CH_4 IEF for cattle is also comparable to Annex 1 parties with similar livestock production systems, such as New Zealand (ranging from 2.2 to 5.2 kg CH_4/head/year).

Feedlot cattle

The IPCC default B_0 value for North America has been chosen for feedlot beef cattle based on the recommendations contained in Wiedemann *et al.* (2014). They noted that the IPCC (2006) default for Oceania did not correspond with measurements by Gopalan *et al.* (2013) from four Australian feedlots, which were more aligned to the IPCC default for North America.

Sheep

Australia's sheep IEF is within the IPCC default EF range.

The reasons for being at the higher end of the range are:

- Australia assumes that 5 per cent of sheep manure is deposited into constructed ponds, which is included in manure management CH_4 emissions. The anaerobic lagoon EF applied to constructed ponds is significantly higher than the PRP EF, therefore, raising Australia's overall IEF.
- The default factors for Oceania include a number of developing nations in the region which have different production systems for livestock compared to those in Australia.

Swine

The swine IEF is on the high end of the IPCC range. The IPCC (2006) default assumes that 50 per cent of manure passes through an anaerobic pond, while Australian management practices for swine see this elevated to around 70 per cent.

Poultry

The poultry IEF is within the range of the IPCC (2006) default EFs.

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 swine 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, swine and poultry (Table 5.19). The volatile solid production of feedlot cattle was lower than the IPCC (2006) defaults, as an ash content of 16 per cent is used compared with the default of 8 per cent. The slightly higher values reported for swine are likely the consequence of including VS from feed waste.

Table 5.19 Volatile solids (kg/head/day)

Livestock type	Australia	IPCC 2006 default	IPCC 2019
Dairy cows	3.3	1.9–5.4	2.9–5.4
Beef cattle – Feedlot	1.7	1.4–3	2.3–3.9
Swine			
Breeders	0.4–0.55	0.3–0.5	0.3–0.6
Other pigs	0.39	0.27–0.3	0.3–0.32
Poultry			
Layers	0.014	0.02	0.02
Meat	0.016–0.017	0.01–0.02	0.01–0.02

Source: IPCC (2006 and 2019).

5.4.10.4 Nitrogen excretion

The CS estimates of nitrogen excretion were compared against the IPCC defaults (Table 5.20). Feedlot cattle, sheep and poultry excretion rates are consistent with IPCC (2019) values.

For other animals, excretion rates differ from the IPCC values. However, 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 consistent with the IPCC (2019) values. 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 rapidly 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 available for range-kept cattle consumption.

Swine N excretion rates were generally consistent with IPCC (2019) values, although Australia's 'other pig' rate was slightly higher. Differences could be related to different feed intake, crude protein intake or N retention assumptions compared to the IPCC.

Table 5.20 Nitrogen excretion rates (kg/head/year)

Livestock type	Australia	IPCC 2006	IPCC 2019
Dairy cattle (455 kg)	124	58–80	42–142
Beef cattle			38–94 (other cattle)
Pasture (378 kg)	42	43–69	43–69
Feedlot (524 kg)	71	60–96	60–96
Sheep (43 kg)	7	5–8	5–9
Swine			
Sows (188 kg)	18	21–34	11–27
Growers (39 kg)	11	4–7	7–17
Poultry	0.6–0.7	0.6–1.0	0.4–0.7

Source: IPCC 2006 and 2019.

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, swine 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 2018 Inventory

Recalculations for Manure Management have occurred in the 2021 submission due to:

- A review of N_2O EF research for drylots in Australian beef feedlots, resulting in an update for the 2021 submission (Wiedemann and Longworth 2020). Table 5.21 shows the impact of these recalculations. Drylots had previously been identified as a major emission source in Australian feedlots, and it was suggested that the EF used in the inventory was over-predicting emissions under Australian conditions (Wiedemann *et al*. 2014). The current review analysed recent published Australian studies to develop the revised EF. Although the revised factor is much lower than the IPCC 2006 default (not revised in IPCC 2019), it follows the IPCC guidelines for good practice as the EF was developed using CS peer-reviewed data from both experimental and commercial feedlots that experience different climatic conditions.

Table 5.21 Manure Management (3.B): recalculation of total CO_2-e emissions: 1990–2018

Year	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	6,558	6,389	-168	-2.6
2000	6,583	6,295	-288	-4.4
2005	7,339	6,933	-406	-5.5
2010	6,728	6,370	-358	-5.3
2011	6,867	6,492	-374	-5.5
2012	7,034	6,663	-371	-5.3
2013	7,041	6,664	-378	-5.4
2014	7,182	6,793	-390	-5.4
2015	7,150	6,694	-456	-6.4
2016	6,998	6,536	-462	-6.6
2017	7,215	6,753	-462	-6.4
2018	7,361	6,863	-499	-6.8

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 few years. Areas for improvement are identified through the UNFCCC expert reviews, domestic QA/QC processes 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. *Manure mass and N_2O emissions* – 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. This finding was supported by the recent review of the drylot N_2O EF by Wiedemann and Longworth (2020), who noted that as manure nitrogen is not the first limiting factor driving N_2O emissions from drylots, reducing manure N is less likely to influence emissions than would be suggested by the EF. Research to provide a prediction method based on key drivers; temperature, rainfall and manure moisture (Parker *et al.*, 2018, Redding *et al.*, 2015a, Sun *et al.*, 2016, Waldrip *et al.*, 2016), may lead to better process knowledge and a revised emission factor or prediction method in the future. (Wiedemann & Longworth 2020)
2. *Methane Capture and Destruction* – a number of piggeries and poultry operations are capturing and destroying methane from digesters/covered lagoons. Those farms who participated in the Emissions Reduction Fund 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.
3. *MMS FracLEACH factor* – Review and update FracLEACH factor for MMS, based on an ERT recommendation, to differentiate between the factor used in agricultural soils equations.

5.5 Source Category 3.C Rice Cultivation

5.5.1 Source category description and methodology

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.

A CS method is applied to estimate emissions from rice cultivation.

The IPCC (2019) EF of 1.19 kg CH_4/ha/day is used, with appropriate scaling factors applied for a continuously flooded water regime (SFw = 1) and a non-flooded pre-season of > 180 days (SFp = 0.89). These factors were selected as they are based on the latest science, are disaggregated by water regime type prior to and during cropping, and they have reduced levels of uncertainty than IPCC (2006) defaults.

Over the average 150 day growing season this gives an emission rate for Australia of 158.9 kg CH_4/ha as per Equation 5.2 in IPCC 2019:

Rice EF = EFc x SFw x SFp x SFo

Where EFc is the baseline EF for continuously flooded fields without organic amendments (1.19 kg CH_4/ha/day)

SFw is the scaling factor to account for the differences in water regimes during the cultivation period (irrigated, continuously flooded production systems)

SFp is the scaling factor to account for the differences in water regimes in the pre-season before the cultivation period (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)

Australia's Rice EF = 1.19 x 150 x 1 x 0.89

Table 5.22 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 (E_i Gg) is calculated as:

$$E_i = A_i \times EF \times 10^{-6} \quad (3C\_1)$$

Where A_i = area under rice cultivation (ha)

EF = emission factor integrated over the whole season (158.9 kg CH_4/ha)

5.5.2 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 2. Time series consistency is ensured by the use the same methods and data sources for the full time series.

5.5.3 Source specific QA/QC

This source category is covered by the general QA/QC procedures detailed in Chapter 1.

5.5.4 Recalculations since the 2018 Inventory

There were no recalculations affecting this subsector in the 2021 submission.

Table 5.23 Rice cultivation (3.C): recalculation of total CO_2-e emissions (Gg), 1990–2018

Year	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	476	476	-	0
2000	520	520	-	0
2005	205	205	-	0
2010	75	75	-	0
2011	301	301	-	0
2012	410	410	-	0
2013	451	451	-	0
2014	305	305	-	0
2015	277	277	-	0
2016	110	110	-	0
2017	342	342	-	0
2018	254	254	-	0

5.5.5 Source specific 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

Direct and indirect 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.

Nitrogen compounds can be added to the soil through the following processes:

a) the application of inorganic nitrogen fertilisers

b) the application of animal wastes and sewage sludge to pastures

c) the application of crop residues

d) mineralisation due to loss of soil carbon

e) mineralisation due to cultivation of organic soils

e) atmospheric nitrogen deposition

A further source of nitrous oxide is associated with leaching of N from soils and surface runoff, and subsequent denitrification in rivers and estuaries.

5.6.2 Inorganic fertilisers (3.D.A.1)

A CS method is used to estimate emissions from inorganic fertilisers. The EFs are based on analyses of Australian measurement studies (Scherbak and Grace 2014; Scherbak *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). The work of Scherbak and Grace was reviewed by the Expert Advisory Panel and approved for use in the Australian NIR (see Table 5.4).

This experimental work on the application of fertilisers to different production systems and climatic regions in Australia has shown large variations from the IPCC 2006 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 low rates of nitrogen fertiliser inputs, low decomposition rates and low 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 production systems increase with nitrogen application rates. For example, Scherbak *et al.* (2014) have developed a two component (linear + exponential) model for cotton which gives EF (per cent) = 0.29 + (0.007($e^{0037*\text{N application rate}}$ -1)/N application rate.

The EFs used in the inventory for inorganic fertiliser are provided in Table 5.25.

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 2020a) and the average fertiliser application rates for each of these crops. The balance of the fertiliser is then distributed to rain-fed crops and modified pastures (derived from Stewart *et al.* 2001) in proportion to their respective areas.

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 5.24 Symbols used in algorithms for inorganic 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 5.25 Nitrous oxide EFs for inorganic fertiliser

Production system	Emission factor [a] ($Gg\ N_2O$-N/ Gg N)
Irrigated pasture	0.0039
Irrigated crop	0.0085
Non-irrigated pasture	0.0021
Non-irrigated crop	0.0020 [b]
Sugar cane	0.0199
Cotton	0.0055 [c]
Horticulture	0.0085

(a) Based on Scherbak and Grace (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 via crop production systems (M_{ij} Gg N) is calculated as:

$$M_{ij} = TM_{ij} \times FN_{ij} \qquad \text{(3DA\_1)}$$

Where 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 organic fertilisers (E_{ij} Gg N_2O) is calculated as:

$$E_{ij} = \Sigma_i \Sigma_j (M_{ij} \times EF_{ij} \times C_g) \qquad \text{(3DA\_2)}$$

Where EF_{ij} = emission factor (Gg N_2O-N/Gg N applied) (Table 5.25)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.3 Organic fertilisers (3.D.A.2)

Direct emissions from organic fertilisers arise from two sources:

- Animal wastes applied to soils
- Sewage sludge applied to land

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 (2006) default EF for N_2O emissions from animal wastes applied to soils (1 per cent) is used for dairies, feedlots and poultry houses. Piggeries uses a direct N_2O factor of 0.0039 N_2O-N/Gg N deposited based on the output of the PigBal model (Skerman *et al.* 2013).

Inputs to this subsector are calculated using MMS equations in Section 5.4.

Table 5.26 Symbols used in algorithms for animal wastes applied to soils

State (i)	Activity (j)
1 = ACT	1 = Dairy cattle
2 = Northern Territory	2 = Beef cattle – feedlot
3 = NSW	3 = Swine
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 MMS.

Thus the nitrogen content of animal wastes applied to agricultural soils (MN $Soil_{ij)}$ is calculated as:

$$MN\ Soil_{ij} = \Sigma_{MMS} ((AE_{ij\ MMS=1\text{-}13} \times (1 - EF_{MMS=1\text{-}13} - FracGASM_{j\ MMS=1\text{-}13})) - MNLEACH_{ij\ MMS=1\text{-}13}) \quad \text{(3DA\_3)}$$

Where $AE_{ij\ MMS=1\text{-}13}$ = mass of N excreted, calculated in Section 5.4. For dairy cattle AE_{ij} is the sum of faecal (AF) and urinary (AU) nitrogen

$EF_{MMS=1\text{-}13}$ = direct nitrous oxide EF from the different MMS (Appendix 5)

$FracGASM_{j\ MMS=1\text{-}13}$ = fraction of animal waste N volatilised from the different MMS (Appendix 5)

$MNleach_{ij\ MMS=1\text{-}13}$ = mass of animal waste N from leaching and runoff, calculated in Section 5.4

Annual nitrous oxide production from animal wastes applied to soils (E_{ij} Gg N_2O) is calculated as:

$$E_{ij} = \Sigma_i \Sigma_j (MN\ Soil_{ij} \times EF \times C_g) \quad \text{(3DA\_4)}$$

Where EF = 0.01 (Gg N_2O-N/Gg N deposited) IPCC 2006

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 CS EF 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 EF of 0.9 per cent (range 0.8 to 1.0 per cent).

Activity data is from the *waste* sector (category 5.D wastewater treatment and discharge – domestic and commercial). The quantity of sewage sludge removed from wastewater treatment plants for application to land is reported by wastewater treatment plants under the National Greenhouse and Energy Reporting System (NGERS). See Section 7.6 'Waste Wastewater Treatment and Discharge' in Volume 2 of the NIR for further information.

Table 5.27 Symbols used in algorithms for sewage sludge applied to land

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 from sewage sludge applied to land (E_i Gg N_2O) is calculated as:

$$E_i = \Sigma_i (M_i \times EF \times C_g) \qquad (3DA\_5)$$

Where M_i = Mass of sewage sludge N applied to lands (Gg)

EF = 0.009 (Gg N_2O-N/Gg N) Bouwman *et al.* 2002

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.6.5 Urine and dung deposited by grazing animals (3.D.A.3)

Nitrous oxide is emitted from soil through the metabolism of urine and faeces deposited directly onto pastures.

Urine experiments conducted on rain-fed legumes and annual pastures in central NSW (Galbally *et al.* 1994), and irrigated pastures in 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. This value is within the uncertainty range for both the IPCC 2006 and IPCC 2019 EF.

Table 5.28 Symbols used in algorithms for urine and dung deposited by grazing animals

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 from urine and dung deposited by grazing animals (E_{ij} Gg N_2O) is calculated as:

$$E_{ij} = \Sigma_i \Sigma_j ((AF_{ij\ MMS=14} \times EF_j \times C_g) + (AU_{ij\ MMS=14} \times EF_j \times C_g)) \qquad (3DA\_6)$$

Where $AF_{ij\ MMS=14}$ and $AU_{ij\ MMS=14}$ = 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 EF but using CS crop production activity data. This subsector also includes emissions from pasture residues returned to the soil. The IPCC (2006) default EF for N_2O emissions from crop residues (1 per cent) is used. This value did not change in the IPCC 2019 Refinement.

Table 5.29 Symbols used in algorithms for crop residues

State (i)	Crops (j)	Pasture (k)	Pasture 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 = Tubers 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 (M_{ijk} Gg N) is calculated as:

$$M_{ijk} = (P_{ij} \times R_{AGj} \times (1 - F_{ij} - FFOD_{ij}) \times DM_j \times NC_{AGj}) + (P_{ij} \times R_{AGj} \times R_{BGj} \times DM_j \times NC_{BGj}) \quad (3DA\_7)$$

Where P_{ij} = annual production of crop (Gg)

R_{AGj} = residue:crop ratio (kg crop residue/kg crop) (Appendix 5.I.1)

R_{BGj} = below ground-residue:above ground residue ratio (kg /kg) (Appendix 5.I.1)

F_{ij} = fraction of crop residue that is burnt (Appendix 5.I.1)

$FFOD_{ij}$ = fraction of crop residue that is removed (Appendix 5.I.1)

DM_j = dry matter content (kg dry weight/kg crop residue) (Appendix 5.I.1)

NC_{AGj} = N content of above-ground crop residue (kg N/kg DM) (Appendix 5.I.1)

NC_{BGj} = N content of below-ground crop residue (kg N/kg DM) (Appendix 5.I.1)

The mass of N in pasture residues returned to soils (M_{ikl} Gg N) is calculated as:

$$M_{ikl} = (A_{ikl} \times Frac_{Renewal} \times (Y_k / 1000) \times (1 - FFOD_{ik}) \times NC_{AGk}) + (A_{ikl} \times Frac_{Renewal} \times (Y_k / 1000) \times R_{BGk} \times NC_{BGk}) \quad (3DA\_8)$$

Where A_{ikl} = Area of pasture (ha)

$Frac_{Renewal}$ = Fraction of pasture renewed = 1/ X where X is the average renewal period in years: 10 years for intensive systems and 30 years for other systems

Y_k = Average yield (t DM/ha) (Appendix 5.I.2)

R_{BGk} = below ground-residue:above ground residue ratio (kg /kg) (Appendix 5.I.1)

NC_{AGk} = N content of above-ground crop residue (kg N/kg DM) (Appendix 5.I.1)

NC_{BGk} = N content of below-ground crop residue (kg N/kg DM) (Appendix 5.I.1)

$FFOD_{ik}$ = fraction of pasture yield that is removed (Appendix 5.I.2)

Annual nitrous oxide production from crop residues (E_j Gg N_2O) is calculated as:

$$E_i = \Sigma_i \Sigma_k \Sigma_l (M_{ijkl} \times EF \times C_g) \quad (3DA\_9)$$

Where M_{ijkl} = mass of N in crop residues (Gg N)

EF = 0.01 (Gg N_2O-N/Gg N) IPCC 2006 default

C_g = 44/28 factor to convert from elemental mass of N_2O to molecular mass

5.6.7 Mineralisation due to loss of soil carbon (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, along with mineralised N released through the decomposition of crop residues (IPCC 2006). In years in which *cropland remaining cropland* is a net sink there may be no emissions reported in this category.

The IPCC (2006) method, using CS 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 CS EF for fertiliser additions to non-irrigated crops is then applied (see Table 5.25). The EF is based on analyses of Australian measurement studies (Scherbak and Grace 2014; Scherbak *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).

The experimental work on the application of fertilisers to different Australian production systems showed large variations from the IPCC default EF of 1 per cent, across different classes of crop and pasture systems. The work of Scherbak and Grace was reviewed by the Expert Advisory Panel and approved for use in the Australian NIR (see Table 5.4).

Table 5.30 Symbols used in algorithms for mineralisation due to 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 from mineralisation due to loss of soil C (E_{ij} Gg N_2O) is calculated as:

$$E_i = \Sigma_i (M_i \times NC \times EF \times C_g) \qquad (3DA\_10)$$

Where M_i = loss of soil carbon in *cropland remaining cropland* (Gg)

NC = nitrogen to carbon ratio for cropland soils

EF = 0.002 (Gg N_2O-N/Gg N) Scherbak and Grace 2014

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 area of cultivated histosols is very limited in Australia (known as organosols in the Australian Soil Classification 2016). Organosols occur in Queensland where they are mostly used for sugar cane production, and small locations in Victoria where peatlands were cleared and subsequently grazed or cropped. Individual patches are typically very small, which leads to significant uncertainty when estimating the national area. The land area for histosols was estimated using expert judgement (C. Meyer pers. comm.). There is also a large area of histosols in Tasmania, although this land is not cultivated, so is not included in Australia's calculations for cultivation of histosols.

The EF used takes into account the different climatic conditions associated with the two isolated areas. A weighted average of 14 is applied, calculated from a factor of 16 for Queensland, for tropical organic crop and grassland soils, and 8 for Victoria, for temperate organic crop and grassland soils (IPCC 2006).

Table 5.31 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 from cultivation of histosols (E_i Gg N_2O) is calculated as:

$$E_i = \Sigma_i (A_i \times EF \times C_g \times 10^{-6}) \quad (3DA\_11)$$

Where A_i = area of cultivated histosols (ha)

EF = 14 kg N_2O-N/ha (weighted average of IPCC 2006 default values)

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 CS method is used to estimate indirect emissions for atmospheric N_2O deposition from inorganic fertilisers, manure and sewage sludge. 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 N.

For N volatilised from inorganic fertilisers or sewage sludge, the CS EFs applied for atmospheric deposition are the same as those applied for direct N_2O emissions (see Table 5.25). The EFs are based on analyses of Australian measurement studies (Scherbak and Grace 2014; Scherbak *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 showed large variations from the IPCC default EF of 1 per cent across different types of crop and pasture systems. The work of Scherbak and Grace was reviewed by the Expert Advisory Panel and approved for use in the Australian NIR (see Table 5.4).

For N derived from a manure source, the inorganic fertiliser EF which best represents the production system immediately surrounding the farm is used to estimate atmospheric deposition emissions.

Country specific FracGASMsoil and FracGASF values are used to calculate N volatilised from organic and synthetic fertilisers, and animal waste deposited on soils. They are based on syntheses of the latest internationally-assessed science, as reported in IPCC (2019). The *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019) informed improvements to Australia's country-specific emission estimation approaches consistent with decision 24/CP.19 (Annex I.E, para 10, *Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention*). The reported uncertainty range for the revised values have narrowed (IPCC 2019), indicating better accuracy than the previous IPCC 2006 default value.

Table 5.32 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 N volatilised from inorganic fertiliser applied to soils ($M_{ij=1}$ Gg N) is calculated as:

$$M_{ij=1} = TM_{ij=1} \times FracGASF_j \quad (3DB\_1)$$

Where $TM_{ij=1}$ = total mass of fertiliser (Gg N), estimated in Section 5.6.2

$FracGASF_j$ = 0.11 (Gg N/Gg applied) (CS EF, source IPCC (2019))

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The mass of N volatilised from animal waste deposited on or applied to soils ($M_{ij=2}$ Gg N) is calculated as:

$$M_{ij=2} = \Sigma\ (MNsoil_{ij} + UNsoil_{ij} + FNsoil_{ij}) \times FracGASMsoil_{ij} \qquad (3DB\_2)$$

Where $MNsoil_{ij}$ = mass of manure N applied to soils (Gg N)

$UNsoil_{ij}$ = mass of urinary N excretion on pasture (Gg N)

$FNsoil_{ij}$ = mass of faecal N excretion on pasture (Gg N)

$FracGASMsoil_{ij}$ = 0.21 (kg NH_3–N + NOx–N) (kg N applied or deposited)$^{-1}$ (CS EF, source IPCC (2019))

The mass of N volatilised from sewage sludge applied to soils ($M_{ij=3}$ Gg N) is calculated as:

$$M_{ij=3} = TM_{ij=3} \times FracGASS_j \qquad (3DB\_3)$$

Where $TM_{ij=3}$ = total mass of sewage sludge (Gg N)

$FracGASS_j$ = 0.21 (Gg N/Gg applied) (CS EF, source IPCC (2019))

Annual nitrous oxide production from atmospheric deposition (E Gg N_2O) is calculated as:

$$E = \Sigma_i \Sigma_j (M_{ij} \times EF_{ij} \times C_g) \qquad (3DB\_4)$$

Where M_{ij} = mass of N volatilised from each sub-sector (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 (3.D.B.2)

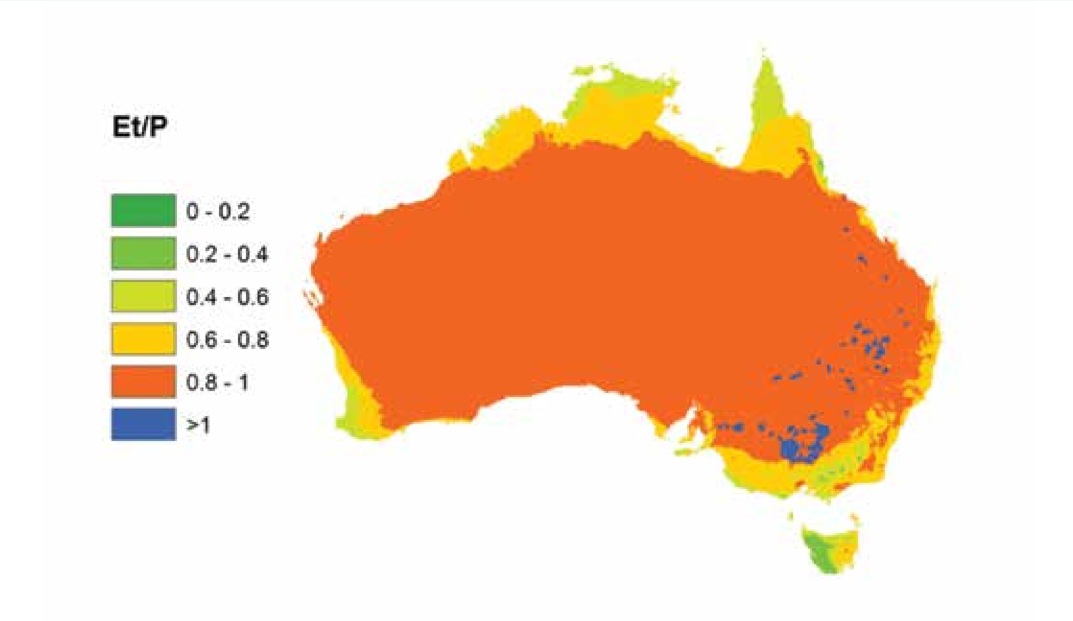
Australia is the driest continent, with substantially less runoff than all other continents. In Australia, much of the cropping takes place in semi-arid regions, or regions of marginal rainfall. Leaching of applied nitrogen into waterways and estuaries is unlikely where evaporation exceeds precipitation (IPCC 2019).

Areas in 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 different vegetation types (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 5.5). 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 (FracWET) were determined by overlaying the dryland area mask onto the spatial map of crops, pastures and animal density from the 1997 Agricultural census (ABS 1999).

Figure 5.5 The ratio of mean annual evapotranspiration to annual precipitation (Et/P)



Indirect emissions from leaching and runoff arise from five sources:

- Inorganic fertiliser
- Animal wastes applied to soils
- Sewage sludge applied to land
- Crop residues
- Mineralisation due to loss of soil C

A CS FracLEACH value and a CS N_2O EF are used to calculate N that is lost through leaching and runoff, based on the latest internationally-assessed science, as reported in IPCC (2019). The *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019) informed improvements to Australia's country-specific emission estimation approaches consistent with decision 24/CP.19 (Annex I.E, para 10, *Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention*).

Consistent with decision 24/CP.19 (Annex I.E, para 10), these country-specific approaches draw on the IPCC 2019 to the extent they are better able to reflect Australia's situation than the IPCC 2006. The introduction of the new estimation approaches has improved the accuracy and completeness of Australia's inventory.

Table 5.33 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 = 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 ($M_{ij=1}$ Gg N) is calculated as:

$$M_{ij=1} = M_{ij} \times FracWET_{ij} \times Frac_{LEACH} \qquad (3DB\_5)$$

Where M_{ij} = mass of fertiliser in each production system (Gg N), calculated in Section 5.6.2.

$FracWET_{ij}$ = fraction of N available for leaching and runoff (Appendix 5.J.1)

$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (CS EF, source IPCC (2019))

The mass of animal waste N excreted or applied to soil that is lost through leaching and runoff ($M_{ij=2}$ Gg N) is calculated as:

$$M_{ij=2} = (MNsoil_{ij} + UNsoil_{ij} + FNsoil_{ij}) \times FracWET_{soilij} \times Frac_{LEACH} \qquad (3DB\_6)$$

Where $MNsoil_{ij}$ = mass of manure N applied to soils (Gg N), calculated in Section 5.6.3

$UNsoil_{ij}$ = mass of urinary N excretion on pasture (Gg N), calculated in Section 5.6.9

$FNsoil_{ij}$ = mass of faecal N excretion on pasture (Gg N), calculated in Section 5.6.9

$FracWET_{soilij}$ = fraction of N available for leaching and runoff (Appendix 5.J.2)

$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (CS EF, source IPCC (2019))

The mass of sewage sludge N applied to soils that is lost through leaching and runoff ($M_{ij=3}$ Gg N) is calculated as:

$$M_{ij=3} = M_{ij} \times FracWET_{ij} \times Frac_{LEACH} \qquad (3DB\_7)$$

Where M_{ij} = mass of sewage sludge N (Gg N), calculated in Section 5.6.4

$FracWET_{ij}$ = fraction of N available for leaching and runoff = 1.0

$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (CS EF, source IPCC (2019))

The mass of crop residue that is lost through leaching and runoff ($M_{ij=4}$ Gg N) is calculated as:

$$M_{ij=4} = M_{ij} \times FracWET_{ij} \times Frac_{LEACH} \qquad (3DB\_8)$$

Where M_{ij} = mass of crop residue N (Gg N), calculated in Section 5.6.6

$FracWET_{ij}$ = fraction of N available for leaching and runoff (Appendix 5.J.1)

$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (CS EF, source IPCC (2019))

The mass of N mineralised due to a loss of soil C lost through leaching and runoff ($M_{ij=5}$ Gg N) is calculated as:

$$M_{ij=5} = M_{ij} \times FracWET_{ij} \times Frac_{LEACH} \qquad (3DB\_9)$$

Where M_{ij} = mass of N mineralised due to a loss of soil C (Gg N)

$FracWET_{ij}$ = fraction of N available for leaching and runoff (Appendix 5.J.I – non-irrigated crops)

$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (CS EF, source IPCC (2019))

Annual nitrous oxide production from leaching and runoff (E Gg N_2O) is calculated as:

$$E = \Sigma_i \Sigma_j (M_{ij} \times EF \times C_g) \qquad (3DB\_10)$$

Where M_{ij} = mass of N lost through leaching and runoff (Gg N)

EF = 0.011 (Gg N_2O-N/Gg N) (CS EF, source IPCC 2019)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

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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 2.

Time series consistency is ensured by the use of consistent methods and full time series recalculations for all refinements to methodology. See section 5.2.1 regarding how changes to data collection methods by the Australian Bureau of Statistics have been addressed to ensure time series consistency of livestock numbers, and reasons for differences in beef cattle and poultry populations with published FAO data..

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 DISER.

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 representing 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 data supplied by Fertilizer Australia and used in the inventory is compared with data published by the FAO. The results are very close between the two data sources (typically less than 1 per cent) throughout the time-series.

DISER 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 '000 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 DISER. These revisions are not reflected in the FAO data.

5.6.12.2 Quality assurance

As data from additional research into 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 2018 Inventory

Recalculations of *agricultural soils* estimates have occurred in the 2021 submission due to:

- changes to the N_2O EF for the cultivation of histosols for Queensland, in response to an ERT recommendation.
- revisions of *cropland remaining cropland* activity data (see Section 6.6, NIR Volume 2) have impacted upon direct and indirect emissions from mineralisation due to loss of soil C.
- changes to the N_2O EF for beef cattle feedlots (see Section 5.4.11). This has impacted on direct emissions for organic fertilisers – animal wastes applied to soils; and indirect emissions – atmospheric deposition and N leaching and runoff, although the impacts are minimal.

Table 5.34 shows the impacts of recalculations.

Table 5.34 Agricultural soils (3.D): recalculations of total CO_2-e emissions, 1990–2018

Year	2020 submission	2021 submission	Change Cultivation of histosols	Change Mineralisation due to loss of soil C	Change Beef cattle feedlots N_2O EF
	(Gg CO_2-e)		(Gg CO_2-e) (per cent)	(Gg CO_2-e) (per cent)	(Gg CO_2-e) (per cent)
1990	12,101	12,343	11.24 (0.09)	228.54 (1.89)	1.42 (0.01)
2000	13,314	13,327	11.24 (0.09)	-0.18 (-0.001)	2.32 (0.02)
2005	12,843	12,949	11.24 (0.09)	91.07 (0.71)	3.11 (0.02)
2010	11,553	11,546	11.24 (0.09)	-20.45 (-0.18)	2.74 (0.02)
2011	12,714	12,702	11.24 (0.09)	-26.35 (-0.21)	2.87 (0.02)
2012	13,196	13,165	11.24 (0.09)	-45.33 (-0.34)	2.84 (0.02)
2013	12,992	12,964	11.24 (0.09)	-41.45 (-0.32)	2.88 (0.02)
2014	13,574	13,540	11.24 (0.09)	-47.78 (-0.35)	2.98 (0.02)
2015	12,960	12,939	11.24 (0.09)	-35.82 (-0.28)	3.49 (0.03)
2016	13,082	13,063	11.24 (0.09)	-33.91 (-0.26)	3.54 (0.03)
2017	14,590	14,590	11.24 (0.09)	-14.28 (-0.10)	3.53 (0.02)
2018	13,304	13,370	11.24 (0.09)	50.71 (0.38)	3.81 (0.03)

Source specific planned improvements

The inventory improvement plan for the agriculture sector identified areas which require updating or review over the next few years. Areas for improvement are identified through the UNFCCC expert reviews, domestic QA/QC processes 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. Work towards phased transition of emissions estimation methods to more complex IPCC tier 3 methods for some elements of the agricultural soils subsector.
2. In response to an ERT recommendation, locate source data to provide information on how inorganic fertiliser EFs are weighted by crop type, climate region, management system and fertiliser type.
3. Consider the disaggregation of inorganic fertiliser EFs into urea and non-urea fertiliser EFs in response to an ERT recommendation.

5.7 Source Category 3.E Prescribed Burning of Savannas

Non-CO_2 emissions from prescribed burning of savannas has been reallocated to 4.A.1 *Forestland remaining forestland*, 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 and methodology

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. However emissions from the other gases are included in the inventory.

Stubble burning involves firing the standing stalks in either late autumn or spring. Increasingly, this form of land management 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 5.35 Burning of agricultural residues – EFs

Gas species	Emission factor 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), Hurst and Cook (1994).

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Table 5.36 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 = Tubers and roots
	11 = Peanuts
	12 = Sugar cane
	13 = Cotton
	14 = Hops
	15 = Oilseeds
	16 = Forage crops

The mass of residue burnt (M_{ij} Gg) 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 P_{ij} = annual production of crop (Gg)

R_j = residue: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; Hurst and Cook, 1994)

F_{ij} = fraction of the annual production of crop that is burnt (ha burnt/ ha harvested) (Appendix 5.I.1 and 5.I.3)

The mass of fuel burnt is converted to emissions of CH_4, CO or NMVOC by multiplying by the carbon content of the fuel, and an EF:

$$E_{ij} = M_{ij} \times CC_j \times EF_g \times C_g \quad (3F\_2)$$

Where E_{ij} = annual emissions from burning of crop residue (Gg)

CC_j = carbon mass fraction in crop residue (Appendix 5.I.1)

EF_g = emission factor (Gg element /Gg burnt) (Table 5.35)

C_g = factor to convert from elemental mass of gas to molecular mass (Table 5.35)

For N_2O and NO_x an additional term in the algorithm, the nitrogen to carbon ratio (NC), is required in order to calculate the fuel nitrogen content. Hence:

$$E_{ij} = M_{ij} \times NC_j \times EF_g \times C_g \quad (3F\_3)$$

Where E_{ij} = annual emissions from burning of crop residue (Gg)

NC_j = nitrogen content in above ground residue (Appendix 5.I.1)

EF_g = emission factor (Gg element /Gg burnt) (Table 5.35)

C_g = factor to convert from elemental mass of gas to molecular mass (Table 5.35)

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 2. 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 2018 Inventory

There were no recalculations to *Field Burning of Agricultural Residues* in the 2021 submission.

Table 5.37 Field Burning of Agricultural Residues (3.F): recalculation of total CO_2-e emissions 1990–2018

Year	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	431	431	-	0
2000	511	511	-	0
2005	338	338	-	0
2010	255	255	-	0
2011	376	376	-	0
2012	381	381	-	0
2013	359	359	-	0
2014	332	332	-	0
2015	317	317	-	0
2016	288	288	-	0
2017	468	468	-	0
2018	326	326	-	0

5.8.5 Source specific planned improvements

All data and methodologies are kept under review.

5.9 Source Category 3.G Liming

5.9.1 Source category description and methodology

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 *forestland.* Adding carbonates to soils in the form of lime (eg. calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$)) results in 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.

Table 5.38 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 (E_{ij} Gg) are calculated as:

$$E_{ij} = ((M_{ij} \times FracLime_{ij} \times P_{j=1} \times EF_{j=1}) + (M_{ij} \times (1-FracLime_{ij}) \times P_{j=2} \times EF_{j=2})) \times C_g / 1000 \qquad (3G\_1)$$

Where M_{ij} = mass of limestone and dolomite applied to soils

$FracLime_{ij}$ = fraction limestone

$P_{j=1}$ = fractional purity of limestone = 0.9 (DCC 2006)

$P_{j=2}$ = fractional purity of dolomite = 0.95 (DCC 2006)

$EF_{j=1}$ = 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

5.9.2 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 2.

National data on limestone and dolomite application 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 the following years: 1996, 2001, 2002, 2008, 2013, 2015, 2016 and 2017.

Additional data is available for Western Australia (1991, 1995, 1998–2000 and 2004). Interpolation techniques were 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.

5.9.3 Source specific QA/QC

This source category is covered by the general QA/QC procedures detailed in Chapter 1.

5.9.4 Recalculations since the 2018 Inventory

There were no recalculations affecting this subsector in the 2021 submission.

Table 5.39 Liming (3.G): recalculation of total CO_2-e emissions 1990–2018

Year	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	215	215	-	0
2000	738	738	-	0
2005	1,076	1,076	-	0
2010	1,253	1,253	-	0
2011	1,088	1,088	-	0
2012	925	925	-	0
2013	760	760	-	0
2014	1,139	1,139	-	0
2015	1,224	1,224	-	0
2016	1,153	1,153	-	0
2017	1,318	1,318	-	0
2018	1,318	1,318	-	0

5.9.5 Source specific planned improvements

All data and methodologies are kept under review.

5.10 Source Category 3.H Urea Application

5.10.1 Source category description and methodology

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.

For urea application, the annual emissions of CO_2 (E_i Gg) are calculated as:

$$E_i = M_i \times EF \times C_g / 1000 \qquad (3H\_1)$$

Where M_i = mass of urea applied to soils

EF = 0.2 – IPCC (2006) default EF for urea

C_g = 44/12 factor to convert elemental mass of CO to molecular mass

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5.10.2 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 2. Time series consistency is ensured by the use of the same methods and data source for the full time series.

5.10.3 Source specific QA/QC

This source category is covered by the general QA/QC procedures detailed in Chapter 1.

5.10.4 Recalculations since the 2018 Inventory

There were no recalculations affecting this subsector in the 2021 submission.

Table 5.40 Urea Application (3.H): recalculation of total CO_2-e emissions 1990–2018

Year	2020 submission	2021 submission	Change	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)
1990	367	367	-	0
2000	963	963	-	0
2005	887	887	-	0
2010	936	936	-	0
2011	1,112	1,112	-	0
2012	1,120	1,120	-	0
2013	1,278	1,278	-	0
2014	1,352	1,352	-	0
2015	1,309	1,309	-	0
2016	1,510	1,510	-	0
2017	1,543	1,543	-	0
2018	1,356	1,356	-	0

5.10.5 Source specific 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
2010–2014	550	370	179	600	225
2015–2019	550	370	179	600	225

Source: Dairy Technical Working Group (2015).

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
2010–2014	0.016	0.6	0.57	0.1	0.8
2015–2019	0.016	0.6	0.57	0.1	0.8

Source: Dairy Technical Working Group (2015).

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
2010–2014	590	590	590	770	770
2015–2019	590	590	590	770	770

Source: Dairy Technical Working Group (2015).

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	0.0180	0.2738	0.0055	0.0084
1995–1999	Heifers<1	0.0178	0.2715	0.0055	0.0083
2000–2004	Heifers<1	0.0177	0.2700	0.0055	0.0082
2005+	Heifers<1	0.0176	0.2685	0.0055	0.0082
All years	Bulls<1	0.0204	0.3003	0.0050	0.0042

Source: Dairy Technical Working Group (2015).

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	0.0548	0.0370	0.0382	0.0512	0.0563	0.01
1995–1999	0.0328	0.0345	0.0699	0.0536	0.0428	0.0415	0.0575	0.0578	0.01
2000–2004	0.0440	0.0456	0.0809	0.0597	0.0524	0.0467	0.0683	0.0619	0.01
2005–2009	0.0743	0.0765	0.0990	0.0819	0.0749	0.0561	0.0871	0.0730	0.01
2010–2014	0.0988	0.1016	0.1032	0.0994	0.0902	0.0670	0.0958	0.0894	0.01
2015–2019	0.0988	0.1016	0.1032	0.0345	0.0902	0.0670	0.0958	0.0894	0.01

Table 5.A.7 Dairy cattle – MCFs

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 (bc)	0.15	0.18	0.50	0.24	0.17	0.13	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 MMS – 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

	ACT/ NSW	NT/QLD	SA	TAS	VIC	WA
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	1.5	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
Anaerobic lagoon	8.6	7.4	8.7	6.3	10.4	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	0.8	1.5
Solid Storage	2.8	3.1	2.6	0.8	1.8	1.6
2010–2014						
Pasture	79.3	79.4	80.7	85.2	84.3	81.9
Anaerobic lagoon	12.0	9.7	10.8	8.0	11.6	10.4
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
2015–2019						
Pasture	79.3	79.4	80.7	85.2	84.3	81.9
Anaerobic lagoon	12.0	9.7	10.8	8.0	11.6	10.4
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

Source: Dairy Technical Working Group (2015).

Table 5.A.9 Dairy Cattle – N_2O oxide EFs and fraction of N volatilised by MMS

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 sources.

(b) Considered similar to a liquid slurry system (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	2015	2018	2019
NSW/ACT	3,603	4,519	4,827	4,925	5,329	6,572	6,948	6,683
NT	3,123	3,964	4,349	3,735	5,052	4,388	4,670	4,320
Queensland	3,123	3,964	4,349	3,735	5,052	4,388	4,670	4,320
South Australia	3,934	5,057	6,790	5,862	5,907	7,411	7,196	6,927
Tasmania	3,775	3,781	4,381	4,497	4,640	6,400	5,805	5,203
Victoria	3,920	4,653	4,989	5,101	5,518	5,795	6,058	5,620
Western Australia	4,202	4,609	6,338	5,418	6,641	5,752	6,199	6,674

Source: Dairy Australia.

Table 5.A.11 Dairy cattle – Population

Year	Population (1000s)	Bulls greater than one year	Bulls less than one year	Heifers greater than one year	Heifers less than one year	Milking Cows
1990	2561.9	25.7	8.7	448.1	381.9	1697.5
1991	2497.0	23.8	8.1	422.2	360.6	1682.3
1992	2500.5	23.7	8.1	415.2	354.3	1699.2
1993	2531.9	23.7	8.1	423.3	361.0	1715.8
1994	2677.6	26.5	9.1	461.3	394.4	1786.4
1995	2740.1	27.3	9.3	475.8	406.8	1820.9
1996	2808.0	27.5	9.4	477.6	409.4	1884.1
1997	2959.3	29.3	10.0	507.3	435.3	1977.5
1998	3075.7	30.2	10.4	525.0	449.5	2060.6
1999	3219.8	31.8	10.9	550.1	472.1	2154.8
2000	3140.4	28.8	9.8	502.4	427.5	2171.8
2001	3217.3	31.0	10.6	538.5	460.7	2176.4
2002	3135.3	30.2	10.3	521.2	447.5	2126.2
2003	3057.0	29.9	10.2	516.1	444.2	2056.6
2004	3067.7	30.4	10.3	526.3	451.6	2049.1
2005	3073.0	29.4	10.0	507.2	436.7	2089.7
2006	2788.5	27.2	9.3	467.6	404.0	1880.4
2007	2663.7	26.0	8.9	446.6	386.3	1795.9
2008	2537.0	15.9	5.4	637.6	237.7	1640.5
2009	2612.3	47.3	16.1	521.7	351.0	1676.2
2010	2542.4	29.6	9.9	697.0	210.1	1595.7
2011	2570.0	61.9	21.1	485.8	412.5	1588.7
2012	2733.2	43.7	14.8	689.3	285.0	1700.4
2013	2833.9	105.0	22.5	576.7	441.3	1688.3
2014	2807.2	96.7	22.6	602.5	438.8	1646.7
2015	2810.6	83.0	22.0	588.3	427.9	1689.4
2016	2742.9	84.8	22.9	595.4	441.5	1598.4
2017	2681.4	85.6	22.9	579.0	438.0	1555.9
2018	2703.9	83.0	22.9	572.0	442.9	1583.1
2019	2410.2	99.3	19.6	505.5	376.9	1408.9

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 1–2 (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 1–2 (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

Sources: QLD and NT data from Bray *et al.* (2015). All other states from NGGIC (2007).

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 1–2 (kg/day)	Cows >2 (kg/day)	Steers <1 (kg/day)	Steers >1 (kg/day)
ACT/NSW		Spring	0.5	0.2	0.5	0.4	0.3	0.5	0.4
		Summer	1.0	0.4	0.9	0.7	0.3	0.9	0.4
		Autumn	0.8	0.3	0.7	0.3	0.2	0.7	0.3
		Winter	0.4	0.1	0.4	0.2	0.1	0.4	0.1
South Australia		Spring	0.99	1.1	0.88	0.55	0.55	0.88	0.22
		Summer	0.77	0.0	0.66	0.22	0.0	0.66	0.0
		Autumn	0.9	-1.1	0.7	0.22	-0.55	0.8	-0.22
		Winter	0.88	0.0	0.77	0.55	0.0	0.82	0.0
Tasmania		Spring	1.0	0.50	1.0	1.0	-0.44	1.0	0.5
		Summer	0.82	0.55	0.71	0.55	0.99	0.77	0.5
		Autumn	0.77	0.50	0.55	0.11	-0.33	0.6	0.33
		Winter	0.11	-0.27	0.11	0.22	-0.44	0.16	-0.22
Victoria		Spring	1.10	1.10	1.10	0.99	0.99	1.10	0.77
		Summer	0.33	0.33	0.22	0.33	-0.10	0.33	0.11
		Autumn	0.50	0.20	0.55	0.44	0.20	0.55	0.20
		Winter	0.55	0.22	0.49	0.22	0.22	0.49	0.33
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	-0.55
		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	0.55
		Winter	0.33	-0.55	0.11	0.11	-0.44	0.33	-0.55

State	Region	Season	Bulls <1 (kg/day)	Bulls >1 (kg/day)	Cows <1 (kg/day)	Cows 1–2 (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	-0.19	0.38	0.25	0.07	0.05	0.52	0.55	0.19	0.60
		Summer	0.16	0.16	0.80	0.57	0.76	0.49	0.84	0.51	0.36	0.17
		Autumn	0.45	0.10	0.49	0.41	0.40	0.17	0.54	0.64	-0.05	0.32
		Winter	0.51	-0.07	0.13	-0.09	-0.13	0.07	0.25	0.71	0.17	0.43
	Moderate/ High	Spring	-0.12	-0.19	0.41	0.09	0.41	-0.19	0.07	1.07	-0.08	0.00
		Summer	0.65	0.19	0.65	0.51	0.18	0.63	1.30	0.48	1.12	0.38
		Autumn	0.70	0.13	0.52	0.34	0.02	0.04	0.77	0.42	0.12	0.74
		Winter	0.32	-0.06	0.25	0.19	-0.10	-0.02	0.02	0.23	-0.13	0.00
	Moderate/ Low	Spring	0.62	-0.19	0.37	0.41	0.06	-0.02	0.47	0.44	0.30	0.13
		Summer	0.05	0.19	0.31	0.54	0.53	0.15	0.28	0.57	0.42	0.40
		Autumn	0.33	0.13	0.39	0.36	0.26	0.11	0.40	0.44	0.37	-0.01
		Winter	0.61	-0.06	0.21	0.18	0.12	0.06	0.29	0.41	0.41	-0.15
	Low	Spring	-0.20	0.02	0.24	0.30	0.23	-0.05	0.34	0.30	0.57	0.52
		Summer	0.62	0.21	0.25	0.32	0.47	0.31	0.14	0.40	0.26	0.43
		Autumn	0.40	0.13	0.12	0.27	0.30	0.08	0.13	0.24	0.15	0.21
		Winter	0.08	0.04	0.06	0.18	0.11	-0.07	0.13	0.16	0.40	0.33

Sources: QLD and NT data from Bray *et al.* (2015). All other states from NGGIC (2007).

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
	South West	80	58	50	75
WA	Pilbara	40	65	55	45
	Kimberley	40	65	55	45

Sources: QLD and NT data from Bray *et al.* (2015). All other states from NGGIC (2007).

Table 5.B.4 Beef cattle – Crude protein content of feed intake (fraction)

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		0.072	0.099	0.078	0.059
SA		0.16	0.07	0.09	0.2
TAS		0.2	0.1	0.16	0.2
VIC		0.25	0.07	0.1	0.21
	South West	0.2	0.09	0.06	0.2
WA	Pilbara	0.04	0.12	0.09	0.06
	Kimberley	0.04	0.12	0.09	0.06

Sources: QLD and NT data from Bray *et al.* (2015). All other states from NGGIC (2007).

Table 5.B.5 Beef Cattle – Feed intake adjustment and milk production and production

State	Region	Season	Feed intake 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
		Winter	0	0

Source: NGGIC (2007).

Table 5.B.6 Beef cattle – Standard reference weights

State	Bulls <1 (kg)	Bulls >1 (kg)	Cows <1 (kg)	Cows 1–2 (kg)	Cows >2 (kg)	Steer <1 (kg)	Steer >1 (kg)
ACT/NSW	700	700	500	500	500	600	600
Northern Territory	770	770	550	550	550	660	660
Queensland	770	770	550	550	550	660	660
South Australia	770	770	550	550	550	660	660
Tasmania	770	770	550	550	550	660	660
Victoria	770	770	550	550	550	660	660
Western Australia	770	770	550	550	550	660	660

Source: NGGIC (2007), based on SCA 1990.

Table 5.B.7 Beef cattle – Allocation of animals to climate regions

State	Region	Proportion Warm	Proportion Temperate
ACT/NSW		0	1
Northern Territory	Alice Springs	0	1
	Barkly	0.5	0.5
	Northern	1	0
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

Sources: QLD and NT data from Bray *et al.* (2015). All other states from NGGIC (2007).

Table 5.B.8 Beef cattle – Population

Year	Total beef cattle population (1000s)	Bulls <1 year	Bulls >1 year	Cows <1 year	Cows 1–2 years	Cows >2 years	Cows >2 years (Cows 2–3)
1990	21,947.5	111.6	410.5	3010.5	2645.8	4463.9	928.3
1991	22,538.9	106.8	400.0	3091.7	2661.4	4361.3	962.9
1992	22,446.2	102.7	387.8	3069.2	2649.7	4326.3	962.9
1993	22,253.5	100.4	378.5	2983.5	2696.4	4553.5	945.7
1994	22,645.6	102.4	381.0	3029.6	2758.5	4846.3	926.2
1995	22,544.9	101.0	376.1	3123.2	2662.5	4463.8	935.6
1996	23,115.4	100.0	376.4	3140.3	2727.5	4551.3	963.4
1997	23,286.0	99.3	376.0	3235.4	2770.2	4604.8	982.5
1998	23,272.0	98.9	378.0	3250.7	2739.8	4369.5	1013.0
1999	22,812.4	95.0	365.3	3146.7	2694.8	4279.3	1001.5
2000	23,872.2	98.7	384.6	3295.2	2839.7	4353.5	1088.3
2001	23,859.1	107.1	408.6	3252.6	2766.6	4367.2	1052.5
2002	24,180.2	110.2	419.2	3177.4	2832.5	4461.8	1079.2
2003	23,149.0	108.4	405.3	3050.7	2752.5	4499.9	1011.8
2004	24,084.0	110.0	417.2	3042.8	2869.1	4575.0	1080.9
2005	24,389.0	116.2	434.7	3149.3	2921.7	4684.9	1094.7
2006	24,746.8	123.7	454.6	3231.2	2936.2	4802.9	1071.4
2007	24,487.8	134.3	484.8	3195.2	2896.1	4583.0	1095.7
2008	24,098.5	117.2	440.6	2990.9	2995.4	4705.8	1138.0
2009	24,589.5	120.6	453.6	3200.8	2941.8	4544.3	1131.3
2010	23,262.7	117.8	438.5	2951.0	2825.2	4381.2	1091.1
2011	25,156.9	118.8	460.9	3364.0	2953.6	4346.9	1211.0
2012	24,912.8	124.4	466.1	3126.2	3037.4	4754.2	1169.7
2013	25,671.1	143.0	472.0	3437.6	3034.3	4517.7	1220.4
2014	25,484.9	137.6	479.3	3383.4	3003.6	4389.5	1226.6
2015	23,676.5	129.9	460.5	3103.4	2807.8	4362.1	1089.0
2016	23,334.1	135.8	423.8	3163.3	2764.3	4246.9	1070.5
2017	23,971.5	135.9	435.2	3144.6	2850.5	4516.5	1070.6
2018	24,108.3	134.4	426.9	3234.4	2865.5	4235.7	1143.3
2019	22,538.8	123.3	409.3	3009.5	2684.2	3928.9	1080.6

Year	Cows >2 years (Cows >3)	Steers <1 year	Steers >1 year	Steers >1 year (Steers 1–2)	Steers >1 year (Steers 2–3)	Steers >1 year (Steers >3)
1990	3484.9	3170.5	1640.4	1225.2	663.7	192.2
1991	3613.8	3255.4	1922.7	1273.0	690.1	199.9
1992	3613.7	3231.0	1939.8	1273.0	690.2	199.9
1993	3551.2	3138.2	1783.1	1249.4	677.4	196.2
1994	3487.4	3198.4	1853.6	1214.8	657.5	190.0
1995	3476.2	3303.8	2085.0	1203.0	625.1	189.7
1996	3583.4	3317.4	2283.9	1235.8	641.6	194.5
1997	3648.8	3419.6	2029.3	1263.0	657.7	199.2
1998	3763.6	3426.7	2042.3	1303.7	679.8	206.0
1999	3722.5	3313.8	2031.1	1287.6	671.3	203.4
2000	4034.1	3464.8	1944.5	1409.2	736.1	223.5
2001	4045.9	3427.2	2113.0	1360.2	736.2	222.1
2002	4151.6	3335.2	2241.1	1391.9	753.1	227.0
2003	3894.7	3207.1	1998.2	1303.1	704.8	212.4
2004	4156.0	3182.7	2268.7	1397.0	756.4	228.2
2005	4209.0	3300.4	2062.9	1416.3	767.4	231.5
2006	4100.1	3397.3	2264.1	1391.3	753.8	220.1
2007	4198.5	3352.3	2141.8	1416.6	766.1	223.4
2008	4361.0	3110.2	1753.1	1465.6	790.3	230.4
2009	4307.5	3350.5	2008.2	1486.3	807.9	236.6
2010	4193.1	3079.3	1817.3	1396.9	752.2	218.9
2011	4619.6	3513.7	1882.2	1551.9	871.4	262.9
2012	4551.5	3253.1	1947.2	1467.2	778.8	237.0
2013	4741.1	3588.1	1910.6	1538.6	818.4	249.3
2014	4761.3	3527.8	1948.0	1550.5	825.6	251.7
2015	4247.0	3247.5	1927.7	1360.4	721.8	219.5
2016	4141.7	3328.5	1736.1	1365.3	742.4	215.7
2017	4128.7	3298.6	2064.2	1369.1	743.7	213.9
2018	4389.5	3381.7	1773.7	1481.0	808.7	233.5
2019	4161.8	3144.0	1682.6	1387.4	754.9	217.4

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)	2010–2014 (a)	2015–2019
Domestic							
Days on feed		75	75	70	70	70	70
Average daily gain	kg/d	1.5	1.6	1.7	1.7	1.7	1.7
Mean liveweight	kg LW	356	360	381	400	410	410
N retention (b)	per cent of intake	21.4	22.3	22.2	21.1	20.4	20.4
Mid-fed							
Days on feed		140	120	115	115	115	115
Average daily gain	kg/d	1.5	1.5	1.6	1.7	1.7	1.7
Mean liveweight	kg LW	520	529	534	538	538	538
N retention (b)	per cent of intake	11.8	11.6	12.0	12.5	12.7	12.7
Long-fed							
Days on feed		250	250	250	250	250	250
Average daily gain	kg/d	1.1	1.1	1.1	1.2	1.3	1.3
Mean liveweight	kg LW	598	598	598	600	613	613
N retention (b)	per cent of intake	6.4	6.3	6.1	6.6	7.0	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 known industry performance (Dr Rob Lawrence Integrated Animal Production, pers. comm. 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)	2010–2014 (b)	2015–2019
Domestic and Mid-fed							
Dry matter digestibility	per cent	80	81	81	81	81	81
Crude protein	per cent	13.2	13.2	13.2	13.3	13.4	13.4
Net Energy (NEma)	MJ/kg	8.0	8.0	8.0	8.2	8.4	8.4
Soluble residue		0.58	0.61	0.64	0.63	0.62	0.62
Hemi-cellulose		0.09	0.09	0.10	0.10	0.10	0.10
Cellulose		0.12	0.08	0.05	0.05	0.05	0.05
Long-Fed							
Dry matter digestibility	per cent	80	80	80	79	79	79
Crude protein	per cent	13.2	13.6	14.0	13.6	13.2	13.2
Net Energy (NEma)	MJ/kg	8.0	8.0	8.1	8.2	8.3	8.3
Soluble residue		0.57	0.57	0.57	0.57	0.58	0.58
Hemi-cellulose		0.12	0.12	0.12	0.12	0.12	0.12
Cellulose		0.06	0.06	0.06	0.07	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, pers. comm.) in 2014.

Table 5.C.3 Feedlot cattle – Integrated EFs

	1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2019
iMCF						
NSW	0.03420	0.03420	0.03345	0.03230	0.03230	0.03230
QLD	0.04213	0.04213	0.04138	0.04023	0.04023	0.04023
SA	0.03420	0.03420	0.03345	0.03230	0.03230	0.03230
VIC	0.03420	0.03420	0.03345	0.03230	0.03230	0.03230
WA	0.03460	0.03460	0.03385	0.03270	0.03270	0.03270
$iFracGASM_{MMS}$	0.68980	0.68980	0.69790	0.71032	0.71032	0.71116
iNOF	0.021656	0.021656	0.021926	0.022340	0.022340	0.019420

Note: Integrated factors are derived from the allocation of waste to different MMS (Table 5.C.4) and the specific MCF (Table 5.C.5), N_2O EF (Table 5.C.6) and $FracGASM_{MMS}$ (Table 5.C.7) of each MMS.

Table 5.C.4 Feedlot cattle – Allocation of waste to MMS (per cent)

MMS	1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2019
Primary Systems						
Drylot (Feedpad)	100.0	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	54.0
Composting (Passive windrow)	0.0	0.0	15.0	38.0	38.0	38.0
Direct Application	8.0	8.0	8.0	8.0	8.0	8.0
Tertiary System (b)						
Uncovered anaerobic lagoon (Effluent pond)	2.0	2.0	2.0	2.0	2.0	2.0

(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 – 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 (c) (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 EFs (kg N_2O-N / kg N)

MMS	N_2O	Source
Dry lot (Feedpad)	0.0054	Wiedemann & Longworth (2020)
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 MMS

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 (2019)

Table 5.C.8 Feedlot cattle – Population

Year	Population 1000s	Domestic	Export Mid-fed	Export Long-fed
1990	328.8	30821.9	143835.6	154109.6
1991	345.2	32363.0	151027.4	161815.1
1992	379.7	35599.3	166130.1	177996.6
1993	394.9	48949.1	182743.2	163163.5
1994	434.3	53844.0	201017.5	179479.9
1995	446.2	59228.4	189530.8	197427.9
1996	453.9	77074.3	205531.4	171276.2
1997	450.5	95562.5	218428.6	136517.9
1998	503.7	106847.6	244223.1	152639.5
1999	545.7	115752.9	264578.1	165361.3
2000	575.8	116731.9	268483.4	190582.7
2001	644.2	130594.5	300367.3	213215.5
2002	678.3	137236.9	314452.0	226653.6
2003	695.4	140677.9	322336.3	232336.5
2004	684.6	138498.7	317343.1	228737.5
2005	817.0	165288.4	378726.6	272982.0
2006	858.7	173731.0	398071.1	286925.3
2007	885.5	179139.3	410463.3	295857.4
2008	685.6	138697.5	317798.5	229065.7
2009	705.0	176097.5	353056.9	175864.6
2010	745.1	186099.6	373110.0	185853.4
2011	779.2	194635.4	390223.3	194377.9
2012	772.4	192929.7	386803.7	192674.5
2013	785.8	196276.2	393513.1	196016.6
2014	810.9	202532.1	406055.5	202264.2
2015	925.7	187676.0	431654.9	306409.9
2016	936.6	189883.6	436732.3	310014.0
2017	939.7	197257.9	441857.7	300583.5
2018	1031.3	217121.0	581574.0	232629.6
2019	1111.8	240978.7	630178.3	240659.9

Appendix 5.D Sheep

Table 5.D.1 Sheep – Liveweight (kg)

				Sheep > 1			Sheep < 1
State	Season	Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
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

Source: NGGIC (2007).

Table 5.D.2 Sheep – Dry matter digestibility of feed intake (per cent)

State	Season	Rams	Wethers	Sheep > 1 Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Sheep < 1 Lambs & Hoggets
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

Source: NGGIC (2007).

Table 5.D.3 Sheep – Feed availability (t/ha)

State	Season	Rams	Wethers	Sheep > 1 Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Sheep < 1 Lambs & Hoggets
ACT/NSW	Spring	2.9	2.9	2.9	2.9	2.9	2.9
	Summer	2.5	2.5	2.5	2.5	2.5	2.5
	Autumn	1.6	1.6	1.6	1.6	1.6	1.6
	Winter	1.7	1.7	1.7	1.7	1.7	1.7
Queensland	Spring	1.5	1.5	1.5	1.5	1.5	1.5
	Summer	2.0	2.0	2.0	2.0	2.0	2.0
	Autumn	2.2	2.2	2.2	2.2	2.2	2.2
	Winter	1.7	1.7	1.7	1.7	1.7	1.7
South Australia	Spring	4.0	4.0	4.0	4.0	4.0	4.0
	Summer	2.5	2.5	2.5	2.5	2.5	2.5
	Autumn	0.7	0.7	0.7	0.7	0.7	0.7
	Winter	0.9	0.9	0.9	0.9	0.9	0.9
Tasmania	Spring	2.5	2.5	2.5	2.5	2.5	2.5
	Summer	2.5	2.5	2.5	2.5	2.5	2.5
	Autumn	1.3	1.3	1.3	1.3	1.3	1.3
	Winter	0.8	0.8	0.8	0.8	0.8	0.8
Victoria	Spring	3.2	3.2	3.2	3.2	3.2	3.2
	Summer	3.0	3.0	3.0	3.0	3.0	3.0
	Autumn	1.8	1.8	1.8	1.8	1.8	1.8
	Winter	1.0	1.0	1.0	1.0	1.0	1.0
Western Australia	Spring	3.5	3.5	3.5	3.5	3.5	3.5
	Summer	1.5	1.5	1.5	1.5	1.5	1.5
	Autumn	0.7	0.7	0.7	0.7	0.7	0.7
	Winter	1.2	1.2	1.2	1.2	1.2	1.2

Source: NGGIC (2007).

Table 5.D.4 Sheep – Crude protein content of feed intake (per cent)

		Sheep > 1					Sheep < 1
State	Season	Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
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

Source: NGGIC (2007).

Table 5.D.5 Sheep – Liveweight gain (kg/day)

State	Season	Rams	Wethers	Sheep > 1 Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Sheep < 1 Lambs & Hoggets
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

Source: NGGIC (2007).

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: NGGIC (2007). 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)

			Sheep > 1			Sheep < 1
State	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

Source: NGGIC (2007), based on SCA 1990.

Table 5.D.8 Sheep – Population

Year	Population 1000s	Rams	Wethers	Maiden Ewes	Breeding Ewes	Other Ewes	Lambs and Hoggets
1990	173,738.0	1,804.9	48,749.1	13,704.5	62,700.5	6,079.6	40,699.5
1991	166,526.4	1,732.6	49,741.2	12,309.4	56,167.0	9,916.9	36,659.3
1992	150,960.8	1,594.7	46,354.3	11,987.1	54,743.4	8,015.7	28,265.7
1993	140,531.0	1,470.7	41,006.3	11,222.1	51,335.0	6,697.6	28,799.2
1994	132,569.2	1,431.9	34,753.7	10,894.6	49,884.1	5,866.2	29,738.7
1995	120,861.7	1,280.3	34,509.9	9,662.1	44,210.9	4,368.8	26,829.7
1996	121,115.9	1,094.1	29,734.7	10,233.6	46,948.3	3,695.5	29,409.5
1997	120,228.1	1,023.9	27,916.1	10,270.0	47,110.4	3,446.7	30,461.1
1998	117,491.5	1,004.8	27,470.6	9,964.9	45,731.0	3,362.8	29,957.4
1999	115,456.1	959.4	26,190.6	9,940.5	45,668.2	3,201.1	29,496.2
2000	118,551.7	1,048.9	28,562.0	9,757.3	44,965.8	3,518.5	30,699.2
2001	110,927.7	930.6	25,513.6	9,530.3	43,894.8	3,089.1	27,969.3
2002	106,056.5	798.2	21,758.6	9,348.9	43,139.4	2,652.8	28,358.7
2003	99,048.8	704.0	19,082.2	9,085.8	42,023.7	2,362.1	25,790.9
2004	100,973.1	663.4	17,916.9	9,122.1	42,207.4	2,253.3	28,810.0
2005	100,705.9	616.7	16,679.5	9,292.1	42,988.2	2,102.8	29,026.7
2006	91,026.0	756.6	20,337.0	7,588.5	35,096.5	2,565.3	24,682.0
2007	85,711.2	665.3	17,867.3	7,371.3	34,146.6	2,240.6	23,420.1
2008	76,937.5	472.2	12,757.4	8,059.9	37,351.4	1,589.7	16,706.8
2009	72,739.7	370.2	10,013.7	7,256.6	33,610.3	1,239.9	20,249.0
2010	68,085.5	299.5	8,120.1	7,502.7	34,762.7	1,010.1	16,390.4
2011	73,096.9	304.3	8,204.2	7,420.7	34,400.8	1,009.5	21,757.4
2012	74,721.6	290.8	7,864.5	7,955.1	36,895.2	970.7	20,745.1
2013	75,547.8	343.2	9,224.4	7,136.1	33,114.2	1,160.5	24,569.5
2014	72,612.3	337.1	9,025.3	7,203.3	33,447.0	1,132.8	21,466.8
2015	70,909.6	321.3	8,535.4	6,970.3	32,380.4	1,064.0	21,638.3
2016	70,866.6	306.4	8,159.5	6,949.8	32,297.7	1,032.3	22,120.8
2017	75,686.6	318.9	8,481.6	7,456.6	34,670.0	1,063.4	23,696.2
2018	74,082.6	295.0	7,878.3	7,452.3	34,669.1	983.3	22,804.6
2019	69,003.2	287.8	7,727.2	7,051.1	32,809.4	977.2	20,150.5

Appendix 5.E Swine

PIGBAL (v4; Skerman *et al.* 2013) is a nutrient balance model for intensive piggeries in Australia. By entering typical animal characteristics, intakes, diet compositions and wastage rates (Tables 5.E.1 and 5.E.2), the model calculates the volatile solids in animal manure and waste feed and the nitrogen retained by the animals (Table 5.E.3).

Swine industry experts provided information such as average intakes for a typical herd.

Table 5.E.1 Swine – Herd characteristics

	Units	1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2019
Swine mass and productivity							
Avg live weight							
Sows	kg/pig	188	188	198	198	188	188
Boars	kg/pig	201	204	206	207	206	206
Gilts	kg/pig	115	121	125	127	125	125
Slaughter pigs	kg/pig	34	36	34	38	39	39
Slaughter pigs at turnoff	kg/pig	85	91	95	94	97	97
Avg slaughter pig age at turnoff	weeks	21	21	21	20	21	21
Breeder mortality	per cent	10	10	10	10	10	10
Slaughter pig mortality	per cent	5	5	5	5	5	5
Pigs slaughtered / sow per year	pigs/sow/yr	19	18	19	19	21	21
Dressing percentage	per cent	76	77	77	78	78	78
FCR (whole herd)	kg feed fed / kg live weight	3	3	3	3	3	3
ADG (wean-finish)	g/day/pig	658	690	721	727	730	730
Feed intake (ingested as-fed)							
Sows	kg/pig/day	2.98	2.92	3.31	2.58	2.62	2.62
Boars	kg/pig/day	2.20	2.20	2.20	2.30	2.30	2.30
Gilts	kg/pig/day	2.20	2.20	2.80	2.50	2.50	2.50
Slaughter pigs (mean LW)	kg/pig/day	1.49	1.47	1.63	1.65	1.71	1.71
Feed wastage (per cent)							
Sows	per cent	5.0	5.0	5.0	5.0	5.0	5.0
Boars	per cent	5.0	5.0	5.0	5.0	5.0	5.0
Gilts	per cent	10.0	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	11.0

Source: Wiedemann *et al.* (2014)

Table 5.E.2 Pigs – Feed specifications

Diet characteristics		1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2019
Breeder herd							
Dry matter	per cent	90.2	90.2	91.2	91.2	88.8	88.8
DMD	per cent	82.7	82.5	82.1	82.2	80.3	80.3
CP	per cent	2.6	2.5	2.4	2.4	2.3	2.3
Slaughter pig herd							
Dry matter	per cent	90.2	90.2	90.2	90.2	88.8	88.8
DMD	per cent	86.9	87.0	86.2	85.8	82.5	82.5
CP	per cent	3.5	3.5	3.1	3.0	2.6	2.6

Source: Wiedemann *et al.* (2014)

Table 5.E.3 Swine – Manure characteristics derived from PigBAL

Diet characteristics		1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2019
Breeder herd							
Manure ash							
Boars	per cent	26.3	26.3	25.3	25.4	26.7	26.7
Sows	per cent	27.0	27.1	26.7	26.0	25.5	25.5
Gilts	per cent	31.4	31.7	25.7	25.4	24.7	24.7
N retention							
Boars	per cent DMI	24.3	23.2	21.8	23.9	27.6	27.6
Sows	per cent DMI	7.9	7.7	7.4	10.1	9.7	9.7
Gilts	per cent DMI	24.3	23.2	21.8	23.9	27.6	27.6
Volatile solids							
Boars	kg/hd/day	0.37	0.37	0.39	0.40	0.40	0.40
Sows	kg/hd/day	0.47	0.47	0.55	0.43	0.46	0.46
Gilts	kg/hd/day	0.41	0.41	0.57	0.51	0.55	0.55
Nitrogen in waste							
Boars	kg/hd/yr	17.11	17.19	16.47	17.35	16.93	16.93
Sows	kg/hd/yr	23.37	23.27	25.91	19.24	17.91	17.91
Gilts	kg/hd/yr	21.84	22.12	22.57	19.69	16.70	16.70
Slaughter pig herd							
Manure ash	per cent	34.7	34.4	29.5	28.1	21.7	21.7
N retention	per cent	32.0	33.9	36.8	37.3	42.1	42.1
Volatile solids	kg/hd/day	0.28	0.27	0.32	0.36	0.39	0.39
Nitrogen in waste	kg/hd/yr	15.6	15.0	14.0	14.2	11.4	11.4

Source: PigBal v4 – Skerman *et al.* (2013).

Table 5.E.4 Swine – Integrated EFs

	NT	NSW	QLD	SA	TAS	VIC	WA
1990–1994							
iMCF	0.72623	0.68299	0.72623	0.66132	0.61742	0.65483	0.68924
$iFracGASM_{MMS}$	0.53068	0.52283	0.53068	0.51433	0.51433	0.51948	0.51853
iNOF	0.00035	0.00105	0.00035	0.00120	0.00120	0.00116	0.00117
1995–1999							
iMCF	0.70229	0.65038	0.70229	0.62570	0.58435	0.62654	0.62798
$iFracGASM_{MMS}$	0.52280	0.51124	0.52280	0.50154	0.50154	0.50915	0.49734
iNOF	0.00096	0.00178	0.00096	0.00203	0.00203	0.00182	0.00255
2000–2004							
iMCF	0.64298	0.51916	0.64298	0.45333	0.42448	0.47581	0.45708
$iFracGASM_{MMS}$	0.50266	0.46475	0.50266	0.44051	0.44051	0.45409	0.43856
iNOF	0.00227	0.00470	0.00227	0.00593	0.00593	0.00534	0.00630
2005–2009							
iMCF	0.64598	0.52826	0.64598	0.46862	0.43867	0.48901	0.47428
$iFracGASM_{MMS}$	0.50406	0.46832	0.50406	0.44630	0.44630	0.46215	0.44490
iNOF	0.00225	0.00454	0.00225	0.00563	0.00563	0.00489	0.00600
2010–2014							
iMCF	0.64598	0.44174	0.61990	0.56080	0.52430	0.45067	0.52871
$iFracGASM_{MMS}$	0.50406	0.45946	0.50371	0.47860	0.47860	0.45279	0.46465
iNOF	0.00225	0.00517	0.00243	0.00343	0.00343	0.00533	0.00498
2015–2019							
iMCF	0.64598	0.44174	0.61990	0.56080	0.52430	0.45067	0.52871
$iFracGASM_{MMS}$	0.50406	0.45946	0.50371	0.47860	0.47860	0.45279	0.46465
iNOF	0.00225	0.00517	0.00243	0.00343	0.00343	0.00533	0.00498

Table 5.E.5 Swine – Allocation of waste to MMS (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 [(c)]	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 [(c)]	3.4	3.6	3.6	3.4	3.4	3.4	3.2

	NSW	NT	QLD	SA	TAS	VIC	WA
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
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 [(c)]	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 [(c)]	1.8	2.2	2.2	1.6	1.6	1.7	1.6
2010–2014							
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 [(c)]	1.7	2.2	2.1	2.0	2.0	1.7	1.8
2015–2019							
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 [(c)]	1.7	2.2	2.1	2.0	2.0	1.7	1.8

Source: Wiedemann *et al.* (2014)

(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 Swine – 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 Swine – Nitrous oxide EFs by MMS

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 Swine – Fraction of N volatilised by MMS

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)

Table 5.E.9 Swine – Population

Year	Population 1000s	Boars	Sows	Gilts	Others
1990	2,689.9	21.7	295.7	41.0	2,331.5
1991	2,572.2	21.6	274.2	38.1	2,238.3
1992	2,618.8	21.5	289.4	40.3	2,267.7
1993	2,672.2	20.9	276.4	38.4	2,336.5
1994	2,775.3	21.4	283.2	39.3	2,431.3
1995	2,652.8	21.5	291.6	40.7	2,299.0
1996	2,526.4	20.5	277.7	38.9	2,189.3
1997	2,555.2	20.1	266.3	37.1	2,231.7
1998	2,768.3	19.7	280.9	39.0	2,428.7
1999	2,626.4	16.7	271.3	37.8	2,300.7
2000	2,510.9	15.2	257.4	35.8	2,202.4
2001	2,748.0	16.5	293.1	39.4	2,399.0
2002	2,980.2	17.0	315.6	44.2	2,603.4
2003	2,730.1	14.1	308.2	52.4	2,355.4
2004	2,651.1	12.7	291.8	37.7	2,309.0
2005	2,675.1	11.5	298.5	45.6	2,319.4
2006	2,733.0	12.3	301.9	50.2	2,368.6
2007	2,604.7	11.4	285.6	53.8	2,253.8
2008	2,411.5	10.5	263.0	49.9	2,088.2
2009	2,301.8	8.4	242.2	35.7	2,015.5
2010	2,289.3	10.1	231.7	49.9	1,997.7
2011	2,285.2	8.8	261.2	33.9	1,981.3
2012	2,137.9	8.4	236.6	32.1	1,860.9
2013	2,098.1	8.4	224.5	31.9	1,833.3
2014	2,308.2	8.8	266.2	34.8	1,998.4
2015	2,272.2	8.7	271.1	33.9	1,958.4
2016	2,320.3	9.2	243.4	35.6	2,032.0
2017	2,515.0	9.9	282.5	38.2	2,184.5
2018	2,563.1	10.1	278.8	38.6	2,235.7
2019	2,345.8	9.1	274.1	34.8	2,027.9

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/head/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

Source: Wiedemann *et al.* (2014)

(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 chickens – Integrated EFs

	1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2019
iMCF						
Meat chickens						
ACT/NSW	0.024830	0.024830	0.024771	0.024711	0.024414	0.024414
NT/QLD	0.024870	0.024870	0.024891	0.024911	0.025014	0.025014
SA	0.024830	0.024830	0.024771	0.024711	0.024414	0.024414
TAS	0.023812	0.023812	0.023757	0.023702	0.023425	0.023425
VIC	0.024830	0.024830	0.024771	0.024711	0.024414	0.024414
WA	0.024830	0.024830	0.024771	0.024711	0.024414	0.024414
Layer chickens						
ACT/NSW	0.029841	0.029887	0.030655	0.031527	0.031702	0.031702
NT/QLD	0.029869	0.029927	0.030743	0.031687	0.031930	0.031930
SA	0.029841	0.029887	0.030655	0.031527	0.031702	0.031702
TAS	0.029229	0.029273	0.030009	0.030845	0.031011	0.031011
VIC	0.029841	0.029887	0.030655	0.031527	0.031702	0.031702
WA	0.029841	0.029887	0.030655	0.031527	0.031702	0.031702
$iFracGASM_{MMS}$						
Meat chickens	0.397064	0.397064	0.395473	0.393881	0.385924	0.385924
Layer chickens	0.483880	0.478978	0.413370	0.336948	0.315956	0.315956
iNOF						
Meat chickens	0.004277	0.004277	0.004260	0.004242	0.004157	0.004157
Layer chickens	0.004327	0.004261	0.004454	0.004675	0.004728	0.004728

Table 5.F.3 Poultry – Meat chickens allocation of waste to MMS (per cent)

MMS	1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2019
Primary system						
Poultry manure with litter (housing)	99.8	99.8	99.4	99.0	97.0	97.0
Pasture range and paddock (free range)	0.2	0.2	0.6	1.0	3.0	3.0
Secondary system [(a)]						
Solid storage (stockpile)	46.0	46.0	46.0	46.0	46.0	46.0
Composting (passive windrow)	24.0	24.0	24.0	24.0	24.0	24.0
Direct application to soil	30.0	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 MMS (per cent)

MMS	1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2019
Primary system						
Poultry manure without litter (housing)	98	97.2	93.8	89.0	85.4	85.4
Belt manure removal	8	9.4	31	55.8	61.6	61.6
Manure stored in house under cages or slat	90	87.8	62.8	33.2	23.8	23.8
Poultry manure with litter (housing)	1.86	2.6	5.76	10.2	13.46	13.46
Pasture range and paddock (free range)	0.14	0.2	0.44	0.8	1.14	1.14
Secondary System [(a)]						
Solid storage (stockpile)	76.0	76.0	76.0	76.0	76.0	76.0
Composting (passive windrow)	15.0	15.0	15.0	15.0	15.0	15.0
Direct application to soils	5.0	5.0	5.0	5.0	5.0	5.0
Direct processing	2.5	2.5	2.5	2.5	2.5	2.5
Anaerobic digester / covered pond	1.5	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 – MCFs

MMS	All states	NSW/ACT	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 EFs by MMS

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 MMS

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)

Table 5.F.8 Poultry – Population

Year	Population (1000s)	Layers	Meat chickens	Ducks	Other
1990	58,982.6	13,090.2	43,926.8	275.9	1,689.6
1991	54,764.0	12,595.6	39,901.8	364.3	1,902.2
1992	56,627.2	9,561.5	44,771.4	413.7	1,880.6
1993	64,472.0	10,886.6	51,688.7	403.9	1,492.8
1994	62,161.0	9,792.9	50,659.4	447.2	1,261.4
1995	68,172.2	11,120.7	54,855.3	429.3	1,766.9
1996	71,475.3	10,119.1	58,646.2	411.4	2,298.6
1997	76,517.5	10,306.1	63,674.1	390.2	2,147.1
1998	82,246.9	9,660.8	70,153.5	455.6	1,977.0
1999	94,159.7	13,608.9	78,472.5	370.1	1,708.1
2000	87,716.2	12,015.6	73,486.8	517.0	1,696.7
2001	93,612.2	14,276.0	77,254.0	769.7	1,312.6
2002	87,368.9	12,857.7	72,739.2	567.4	1,204.6
2003	86,473.0	12,913.4	71,737.9	694.1	1,127.6
2004	85,455.7	12,668.7	70,734.7	953.1	1,099.2
2005	78,196.8	13,174.7	62,728.1	1,309.4	984.6
2006	97,016.9	15,935.7	78,448.4	766.1	1,866.7
2007	100,802.1	15,316.2	82,114.3	905.9	2,465.8
2008	90,900.8	14,759.8	73,869.2	807.8	1,464.0
2009	102,271.2	12,604.2	82,805.1	1,472.8	5,389.0
2010	90,048.5	11,733.8	71,290.1	1,360.6	5,663.9
2011	98,767.3	13,111.2	77,632.8	1,000.0	7,023.3
2012	100,996.2	13,378.6	80,841.7	773.3	6,002.7
2013	105,794.7	14,617.8	84,035.1	953.2	6,188.6
2014	105,927.4	15,332.0	84,035.1	949.7	5,610.6
2015	109,797.5	17,500.2	88,658.8	615.1	3,023.4
2016	111,490.2	15,978.3	92,424.2	658.3	2,429.3
2017	117,556.2	16,498.8	97,491.5	709.2	2,856.7
2018	122,407.6	16,574.0	102,365.6	658.3	2,809.7
2019	136,250.9	16,782.3	114,696.0	872.3	3,900.3

Appendix 5.G Other livestock

Table 5.G.1 Other livestock – Manure production (kg DM/head/year)

Livestock type	Manure production (kg DM/head/year)	Expert Working Group Assumption
Goats, alpacas, emus and ostriches	114	Equivalent to one sheep
Deer, mules and asses	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	Nitrogen excretion factors (kg N/head/year)	Expert Working Group Assumption
Goats, alpacas, emus and ostriches	7.0	Equivalent to one sheep
Deer, mules and asses	13.2	One-third of beef cattle – pasture
Horses, buffalo and camels	39.5	Equivalent to beef cattle – pasture

Table 5.G.3 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
TAS	0	1
VIC	0	1
WA	0	1

Table 5.G.4 Other livestock – Population

Year	Buffalo ('000)	Camels ('000)	Deer ('000)	Goats ('000)	Horses ('000)	Mules/ asses ('000)	Alpacas ('000)	Ostriches/ emus ('000)
1990	13.4	0.7	61.4	660.6	359.3	2.7	0.3	4.1
1991	18.6	1.0	80.4	530.5	347.0	3.3	0.8	8.6
1992	13.0	1.7	101.7	411.3	334.8	4.0	0.9	14.5
1993	11.4	1.8	130.6	286.1	314.8	2.9	1.8	23.7
1994	11.6	1.5	148.8	231.6	294.4	2.5	3.0	45.1
1995	10.9	1.1	144.3	132.8	237.7	1.6	1.8	32.5
1996	8.9	0.9	136.2	154.5	235.1	1.1	4.3	100.3
1997	9.4	1.1	152.4	176.4	234.0	0.8	6.7	168.1
1998	11.2	1.4	165.8	218.9	233.3	0.4	4.6	170.1
1999	8.5	1.9	127.0	193.5	215.4	0.4	5.7	105.0
2000	6.1	2.0	150.8	327.4	212.1	0.6	12.1	93.9
2001	7.3	2.6	131.9	391.1	224.0	0.9	18.1	82.8
2002	13.6	2.6	101.2	386.7	204.3	0.8	24.4	71.6
2003	8.6	2.5	100.2	485.8	231.2	0.5	30.8	60.5
2004	8.4	2.0	78.7	594.7	219.1	0.3	37.1	49.3
2005	6.2	1.9	59.5	461.5	221.0	0.3	61.0	38.2
2006	3.2	1.8	68.7	517.7	257.1	0.4	73.7	32.9
2007	2.7	2.0	79.7	518.0	263.3	0.4	98.1	32.9
2008	3.3	2.2	62.4	622.9	259.9	0.5	103.6	22.4
2009	8.6	2.4	46.1	727.7	256.4	0.6	106.5	12.0
2010	6.5	2.8	45.6	513.3	258.0	0.7	122.0	8.5
2011	4.4	3.1	45.1	546.6	259.5	0.8	134.0	9.9
2012	5.1	3.3	38.4	516.1	254.2	0.9	132.0	9.7
2013	5.1	3.3	38.4	516.1	254.2	0.9	132.0	9.7
2014	5.1	3.3	38.4	516.1	254.2	0.9	132.0	9.7
2015	5.1	3.3	38.4	516.1	254.2	0.9	132.0	9.7
2016	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8
2017	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8
2018	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8
2019	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8

Appendix 5.H Synthetic fertilisers

Table 5.H.1 Sugar cane N fertiliser application rates (kg/ha)

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	183	160
2018	189	161
2019	170	140

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 above-ground	N content below-ground	Fraction of residue remaining at time of burning[(b)]	Fraction burnt	Fraction removed
k	R_{AGk}	R_{BGk}	DMk	CCk	NC_{AGk}	NC_{BGk}	S_k	F^{ik}	$FFOD^{lk}$
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	1.46	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
Tubers 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	2.08	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

	Fraction renewed		Average yield [a]	N content [b]			
Pasture type	Intensive	Other	(t DM ha)	Below-ground: above-ground residue ratio [b]	Above-ground	Below-ground	Fraction above-ground residue removed
	$Frac_{Renew}$		Y	R_{BG}	nc_{ag}	nc_{bg}	FFOD
Annual grass	0.1	0.03	4.41	0.4	0.015	0.012	0.8
Grass clover mixture	0.1	0.03	8.34	0.8	0.025	0.016	0.8
Lucerne	0.1	0.03	8.62	0.4	0.027	0.019	0.8
Other legume	0.1	0.03	5.62	0.4	0.027	0.022	0.8
Perennial pasture	0.1	0.03	8.35	0.8	0.015	0.012	0.8

(a) Average yields estimated by FullCAM (b) IPCC (2006).

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Table 5.I.3 Crop residues – Proportion burnt or removed

Year	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
2010–2014	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

Year	State	Proportion burnt	Proportion removed
2015–2019	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

Source: Estimated by FullCAM.

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	0.405	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	1.000
2010	0.797	0.287	1.000
2011	0.874	0.359	1.000
2012	0.958	0.374	1.000
2013	0.896	0.265	1.000
2014	0.896	0.265	1.000
2015	0.919	0.250	1.000
2016	0.934	0.278	1.000
2017	0.959	0.278	1.000
2018	0.953	0.278	1.000
2019	0.934	0.278	1.000

Source: Canegrowers Association Queensland and NSW Sunshine Sugar.
NO – not defined.

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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.

Source: Stewart *et al.* (2001).

Table 5.J.2 Fraction of animal waste available for leaching and runoff (FracWET)

State	Region	Dairy cattle [(a)]	Beef cattle		Sheep	Pigs	Poultry		Other categories
			Pasture	Feedlot			Meat	Layer	
ACT		1	0.785		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					0.733	0.733	0.773
NT	Alice Springs								
NT	Barkly								
NT	Northern		0.582						
QLD		1		0.043	0.018	0.250	0.578	0.131	0.107
QLD	High		0.07						
QLD	Moderate/ High								
QLD	Moderate/ Low		0.01						
QLD	Low		0.66						
SA		1	0.691	0.279	0.516	0.750	0.147	0.443	0.415
TAS		1	0.997		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	0.510	0.400	0.891	0.869	0.668
WA	South West		0.826						
WA	Pilbara								
WA	Kimberley		0.392						

Source: (a) Dairy Technical Working Group (2015). All other fractions from Wiedemann *et al.* (2014).

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