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Department of Climate Change, Energy, the Environment and Water

National Inventory Report 2024

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

Australian National Greenhouse Accounts

April 2026



VOLUME 1

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Acknowledgement of Country

In delivering this National Inventory Report, we pay our respects to our First Nations peoples, Elders, and ancestors who have cared for their lands, waters, and skies for over 65,000 years, and who continue to care for Country today.

First Nations peoples have loved, cared for, and listened to Country for thousands of generations, so it is important to reflect on these ongoing connections and guardianships. These enduring cultures are amongst the oldest on Earth. Guided by traditional knowledges, First Nations peoples have sustained a deep and enduring relationship with Country, adapting to Australia's changing climate over millennia. Their resilience and stewardship continue to inspire this Government.

First Nations peoples' voices and knowledges are critical to addressing the impacts of climate change and responding to the challenges we all now face. In the spirit of reconciliation, we commit to improving how these voices are heard and represented in Australian Government action and decision making, especially in our current climate and environmental crisis.

Australia recognises and pays respect to First Nations peoples as the Traditional Owners of Australia. We would like to thank the Traditional Owners for their continuing custodianship of the lands, waters, and skies that we live and work within today.



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Other acknowledgements

The Department of Climate Change, Energy, the Environment and Water acknowledges the many individuals and organisations that have contributed to the development of the national methods applied in successive editions of this Report over the years.

We would like to extend particular thanks to the National Greenhouse Gas Inventory Committee and National Inventory User Reference Group who provided quality assurance on the methods and emissions estimates contained in this Report.

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

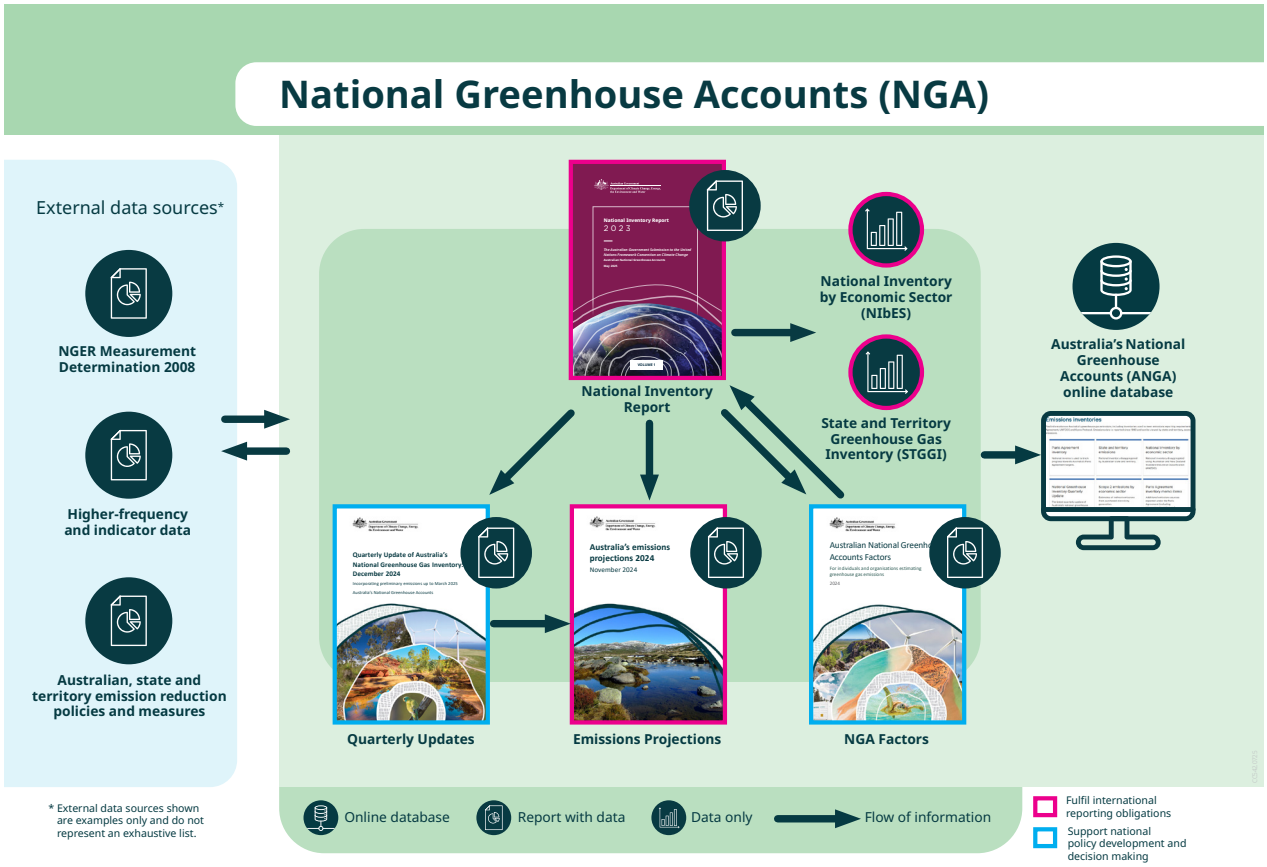
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- Department of Industry, Science and Resources
- Department of Infrastructure, Transport, Regional Development, Communications and the Arts
- Geoscience Australia

Preface: Australia's National Greenhouse Accounts Overview

Australia's National Greenhouse Accounts (NGA) are a series of comprehensive reports and databases produced by the Department of Climate Change, Energy, the Environment and Water (DCCEEW). Together, the NGA estimate and account for Australia's greenhouse gas emissions from 1989–90 onwards. Each publication serves a distinct purpose and contributes to a comprehensive understanding of national emissions. Together, the NGA:

- fulfil Australia's international greenhouse gas inventory reporting commitments,
- provide the official basis for tracking and assessing progress toward national emissions reduction targets,
- support the development and evaluation of domestic emission reduction policies, and
- inform future commitments to reduce emissions.

Figure P.1: Reports and databases that comprise Australia's National Greenhouse Accounts (NGA)



National Inventory Report (NIR): The most detailed and technical NGA document, fulfills international reporting obligations under the UNFCCC and Paris Agreement. Provides detailed information and analysis of emissions from 1989–90 to the financial year ending 2 years before publication.

Quarterly Updates of Australia's National Greenhouse Gas Inventory (Quarterly Updates): The most current source of emissions data, published five months after the end of each quarter. Provides emissions estimates from 2004–05 up to the latest quarter, with a focus on the most recent quarter and year-to-date. Quarterly Updates build on methods in the NIR, incorporating more current, higher-frequency data. Provides the starting point for Australia's Emissions Projections.

State and Territory Greenhouse Gas Inventory (STGGI): Disaggregates NIR data by state and territory from 1989–90 to the financial year ending 2 years before publication to enable regional insights. No written report, data and detail on the methodology is available on the webpage.

National Inventory by Economic Sector (NIBES): Disaggregates NIR data by industry sector using Australia and New Zealand Standard Industry Classifications (ANZSIC), from 1989–90 to the financial year ending 2 years before publication. No written report, data and detail on the methodology is available on the webpage.

Australia's Emissions Projections: Provides estimates of national greenhouse gas emissions to 2040, assessing progress toward 2030 and 2035 emissions reduction commitments emissions reduction commitments by analysing the potential impacts of current emission reduction policies and measures. Builds on historical data in the NIR, uses the latest Quarterly Update as a starting point.

National Greenhouse Accounts Factors: Provides emission factors and methodologies for estimating emissions from various activities, based on the National Greenhouse and Energy Reporting Measurement Determination 2008. Supports consistency in emissions reporting, aimed at businesses and individuals.

Australian National Greenhouse Accounts (ANGA): An online platform hosting data from all NGA publications (except Quarterly Updates). Enables users to customise queries to visualise data by sector, gas and locations. Data can be downloaded as a graph or table, or accessed directly via an API.

ANGA can be found at greenhouseaccounts.climatechange.gov.au.

Figure P.2: Time-series coverage of National Greenhouse Accounts (NGA) publications

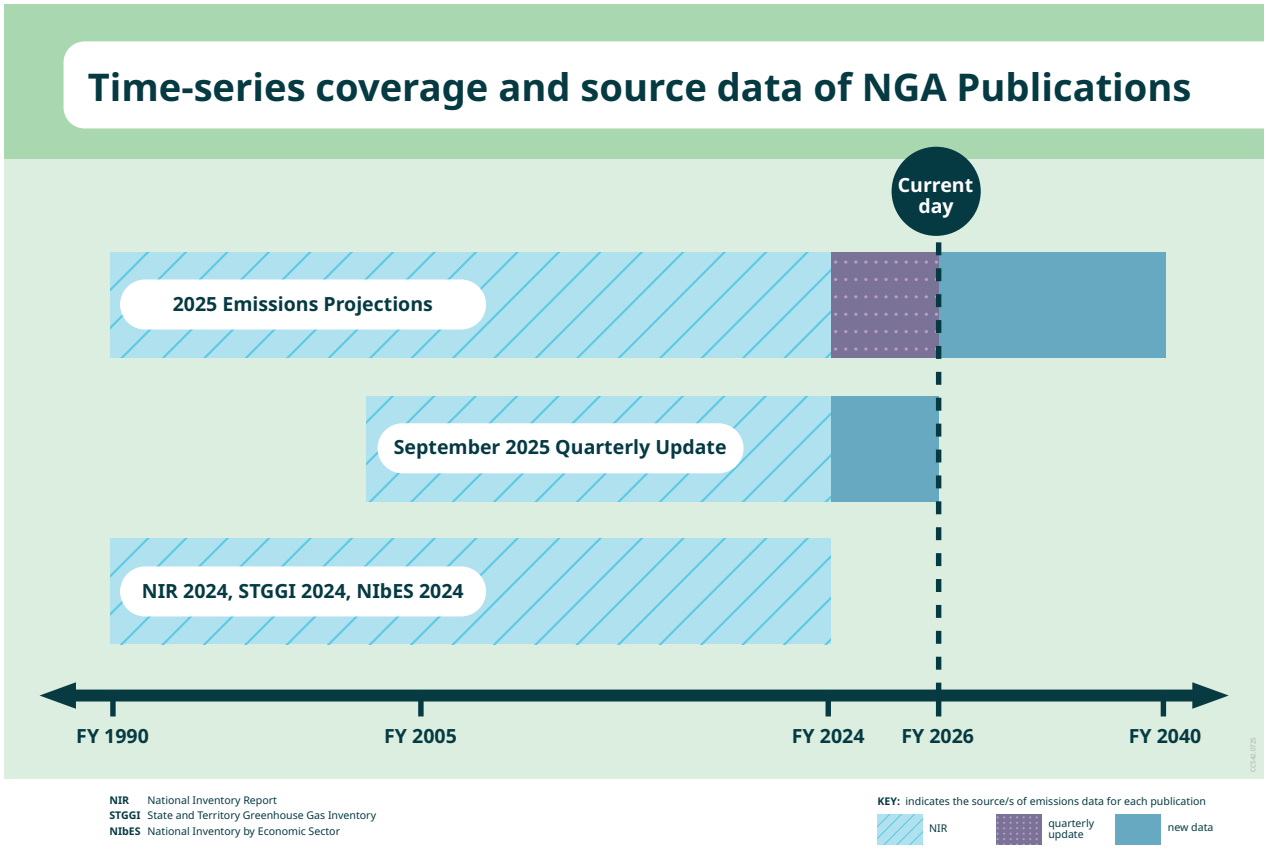


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Executive Summary

ES.1 Background information on greenhouse gas inventories and climate change

This document is Australia's *National Inventory Report 2024* ("this Report") and, in conjunction with associated Common Reporting Tables (CRTs), is Australia's third national inventory submission under the Paris Agreement (PA). The submission of this Report and associated CRTs also fulfils Australia's annual national greenhouse gas inventory reporting obligation with decision 1/CP.24 of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC).

This Report provides estimates of Australia's net greenhouse gas emissions for the period 1989–90 to 2023–24. Emissions estimates are reported according to the UNFCCC classification system. That is, this Report includes emissions and removals from the energy, industrial processes and product use (IPPU), agriculture, waste, and the land use, land use change and forestry (LULUCF) sectors.

This Report has been prepared in accordance with the *Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement* agreed by the Conference of Parties (COP) serving as the meeting of the Parties to the Paris Agreement at its first session (decision 18/CMA.1) and known as MPG, and *Guidance for operationalizing the modalities, procedures and guidelines for the enhanced transparency framework referred to in Article 13 of the Paris Agreement* (decision 5/C.M.A.3).

Consistent with decision 18/CMA.1 and decision 5/CMA.3, emissions 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 Guidelines), supplemented by aspects of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (2019 IPCC Refinement), and the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2013 Wetlands Supplement). Australia's methodologies have been improved over time and will continue to be refined as new information emerges, and as international practice evolves. 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 Parties.

The responsibility for Australia's greenhouse gas emissions reporting has been assigned to the Department of Climate Change, Energy, the Environment and Water (the department). The department is responsible for all aspects of the national inventory systems, including activity data coordination, emissions estimation, quality control, preparation of reports and their submission to the UNFCCC on behalf of the Australian Government.

In addition to this Report, the department publishes a range of supporting emissions estimates that, together, constitute the Australian National Greenhouse Accounts (see Figures P.1 and P.2). These documents are available on the department's website Tracking and reporting greenhouse gas emissions.

The department also publishes annual emissions projections, which estimate Australia's future greenhouse gas emissions and help determine how Australia is tracking against its emissions reduction targets. Projections reports are published at Projecting greenhouse gas emissions.

Emissions data from the aforementioned reports are published in an interactive online database: Australia's National Greenhouse Accounts (ANGA). ANGA allows users to interrogate historical and projected emissions estimates by a wide range of variables. Data are presented in customised tables and charts and can be downloaded as images or Microsoft Excel spreadsheets. These supplementary reports and databases provide additional information with respect to Australia's emissions on a regional, industry, gas (raw and carbon dioxide equivalent), quarterly, scope 1 and scope 2 basis.

This Report presents emissions for each of the major greenhouse gases as carbon dioxide equivalents (CO_2-e) using 100-year global warming potentials (GWPs). 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. In accordance with Paris Agreement requirements[1], this Report applies 100-year GWPs contained in Table 8.A.1 of Chapter 8 Anthropogenic and Natural Radiative Forcing of the 2014 IPCC Fifth Assessment Report (AR5) (IPCC 2014).

A summary of the AR5 GWPs is presented in Table ES.01.

Table ES.01 Global warming potentials (GWPs) applied to the National Inventory Report 2024

Greenhouse gas	AR5[1] GWPs (t CO_2-e per t of gas)
CH_4	28
N_2O	265
SF_6	23,500
PFC-14[2] (tetrafluoromethane)	6,630
PFC-116[2] (hexafluoroethane)	11,100
HFCs[3]	dependent on HFC type[4]

Notes: 1) IPCC 2014 Fifth Assessment Report (AR5) (IPCC 2014), 2) PFC = perfluorocarbons, 3) HFC = hydrofluorocarbons, 4) GWPs for the various HFCs are available in AR5.

Emission estimates presented in this Report are provided on an Australian financial year basis (Jul–Jun) rather than on a calendar year basis (Jan–Dec) because key data sources for Australia's national greenhouse gas inventory are published on this basis. For example, the Australian financial year 1990 commences on 1 July 1989, ends on 30 June 1990, and is commonly cited as "1989–90". This Report covers the Australian financial years 1989–90 to 2023–24. The use of financial year data is consistent with the IPCC 2006 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.

Information on Australia's national circumstances and climate change policies are detailed in Australia's First Biennial Transparency Report and the Annual Climate Change Statement 2025.

1 Decision 18/CMA.1, annex, paragraph 37, and decision 5/CMA.3, paragraph 25.

ES.2 Summary of trends related to national emissions and removals

Australia's net greenhouse gas emissions from all sectors were 466.4 million tonnes (Mt) of carbon dioxide equivalent (CO_2-e) in 2023–24. Including the LULUCF sector, which is a net sink in 2023–24, this is:

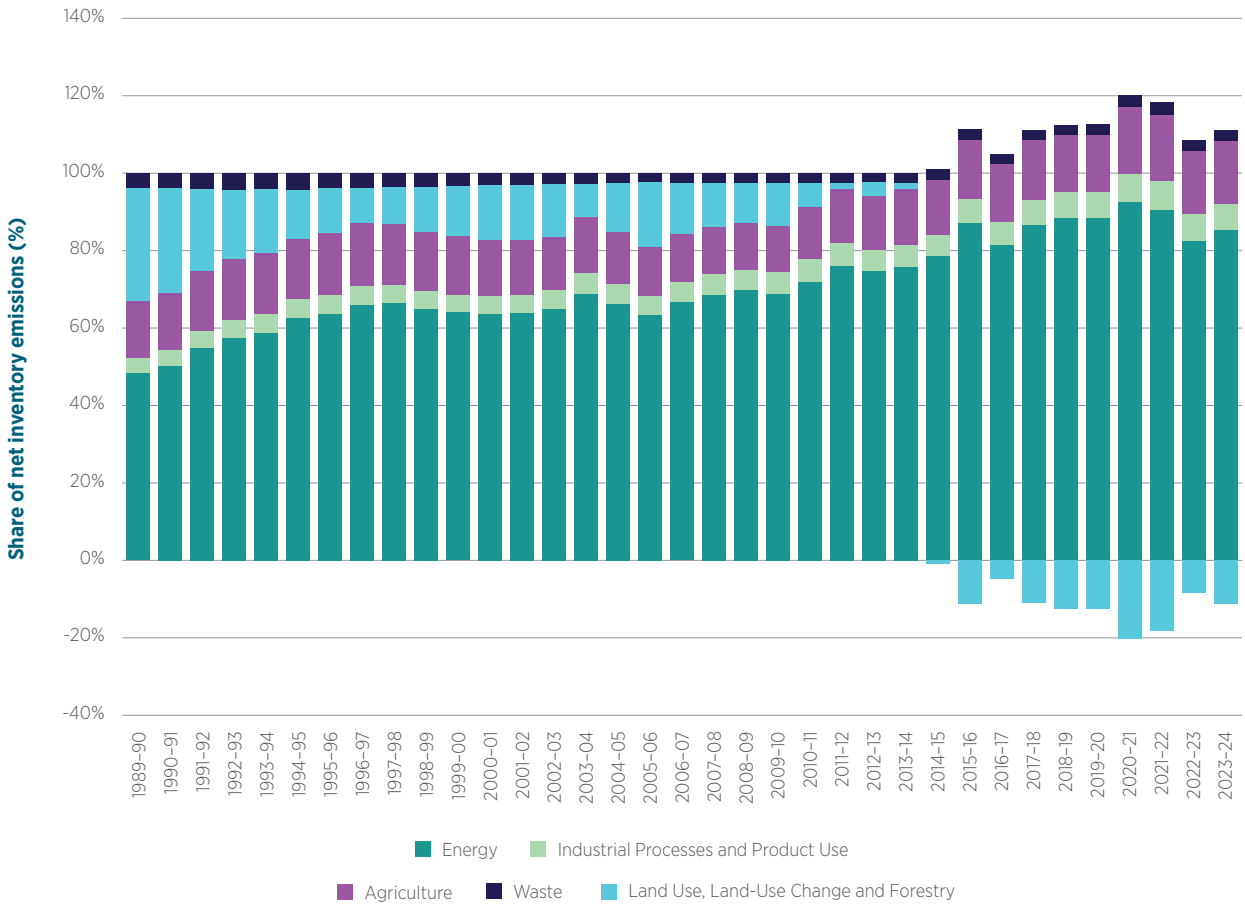
- a decrease of 24.3 per cent (149.5 Mt CO_2-e) from 615.9 Mt CO_2-e in 1989–90,
- a decrease of 23.3 per cent (141.3 Mt CO_2-e) from 607.7 Mt CO_2-e in 2004–05, and
- a decrease of 3.8 per cent (18.3 Mt CO_2-e) from 484.7 Mt CO_2-e in 2022–23.

Emissions by sector for key years, including changes between 2023–24 and the years 1989–90, 2004–05, and the previous year (2022–23), are presented in Tables ES.02 and 2.1.

As the LULUCF sector is a net sink in 2023–24, emissions by sector are described with and without LULUCF in ES.2 and ES.3 and are largely described excluding LULUCF in Section 2.2 and sectoral Chapters 3–5 and 7. Emissions by sector, as a share of Australia's total inventory, are presented in Figure ES.01. In 2023–24:

- Energy sector emissions accounted for the largest proportion of Australia's emissions profile, contributing 85.4 per cent of Australia's net national emissions (or 76.8 per cent excluding LULUCF). This is an increase in contribution from 48.3 per cent in 1989–90.
- Agriculture sector emissions accounted for the second largest proportion of Australia's emissions profile, comprising 16.2 per cent of Australia's net national emissions (or 14.6 per cent excluding LULUCF). This is an increase in contribution from 14.6 per cent in 1989–90.
- Industrial processes and product use sector emissions accounted for 6.6 per cent of Australia's net national emissions (or 5.9 per cent excluding LULUCF). This is an increase in contribution from 4.1 per cent in 1989–90.
- Waste sector emissions accounted for 3.0 per cent of Australia's net national emissions (or 2.7 per cent excluding LULUCF). This is a decrease in contribution from 3.8 per cent in 1989–90.
- Land use, land use change and forestry (LULUCF) was a net sink of 11.2 per cent of Australia's net national emissions (or equivalent to 10.1 per cent of non-LULUCF emissions). In contrast, LULUCF accounted for 29.3 per cent of Australia's net national emissions in 1989–90.

Figure ES.01 Contribution to total net emissions by sector, Australia, 1989–90 to 2023–24 (per cent)



Trends in emissions are discussed further in Chapter 2, and trends in emissions from each sector and their sub-sectors are discussed further in Chapters 3–7.

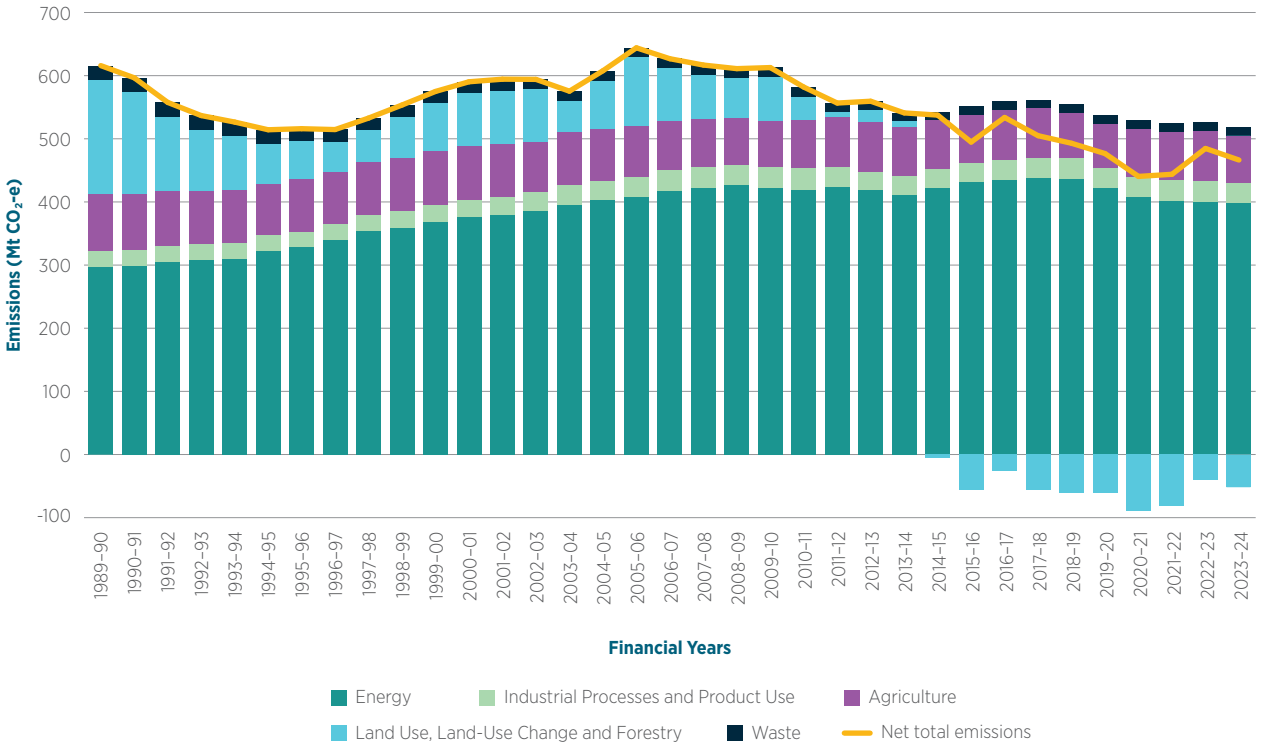
ES.3 Overview of source and sink category emissions estimates and trends

The full time series of the national inventory, including for major sectors, is presented in Figure ES.02. A summary table is presented in Table ES.02 containing annual emissions by sector and comparison between key years. As the LULUCF sector is a net sink in 2023–24, emissions by sector are described with and without LULUCF in ES.2 and ES.3 and are largely described excluding LULUCF in Section 2.2.

Table ES.02 Net greenhouse gas emissions by sector, Australia (Mt CO_2-e)

UNFCCC classification sector and subsector	Net emissions (Mt CO_2-e)							Per cent change in emissions in 2023–24 since:		
	1989–90	2004–05	2009–10	2014–15	2019–20	2022–23	2023–24	1989–90	2004–05	2022–23
1. Energy (combustion + fugitive)	297.3	402.3	421.8	421.8	421.3	400.0	398.1	33.9	-1.0	-0.5
Stationary energy	*195.7*	*277.9*	*287.9*	*277.9*	*272.0*	*252.3*	*250.5*	28.0	-9.9	-0.7
Transport	*61.2*	*81.8*	*88.4*	*94.9*	*93.2*	*98.2*	*100.4*	64.1	22.7	2.2
Fugitive emissions from fuel	*40.4*	*42.6*	*45.5*	*49.1*	*56.1*	*49.5*	*47.2*	16.9	10.9	-4.5
Carbon capture and storage	*NO*	*NO*	*NO*	*NO*	*0.01*	*0.002*	*0.0001*	NA	NA	-96.8
2. Industrial processes and product use	25.1	30.1	33.5	30.5	31.9	33.1	30.8	22.8	2.4	-6.8
3. Agriculture	89.8	82.7	72.9	76.1	70.2	78.8	75.7	-15.8	-8.5	-3.9
4. Land use, land use change and forestry	180.2	76.8	68.5	-5.1	-60.3	-41.1	-52.1	-128.9	-167.9	-27.0
5. Waste	23.5	15.8	16.1	14.1	13.5	13.9	13.9	-40.6	-11.6	0.4
Total net emissions	**615.9**	**607.7**	**612.8**	**537.5**	**476.6**	**484.7**	**466.4**	**-24.3**	**-23.3**	**-3.8**
Memo: *Total net emissions without natural disturbances provision*	*612.7*	*580.2*	*601.7*	*526.1*	*1186.1*	*421.2*	*457.3*	-25.4	-21.2	8.6

Figure ES.02 Greenhouse gas emissions by sector, Australia, 1989–90 to 2023–24 (Mt CO_2-e)



The *Energy* sector was the largest source of greenhouse gas emissions in 2023–24 comprising 85.4 per cent (398.1 Mt CO_2-e) of total net emissions (or 76.8 per cent excluding LULUCF). *Energy* emissions increased by 33.9 per cent (100.8 Mt CO_2-e) between 1989–90 and 2023–24 and decreased by 0.5 per cent (1.9 Mt CO_2-e) between 2022–23 and 2023–24. Trends for this sector and its sub-sectors are described in more detail in Chapter 3.

Industrial processes and product use comprised 6.6 per cent (30.8 Mt CO_2-e) of total net emissions (or 5.9 per cent excluding LULUCF) in 2023–24, increased 22.8 per cent (5.7 Mt CO_2-e) between 1989–90 and 2023–24, and decreased by 6.8 per cent (2.2 Mt CO_2-e) between 2022–23 and 2023–24. Trends for this sector and its sub-sectors are described in more detail in Chapter 4.

Agriculture emissions made up 16.2 per cent (75.7 Mt CO_2-e) of total net emissions (or 14.6 per cent excluding LULUCF) in 2023–24, decreased 15.8 per cent (14.2 Mt CO_2-e) between 1989–90 and 2023–24, and decreased by 3.9 per cent (3.1 Mt CO_2-e) between 2022–23 and 2023–24. Trends for this sector and its sub-sectors are described in more detail in Chapter 5.

The *Land use, land use change and forestry* (LULUCF) sector was a net sink of 52.1 Mt CO_2-e in 2023–24, equivalent to 11.2 per cent of total net emissions (including LULUCF). Between 1989–90 and 2023–24 there was a decrease of 128.9 per cent (232.3 Mt CO_2-e), with the sector changing from a net source to a net sink. Between 2022–23 and 2023–24 there was a 11.1 Mt CO_2-e increase in the net sink from the *LULUCF* sector. Trends for this sector and its sub-sectors are described in more detail in Chapter 6.

The *Waste* sector contributed 3.0 per cent (13.9 Mt CO_2-e) of total net emissions (or 2.7 per cent excluding LULUCF) in 2023–24, decreased 40.6 per cent (9.5 Mt CO_2-e) between 1989–90 and 2023–24, and decreased by 0.4 per cent (0.1 Mt CO_2-e) between 2022–23 and 2023–24. Trends for this sector and its sub-sectors are described in more detail in Chapter 7.

A full overview of emissions estimates by source, sink, and gas is given in Chapter 2.

ES.4 Other Information

The Australian Government submitted its latest Nationally Determined Contribution (NDC) under Article 4 of the Paris Agreement in September 2025 (DCCEEW 2025). It sets out Australia's ambitious and achievable 2035 emissions reduction target. The target commits Australia to reduce emissions by 62–70% below 2005 levels by 2035. It is an absolute, economy-wide net national greenhouse gas emissions reduction target, implemented as an emissions budget covering the period 2031–35. It covers all gases, sectors, categories and carbon pools included in Australia's annual National Inventory Report.

Australia's 2035 NDC is a 19–27 percentage point increase over its 2030 emissions reduction target. The latest NDC affirms Australia's existing 2030 and 2050 emission reduction commitments. Australia has committed to reduce greenhouse gas emissions 43 per cent below 2005 levels by 2030 and achieve net zero emissions by 2050. These targets are also economy-wide emissions reduction commitments, covering all sectors and gases included in Australia's annual National Inventory Report. The 2030 commitment is both a single-year target to reduce emissions 43 per cent below 2005 levels by 2030 and a multi-year emissions budget from 2021–2030.

Australia's 2035 emissions reduction target is built on comprehensive consultation, analysis and planning for implementation, including its detailed Net Zero Plan and 6 sector emissions reduction plans.

Descriptions of Australia's national circumstances and climate change policies are detailed in Australia's First Biennial Transparency Report, and the Annual Climate Change Statement 2025.

ES.5 Key category analysis

A key category is defined in the IPCC 2006 Guidelines (Volume 1, Chapter 4) (IPCC 2006) as an emissions source that is prioritised within the national inventory system because it has a significant influence on total, trend and uncertainties of total greenhouse gas emissions. In general, higher tier methods should be used for estimating emissions from key categories. Consistent with the IPCC 2006 Guidelines (section 4.1.2), Tier 1 Methods can be used where application of a higher tier method is not possible.

Key categories are identified by undertaking the level and trend assessments described in the IPCC 2006 Guidelines (Volume 1, Chapter 4, Section 4.3) (IPCC 2006) by all inventory sub-categories by greenhouse gas. These approaches identify the emissions sources that contribute to 95 per cent of total emissions or of the trend of the inventory in absolute terms.

Australia's analyses have been undertaken using a disaggregation of sources, as recommended in Table 4.1 of the 2006 IPCC Guidelines (IPCC 2006).

With the exception of the four key categories below, all key categories, and a significant proportion of non-key categories, are reported using Tier 2 or Tier 3 Methods. The full results are detailed in Volume 2, Annex I to this Report.

Three key categories were estimated using Tier 1:

- **2.B.9 – IPPU, Chemical Industry / Fluorochemical Production – HFC-23**

  HFC-23 (trifluoromethane) is generated as a by-product of production of the refrigerant HCFC-22 (chlorodifluoromethane). The production of HCFC-22 last occurred in Australia in 1994–95, following international agreement of the Montreal Protocol on Substances that Deplete the Ozone Layer (the Montreal Protocol) in 1987.

  Emissions from this sub-category were identified as a key category on a trend basis. Emissions from this source have not occurred since 1994–95 and plant-specific (facility-specific) data are not available.

- **3.H – Agriculture, Urea Application – CO_2 (carbon dioxide)**

  Adding urea to soils leads to a loss of CO_2 that was fixed during the industrial process of urea manufacturing. Australia applies a Tier 1 Method for this category. Historically, this sub-category was not considered a key category for Australia. It contributes 0.7 to 2.1 Mt CO_2-e per year from 2004–05 onwards, and 0.3 per cent of net emissions in 2023–24.

  This category only recently became a key category, due to lowering national emissions resulting in smaller sources now becoming a higher proportion of national emissions, and emissions from this source significantly increasing since 1989–90. As described in Section 5.9.6 of this Report, improvements to develop a Tier 2 Method for this category are under consideration.

ES.6 Improvements introduced

Australia's inventory is subject to continuous, incremental improvement to incorporate the latest verifiable research, data, technologies and practices.

ES.6.1 Improvements implemented in 2023–24

For this Report, UNFCCC Expert Review Team (ERT) recommendations from previous submissions were progressed or addressed. The status of these improvements is described in Chapter 10.4, as well as a summary of responses to the simplified review for the 2023 inventory submission. In addition, the following improvements were implemented:

Method improvements were applied to improve the accuracy and comparability of Australia's emissions estimates

Improvements typically result in recalculations to Australia's emissions. The impacts of recalculations on national totals are summarised in ES.6.2 Recalculations and in Chapter 10, and the details are presented in sectoral Chapters 3–7. The main method improvements are described by sector, below.

Energy

Energy Industries: NGER data has informed a reallocation of natural gas to unprocessed natural gas in Oil and Gas Extraction.

Manufacturing Industries and Construction: Additional plant-specific activity data and emissions factors reported under the National Greenhouse and Energy Reporting (NGER) scheme have been incorporated.

Abandoned underground mines: Additional plant-specific data reported under the National Greenhouse and Energy Reporting (NGER) scheme have been incorporated.

Venting and flaring from oil and natural gas extraction: Additional plant-specific data reported under the National Greenhouse and Energy Reporting (NGER) scheme were used to further disaggregate emissions from past submissions (2021–22 onwards) and to improve time series consistency. Several emission sources were reallocated within CRT category 1.B.2 *Oil, natural gas and other emissions from energy production*, from 1.B.2.a *Oil* and 1.B.2.b *Natural gas* to 1.B.2.c *Venting and flaring*, in order to improve the international comparability of Australia's emission estimates.

Transport: Revised transport fuel consumption data from the Australian Energy Statistics and Australian Petroleum Statistics has been incorporated, particularly impacting CRT categories 1.A.3.a Domestic aviation, 1.A.3.b Road Transportation and 1.A.3.d Domestic navigation.

More detail on method improvements in the energy sector is provided in Chapter 3 of this Report.

Agriculture

Manure management: A new method was implemented for calculating methane emissions from grazing livestock (pasture-fed beef, sheep, and Other Livestock). The new method is comparable to the approach for intensive livestock, estimating volatile solid production and allocating it between two manure management systems: pasture, range and paddock; and farm dams which are treated as anaerobic lagoons. Previously a constant fraction of manure nationwide was allocated to farm dams. With this change, the allocation is estimated using a spatial map of farm dam locations. This results in lower allocations over much grazing land, and hence lower estimated emissions.

Rice cultivation: A scaling factor to the Tier 1 method has been improved, incorporating new data on sowing practices. Drill sowing results in a shorter period of continuous flooding, and as this has become more prevalent over time the emissions estimates have been revised downward more in recent years with this change, the method is elevated to a Tier 2 method, incorporating two new country-specific attributes.

Agricultural Soils: New EFs have been adopted for emissions from Urine and Dung Deposited by Grazing Animals. Previously a single value was used nationwide. Now, livestock location data are combined with the dry- and wet-climate zone EFs from IPCC (2019). As most Australian livestock graze in dry climates, the resulting EF and estimated emissions are lower.

Liming: Activity data for liming have been estimated by extrapolating historical trends, as the ABS has not reported it in this period. Previously, activity data were held constant over this period.

More detail on method improvements in the agriculture sector is provided in Chapter 5 of this Report.

LULUCF

The National Inventory Report 2022 identified planned improvements to the remote sensing program for forest cover change.

The scale and complexity of transitioning this continental-scale program, development of new data processing pipelines, and ensuring time-series consistency of a composite time-series based on different satellite technologies, has resulted in delays in data availability. Due to delays in this project, the updated dataset was not available to be included in the current inventory submission. The department is continuing to undertake QA/QC of the data received so far which provides partial coverage of Australia. The outcomes of the QA/QC will inform the next steps for this improvement. In NIR 2023 and NIR 2024 this has meant that for several LULUCF land use categories that rely on the forest cover monitoring system for activity data, the emissions reported for 2022–23 and 2023–24 are an extrapolation of the 2021–22 results to ensure completeness of reporting, consistent with the IPCC 2006 Guidelines (Volume 1 Chapter 5.3: Resolving data gaps).

For the current submission, updates to climate data, crop and grass yields and forest productivity data were incorporated to improve estimates of emissions and removals from regenerating forests and from previously cleared lands, where emissions had been held constant at 2021–22 levels in the previous submission. This has resulted in upward revisions to emissions in 2022–23 for forests converted to other land uses, and a reduction of the net sink for land converted to forest lands.

The increases in net emissions in 2022–23 reflect the moderation of forest growth and sequestration rates on previously cleared croplands and grassland to more typical levels, as climate conditions transition out of the prolonged La Niña period, that had led to elevated rainfall and significant flooding in different regions of Australia in 2020, 2021 and 2022. This hybrid approach provides the most reliable estimates given current data constraints. It balances the need for completeness and methodological consistency with the opportunity to incorporate category-specific updates where supporting data exist.

In other land use categories, holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data and uncertainty regarding the influence of interannual variability in climate drivers.

LULUCF subsectors that have updated emissions estimates for the National Inventory Report 2024 are: *cropland remaining cropland, grassland remaining grassland, land converted to forest land, emissions on previously cleared land, biomass burning* (wildfire, temperate prescribed burning and non-temperate fire management), *Harvested Native Forests, wetlands* and *Harvested Wood Products.* A more detailed update on these ongoing improvements is provided in Chapter 6.

Following independent expert review of the implementation of improvements to the calibrations used to model non-temperate fires reported in the 2022 submission, further refinements to the sub-model in FullCAM were identified. These refinements include a revision to the fire patchiness values for one species type and a revision to the time series of grass yield parameters for monsoonal perennial grass species.

There have also been upward recalculations towards the end of the time series for emissions from *grassland remaining grassland* and *cropland remaining cropland* (grasslands and cropland soils) *land converted to forest land* and *land converted to cropland, grassland and settlements*. For cropland and grassland soils, the final last years of the time series for these sub-sectors are recalculated each year as a result of updating the climate and crop and grass yield time series and adding an additional year of data.

For *land converted to forest land* and *land converted to cropland, grassland and settlements* there was a recalculation for 2022–23 due to incorporating updates to climate data, crop and grass yields and forest productivity data that were not applied in the 2023 submission due to activity data availability.

More detail on method improvements in the LULUCF sector is provided in Chapter 6 of this Report.

Waste

This submission reflects updated waste composition profiles for Municipal Solid Waste (MSW) and Commercial and Industrial (C&I) waste streams to better reflect contemporary disposal practices. The updated composition values have been applied from 2014–15 onwards to capture changes in disposal behaviour, including increased diversion of food and garden organics over the past decade.

More detail on method improvements in the waste sector is provided in Chapter 7 of this Report.

ES.6.2 Recalculations

The impact of the method improvements and other recalculations across the time series ranged from -5.0 Mt CO_2-e (-0.8 per cent) to 31.2 Mt CO_2-e (6.9 per cent) per year. Recalculations are presented in absolute and relative terms in Table ES.03.

Table ES.03 Recalculations for this submission (NIR 2024) compared with last year's submission (NIR 2023), AR5 GWPs

	NIR 2023	NIR 2024	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)
1989–90	620,858.9	615,876.2	-4,982.7	-0.8%
1994–95	518,244.1	514,328.4	-3,915.7	-0.8%
1999–00	579,168.8	574,975.4	-4,193.4	-0.7%
2004–05	611,931.6	607,729.3	-4,202.3	-0.7%
2005–06	648,433.1	644,086.0	-4,347.0	-0.7%
2006–07	630,781.1	626,774.8	-4,006.3	-0.6%
2007–08	620,771.4	616,828.7	-3,942.7	-0.6%
2008–09	615,338.9	611,108.7	-4,230.2	-0.7%
2009–10	616,619.4	612,768.7	-3,850.7	-0.6%
2010–11	585,553.1	581,900.3	-3,652.7	-0.6%
2011–12	560,612.7	556,626.1	-3,986.5	-0.7%
2012–13	563,013.6	559,527.5	-3,486.1	-0.6%
2013–14	544,760.2	541,035.9	-3,724.3	-0.7%
2014–15	540,133.9	537,499.4	-2,634.5	-0.5%
2015–16	496,835.1	494,769.3	-2,065.8	-0.4%
2016–17	536,720.9	533,766.7	-2,954.2	-0.6%
2017–18	508,322.5	504,911.2	-3,411.4	-0.7%
2018–19	496,254.6	492,868.5	-3,386.0	-0.7%
2019–20	477,710.4	476,636.5	-1,073.9	-0.2%
2020–21	439,924.7	440,366.0	441.4	0.1%
2021–22	440,620.8	443,766.5	3,145.7	0.7%
2022–23	453,448.9	484,679.2	31,230.3	6.9%

Method improvements, data corrections, and the incorporation of improved activity data are detailed in sectoral Chapters 3–7 and summarised in ES.6.1 and Chapter 10. Recalculations by sector are presented in Table ES.04.

Table ES.04 Recalculations for this submission (NIR 2024) compared with last year's submission (NIR 2023) by sector, Gg CO_2-e AR5 GWPs

	1 Energy	1.A.1, .2, .4, and .5 Stationary Energy	1.A.3 Transport	1.B Fugitive emissions	2 IPPU	3 Agriculture	4 LULUCF	5 Waste
1989–90	-47.0	0.0	0.0	-47.0	0.0	-4,406.3	-529.4	0.0
1994–95	-36.8	0.0	0.0	-36.8	0.0	-3,783.6	-111.2	16.0
1999–00	-36.2	0.0	0.0	-36.2	0.0	-4,029.2	-154.7	26.7
2004–05	-184.9	0.0	0.0	-184.9	0.0	-3,956.9	-105.4	44.9
2005–06	-99.2	0.0	0.0	-99.2	0.0	-4,139.2	-159.4	50.8
2006–07	103.1	0.0	0.0	103.1	0.0	-4,050.5	-115.2	56.3
2007–08	72.2	-85.2	84.2	73.2	0.0	-4,000.6	-75.7	61.4
2008–09	-253.2	-379.3	54.3	71.9	-45.7	-3,967.2	-30.2	66.1
2009–10	-110.8	-239.5	65.1	63.7	-31.0	-3,872.0	92.4	70.7
2010–11	49.6	-1.2	1.0	49.8	-45.7	-3,877.6	146.1	74.8
2011–12	44.3	-4.9	4.7	44.6	-38.0	-4,126.5	54.8	78.9
2012–13	-18.2	-0.3	0.1	-17.9	-2.4	-4,193.0	129.9	597.7
2013–14	11.3	-0.2	-0.2	11.7	49.7	-4,169.3	70.8	313.2
2014–15	15.1	18.5	-18.4	15.0	24.5	-3,941.2	-103.6	1,370.8
2015–16	76.5	21.2	-21.4	76.7	-0.4	-3,879.0	248.6	1,488.5
2016–17	190.6	22.6	-22.6	190.6	19.9	-4,151.1	-54.6	1,041.0
2017–18	517.2	100.1	-8.1	425.2	37.2	-4,131.1	-189.0	354.4
2018–19	481.5	488.3	-667.3	660.5	34.9	-3,804.8	-136.6	39.0
2019–20	2,027.2	692.0	525.3	809.9	88.6	-3,550.8	327.8	33.3
2020–21	2,678.8	789.7	908.2	980.9	-45.2	-3,264.1	904.2	167.6
2021–22	4,314.6	826.6	2,723.9	764.1	64.8	-3,084.4	1,835.2	15.5
2022–23	2,030.8	-181.4	1,621.7	590.5	94.4	-3,606.1	32,634.9	-181.4

1. Introduction and inventory context

1.1 Background information on greenhouse gas inventories and climate change

1.1.1 Inventory reporting

Australia is Party to both the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement (PA). One of the principal commitments made by Parties to these treaties is to develop, publish, and regularly update national greenhouse gas inventories.

Australia's National Inventory Report 2024 (the Report) and associated Common Reporting Tables (CRTs) fulfil its national inventory reporting obligations for the year 2023 under both the UNFCCC and the PA, in accordance with decision 1/CP.24[2] of the Conference of the Parties to the UNFCCC. The Report provides estimates of Australia's net greenhouse gas emissions for the period from 1 July 1989 to 30 June 2024, i.e. from financial years 1989–90 to 2023–24.

This Report has been prepared in accordance with chapter II of the annex to the decision 18/CMA.1 *Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement*[3] (known as the MPG) and decision 5/CMA.3 *Guidance for operationalizing the modalities, procedures and guidelines for the enhanced transparency framework referred to in Article 13 of the Paris Agreement*[4].

Consistent with the MPG and decision 5/CMA.3, emissions 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 Guidelines) (IPCC 2006), supplemented by aspects of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (2019 IPCC Refinement) (IPCC 2019), and the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (IPCC 2013 Wetlands Supplement) (IPCC 2013). Australia's methodologies have been improved over time and will continue to be refined as new information emerges, and as international practice evolves. 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 Parties.

1.1.2 Gases

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

2 FCCC/CP/2018/10/Add.1, paragraph 42, https://unfccc.int/sites/default/files/resource/10a1.pdf

3 FCCC/PA/CMA/2021/10/Add.2, chapter II, https://unfccc.int/sites/default/files/resource/CMA2021_L10a2E.pdf

4 FCCC/PA/CMA/2021/10/Add.2, https://unfccc.int/sites/default/files/resource/CMA2021_L10a2E.pdf

This 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 2014 *IPCC Fifth Assessment Report* (IPCC 2014)[5]. 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, in accordance with those included in the IPCC 2006 Guidelines (IPCC 2006). 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 (IPPU),
- Agriculture,
- Land use, land use change and forestry (LULUCF), and
- Waste.

1.1.4 Reporting year

The Australian greenhouse gas inventory is reported for Australian financial years as key data sources, such as data collected under the National Greenhouse and Energy Reporting (NGER) scheme and energy and agricultural statistics obtained from national statistical agencies, are published on this basis. The Australian financial year runs from 1 July of a given year to 30 June of the following year. This Report covers the Australian financial years 1989–90 to 2023–24. The use of financial year data is consistent with the IPCC 2006 Guidelines as the use of these data conforms to the normal practice of Australia's national statistical agencies and leads to more accurate emissions estimates.

1.1.5 Structure of the National Inventory Report

The structure of this Report has been organised to conform to the requirements of Annex V to decision 5/CMA.3 on the *outline of the national inventory document, pursuant to the modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement.*

This Report provides estimates of Australia's total net emissions 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 to facilitate international review and comparison with the inventories of other countries.

5 GWPs used are, 1 for CO_2, 28 for CH_4, 265 for N_2O, 6,630 for the PFC perfluoromethane (CF_4), 11,100 for the PFC perfluoroethane (C2F6), 23,500 for SF_6 and 16,100 for nitrogen trifluoride (NF_3). The full list of GWPs can be found in Table 8.A.1 of Chapter 8: Anthropogenic and Natural Radiative Forcing of the 2014 IPCC Fifth Assessment Report (AR5). GWPs are not available for the indirect greenhouse gases and in accordance with the Paris Agreement reporting guidelines, are reported but are not included in the inventory total.

1.1.6 National Greenhouse Accounts

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*, comprising emissions estimates for Australian states and territories, and
- the *National Inventory by Economic Sector,* comprising emissions estimates for industries and households rather than by IPCC sectors as in this Report.

These documents are available on the department's website: Tracking and reporting greenhouse gas emissions. They provide additional information with respect to Australia's emissions on both a regional and industry basis.

The department also publishes annual emissions projections, which estimate Australia's future greenhouse gas emissions and help determine how Australia is tracking against its emissions reduction targets. Projections reports are published at Projecting greenhouse gas emissions.

Emissions data from the aforementioned reports are published through an interactive online database: Australia's National Greenhouse Accounts (ANGA). It allows users to interrogate historical and projected emissions estimates by a wide range of variables. Data are presented in customised tables and charts and can be downloaded as images or Excel sheets. These supplementary reports and databases provide additional information with respect to Australia's emissions on a regional, industry, gas (raw and CO_2-e), quarterly, scope 1, and scope 2 basis.

1.2 A description of national circumstances and institutional arrangements

1.2.1 National entity and focal point

On 1 July 2022 responsibility for Australia's national inventory was assigned to a single agency, the Department of Climate Change, Energy, the Environment and Water (the department). The department has responsibility for all aspects of the national inventory systems, including 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:

Branch Head
National Inventory Systems and International Reporting Branch
Department of Climate Change, Energy, the Environment and Water
Australian Government
Ngunnawal Country
GPO Box 3090
Canberra ACT 2601
AUSTRALIA

The department can be contacted at nationalgreenhouseaccounts@dcceew.gov.au.

1.2.2 Inventory preparation process

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, emissions estimation, report preparation, emissions and report review and report publication.

To meet the 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.

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 section 1.2.2.a and Figures 1.1 and 1.2).

Where possible, data sources reported under Australia's legislated NGER scheme (see section 1.2.2.b and Annex V.I) 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. Australia's supplementary data sources draw on data collected and published by Australia's principal economic statistics and state and territory government agencies (for example, the Australian Bureau of Statistics (ABS), and the Department's Energy Statistics & Analysis (ESA) team in the Office of Energy Economics Branch). The collection process for these other data is well-integrated with the objectives of other programmes, for example, the ESA team has collected energy statistics for over 40 years and uses these data to meet Australia's energy reporting commitments to the International Energy Agency (IEA). The ABS is the national statistical agency with legislative backing for its data collection powers. The ABS, in conjunction with the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), is the major source of agricultural activity data.

The department employs consultants to help process the satellite imagery used to determine land cover change for the *LULUCF* sector. Satellite imagery is sourced from Geoscience 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 1989 Management. Act .1989 (Cwlth). Solid waste disposal data are provided by the Circular Economy Division of the department. Disposal data are collected annually as part of the National Waste Reporting initiative.

1.2.2.a IT Software Systems

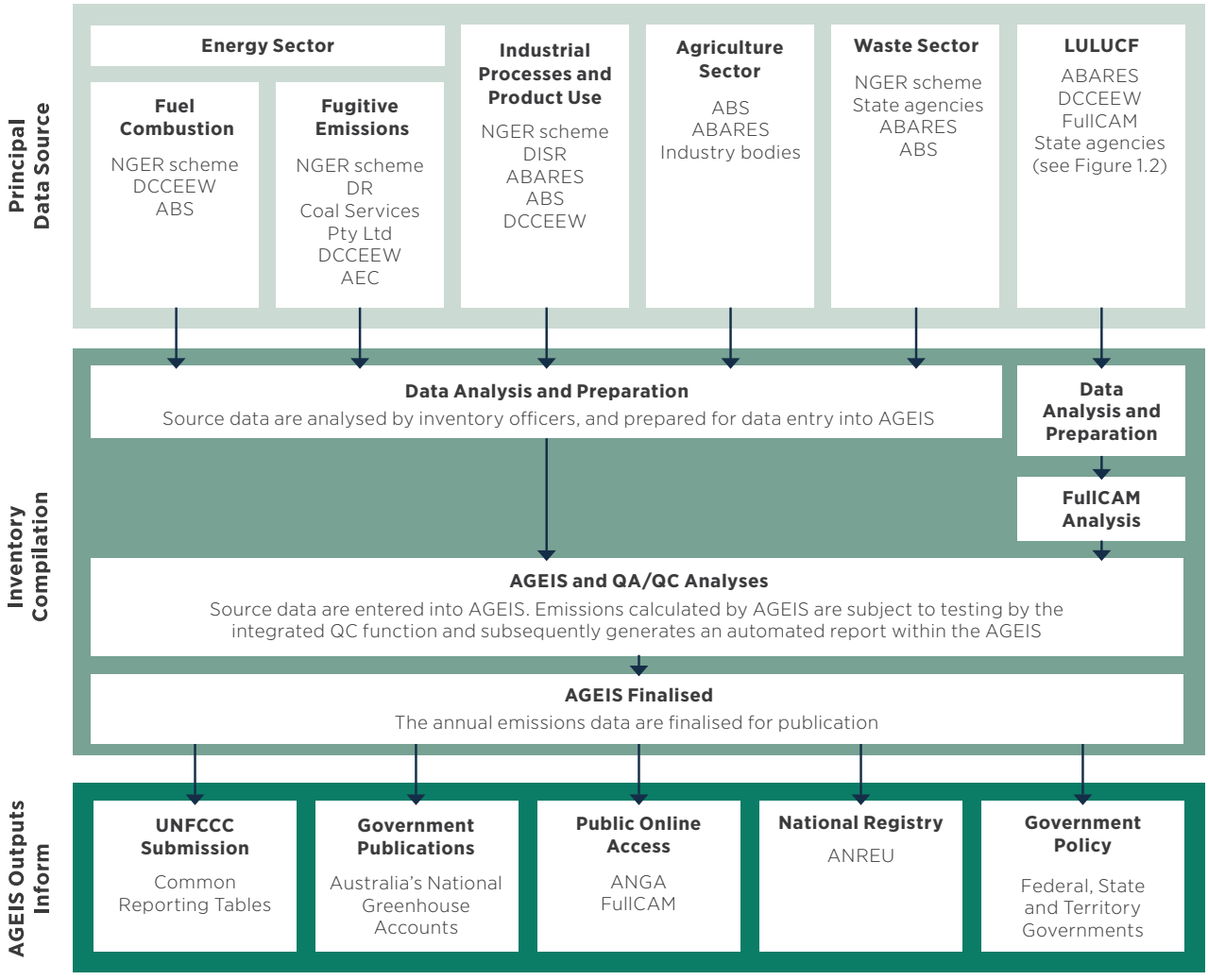
The Australian Greenhouse Emissions Information System (AGEIS) has been designed to meet the requirements for national inventory systems and is an integral part of the inventory preparation and publishing processes.

In particular, it integrates numerous quality control procedures into the compilation process as well as centralising emissions estimation, inventory compilation and reporting, and data storage activities. AGEIS provides high transparency levels for the inventory, with emissions data for the *National Greenhouse Accounts* publicly accessible through an interactive web interface: Australia's National Greenhouse Accounts (ANGA).

The AGEIS continues to be expanded and refined to support the range of Australia's National Greenhouse Accounts in accordance with the *AGEIS and ANGA 3.0 Project Work Plan* 2024–2026. Investment priorities include emission estimation method improvements in accordance with Paris Agreement requirements, enhanced capabilities for tracking emissions in a spatial inventory, and enhancements of models to estimate Australia's emissions projections and historical emissions on a quarterly basis.

While AGEIS is used for final preparation of the National Greenhouse Accounts, the inventory uses FullCAM to estimate emissions and removals from the *LULUCF* sector. FullCAM is a spatially explicit, process-based ecosystem model which uses inputs from a range of national datasets including on vegetation cover and climate. FullCAM's capability now covers nearly all aspects of LULUCF and continues to be expanded.

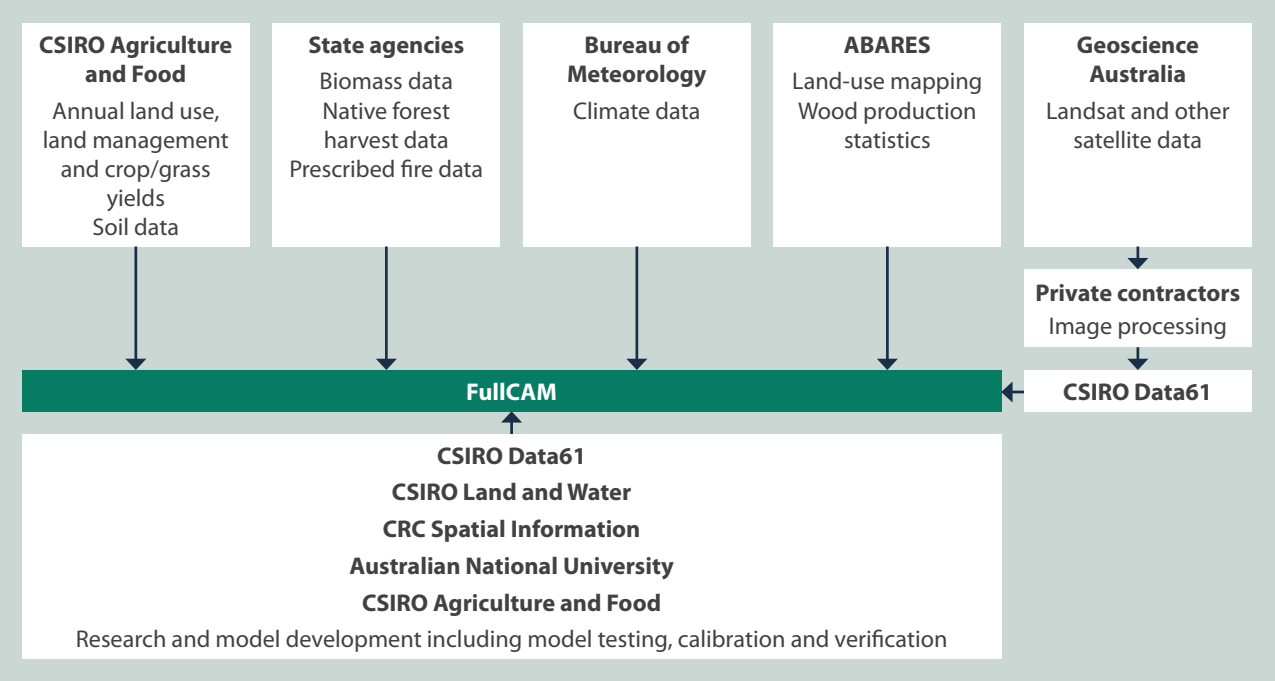
Figure 1.1 Department of Climate Change, Energy, the Environment and Water inventory asset structures and relationship



Acronym Key

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences	**DCCEEW**	Department of Climate Change, Energy, the Enviroment and Water
ABS	Australian Bureau of Statistics	**DISR**	Department of Industry, Science and Resources
AEC	Australian Electoral Commission	**DR**	Department of Resources (Queensland)
AGEIS	Australian Greenhouse Emissions Information System	**FullCAM**	Full Carbon Accounting Model
ANGA	Australia's National Greenhouse Accounts	**LULUCF**	Land use, land use change and forestry
ANREU	Australian National Registry of Emissions Units	**QA**	Quality assurance
CRC	Cooperative Research Centres	**QC**	Quality control

Figure 1.2 FullCAM institutional arrangements



1.2.2.b National Greenhouse and Energy Reporting (NGER) scheme

The NGER scheme, established by the *National Greenhouse and Energy Reporting Act 2007* (Cwlth) (NGER Act), is a single national framework for reporting and disseminating company information about greenhouse gas emissions, energy production, energy consumption and other information specified under NGER scheme legislation. Several legislative instruments sit under the NGER Act, providing greater detail about corporations' obligations, including:

- The *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (Cwlth) (the Determination) — describes the methods, standards and criteria to be applied when estimating greenhouse gas emissions, energy production and energy consumption, and
- The *National Greenhouse and Energy Reporting Regulations 2008* (Cwlth) (the Regulations) — sets out the details that establish compliance rules and procedures for administering the NGER Act.

The NGER scheme is administered by the independent Clean Energy Regulator (CER), which manages the process of NGER scheme data collection from companies, verification, auditing, and disseminating this data to relevant agencies. The CER's online Emissions and Energy Reporting System (EERS) is used for collecting data directly from companies.

An explicit objective of the NGER Act is to collect information to support the development of the national inventory. The NGER scheme 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. NGER scheme data are used to estimate approximately 65 per cent of total inventory emissions.

Under the NGER scheme, 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 CER. The NGER scheme provides activity data inputs, such as fuel combustion, emissions factors (EF) at facility level and, in some cases, directly measured emissions.

The rules for the estimation of activity data, emissions factors, and emissions by companies are well specified and set out in the Determination.

The methodologies used by facilities under the NGER scheme are developed in line with 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 commonly derived from the national inventory methods.

There are four method tiers available for estimating emissions under the Determination, noting that not all tiers are available under all activities. These are described in more detail in Annex V.I. These tiers do not align directly with IPCC tiers. However, most data collected through the NGER scheme adheres to an IPCC Tier 2 approach using either country- or facility- specific approaches. Some data are also collected using an IPCC Tier 3 approach, and a minority of emissions are estimated using an IPCC Tier 1 approach using default emission factors.

There are four measurement criteria used to describe how activity data was collected through the NGER scheme. The vast majority of emissions data collected under the NGER scheme are supported by commercial transactions, stockpile change estimation and invoices, or high-quality measurements at the point of sale, consumption, or production of a fuel.

Annual reports have been submitted by companies under the NGER scheme for Australian financial years since 2008–09. Data collected through these annual reports have been used in the preparation of this Report. The NGER Act requires the CER to publish summaries of NGER scheme data on its website each year by 28 February following the financial year the data covers. This results in publication of NGER data summaries a financial year ahead of the data published in the NIR, including:

- data highlights and data on corporate emissions and energy, electricity sector emissions and generation, and net energy consumption.
- Safeguard net emissions data, which comprise summaries and more detailed data on Australia's largest emitting facilities.

Further information on the design, operation, and quality assurance of the NGER scheme is included in Annex V.I.

Each year the department reviews and makes improvements to NGER scheme rules for the estimation of activity data, EFs and emissions based on latest available research, data, technologies and practices, and feedback from stakeholders and the CER. In addition, every five years the Climate Change Authority (CCA), an independent statutory authority, is required by law to review the operation of the NGER scheme legislation and may make recommendations to the Australian Government for its improvement. The CCA published its second review of the NGER scheme in December 2023. Its high-level findings included:

- The scheme is performing well and continuing to play its crucial role in meeting Australia's international energy and emissions reporting obligations and underpinning the Safeguard Mechanism.
- Compliance within the scheme is high, and the CER is taking appropriate enforcement action in instances of non-compliance.
- The scheme is informing the development, implementation and monitoring of government policies, programs and activities, as well as the Australian community.

The CCA made 25 recommendations focused on enhancements to data transparency, coverage, methane emissions measurement, reporting and verification, and administration (CCA 2023). In the Government's response to the Authority's review it agreed or agreed in principle to 24 recommendations and noted one recommendation. Further information on the Government's response is included in Annex V.I.

1.2.2.c Compilation procedures

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 1–18 below provide an overview of a typical inventory cycle. The cycle commences with a review of emissions estimation methods, allocation of tasks, selection of external consultants, and the preparation of AGEIS for the compilation of the forthcoming inventory.

Steps 1–5 that follow have been revised and expanded in response to area of improvement #2.G.1 (TERR 2025).

Inventory review process and improvement

1. Review process phase 1. At the start of each annual inventory cycle, sector experts develop and document potential improvements. This documentation identifies the nature of the proposed improvement, its expected benefits and resource and time requirements. In developing potential improvements sector experts consider:
    a. outstanding recommendations from previous UNFCCC/Paris Agreement technical expert reviews,
    b. status of multi-year improvements,
    c. commitments to future improvements documented in the last NIR,
    d. results of the last NIR's quality control measures, as documented in the Evaluation of Outcomes document (May–June),
    e. learnings from participation in UNFCCC/Paris Agreement technical expert reviews of other countries' inventories,
    f. new science, data, practices, technologies available since the last NIR,
    g. application of new abatement technologies and practices (to consider whether current methods can capture the change in emissions resulting from their application),
    h. outcomes from ad hoc and periodic external reviews or expert advisory processes (e.g. ANAO performance audits, Climate Change Authority reviews of the National Greenhouse and Energy Reporting scheme),
    i. feedback on the national inventory received from key inventory users through the year, including Commonwealth, State and Territory government agencies, industry,
    j. non-government organisations, the scientific and academic community and general public,
    k. outcomes of research, data collection and analysis commissioned to inform potential improvements,
    l. updates to UNFCCC and Paris Agreement reporting rules, including Intergovernmental Panel on Climate Change national greenhouse gas inventory guidelines for emission estimation, and
    m. current and emerging Australian Government emission reduction policy priorities.

    This results in the preparation of QA/QC and Inventory Improvement plans (July-Feb).
2. Preliminary prioritisation process. The NISIR Branch Head is briefed on identified potential improvements by the relevant sector experts. In consultation with NISIR inventory directors, the Branch Head makes a preliminary decision on the identified potential improvements, determining those improvements that should be:
    a. pursued in the current inventory cycle,
    b. progressed for application in future inventory cycles,
    c. revisited next cycle, and
    d. parked for the foreseeable future.

This preliminary decision considers:

e. data availability,

f. resource and time requirements,

g. materiality of the issue that an improvement seeks to address, and

h. government policy priorities.

3. Review process phase 2. Potential improvements identified for the current inventory cycle are tested with the national inventory's external advisory bodies (September–November):

   i. National Greenhouse Gas Inventory Committee, NGGIC, which comprises state and territory government agency representatives, and

   j. National Greenhouse Gas Inventory User Reference Group, NURG, which comprises representatives from CSIRO, academia, industry, forestry and carbon market stakeholder organisations.

4. Following any further refinement/prioritisation of the potential improvements based on NGGIC and NURG information and feedback, approved is sought from the Deputy Secretary of the department to implement the potential improvements in the current inventory cycle (December–January).
5. The planned improvements and QA/QC plan feed into development of investment and maintenance plan for AGEIS (July–Aug). Methodology development and incorporation into AGEIS (July–February).

Data collection and entry

6. Activity data collection is conducted annually by the department. This is heavily reliant on NGER scheme data and published data from Australia's national, state, and territory statistical agencies and industry bodies (June–December).
7. Activity data entry into the AGEIS input database, by the department, through predefined data entry templates (August–February).

Implementation of quality control measures

8. Tier 1 quality control measures – conducted by the department, including through AGEIS to, among other things, reduce the risk of errors associated with the input of activity data, missing data, recalculations, and the time series consistency of generated emissions estimates (June-January).
9. Tier 2 quality control measures – category-specific QC checks for all sectors conducted by the department to test for completeness, international comparability and verification of country-specific parameters (December–January).
10. Completion of all quality control measures to ensure estimates meet quality criteria (February).
11. Results of quality control measure tests are documented in an *Evaluation of Outcomes* report (March–April). See Section 1.5.

Emissions and report review

12. Emissions estimates verification is undertaken by department analysts by repeating the range of tests on emissions estimates generated by AGEIS to ensure time series consistency, consistency across sectoral emissions estimates, and accuracy of recalculations (December-February).
13. AGEIS is used to generate final emissions estimates for all inventory years using time series consistent methodologies (February).

14. A disaggregation of draft national inventory estimates by state and territory is circulated to the National Greenhouse Gas Inventory Committee of state and territory government representatives for external quality assurance prior to public release (December-February).
15. Emissions trends, anomalies, and recalculations by sector, national, state and territory, and greenhouse gas dimensions are reviewed, explained, and documented by department analysts. Emissions trends are compared with a range of external contextual factors (for example, economic, technological, policy, regulatory, etc) to ensure emissions results are consistent with observed real-world activity. Implied Emission Factors (IEFs) are compared with those of other Parties and significant anomalies are understood (December–February).

Report publication

16. Population of CRTs using the online Enhanced Transparency Framework (ETF) GHG Inventory Reporting Tool (February-March). Note: The function to create a new 2025 CRT inventory submission from an existing inventory was not available in the online ETF GHG Inventory Reporting Tool for this year's submission. To navigate this issue, the 2025 CRT inventory submission was created manually from a blank inventory, requiring re-entry of all indicators. The population of Australia inventory data into the ETF GHG Inventory Reporting Tool was largely accomplished using export and download of inventory data entry grids in Excel format.
17. Following approval by the Deputy Secretary of the department, informed by the *Evaluation of Outcomes* report, the inventory is submitted to the UNFCCC and Paris Agreement secretariat and made available for public release (April).
18. Release of emissions estimates and background data on Australia's National Greenhouse Accounts interactive online database and the National Inventory Report volumes on the department's website (April–May).

1.2.3 Archiving of information

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.

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, EFs, and other parameters and models,
- archival and storage of data source descriptions, methodology descriptions, and source reference materials, and
- integrated access to the documentation of data sources; methodology description and source reference materials.

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 emissions estimates from past submissions.

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

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

FullCAM, through which spatial simulations are run for estimating LULUCF emissions and activity data, also contains archiving functionality. FullCAM data management functions include:

- archival and storage of data utilised for spatial simulations for estimating LULUCF emissions for past simulations,
- version control of application coding of the FullCAM spatial simulator used for past simulations,
- records of key decisions for modifying the FullCAM spatial simulator coding, and
- storage of output SQL & SASS databases used to record spatial simulator results.

1.2.4 Process for official consideration and approval of the Inventory

The draft method improvements and estimates are 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 (CSIRO), academics, and industry representatives.

The National Greenhouse Gas Inventory Committee and the National Inventory Users Reference Group are the principal mechanisms for formal external review of key aspects 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.

1.3 Brief general description of methodologies and data sources

1.3.1 Estimation methods

The Australian methodology for estimating greenhouse gas emissions and sinks uses a combination of country-specific (CS) and IPCC methodologies and EFs. These methods are consistent with the IPCC 2006 Guidelines (IPCC 2006), supplemented by aspects of the 2019 IPCC Refinement (IPCC 2019) and the IPCC 2013 Wetlands Supplement (IPCC 2013). They are consistent with international practice.

In accordance with the IPCC 2006 Guidelines (Volume 1, Chapter 4), Australia's national inventory predominantly uses a mix of Tier 2 and Tier 3 estimation methods that incorporate:

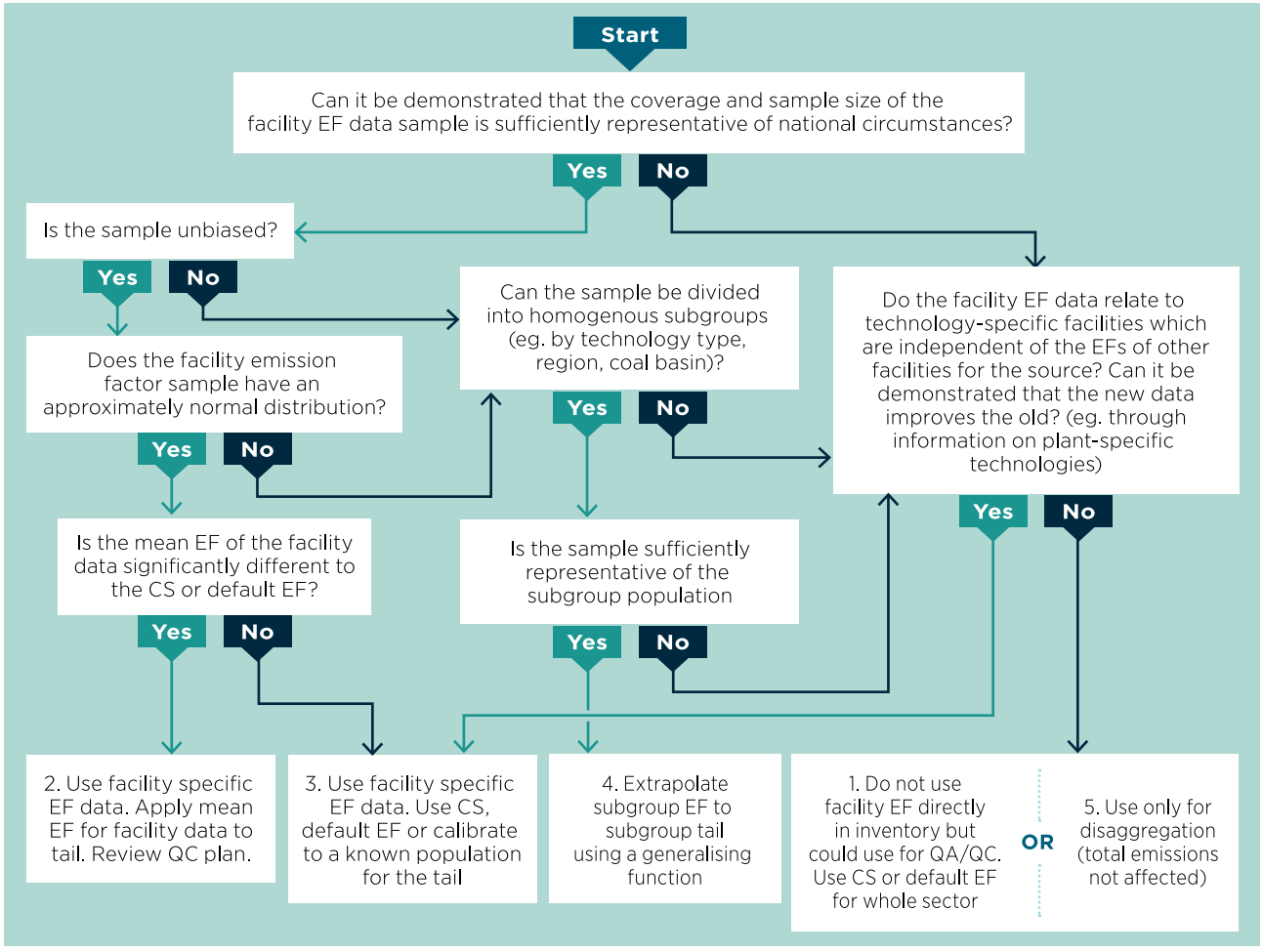
- plant-specific emissions estimation processes,
- characterisations of the capital and technology types at the point of emissions,
- dynamic relationships that link current emissions outcomes with the activity levels of previous years, and
- spatial differences in emissions processes across Australia.

The additional complexity of these methods and preferential use of country-specific and plant-specific data allows emissions to be estimated more accurately. Detailed descriptions of the methods used are set out in the Chapters 3–7 of this Report.

Tier 3 approaches are in place for fuel combustion in the electricity industry, non-CO_2 emissions in road transport, fugitive emissions from underground coal mining sources, fugitive emissions from oil and natural gas extraction (production and processing leakage emissions, and venting), carbon capture and storage, and vegetation modelling in LULUCF. 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 plant-specific measurement of emissions or key data inputs are adopted by reporters under the NGER scheme and as key pre-conditions for implementation of the new methods are met. These conditions 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 emissions 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 plant-specific EF data obtained from the NGER scheme have been used where the sample size of the available NGER scheme data is sufficiently large and when there is no evidence of bias in the distribution of the NGER scheme EF data. For the balance of a source where there are facilities for which no plant-specific data are available, a country-specific factor is applied.

Tier 3 Methods incorporating NGER scheme plant-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, several 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 scheme 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 scheme data has not yet been collected.

1.3.2 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 1.1.

Table 1.1 Principal data sources for the estimation of Australia's inventory

Category (UNFCCC sector)	Principal data sources	Principal collection mechanism
Energy sector (1.A.1, 1.A.2, 1.A.4, 1.A.5)	Australian Energy Statistics (DCCEEW) NGER scheme (CER)	Published Mandatory data reporting system
Energy sector (1.A.3)	Australian Energy Statistics and Australian Petroleum Statistics (DCCEEW) Various national statistics (ABS, BITRE, CASA)	Published
Energy sector (1.B)	NGER scheme (CER)	Mandatory data reporting system
	Australian Energy Statistics (DCCEEW)	Published
	Australian Petroleum Statistics (DCCEEW)	Published
	Various national, state, and territory statistics (NSW DPIRD, Vic DEECA, WA DMIRS, Qld DNRMMRRD, SA DEM, NT DME, Tas DSG)	Published
	Various industry statistics (Coal Services Pty Ltd, AEP, AEC)	Published
1.C Carbon Capture and Storage	NGER scheme (CER)	Mandatory data reporting system
Industrial processes and product use (2)	NGER scheme (CER)	Mandatory data reporting system
	Import data of HFC gases (DCCEEW)	Mandatory reporting of HFCs under import licensing arrangements
Agriculture (3)	Various national statistics (ABS and ABARES)	Published
	Various statistics provided by industry	Published and unpublished
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
	Forestry Corporation of New South Wales	Data Supply Licence, published

Category (UNFCCC sector)	Principal data sources	Principal collection mechanism
	Victorian Department of Jobs, Skills, Industry and Regions	Published
	Sustainable Timber Tasmania	Data Supply Licence
	Queensland Department of Primary Industries	Data Supply Licence
	Australian National University	Data Supply Licence
Waste (5)	NGER scheme (CER)	Mandatory data reporting system
	National Waste Report (DCCEEW)	Published
	National and state statistics (ABS)	Published

Detailed descriptions of the NGER scheme, Australian Energy Statistics, and satellite data processing are provided in Volume 2, Annex V, Sections A5.1, A5.2, and A5.6 of this Report respectively. The data sources presented in Table 1.1 along with additional data sources are described in more detail in Chapter 3–7 of this Report.

1.4 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 Guidelines (Volume 1, Chapter 4) and adopted by the MPGs. 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),* and *road transportation (liquid fuels)* as the most significant of the key categories.

When the LULUCF sector is excluded from the analysis the most significant key categories are *public electricity (solid fuel)* and *road transportation (liquid fuels).*

Australia's key category analyses use a relatively high degree of disaggregation of sources, as recommended in table 4.1 of the IPCC 2006 Guidelines. The full analyses are detailed in Annex I, Volume 2 of this Report.

1.5 Brief general description of QA/QC plan and implementation

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

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

The IPCC defines a 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:

- ensures data integrity,
- identifies and addresses errors and omissions,

- documents and archive inventory materials, and
- records all QC activities and results.

The QA/QC processes aim to conform to the IPCC 2006 Guidelines. These processes further aim to contribute to the production of inventories which are accurate transparent, documented, consistent over time, complete, comparable, and uncertainties are reduced to the extent practicable.

The QA/QC plan identifies key risks to the achievement of these objectives and sets out the mitigation strategies employed to ensure that they are attained. Systems have been established to monitor the outcomes of risk mitigation strategies and control measures, principally managed through the AGEIS which integrates QC operations directly with inventory compilation. 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.

Principal risk mitigation strategies are discussed in Annex IV. This includes a discussion on the QC operations undertaken on principle data sources and the outcomes of the national carbon balance. Australia's QA systems operate at a number of levels. QA controls that are implemented annually include:

- the review of key data from 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, which comprises representatives from Australia's premier science organisation, academics, sectoral experts from the consulting sector and industry representatives,
- review by external consultants for specified sectors,
- 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,
- opening the inventory emissions estimates and methods for public review through the release of transparent and easily accessible information via the Department and the Australia's National Greenhouse Accounts webpage. Industry and public feedback is accepted through the inventory e-mail facility nationalgreenhouseaccounts@dcceew.gov.au, and
- Paris Agreement technical expert review processes conducted in accordance with the MPGs (chapter VII, annex to decision 18/CMA.1).

This Report is also informed by the valuable feedback provided by successive UNFCCC expert review teams. Australia's inventory has been reviewed by in-country expert review teams in 2002, 2005, 2008, 2010, 2015, 2022 and 2025 and by a desktop review in 2017, with centralised reviews in other years. A simplified Paris Agreement review under the MPGs by the UNFCCC Secretariat was undertaken in 2023.

Further information on Australia's quality assurance and quality control plan and implementation, including Tier 1 and 2 and source-based quality control checks, are set out in Annex IV.

1.6 General uncertainty assessment, including data pertaining to the overall uncertainty of inventory totals

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 uncertainty, and reducing it over time, is recognised by IPCC 2006 as an important element of inventory preparation and development. Uncertainty can arise from the limitations of measuring instruments, sampling processes and the complexity of modelling highly variable sources of emissions over space and time, particularly for some biological sources.

Emissions estimate uncertainties are typically low for CO_2 from energy consumption as well as from some *industrial process and product use* emissions. Uncertainty surrounding estimates of emissions were 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 II 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 Guidelines.

At an aggregate level, using IPCC good practice Tier 1 uncertainty Methods, the overall uncertainty surrounding the Australian inventory estimate for 2023–24 is estimated at ± 5.0 per cent. The uncertainty for the trend in total inventory emissions is estimated to be ± 4.9 per cent. When the LULUCF sector is excluded from the analysis, national inventory uncertainty is estimated at ± 3.5 per cent for 2023–24 emissions and ± 3.4 per cent for the trend in emissions. These uncertainties are summarised in Table 1.2.

Table 1.2 Uncertainty percentage for 2023–24 including and excluding LULUCF

	2023–24	
	Including LULUCF	Excluding LULUCF
Uncertainty (%)	±5.0	±3.5
Trend Uncertainty (%)	±4.9	±3.4

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

1.7 General assessment of completeness

The Paris Agreement MPGs require that national inventories are assessed by inventory compilers to determine the level of completeness of reported sources. The sources of greenhouse gas emissions are many and diverse and, in general, are not directly observable without human and financial investment. Many emission sources are minor and resource intensive to estimate. Consequently, all national inventories have minor omissions which, for transparency, need to be identified. This section addresses the completeness of key activity datasets and the completeness of the coverage of emissions and removals sources for the Australian inventory.

1.7.1 Information on completeness

The inventory is largely complete with a few minor sources not estimated due to either a lack of available information or methodology in the IPCC 2006 Guidelines. Australia also reports a number of additional, voluntary emissions sources from the IPCC 2019 Refinement (IPCC 2019) and the IPCC 2013 Wetlands Supplement (IPCC 2013).

For the industrial sectors, the primary data source is NGER scheme data. The data collected under this scheme is not complete for a range of reasons, including reporting thresholds.

Table 1.3 summarises how completeness is achieved in those categories where NGER scheme data is not solely used to achieve completeness.

Table 1.3 Summary of data sources used to achieve completeness, where NGER scheme data is not the sole source, by IPCC category

Category		Source
1.A.1.a	Electricity (gas)	Completeness is achieved through use of data from the Australian Energy Statistics (AES) published by the department. As explained in Chapter 3, Section 3.2.4.2 Methodological issues – Activity Data of this Report, the energy use of the small power stations that do not meet the NGER scheme reporting thresholds are estimated as the difference between the total of reported data under the NGER scheme and AES for ANZSIC subdivision 26. This approach has been adopted throughout the time series. Therefore, the improved coverage of power stations under the NGER scheme does not alter the method for estimating total fuel consumption in this sector.
1.A.1.a	Electricity (liquid)	As above.
1.A.1	Energy industries (excluding Electricity)	Completeness is achieved through the use of energy balance data, by fuel type and subsector from the AES published by the department. Further detail is provided in Volume 1, Chapter 3, Section 3.2.4 and Volume 2, Annex 5 of this Report.
1.A.2	Manufacturing	Completeness is achieved through use of energy balance data, by fuel type and subsector from the AES published by the department. Further detail is provided in Volume 1, Chapter 3, Section 3.2.5 and Volume 2, Annex 5 of this Report.
1.A.3	Transport	Completeness is achieved through use of national transport fuel use data, by fuel type and subsector from the AES and Australian Petroleum Statistics (APS), published by the department. Further detail is provided in Volume 1, Chapter 3, Section 3.2.6 and Volume 2, Annex 5 of this Report.
1.A.4	Other sectors	Completeness is achieved through use of energy balance data, by fuel type and subsector from the AES published by the department. Further detail is provided in Volume 1, Chapter 3, Section 3.2.7 and Volume 2, Annex 5 of this Report.
1.A.5	Other	This category comprises military transport only. Completeness is achieved for this source using data obtained directly from Australia's Department of Defence. Further detail is provided in Volume 1, Chapter 3, Section 3.2.8 and Volume 2, Annex 5 of this Report.
1.B.2	Fugitive Oil & Gas	NGER scheme data are complemented by a range of data sources to ensure completeness. Further detail is provided in Volume 1, Chapter 3, Section 3.3.2 and Volume 2, Annex 5 of this Report.
2	IPPU	Completeness is achieved through the use of consultancy reports in sectors and years where NGER data is not available.
3	Agriculture	Completeness is principally achieved through using Australian Bureau of Statistics agricultural census data. Further detail is provided in Volume 1, Chapter 5 and Volume 2, Annex 5 of this Report.
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 AES published by the department. Further detail is provided in Volume 1, Chapter 6 and Volume 2, Annex 5 of this Report.
5.A	Solid waste	Completeness for solid waste disposal is discussed in Volume 1, Chapter 7, Section 7.2 of this Report. NGER scheme data covers about 70 per cent of total waste disposal in Australia. Disposal data not covered under the NGER scheme is collected from the relevant state and territory governments. The residual disposal not covered by the NGER scheme is calculated as the total disposal in each state and territory minus the sum of NGER scheme disposal in each state and territory. Figure 7.5 graphs the relationship between state and territory reported disposal and disposal reported under the NGER scheme. Methane capture data obtained under the NGER scheme are considered complete as they are supplied by gas capture companies (as distinct from landfill operators) all of which trigger reporting thresholds of the NGER scheme.

Category		Source
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. Further detail is provided in Volume 1, Chapter 7, Section 7.3 of this Report.
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 scheme, by O'Brien (2006b) and an estimate of state population reported by the Australian Bureau of Statistics. Further detail is provided in Volume 1, Chapter 7, Section 7.4 of this Report.
5.D.1	Domestic and commercial wastewater	Major wastewater treatment facilities report under the NGER scheme. NGER scheme 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. Further detail is provided in Volume 1, Chapter 7, Section 7.5 of this Report.
5.D.2	Waste incineration	Where appropriate, national commodity production statistics are used to ensure completeness of AD for industrial wastewater. Further detail is provided in Volume 1, Chapter 7, Section 7.5 of this Report.

As the land sectors are not covered by the NGER scheme, a range of quality data sources and verification activities are undertaken to ensure completeness of Australia's inventory. These are detailed in Volume 1, Chapters 5 and 6, and Volume 2, Annexes A5.5 and A5.6 of this Report.

1.7.2 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

  Norfolk Island is an external Australian territory in the Pacific Ocean about 1600 km northeast of Sydney. Norfolk Island is one of Australia's most isolated communities and one of its oldest territories. Norfolk Island has a diverse environment and notable historic sites, and during the most recent census recorded a population of 2,188 (ABS 2021c) (DITRDCA 2024a).

- Christmas Island and Cocos (Keeling) Islands

  The Australian Government has responsibility for the external territories of Christmas Island and the Cocos (Keeling) Islands, collectively known as the Indian Ocean Territories (IOT). Christmas Island has an area of 137.4 square kilometres and includes the Christmas Island National Park (85 square kilometres). Christmas Island had a population of 1,692 in the most recent census (ABS 2021d). The Cocos (Keeling) Islands consist of 27 coral islands in the group with a total land area of approximately 15.6 square kilometres. North Keeling Island was declared a National Park in 1995. During the most recent census, Cocos (Keeling) Islands recorded a population of 593 (ABS 2021e) (DITRDCA 2024c).

- Heard and McDonald Islands

  Heard Island and McDonald Islands (HIMI) are a sub-Antarctic Island group. They are located in the Southern Ocean, about 4,000 km southwest of mainland Australia. The islands have a World Heritage protection and marine reserve status and are uninhabited (AAP 2026)

Australia's Antarctic Program operations are also covered, which occur across four stations (Macquarie Island, Casie, Davis, and Mawson). Approximately 500 people inhabit these stations in summer, dropping to around 80 people in the winter (AAP 2021)

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

- Coral Sea Islands (Queensland)

  The Coral Sea Islands Territory is made up of the islands situated in an area of approximately 780,000 square kilometres of the Coral Sea extending from the outer edge of the Great Barrier Reef. The coral and sand islands are quite small with some grass and low vegetation cover. Only Willis Island is inhabited by Bureau of Meteorology staff. Unmanned weather stations, beacons and a lighthouse are located on several other islands and reefs. During the most recent census, Willis Island recorded a population of 78 (ABS 2021f) (DITRDCA 2024b).

- Ashmore and Cartier Islands (Northern Territory)

  The Territory of Ashmore and Cartier Islands comprises West, Middle and East Islands of the Ashmore Reef, Cartier Island and the 12 nautical mile territorial sea generated by these islands. The islands are uninhabited and composed of coral and sand with some grass cover (DITRDCA 2024a).

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
- *LULUCF* emissions and removals are not estimated but are likely to be negligible.

1.7.3 Total aggregate emissions considered insignificant (per MPG paragraph 32)

In accordance with paragraph 32 of the MPG, a Party may use the notation key "NE" (not estimated) for a source when the estimates would be insignificant. Insignificance is defined as having a likely emissions value below 0.05 per cent of the national greenhouse gas emission total (excluding LULUCF), does not exceed 500 kt CO_2-e, and that the aggregate of all "NE" sources remains below 0.1 per cent of the national greenhouse gas emission total (excluding LULUCF).

In 2023–24, Australia's total national aggregate of "NE" emissions for all gases and categories represent 0.035 per cent of Australia's total emissions (excluding LULUCF), which is below the 0.1 per cent significance threshold (Table 1.4). No individual sources exceed the 500 kt CO_2-e significance threshold.

Table 1.4 Emissions sources reported as "NE"

Source	Absolute Estimated Emissions (kt CO_2-e)	Relative Estimated Emissions (%)
Total national inventory (excluding LULUCF)	**518,566.8**	**100**
Total inventory significance threshold	518.6	0.1
Total omitted sources estimate	**167.0**	**0.032**
1.A.3.b.vi Urea-based catalysts [(a)]	54.0	0.01
1.A.3.c Railways – Solid Fuels	38.8	<0.01
1.B.2.a.iii Crude oil transport	0.004	<0.001
1.B.2.b.iv Transmission and storage – Natural gas storage	0.3	<0.001
2.D.2 Paraffin Wax Use	0.7	<0.001

Source	Absolute Estimated Emissions (kt CO_2-e)	Relative Estimated Emissions (%)
3.D.1.d Other organic fertilisers	0.6	<0.001
5.B.2 Anaerobic digestion at biogas facilities	2.9	<0.001
5.C.1 Incineration of clinical waste	0.8	<0.001
5.C.2 Accidental fires at solid waste disposal sites	16.9	<0.01
5.C.1 Incineration of waste other than clinical waste and solvents	52.0	0.01

Notes: (a) This activity is sometimes identified as a part of the IPPU sector due to the process not being a fuel combustion activity.

1.7.4 Description of insignificant ("NE") categories

Australia's omitted insignificant emissions sources are categories as "NE" and are estimated using simple methods in line with paragraph 32 of the MPGs.

The data and assumptions Australia has used to derive the likely emissions levels presented in Table 1.4 are described by category below.

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

Urea-based additives (diesel exhaust fluid – DEF) are used in Australia in modern diesel engines fitted with selective catalytic reduction (SCR) emissions control systems. SCR is an emissions control technology that reduces tailpipe emissions of NO_x.

It is estimated that national demand for DEF is approximately 4 million litres per week, resulting in approximately 54.0 kt CO_2-e (0.01 per cent of the national total).

Australia has no immediate plans to report emissions from Urea-based catalysts category (1.A.3.b.vi) – there is a considerable data requirement to estimate the emissions considering fuel consumption rates and penetration of the technology in the fleet. Given the insignificance of the source, this is not considered to add materially to the completeness of the inventory.

Railways – Solid Fuels (CRT category 1.A.3.c)

Australia has several tourist railways operating historic coal powered steam trains. Based on information published in the 2023–24 annual report of the Puffing Billy Historic Railway on their coal consumption and associated emissions (which is assumed to be representative of the broader industry's activities) and information on the number active historic railways from the Association of Tourist and Heritage Rail Australia, it is estimated that emissions from solid fuel use in railways are approximately 38.8 kt CO_2-e. This is considered insignificant and emissions are "not estimated".

Crude oil transport (CRT category 1.B.2.a.iii)

Australia reports CH_4 leakage emissions from the marine transport of oil under CRT category 1.B.2.a.iii. Further details on the estimation methodology can be found in Section 3.3.2.2, *Crude oil transport* (CRT category 1.B.2.a.iii). Currently, Australia does not estimate CO_2 emissions for CRT category 1.B.2.a.iii.

In the absence of a marine transport-specific or country-specific factor, an estimate for CO_2 leakage from the marine transport of oil was made using the "Tanker Trucks and Rail Cars" Tier 1 emission factor from the 2006 IPCC guidelines (2006 IPCC Guidelines, Vol 2, Chapter 4, Table 4.2.4, IPCC 2006). It was estimated that 0.004 kt CO_2-e resulted from CO_2 leakage in 2023–24 (<0.01 per cent of the national total excluding LULUCF), which is well below the significance threshold. Subject to resources and priorities, Australia intends to undertake further research to determine if CO_2 emissions from the domestic marine transport of oil occur in Australia.

Transmission and storage (CRT category 1.B.2.b.iv)

Leakage emissions from natural gas storage are a subset of CRT category 1.B.2.b.iv. Australia reports methane emissions under *transmission and storage* (CRT category 1.B.2.b.iv) for:

- natural gas transmission pipelines,
- natural gas storage,
- liquefied natural gas storage, and
- liquefied natural gas export terminals.

Australia also reports carbon dioxide emissions under CRT category 1.B.2.b.iv, but only for emissions associated with natural gas transmission pipelines (see Section 3.3.2.2, *Natural Gas Transmission and Storage (CRT category 1.B.2.b.iv)* for further details). Australia does not currently estimate CO_2 emissions from natural gas storage.

An estimate was made for CO_2 emissions from natural gas storage using the Tier 1 emission factor from 2019 IPCC Refinements (2019 IPCC Refinements, Vol 2, Chapter 4, Table 4.2.4.I, IPCC 2019), which was further adjusted to leakage emissions using the CO_2 leakage percentage (2019 IPCC Refinements, Vol 2, Chapter 4, Table 4A.2.7, IPCC 2019). It was estimated that 0.32 kt CO_2-e result from the CO_2 leakage (<0.01 per cent of the national total excluding LULUCF), which is well below the significance threshold. Dependent on resources and priorities, Australia intends to undertake further research to determine if CO_2 emissions from natural gas storage occur in Australia with a view to ensure completeness of inventory estimates.

Paraffin Wax Use (CRT category 2.D.2)

Australia derived a paraffin wax use factor weighted per-capita from all Annex-1 Parties reporting emissions from this source. This per capita factor was applied to Australia's population to estimate emissions for 2023–24, resulting in 0.7 kt CO_2-e of emissions (approximately 0.001 per cent of the national total excluding LULUCF). This is well below the significance threshold for reporting. Accordingly, this source is reported as Not Estimated ("NE").

Other organic fertilisers (CRT category 3.D.1.d)

The organic fertilisers used in Australia are principally derived from animal wastes (3.D.1.d). Emissions from this organic N source are covered elsewhere. Data on the application of other organic N fertiliser is not available through either ABS or industry data collections, nor is a comprehensive list of organic fertiliser producers available. To assess the significance of the category, data was sourced from one of the largest commercial producers. They reported production of meat and fish meal containing 117.8 tonnes of Nitrogen. Applying the IPCC default EF of 1 per cent this equates to 0.6 kt CO_2-e of emissions. Even allowing for the complete estimate to be over 900 times greater, this category can be considered insignificant (<500 kt CO_2-e) and as such, emissions are "not estimated".

Land use, land use change and forestry (external territories) (CRT category 4)

As described in Section 1.7.2, Australia's external territories are largely uninhabited, and include large areas of national terrestrial and marine parks. In 2020–21 during the most recent census, the population was approximately 5,000 people across all external territories. On this basis, any LULUCF emissions from this source are likely negligible and are not estimated.

Anaerobic digestion of solid waste at biogas facilities (CRT category 5.B.2)

To date, no facilities have reported emissions associated with the anaerobic digestion of solid waste at biogas facilities under the NGER scheme. The Australian biogas industry is emerging. There are three known facilities in operation in Australia that could be classed as anaerobic digestion facilities for solid waste.

The Richgro facility in Jandakot Western Australia became operational in 2015 and has the capacity to process up to 140 tonnes of food waste per day. Another facility known as Earthpower has been operating in Sydney since 2003 and can process up to 130 tonnes of organic waste per day. As with the Richgro facility, emissions of less than 1,000 tonnes of CO_2-e are estimated. A third facility in Wollert, to the north of Melbourne, has been operating since May 2017. The facility has the capacity to process around 90 tonnes of food waste per day.

When the IPCC default CH_4 EF of 0.8 g CH_4/kg wet waste treated is applied to the maximum quantity of waste that could be processed at these three facilities, it results in annual emissions of around 2.9 kt CO_2-e. This is well below the significance threshold for reporting. Accordingly, this source is reported as Not Estimated ("NE").

Incineration of clinical waste and solvents (CRT category 5.C.1)

For the incineration of clinical waste and solvents (5.C.1), the IPCC 2006 do not provide default CH_4 and N_2O emission factors. Furthermore, when the highest IPCC 2006 default EFs for CH_4 and N_2O listed for municipal solid and general industrial waste incineration are applied to the AD for clinical waste and solvents incineration, emissions estimates contribute less than 0.001 per cent (0.8 Kt CO_2-e) of total emissions from all sectors. Accordingly, emissions of CH_4 and N_2O from this source can be considered insignificant (<500 kt CO_2-e) and as such, emissions are "not estimated".

Accidental fires at solid waste disposal sites (CRT category 5.C.2)

For unintentional (accidental) fires on solid waste disposal sites (5.C.2), Australia has estimated emissions of CO_2, CH_4 and N_2O to contribute around 16.9 kt CO_2-e or 0.004 per cent of total emissions from all sectors in 2023–24. Accordingly, emissions from this source are reported as "not estimated" on the grounds that they fall below the significance threshold.

State/territory reported fire records and population data were used to estimate the volume of waste burnt per capita per day. As a conservative approach, all burnt waste was assumed to be converted into CO_2 and other gases (B_{frac} = 1). The IPCC 2006 default EF for CH_4 for open burning of waste was applied, while country specific EFs for CO_2 and N_2O were applied, consistent with the EFs used in the inventory.

Incineration of waste other than clinical waste and solvents (CRT category 5.C.1)

For the incineration of waste other than solvents, municipal and clinical waste (5.C.1), when the highest IPCC 2006 default EFs for CO_2 and N_2O listed for waste lubricant, hazardous waste and biosolids are used, emissions are estimated to contribute around 52.0 kt CO_2-e or 0.01 per cent of total emissions from all sectors in 2023–24. Accordingly, emissions from this source are reported as "not estimated" on the grounds that they fall below the significance threshold.

1.8 Metrics

Consistent with paragraph 37 of the MPG, this Report is prepared using 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report (AR5).

2. Trends in emissions

2.1 Description of emission and removal trends for aggregated GHG emissions and removals

2.1.1 Overview of emissions trends since 1990

Australia's total greenhouse gas emissions were 466.4 million tonnes (Mt) of carbon dioxide equivalent (CO_2-e) in 2023–24. Total net emissions, presented in Table 2.1, have decreased by 3.8 per cent (or 18.3 Mt CO_2-e) on 2022–23 levels, decreased by 23.3 per cent (or 141.3 Mt CO_2-e) on 2004–05 levels, and decreased by 24.3 per cent (or 149.5 Mt CO_2-e) on 1989–90 levels.

Decreases on the previous year were driven by:

- reductions in underground coal mining activity reducing *fugitive* emissions,
- reductions in gas consumption in chemical manufacturing and ongoing reductions in the emissions intensity of electricity generation reducing *stationary energy* emissions,
- reductions in the minerals, chemicals, metals and substitutes for ozone depleting substances sectors reducing *industrial processes and product use emissions,*
- lower crop production after the record set in 2022–23 reducing *agriculture* emissions, and
- climate impacts in 2023–24 affecting *LULUCF* emissions, in part due to limited activity data updates. The net sink from the LULUCF sector increased as sequestration rates returned to more typical levels following the sharp reduction in the land sink in 2022–23. That reduction had followed the 2020–2022 La Niña and associated wetter conditions which temporarily elevated land-based growth and sequestration.

These decreases were partially offset by increased emissions from transport, particularly from road transport and domestic aviation, reflecting the continuing recovery from COVID-related movement restrictions.

In the LULUCF sector, planned improvements to the remote sensing program for forest cover change have proven complex and taken longer than expected, and validation of data received to date is ongoing. As a result, updates to forest cover mapping were not available for use in this submission. For several land use categories that rely on the forest cover monitoring system for activity data, the emissions reported for 2022–23 and 2023–24 are an extrapolation of the 2021–22 results, to ensure completeness of reporting, consistent with the IPCC 2006 Guidelines (Volume 1 Chapter 5.3: Resolving data gaps).

Updates to climate data, crop and grass yields and forest productivity data, were incorporated to improve estimates of emissions and removals from regenerating forests and emissions on previously cleared lands. This hybrid approach provides the most reliable estimates given current data constraints. It balances the need for completeness and methodological consistency with the opportunity to incorporate category specific updates where supporting data exist.

Other land use categories were not updated because the impacts of climate data and vegetation monitoring activity data were not able to be updated independently, or independent climate updates were considered unlikely to be representative of emissions trends and subject to material revision once activity data becomes available. In these land use categories, holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data, and unsuitability of trend extrapolation given interannual variability of climate drivers. Consistent with the IPCC 2006 Guidelines (Volume 1 Chapter 5.3: Resolving data gaps), emissions for these categories have generally been held constant at 2021–22 levels for 2022–23 and 2023–24.

More information on land use categories where extrapolation has been used is included in Chapter 6.

Figure 2.1 Comparison of 2023–24 emissions with past emissions levels by sector, million tonnes of carbon dioxide equivalent (Mt CO_2-e) and percentage change (%)

Emissions Sectors	2023–24 emissions	Change in 2023–24 emissions since: 1989–90	2004–05	2022–23
Total emissions	466 Mt CO_2-e	-149 Mt CO_2-e, -24%	-141 Mt CO_2-e, -23%	-18 Mt CO_2-e, -4%
1. Energy	398 Mt CO_2-e	+34%, +101 Mt CO_2-e	-4 Mt CO_2-e, -1%	-2 Mt CO_2-e, -0.5%
2. Industrial Processes and Product Use	31 Mt CO_2-e	+23%, +6 Mt CO_2-e	+2%, +1 Mt CO_2-e	-2 Mt CO_2-e, -7%
3. Agriculture	76 Mt CO_2-e	-14 Mt CO_2-e, -16%	-7 Mt CO_2-e, -9%	-3 Mt CO_2-e, -4%
4. Land use, land use change and forestry	-52 Mt CO_2-e	-232 Mt CO_2-e, -129%	-129 Mt CO_2-e, -168%	-11 Mt CO_2-e, -27%
5. Waste	14 Mt CO_2-e	-10 Mt CO_2-e, -41%	-2 Mt CO_2-e, -12%	+0.4%, +0.1 Mt CO_2-e

Note: Icons in this figure are sourced from Freepik, and Uniconlabs on flaticon.com.

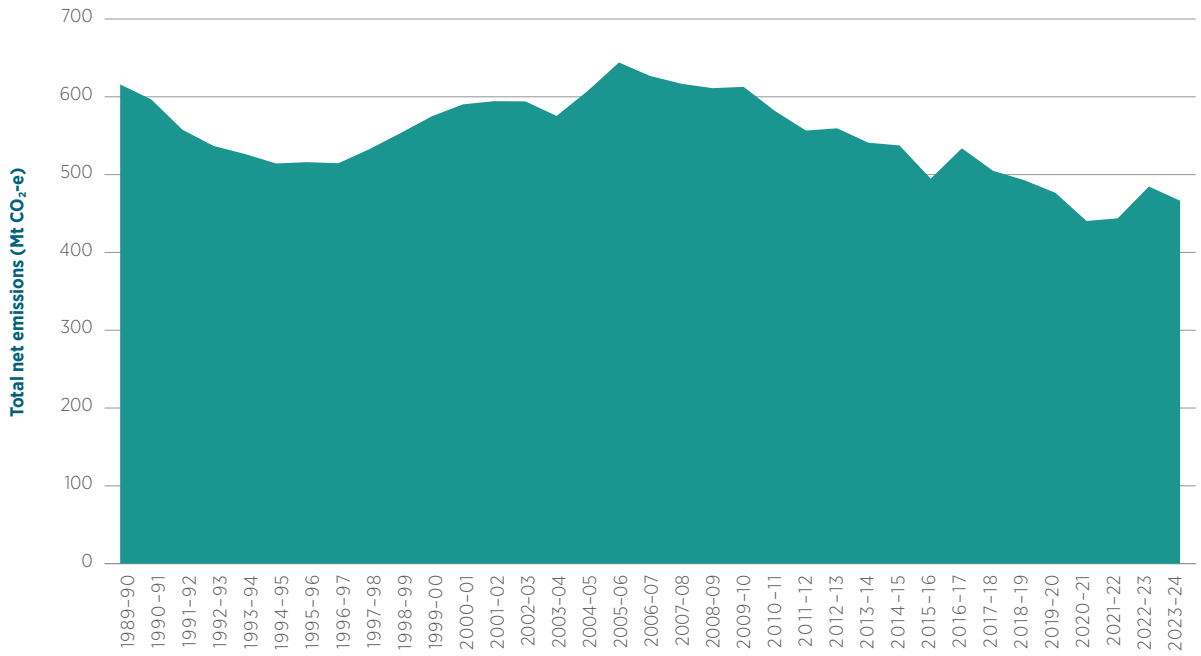
Table 2.1 Net greenhouse gas emissions by sector, Australia (Mt CO_2-e)

UNFCCC classification sector and subsector	Net emissions (Mt CO_2-e)							Per cent change in emissions in 2023–24 since:		
	1989–90	2004–05	2009–10	2014–15	2019–20	2022–23	2023–24	1989–90	2004–05	2022–23
1. Energy (combustion + fugitive)	297.3	402.3	421.8	421.8	421.3	400.0	398.1	33.9	-1.0	-0.5
Stationary energy	*195.7*	*277.9*	*287.9*	*277.9*	*272.0*	*252.3*	*250.5*	28.0	-9.9	-0.7
Transport	*61.2*	*81.8*	*88.4*	*94.9*	*93.2*	*98.2*	*100.4*	64.1	22.7	2.2
Fugitive emissions from fuel	*40.4*	*42.6*	*45.5*	*49.1*	*56.1*	*49.5*	*47.2*	16.9	10.9	-4.5
Carbon capture and storage	*NO*	*NO*	*NO*	*NO*	*0.01*	*0.0023*	*0.0001*	*NA*	*NA*	*-96.8*
2. Industrial processes and product use	25.1	30.1	33.5	30.5	31.9	33.1	30.8	22.8	2.4	-6.8
3. Agriculture	89.8	82.7	72.9	76.1	70.2	78.8	75.7	-15.8	-8.5	-3.9
4. Land use, land use change and forestry	180.2	76.8	68.5	-5.1	-60.3	-41.1	-52.1	-128.9	-167.9	-27.0
5. Waste	23.5	15.8	16.1	14.1	13.5	13.9	13.9	-40.6	-11.6	+0.4
Total net emissions	**615.9**	**607.7**	**612.8**	**537.5**	**476.6**	**484.7**	**466.4**	**-24.3**	**-23.3**	**-3.8**
Memo: *Total net emissions without natural disturbances provision*	*612.7*	*580.2*	*601.7*	*526.1*	*1186.1*	*375.7*	*457.3*	-25.4	-21.2	21.7

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. Australia's approach to addressing emissions and subsequent removals from natural disturbances is detailed in Chapter 6 of this Report and the full time series is provided in Table 4 of the CRT.

Australia's net emissions peaked in 2005–06 and have generally been on a long-term decline since that year (Figure 2.2).

Figure 2.2 Total net emissions per year, Australia, Mt CO_2-e



The decline in emissions from the 2005–06 peak is caused by a complex mixture of long-term and short-term factors. Long-term downward pressures on emissions include changes in the electricity generation mix (including strong growth in renewable sources), increased methane capture in the energy and waste sectors, technology innovations and the LULUCF sector changing from a net source to a net sink (including in response to reduced land clearing, increasing forest cover through plantations and natural regeneration). There are also several shorter-term drivers of emissions reduction since the 2005–06 peak, including general economic downturn during the Global Financial Crisis (2007 to 2009), temperature influences on electricity demand, the Australian Government's Carbon Pricing Mechanism (2012–15; CER 2015), broader climatic factors (including from the El Niño and La Niña cycle, which has the strongest impact on year-to-year climate variability in Australia – BoM 2021), multiple significant flooding events (2007, 2009 to 2015, 2020, 2021, and multiple events of widespread flooding in 2022; BoM 2022a, BoM 2022b, BoM 2024a), two significant drought events (the Millennium drought 1997 to 2009, and 2017 to 2019; BoM 2024b), broadscale impacts resulting from the COVID-19 pandemic, including reductions in travel including as a result of international and state/territory border restrictions (2020 to 2022; JSCFADT 2020), and the ending of the 'triple-dip' La Niña event in 2023 (BoM 2025). In 2023–24, the trend reflects post-COVID-19 recovery (particularly in transport) and the LULUCF sector moderating back to more typical sequestration rates following the 2020–2022 La Niña, with a slight increase in the net sink compared with 2022–23, but remaining a smaller net sink than 2021–22.

Further detail on Australia's emissions trends by sector, are provided in Section 2.2.1 and sectoral Chapters 3–7 of this Report.

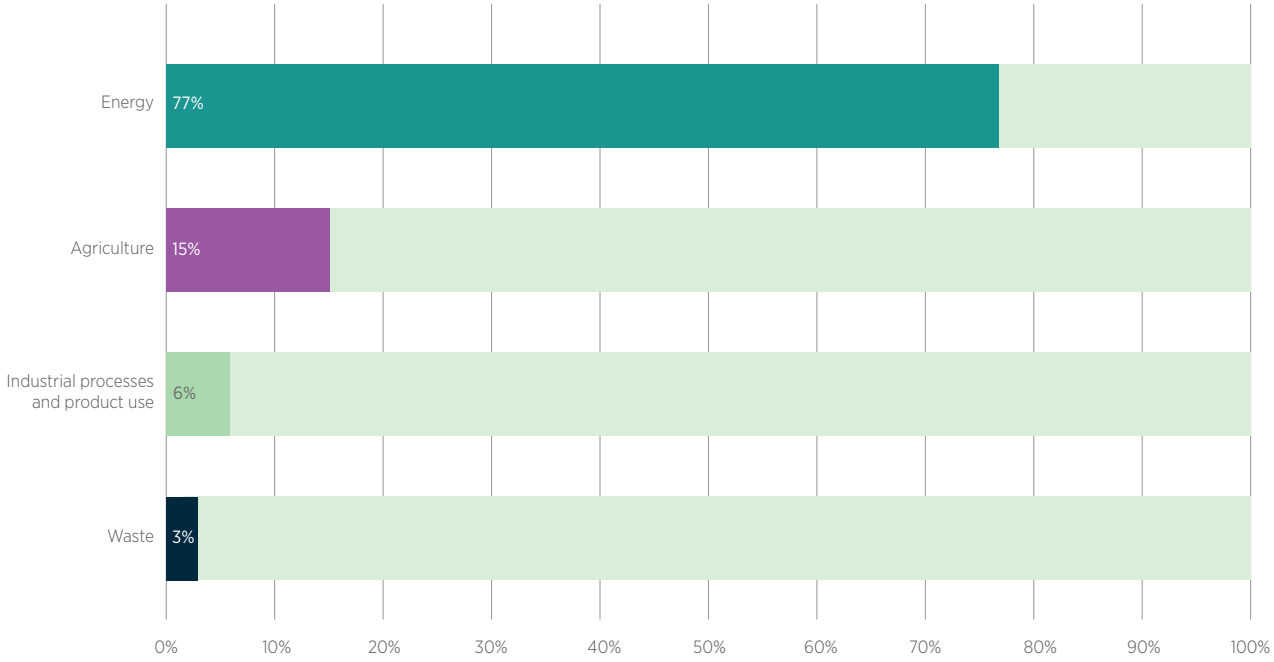
2.2 Description of emission and removal trends by sector and by gas

The following sections present Australia's emissions trends by sector, by greenhouse gas, and by ozone precursor and indirect gas. As the LULUCF sector is a net sink in 2023–24, emissions by sector are described with and without LULUCF in ES.2 and ES.3, and are largely described excluding LULUCF in Section 2.2.

2.2.1 Sectoral trends

Emissions by sector (excluding LULUCF, which is a net sink in 2023–24) are presented in Figure 2.3. The combined *energy* subsectors (including *stationary energy, transport* and *fugitive emissions)* were the largest source of greenhouse gas emissions in 2023–24, followed by the *agriculture* sector.

Figure 2.3 Share of national emissions (excluding LULUCF) on a CO_2-e basis by sector, 2023–24



Note: LULUCF emissions are a net sink in 2023–24 and have been excluded from this figure.

Emissions decreased in 2023–24 in *stationary energy, fugitive emissions from fossil fuels, industrial processed and product use, agriculture and LULUCF.* Conversely, emissions from *transport increased.* Emissions from *waste* were essentially flat.

The contribution of each sector to total emissions by year is presented in Figure ES.01, with total and net total emissions by year presented in Figure ES.02. The principal drivers of these emissions trends are as follows:

- ***Energy:*** The largest sectoral increase in greenhouse gas emissions over the reporting period 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 have continued to decrease from the peak in 2008–09, despite continuing population and economic growth. This is primarily driven by a decrease in the share of generation from coal, along with an 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 consistent and significant increase in *transport* emissions since 1989–90 (other than where impacted by the COVID-19 pandemic across 2019–20 to 2022–23) are ongoing growth in the size of the passenger vehicle stock, along with consistently increasing consumption of diesel in light commercial and heavy vehicles as population and economic growth lead to increasing demands for freight. Increasing domestic aviation activity, especially since the early 2000s, has also contributed to increasing transport emissions. *Fugitive emissions from fossil fuels* have increased over the period to a peak in 2018–19, largely due to increased production from open cut coal mines and increased natural gas production. Emissions from coal mining have generally decreased since 2017–18. Fugitive emissions from natural gas production increased from 2014–15 due to expansion in LNG exports, fell sharply from 2018–19 as LNG expansion stabilised, and have remained flat in 2022–23 and 2023–24.

- ***Industrial processes and product use:*** Emissions in the *industrial processes and product use* sector increased over the period from 1989–90 to 2022–23, with notable decreases in 2008–09, 2011–12 and 2012–13 driven primarily by falls in iron and steel production. Emissions declined by 2.2 Mt CO_2-e / 6.8% in 2023–24 driven by reductions in the chemical, metal and mineral industries as well as in the *Product uses as substitutes for ozone depleting substances* sector. Long-term increases in emissions have been primarily driven by the *Product uses as substitutes for ozone depleting substances* sector due to growth of the bank of HFCs used in refrigeration and air-conditioning equipment. This has been partly offset by sustained decreases in emissions from metals production, driven by declines in steel production since a peak in 1997–98 and ongoing reductions in the rate of PFC emissions from aluminium smelting due to process improvements.
- ***Agriculture:*** Agricultural emissions have decreased since 1989–90. 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 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 1994–95 to 1999–2000 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 1999–2000 until 2009–10, 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 2010–11 and 2016–17, as farmers were able to increase herds and flocks and crop production. Drought conditions in more recent years resulted in a lack of feed and elevated levels of turn-off of cattle and sheep and a contraction in the livestock population. Crop production and fertiliser consumption also decreased, with corresponding decreases in emissions. The higher rainfall from 2019–20 to 2023–24 was mostly reflected in improved growing conditions and water availability leading to record crop production and higher emissions in 2022–23, although flooding did impact horticultural production regionally.
- ***Waste:*** Emissions from the *waste* sector have decreased over time, 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, which has experienced a substantial improvement in methane recovery rates since 1989–90. The decrease in emissions in 2023–24 was primarily driven by increases in methane recovery over the year.
- ***Land use, land use change and forestry:*** The decrease in emissions from *land use, land use change and forestry* (LULUCF) since 1989–90 has been mainly driven by the decline in emissions from land clearing (forest land converted to other land uses), forest cover expansion (including plantation establishment), and declines in the harvesting of native forests. Note that in this submission, extrapolation has been used to fill data gaps for some land use categories, as explained in section 2.1.1 above.

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

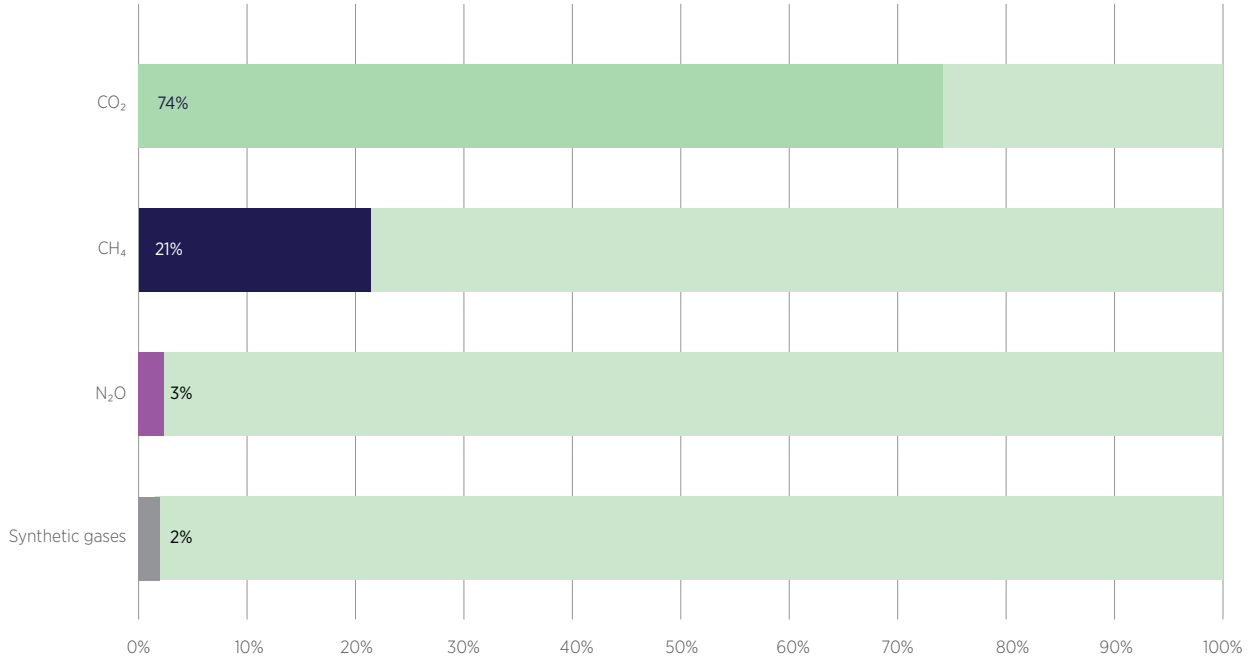
2.2.2 Trends by gas

Greenhouse gases

Greenhouse gases are those which absorb infrared radiation, heating the atmosphere. The greenhouse gases, and associated GWPs, included in this Report are set out in section 1.1.2. Greenhouse gases by sector are discussed in more detail at the start of Chapters 3–7 in this Report.

Australia's inventory by greenhouse gas for 2023–24 is presented in Figure 2.4. The LULUCF sector is excluded from this figure as it is a net sink in this year, however, this sector and its trends are explained in more detail in Volume 1, Chapter 6 of this Report.

Figure 2.4 Share of national emissions (excluding LULUCF) on a CO_2-e basis by gas, 2023–24



Note: Synthetic gases refers to SF_6, NF3, HFCs, and PFCs.

Changes in emissions by greenhouse gas since 1989–90 and 2004–05 are presented in Table 2.2.

Table 2.2 National emissions totals (excluding LULUCF) by greenhouse gas, Australia, Gg CO_2-e

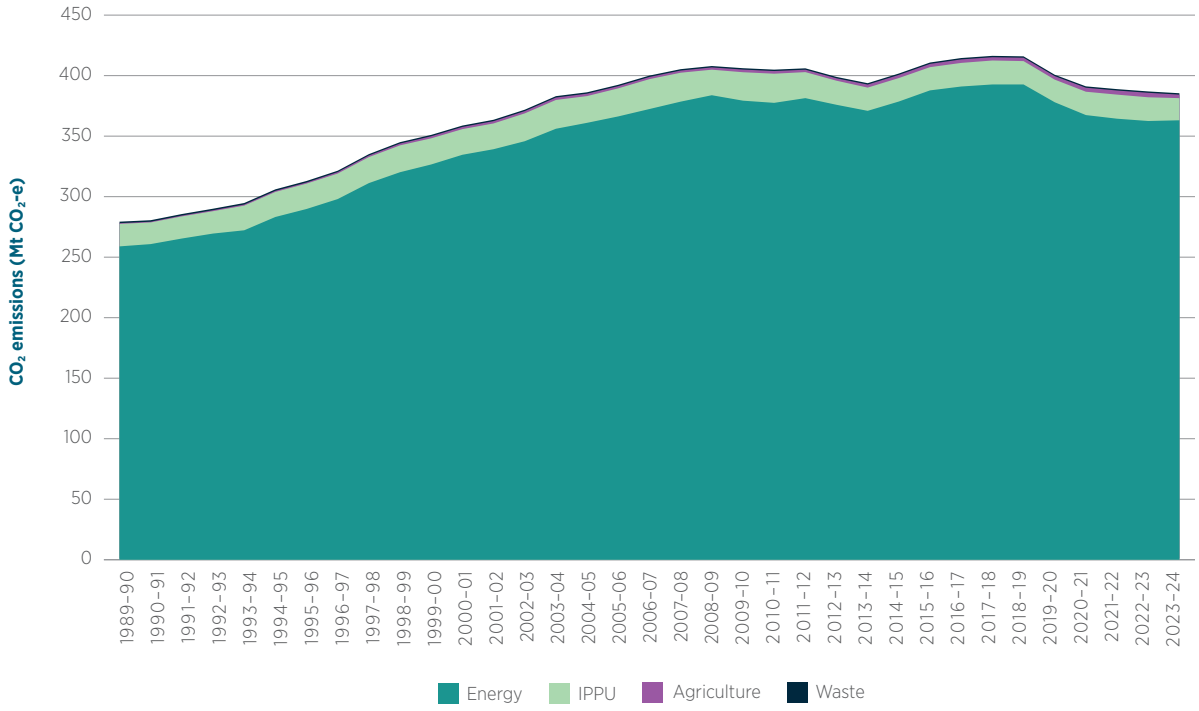
Greenhouse gas	1989–90	2004–05	2023–24	Per cent change since 1989–90	Per cent change since 2004–05
CO_2	278,068	385,090	384,286	38.2	-0.2
CH_4	140,344	124,706	109,558	-21.9	-12.1
N_2O	11,728	15,594	13,205	12.6	-15.3
HFCs	1,194	3,700	11,112	830.9	200.4
PFCs	4,144	1,611	311	-92.5	-80.7
SF_6	227	197	94	-58.7	-52.4
Total	**435,704**	**530,897**	**518,567**	**19.0**	**-2.3**

Note: LULUCF emissions are a net sink in 2023–24 and, therefore, they have been excluded from this table.

CO_2 represents the largest share of anthropogenic greenhouse gases globally and contributes 74.1 per cent of Australia's emissions in 2023–24 (excluding LULUCF) (Figure 2.4). Most CO_2 emissions are produced through combustion of fossil fuels in the energy sector.

Excluding LULUCF, CO_2 emissions have increased by 38.2 per cent since 1989–90 and decreased by 0.2 per cent since 2004–05 (Figure 2.5). CO_2 emissions have decreased 1.6 Mt (0.4 per cent) since 2022–23, driven by decreases in the IPPU (down 1.3 Mt CO_2, 6.8 per cent) and agriculture (down 0.8 Mt CO_2, 22.7 per cent) sectors, partially offset by increases in the energy sector (up 0.6 Mt CO_2, 0.2 per cent). The minor overall increase in CO_2 emissions in the energy sector between 2022–23 and 2023–24 is primarily driven by a substantial increase in CO_2 emissions from the *transport* sector as it recovers from the effects of the COVID-19 pandemic, offset by the continuing decrease in emissions intensity of electricity generation due to fuel switching and decreases in other stationary energy sources.

Figure 2.5 National CO_2 emissions (excluding LULUCF) by year, Australia, Mt CO_2-e



Note: LULUCF emissions are a net sink in 2023–24 and, therefore, they have been excluded from this figure.

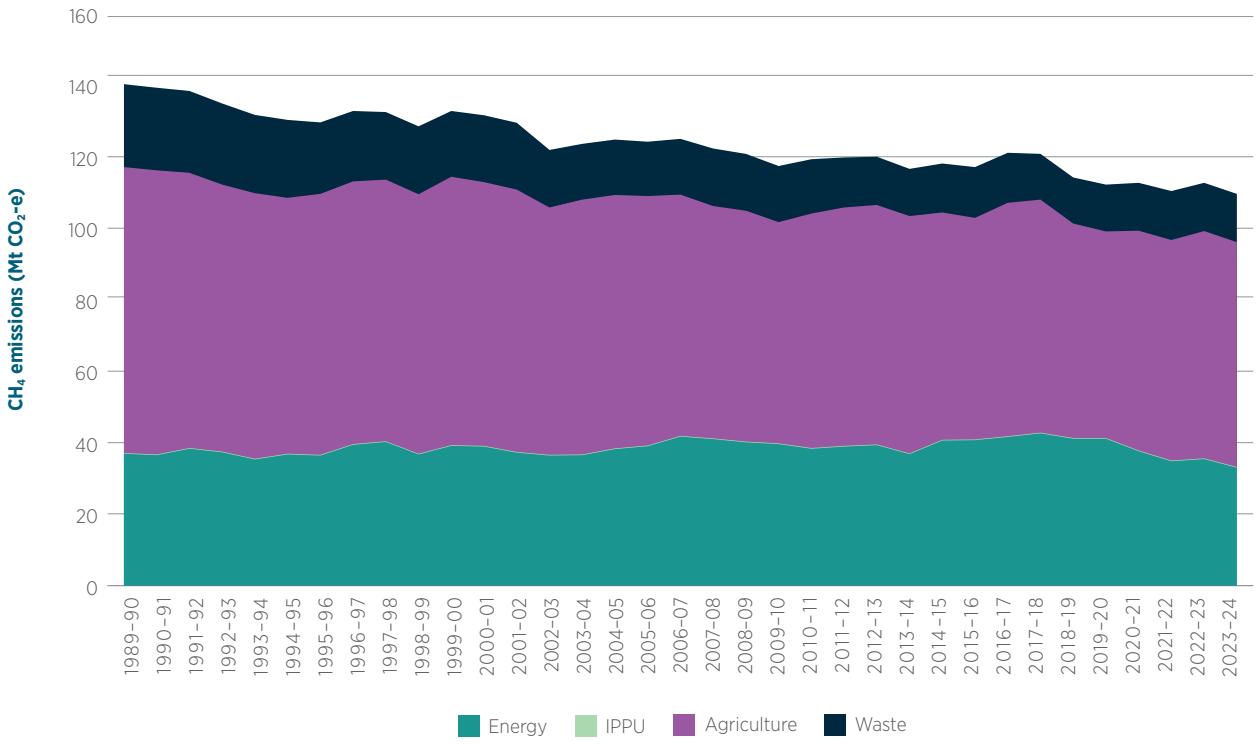
CH_4 emissions are the second largest share of greenhouse gases in Australia's inventory, contributing 21.1 per cent of total emissions in 2023–24 (excluding LULUCF) (Figure 2.4). The largest sources of CH_4 (Figure 2.6) are from the following sectors:

- agriculture (63.0 Mt CO_2-e), predominantly consisting of enteric fermentation by livestock,
- energy (33.0 Mt CO_2-e), predominantly consisting of fugitive emissions from coal, crude oil, and natural gas extraction, and
- waste (13.5 Mt CO_2-e), predominantly generated through the anaerobic decomposition of organic matter.

Excluding LULUCF, CH_4 emissions have decreased 30.8 Mt CO_2-e (21.9 per cent) since 1989–90, 15.1 Mt CO_2-e (12.1 per cent) since 2004–05 and 3.0 Mt CO_2-e (2.7 per cent) when compared with the previous year (2022–23). Long-term decreases in CH_4 are driven by:

- CH_4 capture and flaring in the waste sector,
- fluctuations in absolute number and composition of livestock numbers which are, in turn, driven by Australia's complex climatic variations and market conditions,
- decreased share of coal production in the gassiest southern coal field, flaring of pre-drainage gas, and adoption of technologies to recover and utilise coal mine waste gas for electricity generation, and
- reductions in CH_4 venting in the oil and gas sub-sector.

Figure 2.6 National CH_4 emissions (excluding LULUCF) by year, Australia, Mt CO_2-e

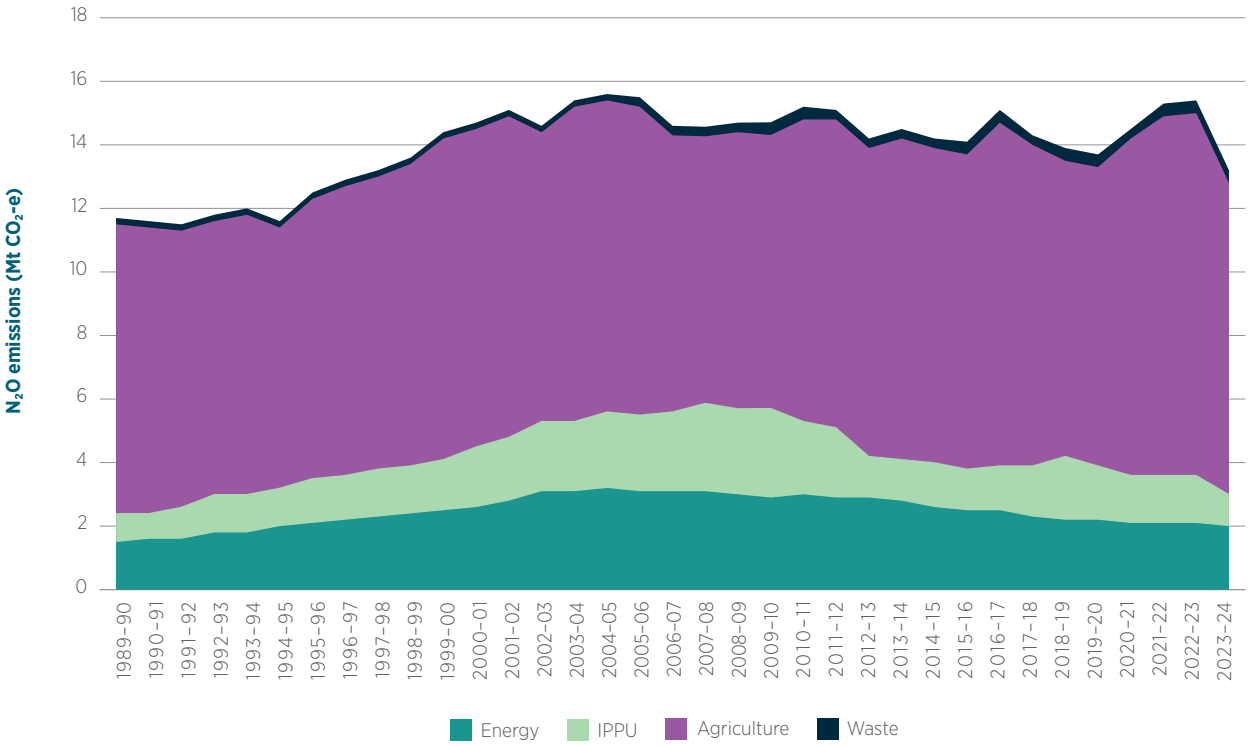


Note: LULUCF emissions are a net sink in 2023–24 and, therefore, they have been excluded from this figure.

N_2O emissions contribute 2.5 per cent of Australia's greenhouse gas inventory in 2023–24 (excluding LULUCF) (Figure 2.4). The majority of N_2O emissions (Figure 2.7) are sourced from the *agriculture* sector (74.4 per cent of the national total, excluding LULUCF), predominantly arising from microbial and chemical transformations that produce and consume nitrous oxide in agricultural soils. N_2O is also generated as a by-product of combustion in the *energy* sector and of nitric acid production in the IPPU sector. Excluding LULUCF, N_2O emissions have increased 12.6 per cent (1.5 Mt CO_2-e) since 1989–90, and decreased 15.3 per cent (2.4 Mt CO_2-e) since the peak of 15.6 Mt CO_2-e in 2004–05. Conversely, N_2O emissions decreased 13.9 per cent (2.1 Mt CO_2-e) since 2022–23 to 13.2Mt CO_2-e in 2023–24.

Notably, *IPPU* sector N_2O emissions have decreased substantially (-64.8 per cent, -1.8 Mt CO_2-e) since their peak in 2009–10 due to improvements in abatement practices at nitric acid plants. *Transport* sector N_2O emissions have also decreased substantially (-62.2 per cent, -1.0 Mt CO_2-e) since their peak in 2003–04, driven by increased penetration of catalytic control technology.

Figure 2.7 National N_2O emissions (excluding LULUCF) by year, Australia, Mt CO_2-e



Note: LULUCF emissions are a net sink in 2023–24 and, therefore, they have been excluded from this figure.

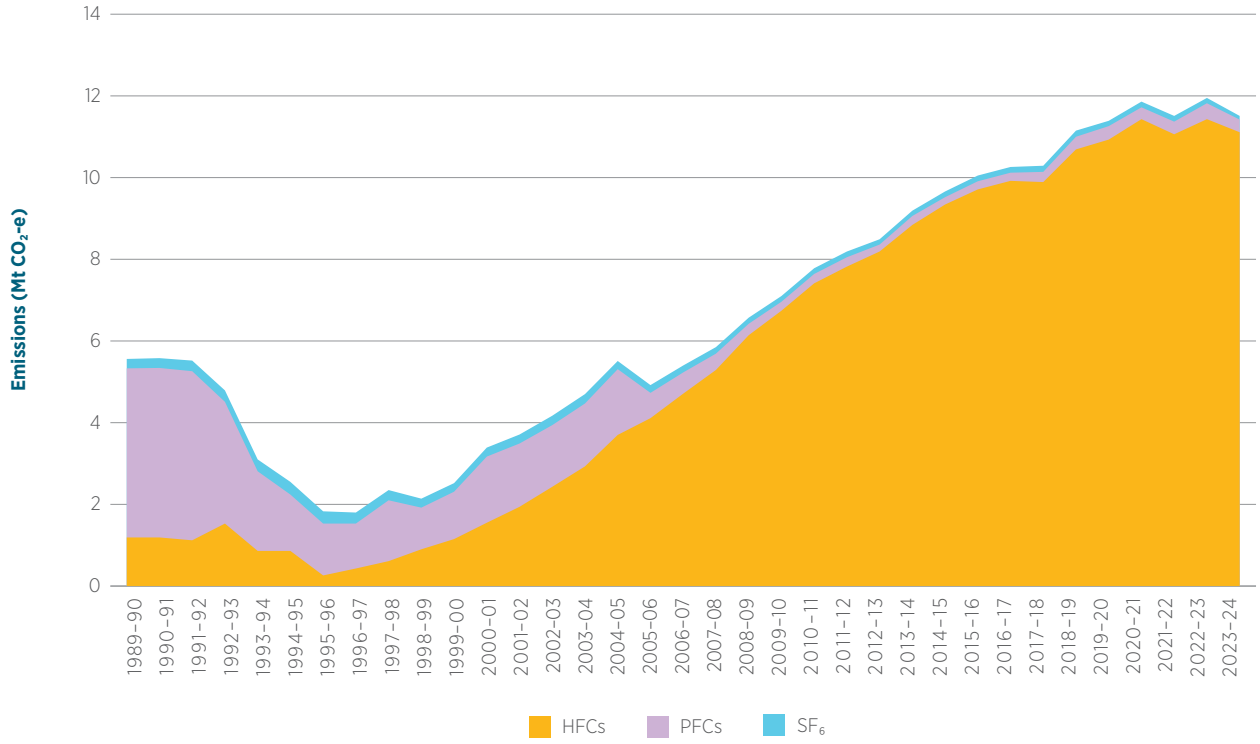
IPPU is the only sector that emits synthetic greenhouse gases, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). Nitrogen trifluoride (NF_3) is a reportable synthetic gas used in electronics manufacturing; however, Australia reports this source as not occurring (see Chapter 4.6 of this Report). Synthetic gases contribute 2.2 per cent of the national total (excluding LULUCF) in 2023–24 (Figure 2.4). They have increased 6.0 Mt CO_2-e (107.0 per cent) since 1989–90, increased 6.0 Mt CO_2-e (109.1 per cent) since 2004–05, and decreased 0.4 Mt CO_2-e (3.6 per cent) since 2022–23 (Figure 2.8).

HFC gases, primarily used as refrigerants, have increased in use since the early 1990s to replace ozone-depleting refrigerants phased out by the Montreal Protocol. They currently dominate synthetic gas emissions, growing from a 21.5 per cent share in 1989–90 to a 96.5 per cent share in 2023–24, from 1.2 Mt CO_2-e to 11.1 Mt CO_2-e.

Conversely, PFC emissions have reduced significantly driven by lower emissions rates from aluminium production. Australia's PFC intensity in aluminium production has decreased approximately 94 per cent since the year 1989–90. Australia's PFC emissions have reduced from 4.1 Mt CO_2-e in 1989–90 to 0.3 Mt CO_2-e in 2023–24.

SF_6 is predominantly used in electrical equipment. Emissions of SF_6 have decreased 0.1 Mt CO_2-e (58.7 per cent) since 1989–90 and have decreased 0.04 Mt CO_2-e (29.0 per cent) since 2022–23.

Figure 2.8 Synthetic greenhouse gas emissions by year, Australia, Mt CO_2-e

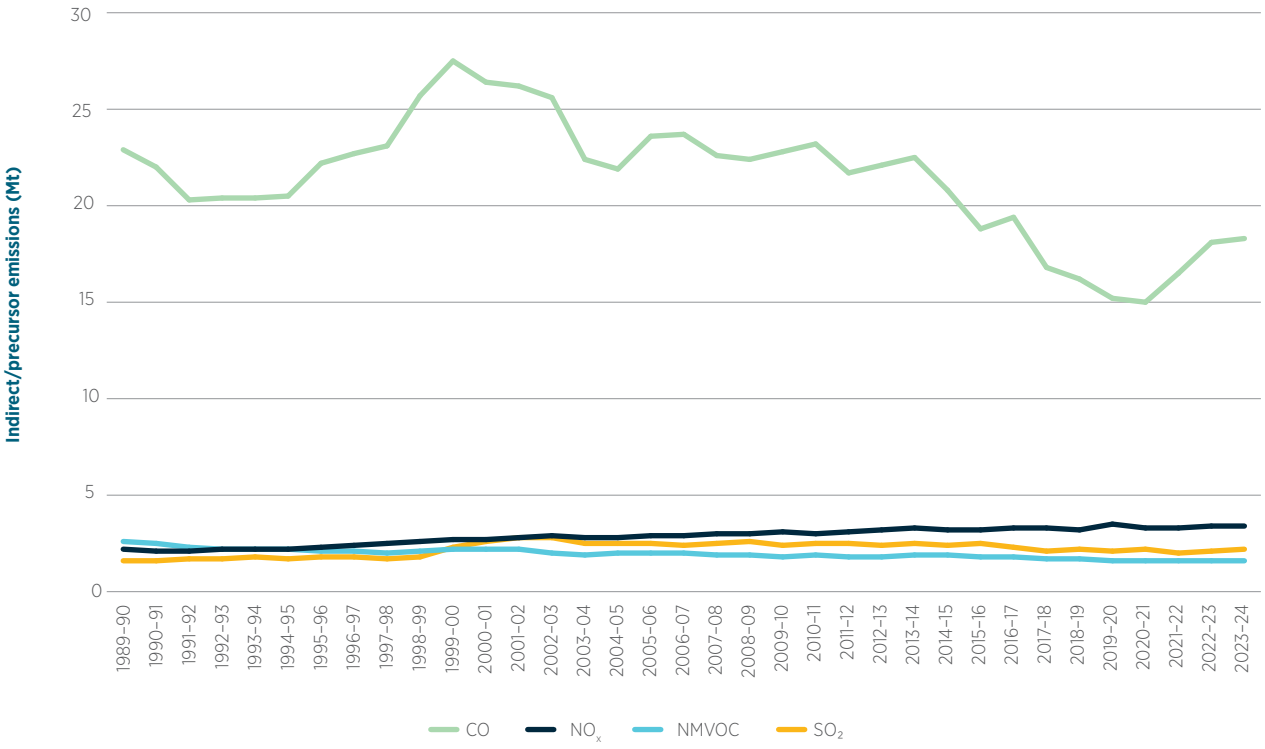


Ozone precursors and indirect emissions

In line with IPCC 2006 Guidelines (Volume 1, Chapter 7), Australia reports emissions estimates of greenhouse gas precursors of ozone (O_3 – a greenhouse gas) and other indirect emissions. These include carbon monoxide (CO), oxides of nitrogen (NO_x), non-methane volatile organic compounds (NMVOCs), and sulphur dioxide (SO_2). These gases are not greenhouse gases themselves and are not included in the national emissions totals, however, they chemically alter the atmosphere leading to an increase in the greenhouse gases known as tropospheric (ground-level) ozone and aerosols.

Precursor emissions by gas by year are presented in Figure 2.9.

Figure 2.9 Precursor and indirect emissions by year, Australia, million tonnes of gas



CO represents the largest precursor greenhouse gas by mass in Australia, representing 71.5 per cent (18.3 Mt) of these emissions in 2023–24. It is predominantly emitted by biomass burning in the *LULUCF* sector, and is also emitted by the *energy*, *IPPU*, and *agriculture* sectors. CO emissions have decreased 20.1 per cent (4.6 Mt) since 1989–90, 16.5 per cent (3.6 Mt) since 2004–05, and have increased 1.1 per cent (0.2 Mt) since the previous year (2022–23).

NO_x represents 13.4 per cent (3.4 Mt) of the precursor greenhouse gases by mass in Australia. They are emitted by the *agriculture*, *IPPU*, and *LULUCF* sectors and are dominated by the *energy* sector. Most energy-related NO_x emissions result from fuel combustion, formed by the conversion of chemically bound nitrogen of the fuel. NO_x emissions have increased 57.1 per cent (1.3 Mt) since 1989–90, 21.2 per cent (0.6 Mt) since 2004–05, and 1.1 per cent (0.04 Mt) since the previous year (2022–23). Whilst most energy-related NO_x has been increasing through time reflecting increasing combustion, NO_x from transport has been decreasing since its peak in 1995–96 despite increasing activity, attributable to increasing uptake of emissions-control technologies in road transport vehicles.

NMVOCs represent 6.4 per cent (1.6 Mt) of the precursor greenhouse gases by mass in Australia. They are predominantly emitted by biomass burning in the *LULUCF* sector, gasoline consumption in road transport, and gasoline and wood consumption in the residential energy sectors. NMVOC emissions have decreased 36.5 per cent (0.9 Mt) since 1989–90, 16.3 per cent (0.3 Mt) since 2004–05, and have increased 2.0 per cent (0.03 Mt) since the previous year (2022–23). This long-term reduction trend has largely been driven by reductions in biomass burning.

SO_2 represents 8.6 per cent (2.2 Mt) of the precursor greenhouse gases by mass in Australia. It is emitted by the *energy* and *IPPU* sectors. Emissions have increased 39.0 per cent (0.6 Mt) since 1989–90 but have decreased 12.6 per cent (0.3 Mt) since 2004–05 and increased 3.0 per cent (0.1 Mt) since 2022–23.

Australia's metal ores are predominantly sulphide ores, leading to the generation of SO_2 as a by-product of metal production. IPPU is the predominant source for SO_2 in Australia, all emitted from the metal industry – particularly from copper and zinc production under 2.C.7 *Other.* Variations and levels of SO_2 reflect variations and level of production of these metals.

SO_2 in the *energy* sector is largely emitted from coal-generated electricity and has been decreasing since peaking in 2007–08. This trend is driven by black coal consumption decreasing, substituted by gas and renewable energy sources, and one third of brown coal generating capacity being decommissioned since 2013–14 (GA 2022).

Black carbon

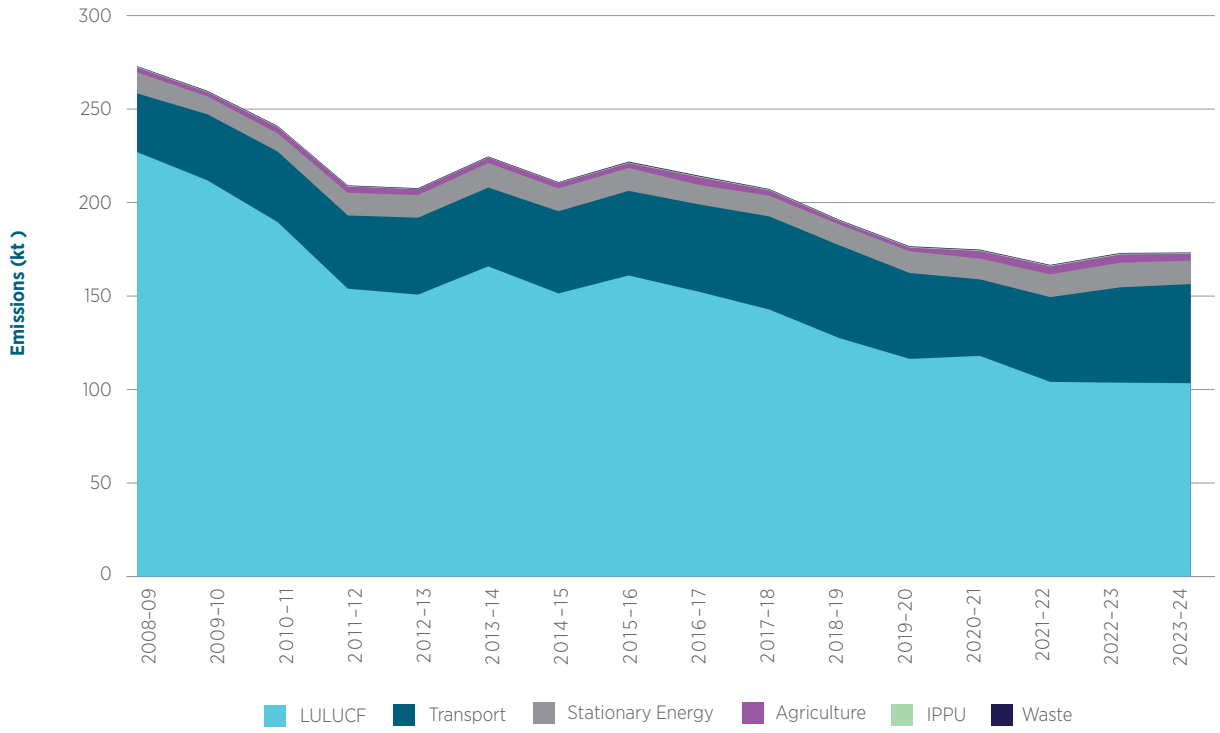
Black carbon is a fine particulate formed by the incomplete combustion of fossil fuels and biomass. The global warming potential of black carbon is estimated to be approximately 1,600 times more potent than CO_2 on a 100-year AR5 basis (Chapter 8, Section 8.5.2.1.3, IPCC 2013). Black carbon is, however, short-lived in the atmosphere lasting days or weeks at most, compared with gaseous CO_2 which may remain in the atmosphere for hundreds or thousands of years (Cho, R., 2016).

Australia voluntarily reports black carbon emissions using Tier 2 and Tier 3 Methods based on data collected under its National Pollutant Inventory (NPI). It is mandatory for Australian facilities that exceed defined thresholds for 93 specified substances to report estimates of these substances to the NPI, which includes emissions of black carbon. Further information about the NPI is available on the DCCEEW website. The NPI includes emissions of fine particulates of 2.5 microns in diameter or less (PM2.5), to which fractions of black carbon content provided in the USEPA speciate database are applied.

Biomass burning in the LULUCF sector is the largest source of black carbon in Australia, contributing 59.8 per cent (103.4 kt) of emissions in 2023–24. This is followed by the energy sector (37.9 per cent, 65.5 kt). Agriculture accounts for 2.1 per cent or 3.7 kt. The IPPU and waste sectors contribute 0.2 per cent (0.4 kt), combined.

Estimates of black carbon emissions are available from 2008–09 onwards. Since 2008–09 black carbon emissions have generally decreased, reducing 36.5 per cent (99.7 kt) by 2023–24. This is largely driven by reduced biomass burning in the LULUCF sector.

Figure 2.10 Black carbon emissions by year, Australia, kilotonnes



Information on the methods and definitions used by Australia to estimate black carbon emissions is provided in Volume 2, Annex 5.7 of this report. This annex also provides data tables and graphs of black carbon by year and by sector.

2.3 Description of emissions trends by emissions intensity

2.3.1 Kaya Identity analysis

Methodology

The Kaya Identity is an equation which relates CO_2 emissions caused by human activity to key economic and demographic metrics. It expresses the emissions as a product of human population, gross domestic product (GDP) per capita, the energy intensity of the economy and the carbon intensity of energy consumption (González-Torres et al., 2021). This simple model allows for identification and analysis of high-level changes in those factors and how they affect emissions.

Population growth often leads to a proportional growth in CO_2 emissions at both global and national scales. Changes in GDP per capita typically also affect proportional changes in CO_2 emissions, because of economic connections to energy demand as well as industrial and transport activities. Energy intensity measures the energy efficiency of such activities and other uses of powered products. Decreases in energy intensity may be caused, for example, by technological advancement or an increasing economic share of services relative to manufacturing. Lastly, carbon intensity measures the amount of CO_2 emitted per unit of energy consumed by the population. Decreases in carbon intensity reflect the combined effects of transitioning to renewable energy and abatement of emissions from fossil fuels.

The Kaya Identity model presented in Equation 2.1 expresses Australia's national CO_2 emissions from both fuel combustion and industrial processes and product use (IPPU) as the product of these four factors:

CO_2 emissions = P × (GDP ÷ P) × (Z ÷ GDP) × (E ÷ Z) **(2.1)**

Where P = Population size
GDP = Gross domestic product (Chain volume measures, $ millions)
Z = Total primary energy consumption (PJ)
E = Emissions from fuel combustion and IPPU (Mt CO2-e)

Trends in emissions

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 the decomposition in Equation 2.1 assumes independence of the four factors. In reality, these factors are not necessarily independent of each other (e.g. increases in GDP per capita may change the energy intensity of the economy) and changes in a single factor will not automatically result in corresponding changes in CO_2 emissions (e.g. an increase in energy intensity does not automatically result in an equivalent increase in CO_2 emissions).

The Kaya Identity model presented in Equation 2.1 considers a subset of Australia's total CO_2 emissions. At the national level, increases in CO_2 emissions from fuel combustion and IPPU have been offset by declines in other emissions sources. Equation 2.2 expands the decomposition to include "other CO_2 emissions" as a fifth driver of total CO_2 emissions. The model does not attempt to break down other CO_2 emissions into underlying drivers such as energy consumption, population or GDP growth, which have less of an effect on these remaining emissions sources.

CO_2 emissions = P × (GDP ÷ P) × (Z ÷ GDP) × (E ÷ Z) + other CO_2 emissions **(2.2)**

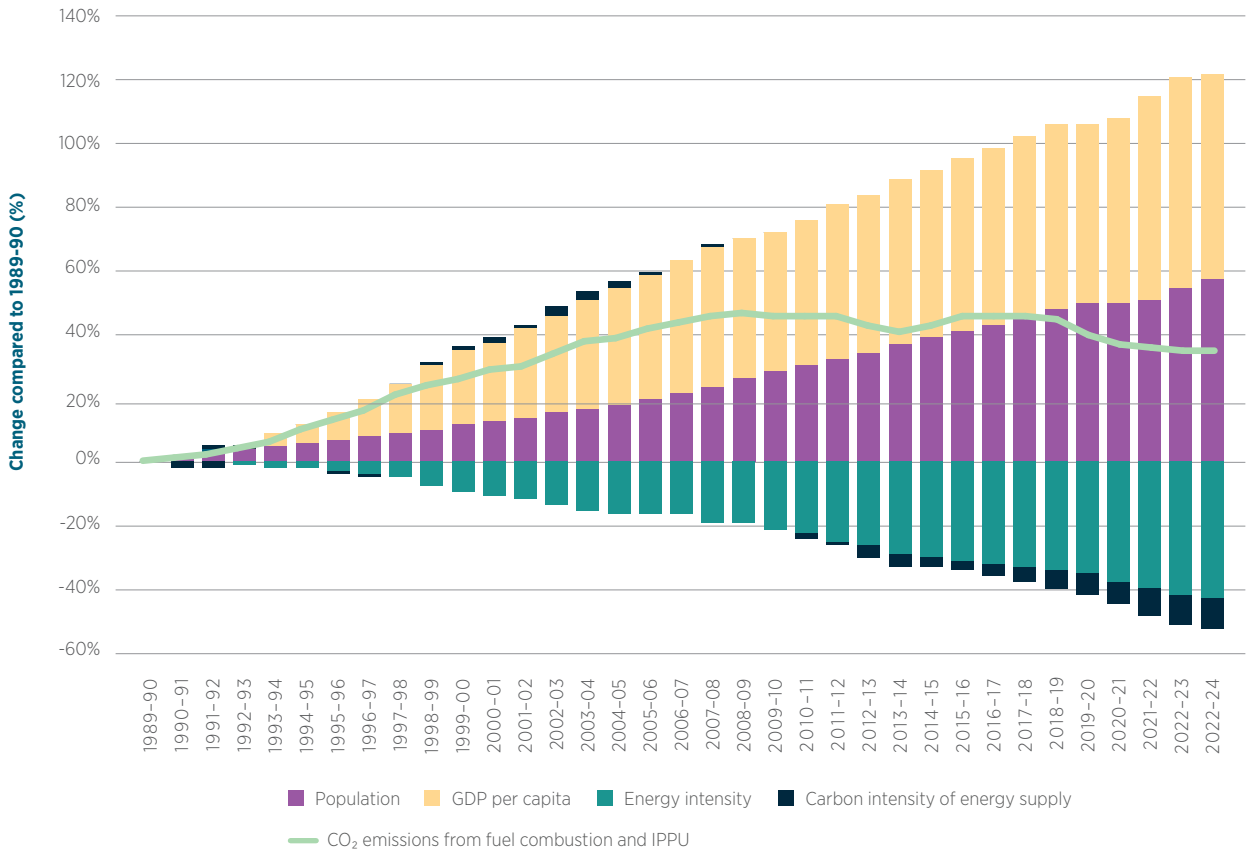
Where P = Population size
GDP = Gross domestic product (Chain volume measures, $ millions)
Z = Total primary energy consumption (PJ)
E = Emissions from fuel combustion and IPPU (Mt CO2-e)

Changes in other emissions sources generally have a downward impact on total emissions; however, annual changes are subject to considerable variation, as demonstrated in Figure 2.17.

Results

Between 1989–90 and 2023–24, CO_2 emissions from fuel combustion and IPPU increased by 35 per cent (Figure 2.11). Underlying growth factors were a 59 per cent increase in population and a 66 per cent increase in GDP per capita. Declining factors were a 44 per cent decline in the energy intensity of the economy and a 10 per cent decline in the emissions intensity of energy consumption. Over the time series, Australia's CO_2 emissions from fuel combustion and IPPU trended upwards to a peak in 2008–09 before largely declining to 2023–24 as the impacts of improved energy intensity of the economy and emissions intensity of energy supply more than offset increases in population and GDP per capita.

Figure 2.11 Growth in CO_2 emissions from fuel combustion and IPPU and underlying drivers, Australia, 1989–90 to 2023–24

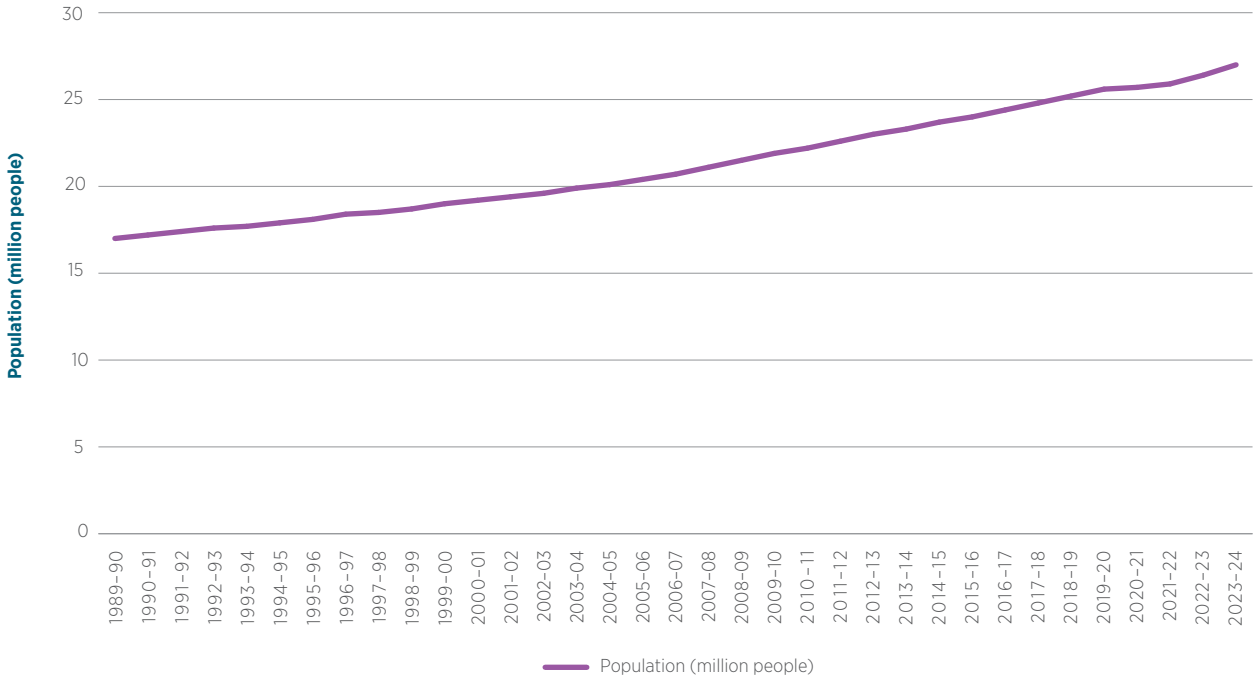


Total CO_2 emissions from fuel combustion and IPPU fell by 0.3 per cent in 2023–24 compared to 2022–23, or by 2.5 per cent on a per capita basis. Similarly, energy intensity improved by 1.7 per cent.

Australia's population has increased 59 per cent from 17.0 million people in 1989–90 to 27.0 million people in 2023–24 (Figure 2.12). Australia's population grew by 2.3 per cent (0.6 million) in 2023–24, predominantly driven by immigration (ABS 2025).

Since 1989–90, Australia's population has increased an average of 1.3 per cent per annum. The lowest population growth in the time series occurred in 2020–21 (0.4 per cent increase) and 2021–22 (0.8 per cent increase). This reduced growth can be attributed to the Australian Government's closure of the international border from 20 March 2020 in response to the COVID-19 pandemic. The border was not fully re-opened until 21 February 2022 (ABS 2022; Australian Government 2022).

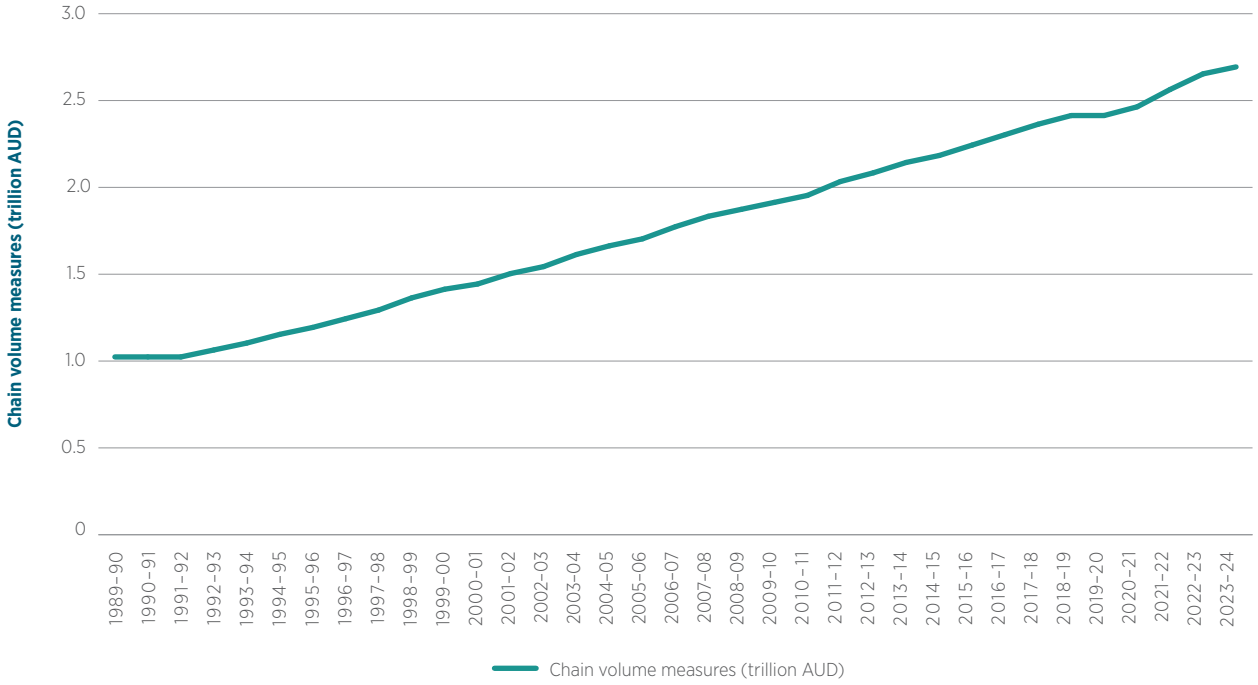
Figure 2.12 Australia's annual population, 1989–90 to 2023–24



Source: ABS 2025.

Economic growth refers to an increase in the size of a country's economy over a period of time. The size of an economy is typically measured by the total production of goods and services in the economy, which is called gross domestic product (GDP) (RBA, 2025). Australia's GDP for 1989–90 to 2023–24 is presented in Figure 2.13.

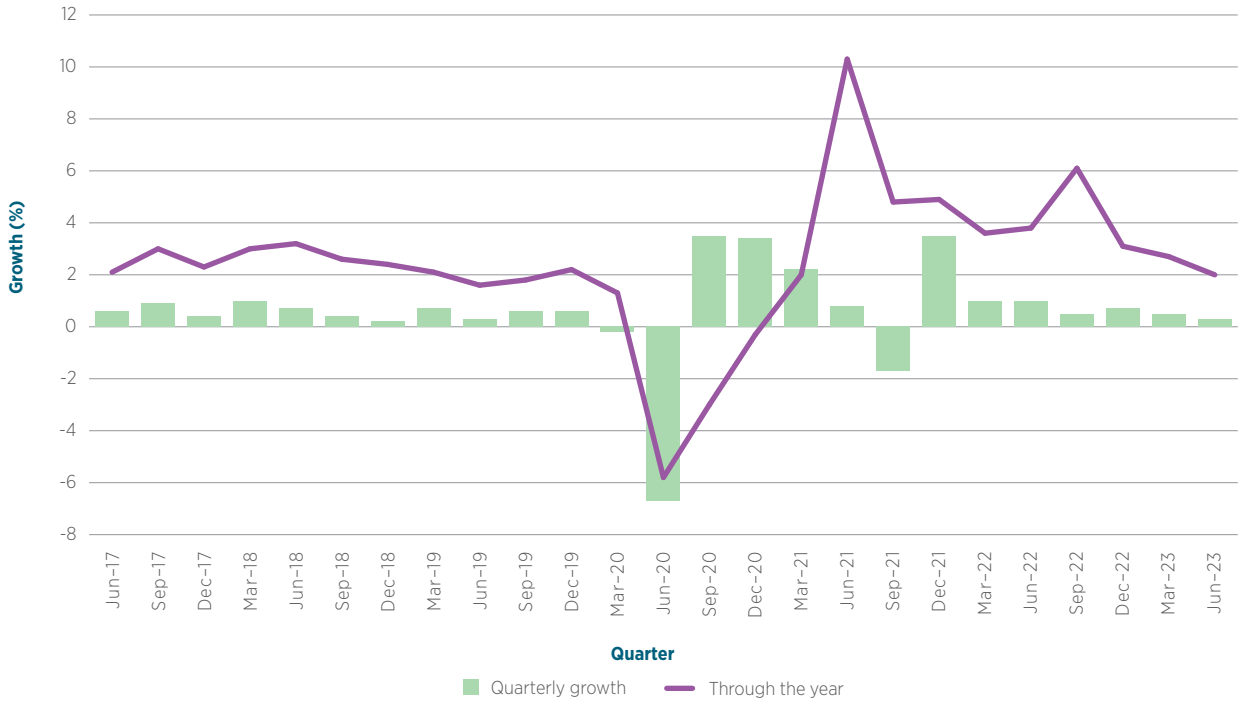
Figure 2.13 Gross domestic product, chain volume measures, 1989–90 to 2023–24



Source: ABS 2025.

Like many other regions, Australia's economic activity was impacted by the COVID-19 pandemic (Figure 2.14). In 2020, Australia's economy went into recession for the first time in 30 years as a result of the pandemic. In 2021 and 2022, pandemic conditions continued to dampen the economy, albeit to a lesser degree than observed in 2020 (ABS 2022a). Australia's economy grew at a moderate pace in 2023 whilst experiencing below-trend growth (RBA 2023; Nguyen et al 2024).

Figure 2.14 Gross domestic product, chain volume measures, seasonally adjusted



Source: ABS 2025.

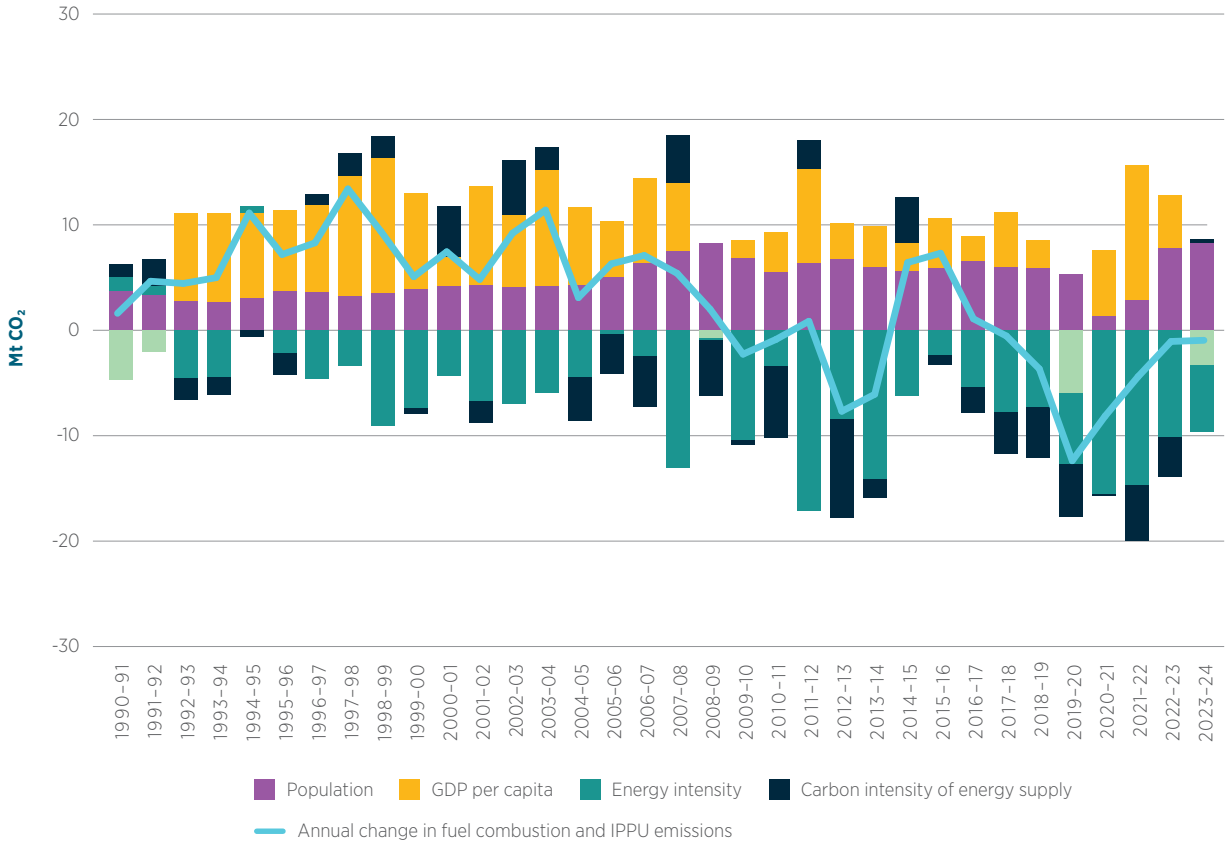
GDP per capita fell by 1.5 per cent in 2019–20 (the only other falls in GDP per capita were 1.7 per cent in 1990–91 and 0.2 per cent in 2008–09). GDP per capita also fell in 2023–24, decreasing 0.9 per cent on the previous year. When compared with the pre-COVID-19 year 2018–19, GDP per capita increased 4.0 per cent, which is well above the average GDP per capita rate of +1.5 per cent per year since 1990–91.

The energy intensity of the economy decreased in 30 of the 34 years at varying annual rates, reflecting energy efficiency improvements and structural change in the economy towards less energy intensive service sectors.

The emissions (carbon) intensity of energy supply has fluctuated over the time series, however, there has been a declining trend since 2004–05 as the proportion of electricity generation from coal has declined (see Figure 3.11 for more details).

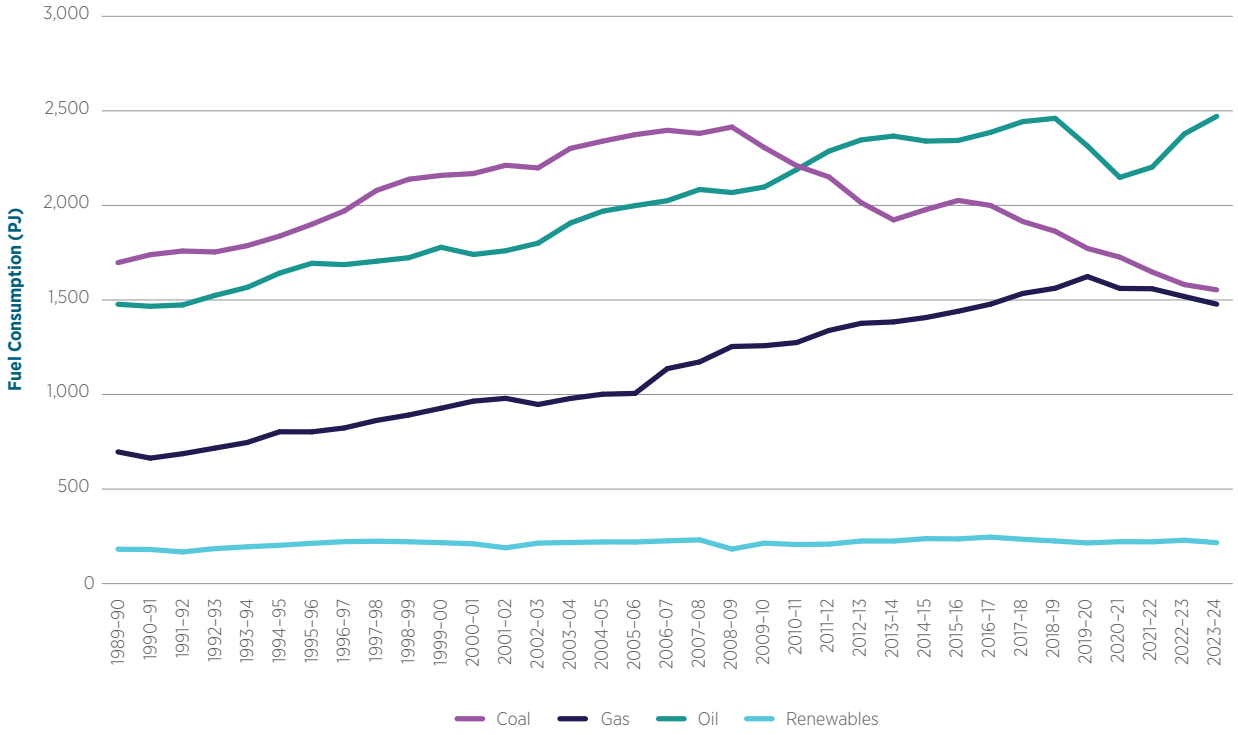
Figure 2.15 attributes annual emissions changes to the four underlying factors. The combined impact of increases in population and GDP per capita have contributed to increasing emissions since 1989–90.

Figure 2.15 Annual change in CO_2 emissions from fuel combustion and IPPU from underlying drivers, Australia, 1990–91 to 2023–24, Mt CO_2



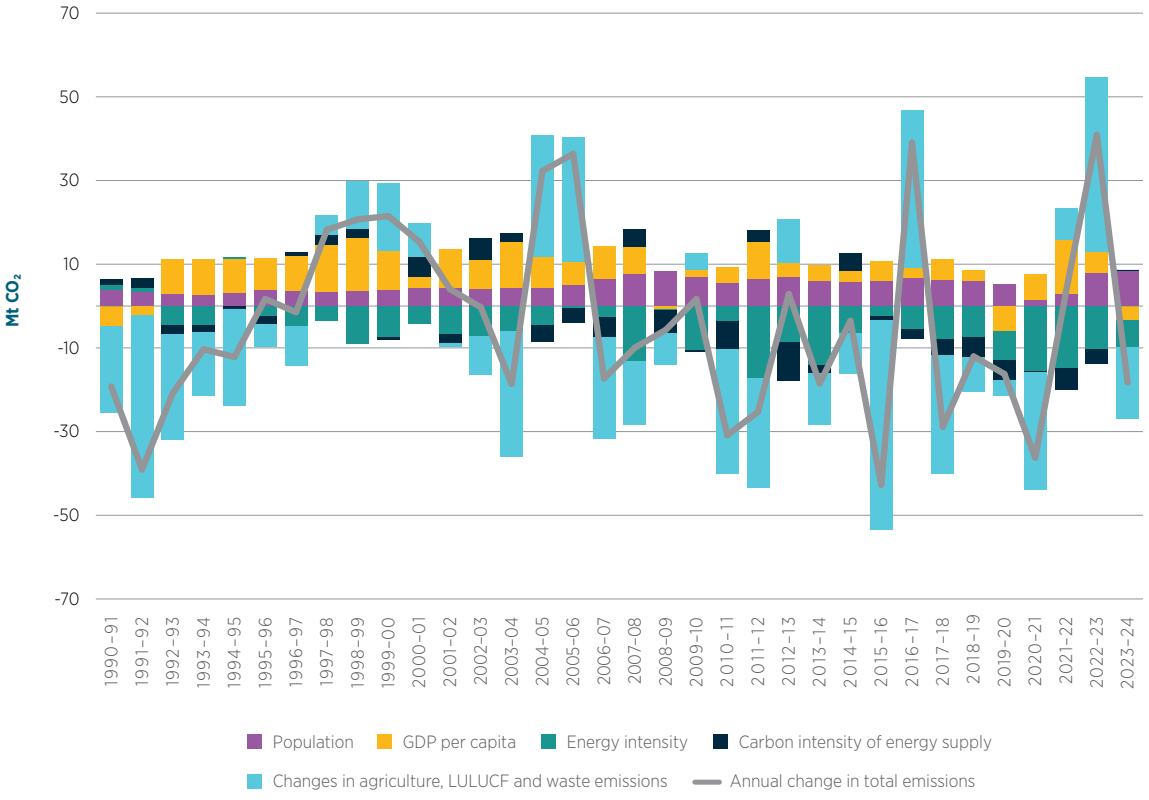
This trend is reflected in the fuel switching evident in the observed choice of fuel for energy consumption (Figure 2.16). Over the period 1989–90 to 2008–09, consumption of coal, oil and natural gas (for fuel combustion) increased. From 2008–09, oil and gas consumption continued to grow, driven by the transport and electricity sectors. In contrast, coal consumption has largely continued to decline since 2008–09. In 2023–24, coal consumption was 35.7 per cent below its 2008–09 peak level of 2,414 PJ. Oil consumption in 2023–24 increased 3.9 per cent on 2021–22 levels, reaching 0.4 per cent below its peak in 2018–19, indicating that post-COVID-19 recovery is nearly complete.

Figure 2.16 Energy consumption by fuel type, Australia, PJ, 1989–90 to 2023–24



Source: (DCCEEW 2025a): Australian Energy Statistics Table D

Figure 2.17 Annual change in total emissions from underlying drivers, Australia, 1989–90 to 2023–24, Mt CO_2-e



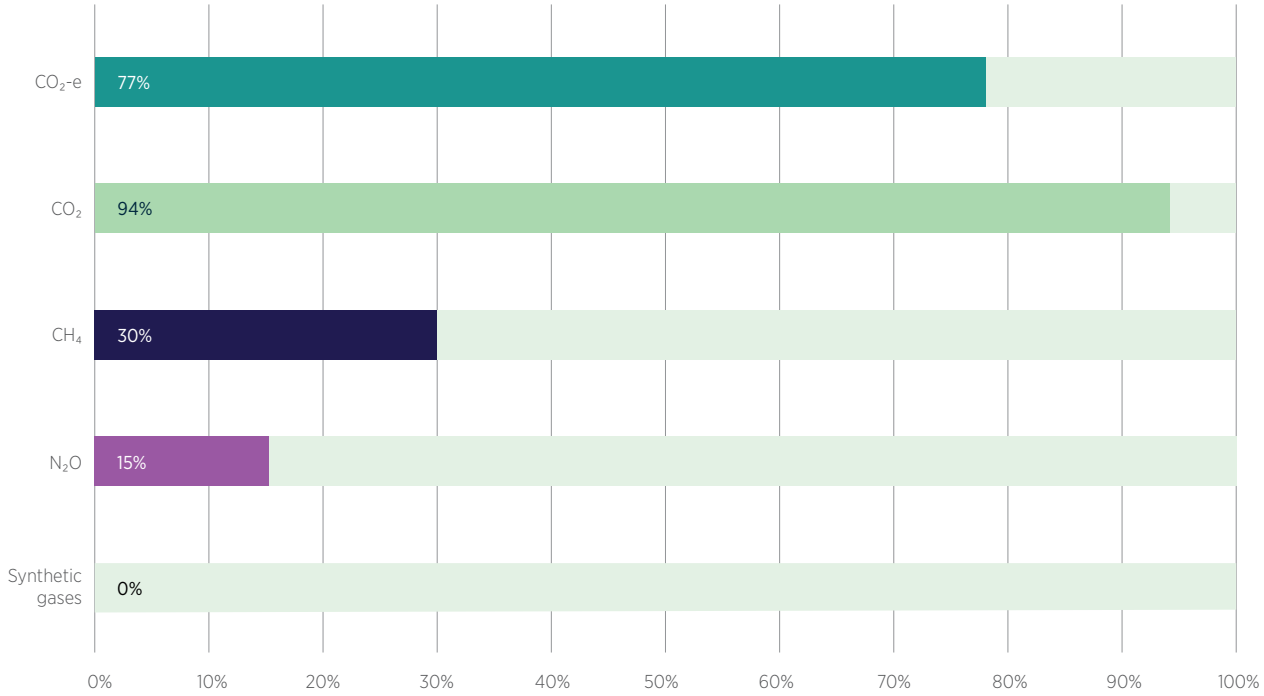
(a) Note that "changes in agriculture, LULUCF and waste emissions" in this graph refers to changes in the sum of non-CO_2 emissions from fuel combustion and IPPU, and total emissions from the fugitive emissions, agriculture, LULUCF, and waste sectors (that is, the national inventory total with the CO_2 emissions from fuel combustion and IPPU excluded).

3. Energy

3.1 Overview

The *energy* sector is Australia's largest source of emissions, which are largely emitted as CO_2 from fuel combustion activities such as electricity generation and transportation. This sector is the second largest source of methane emissions, with the majority comprised of fugitive emissions from coal, oil, and gas extraction and processing. The *energy* sector as a portion of total emissions (excluding LULUCF) is presented in Figure 3.1.

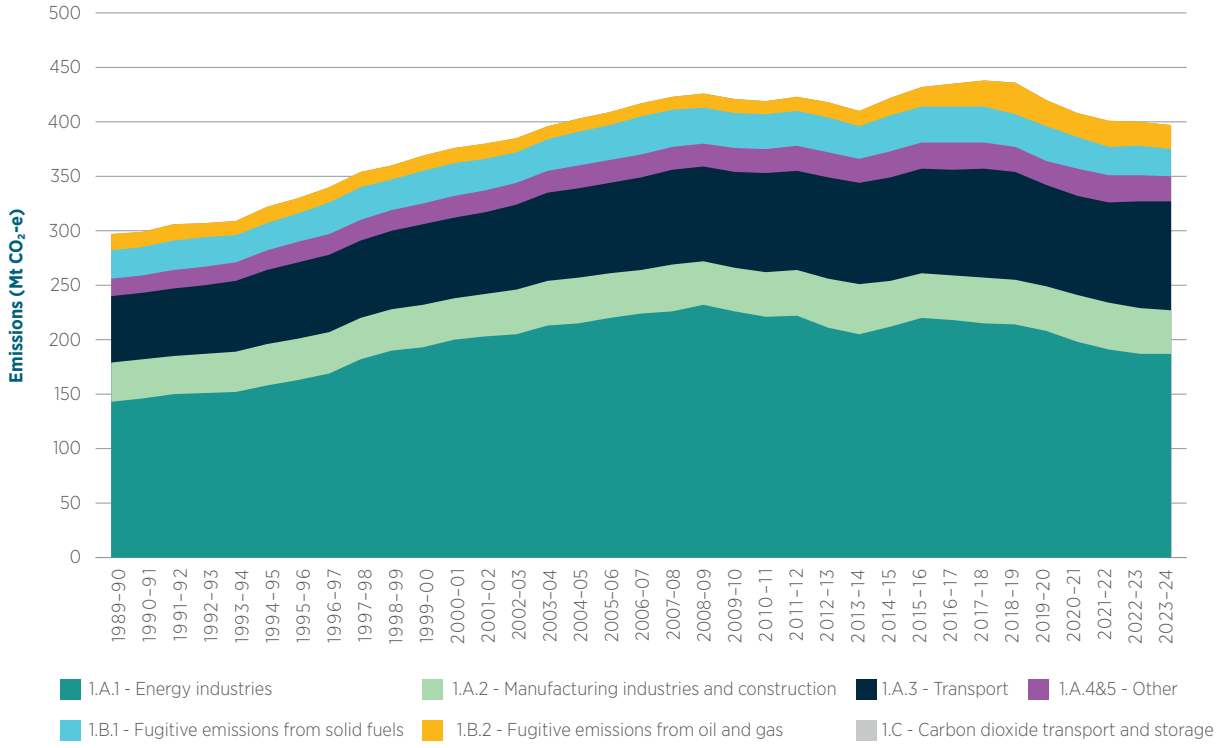
Figure 3.1 Share of national emissions (excluding LULUCF) for the energy sector by gas, 2023–24



Note: Synthetic gases refers to SF_6, NF_3, HFCs, and PFCs.

The full time series of *energy* emissions by subsector is presented in Figure 3.2. Emissions from energy industries (including from electricity generation) form the largest contribution to total *energy* sector emissions, followed by emissions from transport, and fugitive emissions from fuels.

Figure 3.2 Energy emissions by subsector, 1989–90 to 2023–24



Changes in emissions by energy subsector in 2023–24 since 1989–90, 2004–05, and 2022–23 are shown in Figure 3.3. Tables of energy emissions by subsector and by gas are presented in NIR Volume 2, Annex 5.8. Decreases in the most recent years have been largely driven by the continuing decrease in the emissions intensity of electricity generation.

Figure 3.3 Comparison of 2023–24 emissions with past emissions levels from key energy subsectors, million tonnes of carbon dioxide equivalent (Mt CO_2-e) and percentage change (%)

Energy Subsectors	2023–24 emissions	Change in 2023–24 emissions since: 1989–90	2004–05	2022–23
1.A.1 Energy industries (including electricity)	187 Mt	+30% +44 Mt CO_2-e	-29 Mt CO_2-e -13%	-0.3 Mt CO_2-e -0.2%
1.A.2 Manufacturing Industries and Construction	40 Mt	+11% +4 Mt CO_2-e	-1 Mt CO_2-e -3%	-1 Mt CO_2-e -3%
1.A.3 Transport	100 Mt	+64% +39 Mt CO_2-e	+23% +19 Mt CO_2-e	+2% +2 Mt CO_2-e
1.A.4&5 Other	23 Mt	+44% +7 Mt CO_2-e	+13% +3 Mt CO_2-e	-0.1 Mt CO_2-e -1%
1.B Fugitive emissions from coal, oil, and gas	47 Mt	+17% +7 Mt CO_2-e	+11% +5 Mt CO_2-e	-2 Mt CO_2-e -5%
1.C Carbon dioxide transport and storage	<0.1 Mt	–	–	<0.01 Mt CO_2-e -97%

Note: Icons in this figure are sourced from Geotata, adi_sena, Freepik, and Creatype on flaticon.com.

3.2 **Fuel Combustion** (CRT category 1.A)

The Fuel Combustion category is comprised of the combustion of fossil fuels and biomass to produce thermal energy for stationary and mobile sources. Emissions from the combustion of solid, liquid, and gaseous fuels for energy use have been identified as key sources in Australia's inventory and, along with biomass, are presented in Figure 3.4.

Figure 3.4 Fuel combustion emissions by fuel type, 1989–90 to 2023–24

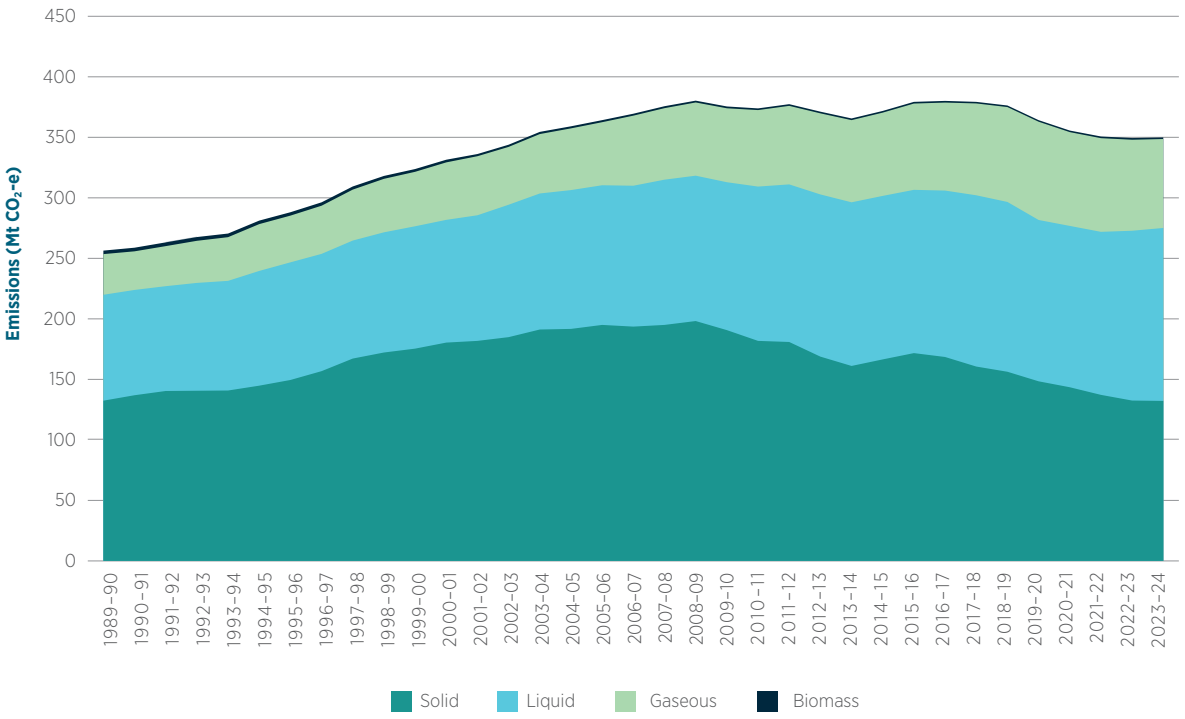
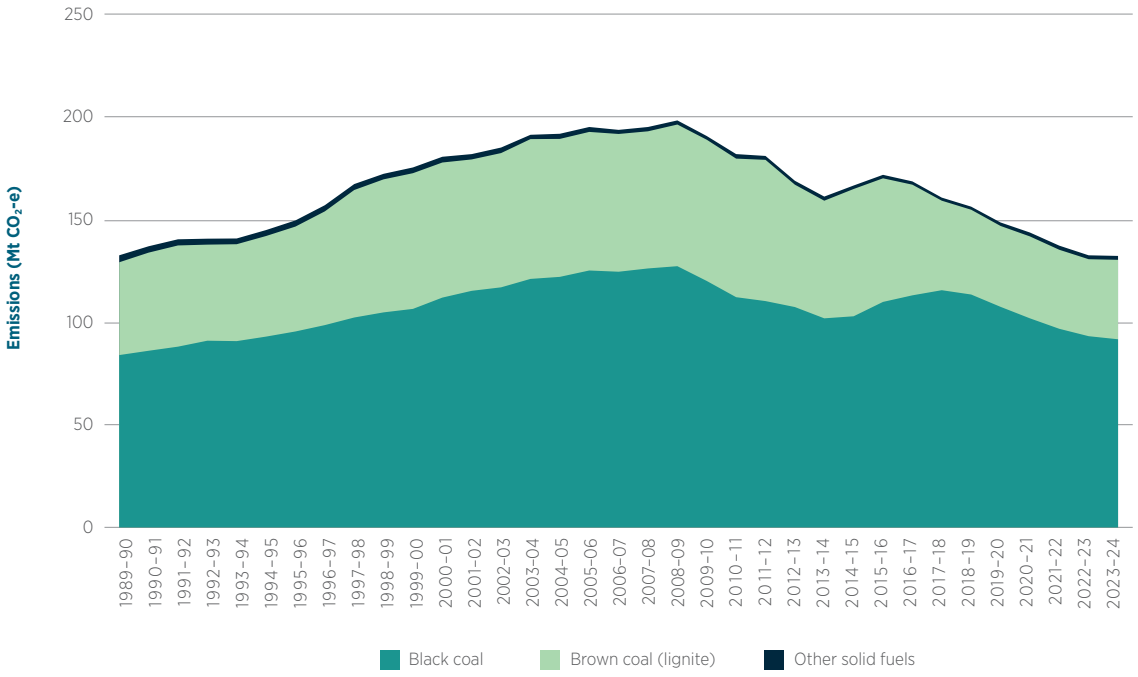


Figure 3.5 presents emissions from combustion of solid fuels over time for black coal, brown coal, and other solid fuels. Emissions from black coal combustion have decreased since 2008–09 as this fuel is substituted for gas and renewable energy sources such as wind, solar and hydro. Around one third of brown coal generating capacity has been decommissioned since 2013–14 (GA 2022).

Figure 3.5 Emissions from solid fuel combustion, 1989–90 to 2023–24

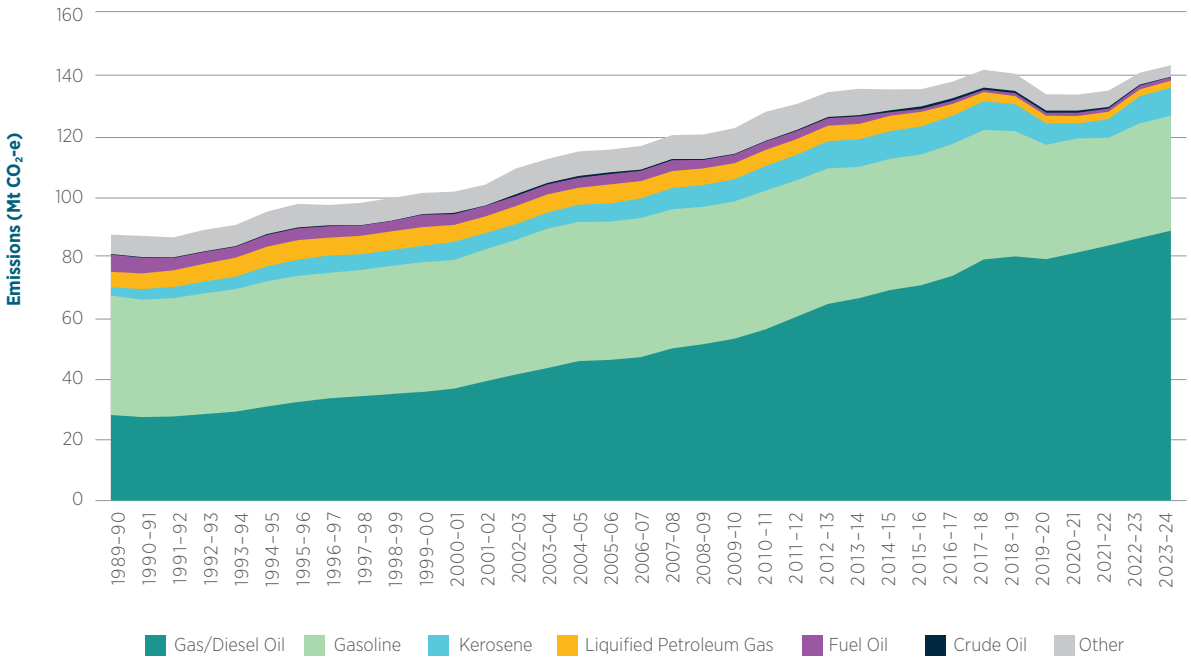


Note: 'Other solid fuels' includes coking coal, black coal by-products, brown coal briquettes, coke oven coke, and recycled materials.

The *transport* subsector is the main source of emissions from liquid fuels. Trends in liquid fuels emissions largely follow consumption patterns in this subsector.

The growth in emissions from the combustion of liquid fuels over time has primarily been driven by an increase in diesel consumption (Figure 3.6). The underlying reasons for this growth include the population and economically driven increase in the road transport fleet, a shift in the vehicle fleet away from petrol towards diesel fuelled vehicles and the use of diesel in the resources sector.

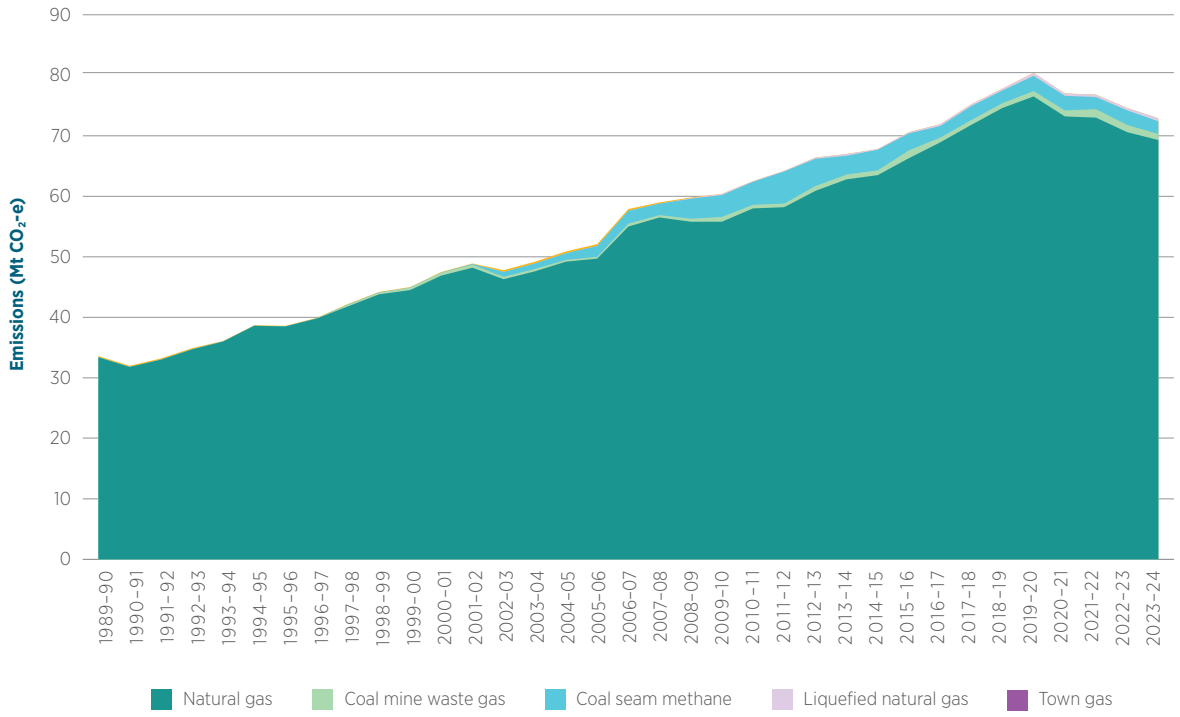
Figure 3.6 Emissions from liquid fuel combustion, 1989–90 to 2023–24



In Australia, the majority of gaseous fuels are consumed within the electricity generation and oil and gas extraction sectors, with growth since 2015 attributed to the expansion of the liquified natural gas export industry.

Natural gas is the most significant gaseous fuel combusted in Australia (Figure 3.7). The decrease in emissions in 2023–24 is due to reduced gas combustion in electricity generation, residential and the chemical manufacturing sector.

Figure 3.7 Emissions from gaseous fuel combustion, 1989–90 to 2023–24



Sources The primary data sources for fuel combustion emissions and activity data are the Australian Energy Statistics (AES) (DCCEEW 2025a) and data collected under the mandatory National Greenhouse and Energy Reporting scheme, which are described in more detail in NIR Volume 2, Annexes 5.1 and 5.2.

3.2.1 Comparison of the sectoral approach with the reference approach (CRT categories 1. AA and 1.AB)

In accordance with the 2006 IPCC Guidelines (volume 2, chapter 6) (IPCC 2006), Australia estimates its CO_2 emissions from fuel combustion using a top-down reference approach independent of the sectoral approach used in CRT category 1.AA. Whilst these two approaches are not expected to match each other, significant differences between the reference and sectoral approaches may indicate problems in inventory data.

AES and APS (Australian Petroleum Statistics) datasets are used to estimate Australia's energy balance for production, imports, exports, and stock changes (DCCEEW 2025a and DCCEEW 2025b). The difference between the reference approach and the sectoral approach at the total level is within 2 per cent for all years (Figure 3.8). However, the differences between the reference approach and the sectoral approach for specific fuel types does exceed 2 per cent for some years. The main reason for these differences, for petroleum fuels, relates to the sensitivity of final apparent consumption and emissions estimates to the average density and energy content values used to convert production, exports, imports, and stock changes from volume/mass units into energy units. Other minor differences can be attributed to the derived implied emission factors used by the reference approach and the different reporting techniques and categories used by the publications used for activity data.

Figure 3.8 Fuel combustion emissions under the sectoral and reference approaches, 1989–90 to 2023–24



For additional information on the reference approach, including source data, see Annex III.

3.2.2 International Bunker Fuels (CRT category 1.D.1)

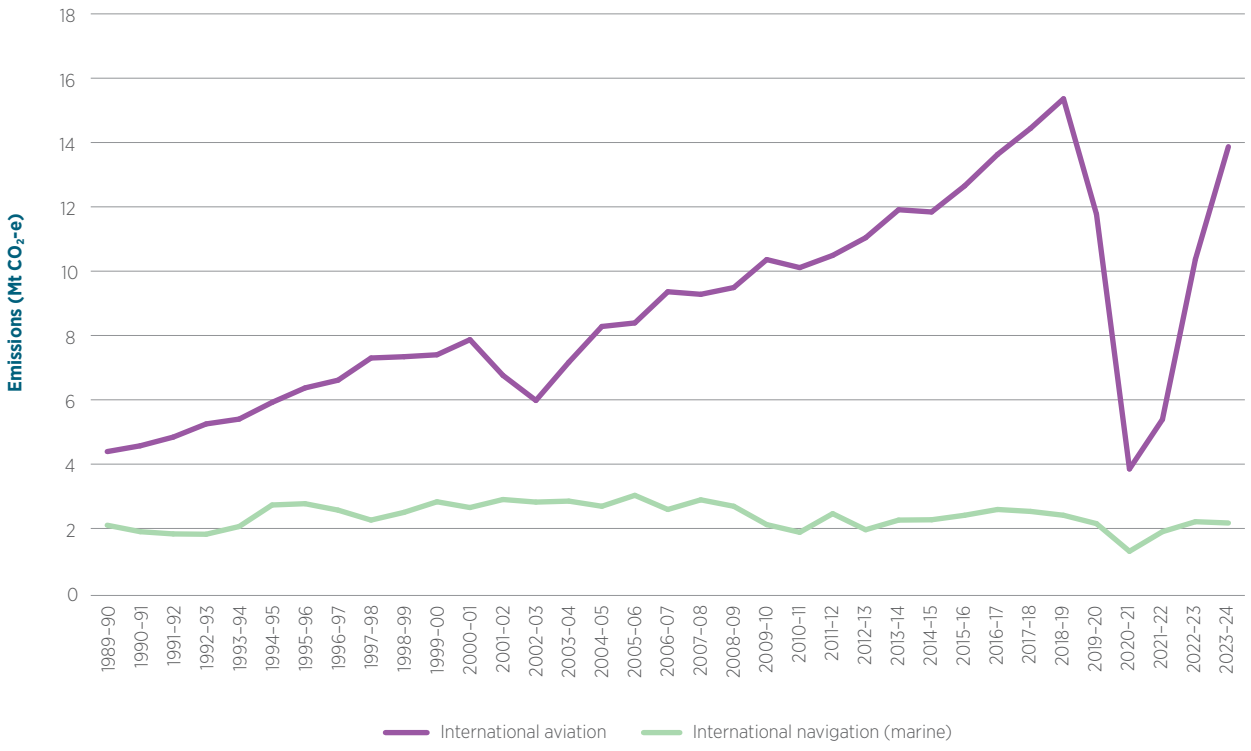
The 2006 IPCC Guidelines require emissions from international aviation and marine bunkers to be reported separately to the national total emissions from the *energy* sector (IPCC 2006). They are instead reported as memo items (CRT table 1.D.1) and are used in the carbon balance and in the reference approach (CRT Table 1. A(b)) as a quality control tool.

Activity data for both international marine and aviation bunkers are estimated using the annual Australian Energy Statistics (DCCEEW 2025a). Differentiation between international and domestic fuel consumption is made according to fuel sales data collected according to deliveries to domestic and international airport terminals and the tax treatment of marine bunker fuels.

Emissions from international aviation rose 34 per cent in 2023–24 compared to the previous year as activity continued to increase after the lifting of border lockdowns and restrictions on movement in place during the COVID-19 pandemic (Figure 3.9). Despite this large year-on-year increase, emissions from international aviation remain below the long-term trend. The Australian Government closed the borders to most international travel to and from Australia between March 2020 and February 2022, which significantly reduced international aviation activity and emissions from 2019–20 to 2021–22.

Emissions from international marine bunkers fell slightly in 2023–24, down 2 per cent on the previous year.

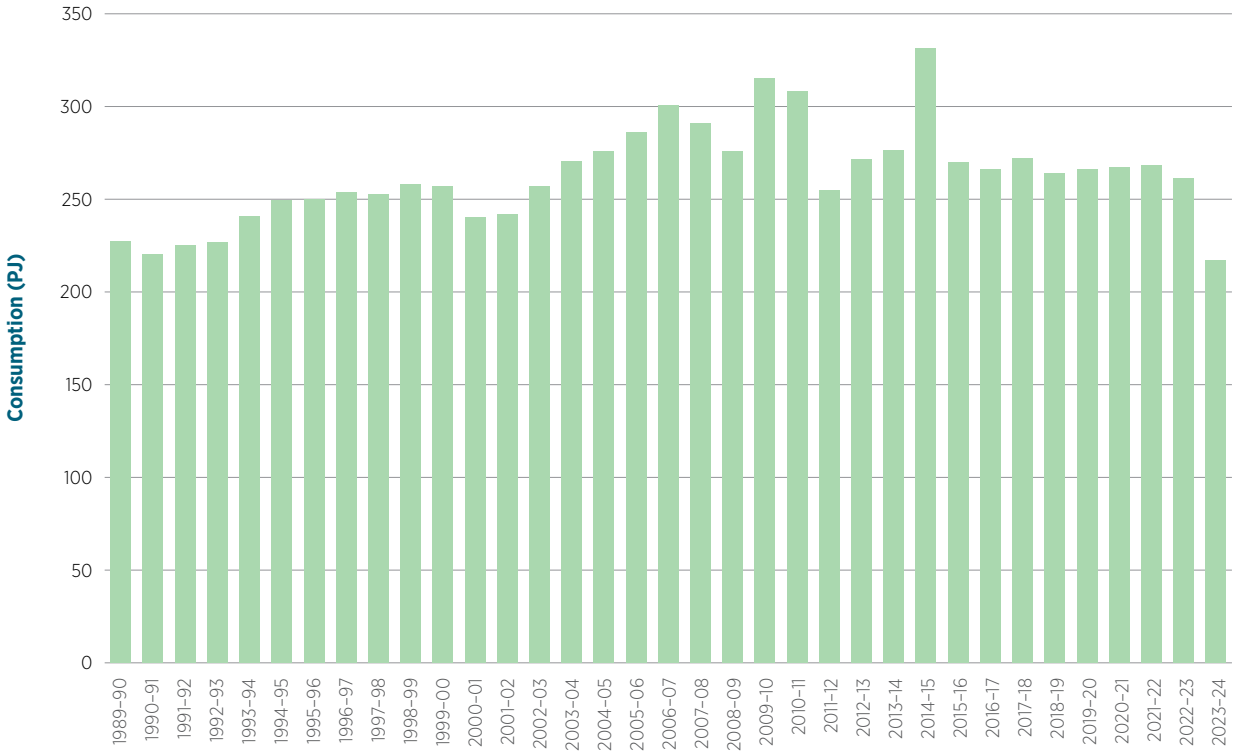
Figure 3.9 Emissions from combustion of international bunker fuels, 1989–90 to 2023–24



3.2.3 Feedstocks and non-energy use of fuels (CRT category 1.AD)

This category includes excluded carbon, which includes both stored carbon and carbon used and emitted as CO_2 in other sectors. The total consumption of these fuels per year is presented in Figure 3.10.

Figure 3.10 Consumption of non-energy uses of energy products, petajoules, 1989–90 to 2023–24



Source: Australian Energy Statistics (DCCEEW 2025a)

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* subsector as follows (IPCC 2006):

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 as a feedstock in Ammonia production – reported in 2.B.1 Ammonia Production;
- Coke where used as a reductant in soda ash production – reported with other emissions from soda ash production in 2.B.7 Soda Ash Production; and
- Lubricants and grease consumption where used for non-energy purposes – reported in 2.D.1 Lubricant use.

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.

3.2.4 Energy industries (CRT category 1.A.1)

3.2.4.1 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.

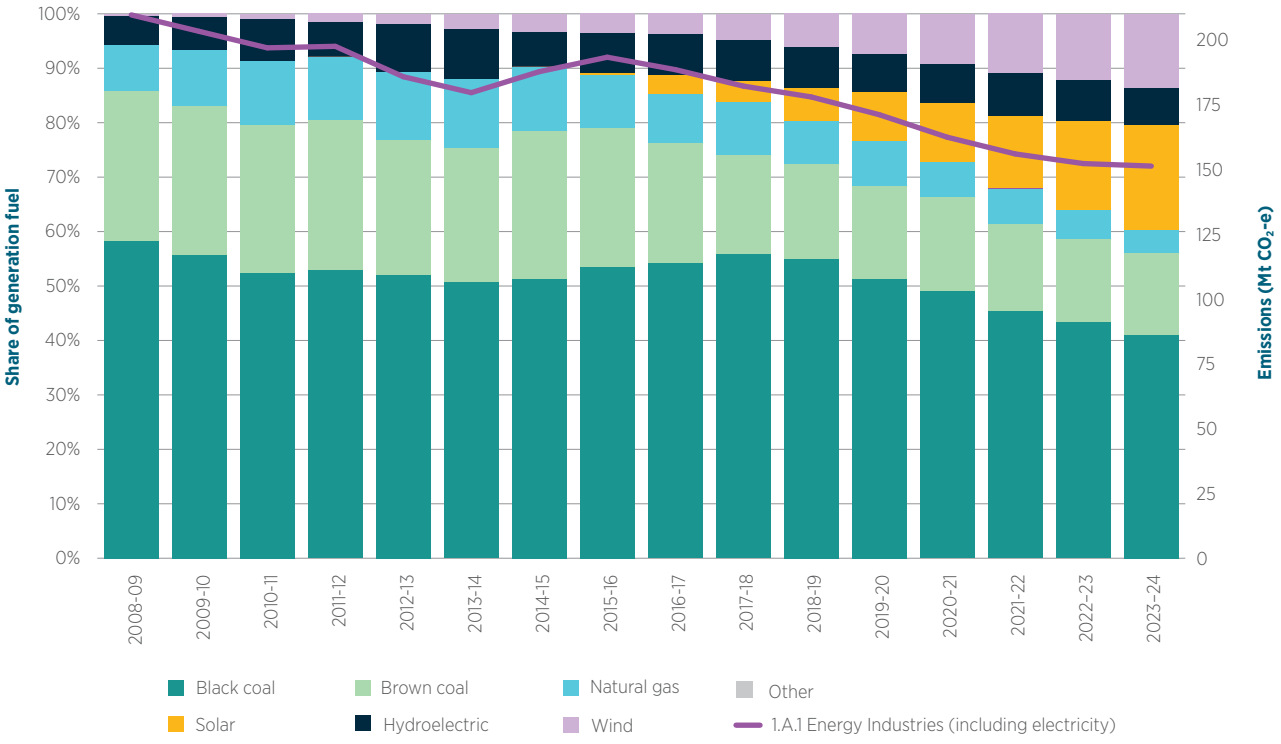
Public electricity and heat production (CRT category 1.A.1.a)

This is a key category for CO_2 emissions from solid, gaseous, and liquid fuel combustion.

Emissions from public electricity generation have increased steadily from 1989–90, reaching a peak in 2008–09. Since then, emissions have decreased despite continuing population and economic growth. This primarily reflects the ongoing displacement of coal and, to a lesser extent, gas fuel sources, replaced by renewable generation sources.

Coal combustion remains the largest source of electricity generation in Australia, however it has been declining with the significant scale up of renewable generation sources. Combined with system-wide energy efficiency improvements this has driven the reduction in emissions since 2008–09. This trend can be observed in data from the National Electricity Market (NEM), which connects six of Australia's eastern and southern states and territories and generates the majority of Australia's electricity (Figure 3.11).

Figure 3.11 Emissions from electricity generation and shares of generation fuel since 2008–09



Source: Generation by fuel from Australia's National Electricity Market (NEM) queried using NEMReview v6

Petroleum refining (CRT category 1.A.1.b)

This is a key category for CO_2 emissions from gaseous and liquid fuel combustion. Australia uses facility-level emission factors (EF) and activity data to estimate emissions from this category.

This category is defined by the 2006 IPCC Guidelines as including all combustion activities supporting the refining of petroleum products (IPCC 2006). It does not include evaporative emissions occurring at refineries, which are reported under fugitive emissions from crude oil refining/storage (1.B.2.a.iv) and flaring (1.B.2.c.ii.1).

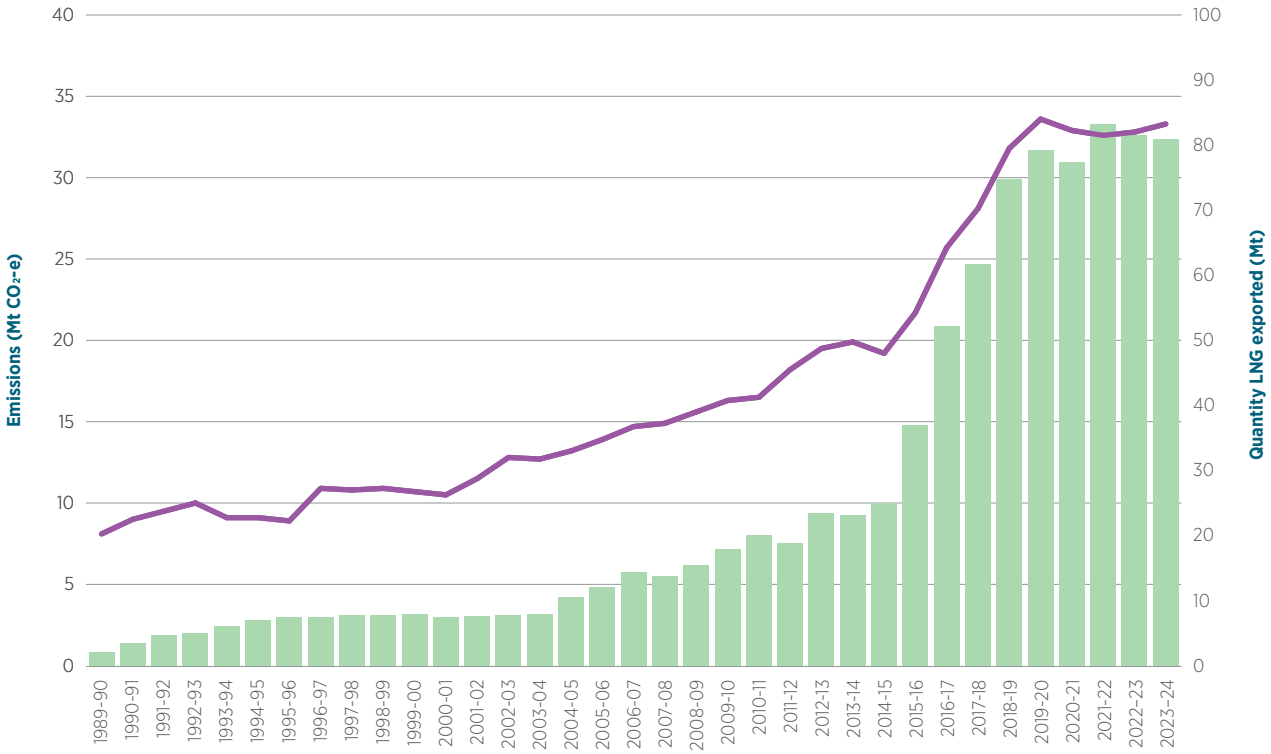
The number of refineries in operation has experienced a steep decline in recent years. Imports, largely from the Asian region, make up the difference between capacity and demand (GA 2022).

Manufacture of solid fuels and other energy industries (CRT category 1.A.1.c)

This is a key category for CO_2 emissions from solid, gaseous, and liquid fuel combustion. Australia uses country-specific EFs or models and a combination of facility-level and AES activity data to estimate emissions from this category.

The 2006 IPCC Guidelines describe this category as comprising combustion emissions of fuels used during the manufacture of secondary and tertiary products (IPCC 2006). Trends in this category have been dominated since 2015 by the consumption of energy associated with gas extraction for the expansion of Australia's liquefied natural gas (LNG) export industry (Figure 3.12).

Figure 3.12 Emissions from the manufacture of solid fuels and other energy industries, and liquefied natural gas (LNG) exports, 1989–90 to 2023–24



Source: Exports data from Table N of the Australian Energy Statistics (DCCEEW 2025a)

Manufacture of solid fuels (CRT category 1.A.1.c.i)

This category includes emissions arising from fuel combustion to produce coke, brown coal briquettes, and patent fuel.

In Australia, the production of coke in the iron and steel industry is the most significant source of emissions from this category. Brown coal briquetting has ceased production.

Other energy industries (CRT category 1.A.1.c.ii)

This category includes combustion emissions from energy industries other than the above-mentioned categories. In Australia, this is comprised of fuels combusted for coal mining and gas production and distribution.

3.2.4.2 Methodological issues

The Australian Energy Statistics report energy consumption by functional activity and classifies these to industries associated with them as a primary activity using the Australian and New Zealand Standard Industrial Classification (ANZSIC) (ABS 2006). These activities can be mapped to IPCC classifications (Table 3.1).

Table 3.1 Relationship between IPCC source categories and ANZSIC classifications: Energy Industries

	ANZSIC Subdivision		
IPCC Source Category	**Division**	**Subdivision**	**Description**
a Electricity and heat production [a]	D Electricity, Gas and Waste Services	26	Electricity supply
b Petroleum refining	C Manufacturing	17	Petroleum refining [b]
c Solid fuel transformation and other energy industries	B Mining	06	Coal mining (incl. briquette production)
	B Mining	07	Oil and gas extraction
	C Manufacturing	21	Coke ovens associated with Basic iron and steel manufacturing
	D Electricity, Gas and Waste Services	27	Gas supply

Notes:

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

(b) Coal briquette manufacturing, which no longer occurs in Australia, has in historical data been reallocated to solid fuel transformation and other energy industries.

Electricity generation (CRT category 1.A.1.a)

The 2006 IPCC Guidelines define this category as converting the chemical energy stored in fuels to electrical power (IPCC 2006). Public heat production from a central point to consumers via a pipeline grid is also described, however, this activity does not occur in Australia.

Electricity generation includes both power for supply to the main electricity grids of each state or territory and all off-grid generation.

The methods and data used to estimate emissions from this source category are presented in Table 3.2.

Table 3.2 Summary of methods and emission factors: Public Electricity and Heat Production

	CO_2		CH_4		N_2O	
1.A.1.a Public Electricity and Heat Production	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
Liquid Fuels	T2	CS	T2	CS	T2	CS
Solid Fuels	T2	PS,CS	T2	CS	T2	CS
Gaseous Fuels	T2	PS,CS	T2	CS	T2	CS
Biomass	T2	CS	T2	CS	T2	CS

T1 = Tier 1, T2 = Tier 2, CS = country specific, PS = plant specific, NO = not occurring, NA = not applicable, = key category

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 by source and over time.

Data is collected from power stations through the National Greenhouse and Energy Reporting (NGER) scheme. Under this scheme, 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 2008* (Cwlth) (the Determination). 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 the NGER scheme, methods for estimation were provided by the Generator Efficiency Standards program – as detailed in the *Generator Efficiency Standards Technical Guidelines* (AGO 2006). The adoption of consistent methods in the NGER scheme 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 scheme data are received from all large and medium sized power stations in Australia. These data are currently available for over 450 fossil-fuel and biofuel based power stations in Australia. The energy use of small power stations that do not meet the NGER scheme reporting thresholds are estimated as the difference between the total of reported values under the NGER scheme and AES for ANZSIC subdivision 26. This approach has been adopted throughout the time series. Therefore, the improved coverage of power stations under the NGER scheme does not alter the method for estimating total fuel consumption in this sector. The coverage of individual coal power station NGER scheme data is comprehensive and has displaced the necessity to use AES data to inform coal activity data.

NGER scheme coverage of these electricity generators is virtually complete, with 100 per cent of electricity generation from coal, 98.5 per cent from gas, 59.8 per cent from liquid fuels and 62.7 per cent from biofuels reported at facility level.

Oxidation factors and the EFs are linked in that coal power station operator's report. CO_2 EFs include the effects of oxidation based on analysis of ash contents in accordance with the NGER scheme. 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 scheme requires EFs reported by generators to use a default oxidation factor of 100 per cent unless measurements are undertaken to support an alternative value.

Emissions from landfill gas captured for combustion for electricity generation are reported in this subsector. CH_4 and N_2O are included in the energy industries aggregates, while CO_2 emissions are included in the memo item on CO_2 emissions from biomass (CRT category 1.D.3) in accordance with IPCC Guidelines on the treatment of CO_2 emissions from biogenic fuels.

Petroleum refining (CRT table 1.A.1.b)

The 2006 IPCC Guidelines (Volume 2) describe that, in a petroleum refinery, crude oil is converted into a broad range of products (IPCC 2006). Part of the energy content of the products obtained from transformation of crude oil is used at the refinery, complicating the derivation of activity data from energy statistics. As such, it is considered good practice to obtain fuel consumption from the refinery industry to verify the appropriate values reported by energy statistics.

The main fuels used by petroleum refineries are refinery gas/liquids and natural gas, with minor use of other liquids fuels. The combustion of refinery coke is also included under Petroleum Refining 1.A.1.b.

The methods and data used to estimate emissions from this source category are presented in Table 3.3.

Table 3.3 Summary of methods and emission factors: Petroleum Refining

	CO_2		CH_4		N_2O	
1.A.1.b Petroleum Refining	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
Liquid Fuels	T2	PS	T2	CS	T2	CS
Gaseous Fuels	T2	PS	T2	CS	T2	CS
Other Fossil Fuels	T2	PS	T2	CS	T2	CS

T1 = Tier 1, T2 = Tier 2, CS = country specific, PS = plant specific, NO= not occurring, NA = not applicable, = key category

Choice of emission factors

Facility-specific EFs for refinery gas and liquids, refinery coke, and natural gas are sourced from NGER scheme data for all currently operating petroleum refineries.

In line with the relevant decision tree (2006 IPCC Guidelines, Volume 1, Figure 1.2), PS EFs are used for all refineries (IPCC 2006). Refinery EFs for these fuel types are strongly linked with the specific technology types and proc ess 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, considering factors such as the change to low sulphur diesel. The model is used to derive refinery fuel consumption for the years 1999–00 to 2007–08. This approach was adopted 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.

Petroleum refining has had full activity data coverage in the NGER scheme since its introduction in 2008–09. For prior years the AES reports refinery feedstocks as energy outputs, comprising crude oil combined with other undefined petroleum products (DCCEEW 2025a). The various market petroleum products are also 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 (such as distillation, catalytic cracking, etc.). The fuel from which petroleum refining energy consumption is derived is obtained from the crude oil input (referred to in the AES as refinery fuel).

The 2006 IPCC Guidelines are ambiguous as to where emissions from refinery coke should be reported (IPCC 2006). Detailed fuel consumption data was made available via the NGER scheme for all Australian oil refineries from 2008–09 onwards. Refineries captured under the NGER scheme use methodologies involving measurement of flue flow rates, flue gas composition, and reference to the *Fluid Catalytic Cracking* handbook used by the industry. This reports the combustion of refinery gas/liquids and the burning of refinery coke to restore the activity of the catalyst during the refining process separately.

Consistent with the 2006 IPCC Guidelines, flaring at refineries is reported under 1.B.2.c.ii.1 flaring of oil (IPCC 2006).

Implied Emission Factor

NGER scheme plant specific data shows that the total gaseous fuel IEF for petroleum refining fluctuates through the time series. These fluctuations are caused by variances in reported fuel, plant specific emission factors, and plant closures.

"Other gaseous fuels" reported under the NGER scheme is included under the "other fossil fuel" IPCC category to allow a comparable natural gas IEF to be estimated. Manufacture of Solid Fuels and Other Energy industries (CRT category 1.A.1.c)

Manufacturing industries involve converting raw materials into products. This comprises the following subsectors:

- Coke Oven Operation,
- Briquetting,
- Coal Mining,
- Oil and Gas Extraction,
- Other Transport Services and Storage, assumed to be gas pipeline transport, and
- Gas Supply.

Emissions are estimated according to the general methods provided in Annex 5.3.1 and is presented in Table 3.4.

Table 3.4 Summary of methods and emission factors: Manufacture of Solid Fuels and Other Energy Industries

	CO_2		CH_4		N_2O	
1.A.1.c Manufacture of Solid Fuels and Other Energy Industries	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
Liquid Fuels	T2	CS	T2	CS	T2	CS
Solid Fuels	T2	CS	T2	CS	T2	CS
Gaseous Fuels	T2	CS	T2	CS	T2	CS
Biomass	T2	CS	T2	CS	T2	CS

T1 = Tier 1, T2 = Tier 2, CS = country specific, PS = plant specific, NO= not occurring, NA = not applicable, = key category

The *Coke Oven Operation* subsector 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 subsector 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 presented in Table A5.3.2.25.

The *Gas Production and Distribution* sector is also one of the energy transformation industries, manufacturing town gas up until 2011–12 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 AES (DCCEEW 2025a).

It is 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.

Methane EFs in the *oil and gas extraction* category for four-stroke rich burn/lean burn engines were taken from USEPA (AP-42) and weighted in the proportions observed by Zimmerle, et al. (2020) in the US industry to derive a single methane EF for reciprocating engines of 404.61 t CH_4/PJ for use in the Australian inventory.

In accordance with the 2006 IPCC Guidelines, fugitive emissions associated with gathering and boosting stations are reported under 1.B.2.b.ii (IPCC 2006).

3.2.4.3 Uncertainty assessment and time-series consistency

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

Time series variability of IEFs are influenced by changes in the fuel mix within categories, and changes of facility specific fuel emissions factors. Notable examples of where such variations occur in CO_2 IEFs for energy industries (1.A.1) are set out below:

Public electricity (CRT category 1.A.1.a)

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.

Biomass: combustion for electricity consists of a growing proportion of biogas from landfill. Biogas has a relatively low CO_2 EF compared to other biomass fuel; hence Australia's CO_2 biomass IEF is relatively low.

Petroleum refining (CRT category 1.A.1.b)

Liquid fuels: variations in the IEF of around 2 per cent are evident since 2007–08. Facility-specific EFs obtained from the NGER scheme are used, noting that Australia has a small number of refineries. The IEFs vary depending on the liquid fuel mix used and the refinery processes undertaken in the year.

Manufacture of solid fuels and other energy industries (CRT category 1.A.1.c)

Solid fuels: the IEF declines by 10 per cent between 1989–90 and 2000–01. This results from fuel switching from black coal (90 Gg/PJ) to the lower emissions intensive coke oven gas (37 Gg/PJ).

3.2.4.4 Category-specific QA/QC and verification

Results for the reference approach for the *energy* sector, reported in Chapter 3.2.1, and the carbon reconciliation reported in Annex 4.8, 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 scheme data and from AES 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 alternative data sources compiled by 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.

3.2.4.5 Category-specific recalculations

The recalculations reported in the current submission are shown in Table 3.5, and include:

A. Changes to the application of Australian Energy Statistics

A change to the application of the AES to derive emissions from small off grid generators has resulted in a recalculation for 2008/09 and 2009/10.

B. Updates for Oil and Gas Extraction

A reallocation of natural gas to unprocessed natural gas has been made in certain conditions. This reallocation has been informed by NGER data. CH_4 EFs for gas have been adjusted in 2023 to correctly align with Zimmerle, et al.

C. Activity Data in Petroleum Refining

Activity data for a petroleum refining facility has been updated in 2023 to align with NGER.

Table 3.5 Energy Industries: recalculation of total CO_2-e emissions, 1989–90 to 2022–23

	2024 submission	2025 submission	Change		Reasons for recalculation (Gg CO_2-e)		
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%	A	B	C
1989–90	143,172.8	143,172.8	0.00	0.0%	-	-	-
1994–95	158,140.2	158,140.2	0.00	0.0%	-	-	-
1999–00	192,519.7	192,519.7	0.00	0.0%	-	-	-
2004–05	215,385.7	215,385.7	0.00	0.0%	-	-	-
2005–06	220,092.9	220,092.9	0.00	0.0%	-	-	-
2006–07	224,088.0	224,088.0	0.00	0.0%	-	-	-
2007–08	225,886.9	225,886.9	0.00	0.0%	-	-	-
2008–09	232,466.0	232,240.7	-225.33	-0.1%	-225.33	-	-
2009–10	226,604.4	226,431.1	-173.34	-0.1%	-173.34	-	-
2010–11	220,628.4	220,628.4	0.00	0.0%	-	-	-
2011–12	222,400.8	222,400.8	0.00	0.0%	-	-	-
2012–13	211,400.1	211,400.1	0.00	0.0%	-	-	-
2013–14	205,423.3	205,423.3	0.00	0.0%	-	-	-

	2024 submission	2025 submission	Change		Reasons for recalculation (Gg CO_2-e)		
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%	A	B	C
2014–15	212,201.7	212,201.7	0.00	0.0%	-	-	-
2015–16	219,584.8	219,584.8	0.00	0.0%	-	-	-
2016–17	218,445.5	218,445.5	0.00	0.0%	-	-	-
2017–18	214,312.2	214,500.5	188.25	0.1%	-	188.25	-
2018–19	213,407.4	213,893.1	485.66	0.2%	-	485.66	-
2019–20	207,586.2	208,266.4	680.19	0.3%	-	680.19	-
2020–21	197,686.9	198,467.6	780.74	0.4%	-	780.74	-
2021–22	190,657.2	191,471.9	814.70	0.4%	-	814.70	-
2022–23	186,846.6	187,029.7	183.09	0.1%	-	658.09	-511.55

3.2.4.6 Category-specific planned improvements

Emission estimation methods are kept under review as part of Australia's commitment to continuous improvement of its national greenhouse gas inventory.

The incorporation of NGER scheme data into the Inventory is an ongoing improvement, as it is gradually included at the sub-category level to replace AES aggregated data with facility-specific activity data and EFs.

3.2.5 Manufacturing Industries and Construction (CRT category 1.A.2)

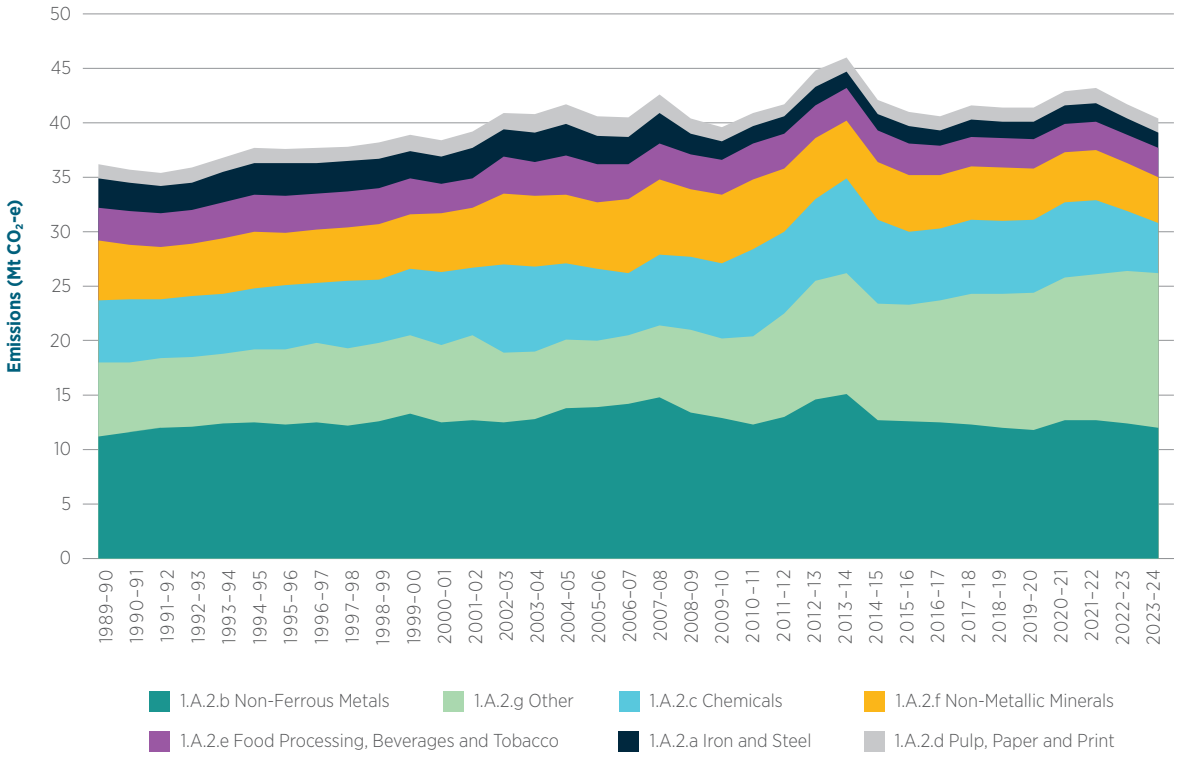
3.2.5.1 Category description

This source category includes emissions from combustion of fuels in the manufacturing and construction industries. In accordance with the 2006 IPCC Guidelines, emissions from fuel combustion in coke ovens in the iron and steel industry are reported under 1.A.1.c (IPCC 2006).

This sector includes emissions from both stationary equipment (such as cranes) and mobile equipment (such as earth moving and mining equipment).

The full time series of energy emissions by subsector are presented in Figure 3.13. Non-ferrous metals is the largest contributor to emissions from this category, followed by other (including construction, manufacturing of machinery, textiles, pulp, paper and print, mining (excluding fuels) and quarrying) and basic chemical manufacturing.

Figure 3.13 Emissions from the manufacturing and construction industries by subsector, 1989–90 to 2023–24



3.2.5.2 Methodological issues

Emissions for *manufacturing industries and construction* are estimated using Tier 2 approaches with country-specific EFs. Key categories and the further application of plant-specific EFs are identified in Table 3.6. Emissions estimated from activity data are based on the energy consumption by industry sector and fuel type. CO_2 EFs are country-specific and direct industry advice on the use of CO_2 EFs 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 Annex 5.3.2, Table A5.3.2.1. Additional stratification is provided for the metal and chemicals industries.

Table 3.6 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
1.A.2.a	Iron and Steel	T2	CS	T2	CS	T2	CS
1.A.2.b	Non-Ferrous Metals	T2	CS, PS	T2	CS	T2	CS
1.A.2.c	Chemicals	T2	CS	T2	CS	T2	CS
1.A.2.d	Pulp, Paper and Print	T2	CS	T2	CS	T2	CS
1.A.2.e	Food Processing, Beverages and Tobacco	T2	CS	T2	CS	T2	CS
1.A.2.f	Non-metallic minerals	T2	CS	T2	CS	T2	CS
1.A.2.g	Other	T2	CS	T2	CS	T2	CS

CO_2 Emission Factors		Liquid fuels	Solid fuels	Gaseous fuels	Biomass
1.A.2.a	Iron and Steel	CS	CS	CS	NO
1.A.2.b	Non-Ferrous Metals	CS	CS, PS	CS, PS	CS
1.A.2.c	Chemicals	CS	CS	CS	CS
1.A.2.d	Pulp, Paper and Print	CS	CS	CS	CS
1.A.2.e	Food Processing, Beverages and Tobacco	CS	CS	CS	CS
1.A.2.f	Non-metallic minerals	CS	CS	CS	CS
1.A.2.g	Other	CS	CS	CS	CS

Notes: T1 = Tier 1, T2 = Tier 2, T3 = Tier 3, CS = country specific, PS = plant specific, D= IPCC default, = key category

The AES reports energy consumption by functional activity and classifies these to industries associated with them as a primary activity using the Australian and New Zealand Standard Industrial Classification (ANZSIC). These activities can be mapped to IPCC classifications (Table 3.7).

Table 3.7 Relationship between IPCC source categories and ANZSIC classifications: Manufacturing and Construction

	ANZSIC Subdivision/Group/Class			
IPCC Source Category	**Division**	**Subdivision**	**Group/ Class**	**Description**
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		Non-metallic mineral product manufacturing
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

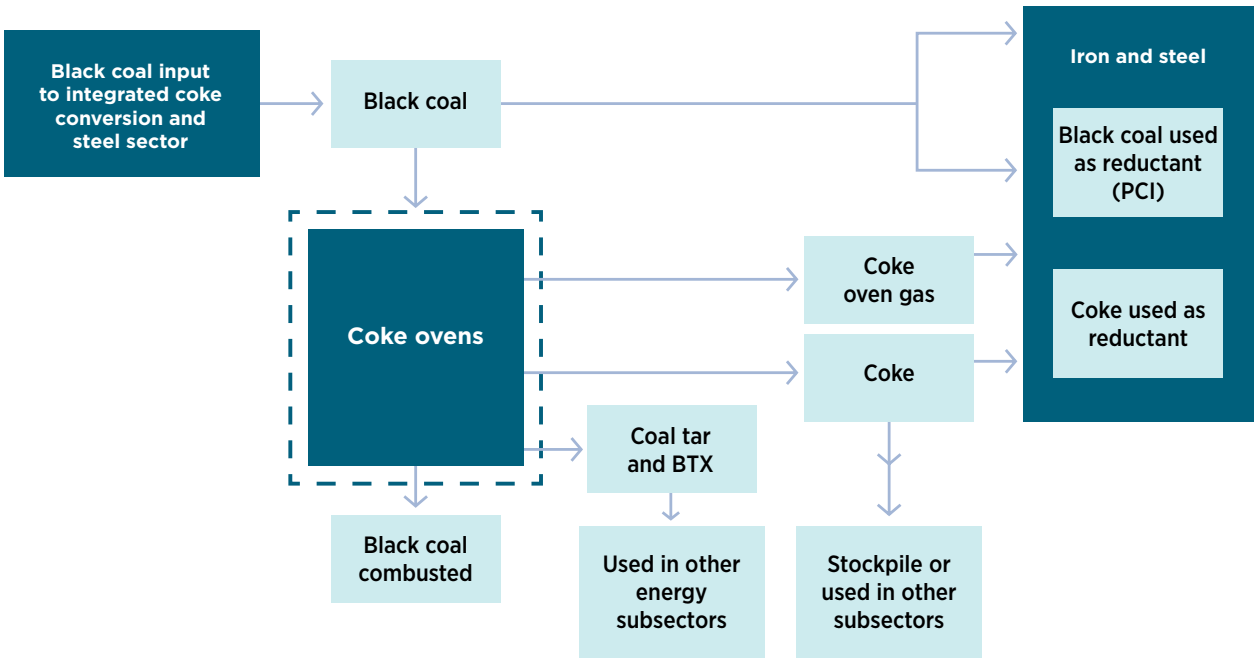
Iron and Steel (1.A.2.a)

The methodology in the *iron and steel* subsector is somewhat more complex than many other sections of the inventory. This complexity arises from several factors:

- 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 they can be reported under IPCC category 1.A.1.c;
- The production of coke yields a variety of by-products, including coke oven gas, coal and tar;
- Liquefied aromatic hydrocarbons and naphthalene each have 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 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 2002–03. Therefore, the consumption and emissions are reported under the *industrial processes and product use* sector in *2.C.1 metal production* rather than the *energy* sector;
- 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 3.14. Energy and carbon flows are balanced between inputs and outputs when compiling the inventory as part of the inventory quality controls. A discrete carbon balance is undertaken around the coke ovens inputs/outputs, as defined by dashed lines in Figure 3.14, to determine the carbon content of coke produced as a balancing item. A time series of coke EFs determined from this balance is shown in Table A5.3.2.21.

Figure 3.14 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 (1.A.2.b)

The consumption of petroleum products NEC (unspecified petroleum products 'not elsewhere classified', meaning other) 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 IPCC category 2.C.3. For years prior to the NGER scheme which rely on the AES, the quantity of petroleum coke and coal tar consumed is subtracted from energy consumption of petroleum products NEC and coal by-products. 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. These fuel quantities are deducted from the *energy* sector fuel consumption and reported under the *industrial processes and product use* sector.

Chemicals (1.A.2.c)

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. The non-energy use of petroleum coke for titanium dioxide production and coke oven coke used in soda ash production is 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* and the *basic chemical and chemical, polymer and rubber* sub-categories, where fossil fuels are used as feedstock. The quantity of carbon sequestered in products from feedstocks is obtained from the NGER scheme, with emissions estimates adjusted accordingly. Prior to the NGER scheme this data was obtained directly from manufacturers.

Coal by-products constitute the largest fuel input into the *other petroleum and coal product manufacturing* 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* 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 sources, while both naturally occurring and ex-refinery propane and butane are used. The AES groups propane and butane together with LPG.

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, was manufactured in Australia from 1993–94 to 2015–16.

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 (IPCC 2006, 2019). The national inventory utilises the actual production figures provided by the companies involved with the use of these fuels. The carbon contents of the various feedstocks and basic chemical products used in estimating the carbon sequestration are reported in Table 3.8 and Table 3.9.

The quantities of feedstocks used in the *Chemical* subsector, and the associated amounts of carbon stored in products, are detailed in CRT 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.2.C 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 3.8 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. Note that GCV stands for gross calorific value.

Table 3.9 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

Pulp, Paper and Print (1.A.2.d)

The manufacture of pulp, paper, and print materials use a range of machinery to process and produce wood.

The majority of fuel consumed in this sector is used for the generation and distribution of steam using boilers. Paper and paperboard production has been increasing, with notable increases during the COVID-19 pandemic lockdown periods in 2020 to 2021. Emissions intensity and fuel use have been reducing as the industry continues to make systemic changes to improve sustainability. As a result, the IEFs for solid and gaseous fuels have been reducing through time.

Emissions in this category are estimated based on fuel combustion reported in the AES (DCCEEW 2025a).

Food Processing, Beverages and Tobacco (1.A.2.e)

Emissions in this category are estimated based on fuel combustion reported in the AES (DCCEEW 2025a).

Non-metallic Minerals (1.A.2.f)

Emissions in this category are estimated based on fuel combustion reported in the AES (DCCEEW 2025a).

Other (1.A.2.g)

Emissions in this category are estimated based on fuel combustion reported in the AES (DCCEEW 2025a).

3.2.5.3 Uncertainties and time series consistency

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

Time series variability of IEFs is likely to be influenced by changes in fuel mix within categories. Notable examples of where such variations occur in Category 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 the *industrial processes and product use* sector in accordance with the 2006 IPCC Guidelines (IPCC 2006). 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.

Australia has allocated black coal used for pulverised coal injection (consumed as a reductant) to the *industrial processes and product use* sector. 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 2002–03 onwards. Table 3.10 shows the percentage of black coal-coke oven gas fuel mix.

Table 3.10 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
1989–90	10	90
1999–00	9	91
2004–05	23	77
2009–10	36	64
2014–15	4	96
2015–16	1	99
2016–17	16	84
2017–18	2	98
2018–19	1	99
2019–20	2	98
2020–21	2	98
2021–22	2	98
2022–23	1	99
2023–24	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 2000–01 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.

3.2.5.4 Category-specific QA/QC and verification

This source category is covered by the general QA/QC of the greenhouse gas inventory described in Annex IV.

3.2.5.5 Category-specific recalculations

The recalculations reported in the current submission are shown in Table 3.11, and include:

A. Updates to the Australian Energy Statistics

Australia's official statistics on energy production and use receives periodic updates to support improved understanding of Australia's energy systems, including for time series consistency. These updates are reflected in the inventory.

B. Activity data adjustments

Various updates to activity data have been made to improve accuracy using latest data sources..

Table 3.11 Manufacturing and Construction: recalculation of total CO_2-e emissions, 1989–90 to 2022–23

	2025 Submission	2026 submission	Change		Reasons for recalculation (Gg CO_2-e)	
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%	A	B
1989–90	36,224.9	36,224.9	0.0	0.0%	-	-
1994–95	37,628.9	37,628.9	0.0	0.0%	-	-
1999–00	38,916.0	38,916.0	0.0	0.0%	-	-
2004–05	41,665.3	41,665.3	0.0	0.0%	-	-
2005–06	40,619.1	40,619.1	0.0	0.0%	-	-
2006–07	40,382.7	40,382.7	0.0	0.0%	-	-
2007–08	42,510.6	42,510.6	0.0	0.0%	-	-
2008–09	40,465.1	40,366.5	-98.6	-0.2%	-	-98.6
2009–10	39,624.1	39,624.1	0.0	0.0%	-	-
2010–11	40,880.4	40,880.4	0.0	0.0%	-	-
2011–12	41,632.7	41,632.7	0.0	0.0%	-	-
2012–13	44,722.3	44,722.3	0.0	0.0%	-	-
2013–14	46,083.9	46,083.9	0.0	0.0%	-	-
2014–15	42,174.6	42,174.6	0.0	0.0%	-	-
2015–16	41,045.6	41,045.6	0.0	0.0%	-	-
2016–17	40,652.8	40,652.8	0.0	0.0%	-	-
2017–18	41,745.0	41,648.7	-96.2	-0.2%	-96.2	-
2018–19	41,368.1	41,368.1	0.0	0.0%	-	-
2019–20	41,361.1	41,361.1	0.0	0.0%	-	-
2020–21	42,927.9	42,927.9	0.0	0.0%	-	-
2021–22	43,208.6	43,208.6	0.0	0.0%	-	-
2022–23	42,042.1	41,665.8	-376.2	-0.9%	-376.2	-

3.2.5.6 Category-specific planned improvements

The department will continue to look at applying revisions to the earlier part of the time series in response to future AES releases.

The incorporation of NGER scheme data into the Inventory is an ongoing improvement, as it is gradually included at the sub-category level to replace AES aggregated data with facility-specific activity data and EFs.

3.2.6 Transport

3.2.6.1 Category description

The *transport* sector covers emissions from the direct combustion of fuels in transportation by road, rail, domestic aviation and domestic shipping, as well as combustion of fuels for the transportation of gas by pipeline.

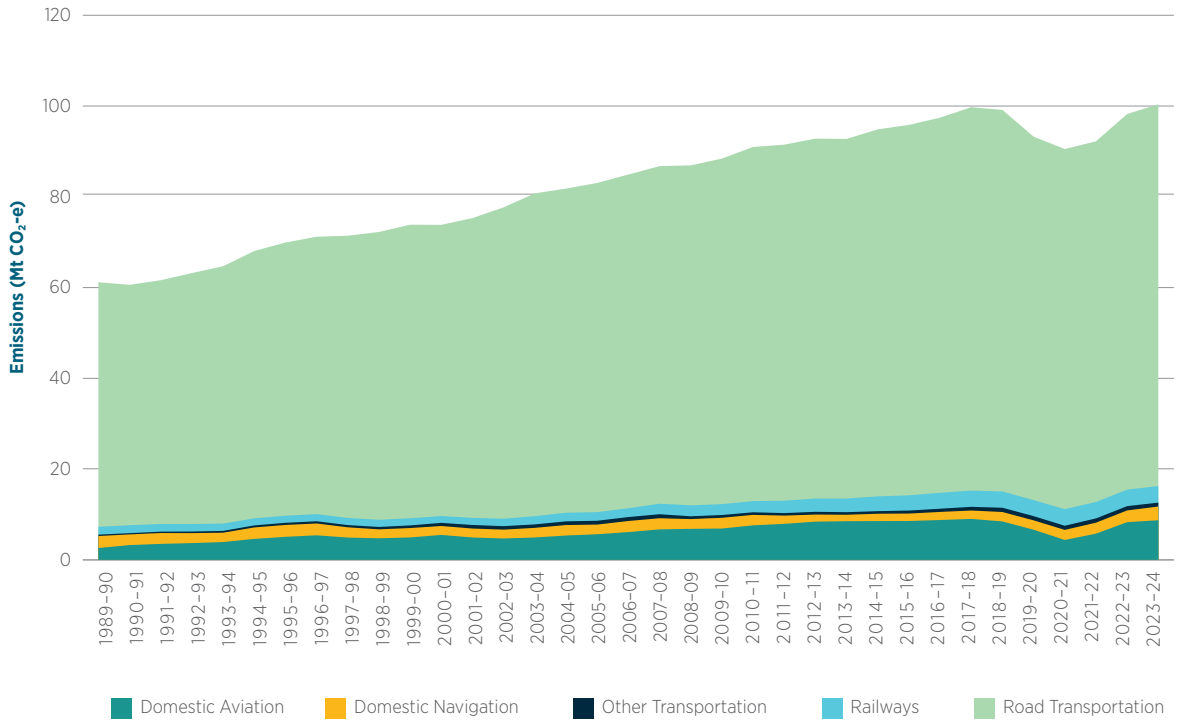
By international agreement, emissions from fuel used for international transport (including aviation and marine 'bunkers') are reported as a memo item, separate from the national total net emissions. More information is available in Chapter 3.2.2.

Transport emissions are one of the strongest drivers of Australia's emissions. *Road transportation* contributes the majority of Australia's transport emissions, largely driven by the importance of motor vehicles for moving both passengers and freight in Australia.

Except for observed decreases caused by the recent COVID-19 pandemic, emissions associated with transport have trended consistently upward over time (Figure 3.15). This is largely attributable to population and economic growth but is partially offset by improved efficiency in the modes of transport.

Emissions from *pipeline transport* are mainly driven by the level of gas throughput, with the large increase in pipeline transport emissions since 2014–15 reflecting the significant expansion of gas production over the period.

Figure 3.15 Transport emissions by subsector, 1989–90 to 2023–24



3.2.6.2 Methodological issues

Like other energy subsectors, 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 road transport (besides motorcycles) 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 domestic 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 aviation gasoline), which takes account of fuel consumed, landing and take-off cycles and Australian fleet characteristics (Table 3.12).

Table 3.12 Summary of methods and emission factors: Transport

	CO_2		CH_4		N_2O	
Source Category	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
1.A.3.a Domestic Aviation						
Aviation Gasoline	T2	CS	T1	D	T1	D
Jet Kerosene	T2	CS	T2	CS	T2	CS
1.A.3.b Road Transportation – Cars, Trucks and Buses						
Liquid Fuels	T2	CS	T3	CS	T3	CS
Gaseous Fuels	T2	CS	T3	CS	T3	CS
Biomass	T2	CS	T3	CS	T3	CS
1.A.3.b Road Transportation – Motorcycles						
Liquid Fuels	T2	CS	T2	CS	T2	CS
Other Fossil Fuels (Lubricants)	T1	D	NE	NA	NE	NA
1.A.3.c Railways						
Liquid Fuels	T2	CS	T1	D	T2	CS
Solid Fuels	NE	NA	NE	NA	NE	NA
Gaseous Fuels	NO	NO	NO	NO	NO	NO
1.A.3.d Domestic Navigation						
Liquid Fuels	T2	CS	T2	CS	T2	CS
Gaseous Fuels	T2	CS	T2	CS	T2	CS
Biomass	T2	CS	T2	CS	T2	CS
Other Fossil Fuels (Coal)	T2	CS	T2	CS	T2	CS
Other Fossil Fuels (Lubricants)	T1	D	NE	NA	NE	NA
1.A.3.e Other Transport – Pipeline Transport						
Gaseous Fuels	T2	CS	T1	D	T1	D
1.A.3.e Other Transport – Off-road vehicles						
Liquid Fuels	T2	CS	T1	D	T1	D
Biomass	T2	CS	T1	D	T1	D
Other Fossil Fuels (Lubricants)	T1	D	NE	NA	NE	NA

Notes: T1 = Tier 1, T2 = Tier 2, T3 = Tier 3, CS = country specific, D = IPCC default, NE = not estimated, NA = not applicable, NO = not occurring, = key category

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:

$$E_{(l)ijk} = Au_{ijk} \times F_{(l)}u_{ijk}$$

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 the Australian Energy Statistics (AES) and Australian Petroleum Statistics (see Annex 5.2) (DCCEEW 2025a, 2025b). Special allocations of AES transport fuel consumption are made to 1.A.5. Other for military transport based on information provided by the Australian Department of Defence since 2007–08. Allocations for prior years are linearly extrapolated between reported data points in 1993–94 and 2007–08. Allocations for the current inventory year are given in Annex 5.3.2, Table A5.3.2.12.

Domestic aviation (1.A.3.a)

CO_2 emissions from civil aviation are estimated using a Tier 2 methodology with EFs given in Annex 5.3.1, Table A5.3.1.1.

Non-CO_2 emissions from domestic civil aviation are estimated using a mix of Tier 2 (for aviation turbine fuel) and Tier 1 (for aviation gasoline) methodologies.

For larger aircraft operating on aviation turbine fuel, emissions are calculated as a function of both the landing and take-off (LTO) cycles and of cruise emissions for both domestic and international aircraft. The Tier 2 estimation of emissions from LTO 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.

Data on the total yearly LTO cycles at Australian airports for domestic and international aircraft are available from the Bureau of Infrastructure, Transport and Regional Economics (BITRE 2025a) within the Department of Infrastructure, Transport, Regional Development, Communications, Sports and the Arts.

The Australian aviation fleet profile is developed using the Australian Aircraft Register which is available from the Civil Aviation Safety Authority (CASA 2025) (Table 3.13). EFs for each aircraft type are taken from the 2006 IPCC Guidelines (IPCC 2006) and are used to estimate weighted average LTO cycle EFs for the domestic and international aviation fleets (Table 3.14). 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 aviation are available from the AES (DCCEEW 2025a). Cruise EFs are taken from the 2006 IPCC Guidelines (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 (except for 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 between states and territories are mainly driven by variations in fuel consumption and the number of LTO cycles, as well as the balance between major interstate and regional movements, which impacts the types of aircraft operating at different airports. National emissions are estimated as the sum of the state and territory emissions.

Small aircraft operating on aviation gasoline make up a small portion of domestic aviation emissions and are estimated using a Tier 1 approach and IPCC default EFs (Table 3.16).

Emissions from international aviation are estimated using the Tier 2 method described above for domestic aviation turbine fuel. By international agreement, emissions from international aviation are reported as a memo item only. Activity data for international aviation are sourced from the AES (DCCEEW 2025a).

Table 3.13 The Australian aircraft fleet, 2023–24, and emission factors by type of aircraft

		Emission Factors				
Type of aircraft	**Number**	**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	9	0.00	0.02	1.51	2.24	0.00
A320	86	0.06	0.10	9.01	6.19	0.51
A330–200/300	28	0.13	0.20	35.57	16.20	1.15
BAE 146	12	0.14	0.00	4.07	11.18	1.27
B717	0	0.01	0.10	10.96	6.78	0.05
B727-200	0	0.81	0.10	11.97	27.16	7.32
B737-300/400/500	4	0.08	0.10	7.19	13.03	0.75
B737-700	10	0.09	0.10	9.12	8.00	0.78
B737-800	165	0.07	0.10	12.30	7.07	0.65
B767-200	1	0.33	0.10	23.76	14.80	2.99
B767-300	3	0.10	0.20	28.19	14.47	1.07
SAAB 340	16	0.00	0.02	1.51	2.24	0.00
SA227	33	0.00	0.02	1.51	2.24	0.00
SA226	11	0.00	0.02	1.51	2.24	0.00
Gulfstream IV	58	0.14	0.10	5.63	8.88	1.23
EMB 110	4	0.06	0.01	0.30	2.97	0.58
EMB 120	14	0.00	0.02	1.51	2.24	0.00
Cessna 525	25	0.33	0.03	0.74	34.07	3.01
Beech (King Air) 200	134	0.06	0.01	0.30	2.97	0.58
F27	153	0.03	0.02	1.82	2.33	0.26
International						
A380	10	0.40	0.30	69.31	28.40	2.02
787	25	0.17	0.18	34.65	15.27	1.08

Source: Australian Civil Aircraft Register (CASA 2025), ICAO Aircraft Engine Emissions Databank (EASA 2023), IPCC (2006).
Note that LTO stands for landing and take-off cycle.

Table 3.14 Weighted average emissions factors per landing and take-off cycle (LTO), 2023–24

Fleet	CH_4 (kg)	N_2O(kg)	NO_x(kg)	CO (kg)	NMVOC (kg)
Domestic Fleet	0.1	0.1	6.3	6.2	0.6
International Fleet	0.2	0.2	44.6	19.0	1.3

Source: DCCEEW estimates derived from CASA (2025) and IPCC (2006).

Table 3.15 Aviation cruise emission factors (grams per tonne of fuel consumed)

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

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

Table 3.16 Aviation Tier 1 Non-CO_2 emission factors

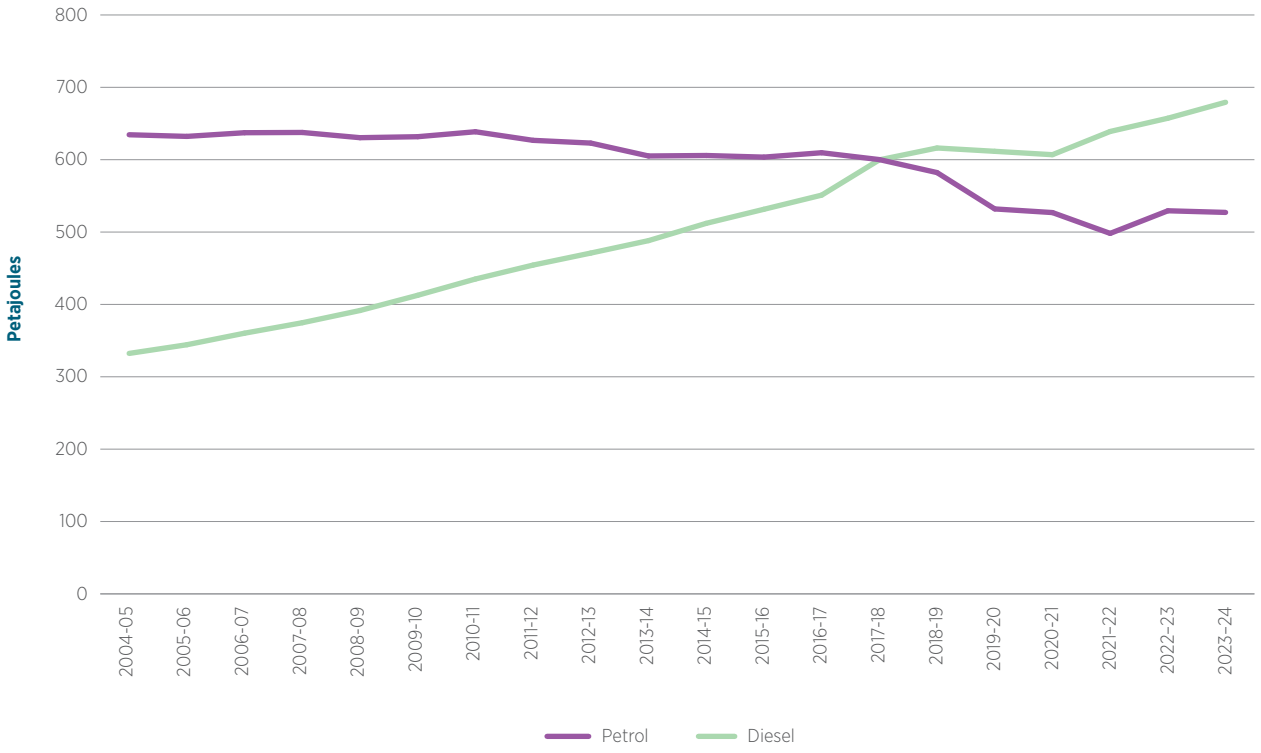
Tier 1 Non-CO_2	CH_4 (kg/TJ)	N_2O (kg/TJ)	NO_x(kg/TJ)	CO (kg/TJ)	NMVOC (kg/TJ)
Aviation gasoline	0.5	2	250	0.024	0.00054

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

Road transportation (1.A.3.b)

Diesel consumption in total road transport has grown significantly and consistently since 1989–90, while petrol consumption has gradually declined since 2010–11, albeit with recent volatility associated with the COVID-19 pandemic (Figure 3.16). This correlates with increasing demands for road freight which is dominated by diesel-powered light commercial and heavy vehicles as well as the increasing popularity of diesel vehicle options for passenger vehicles in Australia, including Sports Utility Vehicles (SUVs) (Figure 3.17). As petrol-powered vehicles are more commonly used for private household purposes, the petrol consumption profile has been more significantly impacted by the net effect of various COVID-19 border and lockdown policies, as well as ongoing mode of work changes with greater working from home levels resulting in fewer car journeys to workplaces. More recently, increasing uptake of hybrid and electric vehicles is also contributing to the decline in petrol consumption (BITRE 2025b).

Figure 3.16 Energy consumption for road transport by fuel type, 2004–05 to 2023–24



Source: Australian Energy Statistics 2025 and Australian Petroleum Statistics 2025 (DCCEEW 2025a, 2025b)

Figure 3.17 Sport utility vehicle (SUV) and passenger new vehicle sales in Australia, 2004–05 to 2023–24

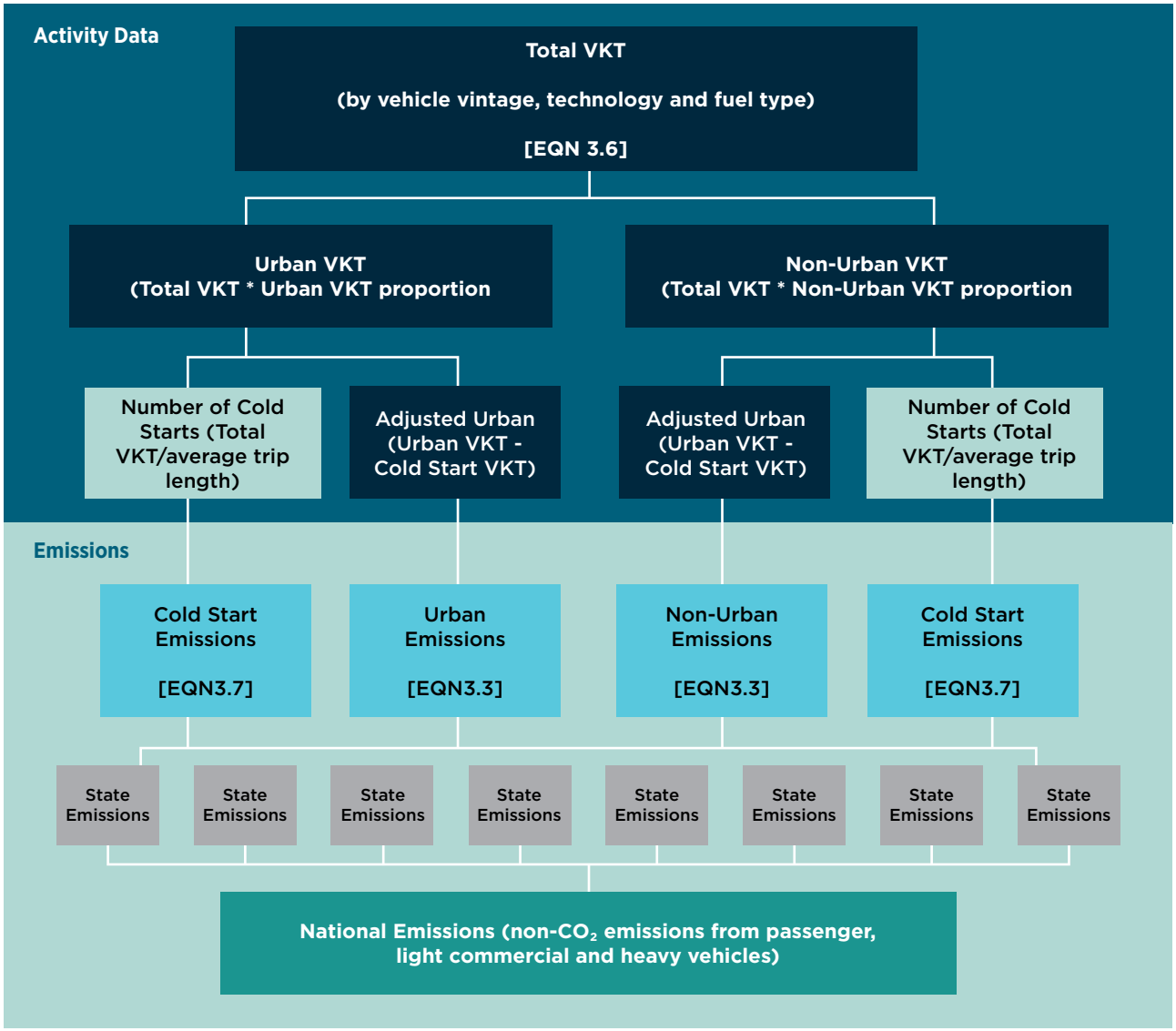


Source: ABS (2017b), Federal Chamber of Automotive Industries (2018–2024).

Emissions from off-road vehicles are allocated to the subsector to which their function is relevant. For example, large trucks used in iron ore mining operations are allocated to 1.A.2.g, and tractors used in farming are allocated to 1.A.4.c. This is consistent with how fuel use is allocated to the industry most closely related to the functional activity in the AES, and the purpose of these vehicles is not transport. Regardless, the emissions associated with off-road vehicles are still estimated using the methods outlined in this chapter.

Like the aviation sector, CO_2 emissions from the road transport sector are estimated using a Tier 2 method with EFs given in Annex 5.3.1, Table A5.3.1.1. Non-CO_2 emissions from road transport are estimated using a Tier 3 method based vehicle type, 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 mainly reflect variations in fuel consumption and the effect of each jurisdiction's vehicle fleet age distribution on non-CO_2 emission. National emissions are estimated as the sum of the state and territory emissions (see Figure 3.18).

Figure 3.18 Methodology for the estimation of non-CO_2 emissions from passenger, light commercial, heavy vehicles and buses



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 multiplied by the CO_2 EF specific to that fuel and the proportion of that fuel which is completely oxidised.

$$E_{ijk} = A^{u=1}_{ijk} \times (F_{(I)k} \times P_k) \quad (3.2)$$

Where $A^{u=1}_{ijk}$ 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 or territory)

$F_{(I)k}$ is the CO_2 EF applicable to complete oxidation of fuel carbon content for fuel type k

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

The CO_2 EFs and oxidation factors for each fuel are summarised in Annex 5.3.1, Table A5.3.1.1.

For all vehicles (besides motorcycles) consuming automotive gasoline, ethanol, diesel and LPG, non-CO_2 emissions for each vehicle 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 jurisdiction; 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 the Australian Transport Facts (PTT 2025). 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. A cold-start duration of 3km (IPCC 2006) is used to determine the total cold start VKT. This is subtracted from total VKT to derive an adjusted total hot-cycle 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 (PTT 2025).

Vehicles using automotive gasoline, ethanol, diesel and LPG are classified by age using data in Road Vehicles, Australia, published by the Bureau of Infrastructure and Transport Research Economics (BITRE 2025b). The age profile of the vehicle fleet enables differences in emissions control technology and 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 1975–76 to 1984–85 group uses a variety of non-catalytic control (such as exhaust gas recirculation) and all groups after 1984–85 use catalytic control.

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

$$E_{(I)ijk} = A^{u=2}_{ijk} \times EF_{(I)ijk} \quad (3.3)$$

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

$EF_{(I)ijk}$ is the exhaust EF for gas I from vehicle type i and age class j using fuel type k

This is conducted for urban and non-urban operation in each state or territory and where vehicle distances travelled during the hot-engine phase of operation are related to energy consumption levels.

$$A^{u=2}_{ijk} = A^{u=1}_{ijk} / R_{ijk} \times D_k \quad (3.4)$$

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

$A^{u=1}_{ijk}$ is the fuel consumption for vehicle type i with emission control technology j and fuel type k

R_{ijk} is the average rate of fuel consumption (in L/km) 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)

$$EF_{(l)ijk} = (ZKL_{(l)ijk} + DR_{ijk} \times CuVKT_{ijk}) \quad (3.5)$$

Where $EF_{(l)ijk}$ is the EF for gas l from each vehicle type i and age class j, using fuel type k

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

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

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

$$CuVKT_{ijk} = \Sigma_t A^{u=2}_{ijk} \quad (3.6)$$

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 3.7:

$$Ecs_{ijk} = CS_{ijk} \times EFcs_{ijk} \quad (3.7)$$

Where Ecs_{ijk} are the cold start emissions for vehicle type i and age class j, using fuel type k

CS_{ijk} is the number of cold starts for vehicle type i and age class j, using fuel type k

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

Activity data on aggregate road transport fuel consumption is sourced exclusively from the AES (DCCEEW 2025a) for all fuels except petrol. For NIR 2024, data on road transport petrol consumption is sourced from the AES for the period 1989–90 to 2017–18. For the period 2018–19 to 2023–24, aggregate road transport petrol consumption is derived using a combination of AES and Australian Petroleum Statistics data (DCCEEW 2025b).

The AES 2025 introduced revised estimates of road transport petrol consumption from 2018–19 onward as part of efforts to improve alignment with Australian Petroleum Statistics petrol sales data. However, a modelling issue in the road transport petrol balance resulted in an overstatement of road transport petrol consumption in the published AES 2025 series for these years. Due to publication timing constraints, this issue could not be corrected prior to release and will be addressed in AES 2026. To maintain time-series consistency and avoid introducing a structural break in the road transport petrol consumption series, road transport petrol activity data for 2018–19 onward in NIR 2024 were derived as the difference between aggregated Australian Petroleum Statistics petrol sales data and AES estimates of petrol consumption in non-road transport sectors. Road transport petrol activity data in the NIR will be realigned with the AES once the corrected series is published in a future release of the AES.

Activity data on aggregate road transport fuel consumption is disaggregated between individual vehicle types using data on fuel consumption by vehicle type from the Survey of Motor Vehicle Use Australia (ABS 2020a) and from the Australian Transport Facts (PTT 2025). The data on average rates of fuel consumption are taken from Survey of Motor Vehicle Use Australia (ABS 2020a). The profile and age of the passenger vehicle stock in each state and territory required for equation 3.5 is taken from Road Vehicles, Australia (BITRE 2025b). The vehicle stock from each historical year varies mainly 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 1990–91 is lower than surrounding years because of lower vehicle sales during an economic recession affecting Australia at the time.

Emissions of CH_4 from motor-vehicles are a function of the emission and combustion control technologies, 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. 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 and deterioration rates 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.

Another report by Orbital Australia (2011) 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 (IPCC 2006, 2019). 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 ADR applicable to each 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 (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 the IPCC 2006 Guidelines are used for earlier vehicle vintages where required (IPCC 2006).

Australian design rules applied to Australia's vehicle fleet, their date of introduction and the European sources for these standards are outlined in Table 3.17. 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 3.17 Australian petrol passenger car exhaust emission standards, Australian heavy duty diesel exhaust emission standards

Australian Standard	Year of application	Source standard
Petrol passenger vehicles		
ADR 79/00	2003–2004	Euro 2
ADR 79/01	2005–2006	Euro 3
ADR 79/02	2008–2010	Euro 4
ADR 79/03	2013	Euro 5
ADR 79/04	2016	Euro 5
ADR 79/05	2025–2028	Euro 6d
Heavy duty diesel vehicles		
ADR 70/00	1995–1996	Euro 1
ADR 80/00	2002–2003	Euro 3
ADR 80/01	2007–2008	Euro 4
ADR 80/02	2007–2008	Euro 4
ADR 80/03	2010–2011	Euro 5
ADR 80/04	2024–2025	Euro 6

Source: DITRDCA 2022, DITRDCA 2023

Note: Where a data range is specified, the first date applies to vehicle models first produced on or after that date, with all new vehicles required to comply by the second date.

There are no country-specific CH_4 EFs available for heavy-duty vehicles. These EFs have been taken from the Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006 (DCC 2006) or the 2006 IPCC Guidelines (IPCC 2006). CH_4 EFs for post-2005 vintage vehicles (Euro 3) have been derived based on the Euro 1 COPERT IV EF (EEA 2011) and an emission reduction factor according to the method in the EMEP/EEA air pollutant emission inventory guidebook (EEA 2009).

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 (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 Orbital Australia's analysis of the *Second National in Service Emissions* study (Orbital Australia 2010) and their review of uncertainty in fuel properties (Orbital Australia 2011).

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 2011). 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 A5.3.2.10. 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, Galbally and Guo-hong 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-1975–76 and the 1975–76 to 1984–85 age groupings and a weighted average of the catalyst equipped emissions used for the 1984–85 to 1996–97 and the post-1996–97 vehicle fleet. The EFs in Weeks et al. are comparable to those reported by the IPCC (2000) and by the USEPA and COPERT IV (2011). N_2O EFs for light duty petrol vehicles of vintage 1994 onwards are estimated on the Orbital Australia (2010) report on NISE 2 data.

There are no country-specific N_2O EFs available for heavy-duty vehicles. These EFs have been taken from DCC (2006) and IPCC (2006). EFs from the 2006 IPCC Guidelines (IPCC 2006) 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 IEFs, 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 IEF fluctuations according to their proportional contributions.

The Australian fleet has a relatively high non-CO_2 emissions profile due to ADR emissions limits lagging behind emission standards applied in Europe and the United States – consequently, the types of emissions control technology employed in Australia lags as these are introduced 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.

Extensive tables containing the factors and other parameters used for the estimation of emissions from road transport are included in Annex 5.3.2.

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

The estimation of emissions for motorcycles is given by equations 3.2 and 3.3. Fleet average EFs for motorcycles are provided in Annex 5.3.2.

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 Annex 5.3.2.

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

Urea-based additives (diesel exhaust fluid – DEF) are used in Australia in modern diesel engines fitted with selective catalytic reduction (SCR) emissions control systems. SCR is an emissions control technology that reduces tailpipe emissions of NO_x.

DEF is predominantly used by heavy vehicles and truck fleets, including in the mining, agriculture and services industries. DEF is also used in newer light passenger vehicles fitted with SCR technology, where it can also act as a coolant.

DEF is a solution of urea and deionised water. Consumption of DEF in SCR emissions control technology produces non-combustive emissions of CO_2 through the chemical decomposition of urea to reduce NO_x.

Australia has made a preliminary estimate of emissions from urea-based catalysts and considers it to be an insignificant source in accordance with paragraph 32 of the Paris Agreement MPGs.

This estimate was made based on information reported in the Independent Review of the *Petroleum and Other Fuels Reporting Act 2017* (POFR Act) published in May 2023, which estimated national demand for DEF to be approximately 4 million litres per week. Based on this, emissions in 2023–24 are estimated to be 54.0 kt CO_2-e (0.01% of the national total emissions) which is well under the threshold for significance according to paragraph 32 of the Paris Agreement MPGs.

Australia has no immediate plans to report emissions from Urea-based catalysts category (1.A.3.b.vi) as there is a considerable data requirement to estimate the emissions considering fuel consumption rates and penetration of the technology in the fleet. Australia will investigate data sources with the aim of addressing this data requirement in a future submission. Given the insignificance of the source, this is not considered to add materially to the completeness of the inventory.

Railways (1.A.3.C)

Emissions are estimated using Tier 2 methods described by equations 3.1 and 3.2.

CO_2 EFs are reported in Table A5.3.1.1 and non-CO_2 EFs are reported in Table 3.18. The EF for CH_4 from railway diesel is the 2006 IPCC Guidelines default value (IPCC 2006). The EF for N_2O from railway diesel is derived from that provided in the *EMEP/EEA air pollutant emission inventory guidebook 2023 1.A.3.c Railways,* an earlier version of which was the primary source document for the default factor in the 2006 IPCC Guidelines. This factor was adopted in response to expert advice from the Bureau of Infrastructure and Transport Research Economics that the default factor for railway diesel N_2O in the 2006 IPCC Guidelines is a substantial overestimate for the Australian context. EFs for NO_x, CO and NMVOC are Australian fleet averages calculated based on data on the composition and engine types in the local fleet, and individual engine EFs from USEPA (1992).

Data on rail transport fuel consumption is taken from the AES (DCCEEW 2025a).

Coal use is confined to historic railways used in tourism operations. Based on information published in the 2023–24 annual report of the Puffing Billy Historic Railway on their coal consumption and associated emissions (which is assumed to be representative of the broader industry's activities) and information on the number of active historic railways from the Association of Tourist and Heritage Rail Australia, it is estimated that emissions from solid fuel use in railways would not exceed 38.8 kt CO_2-e.

Table 3.18 Non-CO_2 emission factors for non-road sources

Source Category	CH_4	N_2O	NO_x	CO	NMVOC
	(g/MJ)				
Rail Transport [a] [c] [d]					
Diesel	0.004	0.00053	1.530	0.202	0.071
Marine Transport [b] [c]					
Domestic					
Petrol – Small Craft	0.360	0.001	0.254	20.300	3.240
Diesel	0.007	0.002	1.105	0.246	0.075
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					
Diesel	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 1992). (b) Lloyd's Register of Shipping (1995, and previous issue). (c) (IPCC 2006). (d) (EEA, 2023)

Domestic navigation (1.A.3.d)

Emissions are estimated using Tier 2 methods described by equations 3.1 and 3.2. CO_2 EFs are reported in Table A5.3.1.1 and non-CO_2 EFs are 2006 IPCC Guidelines default values (IPCC 2006) or taken from Lloyds Register of Shipping (1995) and are reported in Table 3.18. As discussed in Annex 5.3.1, where IPCC 2006 defaults are adopted their appropriateness for Australia has been validated by Orbital Australia (2011).

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 as part of the AES (DCCEEW 2025a).

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 in Annex 5.3.1. Data on fuel consumption is taken from the AES (DCCEEW 2025a).

3.2.6.3 Uncertainty assessment and time-series consistency

The Tier 1 uncertainty analysis in Annex II provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured using 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.

3.2.6.4 Category-specific QA/QC and verification

This source category is covered by the general QA/QC of the greenhouse gas inventory outlined in Annex IV.

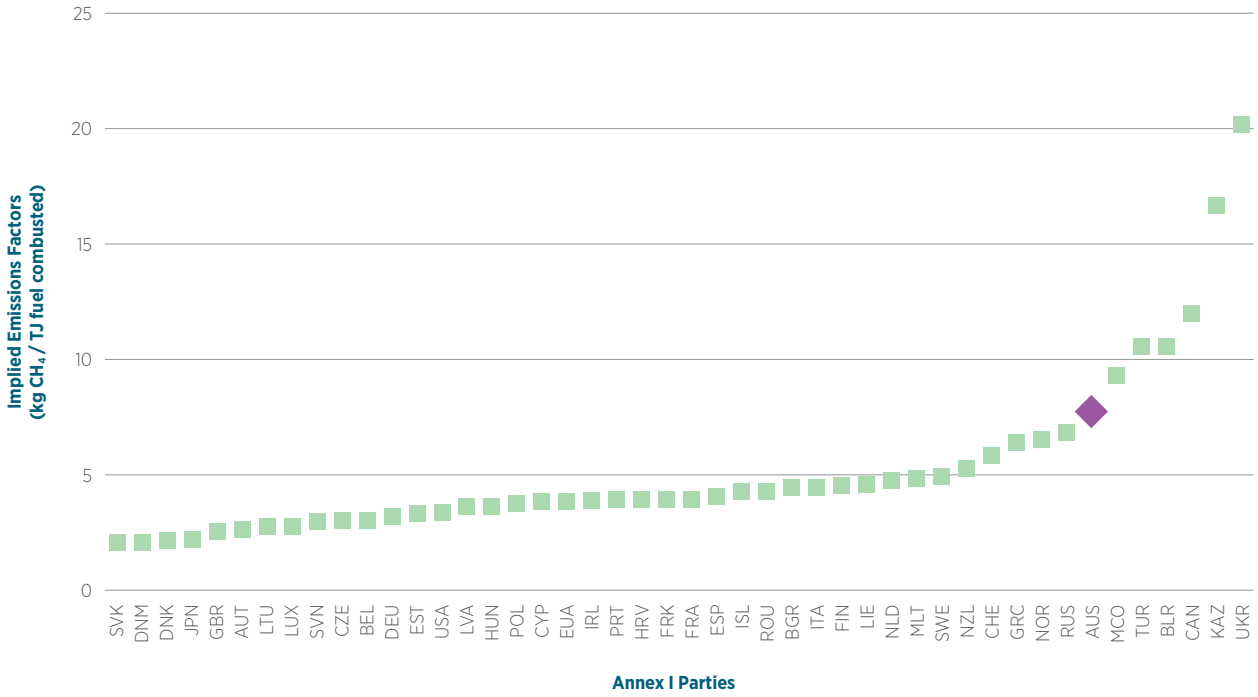
The primary sources of activity data for this sector are from the department's AES, the Bureau of Infrastructure and Transport Research Economics (BITRE) and from the Australian Bureau of Statistics (ABS). These three organisations have systematic quality assurance programmes in place. In addition, there are also several critical user organisations and alternative data sources available for this sector.

Comparisons of IEFs and international data sources are conducted systematically for the Australian inventory. In the 2026 submission, Australia's IEF for CH_4 from the combustion of liquid fuels (7.8 kg CH_4/TJ) remains higher than the average of other developed country parties (5.2 kg CH_4/TJ in 2023 submission year) (Figure 3.19).

Three studies (Orbital 2010, 2011a, 2011b) 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.

Figure 3.19 Implied emission factors from liquid fuel combustion for developed country Parties (2023 submission) and Australia (2026 submission), kg CH_4 per TJ combusted



Source: DCCEEW estimates; UNFCCC GHG Locator Tool

Note: For the purpose of international comparisons, Australia's IEF of 7.4 kg/TJ on a gross calorific value basis has been converted to an approximate IEF of 7.8 kg/TJ on a net calorific value basis.

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 the 2006 IPCC Guidelines.

Independent of the national inventory, the former 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 2012–13 for domestic consumption, and 2.1 per cent for international consumption in 2012–13. This is considered an excellent independent verification of the estimates.

DIRD (now the Department of Infrastructure, Transport, Regional Development, Communications, Sports and the Arts) 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.

In the road transport sector, a recent study (Smit, 2023) modelled greenhouse gas emissions from the road transport sector in calendar year 2019 using an Australian-specific application of the COPERT model. Estimates from this study were compared with road transport emission estimates for Australian financial year 2018–19 reported in NIR 2024 to provide a high-level, macro check of overall transport emissions.

Estimates from the two analyses are well aligned, both in terms of CO_2-e (1.3 per cent difference) and individual gases (1.2 per cent difference for CO_2, 38.2 per cent difference in CH_4, 3.2 per cent difference in N_2O). Differences between the estimates reflect the different modelling approaches and assumptions used in the two analyses. The Smit (2023) study being a bottom-up model based on individual vehicle fuel efficiency and emissions intensity, whereas Australia's inventory uses a model based on official national statistics on road transport fuel consumption published in the AES. The compared estimates also relate to different time periods, with Smit (2023) reporting on a calendar year basis and the inventory reporting on an Australian financial year basis. The biggest difference is observed for CH_4 emissions, which are highly sensitive to technology type modelling assumptions. However, emissions of CH_4 make up a very small amount of overall road transport emissions in both Australia's inventory and the Smit (2023) study.

3.2.6.5 Category-specific recalculations

The recalculations reported in the current submission are shown in Table 3.19, and include:

A. Revision to Domestic aviation turbine fuel AD in the Australian Energy Statistics

Domestic aviation turbine fuel consumption for 2022–23 was revised in the latest release of the AES (DCCEEW 2025a).

B. Revision to Domestic navigation fuel oil AD in the Australian Energy Statistics.

Domestic navigation fuel oil consumption for 2020–21 to 2022–23 was revised in the latest release of the AES (DCCEEW 2025a).

C. Revision to Road Transportation diesel AD in the Australian Energy Statistics

Road transport diesel consumption for 2021–22 and 2022–23 was revised in the latest release of the AES (DCCEEW 2025a).

D. Revision to Road Transportation LPG AD in the Australian Energy Statistics

Road transport LPG consumption for 2020–21 to 2022–23 was revised in the latest release of the AES (DCCEEW 2025a).

E. Revision to Road Transportation petrol AD

Road transport petrol AD for 2018–19 to 2022–23 was revised to align with the AES 2025 and Australian Petroleum Statistics 2025.

The AES 2025 introduced revised estimates of road transport petrol consumption from 2018–19 onward as part of efforts to improve alignment with Australian Petroleum Statistics petrol sales data. However, a modelling issue in the road transport petrol balance resulted in an overstatement of road transport petrol consumption in the published AES 2025 series for these years. Due to publication timing constraints, this issue could not be corrected prior to release and will be addressed in AES 2026. To maintain time-series consistency and avoid introducing a structural break in the road transport petrol consumption series, road transport petrol activity data for 2018–19 onward in NIR 2024 were derived as the difference between aggregated Australian Petroleum Statistics petrol sales data and AES estimates of petrol consumption in non-road transport sectors. Road transport petrol activity data in the NIR will be realigned with the AES once the corrected series is published in a future release of the AES.

F. Revision to the distribution of AES transport fuel consumption between civilian transport, military transport and lawnmower applications

The distribution of aggregate transport fuel consumption between 1.A.3 Transport, 1.A.4.b.ii Lawnmowers and 1.A.5 Other (Military transport) applications was revised, reflecting revisions to road transport, domestic marine transport and domestic aviation transport activity data as mentioned in items A-E above, as well as the introduction of more disaggregated historical defence fuel consumption data.

G. Revision to the split of Australian Energy Statistics transport fuel consumption AD between NSW and the ACT

The split of AES road transport fuel consumption between NSW and the ACT in 2019–20 was revised to correct a minor calculation error. The recalculation of emissions following this revision reflects the different road fleet characteristics of the two jurisdictions.

Table 3.19 1.A.3 Transport: recalculation of total CO_2-e emissions, 1989–90 to 2022–23

	2025 submission	2026 submission	Change		Reasons for recalculation (Gg CO_2-e)						
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%	A	B	C	D	E	F	G
1989–90	61,176	61,176	-	-	-	-	-	-	-	-	-
1994–95	68,043	68,043	-	-	-	-	-	-	-	-	-
1999–00	73,851	73,851	-	-	-	-	-	-	-	-	-
2004–05	81,804	81,804	-	-	-	-	-	-	-	-	-
2005–06	83,054	83,054	-	-	-	-	-	-	-	-	-
2006–07	84,914	84,914	-	-	-	-	-	-	-	-	-
2007–08	86,674	86,758	84	0.1	-	-	-	-	-	84	-
2008–09	86,888	86,942	54	0.1	-	-	-	-	-	54	-
2009–10	88,356	88,421	65	0.1	-	-	-	-	-	65	-
2010–11	90,974	90,975	1	0.0	-	-	-	-	-	1	-
2011–12	91,484	91,488	5	0.0	-	-	-	-	-	5	-
2012–13	92,808	92,808	0	0.0	-	-	-	-	-	0	-
2013–14	92,754	92,754	0	0.0	-	-	-	-	-	0	-
2014–15	94,874	94,856	-18	0.0	-	-	-	-	-	-18	-
2015–16	95,858	95,837	-21	0.0	-	-	-	-	-	-21	-
2016–17	97,462	97,440	-23	0.0	-	-	-	-	-	-23	-
2017–18	99,748	99,740	-8	0.0	-	-	-	-	-	-8	-
2018–19	99,806	99,139	-667	-0.7	-	-	-	-	-650	-17	-
2019–20	92,722	93,248	525	0.6	-	-	-	-	534	-8	-1
2020–21	89,619	90,528	908	1.0	-	148	-	282	484	-5	-
2021–22	89,518	92,241	2,724	3.0	-	167	1,167	29	1,360	1	-
2022–23	96,611	98,232	1,622	1.7	-711	325	1,028	10	969	1	-

Category-specific planned improvements

Emission estimation methods are kept under review as part of Australia's commitment to continuous improvement of its national greenhouse gas inventory.

Australia is investigating the availability of more disaggregated activity data and emission factors to further improve the accuracy of its Tier 3 road transport emissions model in a future submission, an identified area of improvement (#3.E.2, TERR 2025).

This includes investigating:

- the applicability of more recent and disaggregated non-CO_2 EFs available through the COPERT model to the Australian context, including to take account of the latest exhaust emission standards adopted in Australia.
- the availability of disaggregated SUV and non-SUV passenger vehicle stock activity data (current and historical) to make use of separate EFs and deterioration rates for large-SUVs available in Orbital Australia reports (2010, 2011).
- the availability of further disaggregated passenger and LCV drive cycle data to make use of 'hot extra urban' drive cycle EFs available in the *Second National in Service Emissions* study dataset, noting Australia already applies disaggregated activity data and EFs for urban and non-urban drive cycles in its existing road transport model.

Australia continues to investigate sources with the aim of updating non-CO_2 emission factors for domestic navigation. Current navigation factors come from Lloyd's Register of Shipping (1995) which has been noted by a previous ERT as being out of date. Noting that these are minor sources of emissions this analysis will be prioritised accordingly.

3.2.7 Other Sectors

3.2.7.1 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.

3.2.7.2 Methodological issues

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.

Table 3.20 Summary of methods and emission factors: 1.A.4 Other Sectors

	CO_2		CH_4		N_2O	
Source Category	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
1.A.4.a Commercial/Institutional						
Liquid Fuels	T2	CS	T2	CS	T2	CS
Solid Fuels	T2	CS	T2	CS	T2	CS
Gaseous Fuels	T2	CS	T2	CS	T2	CS
Biomass	T2	CS	T2	CS	T2	CS
1.A.4.b Residential						
Liquid Fuels	T2	CS	T2	CS	T2	CS
Solid Fuels	T2	CS	T2	CS	T2	CS
Gaseous Fuels	T2	CS	T2	CS	T2	CS
Biomass	T2	CS	T2	CS	T2	CS
1.A.4.c Agriculture, Forestry and Fisheries						
Liquid Fuels	T2	CS	T2	CS	T2	CS
Gaseous Fuels	T2	CS	T2	CS	T2	CS

Notes: T1 = Tier 1, T2 = Tier 2, T3 = Tier 3, CS = country specific, D = default, = key category

Activity data are taken from the AES published by the Department (DCCEEW 2025a). Non-CO_2 EFs for this sector by ANZSIC Division, are reported in Table A5.3.2.2.

The AES reports energy consumption by functional activity and classifies these to industries associated with them as a primary activity using the Australian and New Zealand Standard Industrial Classification (ANZSIC). These activities can be mapped to IPCC classifications (Table 3.21).

Only the liquid fuels from ANZSIC Subdivision 50–53 Other transport, services and storage are included in this category. The natural gas consumption is accounted for within the Transport sector (Natural Gas Transmission) sub-category. The natural gas and LPG consumption from sub-category 47 Railway Transport is included in this category as it is assumed to be for stationary activities and not for mobile purposes.

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

	ANZSIC Category		
IPCC Source Category	**Division**	**Subdivisions**	**Description**
4. Other Sectors			
a Commercial/Institutional	Division D	28–29	Water and waste services
	Division I	50–53	Other transport, services and storage
	Divisions F-H & J-S	33–45	Commercial services
b Residential	Residential	54–96	Residential
c Agriculture/forestry/fishing	Division A	1–5	Agriculture, Forestry and Fishing

Commercial & Institutional (1.A.4.a)

Emissions in this category are estimated based on fuel combustion reported in the AES (DCCEEW 2025a).

Residential – biomass combustion (1.A.4.b)

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

The Tier 2 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. Information on the model is provided in Annex 5.3.3.

Emissions from lawnmowers are estimated using Tier 2 methods described in Annex 5.3.1, with additional non-CO_2 EFs provided in Annex 5.3.2. 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).

Agriculture, Forestry and Fishing (1.A.4.C)

The AES present a single total figure for diesel fuel consumed in agriculture, fisheries and forestry (DCCEEW 2025a). 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 1987–88 to 1993–94 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 3.22).

Table 3.22 Non-CO_2 emission factors for non-transport uses of transport fuels

	CH_4	N_2O	NO_x	CO	NMVOC
			(g/MJ)		
Other Mobile Sources					
Recreational Vehicles					
Petrol	0.03	0.0009	0.37	7	1.08
Industrial Equipment					
Diesel	0.0057	0.002	1.006	0.39	0.108
LPG	0.022	0.001	0.437	5.465	0.409
Farm Equipment					
Diesel	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.

3.2.7.3 Uncertainty assessment and time-series consistency

The Tier 1 uncertainty analysis in Annex II 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.

3.2.7.4 Category-specific QA/QC and verification

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

3.2.7.5 Category-specific recalculations

The recalculations reported in the current submission are shown in Table 3.23 and include.

A. Revision to the distribution of petrol consumption between civilian transport, military transport and lawnmower applications

Revisions to the distribution of petrol consumption between 1.A.3 Transport, 1.A.4.b.ii Lawnmowers and 1.A.5 Other (Military transport) applications, reflecting revisions to aggregate road transport activity data, as described in section 3.2.6.5.

Table 3.23 1.A.4 Other sectors: recalculation of total CO_2-e emissions, 1989–90 to 2022–23

	2025 submission	2026 submission	Change		Reasons for recalculation (Gg CO_2-e)
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%	A
1989–90	15,884.0	15,884.0	0.00	0.0	-
1994–95	17,428.6	17,428.6	0.00	0.0	-
1999–00	18,416.7	18,416.7	0.00	0.0	-
2004–05	20,212.0	20,212.0	0.00	0.0	-
2005–06	20,364.1	20,364.1	0.00	0.0	-
2006–07	20,197.9	20,197.9	0.00	0.0	-
2007–08	20,542.1	20,537.1	-5.01	0.0	-5.0
2008–09	20,714.2	20,709.1	-5.07	0.0	-5.1
2009–10	21,044.5	21,039.3	-5.21	0.0	-5.2
2010–11	21,452.5	21,447.2	-5.34	0.0	-5.3
2011–12	21,895.8	21,890.3	-5.48	0.0	-5.5
2012–13	22,319.6	22,314.0	-5.68	0.0	-5.7
2013–14	21,403.9	21,398.3	-5.51	0.0	-5.5
2014–15	22,559.2	22,559.2	0.00	0.0	-
2015–16	22,803.4	22,797.7	-5.74	0.0	-5.7
2016–17	23,572.8	23,572.8	0.00	0.0	-
2017–18	23,452.8	23,452.8	0.00	0.0	-
2018–19	21,962.0	21,957.5	-4.44	0.0	-4.4
2019–20	21,377.3	21,380.9	3.60	0.0	3.6
2020–21	23,748.8	23,752.0	3.26	0.0	3.3
2021–22	23,782.4	23,791.6	9.18	0.0	9.2
2022–23	22,517.6	22,524.1	6.55	0.0	6.6

3.2.7.6 Category-specific planned improvements

The department continues to investigate applying revisions to the earlier years of the time series in response to improvements incorporated within future AES releases.

3.2.8 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 3.24.

Table 3.24 Summary of methods and emission factors: Other (Not Elsewhere Classified)

	CO_2		CH_4		N_2O	
1.A.5.b Other (mobile)	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
Liquid Fuels	T2	CS	T1/T2	D/CS	T1/T2	D/CS

Notes: T1 = Tier 1, T2 = Tier 2, T3 = Tier 3, CS = country specific, D = IPCC default, NE = not estimated, NA = not applicable, NO = not occurring, = key category

3.2.8.1 Category description

The source category *1.A.5 Other* consists of emissions arising from fuel used in mobile equipment within defence operations.

3.2.8.2 Methodological issues

Emissions from military vehicles are estimated using Tier 1 and 2 methods described for transport. EFs are reported in Annexes 5.3.1 and 5.3.2.

The allocations of fuel to military transport are based on energy use data provided by the Australian Department of Defence since 2007–08. Allocations for prior years are linearly extrapolated between reported data points in 1993–94 and 2007–08.

The shares used to allocate fuel consumption are reported in Annex 5.3.2.

3.2.8.3 Uncertainty assessment and time-series consistency

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

3.2.8.4 Category-specific QA/QC and verification

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

3.2.8.5 Category-specific recalculations

Recalculations made to *1.A.5 Other* are detailed at the sub-category level in Table 3.25.

Recalculations in this sector are the result of the introduction of more disaggregated historical defence fuel consumption data and revisions to the distribution of petrol consumption between 1.A.3 Transport, 1.A.4.b.ii Lawnmowers and 1.A.5 Other (Military transport) applications.

Table 3.25 1.A.5 Other: recalculation of total CO_2-e emissions (Gg), 1989–90 to 2022–23

	2025 submission Gg CO_2-e	2026 submission Gg CO_2-e	Change	
			Gg CO_2-e	%
1989–90	422.7	422.7	-	-
1994–95	696.0	696.0	-	-
1999–00	627.3	627.3	-	-
2004–05	624.4	624.4	-	-
2005–06	651.2	651.2	-	-
2006–07	782.8	782.8	-	-
2007–08	823.0	742.8	-80.2	-10
2008–09	834.3	784.0	-50.3	-6
2009–10	888.6	827.6	-61.0	-7
2010–11	898.0	902.1	4.1	0
2011–12	871.5	872.1	0.6	0
2012–13	911.1	916.4	5.3	1
2013–14	1025.6	1030.9	5.4	1
2014–15	945.0	963.5	18.5	2
2015–16	1107.5	1134.4	26.9	2
2016–17	923.8	946.4	22.6	2
2017–18	928.4	936.5	8.1	1
2018–19	791.7	798.8	7.1	1
2019–20	946.9	955.1	8.2	1
2020–21	816.1	821.7	5.7	1
2021–22	727.9	730.6	2.7	0
2022–23	1057.9	1063.1	5.1	0

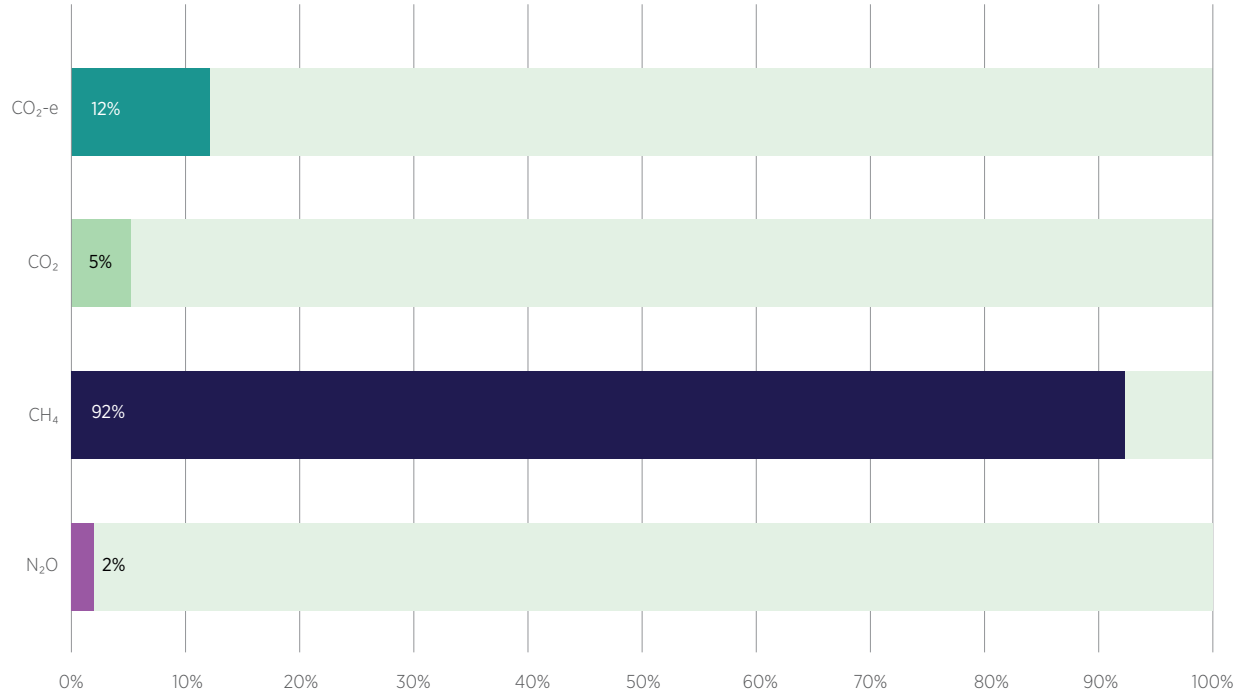
3.2.8.6 Category-specific planned improvements

All relevant data is kept under constant review.

3.3 Fugitive emissions from solid fuels and natural gas and other emissions from energy production (CRT category 1.B)

Fugitive emissions are defined by the 2006 IPCC Guidelines as the intentional or unintentional release of greenhouse gases that occur during the extraction, processing and delivery of fossil fuels to the point of final use (IPCC 2006). Unlike combustion emissions, which are predominantly CO_2, fugitive emissions are predominantly CH_4 (Figure 3.20).

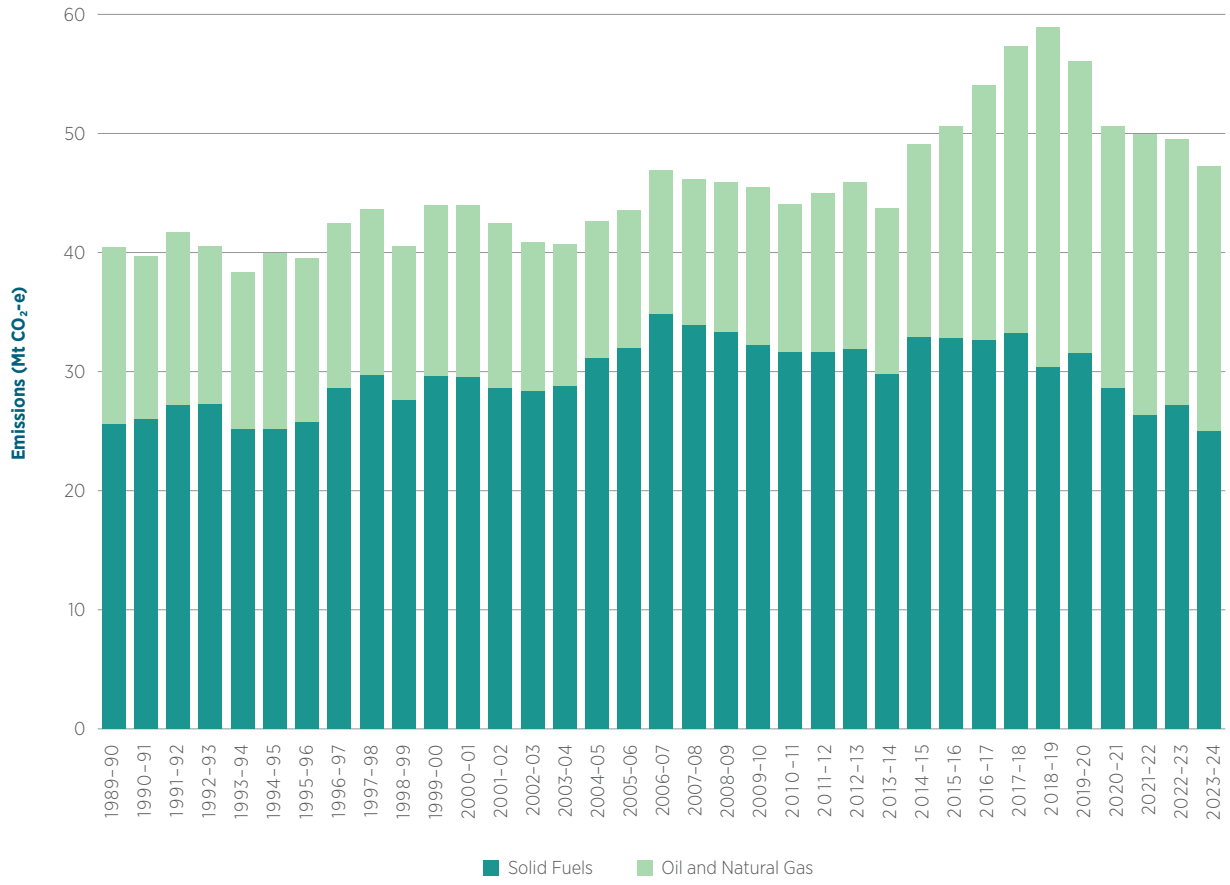
Figure 3.20 Fugitive emissions as a share of total Energy emissions, by gas, 2023–24



Fugitive emissions can be grouped into fugitive emissions from *solid fuels* (1.B.1) and from *oil and natural gas* (1.B.2).

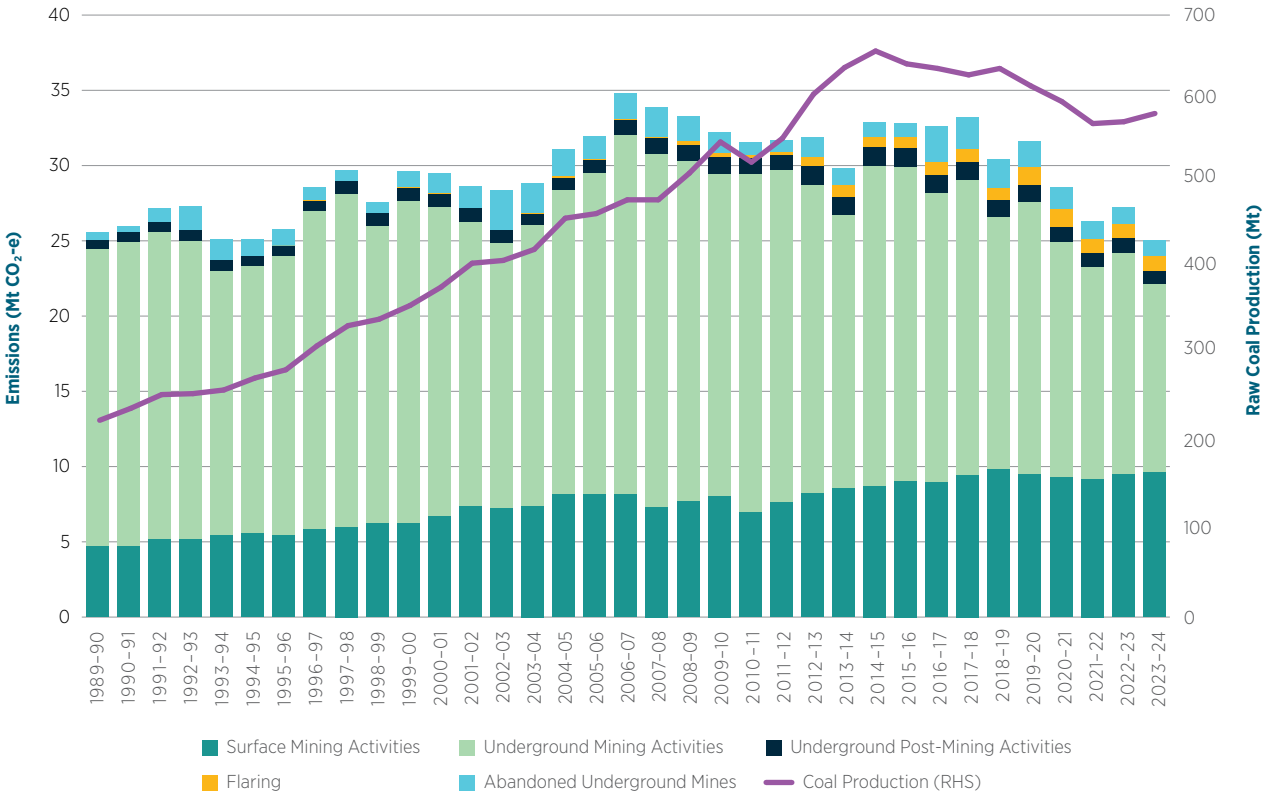
Fugitive emissions have been largely increasing since 1989–90, driven predominantly by increasing coal production. However, activities associated with oil and gas extraction, processing, and distribution are responsible for the most recent growth in fugitive emissions from 2014–15 onwards. This correlates with the expansion of onshore and offshore petroleum projects since the mid-2010s to support increasing liquefied natural gas (LNG) exports (Figure 3.21), with the most significant growth occurring between 2014–15 and 2019–20. Decreases between 2019–20 and 2023–24 were driven by a reduction in production and associated emissions from underground mining (which tends to be gassier than surface mining). In 2023–24, emissions decreased to 47.2 Mt CO_2-e, a 0.95 Mt CO_2-e decrease from 2022–23. Fugitive emissions from oil and gas extraction remained relatively stable, with a minor decrease in 2023–24 in line with a reduction in LNG exports (DISR 2025). Meanwhile, solid fuel emissions decreased primarily due to a reduction in underground mining activities. Emissions from increased surface mining activities partially offset the reduction in underground mining emissions in 2023–24.

Figure 3.21 Fugitive emissions by subsector, 1989–90 to 2023–24



Fugitive emissions from solid fuels 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. Raw coal production increased significantly between 1989–90 and its peak in 2014–15. Methane emissions have reduced in relation to production because of an increasing trend in production in surface mines since 1997–98, which emit less gas than underground mines due to their shallower depth (Figure 3.22). Within underground mines, there has been a decreasing share of production from the gassiest southern coal field since 1990. 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 since 2009.

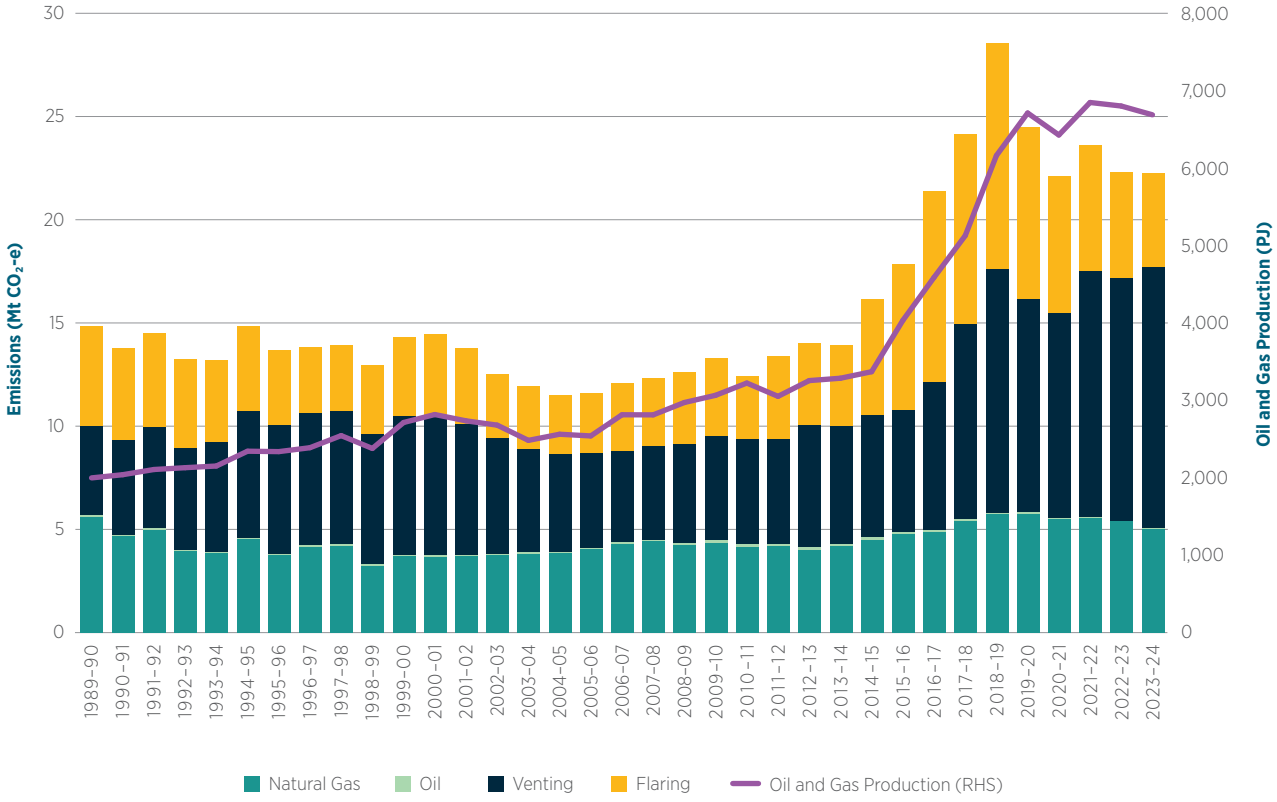
Figure 3.22 Fugitive CO_2-e and coal production from coal mining activities, 1989–90 to 2023–24



Source: Coal production data are from various State government departments (1989–90 to 2007–08) and the NGER scheme (2008–09 to 2023–24).

Until around 2013–14, fugitive emissions from oil and natural gas extraction were relatively stable despite increasing production (Figure 3.23). The reduction in emissions intensity for this sector is driven by improvements in gas distribution and the commencement of large and efficient Liquified Natural Gas (LNG) production, processing, and export facilities. The increase in emissions since 2013–14 is attributable to increased venting and flaring associated with significantly increasing production. Peak venting and flaring occurred in 2018–19, the first year of ramp up of production at several large LNG facilities. Once these facilities reached full production, this resulted in emergency and process venting and flaring falling from their peak. The Gorgon Carbon, Capture and Storage (CCS) project had its first full year of CO_2 injection in 2020–21 (Chevron 2024b), driving a fall in venting emissions compared to 2019–20. Technical issues have resulted in lower injection volumes since 2021–22, which correlated with higher venting emissions in these years (Chevron 2022, 2023, 2024a).

Figure 3.23 Fugitive CO_2-e emissions and production volumes from oil and gas, 1989–90 to 2023–24



Source: Oil and gas production data are from the *Australian Energy Statistics 2025,* (DCCEEW 2025)

3.3.1 Solid fuels

3.3.1.1 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 3.26. Both methane and carbon dioxide emissions are reported under the NGER scheme for both underground and surface coal mines. Carbon dioxide, methane and nitrous oxide emissions are also reported from flaring.

At the end of the 2023–24 reporting year, there were 36 underground mines and 75 surface mines operating nationally, while emissions are estimated for 131 decommissioned mines.

Table 3.26 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	
Decommissioned mines		YES	
Flaring of drained methane	YES	YES	YES
1.B.1.a.ii Surface mines			
Mining	YES	YES	
Post-mining		IE (surface mining)	
Other – flaring of drained methane	YES	YES	YES
1.B.1.b Solid fuel transformation		**IE (IPPU – metals)**	

Fugitive emissions from solid fuels decreased by 8.1 per cent in the 2023–24 reporting year compared with the previous year, while coal production increased by 1.6 per cent.

The flows of fugitive methane and carbon dioxide associated with underground and surface coal mines are shown in Figures 3.24 and 3.25. The underground coal mine model demonstrates the effectiveness of methane capture for electricity generation and flaring in reducing net fugitive emissions – capturing 60 per cent of the gross methane generated from underground coal mining.

Figure 3.24 Fugitive gas balance flow chart for underground mines, 2023–24

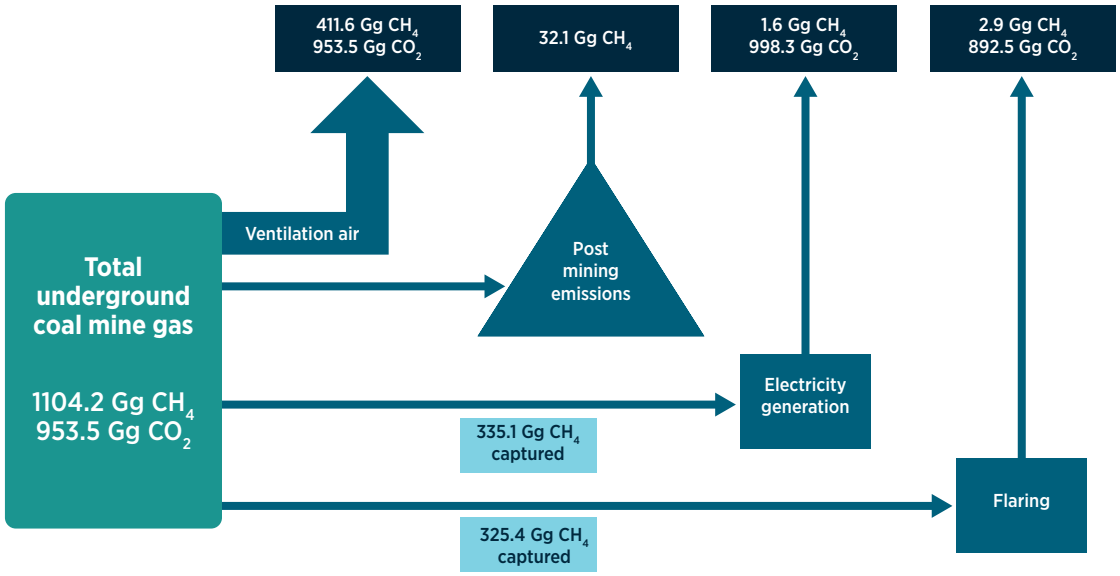
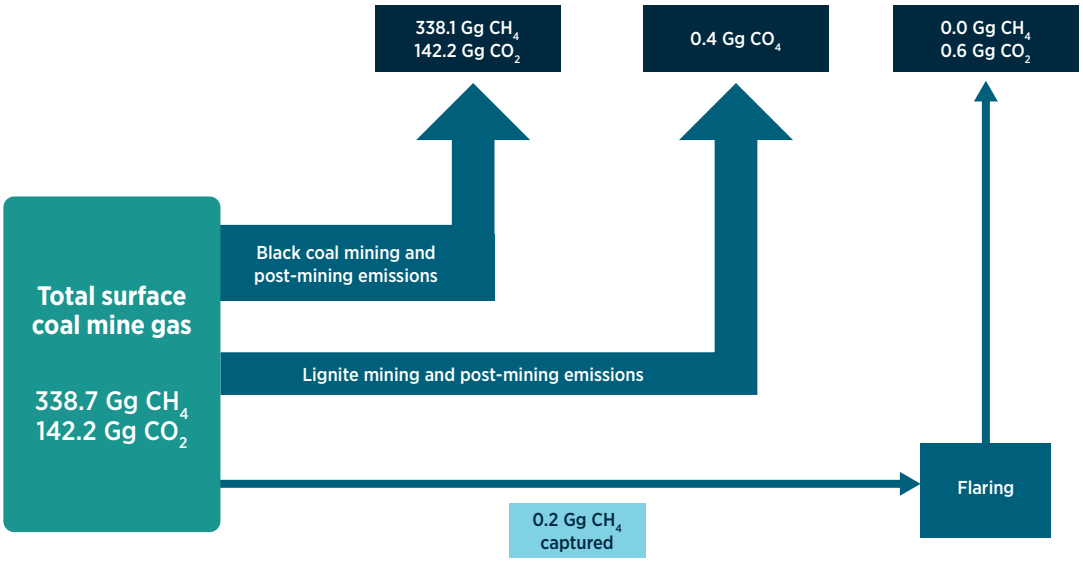


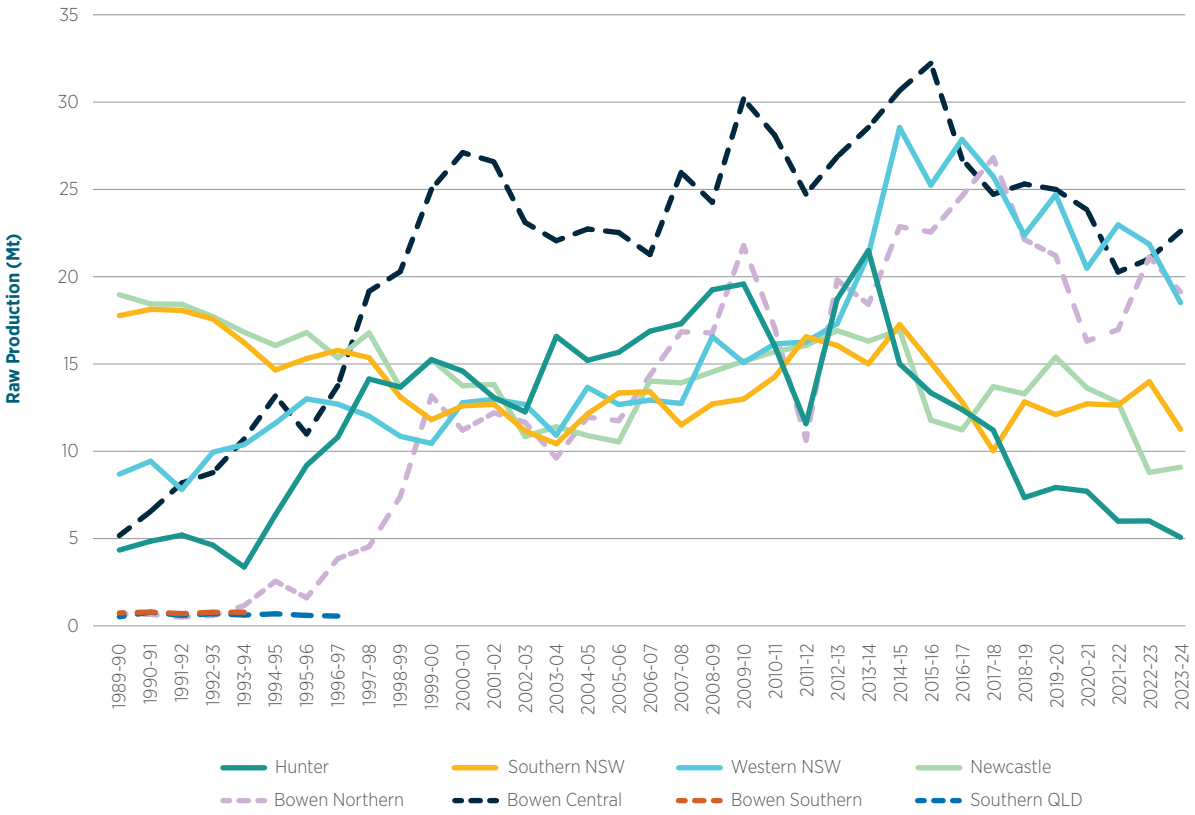
Figure 3.25 Fugitive gas balance flow chart for surface mines, 2023–24



The great majority of Australia's resource and production of black coal is 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 surface operations. A relatively small quantity of sub-bituminous coal is mined in Western Australia. Coal production in South Australia ceased in 2015–16.

In New South Wales, the principal coal fields are located in the Southern, Newcastle, Hunter and the Western New South Wales Basins. In Queensland, the main coal fields are located in the Central Queensland, Northern Bowen Basin, the Central Bowen Basin and the Southern Basin. Since 2009–10, there has been strong growth in underground production from the Western New South Wales basin and declines from the Hunter and Newcastle basins (Figure 3.26).

Figure 3.26 Underground black coal production by coal field since 1989–90



Source: Production data is collected under the NGER scheme.

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 several 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 the thermogenic CH_4 contained in coal layers reaching saturation. As gas is generated during the coalification process, coal can store the gas within its micropore structure. The upper limit of the quantity 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 500–600 m 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 provides 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, 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 Paleogene period introduced CO_2 into the upper, under-saturated Permian coal layers. In more recent times, methanogen-bearing groundwater flowing through the surface fracture system has 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 resulting from these processes has been described (Thomson 2010) and is shown in Table 3.27. 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.

Table 3.27 Generalised model of gas variation in the subsurface for east coast Australia

Zone 1	A surface zone extending to a depth of about 150m, which contains negligible gas. The gas that is present is often CO_2.
Zone 2	The "Biogenic Window", containing shallow methane and extending from a depth of approximately 150m to about 250–350m. The gas content of this zone increases with depth.
Zone 3	A "Mixed Gas Zone", below Zone 2 and extending to a depth of approximately 600–700m. The gases in this zone are both methane and CO_2, but mostly CO_2.
Zone 4	The "Thermogenic Zone" of high methane below Zone 3.

Source: Thomson (2010)

Coal mining on the west coast of Australia is confined to 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. An 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 scheme reporting and is incorporated in this inventory. The data confirms that the Collie Basin coal deposits are characterised by very low gas.

3.3.1.2 Methodological issues

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 the NGER scheme. For the current reporting year, data on measured CH_4 and CO_2 emissions is available for all 36 underground mines. Time series consistency has been maintained for the underground mine emissions estimates with the use of NGER scheme data (see section 3.3.1.3).

For most 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. The remaining decommissioned mines use a plant-specific Tier 3 approach. Flaring uses a Tier 2 approach and a mixture of country-specific and plant-specific CO_2 EF.

Fugitive emissions from surface mining are estimated using state-specific default CH_4 EFs, as well as incorporating facility-specific NGER scheme data for CH_4 and CO_2 emissions, where available and appropriate.

Table 3.28 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
1.B.1.a Coal mining and handling						
I Underground mining						
1 Mining activities	T3	PS	T3	PS	NA	NA
2 Post-mining activities	NA	NA	T2	CS	NA	NA
3 Abandoned underground mines	NA	NA	T2, T3	CS, PS	NA	NA
4 Flaring of drained methane	T2	CS, PS	T2	CS	T2	CS
II Surface mining						
1 Mining activities	NE, T3	NA, PS, M	T2, T3	CS, PS, M	NA	NA
2 Post-mining activities	NE	NA	IE	NA	NA	NA
3 Other – flaring of drained methane	T2	CS, PS	T2	CS	T2	CS
1.B.1.b Fuel transformation	**NO/IE**	**NA**	**NO/IE**	**NA**	**NO**	**NA**

Notes: T1 = Tier 1, T2 = Tier 2, T3 = Tier 3, CS = country specific, PS = plant specific, M = model, NO= not occurring, NA = not applicable, IE = included elsewhere, ▪ = key category

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:

- Australia – Department of Industry, Science and Resources (DISR 2025),
- New South Wales – Coal Services Pty Ltd (2025) (formerly the Joint Coal Board) and NGER scheme data,
- Queensland – Department of Resources (2025) and NGER scheme data,
- Western Australia – Department of Mines, Industry Regulation and Safety (DMIRS 2025) and NGER scheme data, and
- Victoria – Various State government departments and NGER scheme data.

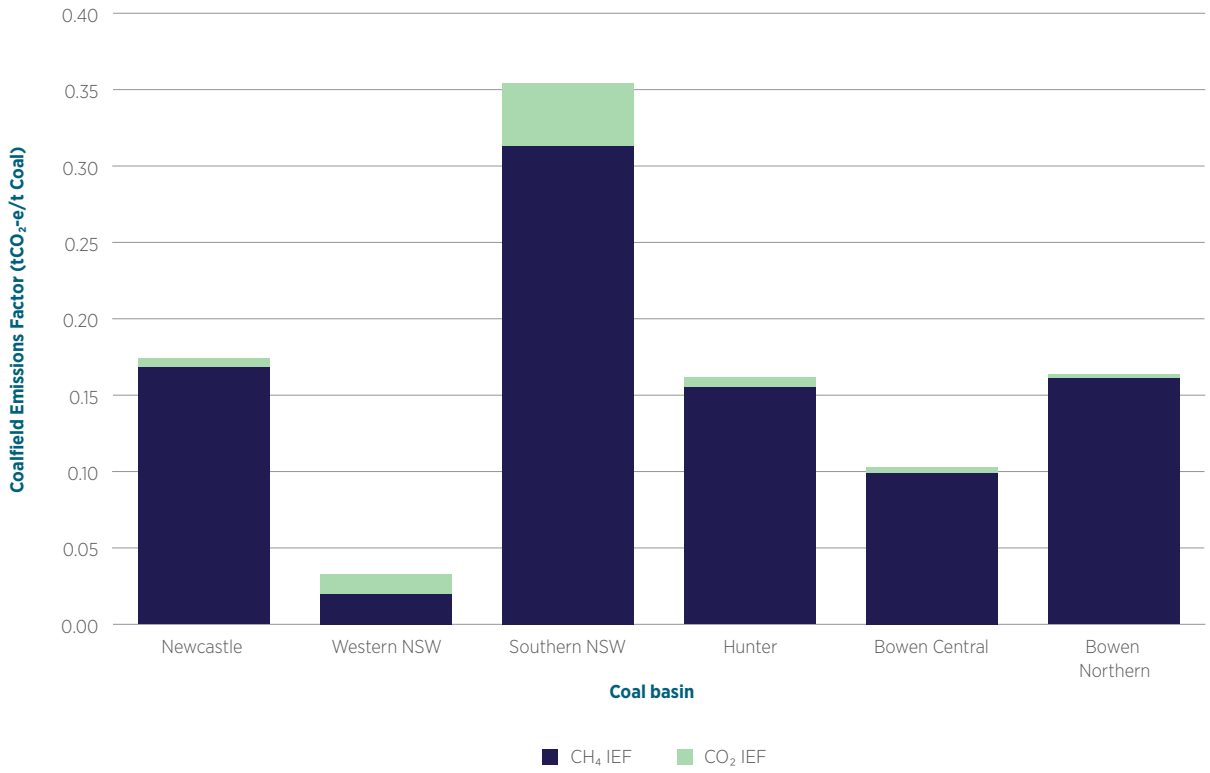
Mining activities – underground mines (1.B.1.a.i.1)

Emissions derived from direct measurement account for all emissions from operating underground mines reported in the inventory. Emissions are estimated using methods set out in 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 *Work Health and Safety (Mines and Petroleum Sites) Act 2013 No 54 (NSW), Work Health and Safety (Mines and Petroleum Sites) Regulation 2022 (NSW), Coal Mining Safety and Health Act 1999 (Qld)* and the *Coal Mining Safety and Health Regulation 2017 (Qld),* which establish mandatory monitoring regulations for mines. The Determination refers to these existing state regulatory processes.

Coal companies reporting measured CH_4 from underground mines under the NGER scheme are also required to measure and report CO_2 emissions. This is significant as, prior to NGER scheme reporting, there was little data available on fugitive CO_2 emissions from Australian coal mining.

The NGER scheme emission data for underground mine emissions has shown that the gas type and content of different coal fields vary significantly. This is evident in Figure 3.27, 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.

Figure 3.27 The gas content profile of Australian underground production by coal field, 2023–24



Choice of emission factor

Estimates based on direct measurements were reported for all operating underground mines under the NGER scheme. Emissions for underground coal mines, which were closed prior to the introduction of the NGER scheme, 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 Figure 1.3 of Chapter 1.3. In applying the decision tree, it was decided that the NGER scheme 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. Information on how time series consistency has been maintained with the inclusion of NGER scheme data for underground mines is given in Chapter 3.3.I.3.

Post-mining activities – underground mines (1.B.1.a.i.2)

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, 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.

$$E_{pm} = QTY_a \times EF_{pm} \times C_{pm} \quad (3.8)$$

The emission factor, EF_{pm}, is the average of the results of the two empirical studies. It was found that the amount of gas retained was quite variable, but an average gas EF of 1.7 m^3/t raw coal was adopted, of which 75 per cent was CH_4 and 25 per cent CO_2 (Williams et al. 1993). The estimated methane factor, equal to 19 per cent of the *in situ* CH_4 content of coal (6.78 m^3/t 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.

Abandoned underground mines (1.B.1.a.i.3)

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* (IPCC 2006). 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 and some mine-specific data is included for facilities that report under the NGER scheme. 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.

As part of the NGER scheme, facilities must report the specific date that the mine closed and the emissions in the last twelve months of operation. They may also report the proportion of the mine that is flooded estimated using mine-specific data.

The EDC methodology used for estimating CH_4 emissions from decommissioned mines can be described as:

$$E_{dm} = (E_{tdm} \times EF_{dm} \times (1 - F_{dm})) - E_{rec} \quad (3.9)$$

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 3.10 and 3.11). The EF is dimensionless

F_{dm} is the fraction of mine flooded at a point in time since decommissioning

E_{rec} is the quantity of methane emissions avoided by recovery

Emission Decay Curves (EDCs)

An EDC describes the decline in fugitive CH_4 emissions over time following mine closure. Hyperbolic curves have been found to function best in portraying the rapid decline in emissions in the 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, Armstrong, Lunarzewski and Creedy 2006). The EDCs are shown in Figure 3.28, and are described in the following formulae:

Gassy mines

$$EF_{dm} = (1 + A \times T)^b - C \quad (3.10)$$

Non-gassy mines

$$EF_{dm} = (1 + A \times T)^b - C \quad (3.11)$$

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

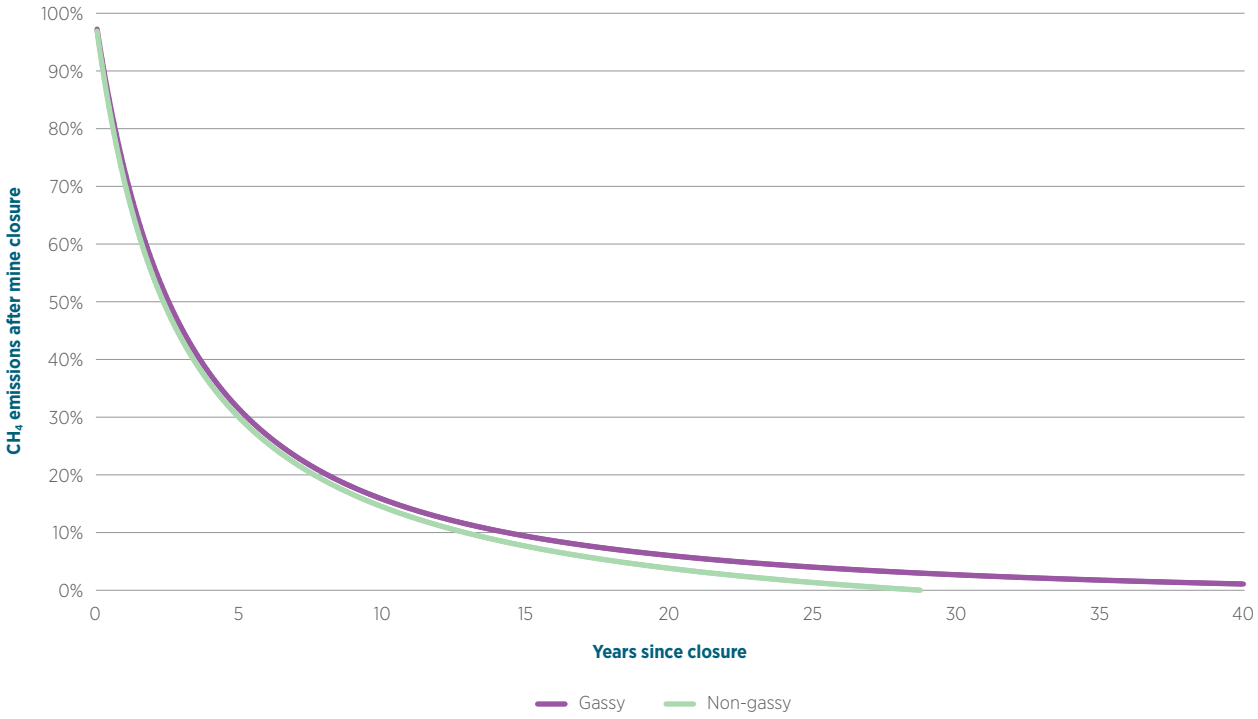
A, b and C are coefficients unique to the decline curves (see Table 3.29)

Table 3.29 Coefficients used in Australian emission decay curves from decommissioned mines

	Coefficients		
Mine category	**A**	**B**	**C**
Gassy Mines	0.23	-1.45	0.0242
Non-Gassy mines	0.35	-1.01	0.0881

Source: Lunarzewski (2006)

Figure 3.28 CH_4 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:

- NGER scheme for all mines from 2008–09;
- Coal Services Pty Ltd, for New South Wales mines from 1971–72; and
- Department of Resources for Queensland mines from 1978–79.

In all datasets, details were obtained for mine type (underground/surface), annual run-of-mine production, and time of closure. Only underground mines were included in the study. Surface 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* (IPCC 2006).

Emissions at Closure

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. The methodology uses either the mine's reported emissions for the last twelve months of operation or, for older mines (i.e. decommissioned prior to NGER reporting), uses the greatest value of emissions in either of the last two years of operation. The latter approach ensures that the inventory does not underestimate the abandoned mine emissions due to closure part way through the reporting year.

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 3.10 and 3.11) 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 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. However, if a NGER mine reports the proportion of the mine flooded, this value is used instead of the basin defaults described below.

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 provide good coverage of groundwater 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).

Flaring of drained methane (1.B.1.a.i.4)

Data for 2008–09 to the current reporting period on the recovery and flaring of CH_4 from coal mines is available from mines reporting under the NGER scheme. 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 2006), which provided flared gas quantities by mine for 2004–05.

For those respective mines, the 2004–05 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 was also considered in producing the time series.

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 the NGER scheme data where available. A flaring efficiency factor of 98 per cent is used, consistent with the 2006 *IPCC Guidelines* (IPCC 2006).

Surface mining (1.B.1.a.ii)

A mix of Tier 3 and country-specific Tier 2 methods are used to estimate fugitive CH_4 and CO_2 emissions across Australia's regional coal basins. Emissions associated with post-mining activities are included in the estimation of mining activities, or in public electricity generation when the mine is directly attached to a power plant.

Table 3.30 Summary of methods and emission factors: 1.B.1 Solid Fuels: Surface mining

	CO_2		CH_4	
Coal field	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
Bowen (Qld)	NA	NA	T2	CS
Surat (Qld)	T3	PS, M	T2, T3	CS, PS, M
Hunter (NSW)	T3	PS, M	T2, T3	CS, PS, M
Newcastle (NSW)	T3	PS, M	T2, T3	CS, PS, M
Western (NSW)	T3	PS, M	T2, T3	CS, PS, M
La Trobe (Vic)	NA	NA	T2	CS
South Australia	NA	NA	T2	CS
Collie (WA)	T3	PS, M	T3	PS, M
Tasmania	T3	PS, M	T2, T3	CS, PS, M

Notes: T2 = Tier 2, T3 = Tier 3, CS = country-specific, PS = plant-specific, M = model, NA = not applicable

Higher tier, facility-specific, NGER scheme Method

Australia has invested in a comprehensive program of measurement technique research and development since 2006–07 to underpin emissions estimation processes under the NGER scheme. An important outcome of the program has been the development of guidelines for the application of the existing NGER scheme mine-specific (Method 2/3) approach to estimating emissions from surface mines. A detailed summary of this methodology is provided in Annex 5.3.4.

Black coal mine production

A study of methane flux measurements from surface coal mines in New South Wales (Williams et al. 1993) and a database of *in situ* measurements from Queensland gas seams (Department of Resources – Queensland 2021) 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 surface black coal mining, as shown in Table 3.31.

Brown coal (lignite) mine production

Surface mining of brown coal (lignite) occurs in Victoria for combustion in electricity generation. A CH_4 EF for Victorian brown coal mining of 0.0162 m^3 per tonne of raw coal mined is applied. The EF 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 CH_4 EF from surface 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[d] kg/m^3
NSW	3.2[a]	0.6767
Bowen (Qld)	1.65[b]	0.6767
Tasmania	1.0[c]	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: Derived from Queensland Petroleum Exploration Data (2021).

(c) Source: D Cain, Australian Coal Association, pers. comm. (1993).

(d) These factors are derived by treating CH_4 as an ideal gas, i.e. 16.043 g (1 mole) occupies 23.645 dm^3 at 15°C and 1 atmosphere.

(e) Source: HRL (2013).

3.3.1.3 Uncertainty assessment and time-series consistency

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

Underground Mines

NGER scheme data is used for inventory years since 2008–09. To ensure time series consistency in the transition from industry surveys and company reports to NGER scheme data for underground coal mines, the surrogate method from the 2006 IPCC Guidelines, involving the use of coal production data and an EF derived from actual mine measurements, was chosen as the most appropriate splicing technique (IPCC 2006).This choice was made because run-of-mine coal production data is available for individual mines for all years and is an underlying activity data parameter that best explains emission trends.

Interpolation was considered as a complementary approach where emissions data are available from non-NGER scheme sources for a previous year, and which could be used to provide an EF per unit of coal production for earlier years. Interpolated estimates were compared with surrogate data as a QA/QC check.

For years before NGER scheme data became available, data on emissions for certain underground mines were available from estimates published within company environmental reports or from industry reports to the Australian Greenhouse Office (AGO 2006). 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 1989–90 to the year when data on emissions first becomes available. For the years between the latest company report and the year of the NGER scheme 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 scheme data for the year 2008–09.

A small number of underground mines closed in the period 1989–90 to 2004–05 for which there are no mine-specific measured data available. Emissions for each year were recalculated using a basin-specific factor, calculated from the NGER scheme data for 2008–09 and multiplied by production.

A summary of the data used throughout the time series for estimating CH_4 and CO_2 emissions from underground mines is provided in Table 3.32 and Table 3.33.

Table 3.32 Time series consistency method for determining underground coal mine emission factors – CH_4

Methane	1989–90 to 2003–04	2004–05 Industry survey	2005–06 to 2007–08	2008–09 to 2022–23 NGER	2023–24 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 scheme data) used for mines for which NGER scheme data was not available	EFs held constant	Actual data	Interpolated EFs	Actual data	NGER scheme data back cast only until an actual emissions data year is available using interpolation to fill intervening years.

Table 3.33 Time series consistency method for determining underground coal mine emission factors – CO_2

Carbon dioxide	1989–90 to 2007–08	2008–09 to 2022–23 NGER	2023–24 NGER
Basin specific factors (based on NGER scheme data) used for mines for which NGER scheme 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 scheme data.

Surface mines

NGER scheme data are used for inventory years since 2008–09. The transition to NGER scheme data for surface coal mines in this inventory submission is undertaken in a manner that maintains time series consistency. A set of rules has been applied that considers the new understanding of gas content gained from NGER scheme data and maintains the relevance of the original 1993 study (Williams et al. 1993) for mines and basins where measurements were previously undertaken.

Where the NGER scheme data are an improvement on the country-specific Tier 2 EF because coal fields are outside the area of the original study (Gunnedah, Western, Surat coal fields), then the earliest NGER scheme facility-specific EF has been applied through the entire time series. Where the new data improves on the old EF because comprehensive NGER scheme measurement provides updated and improved data of the original study area measured in 1993 (Hunter and Newcastle) then, for CH_4, the earliest NGER scheme facility-specific EF back through the time series is applied by interpolating back until the year of the original study (1993) or, if mine was not part of the original study, then the NGER scheme derived factor is applied to the entire time series.

For CO_2, where no measurements previously exist, then the earliest NGER scheme facility-specific EF is applied to the entire time series.

3.3.1.4 Category-specific QA/QC and verification

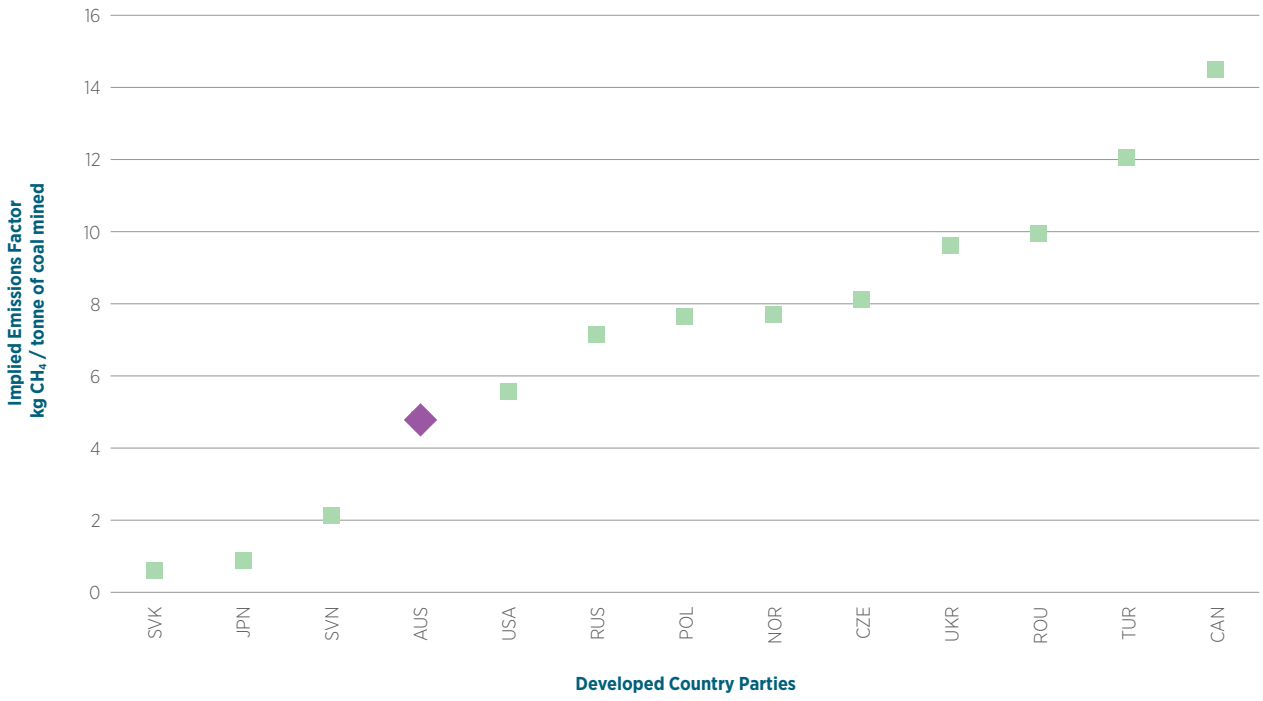
This source category is covered by the general QA/QC of the greenhouse gas inventory in Chapter 1.

Implied emission factors

International comparability

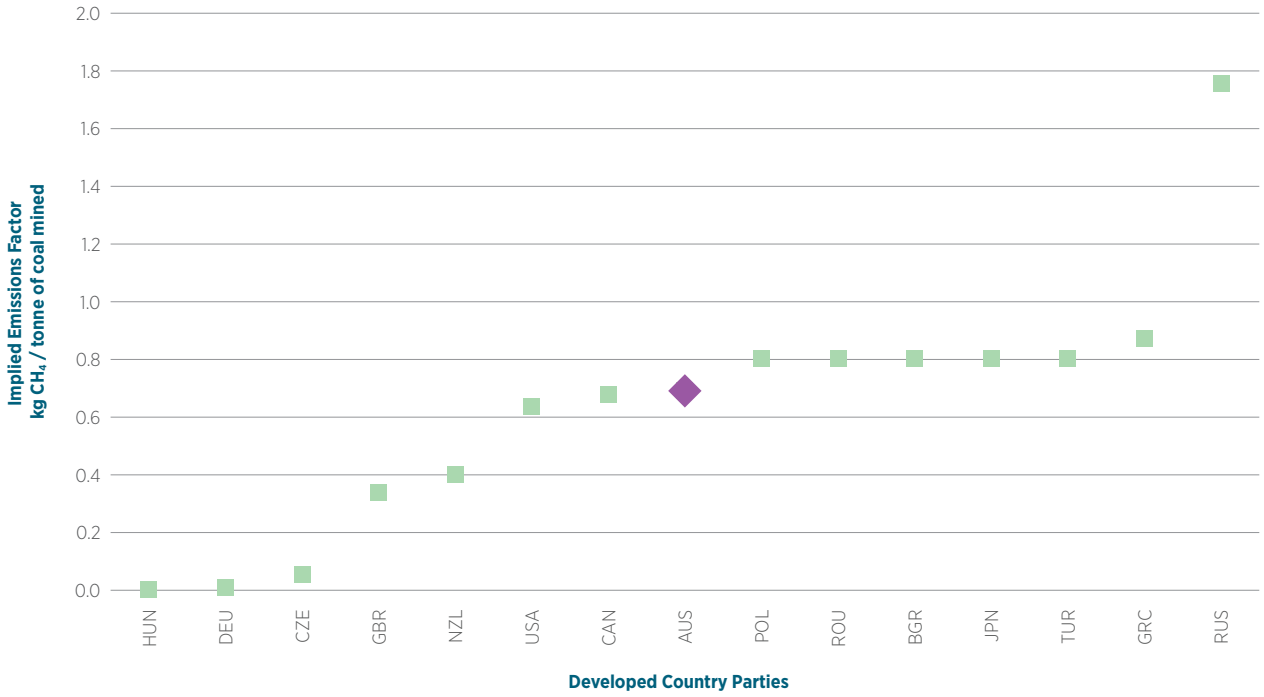
Analysis of CH_4 IEFs for Australian coal mines to compare statistically with the IEFs reported by other countries is undertaken in accordance with the Quality Assurance-Quality Control Plan. The IEFs presented in Figures 3.29 to 3.31 were calculated based on data reported to the UNFCCC by other developed country Parties, in particular activity data and emissions reported under IPCC categories 1.B.1.a.i.1 (for underground mines) and 1.B.1.a.ii.1 (for surface mines). For most Parties, data from GHG inventories submitted in 2025 are used. For the USA, the data is sourced from their latest submission in 2024. For Australia, the IEFs for the current submission are presented.

Figure 3.29 Underground coal mining implied emission factors for developed country Parties (latest submission) and Australia (2026 submission), kg CH_4 per tonne of coal mined



Source: IEFs are based on data as reported to the United Nations Framework Convention on Climate Change for the latest available submission for each Party (2025 for all Parties except USA). Parties above are Slovakia (SVK), Slovenia (SVN), Japan (JPN), Australia (AUS), United States of America (USA), Russia (RUS), Poland (POL), Norway (NOR), Czechia (CZE), Ukraine (UKR), Romania (ROU), Türkiye (TUR), and Canada (CAN). Please note that an outlier has been excluded from the graph (Great Britain, 97.1).

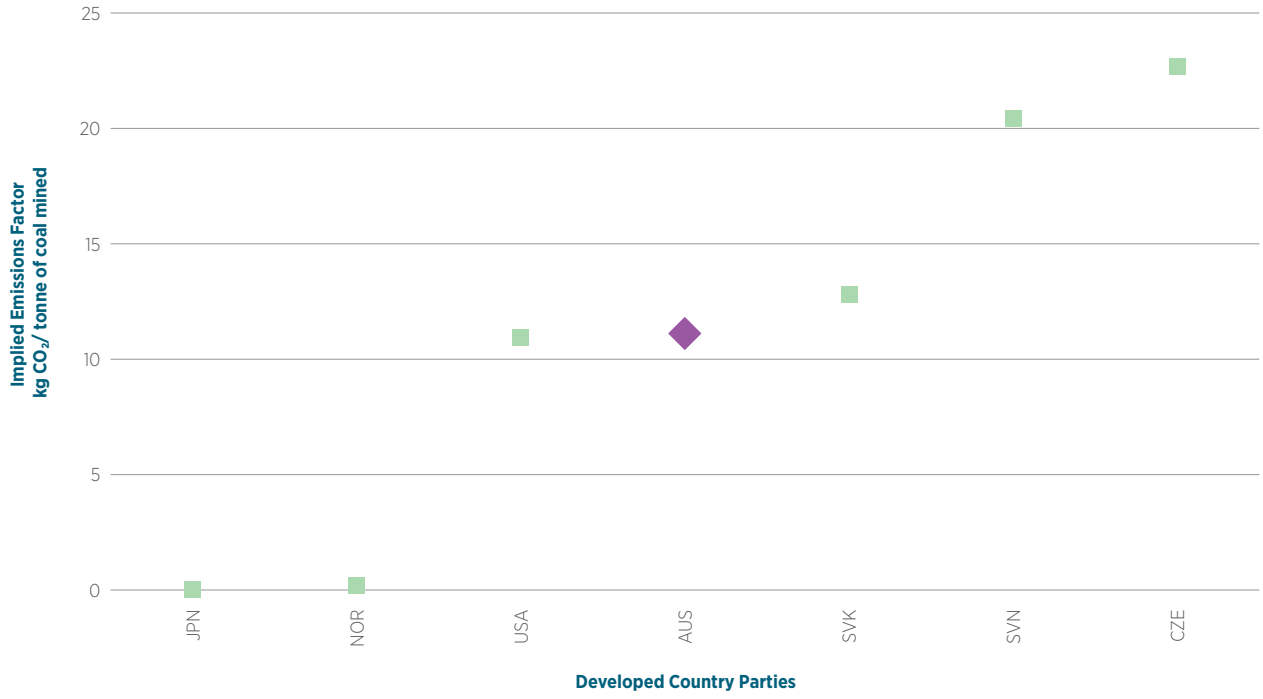
Figure 3.30 Surface coal mining implied emission factors for developed country Parties (latest submission) and Australia (2026 submission), kg CH_4 per tonne of coal mined



Source: IEFs are based on data as reported to the United Nations Framework Convention on Climate Change for the latest available submission for each Party (2025 for all Parties except USA). Parties above are Hungary (HUN), Germany (DEU), Czechia (CZE), Great Britain (GBR), New Zealand (NZL), United States of America (USA), Canada (CAN), Australia (AUS), Poland (POL), Romania (ROU), Bulgaria (BGR), Japan (JPN), Türkiye (TUR), Greece (GRC) and Russia (RUS).

Australia's current-year IEF for methane from underground mines was 4.8 kg CH_4/t compared with 7.7 kg CH_4/t (n =13) for the previously-published median of developed country Parties, and 7.2 kg CH_4/t (n =13) for the previously-published mean of all developed country Parties. Australia's current-year IEF for CH_4 from surface mining was 0.69 kg CH_4/t compared with 0.74 kg CH_4/t (n = 14) for the previously-published median and 0.63 kg CH_4/t (n=14) for the previously-published mean of developed country Parties. In the case of underground mining, Australia's IEF is the fourth-lowest of reporting parties, which reflects the high rate of gas recovery activities which capture around half the original coal CH_4 for electricity generation and flaring (see Figure 3.24).

Figure 3.31 Underground coal mining implied emission factors for developed country Parties (latest submission) and Australia (2026 submission), t CO_2 per tonne of coal mined



Source: IEFs are based on data as reported to the United Nations Framework Convention on Climate Change for the latest available submission for each Party (2025 for all Parties except USA). Parties above are Japan (JPN), Norway (NOR), United States of America (USA), Australia (AUS), Slovakia (SVK), Slovenia (SVN), and Czechia (CZE).

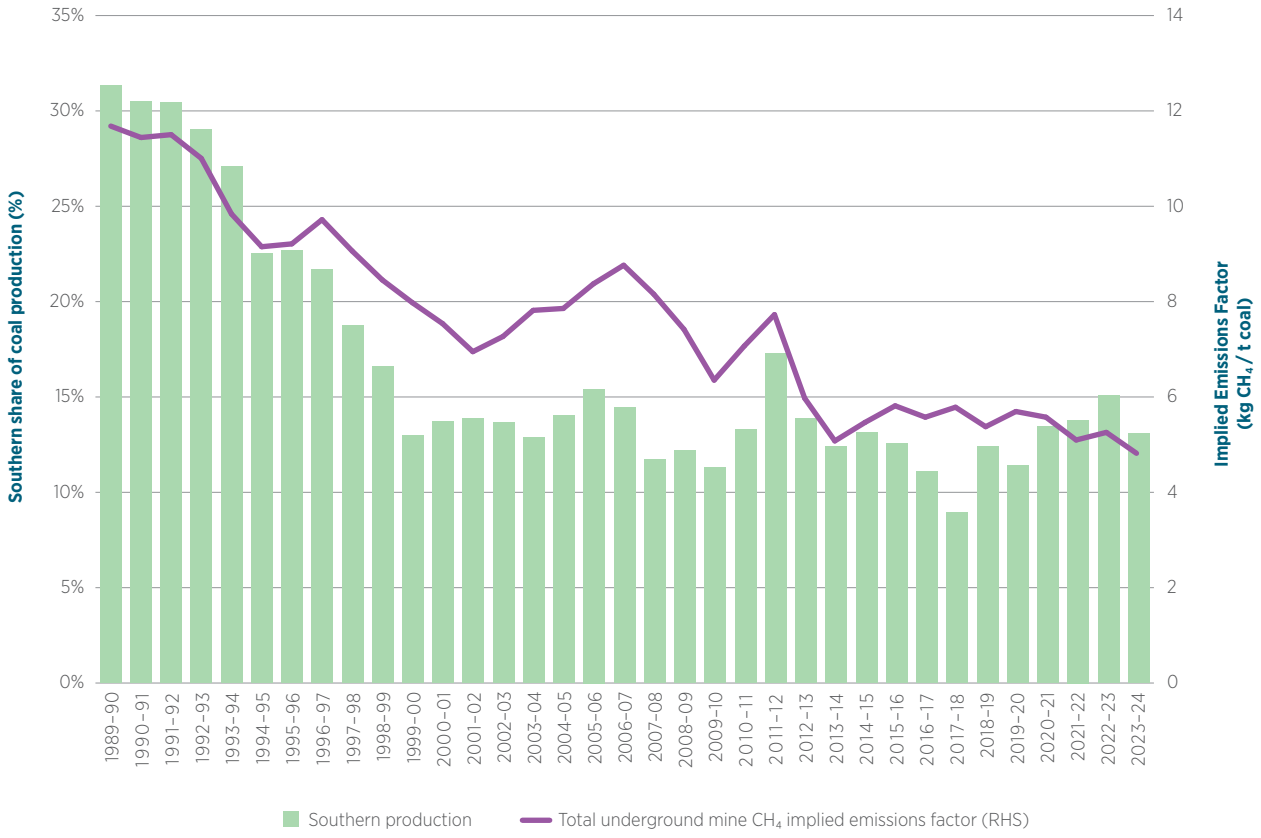
For CO_2 emissions from underground mining, IEFs are variable from country to country. However, Australia sits within the range of non-outlier reporting parties, with an IEF of 11.1 kg CO_2 per tonne of coal mined, which is comparable to the value based on the USA GHG inventory reported in 2024 (10.9 kg/t).

Time series consistency – trends in implied emission factors

Estimates are tested for time-series consistency in accordance with the QA/QC 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 CH_4 recovered. This is evident in a declining trend of the CH_4 IEF for underground mines, which reflects a relative increase in production from less gassy mine regions compared to production from high gas coalfields. The trends in fugitive emissions and emissions intensities from coal production remain driven by emissions from gassy underground mines, many of which have taken actions to flare or capture and use this waste coal mine gas in power stations. Emissions intensities of underground mining can also be impacted by the particular coalbed being mined. For example, the Southern Coal field in NSW has the highest IEF of all Australian coalfields, and higher or lower mining activity in this field has a noticeable impact on trends.

Figure 3.32 details the declining trend of the underground coal mine IEF since 1989–90 and the corresponding fall in production from the New South Wales Southern Coalfield. In more recent years, the increasing use of flaring to combust CH_4 that otherwise would have been vented has acted to reduce the IEF for underground mines in total.

Figure 3.32 Decline of the overall underground coal mine methane implied emission factor compared with the fall in production from the high gas content Southern Coalfield



Source: Production data are sourced from the NGER scheme (CER 2024)

Black coal production in NSW, the second largest coal-producing state in Australia, saw a 9 per cent increase in surface production and a 13 per cent decrease in underground mine production, between the current and previous reporting years. The gassiest coal seam in the southern gas fields saw a 20 per cent decrease in production over this period. NSW has had a 15.6 per cent increase in emissions from surface mining, a 12.2 per cent decrease in underground mining emissions, and a 3.7 per cent increase in emissions from flaring between the current and previous reporting years.

The IEF for all coal mining activities has also declined since 1989–90 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. While emissions peaked in 2007, production peaked in 2015, with the increase in production offset by a change in extraction method. Since peak emissions in 2007, underground coal production has declined by 7.5 per cent, while surface production has grown by 26.0 per cent.

Measurement audits

The NGER scheme 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.

1. The NGER scheme legislation sets out minimum qualifications of the estimator of surface mine emissions using the NGER scheme higher tier method. The Estimator is a person, or team of persons, meeting the minimum qualifications described below, who estimates the fugitive emissions from a surface 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).
2. During the operation of the carbon pricing mechanism (2011–12 to 2014–15), companies that had annual emissions exceeding 125,000 Gg CO_2-e were required to undertake a pre-submission audit report to provide assurance over their NGER scheme 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.
3. The Clean Energy Regulator is empowered under the *National Greenhouse and Energy Reporting Act 2007* to investigate any emission estimates at any time and has a program to undertake a risk-based audit process to provide assurance of the quality of data reported under the NGER scheme.

Use of NGER scheme facility level data in the national inventory

The use of NGER scheme data addresses comments made in previous ERT reports which have both recommended and encouraged Australia to incorporate NGER scheme data for surface mines.

Nonetheless, the application of NGER scheme facility data must be undertaken with care to ensure that issues of selection bias are controlled. 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 (IPCC 2006), and as described in Chapter 1.3.

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 EFs for coal basins in Queensland (other than the Surat Basin). Factors such as cost could deter the measurement of emissions by some companies. 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 for Queensland coal basins other than the Surat Basin, this small risk has been mitigated through the country-specific value – recently updated to 1.65 CH_4 m^3/t raw coal mined – which is within the range of IPCC default values available.

3.3.1.5 Category-specific recalculations

Recalculations are shown in Table 3.34.

A. Decommissioned mines method update

The inventory method for decommissioned mines has been updated to bring it in line with the current NGER Determination Method 1. Under this method, facilities must report the date the mine was closed and the emissions in the last twelve months of operation, and may report the proportion of the mine that is flooded using facility-specific measurement. These three pieces of data have now been incorporated into the inventory method (see section 3.3.1.2 – Abandoned mines). This update resulted in changes to emissions estimates across the time series.

B. Revisions to underground mines

These recalculations are due to corrections to activity and emissions data in 2020–21 to 2022–23.

Table 3.34 1.B.1 Solid Fuels: recalculation of total CO_2-e (Gg), 1989–90 to 2022–23

	2025 submission	2026 submission	Change		Reasons for recalculations (Gg CO_2-e)	
	(Gg CO_2-e)		(Gg CO_2-e)	(per cent)	A	B
1989–90	25,578	25,578	0.0	0.0	-	-
1994–95	25,111	25,130	18.6	0.1	18.6	-
1999–00	29,613	29,638	25.1	0.1	25.1	-
2004–05	31,210	31,079	-131.2	-0.4	-131.2	-
2005–06	32,015	31,961	-54.9	-0.2	-54.9	-
2006–07	34,684	34,818	133.8	0.4	133.8	-
2007–08	33,739	33,844	105.3	0.3	105.3	-
2008–09	33,207	33,292	85.9	0.3	85.9	-
2009–10	32,147	32,219	72.0	0.2	72.0	-
2010–11	31,516	31,578	61.6	0.2	61.6	-
2011–12	31,579	31,633	53.6	0.2	53.6	-
2012–13	31,922	31,901	-20.9	-0.1	-20.9	-
2013–14	29,814	29,812	-2.4	0.0	-2.4	-
2014–15	32,888	32,891	3.0	0.0	3.0	-
2015–16	32,724	32,796	72.5	0.2	72.5	-
2016–17	32,443	32,636	193.0	0.6	193.0	-
2017–18	33,337	33,208	-128.3	-0.4	-128.3	-
2018–19	30,272	30,379	107.2	0.4	107.2	-
2019–20	31,334	31,575	240.6	0.8	240.6	-
2020–21	28,165	28,567	401.7	1.4	279.5	122.2
2021–22	26,083	26,312	228.2	0.9	229.4	-1.2
2022–23	26,827	27,204	377.2	1.4	284.9	92.3

3.3.1.6 Category-specific planned improvements

Uptake of the NGER scheme higher tier method for surface mines is expected to continue over future years resulting in an increase in mine-specific emission data available for compiling emissions for the inventory.

Under the NGER scheme, Method 1 for surface mines is being phased out in tranches from 1 July 2025 for facilities covered by Australia's Safeguard Mechanism, with these mines required to use higher tier methods.

The department is also reviewing NGER Method 2 for surface mines to ensure the method remains fit for purpose and based on the best available science, technologies and practices.

New approaches to estimating fugitive methane emissions by combining atmospheric detection of CH_4 with modelling and other analysis (top-down approaches) are rapidly developing. The Australian government has established an Expert Panel to provide evidence-based advice to government on:

- the current scientific understanding of top-down approaches, and their application and availability in Australia;
- the role top-down approaches could play in the NGER scheme, and the national inventory more broadly; and,
- the improvements in scientific understanding, technology, and Australian capability that are needed to enable optimal use of top-down approaches into the future in the NGER scheme and/or the national inventory more broadly.

The Panel's advice to government will be considered in future national inventory method development as part of the inventory's continuous improvement processes.

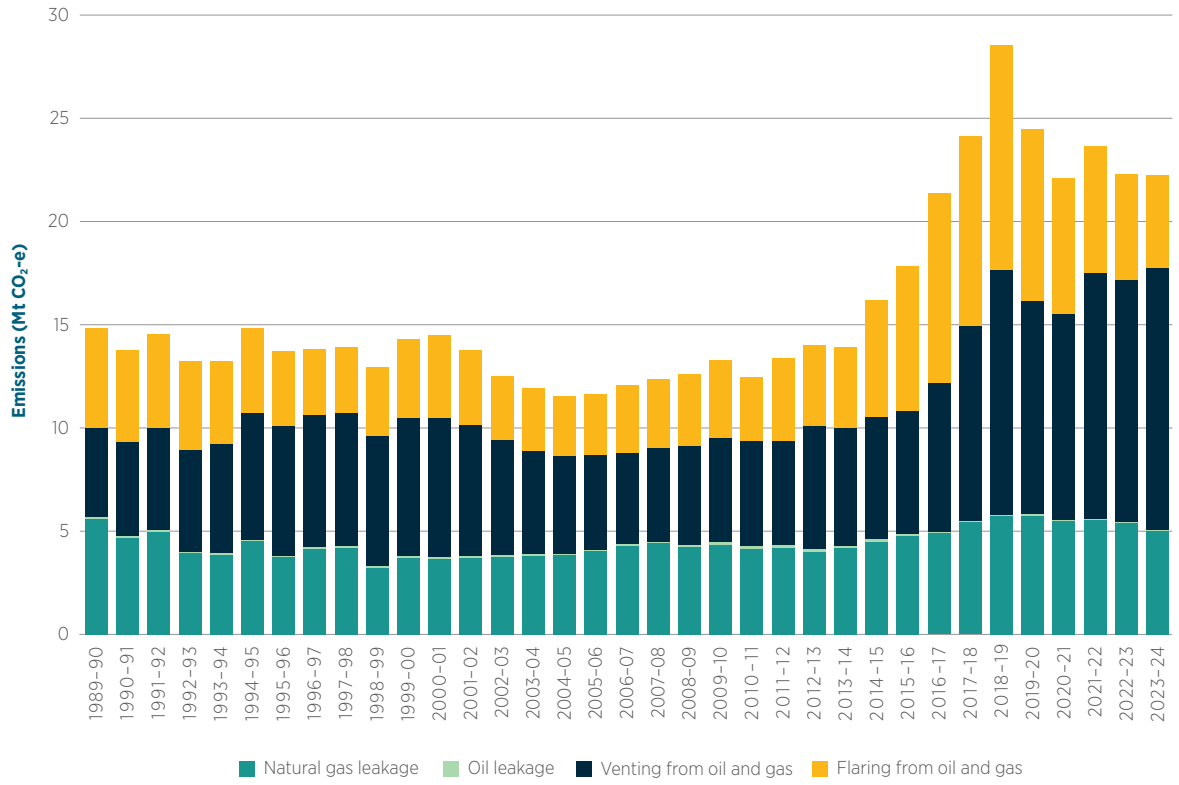
3.3.2 Oil, Natural Gas and other emissions from energy production (CRT category 1.B.2)

3.3.2.1 Category description

Leakage, venting, and flaring associated with oil and natural gas extraction are categorised as fugitive emissions. Fugitive emissions may be unintentional or controlled, and the quantity and composition of emissions is generally subject to significant uncertainty. Oil and natural gas systems include all infrastructure required to produce, collect, process, refine, and deliver natural gas and petroleum products to market. The system begins at the wellhead or oil and gas source and ends at the final sales point to the consumer.

Australia is a leading exporter of liquefied natural gas (LNG) and a minor producer of crude oil. Most emissions from this category come from the natural gas industry (Figure 3.33).

Figure 3.33 Fugitive emissions from oil and gas, 1989–90 to 2023–24



Note that the following related emissions sources are included elsewhere, as per the 2006 IPCC Guidelines (IPCC 2006): *fuel combustion for production of useful heat or energy* (CRT category 1.A), *fugitive emissions from carbon capture and storage projects* (CRT category 1.C), *fugitive emissions associated with facilities from other industries* (CRT category 2), and *fugitive emissions from waste disposal outside of the oil and gas industry* (CRT category 5).

Oil and gas fugitive emissions have trended strongly upwards since 2012–13, corresponding to the rapid growth of LNG production. Fugitive emissions in this category are dominated by venting and flaring of gas and liquids. Peak venting and flaring occurred in 2018–19, the first year of start-up at several large LNG facilities. The start-up phase of LNG facilities involves a range of production and equipment tests as various components are brought online – resulting in relatively low production compared with higher levels of venting and flaring. Once these facilities transitioned from their start-up phase to become fully operational in 2019–20, there was a corresponding reduction in venting and flaring. In the same year, 2019–20, an LNG facility on Barrow Island, WA (Gorgon LNG Plant) began its carbon capture and storage (CCS) program, leading to a reduction in venting and flaring at the facility (Chevron 2024b). Their CCS program experienced issues in 2021–22 which continued across 2022–23 and into 2023–24, resulting in decreases in captured carbon dioxide between 2021–22 and 2023–24 (Chevron 2022, 2023, 2024a). In 2023–24, emissions have slightly decreased following a reduction in LNG exports. These reductions were driven by easing LNG prices due to softening demand and increasing international supply (DISR 2024).

Natural gas production fell by 1.0 per cent in 2023–24, in line with a reduction in LNG exports by 0.8 per cent in the 2023–24 year (DCCEEW 2025b). This reflects continued stabilisation from the 2021–22 peak. The peak had been driven by increased global demand for Australian gas following disruptions to Russian exports and higher post-lockdown demand in Asia. Continued warmer European temperatures in 2023–24 contributed to decreased global demand for LNG and the reduction in Australia's exports (DISR 2024). Domestic demand for gas reduced slightly following decreases in the resource extraction sectors, including at LNG plants. LNG plants accounted for almost a third of Australian gas consumption in 2023–24, when gas used for electricity consumption is included (DCCEEW 2025a). This decreased consumption at LNG plants mirrors the decrease in LNG exports. Decreases in gas demand also occurred across manufacturing and residential sectors (DCCEEW 2025a).

Crude oil and condensate production has decreased 5.7 per cent in 2023–24 as offshore fields are depleted (DCCEEW 2025a). Crude oil imports fell 6.4 per cent in 2023–24, continuing on from decreases since 2021–22 following the closure of Kwinana and Altona refineries in 2021 (BP Australia 2020; ExxonMobil 2022). Refined product imports in 2023–24 grew 5.3 per cent as demand continued to rise from the decline in domestic refining. Refined product imports now account for 82.9 per cent of total refined product consumption in Australia in 2023–24, up from 80.3 per cent in 2022–23, driving a continuing downward trend in oil refining emissions (DCCEEW 2025a).

3.3.2.2 Methodological issues

Key categories for oil, natural gas and other emissions from energy production are shown in Table 3.35.

Detailed emissions factors, activity data, and their data sources are presented in NIR 2025 Volume 2, Annex V.3 (Section 5.3.5 *Emissions Factors and Activity tables for Oil and Gas Fugitive Emissions*).

Table 3.35 Summary of methods and emission factors: 1.B.2 Oil and Natural Gas

	CO_2		CH_4		N_2O	
Source Category	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
1.B.2.a Oil						
i Exploration[1]	T2	CS	T2	CS	NA	NA
ii Production	NA	NA	T2	CS	NA	NA
iii Transport	NA[2]	NA[2]	T1	D	NA	NA
iv Refining/storage	NA	NA	T2	CS	NA	NA
v Distribution	NA	NA	NA	NA	NA	NA
vi Other – Abandoned Wells	NA	NA	T1	D	NA	NA
1.B.2.b Natural Gas						
i Exploration[1]	T2	CS	T2	CS	NA	NA
ii Production	T2/T3	CS/OTH[3]/M	T2/T3	CS/OTH[3]/M	NA	NA
iii Processing	T3	M/OTH[4]	T3	M/OTH[4]	NA	NA
iv Transmission and Storage	T2	CS	T2	CS	NA	NA
1 – Transmission	T2	CS	T2	CS	NA	NA
2 – LNG Terminals	NA	NA	T2	CS	NA	NA
3 – LNG Storage	NA	NA	T2	CS	NA	NA
4 – Natural Gas Storage	NA[5]	NA[5]	T2	CS	NA	NA
v Distribution	T2	OTH[6]	T2	OTH[6]	NA	NA
vi Other						
1 Gas post-meter	T2	CS	T2	CS	NA	NA
2 Abandoned Wells	NA	NA	T1	D	NA	NA
1.B.2.C Venting and Flaring						
i Venting – Combined	T2/T3	CS/PS/M	T2/T3	CS/PS/M	NA	NA
ii Flaring						
1 Oil	T2	CS	T2	CS	T2	CS
2 Gas	T2	CS	T2	CS	T2	CS

Notes: T1 = Tier 1, T2 = Tier 2, T3 = Tier 3, CS = country specific, PS = plant specific, D = default, M = model, NO = not occurring, NA = not applicable, IE = included elsewhere, OTH = Other, = key category

1. Leakage emissions from 1.B.2.a.i *oil exploration* and 1.B.2.b.i *natural gas exploration* are included elsewhere (IE) under 1.B.2.c.i.3 *venting combined*. Further information regarding the sector allocation of exploration emissions can be found under Venting (CRT category 1.B.2.c.i) in Volume 1 of the NIR.

2. Australia has not estimated (NE) CO_2 leakage emissions for CRT category 1.B.2.a.iii *crude oil transport* in this submission. Further information on NE sources can be found in Section 1.7.4 and the corresponding planned improvement for estimation of these sources in Section 3.3.2.6 in Volume 1 of the NIR.
3. Other (OTH) refers to the use of regional-specific emission factors for onshore wells and well pads, offshore platforms and gathering and boosting. The regional EFs are derived by accounting for basin-specific gas composition.
4. Other (OTH) refers to the use of regional-specific emission factors for natural gas processing stations. The regional EFs are derived by accounting for basin-specific gas composition.
5. Australia has not estimated (NE) CO_2 leakage emissions for natural gas storage stations in this submission. Further information on NE sources can be found in Section 1.7.4 and the corresponding planned improvement for estimation of these sources in Section 3.3.2.6 in Volume 1 of the NIR.
6. Other (OTH) refers to the application of a range of state-based regional factors. See Natural Gas Distribution (CRT category 1.B.2.b.v) of Volume 1 of the NIR for further details.

Oil (CRT category 1.B.2.a)

In Australia, *oil flaring* (CRT category 1.B.2.c.ii.1) is a key category for CO_2 emissions.

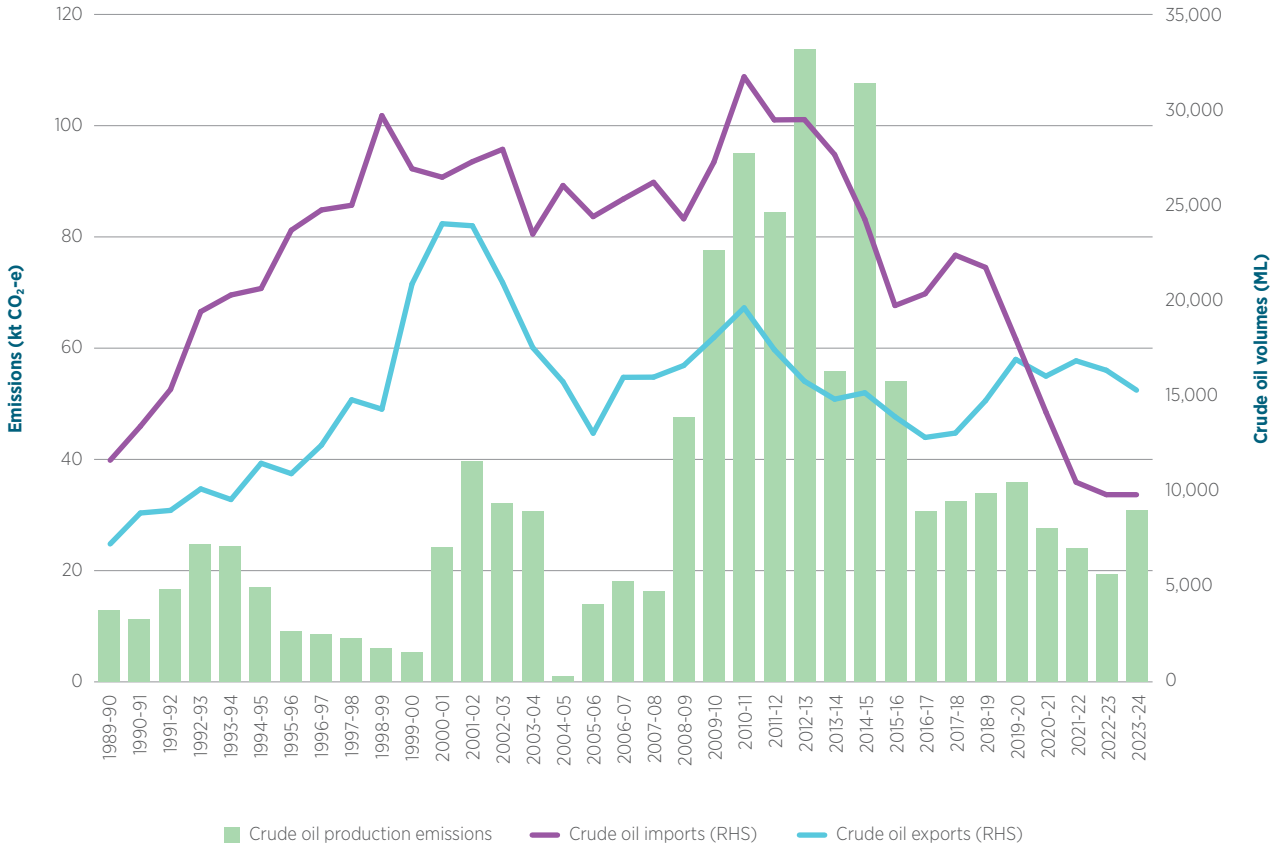
Australia's oil industry is described in the annual Australia's Energy Commodity Resources (AECR) report, published by Geoscience Australia (GA 2025).

Australia is a net importer of oil, with limited identified conventional oil resources. Most production is a vast distance from the domestic east coast refining facilities, and domestically produced grades of crude oil are not suited for local refineries. Additionally, the number and capacities of domestic oil refineries have been generally reducing since 1989–90.

Most oil production occurs in the Carnarvon and Browse basins in north-western Australia, with remaining production from fields in the Gippsland and Cooper basins in south-eastern Australia.

Australian oil production has been declining since 2008–09 as new reserve developments have failed to match the rate of depletion in existing fields. Production and emissions grew since 2016–17 (Figure 3.34), following the start-up of the Greater Enfield, Ichthys and Prelude projects on the North West Shelf, however, emissions have fallen since 2020–21 following the closure of the Kwinana and Altona refineries (BP Australia 2020; ExxonMobil 2022). With Australia's refinery capacity reduced, crude oil imports have remained stagnant and imported refined products have risen to compensate (DCCEEW 2025a).

Figure 3.34 Crude oil production fugitive emissions and trade volumes 1989–90 to 2023–24



Source: Crude oil import and export data are from Table M and N of the Australian Energy Statistics (DCCEEW 2025a)

Oil and Gas Exploration (CRT categories 1.B.2.a.i and 1.B.2.b.i)

Emissions from oil and gas exploration include fugitive emissions sources from drilling mud degassing, well completions and well workovers associated with exploration. In this submission, these sources are included elsewhere (IE) under *venting – gas* (CRT category 1.B.2.c.i.2). Further information can be found in Venting (CRT category 1.B.2.c.i).

Crude Oil Production (CRT category 1.B.2.a.ii)

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.

CH_4 and NMVOC emissions from crude oil production are estimated using the emission factors from Table 4.13 of the E&P Forum report (1994).

Emissions from well workovers associated with crude oil production are included elsewhere (IE) under CRT category 1.B.2.c.i.1 *Venting – oil*.

Crude Oil Transport (CRT category 1.B.2.a.iii)

The marine, road, and rail transport of crude oil results in CH_4 and NMVOC emissions. 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). Using the USEPA finding that CH_4 makes up 15 per cent of the mass of total organic emissions (USEPA 1995), 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.

As part of the inventory's continuous improvement processes, the estimation method used to calculate emissions from crude oil transport was updated to utilise NGER scheme data for Australia's 2024 inventory. Activity data for this sub-sector has been reported under the NGER scheme since 2012–13. The transition to the use of NGER scheme data for crude oil transport has had to be carefully managed to ensure that time series consistency has been respected. To extend the NGER scheme time series back to 1989–90, the surrogate method from the 2006 IPCC Guidelines (Volume 1, Chapter 5, Section 5.3.3.2) involving the use of NGER data and a growth rate derived using the assumed indigenous crude oil transported to by ship to Australian refineries was chosen as the most appropriate splicing technique (IPCC 2006). This choice was made because indigenous crude oil production data is available for all years and is an underlying activity data parameter that best explains emission trends.

The assumed volume of indigenous crude oil transported by ship to Australian refineries was assumed to equal indigenous crude oil production, minus crude oil exports minus the lesser of the following:

- sales of petroleum products in Victoria (DIIS 1996–2016, DoEE 2017a), or
- production of crude oil in Victoria (DIIS 2016, DoEE 2017a).

Fugitive emissions from the cargoes of ships engaged in international trade are reported as a memo item under *international marine bunker fuels* (CRT category 1.D.1).

Crude Oil Refining and Storage (CRT category 1.B.2.a.iv)

Crude oil is refined into numerous petroleum products through a variety of physical and chemical processes. During such processing, fugitive emissions of CH_4 and NMVOC emissions are generated. Fugitive emission sources at crude oil refineries may be released as leaks from 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 storage, CH_4 and NMVOC emissions are emitted through normal processes such as tank breathing, and working and standing losses. Storage or tank losses are a complex function of several 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 are estimated using the default EFs from the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997, Vol 3 – Reference Manual, Energy, Section 1.8, Table 1-58). The mid-range IPCC default CH_4 EFs are adopted for crude oil refining and storage, i.e. 745 kg gas / PJ for refining and 140 kg gas /PJ for storage.

Fugitive emissions of NMVOCs resulting from crude oil refining and storage were estimated for Victoria (Carnovale, et al. 1991), one of the primary states where oil is refined and stored. It was estimated that NMVOC emissions associated with fugitive and tank storage/loading is 20,000 kg/PJ of oil refined.

NGER scheme data have provided information on the emissions associated with the burning of refinery coke to restore the activity of the catalyst during the petroleum refining process. Consistent with previous practice, and to maintain time series consistency, this source of emissions has continued to be included within *petroleum refinery fuel combustion* (CRT category 1.A.1.b).

Distribution of oil products (CRT category 1.B.2.a.v)

The 2006 IPCC Guidelines (Volume 2, Chapter 4, Table 4.2.4) (IPCC 2006) do not provide CH_4 or CO_2 EFs for this source. Australia uses country-specific emissions factors and a combination of facility-level and state-level activity data to estimate NMVOC emissions from this category.

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 several variables and are shown in Table 3.36 based on emissions per sales volumes of each product distributed in Australia. These emissions factors were calculated from a weighted average analysis of fuel transfer and storage regulations in different regions of Australia.

Table 3.36 NMVOC emission factors for petroleum product distribution

	Emission factor (kg/kL distributed)		
Emission Sources	**Petrol**	**Diesel**	**Avgas**
Motor Vehicle/Equipment Refuelling	1.40 [a]	0.84 [b]	NA
Service Station/Premises, Storage/Transfer	0.66 [c]	0.006 [d]	NA
Bulk Fuel Terminal, Storage/Transfer	1.08 [c]	0.009 [d]	NA
Aircraft, Refuelling/Storage	NA	NA	2.69 [e]
Total of all sources	3.14	0.855	2.69

Sources: (a) USEPA (1995) Uncontrolled refuelling and spillage. (b) USEPA (1992) Uncontrolled refuelling and spillage. (c) See Table A5.3.2.21 and A5.3.2.22 in Volume 2 of the NIR. (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).

Several 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 fuelling operations (USEPA 2015). Emissions associated with the normal distribution of LPG are also assumed to be negligible (Carnovale, et al. 1991; EPA NSW 1995). From a consideration of emissions factors (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 assumed to be negligible.

Other – Abandoned oil and gas wells (CRT categories 1.B.2.a.vi.1 and 1.B.2.b.vi.2)

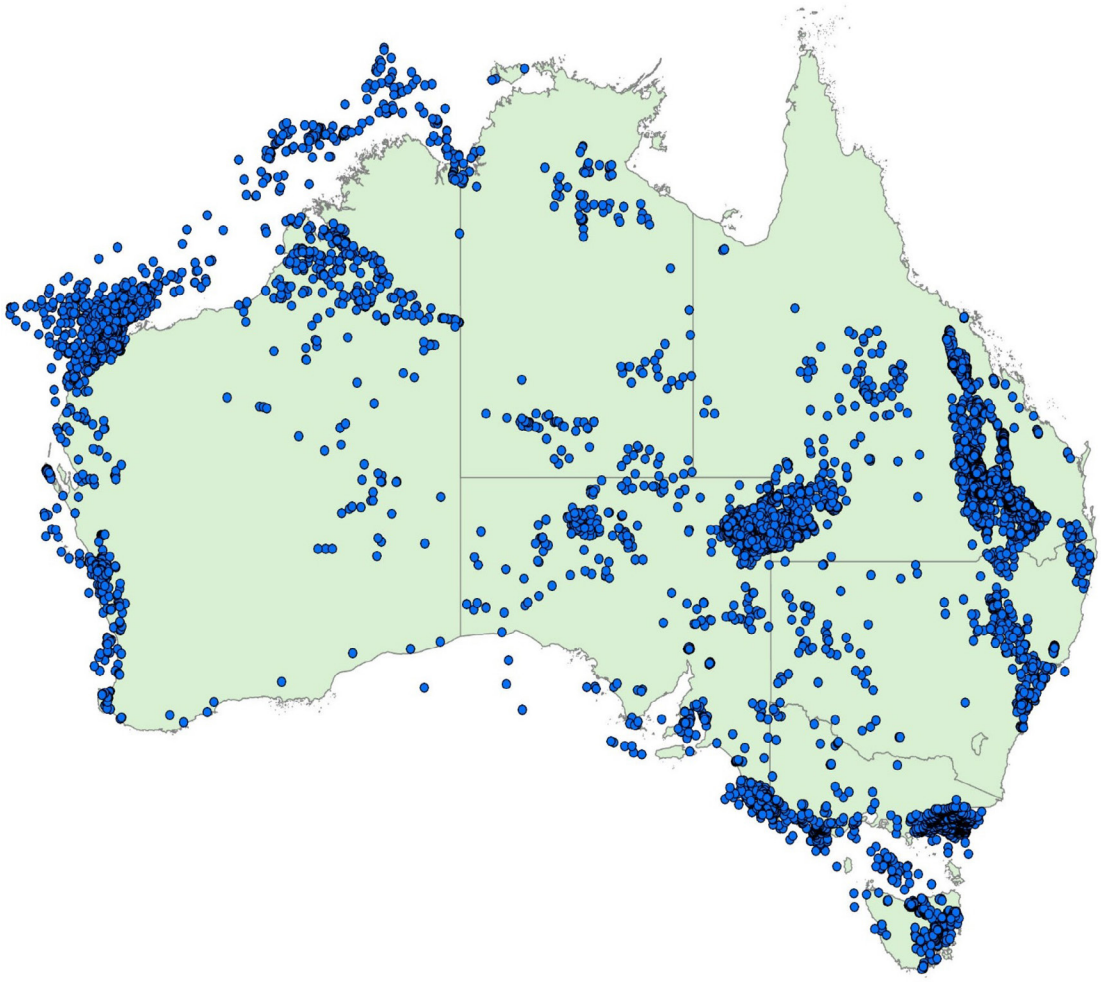
Abandoned wells are defined as wells that are no longer producing petroleum or exploration activities that have ceased. The 2019 IPCC Refinement (Volume 2, Chapter 4, page 4.62) (IPCC 2019) describes that these wells may be abandoned for many reasons such as the resource is drained, surrender of a production license, or geological, technical, or ecological factors.

Data for estimating this source were obtained from datasets published by state and territory governments in 2025, who manage data reported by the petroleum wells' responsible entities. The state and territory datasets contain historical well data, often dating back to the early 1900s. The activity data used were counts of abandoned oil wells by plugging status, production type, and production location (onshore/offshore). State and territory data sets were sourced from:

- NSW Drillholes Petroleum, Department of Primary Industries and Regional Development (NSW DPIRD),
- Petroleum Wells (from Geological Survey of Victoria's DbMap database), Department of Energy, Environment and Climate Action (Vic DEECA),
- Western Australia Minerals and Petroleum Statistics Digest 2023–24, Department of Mines and Petroleum Industry, Regulation and Safety (DMIRS),
- All bore hole and well locations – Queensland, Department of Natural Resources and Mines, Manufacturing and Regional and Rural Development (DNRMMRRD),
- Petroleum Wells, Department of Energy and Mining (SA DEM)
- Tenure and Geoscience Information, Department of Mining and Energy (NT DME), and
- Boreholes (Drill Holes) Data, Department of State Growth (Tas DSG).

Australia currently has around 26,000 identified abandoned oil and gas wells in 2023–24, compared to 3.9 million in the USA in 2022 (USEPA 2024). Abandoned well locations in Australia are presented in Figure 3.35.

Figure 3.35 Map of the locations of Australia's abandoned oil and gas wells, 2023–24



Sources: DCCEEW using data from NSW DPIRD, Vic DEECA, WA DMIRS, Qld DNRMMRRD, SA DEM, NT DME, and Tas DSG.

Where a well produced both oil and gas, or if the production type is unknown, it was allocated to *natural gas* (CRT category 1.B.2.b.vi.2). This assumption reflects the higher prevalence of natural gas production in Australia.

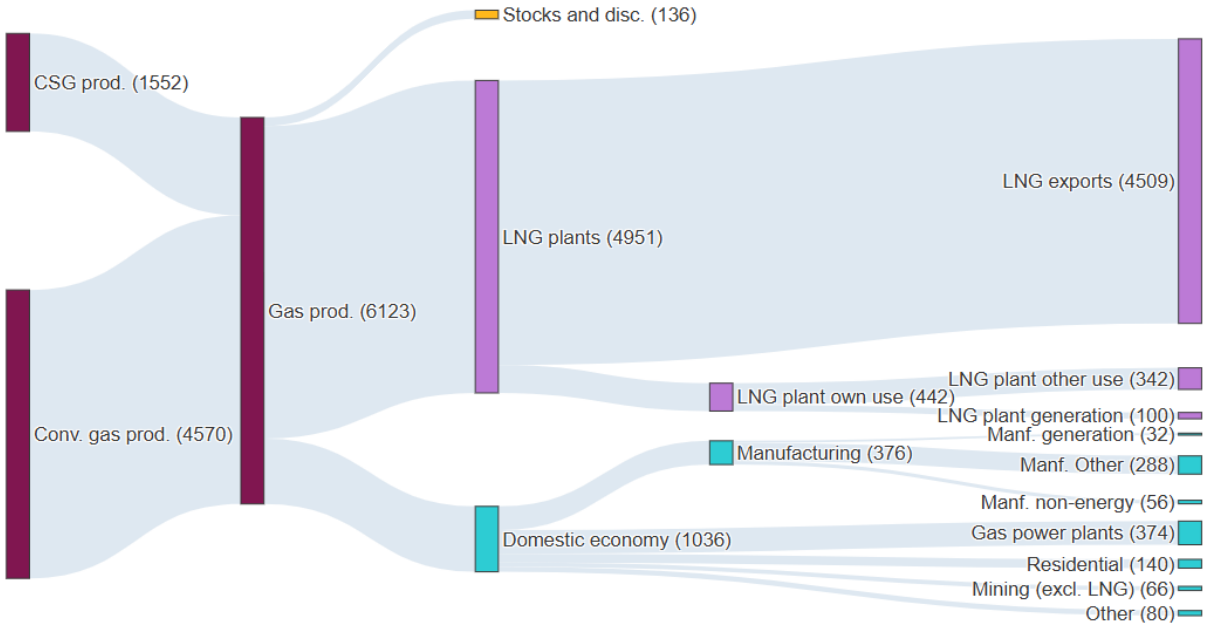
Natural gas (CRT category 1.B.2.b)

CRT category 1.B.2.b consists of leakage emissions associated with natural gas systems. Leakage emissions of CH_4 from natural gas production, processing, and distribution are key categories of CH_4 emissions for Australia. Flaring emissions associated with the natural gas industry are key categories for CO_2 emissions, while venting is a key category for both CO_2 and CH_4 emissions. In accordance with the 2019 IPCC Refinement, venting and flaring are reported under CRT category 1.B.2.c (IPCC 2019).

Gas production occurs predominantly from offshore conventional gas resources; however, Australia also produces significant onshore unconventional gas resources (predominantly coal seam gas). The natural gas flows for the current reporting year are presented in Figure 3.36.

Australia is a net exporter of natural gas, with recent record high exports making it the third largest exporter of liquefied natural gas (LNG) in 2022–23 (GA 2025). Australian LNG exports commenced in 1989 based on long-term contracts with the Japanese market, which remains a primary importer of Australian LNG. LNG exports have expanded through time with several other countries becoming important destinations, predominantly across the Asia region (BREE 2014) (GA 2024). In 2023–24, Australia exported 74% of total gas produced (DCCEEW 2025c) and accounted for a fifth of the global LNG trade (DISR 2025).

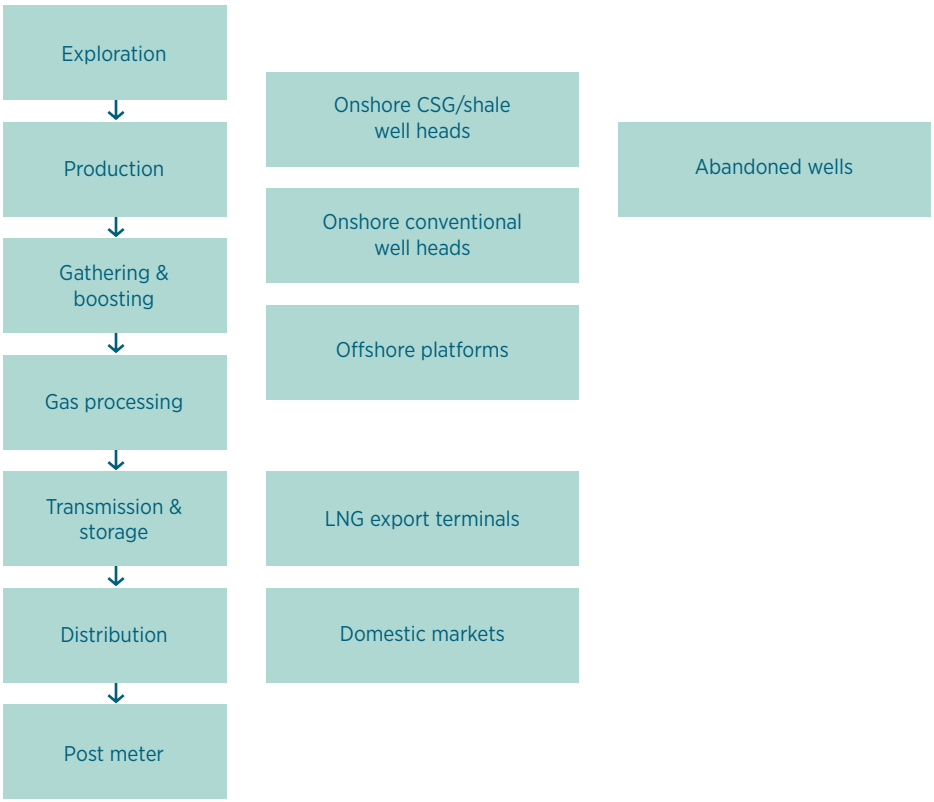
Figure 3.36 Australian natural gas energy flows, PJ, 2023–24



Source: *Australian Energy Update Report 2025* (DCCEEW 2025a).

Australia estimates leakage emissions from natural gas production by segment of the gas supply (see Figure 3.37) at a greater disaggregation than required by the CRTs.

Figure 3.37 Emission estimation segments for the gas supply chain



The EFs for estimating leakage emissions are derived from the following sources:

1. Australia-specific EFs derived from research by the CSIRO, where available;
2. Application of more complex NGER scheme methods; Method 2 where appropriate, using EFs or engineering approaches taken from the API Compendium (API 2009);
3. EFs derived from US and international research, including those that update or supplement factors from the API Compendium (API 2009):
    a. Offshore gas platforms (USEPA 2015b);
    b. Gathering and boosting stations (Zimmerle, et al. 2020);
    c. Gas processing plants (Mitchell, et al. 2015);
    d. Storage and export terminal infrastructure (USEPA 2016b); and
    e. Appliance leakage in the commercial and residential sector (Merrin and Francesco 2019).
4. EFs derived from the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019):
    a. Abandoned oil and gas wells; and
    b. Industrial plants and power stations and natural gas vehicles.

Gas Exploration (CRT category 1.B.2.b.i)

A consistent method is applied to estimate fugitive emissions for offshore/onshore testing and drilling exploration activities for oil and gas. In this submission, leakage emissions from exploration are included elsewhere (IE) under

venting – gas (CRT category 1.B.2.c.i.2). Further information can be found in Venting (CRT category 1.B.2.c.i). These include fugitive emissions from drilling mud degassing, well completions and well workovers associated with exploration.

Subject to resource availability and priorities, the time series will be reviewed to assess whether, for comparability reasons, these data can be reallocated from CRT category 1.B.2.c.i.2. to CRT category 1.B.2.b.i.

Natural Gas Production (other than venting and flaring) (CRT category 1.B.2.b.ii)

The 2019 Refinement (IPCC 2019) provides for a detailed disaggregation of emissions from this category. As a significant gas producer, Australia uses targeted sectoral methods to provide granular emissions estimates for this category.

Leakage emissions from natural gas production arise from the unintentional equipment leaks from valves, flanges, pump seals, compressor seals, relief valves, sampling connections, process drains, open-ended lines, casing, tanks, and any other leakage sources from pressurised equipment not defined as a vent.

Australia reports leakage emissions in this category from:

- Onshore
  - conventional and unconventional (predominantly coal seam gas) production,
  - gathering and boosting stations and pipelines, and
  - produced water from coal seam gas.
- Offshore
  - production in shallow and deep waters.

The descriptions and detailed methods for these sub-sources are provided in the following sections. CO_2 and CH_4 emission factors for all sources, except produced water, are adjusted to a regional-specific value by accounting for the basin-specific gas composition.

Note that well workovers associated with natural gas production are reported elsewhere (IE) under Venting (CRT category 1.B.2.c.i).

Onshore natural gas well production leakage

The leakage rate for coal seam gas production wells is derived from Day et al. (2014). This study collected field data measurements from 43 coal seam gas wells (CSG) in Australia and found the mean emission leakage rates from gas producing wells corresponded to an EF of 4.7×10^{-5} tonnes of CH_4 per tonne of unprocessed natural gas that passes through the wellhead. A molar conversion was used on this factor to derive a CO_2 emissions factor of 1.3×10^{-4} tonnes of CO_2 per tonne of unprocessed natural gas that passes through the wellhead.

In the absence of a source-specific factor for conventional onshore natural gas wells, the Australia-specific leakage rate for CSG was also applied to these wells.

Onshore gathering and boosting stations and pipelines

Unprocessed natural gas is transported from wellheads either directly to the processing facility, or through field compressor boosting stations via gathering pipeline systems.

Leakage emissions from the pipeline system were estimated based on pipeline length using the CH_4 EF from the 2009 API Compendium (Section 6.1.2, Table 6–4).

Leakage emissions from the gathering and boosting stations were estimated using EFs derived from Zimmerle et al. (2020), who collected measurements from 180 gathering and boosting stations across the United States.

Based on the analysis of data from Zimmerle et al. (2020), a non-linear relationship has been identified between the fugitive leakage emission rate emitted to the atmosphere and the quantity of unprocessed natural gas that passes through the station. Stations with low throughputs were found to have higher leakage rates, whereas stations with high throughputs were found to have lower leakage rates. Despite this relationship, high throughput stations were observed to have higher emissions overall caused by the larger quantities being moved.

The equation adopted for the Australian inventory is:

$$E_{ij} = 2.386 \times Q_{ij}^{-0.761}$$

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

2.386 = scaling factor from Zimmerle et al. (2020)

-0.761 = exponential factor from Zimmerle et al. (2020)

Produced water from coal seam gas

Wells drilled into underground coal seams bring water from the seams to the surface. This process reduces pressure in the seams, allowing coal seam gas to be released (Qld DES 2022). Significant water volumes are produced from coal seams and are regulated by state and territory governments (DCCEEW 2022a). This water is pumped into treatment tanks and dams with a view for the water being reusable for some alternative purpose. Residual dissolved methane in the produced water can escape into the atmosphere throughout the treatment process.

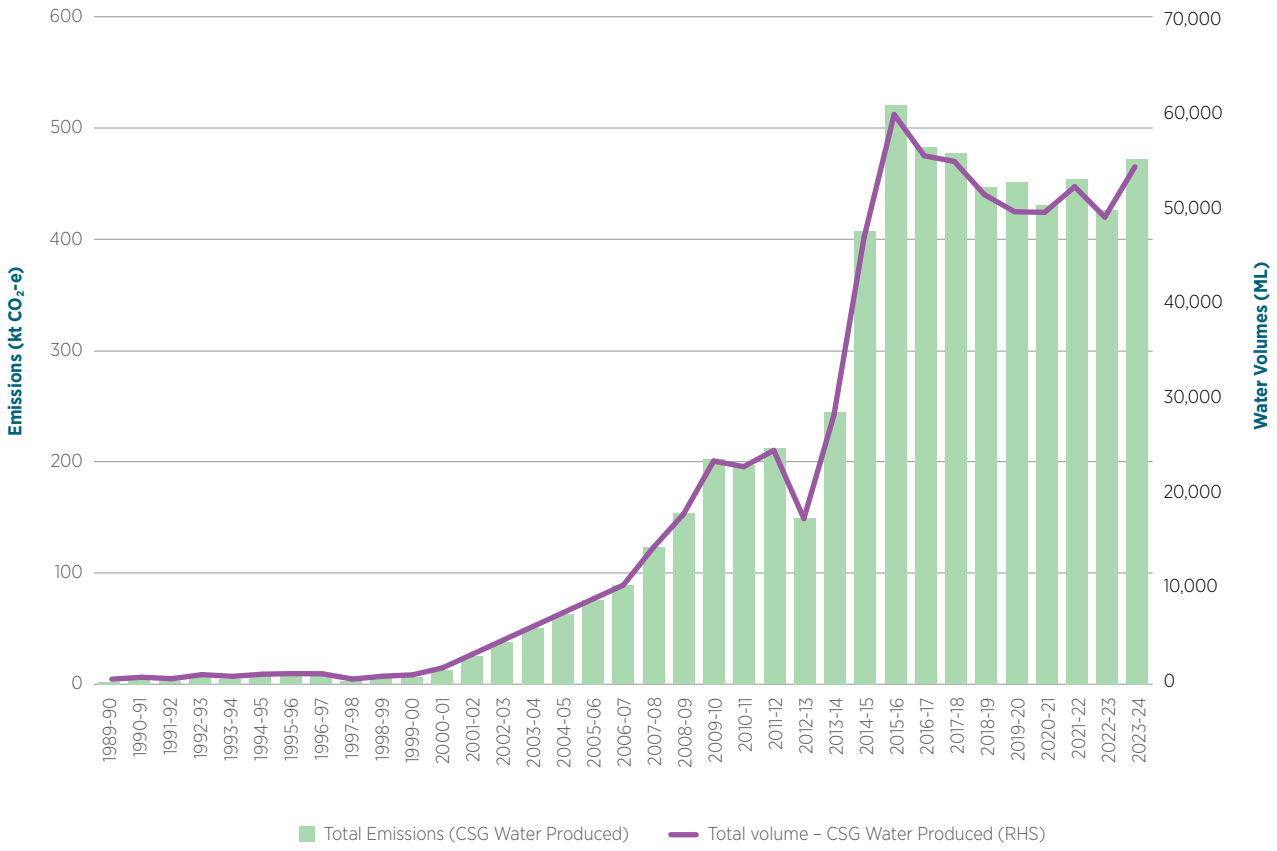
The 2019 Refinement (IPCC 2019) does not provide EFs for produced water. A leakage rate was used from the API Compendium (2009), Table 5–10 of 0.31 tonnes of CH_4 per million litres of produced water to estimate emissions from this source.

Activity data for the volume of produced water has been derived from a variety of sources. From 2011–12 to 2014–15, activity data was sourced for NSW and QLD directly from APPEA CSG industry reporting (APPEA 2013–2015). Prior to 2011–12, a national total for produced water volumes was estimated by taking the average water production per unit of gas production from 2012 to 2014 and projecting backwards to 1989–90 using APPEA reported CSG production statistics (APPEA 1990–2015). The derived national total was split between NSW and Queensland according to the average share of water produced per state for the period 2012 to 2014.

From 2015–16 to 2019–20, water volumes for Queensland were derived using the same water production factor as before but with QLD petroleum production data (Business QLD 2022). NSW estimates were derived for the same period by estimating additional water volumes according to the state's average share of the 2012 to 2014 national total. From 2020–21 onwards, the NGER scheme has included facility level data for produced water volumes and these data have been directly incorporated into the inventory.

Figure 3.38 shows the time series of CSG produced water volumes and the associated emissions.

Figure 3.38 Water produced coal seam gas extraction and associated methane emissions, 1989–90 to 2023–24



Sources: (a) For 2011–12 to 2014–15, CSG produced water volumes from APPEA CSG industry reporting (APPEA 2013–2015). (b) Prior to 2011–12, total derived from 2012 to 2014 average water production per unit of gas production, and projected backwards using APPEA reported CSG production statistics (APPEA 1990–2015). (c) For 2015–16 to 2019–20, projected forwards using QLD production statistics (Business QLD 2022) and 2012 to 2014 NSW average share. (d) For 2020–21 onwards, NGER scheme reported data (CER 2023–2025).

Offshore platforms

Offshore natural gas production includes 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. EFs were taken from the USEPA 2016 in the absence of Australian data or IPCC default factors.

For shallow water platforms (standing in less than 200 metres of water), the EF is 62.6 tonnes of CH_4 per platform per year while for deep water platforms (standing in at least 200 metres of water), the factor is 661.1 tonnes of CH_4 per platform per year (US NIR Table A-134, USEPA 2016). In the current reporting year (2023–24), there were 49 shallow platforms and 6 deep water platforms in Australian waters.

Gas Processing (CRT category 1.B.2.b.iii)

The EF function for gas processing plants was derived from Mitchell et al. (2015), whose data on gas processing plants confirms that 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 3.39). The equation is:

$$Y = 0.6369 \times X^{-0.48}$$

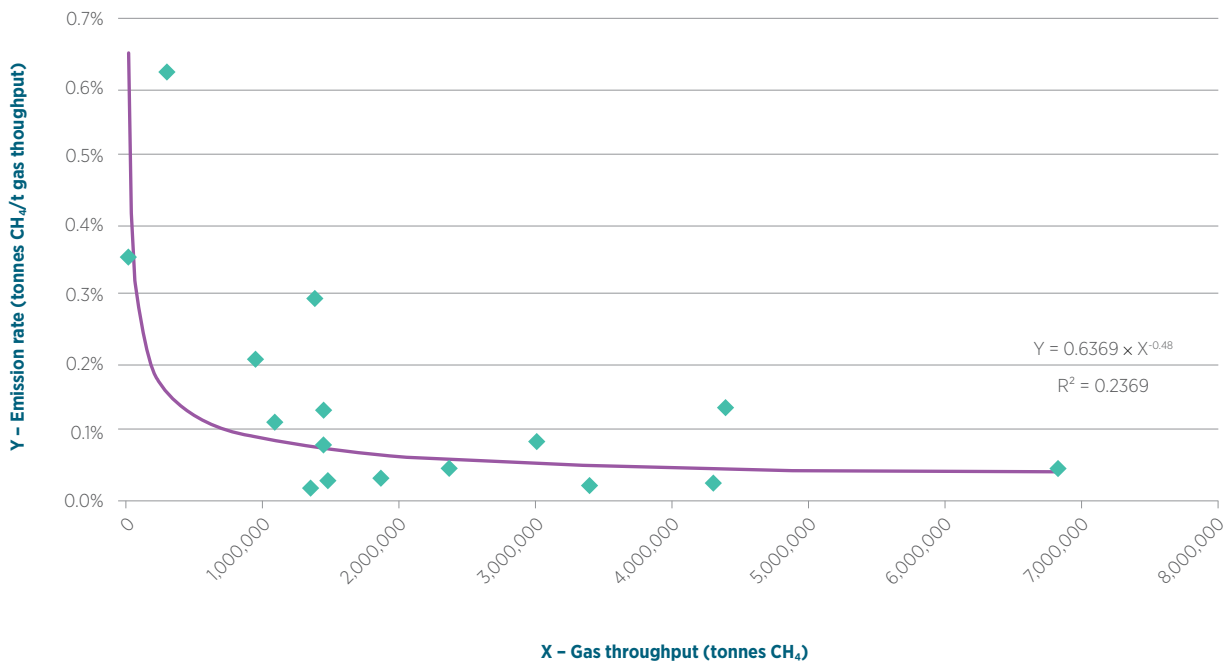
Where Y = emission rate in tonnes of emissions per tonne of gas throughput

X = gas throughput in tonnes

0.6369 = scaling factor from Mitchell et al. 2015

-0.48 = exponential factor from Mitchell et al. 2015

Figure 3.39 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 of CH_4 per tonne of gas throughput and the modelled emission rate for the largest, 0.0004 tonnes of CH_4 per tonne of gas throughput.

The model was applied to gas processing throughput. These data were collected from facility reports under the NGER scheme (CER, 2009 onwards) and AES production data (1989–90 to 2017–18). More details on these activity data and their sources are provided in NIR 2024, Volume 2, Table A5.3.5.12 *Fugitive emissions from natural gas extraction activity data sources*.

Natural Gas Transmission and Storage (CRT category 1.B.2.b.iv)

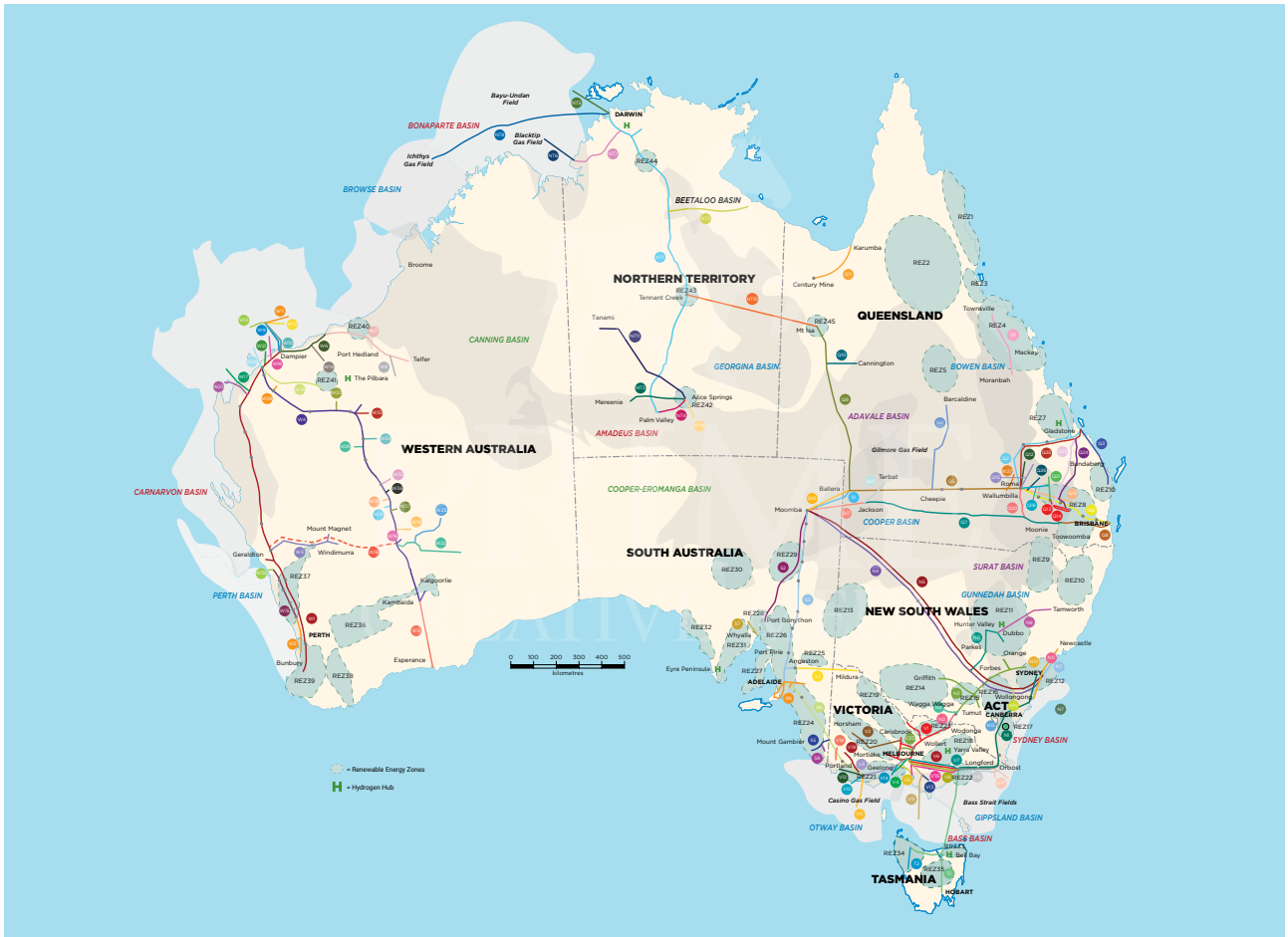
The 2019 IPCC Refinement (IPCC 2019) describes that this category comprises leakage emissions from systems used to transport processed gas to market to industrial consumers and distribution systems. Leakage emissions from related storage systems are also included. The sub-sectors are described below, and include leakage emissions from:

- natural gas transmission pipelines
- natural gas storage
- liquefied natural gas export terminals

Natural gas transmission pipelines

Australia has around 42,000 kilometres of high-pressure natural gas transmission pipelines that transport gas from where it is produced to the outskirts of cities for use (APGA, 2024). This network is of relatively recent vintage (the oldest line dates from 1969), built to high quality standards, is well maintained, and is depicted in Figure 3.40.

Figure 3.40 Map of Australia's gas pipeline network



Source: APGA 2023

Emissions may occur from 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.

Australia-specific CO_2 and CH_4 EFs were developed by multiplying a loss factor by average pipeline gas composition by state and territory. These loss factors were then converted from loss per petajoule of gas transmitted to loss per kilometre of pipeline.

Work undertaken by the Pipeline Authority, the organisation formerly responsible for operation of the Moomba to Sydney pipeline (EMC 2022), concluded that losses from Australia's significant Moomba to Sydney pipeline (MSP) gas transmission pipeline are approximately 0.005 per cent of throughput (NGGIC 2004). As no other country-specific data was available, the losses from this pipeline were considered to be representative of other major pipelines in Australia.

Natural gas composition factors of transmitted gas by state were last reported by the Australian Gas Association in 2000. As no new factors have become available, and this is not a key category for Australia, the 2000 composition factors have been applied to all years.

The EFs, losses, and gas compositions are applied to kilometres of pipeline per year. Pipeline lengths are collected through the NGER scheme (CER 2009 onwards) and were previously published by the AEC.

Natural gas storage

Along with high pressure pipelines, natural gas transmission pipelines include storage facilities. Such facilities include transmission pipelines themselves through linepack, aboveground storage tanks, and underground storage facilities (e.g. depleted gas fields). Storage facilities are used to manage peak demand or emergencies by being able to inject gas into the transmission system at short notice.

The following factors were sourced from the US NIR (USEPA 2016a):

- gaseous storage EF of 370 tonnes of CH_4 per facility per year,
- liquefied natural gas storage EF of 921 tonnes of CH_4 per facility per year.

Liquefied natural gas export terminals

A CH_4 factor of 1,109 tonnes per terminal per year was sourced from the US NIR (USEPA 2016a).

Natural Gas Distribution (CRT category 1.B.2.b.v)

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 transmission 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.

Emissions from the distributor side of the meter are not measured directly and are instead 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. Leakage emissions from distribution systems are dependent on the age and composition. Older, metal pipelines have higher leakage factors than newer PVC pipelines (API 2009).

Since 2008–09, the NGER scheme has collected activity data and EFs for natural gas distribution. The NGER scheme allows natural gas distributors to choose one of three methods to calculate their natural gas distribution emissions (more on NGER methods in NIR 2024, Volume 2, Annex 5.3, Section 5.3.5). Each of the NGER scheme methods apply a variety of country or plant-specific EFs and assumptions to activity data (total gas sales for NGER scheme Methods 1 and 3, and quantities of gas throughput by equipment type for NGER scheme Method 2), resulting in IPCC Tier 2 method estimations of both CO_2 and CH_4 from this source.

Plant-specific information reported through NGER scheme is used to estimate the majority of this source category. Equipment-specific EFs from Section 6–1–2 of the 2009 API Compendium (API 2009) were applied.

Where plant-specific information is not available through the NGER scheme, distribution emissions are estimated using the following formula:

$$E = S \times \%UAG \times LF \times C_{jp}$$

Where: ***E*** is the total leakage emissions resulting from the natural gas distribution pipeline system, measured in tonnes of CO_2-e.

S is the total gas sales during the year from the distribution pipeline system in a state or territory, measured in terajoules. Total annual gas utility sales were derived from the AES for 1989–90 to 2007–08 in lieu of direct data relating to natural gas distribution. By removing gas components 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. For 2007–08 onwards, natural gas sales data was used, collected under the NGER scheme, or through company annual reports.

%UAG is the percentage of unaccounted for gas in the pipeline system in a state, territory or specific to a facility. Facility-specific %UAG is used where available, sourced from annual reports by companies, and data published in the 5-year projected estimates developed by the Australian Energy Regulator for access arrangements. Where a facility does not have a facility-specific %UAG reported as part of their access arrangements or annual reports, the %UAG is estimated as per Table 3.37.

LF is the leakage factor, representing the proportion of UAG that is attributed to leakages in the distribution system (Table A5.3.5.4 of Volume 2 of the NIR). Dixon (1990) estimated an 80 per cent leakage for Australian utilities and Hutchinson et.al (1993) estimated 70–80 per cent, but neither study included leakage from the customer's side of the meter. A 90 per cent leakage factor was settled on for the period 1989–90 to 1993–94 (NGGIC 1994) to provide additional allowance for customer side emissions. An analysis of industry data by Energy Strategies in 2005 determined that a value of 50–60% was more appropriate for the period, and so a factor of 55% was adopted for 2002–03 and 2005–06. In 2020, an internal review of literature, including the 2017 Zincara Review for Victoria's Essential Services Commission and public submissions by distribution companies, concluded that the proportion of unaccounted for gas attributable to distribution leakages was in the range of 35–40 per cent. Based on available reported unaccounted for gas breakdowns from the annual reports of relevant companies, the Australian Energy Regulator, and the Zincara review, the estimate for the leakage proportion of total UAG was set to 37.3 per cent from 2017–18 onwards. A linear interpolation of historic data for the intervening time periods (1994–95 to 2001–02 and 2006–07 to 2016–17) was applied to account for improvements to distribution pipelines overtime.

C_{jp} is the natural gas composition factor for gas type (j), either CO_2 or CH_4, for a pipeline system in a State or Territory (p). The state-based factors were provided by the Australian Gas Association (AGA). Data published by the AGA enabled the definition of annual natural gas composition factors across the 1989–90 to 1999–00 time series. As of 2001, the AGA no longer publishes this data, therefore, it is assumed that all natural gas composition factors have remained unchanged from 1999–00. Values for 2023–24 are presented in Table 3.37.

Table 3.37 Unaccounted for gas percentages (%UAG) and pipeline natural gas compositions by state and territory for 2023–24

Jurisdiction	Unaccounted for gas (%)	Natural gas composition factors ($t CO_2$-e / TJ gas sales)	
		CO_2	CH_4
Australian Capital Territory (ACT) and New South Wales (NSW)	2.0	0.8	437
Northern Territory (NT)	0.1	NO	352
Queensland (Qld)	3.0	0.8	423
South Australia (SA)	2.6	0.8	437
Tasmania (Tas)	0.5	0.9	435
Victoria (Vic)	4.2	0.9	435
Western Australia (WA)	2.7	1.1	408

Sources: (AEC 2021), AGA (2000)

Notes: NO = Not occurring

Other (CRT category 1.B.2.b.vi)

Australia estimates emissions from post-meter leakage and abandoned gas wells under CRT category 1.B.2.b.vi *gas – other*. The activity data and EF sources are presented in Table 3.38.

Table 3.38 Fugitive emission factors for abandoned gas wells and post-meter leakage

Inventory category	Unit	Factor		Source
		CO_2	CH_4	
Abandoned gas wells	• tonnes of emissions / well	NO	Various	2019 IPCC Refinement – Table 4.2.4E – Tier 1 emission factors for abandoned oil wells
Post-meter leakage	• tonnes of emissions / vehicle • tonnes of emissions / appliances • tonnes of emissions / million cubic metres gas consumed	• natural gas vehicles • residential and commercial appliances • industrial power plants and stations		2019 IPCC Refinement – Table 4.2K, Merrin and Francesco 2019, Unburned Methane Emissions from Residential Natural Gas Appliances

Post-meter leakage emissions (CRT category 1.B.2.b.vi.1)

As per the 2019 Refinement (IPCC 2019), this category includes gas leakage emissions from consumer appliances, power plants, and natural gas-fuelled vehicles. The activity data and EF sources for post-meter emissions are summarised above in Table 3.38.

Appliance leakage

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.

An Australia-specific method was applied using EFs by appliance type derived from a measurement study by Merrin and Francesco (2019). The study looked at non-combustion emissions from residential natural gas appliances.

Activity data for appliances in the residential sector was sourced from the *2021 Residential Baseline Study for Australia 2000–2040* (DISER 2021). Activity data for appliances in the commercial sector was inferred from residential data in conjunction with relative natural gas consumption in both sectors (DISER, 2021).

Industrial and power plants

Australia used the EFs for leakages at industrial plants and power stations published in the 2019 Refinement (Volume 2, Chapter 4, Table 4.2.4K) (IPCC 2019). Leakage emissions are already calculated for *oil production* (CRT category 1.B.2.a.ii), *oil refining* (CRT category 1.B.2.a.iv), *gas production* (1.B.2.b.ii) and *gas processing* (CRT category 1.B.2.b.iii), *natural gas transmission* (CRT category 1.B.2.b.iv), and *natural gas distribution* (CRT category 1.B.2.b.v). Activity data relating to these listed leakage categories were excluded to avoid double-counting.

Natural gas vehicles

Leakage emissions from natural gas vehicles include releases from dead volumes during fuelling, emptying of gas cylinders of high-pressure interim storage units, execution of pressure tests, relaxation of residual pressure from vehicles' gas tanks, and pressure tests or decommissioning. Activity data was obtained from New South Wales state motor vehicle registration statistics (Transport NSW 2024). A national time series of natural gas vehicles was then inferred by using the consumption of natural gas in the transport sector, derived from the AES (DCCEEW 2025a), to ensure time series consistency and completeness.

Abandoned gas wells (CRT category 1.B.2.b.vi.2)

The 2006 Guidelines (IPCC 2006) do not provide EFs for abandoned gas wells.

Available data on abandoned oil and gas wells do not clearly differentiate between abandoned oil versus gas wells regarding practices or EFs (2019 Refinement, Volume 2, Chapter 4, p4.83) (IPCC 2019).

Australia estimates emissions from this source under CRT category 1.B.2.a.vi.1 *Other – Abandoned gas wells*. The activity data and EF sources are summarised above in Table 3.38.

Other (CRT category 1.B.2.b.vi.3)

The 2019 IPCC Refinement (IPCC 2019) describes that anomalous leak events can occur across natural gas systems, such as leakage of storage wells, emergency pressure releases, and unintentional gas spills. Australia does not report any emissions under this category.

Instead, several emission sources associated with storage activities that are not directly associated with transmission activities are included elsewhere (IE) under CRT category 1.B.2.b.iv *transmission and storage*. These sources include:

- leakage from natural gas storage stations
- leakage from LNG storage stations
- leakage from LNG export terminals

These sources occur as part of the *storage* stage of the natural gas system. The underlying trends and drivers are the same for these sources and other *transmission and storage* sources and thus the additional *storage* sources have been included under CRT category 1.B.2.b.iv with a view to support the transparency of emissions reporting, time series consistency and comparability to other Parties. Refer to Natural gas storage and Liquefied natural gas export terminals for further details on the methodology used to estimate these sources

Oil and gas production venting and flaring (CRT category 1.B.2.c)

Gas and waste gas/vapour streams at oil and gas facilities are disposed of via venting or flaring.

Venting (CRT category 1.B.2.c.i)

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 during gas processing. As 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 production 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 the 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.

Details on venting emission factors, sources and methodology can be found in Volume 2 of the National Inventory Report 2024 in Annex 5.3.5.5. Details on activity data sources are presented in Volume 2, Annex 5.3.5.6 of the National Inventory Report 2024.

Tonnes of gas vented associated with oil and gas production are obtained through industry reporting. From 1989–90 to 2007–08, estimates of emissions are based on industry data reported by APPEA (1998–2008). These data consist largely of direct monitored emissions associated with controlled vent releases as well as estimates of emissions from cold process vents. NGER scheme data (CER 2025) has been used from 2008–09 and onwards. The NGER scheme approach has built on the APPEA approach and enhanced the methodologies available for technology types by utilising the American Petroleum Institute Compendium (API 2009) methodologies for vents.

Significant work has been undertaken to restructure Australia's venting emissions in this submission. In previous submissions, some venting sources from exploration were included elsewhere (IE) under exploration leakage emissions in CRT category 1.B.2.b.i. These sources included:

- well workovers
- well completions
- mud degassing

All venting sources are now consolidated and reported under CRT category 1.B.2.c.i.

Disaggregation of venting sources

In 2021–22, the NGER scheme methods for venting were amended to provide a greater disaggregation of emissions. In previous years, the NGER scheme required a single total for venting emissions to be reported (even if multiple API Compendium 2009 methods for venting were summed). The NGER scheme now requires that individual activities related to venting be reported separately, giving more insight into the venting profiles of oil and gas facilities.

This has allowed Australia to disaggregate between venting sources from different parts of the oil and gas production chain. There are confidentiality constraints on the data however, which has required Australia to report all venting emissions under 1.B.2.c.3 *Venting – combined*. Where data are not confidential, Australia has published a full disaggregation of venting emissions for 2021–22 to 2023–24 on the ANGA database. They can be accessed by following the links Emissions inventories > UNFCCC/Paris Agreement inventory, and selecting venting sources from the 'select sectors' menu.

Although the available disaggregation of venting across oil, gas, and combined sources varies across the time series, this does not affect the consistency of CRT category 1.B.2.c.i *Venting*.

Reallocation of included elsewhere (IE) venting sources

In previous submissions, Australia reported venting emissions under the following leakage sources:

- Well workovers, previously reported under CRT category 1.B.2.b.i
- Well completions, previously reported under CRT category 1.B.2.b.i
- Mud degassing, previously reported under CRT category 1.B.2.b.i

To better align Australia's CRTs with IPCC definitions (see IPCC 2006 Guidelines, Volume 2, Chapter 4, Table 4.2.1) and to improve comparability, the venting sources listed above have been reallocated in this submission to CRT category 1.B.2.c.i.3 *Venting – combined* for the full time series.

The sub-sources of venting and their associated methods, activity data, and emission factors are presented below.

Venting from condensate production

Methane vented from condensate production was estimated using the average factor in the US NIR (USEPA 2017), and from condensate production data published by the Australian Petroleum Statistics from 1989–90 to 2020–21. From 2021–22 onwards, NGER scheme reporting includes venting associated with condensate production. The inventory uses NGER scheme data for condensate venting from 2021–22 to 2023–24.

Mud degassing

In this submission, Australia reports emissions from mud degassing under *venting – combined* (CRT category 1.B.2.c.3).

Emissions from exploration 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 2009) provides an EF for water-based drilling mud of 0.2605 tonnes CH_4/drilling day. A CO_2 factor was derived from the CH_4 factor using stoichiometry by accounting for the molecular mass ratio of CO_2 and CH_4 (44.01/16.04).

The number of wells drilled by year were obtained from state and territories governments, who manage data reported by the petroleum wells' responsible entities (NSW DPIRD 2025, Vic DEECA 2025, WA DMIRS 2025, Qld DNRMMRRD 2025, SA DEM 2025, NT DME 2025, and Tas DSG 2025). New well drillings were categorised according to the well spud date.

Well completions and workovers

In this submission, Australia reports emissions from well completions and workovers under *venting – combined* (CRT category 1.B.2.c.3).

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 EFs for well completions and workovers are technology-specific and are described below.

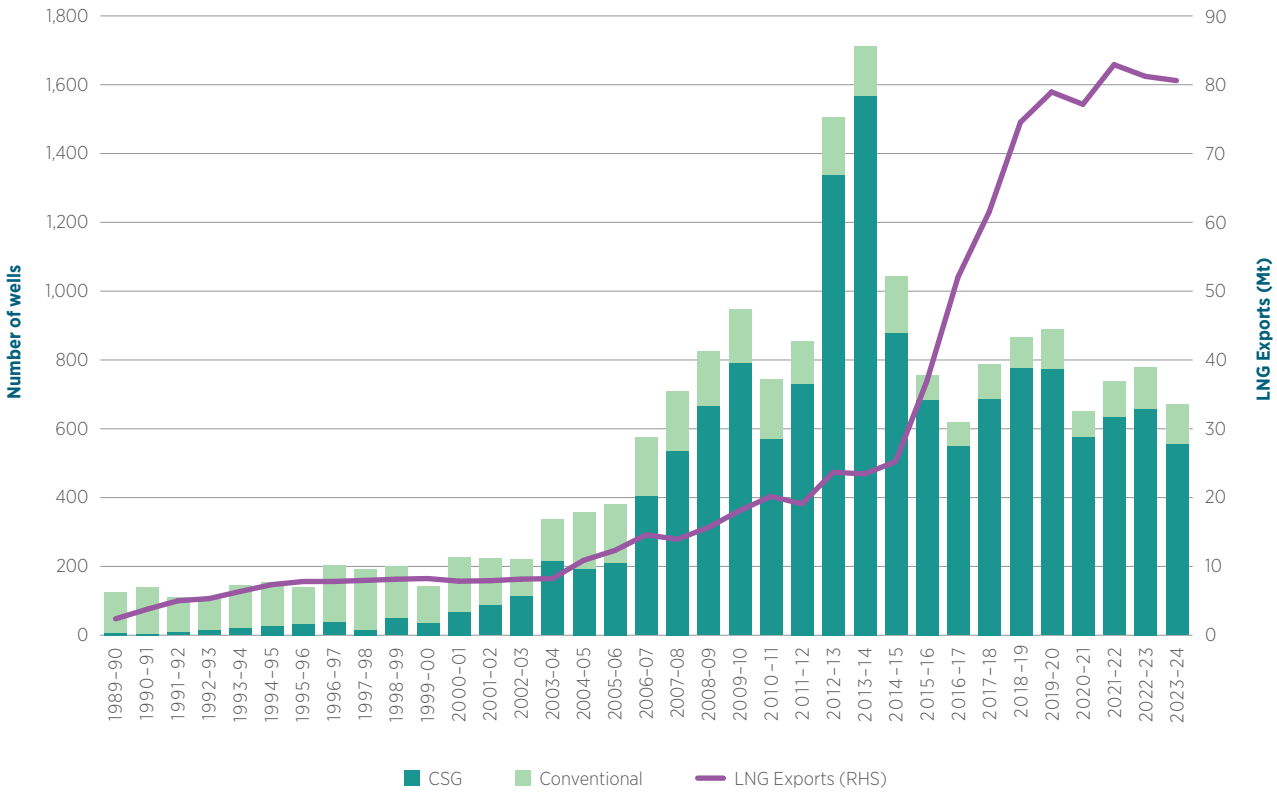
The factors for well completions and well workovers without the stimulation of fracking is derived from a study of Australian well completions by Day et al. (2017).

In cases of well completions and workovers where stimulation of production though fracking occurs, the factors in the US NIR (USEPA 2016a) were applied in the absence of any IPCC default or Australian-specific factors for these types of events, which include:

- with fracturing and venting
- with fracturing and flaring
- with fracturing and green capture

The number of well completions and workovers was derived from production well activity data obtained from ABS exploration and petroleum data (ABS 2023b), historical APPEA reports, state agencies and industry project sources up until 2021–22. It includes conventional, coal seam gas, and shale gas wells from both onshore and offshore locations. From 2021–22 onward, counts of completions and workovers are sourced from NGER scheme reporting, following the expansion of legislated methods in 2021–22 to capture this information. The number of new wells drilled by year is shown in Figure 3.41. The recent expansion of the coal seam gas industry, largely to support growing LNG exports, is evident in the sharp increase in the number of production wells since 2007–08.

Figure 3.41 CSG and conventional wells drilled, and LNG exports, since 1989–90



Sources: DCCEEW using data from NSW DPIRD, Vic DEECA, WA DMIRS, Qld DNRMMRRD, SA DEM, NT DME, and Tas DSG. LNG exports sourced from REQ (DISR 2025).

Flaring (CRT category 1.B.2.c.ii)

Where there is no market for hydrocarbons separated from the wellhead production stream, the hydrocarbons may be reinjected or flared. 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. Condensates and other petroleum liquids may also be flared in small quantities for disposal. As combustion is involved, the predominant emissions from this category are from CO_2.

In this submission, all flaring sources are reported under CRT category 1.B.2.c.ii. Details on flaring emission factors, including sources and methodology, can be found in Volume 2 of the National Inventory Report 2024 in Annex 5.3.5.5. Details on activity data sources are presented in Volume 2, Annex 5.3.5.6 of the National Inventory Report 2024.

Flaring sources associated with the following production stages are reported under *flaring – oil* (CRT category 1.B.2.c.ii.1):

- crude oil production
- crude oil refining

Remaining flaring sources are reported under *flaring – gas* (CRT category 1.B.2.c.ii.2), including sources associated with:

- oil or gas exploration
- natural gas production
- natural gas processing
- natural gas transmission and storage
- natural gas transmission
- natural gas distribution

Gas flared

Emission factors for CO_2 and CH_4 from gas flared are based on a stoichiometric carbon balance approach applied to the quantity of gas flared. These are described in further detail in Volume 2, Annex V: *Flaring emissions factor methodology (CRT category 1.B.2.c.ii).* The EF for N_2O from gas flared is sourced from E&P Forum (1994). These factors have been applied to the entire time series to maintain consistency.

Liquids flared

Emission factors from liquids flared, which include crude oil and condensates, are sourced from E&P Forum (1994) and were applied to the entire time series for consistency.

Activity data

The quantities of gas and liquids flared are sourced from industry (APPEA) for 1989–90 to 2007–08 and from the NGER scheme for 2008–09 to the current year. Time series consistency is maintained by using consistent methodologies and data over time, and through recalculating whole time series as appropriate when methodologies are improved. For the oil and gas categories where NGER scheme data replaced APPEA data for 2008–09, NGER scheme methodologies were designed to be consistent with those used to compile the previous APPEA inventories. This ensured time series consistency in methodologies and emissions between data collected before and after 2008–09.

Prior to 2008–09, APPEA did not provide splits for flaring between oil and gas sources and, therefore, flaring emissions were reported in the oil/gas combined category. With the introduction of the NGER scheme, separate emissions data became available for the individual oil and gas flaring categories for 2008–09 onwards. Following a previous ERT recommendation (E.13, 2015; E.32, 2014), disaggregation of flaring associated with oil and gas operations was achieved by calculating the average implied emissions per petajoule of crude oil and ORF (oil refinery fuel) produced (AES) for NGER scheme years (2008–09 onwards) and applying this factor back through the production time series (1989–90 to 2007–08). 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.

Oil refinery flaring

The composition of refinery flare feed-gas is highly variable and depends on plant processing, process upsets and flare operation. In this inventory the composition of refinery gas directed to flares is assumed to be 30 per cent CH_4, 30 per cent NMVOCs and 40 per cent H_2 (by volume) (NGGIC 2004). An average flare combustion efficiency of 99.5 per cent is used, in line with IPCC guidance from Section 4.2.2.2, Chapter 4, Volume 2 of the 2006 IPCCC guidelines (IPPC 2006).

For the years 1989–90 to 2007–08, the quantity of gas flared is calculated as 0.6 per cent of the total ABARE annual refinery feedstock as no detailed data has been available on refinery flaring volumes. The methodology (E&P 1994) considered the range and age of technologies of the Australian refining industry and publicly available information on annual flaring emissions from Australian facilities.

Facility level data on flaring volumes became available for the first time in 2008–09 through the NGER scheme. Analysis has shown that facility-level flared quantities are consistent with the assumptions used to derive the activity data prior to 2008–09. Given that flaring quantities depend on facility-specific technology types and processes, as well as the episodic nature of flaring, it was not considered appropriate to interpolate NGER scheme activity data back through the time series.

3.3.2.3 Uncertainty assessment and time-series consistency

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

The CO_2 IEF time series for *1.B.2.b.iii. Processing* exhibits time series anomalies in more recent years, with higher values resulting from 2019–20 onwards. Prior to 2019–20, the IEF had an average of 0.27 kilograms of CO_2 per tonne of natural gas processing throughput before rising to an average of 53.89 kilograms of CO_2 per tonne of natural gas processing throughput between 2019–20 and 2022–23. This change reflects the accounting style inherent in the Common Reporting Tables (CRTs) concerning the way CO_2 recovery is accounted for.

Australia has reported CO_2 recovery from carbon capture and storage activities commencing at Gorgon LNG on Barrow Island, Western Australia (Chevron 2024b) against the activity *1.B.2.b.iii. Processing.* The rationale is that, as part of Gorgon LNG's processing activities, a share of the CO_2 stripped from the unprocessed gas stream is recovered for storage.

The calculation of IEFs from CRT data treats recovered gases as emissions that would have otherwise occurred, reflecting the emissions intensity of activities were the recovery not to have occurred. As leakage emissions from gas processing are comparatively minor, the captured CO_2 line item overpowers them in the IEF in years that recovery occurs.

Without the inclusion of the CO_2 recovery, the IEF for 1.B.2.b.iii between 2019–20 and 2022–23 has an average of 0.29 kilograms of CO_2 per tonne of natural gas processing throughput. This is in line with the 1989–90 to 2018–19 time series average of 0.27 kilograms of CO_2 per tonne and gives Australia confidence that the time series is consistent.

For further information on carbon capture, usage, and storage practices in Australia please refer to Chapter 3.4.

3.3.2.4 Category-specific QA/QC and verification

Fugitive emissions from oil and gas extractions are covered by the general greenhouse gas inventory QA/QC Plan summarised in NIR Volume 2, Annex IV.

Implied emission factors

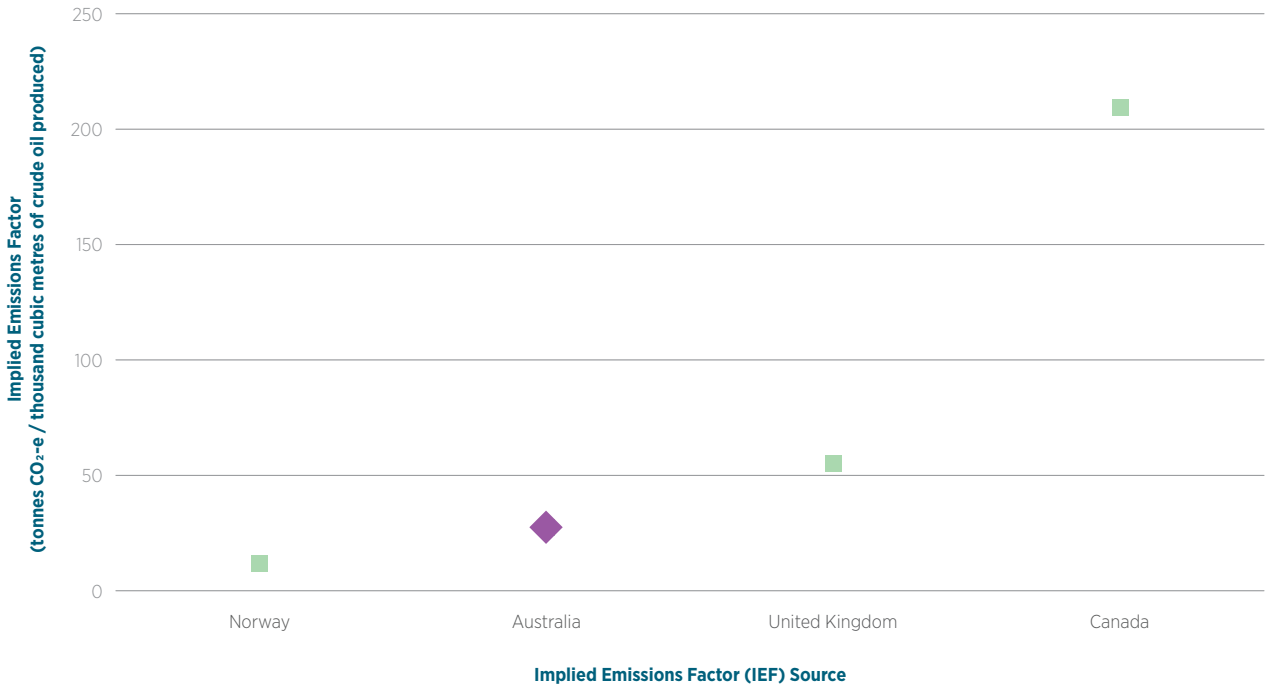
International comparability

Australia primarily uses country specific EFs and Tier 2 IPCC methods to estimate fugitive emissions from oil and natural gas extraction. The 2006 IPCC guidelines (Volume 1, Chapter 6, Section 6.10, IPCC 2006) provides verification methods for increasing the confidence in inventory methods.

Australia's 2023–24 oil and natural gas implied emissions factors have been presented in Figures 3.42 and 3.43 alongside several Parties' 2025 implied emissions to assess comparability, as per the *comparisons of intensity indicators between countries* method (Volume 1, Chapter 6, Section 6.10.1, IPCC Guidelines 2006). In the absence of available data through the UNFCCC Secretariat's locator tool, Norway, Canada, and the United Kingdom's implied emissions were selected for comparison. These Parties were chosen as they are all developed country Parties with mature oil and gas industries with reporting practices comparable to Australia's estimates.

Figure 3.42 presents the oil production implied emission factors (IEF's) for Australia (2026 submission, 2023–24 inventory year) alongside the comparison Parties (2025 submission, 2023 inventory year). The oil production IEF's include the total of oil production fugitive emissions, including all leakage, venting, and flaring. The IEF's were calculated by taking the total oil production fugitive emissions per thousand cubic metres of crude oil produced for each Party in the relevant period.

Figure 3.42 Implied Emission Factor (IEF) comparison between Australia, United Kingdom, Canada, and Norway for oil production fugitive emissions



Source: National Inventory Report 2024 submissions, and associated Common Reporting Tables (CRT's). United Kingdom, Norway, and Canada – Most recent emissions and activity data taken from Party's CRT's (UNFCCC, last accessed 2025) for the 2023 year (2025 submission), converted to the unit of tonnes of emission per thousand cubic metres of crude oil produced.

Australia's 2023–24 oil IEF is 25.3 tonnes CO_2-e per thousand cubic metres of crude oil produced. Australia's IEF is consistent with the oil IEFs from the other Parties (excluding Canada, which appears to be an outlier), falling in the middle of the grouping. It is the second-lowest IEF with only Norway lower with a 2023 IEF of 9.7 tonnes CO_2-e per thousand cubic metres of crude oil produced.

Figure 3.43 shows the natural gas production IEF's for Australia (2026 submission, 2023–24 inventory year) alongside the comparison Parties (2025 submission, 2023 inventory year). The natural gas production IEF's include the total of natural gas production fugitive emissions, including leakage, venting, and flaring. The IEF's were calculated by taking the total natural gas production fugitive emissions per million cubic metres of natural gas produced for each Party in the relevant period.

Figure 3.43 Implied Emission Factor (IEF) comparison between Australia, United Kingdom, Canada, and Norway for natural gas fugitive emissions



Source: National Inventory Report 2024 submissions, and associated Common Reporting Tables (CRT's). United Kingdom, Norway, and Canada – Most recent emissions and activity data taken from Party's CRT's (UNFCCC, last accessed 2025) for the 2023 year (2025 submission), converted to the unit of tonnes of emission per million cubic metres of natural gas produced.

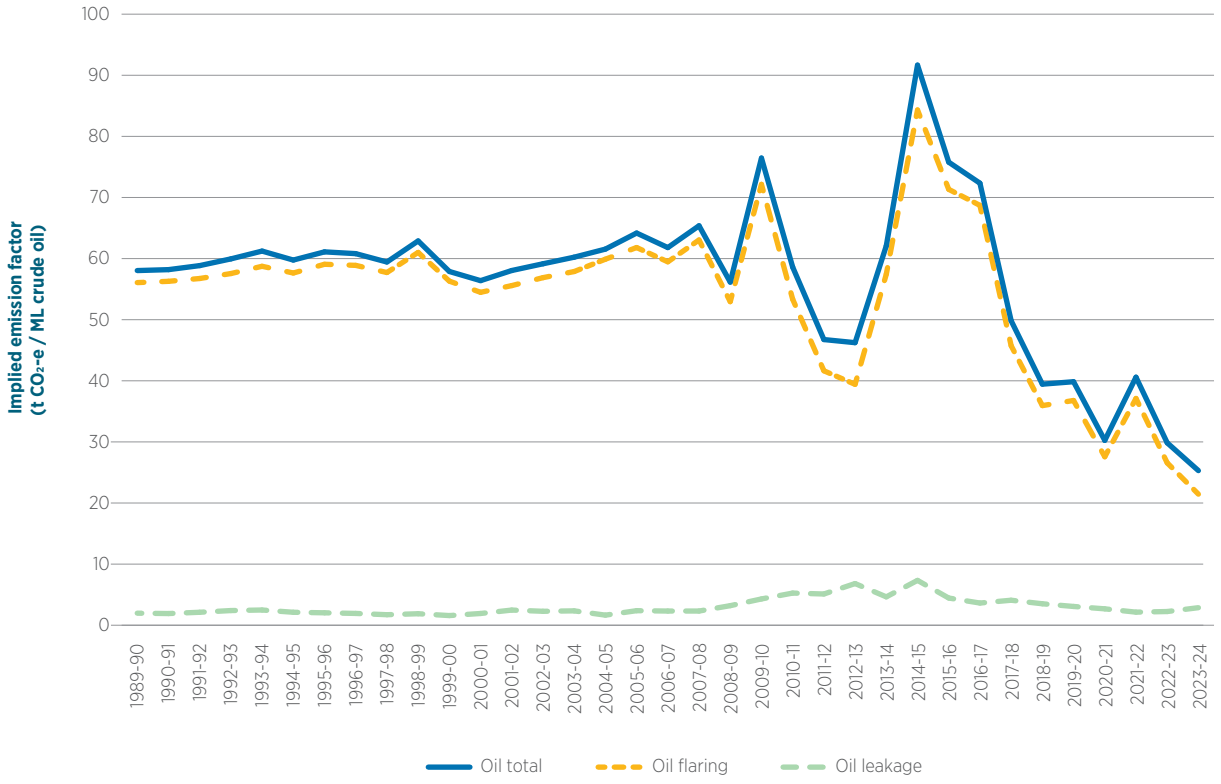
Australia's 2023–24 natural gas IEF is 135.3 tonnes CO_2-e per million cubic metres of natural gas produced. Australia's IEF is consistent with the natural gas IEFs from the comparison Parties, falling in the middle of the grouping (excluding Norway, which appears to be an outlier). Australia has the second-highest IEF, but is quantitively close to Canada's value (123.6 t CO_2-e per million cubic metres of natural gas production) and the United Kingdom's (138.4 t CO_2-e per million cubic metres of natural gas production). Norway's IEF (6.3 t CO_2-e per million cubic metres of natural gas production) is considerably lower than all other Parties reflecting the significant CO_2 recovery of 766.1 kilotonnes CO_2 in 2023.

Time series consistency – trends in implied emission factors

Estimates were tested for time series consistency in accordance with the QA/QC Plan and IPCC guidance (Volume 1, Chapter 6, 2006 IPCC Guidelines). The production IEF's for Australia's fugitive oil and gas emissions were analysed across the time series to validate emission trends. This was completed for oil and gas emissions separately on a total emissions basis and by individual leakage, *venting*, and *flaring* subsectors. The IEF's were calculated using national production data from the September 2025 Resource and Energy Quarterly (DISR 2025).

Figure 3.44 presents the oil production IEF's by total fugitive emissions and by leakage, *venting* and *flaring* separately. The intensity of fugitive oil emissions fluctuated over the time series, driven by oil-related flaring activities. This is because *flaring* is the dominant emissions source in Australia's fugitive oil emissions. Such activities are typically quite variable, which is reflected in the inter-annual time series variations. Australia's oil industry is smaller than its natural gas counterpart, something which has becoming increasingly true over time as indigenous oil production has declined and domestic natural gas production has increased (REQ 2025). Decreasing oil activity has resulted in the emissions intensity of oil becoming increasingly susceptible to fluctuations over time. Overall, the total and *flaring* emissions intensities have both declined across the time series.

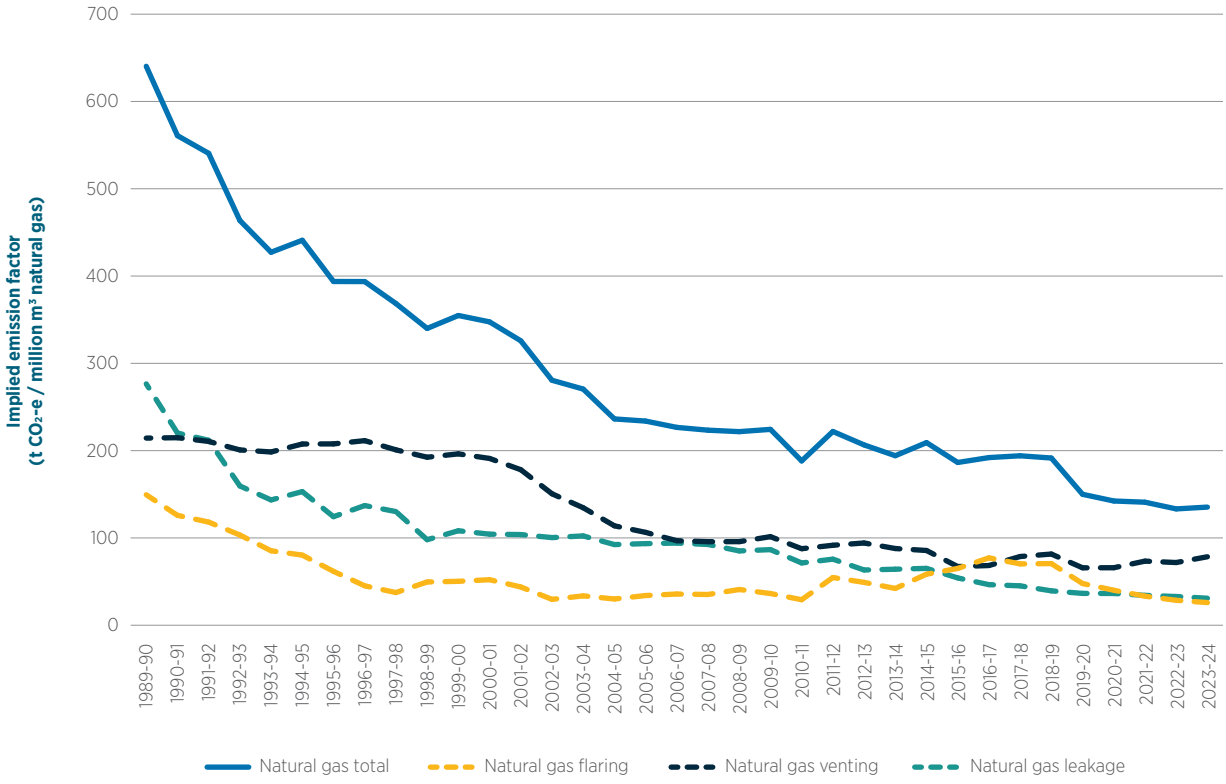
Figure 3.44 Oil implied emission factors by leakage, venting, flaring, and total emissions, 1989–90 to 2023–24



Source: Production data are sourced from the September 2025 REQ (DISR 2025)

Figure 3.45 presents the natural gas IEF's by total fugitive natural gas emissions and by leakage, *venting* and *flaring* separately. The total fugitive natural gas IEF trends down with time despite increasing natural gas production. This follows the expansion of LNG operations in Australia, with large and efficient LNG facilities stabilising in their operations alongside distribution network improvements and shifts away from flaring activities. These factors work in tandem to contribute to the reduction of Australia's natural gas IEF. The individual subsector IEF's also trend downwards across the time series, reflecting the same reductions as the total IEF with emissions intensity decreasing as Australia's natural gas industry has increased in scale.

Figure 3.45 Natural gas implied emission factors by leakage, venting, flaring, and total emissions, 1989–90 to 2023–24



Source: Production data are sourced from the September 2025 REQ (DISR 2025)

Comparison between inventory and top-down studies of Australian coal seam gas field

Results from top-down studies and inverse modelling of CH_4 in Australia's coal seam gas (CSG) fields have been used for QA for validation of national inventory estimates. Australia's CSG fields in the Surat Basin of Queensland generate CH_4 emissions from gas leakages, deliberate losses from gas venting or flaring, and from incomplete oxidation of gas during combustion.

In Australia's national inventory, methane losses from CSG production are estimated to be 0.40 per cent of gas production for the upstream supply chain and 0.56 per cent of gas production for the export supply chain in Australia.

Independent assessments of CH_4 losses from CSG operations in the Surat Basin have been undertaken by researchers at the CSIRO Atmospheric Division (Luhar, A. et al. 2020), and at the UNSW, sponsored by the UN Environment Program (Neininger, et al. 2021). These studies use techniques that attempt to monitor the CH_4 plumes observed in the Surat Basin directly (known as a top-down approach). Working under the Gas Industry Social and Environmental Research Alliance (GISERA) program, the CSIRO study used flux towers stationed at different points in the Basin while the UNEP study used plane flyovers to map and quantify the extent of the CH_4 plumes observed in the Surat Basin.

The CSIRO GISERA program made its own assessment of the extent of the CH_4 losses from CSG production in the Surat Basin, derived from the work of the CSIRO Atmospheric Division, and concluded that CH_4 losses were less than 0.5 per cent of natural gas production (CSIRO GISERA 2019). The UNEP study concluded that CSG sources in the Surat Basin emit about 0.4 per cent of the produced gas (Neininger et al. 2021).

The convergence of CH_4 loss results from both the CSIRO GISERA assessment and the UNEP study with the national inventory provides strong quality assurance that the national inventory estimates of methane losses from CSG gas supply are robust.

3.3.2.5 Category-specific recalculations

Data across the time series are reviewed and improved annually to:

- improve accuracy,
- incorporate revised time series of activity data, and
- implement improved emissions estimation methodologies.

The primary recalculations reported in the current submission are shown in Table 3.39, with the explanations provided below the table.

Table 3.39 1.B.2 Oil and Natural Gas: recalculation of total CO_2-e emissions, 1989–90 to 2022–23

	2025 submission	2026 submission	Change		Reasons for recalculation (Gg CO_2-e)					
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%	A	B	C	D	E	F
1989–90	14,881	14,834	-47.0	-0.3%	-	-	7.5	-56.4	3.8	-0.6
1994–95	14,913	14,857	-55.4	-0.4%	-	-	7.3	-63.3	2.4	-0.7
1999–00	14,348	14,286	-61.3	-0.4%	-	-	5.3	-67.6	2.6	-0.8
2004–05	11,565	11,512	-53.7	-0.5%	-	-	11.1	-62.1	-0.8	-0.8
2005–06	11,660	11,616	-44.2	-0.4%	-	-	13.7	-56.8	0.7	-0.8
2006–07	12,119	12,088	-30.7	-0.3%	-	-	12.5	-42.6	1.4	-0.4
2007–08	12,367	12,335	-32.1	-0.3%	-	-	27.3	-59.3	1.5	-0.4
2008–09	12,615	12,601	-14.1	-0.1%	-	-	28.8	-42.7	1.7	-0.9
2009–10	13,285	13,276	-8.3	-0.1%	-	-	29.1	-37.7	2.0	-0.8
2010–11	12,449	12,437	-11.8	-0.1%	-	-	24.3	-35.7	0.8	-0.6
2011–12	13,380	13,371	-9.0	-0.1%	-	-	26.6	-34.9	0.9	-0.6
2012–13	14,007	14,010	2.9	0.0%	-	-	34.4	-30.5	0.6	-0.7
2013–14	13,899	13,913	14.0	0.1%	-	-	43.6	-29.2	1.9	-1.3
2014–15	16,151	16,163	12.0	0.1%	-	-	36.8	-25.5	2.2	-0.7
2015–16	17,833	17,837	4.2	0.0%	-	-	27.8	-24.0	1.4	-0.7
2016–17	21,384	21,381	-2.4	0.0%	-	-	19.1	-21.8	1.7	-1.1
2017–18	23,559	24,113	553.5	2.3%	537.7	-	25.5	-10.9	3.9	-2.7
2018–19	27,972	28,525	553.3	2.0%	553.4	-	16.9	-16.0	2.0	-3.0
2019–20	23,924	24,494	569.3	2.4%	559.8	-	25.0	-15.0	2.3	-2.9
2020–21	21,497	22,076	579.2	2.7%	571.7	-	20.0	-12.2	2.2	-2.4
2021–22	23,086	23,622	535.9	2.3%	816.0	-317.4	-22.4	61.3	1.5	-3.0
2022–23	22,079	22,292	213.3	1.0%	558.8	-338.1	-27.3	18.3	3.4	-1.8

A. Update to flaring for NGER scheme emissions reported under higher order NGER methods, from 2017–18 to 2023–24

For 2008–09 onwards, the NGER scheme has been the primary source of activity data for flaring of gas emissions (see Flaring (CRT category 1.B.2.c.ii) for more details). Under the NGER scheme, facilities report emissions using Method 1 or higher-order methods (i.e. Methods 2–4). These method numbers differ from IPCC method tiers, as outlined in the NIR 2024, Volume 2, Annex 5.1.

Most oil and gas facilities report flaring emissions using an NGER scheme Method 1. A small number of facilities have transitioned from Method 1 to higher order NGER scheme methods during their reporting history, creating time series inconsistencies. These changes result in reporting-method introduced apparent variations in emissions that do not reflect actual changes in underlying activity or emissions trends. In previous submissions, higher-order flaring emissions data from the NGER scheme were incorporated directly as reported. An internal review identified this approach as inconsistent with IPCC guidance on time series consistency (IPCC 2006, Volume 1, Chapter 5).

For this submission, quantity of gas flared from the higher order NGER scheme methods were used to construct an emissions time series using the flaring estimation method described in Section 3.3.2.2 (Flaring (CRT category 1.B.2.c.ii)). This adjustment ensures methodological consistency across all years. The update affects flaring emissions estimates for years 2017–18 through 2023–24.

Subject to resource availability and priorities, consideration will be given to further analysis of higher-order NGER data to assess the feasibility of applying back-casting adjustments in accordance with IPCC guidance (IPCC 2006, Volume 1, Chapter 5).

B. Removal of duplicated condensate venting sources for 2021–22 and 2022–23

Prior to 2021–22, the NGER scheme did not cover venting emissions associated with the production of condensates. In prior NIR submissions, these emissions across the time series were estimated using production data published by the Australian Petroleum Statistics (APS) (DCCEEW 2025b) (also see Venting from condensate production). The scope of the NGER Measurement Determination was expanded from 2021–22 reporting to include venting emissions from condensate production.

From 2021–22 onwards, facility-level condensate data reported under the NGER scheme were incorporated into the inventory. However, emissions estimated under the previous method were also included, resulting in duplication (i.e. an unintentional over-estimation of emissions occurring under this source).

In this submission, duplicated condensate venting sources estimated using APS data for 2021–22 and 2022–23 were removed. This adjustment ensures that inventory estimates accurately reflect emissions with neither an under- or over-estimate.

Subject to resource availability and priorities, the time series will be reviewed to assess time series consistency between the newer NGER-based data and the previous estimation method, in line with IPCC guidance (IPCC 2006, Volume 1, Chapter 5).

C. Activity data and emission factor revisions for exploration-related venting

In this submission, there was two updates made to venting during oil and gas exploration.

Activity data updates for mud degassing

Emissions from mud degassing uses the annual number of drilling days as activity data across the time series. Surrogate data sources are used to estimate the number of drilling days per year.

In prior submissions, annual counts of wells drilled was used as a surrogate dataset to estimate the number of drilling days. The annual well counts were sourced from a variety of industry and jurisdictional government sources (APPEA 1990–2015, DTI 2017, DNRM 2017). This was done for 1989–90 to 2017–18. From 2018–19 onwards, the surrogate data was changed from counts of wells drilled to annual exploration expenditure data reported by the Australian Bureau of Statistics (ABS 2023b). No adjustments were made when the surrogate data was changed from annual counts of drilled wells to annual exploration expenditure. The lack of adjustment resulted in a time series inconsistency.

In this submission, a new time series of wells drilled per year was compiled from state and territory drilling datasets (NSW DPIRD 2025, Vic DEECA 2025, WA DMIRS 2025, Qld DNRMMRRD 2025, SA DEM 2025, NT DME 2025, and Tas DSG 2025). The new annual count of wells drilled time series was used as a surrogate data series to estimate an annual count of drilling days. This method was applied to the whole time series to ensure methodological consistency. The full mud degassing method used in this submission is described in Venting (CRT category 1.B.2.c.i), Mud degassing.

Subject to resource availability and priorities, the assumptions used to derive the number of drilling days from counts of wells drilled will be reviewed for accuracy, in line with IPCC guidance (IPCC 2006, Volume 1, Chapter 6).

Emission factors for completions and workovers

Well completions and well workovers are estimated using technology-specific EFs, corresponding to the different technologies used in completion and workover activities.

It was found that in previous submissions, some EFs were applied to activity data that did not match the EF's technology type. This led to an underestimate in emissions from well completions and workovers.

In this submission, the method was updated to correctly apply EFs to the corresponding activity data. Estimates now accurately reflect the different completion and workover technology types and the frequency of the technologies used. The update better aligns better with the Paris Agreement TACCC principles for methodological transparency and accuracy.

More details on the different technology types and the corresponding methods for well completions and workovers can be in Well completions and workovers.

D. Updates to flaring of gas

Two updates have been made in this submission to the flaring of gas methods; one to the crude oil refining oxidation factor and one to the nitrous oxide emission factor.

Revised crude oil refining flaring oxidation factor

Gas flaring as part of crude oil refining processes typically has a combustion efficiency higher than gas flaring during other oil and gas operations. To reflect this, the gas flaring emission factor (EF) for crude oil refining was updated in this submission from a flaring destruction efficiency of 0.98 to 0.995, in line with IPCC guidance (Section 4.2.2.2, Chapter 4, Volume 2, 2006 IPCCC guidelines). This change improves the accuracy of refinery flaring estimates by better reflecting industry practices.

Revised nitrous oxide flaring emission factor

The EFs for gas flaring were updated using a stoichiometric method in the 2025 submission. This change was subsequently included in the NGER scheme amendments for the 2025–26 reporting year. Public consultation during the NGER scheme amendment process highlighted a minor revision to the nitrous oxide (N_2O) flaring factor and this revision has been included in the current submission. The amended factor no longer applies the flaring destruction efficiency to N_2O emissions. This change improves the accuracy of N_2O flaring estimates by reflecting current understanding that N_2O emissions from gas flaring are primarily influenced by the flare temperature and the quantity of nitrogen containing compounds present.

E. Revised crude oil transport activity data

Australia's oil industry has changed substantially in recent decades as indigenous production has declined, and domestic refineries have closed. This has had flow-on effects to the transport of crude oil within Australia. Further information on the nature of Australia's oil industry can be found in Section 3.3.2.2, Oil (CRT category 1.B.2.b).

The crude oil transport method in prior submissions used statistics on crude oil production and sales in Victoria, relying on assumptions about production and transport in the state that no longer reflect the nature of the industry. Most notably, Victoria's oil production has declined over time (AES Table I3, DCCEEW 2025a), meaning that activity in Victoria contributes less to oil transport trends in recent years. This has resulted in the previous method under-estimating emissions for 2022–23 and 2023–24, providing trend that did not match expectations.

The crude oil transport method was updated in this year's submission to better reflect the changes in the oil industry. A new activity data time series was created using crude oil transport volumes reported by facilities through the NGER scheme from 2011–12 onwards. This was interpolated back to 1989–90 using the surrogate data method from IPCC guidance (Volume 1, Chapter 5, Section 5.3.3.2, 2006 IPCC Guidelines).

By using NGER scheme facility-level data, the new crude oil transport method better reflects the underlying emissions intensive activities than state level statistics. As a national reporting scheme, the change to NGER scheme data implicitly includes transports activities from other states. This update better aligns with the Paris Agreement TACCC principles for methodological accuracy and completeness.

F. Activity data updates to post meter gas and abandoned oil and gas wells for full time series

Fugitive oil and gas estimates use a number of external data sources that undergo regular updates and revisions (for example, the Australian Energy Statistics time series). There has been several minor time series updates in this submission as a result of updating to the latest time series of these data sources. This includes emissions from:

- distribution of oil products
- post meter gas
- abandoned oil and gas wells

Time series consistency is upheld in these sources by using a consistent input across their time series. Use of the latest data also ensures that estimates reflect up-to-date understandings and inputs, enhancing the accuracy in line with the Paris Agreement TACCC principles.

Other improvements – Venting and flaring reallocations, no net change to emissions

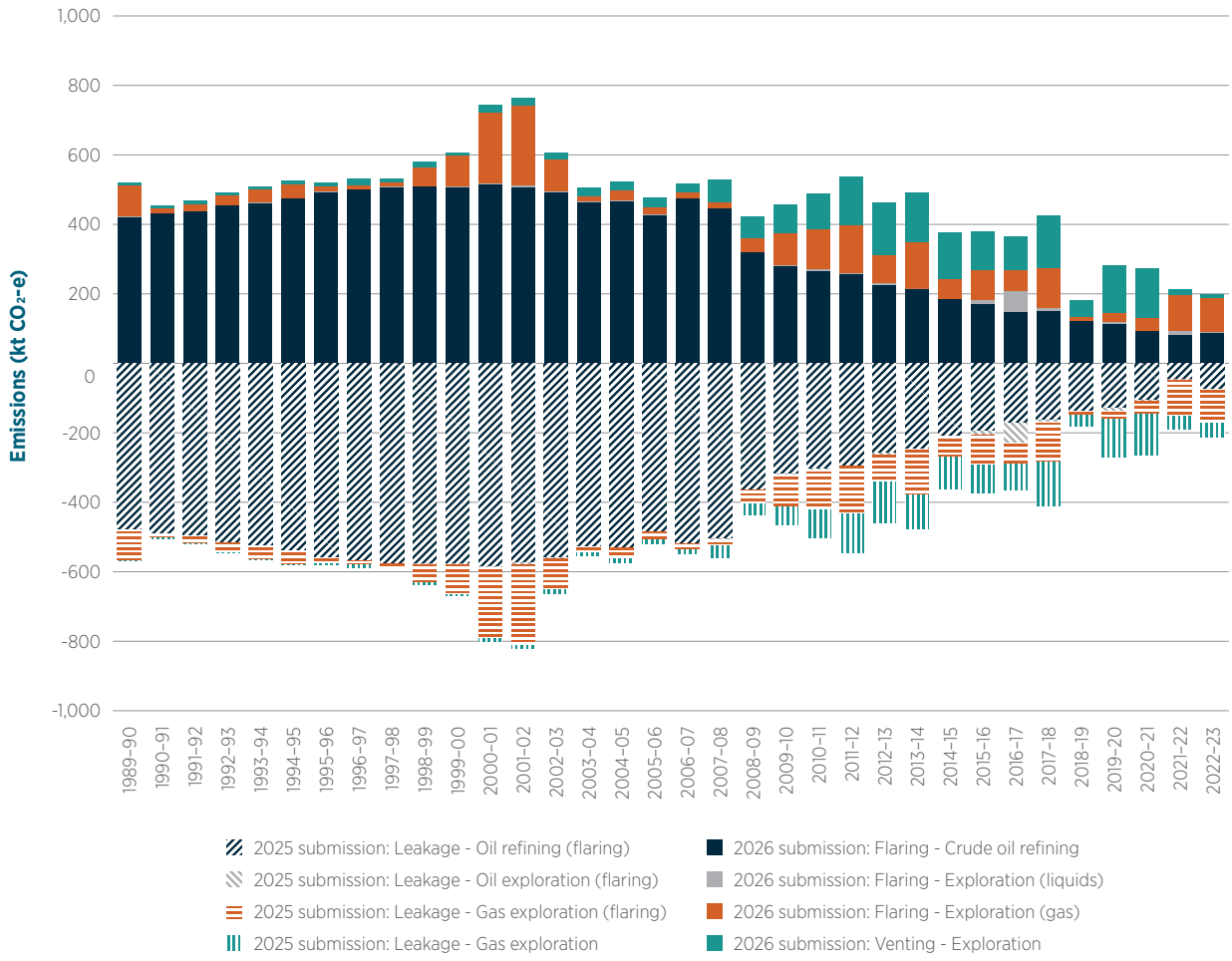
According to IPCC guidance, (Vol 2, Chapter 4, Table 4.2.1, IPCC 2006) all *venting* and *flaring* emission sources should be allocated under the respective *venting* sector (CRT category 1.B.2.c.1) or *flaring* sector (CRT category 1.B.2.c.2).

In previous submissions, Australia reported several venting and flaring emissions sources under leakage sectors (CRT categories 1.B.2.a and 1.B.c.b). In this submission, these emission sources were reallocated to the relevant *venting* and *flaring* sector to better align with IPCC guidance. The emissions that were reallocated were:

- flaring activities as part of oil exploration (previously CRT Category 1.B.2.b.i)
- flaring activities as part of gas exploration (previously CRT Category 1.B.2.a.iii)
- flaring of gas as part of crude oil refining (previously CRT Category 1.B.2.a.iii)
- emissions from well workovers, well completions and mud degassing (previously CRT Category 1.B.2.b.i)

There was no net change in emissions for these sources as part of this reallocation. The only change in fugitive oil and gas emissions this submission were from other updates, as shown in Table 3.39 and as described earlier in Section 3.3.2.5. Figure 3.46 shows the decrease in leakage sectors against the increase *venting* and *flaring*, demonstrating there has been no net change in emissions.

Figure 3.46 Comparison of 2025 and 2026 submission venting and flaring allocations by sector



Including the aforementioned sources under CRT category 1.B.2.c *venting and flaring* improves the comparability of Australia's reporting by improving alignment with the IPCC guidance (Vol 2, Chapter 4, Section 4.2.1, IPCC 2006).

IPCC guidance also states that the emission sources should be allocated by oil and gas systems, depending on where the activity occurred. For oil systems, this includes CRT categories:

- 1.B.2.c.1.i, under *venting*
- 1.B.2.c.2.i, under *flaring*

For gas systems, this corresponds to CRT categories:

- 1.B.2.c.1.ii, under *venting*
- 1.B.2.c.2.ii, under *flaring*

In previous submissions, flaring of liquids and crude oil was allocated to CRT category 1.B.2.c.ii.1 *oil* and flaring of gas was allocated 1.B.2.c.ii.2 *gas*. This was regardless of whether the activity occurred as part of oil production or a gas production.

Emissions were reallocated in this submission under Flaring (CRT category 1.B.2.c.ii) according to which system (oil or gas) they occur under. This improves both consistency with IPCC Guidance (Volume 2, Chapter 4, Section 4.2.1, 2006 IPCC guidelines) and comparability with other Parties' submissions.

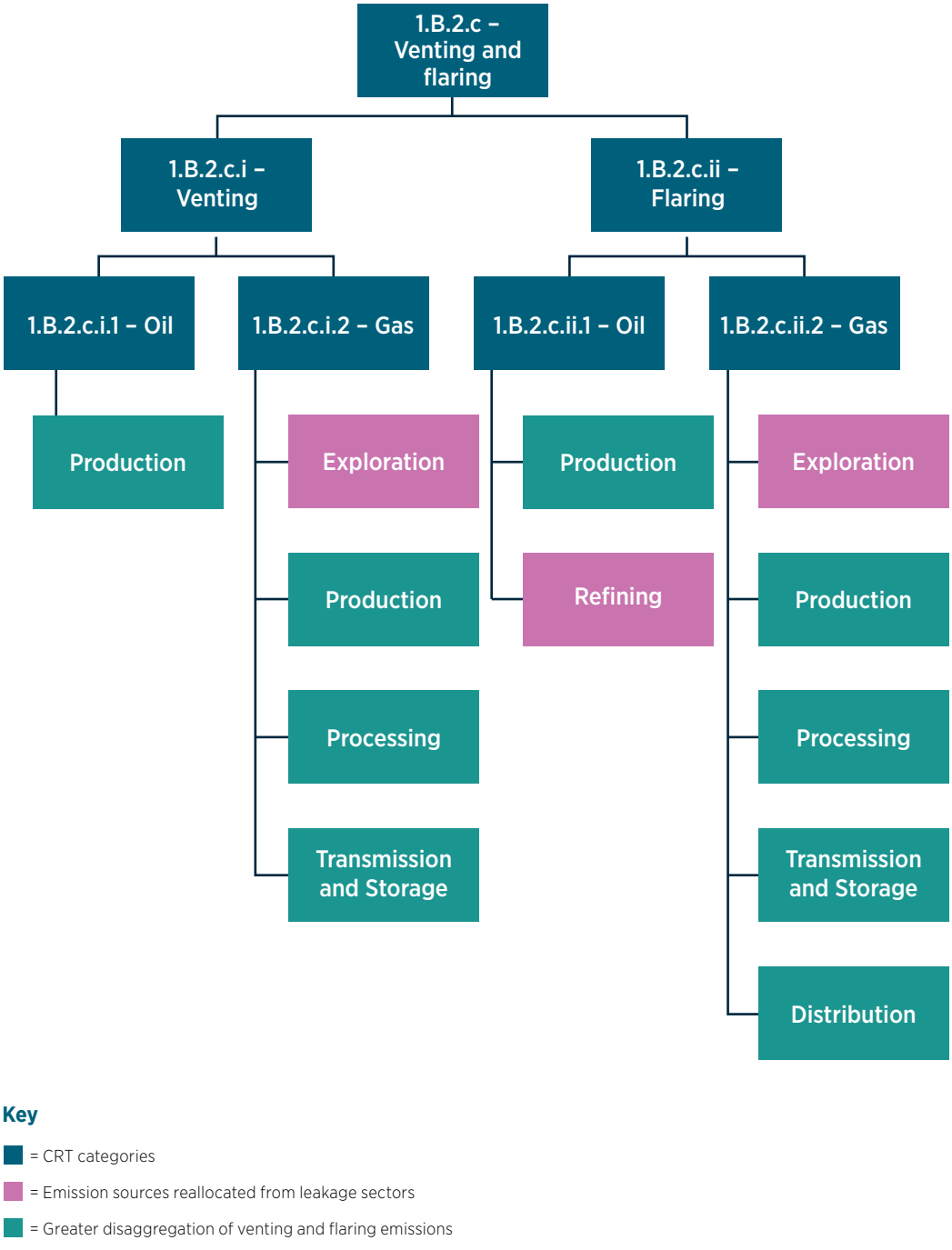
Flaring reallocations included the following:

- flaring activities associated with *crude oil production* and refining has been consolidated under CRT category 1.B.2.c.ii.1
- flaring activities associated with *natural gas production*, *processing*, *transmission* and *distribution* have been consolidated under 1.B.2.c.ii.2

The reallocation of flaring activities by system enhances the comparability of Australia's reporting as per the Paris Agreement TACCC principles. Further information on the allocation of flaring emissions can be found in Flaring (CRT category 1.B.2.c.ii).

Figure 3.47 summarises the allocation of venting and flaring emission sources and indicates where a sector has been reallocated from leakage categories. Further information on reporting can be found in Oil and gas production venting and flaring (CRT category 1.B.2.c).

Figure 3.47 Venting and flaring emission sources with reallocated sources



Note: This diagram shows the CRT categories reported by Australia for 1.B.2.c *venting and flaring*. Below the lowest level of each CRT category is the emission sources that Australia has allocated to these sectors. Whilst the CRT's do not allow inclusion of this additional breakdown of emissions, they can be viewed on the Australian National Greenhouse Accounts (ANGA) interactive online database.

3.3.2.6 Category-specific planned improvements

Not estimated (NE) leakage emissions

In this submission, there are no emissions reported for the following sources:

- CO_2 leakage for CRT category 1.B.2.a.iii *crude oil transport*
- CO_2 leakage from natural gas storage stations, a source in CRT category 1.B.2.b.iv *transmission and storage*

Australia has reported these sources as not estimated (NE). Further details on the NE sources and their estimated size can be found in Chapter 1, Sections 1.7.3 and 1.7.4.

Subject to resources and priorities, further research will be undertaken to determine if emissions from these sources occur in Australia with a view to ensure completeness of inventory estimates.

Oil and gas exploration leakage emissions

In this submission, there are no emissions reported under either 1.B.2.a.i. *oil exploration* and 1.B.2.b.i *gas exploration* as these are included elsewhere (IE). As part of this submission, emissions from well workovers, well completions and mud degassing were moved from 1.B.2.b.i *natural gas exploration* to 1.B.2.c.i.2 *natural gas venting*. The 2006 IPCC guidelines state that emissions from these sources should be reported under the associated leakage sector. Australia intends to review the allocation of these sources to *venting* in a future submission with a view to ensure comparability between all items, dependent on resources and priorities.

Produced water from CSG

From 2020–21 onwards, Australia has directly incorporated NGER scheme facility-level data on CSG produced water volumes. No adjustments were made between the NGER reported data and the prior methods. Dependent on resources and priorities, Australia intends to review the activity data time series with a view to ensure time series consistency for all years.

Review of new NGER scheme data

The National Greenhouse and Energy Reporting Act 2007 requires all major companies in Australia to make estimates of CH_4 emissions from their gas supply operations. The NGER scheme methods for estimating fugitive CH_4 emission losses were updated in 2021. The updated methods significantly improved the granularity of natural gas production and processing reporting, drawing on domestic and international research, including results of Leak Detection and Repair programs (Australian Government 2021). Data using these methods were first reported through the NGER scheme in October 2022 covering the 2021–22 reporting year. Dependent on resources and priorities, these new data will continue to be analysed with a view to incorporate them in future submissions once there are sufficient data available to establish a consistent and appropriate time series.

Review of new scientific information

The CSIRO GISERA program is also undertaking a new 'bottom-up'' empirical study examining leakage measurements of CSG equipment at sites in the Surat Basin (CSIRO GISERA 2025). This study will provide additional data on leakage rates of equipment in Australian conditions and will add significantly to the existing empirical knowledge base. The department expects this study will provide valuable data to inform the development of leakage factors for future national inventory method updates.

New approaches to estimating fugitive methane emissions by combining atmospheric detection of CH_4 with modelling and other analysis (top-down approaches) are rapidly developing. The Australian Government has established an Expert Panel on Atmospheric Measurement of Fugitive Methane Emissions in Australia to provide evidence-based advice to government on:

- the current scientific understanding of top-down approaches, and their application and availability in Australia;
- the role top-down approaches could play in the NGER scheme, and the national inventory more broadly; and,
- the improvements in scientific understanding, technology, and Australian capability that are needed to enable optimal use of top-down approaches into the future in the NGER scheme and/or the national inventory more broadly.

The Panel's advice to government will be considered in future national inventory method development as part of the inventory's continuous improvement processes.

3.4 Carbon Dioxide Transport and Storage (CRT category 1.C)

3.4.1 Category description

The 2006 IPCC Guidelines define carbon capture and storage (CCS) as a chain subdivided into four systems – capture and compression, transport, injection, and geological storage.

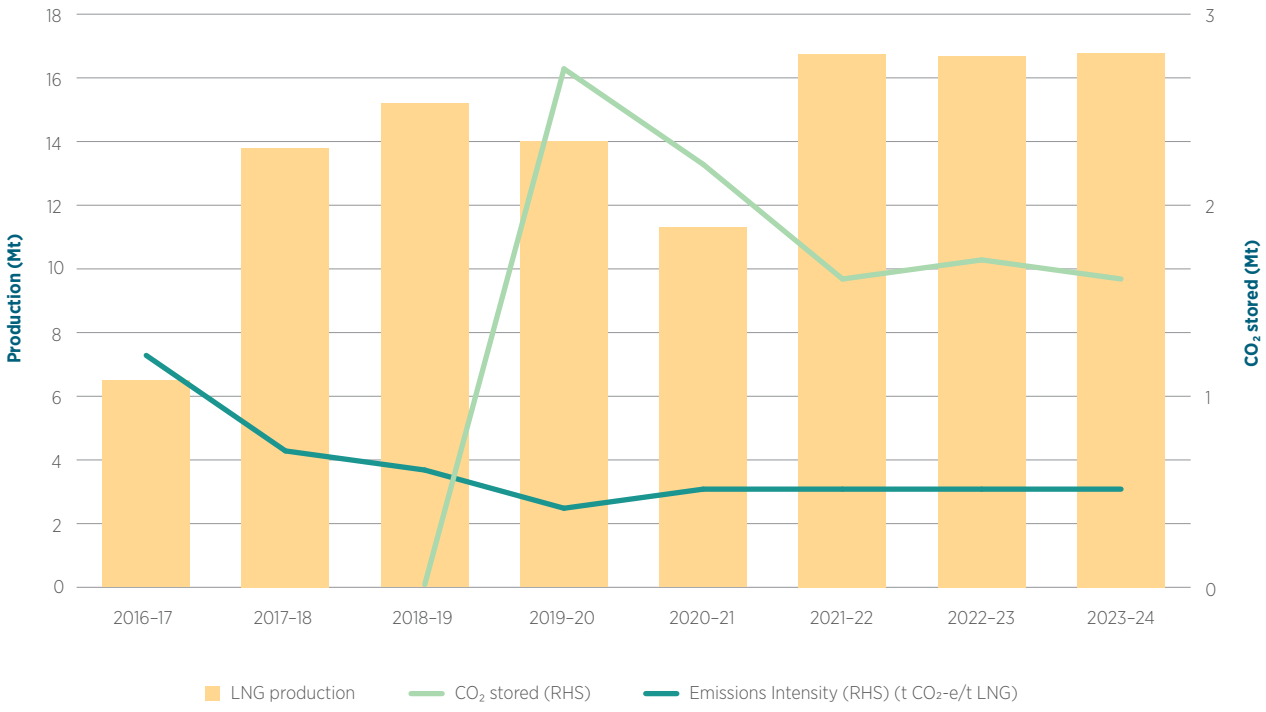
Existing projects

There are two commercial CCS projects currently operating in Australia, with one project operating within the relevant time period for this submission.

The Gorgon Project has been operating since 2019, by Chevron Australia. The project commenced LNG exports in March 2016, with trials of the CO_2 underground injection system commencing in August 2019.

With increased LNG production (resulting in increased fuel gas usage) and lower CO_2 injection than planned from 2021–22, emissions intensities have been increasing from the level achieved in 2019–20 (Figure 3.48).

Figure 3.48 Gorgon LNG production and CO_2 injected for storage



Source: Production at Gorgon LNG facility data from EnergyQuest Reports. Note that CO_2 injection began in August 2019, and therefore injection did not occur prior to 2019–20.

Carbon dioxide is separated from the natural gas and captured at the Barrow Island gas processing plant and transported by a 7 km 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 several surveillance wells and seismic surveying.

In October 2024 Santos commenced injection at their Moomba CCS project, with an expected 1.7 Mt per annum injection and potential for up to 20 Mt pa from planned future stages which may include CO_2 imported from Japan and Republic of Korea. Activity data and emissions from the Moomba CCS project will first be included in Australia's inventory in the next submission.

The Moomba CCS project is a depleted gas field storage, utilising the geological formations that have been producing natural gas since the 1960s. Like Gorgon, it is storing CO_2 that has been separated from natural gas at an adjacent gas processing plant and includes long term monitoring via surveillance wells and seismic surveying.

The project also has potential to incorporate CO_2 storage from Direct Air Capture and SCR Hydrogen production.

Research projects

Carbon dioxide Cooperative Research Centre (CO_2CRC) operates the Otway International Test Centre in Nirranda South in Victoria (CO_2CRC 2022 to 2023). This CCS demonstration and research program commenced CO_2 sequestration in 2006. The project has injected small quantities of gas since commencement, including:

- 65,000 tonnes of CO_2-rich gas into 25-metre-thick sandstone at a depth of 2,000m between 2006 and 2011,
- 150 tonnes of pure CO_2 and 450 tonnes of CO_2 saturated formation water into a single well in 2011,
- 15,000 tonnes of CO_2-rich gas into the Paaratte Formation saline aquifer in 2016, and
- 15,050 of buttress gas into the Paaratte Formation saline aquifer in 2020–21.

This demonstration project does not constitute a CCS activity in accordance with the 2006 IPCC Guidelines (IPCC 2006) (Volume 2, Chapter 5, Section 5.3) because naturally occurring CO_2 is extracted from a geological reservoir of CO_2 and is not captured for abatement purposes. The CO_2 is dried, purified, and transported by a short 2 km pipeline for reinjection into a nearby depleted natural gas field and a deeper saline aquifer. This research project is reinjecting small quantities of naturally occurring reservoir CO_2 that has been extracted from nearby geological formation and does not involve capture or abatement. An insignificant quantity of fugitive emissions would be associated with the processing, transport, and reinjection. Australia does not estimate emissions from this project.

3.4.2 Methodological issues

In line with the 2006 IPCC Guidelines (IPCC 2006) (Volume 1, Chapter 5, Section 5.7), Australia uses Tier 3, facility-specific modelling to estimate emissions from this category.

Table 3.40 Summary of methods and emission factors: Carbon Dioxide Transport and Storage

	CO_2	
1.C Carbon Dioxide Transport and Storage	**Method applied**	**Emission factor**
1 Transport of CO_2	T3	PS
2 Injection and Storage	T3	PS
3 Other	NO	NA

T3 = Tier 3, PS = plant specific, NO = not occurring, NA = not applicable, IE = included elsewhere, = key category

Emissions data from commercial CCS projects is collected under the NGER scheme. The NGER scheme provides methods for estimating emissions from CCS projects that have been developed to be consistent with IPCC 2006 Inventory Guidelines (IPCC 2006).

For estimating fugitive emissions from the transport and injection phases of CCS, NGER scheme methods reference existing guidance for the natural gas industry, providing for the use of industry best practice methods for pipeline and injection well operations.

In Australia, any CCS project is undertaken under a licence provided under state or commonwealth legislation depending on the jurisdiction in which the project is located. Under these licences, strict project specific conditions for monitoring and reporting of leaks are given. Hence, for estimating leakage from the storage formation, the NGER scheme mirrors estimates made in accordance with the measurement, reporting, and verification (MRV) requirements of the licence. This is particularly important given the project-specific nature of monitoring and reporting requirements for CCS projects.

Emissions from the Transport of CO_2 are identified as Not Occurring on the basis that the pipelines at Gorgon are short and no leaks have been identified for inclusion in reporting to date.

3.4.3 Uncertainty assessment and time-series consistency

The Tier 1 uncertainty analysis in Annex II provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by using consistent models, model parameters and datasets for the calculations of emissions estimates.

3.4.4 Category-specific QA/QC and verification

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

3.4.5 Category-specific recalculations

There are no recalculations to this category in this submission.

3.4.6 Category-specific planned improvements

There are no planned improvements for this category in this submission.

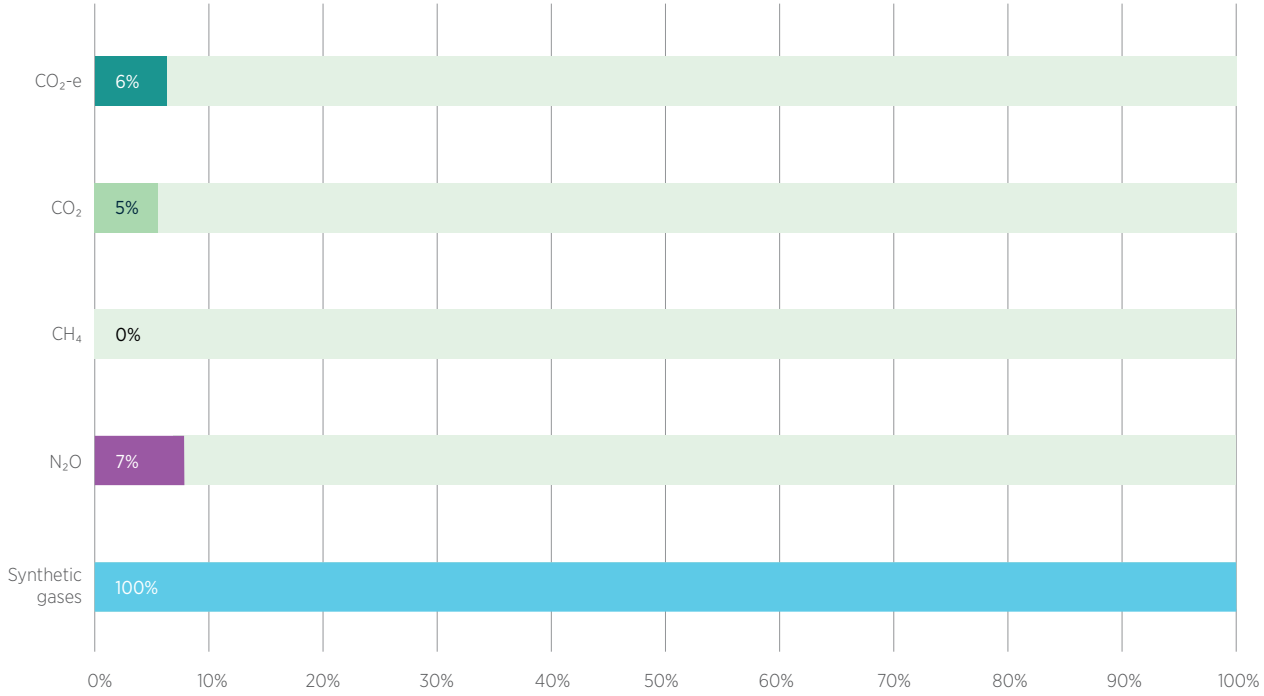
4. Industrial Processes and Product Use

4.1 Overview of the sector and background information

The *industrial processes and product use* (IPPU) category covers greenhouse gas emissions resulting from industrial processes, the use of gases in products, and from non-energy uses of fossil fuels.

The industrial processes and product use sector as a portion of total emissions (excluding LULUCF) is presented in Figure 4.1.

Figure 4.1 Share of national emissions (excluding LULUCF) for the industrial processes and product use sector, by gas, 2023–24



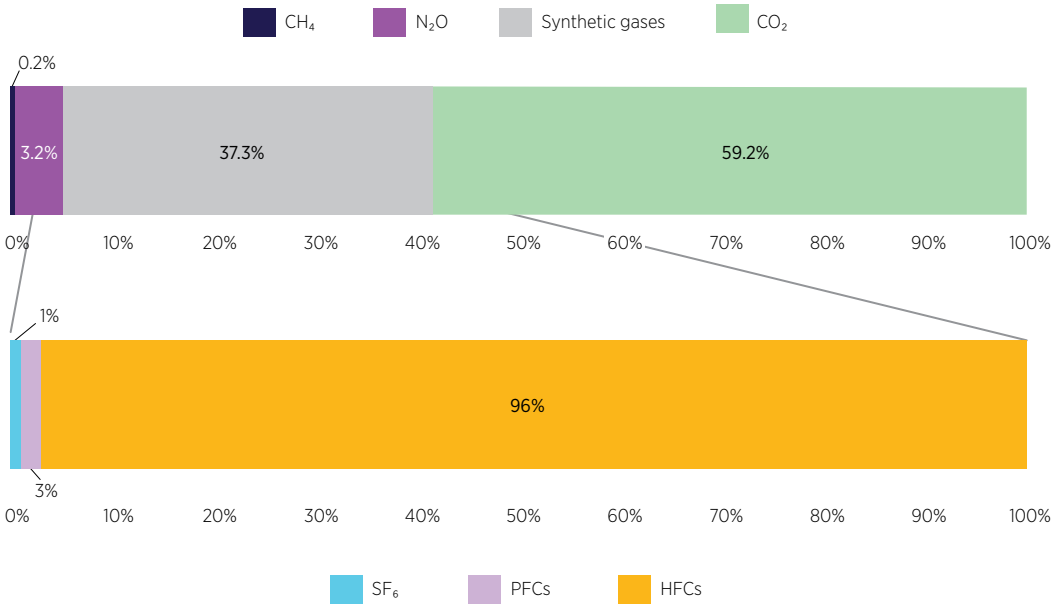
Note: Synthetic gases refers to SF_6, NF3, HFCs, and PFCs.

Emissions in this sector occur:

- as the result of chemical or physical transformation involved in the production of mineral, chemical and metal products such as cement, ammonia and steel;
- from the use of products, including emissions of HFCs used as refrigerants and SF_6 from electrical equipment, and from the use of fossil fuels for purposes other than to produce energy (for example as lubricants).

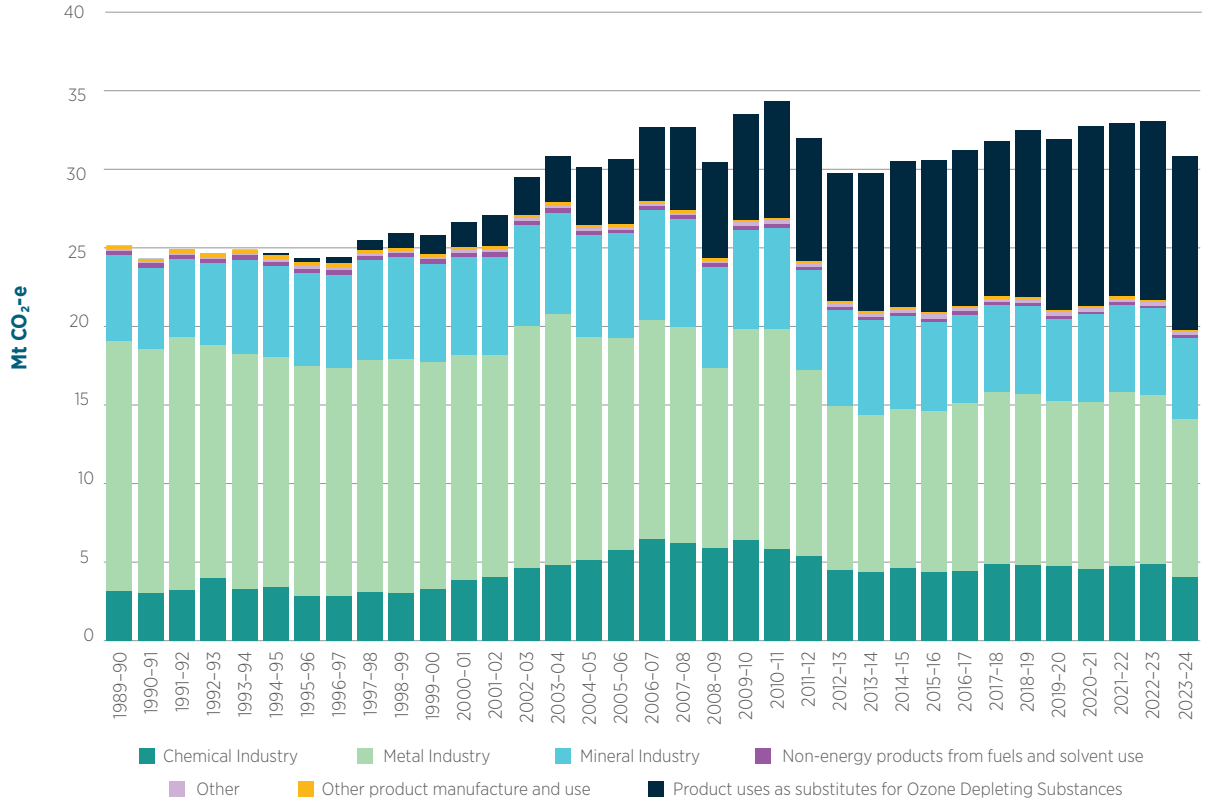
The most significant gases emitted by this category are CO_2 and HFCs, with emissions of N_2O, CH_4, and PFCs also occurring. All emissions of synthetic gases (HFCs, PFCs, and SF_6) in the Australian inventory occur in the industrial processes and product use category. NF_3 is also a reportable synthetic gas, however, Australia reports these emissions as NO (see chapter 4.6).

Figure 4.2 Gases as a share of total emissions within the Industrial Process and Product Use sector, CO_2-e basis, 2023–24 (top: all gases, bottom: synthetic greenhouse gases)



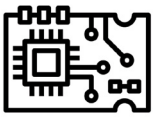
The manufacturing industry, producing metals, chemicals and mineral products such as cement clinker, is a major source of emissions from this category. The full time series of industrial processes and product use emissions by subsector is presented in Figure 4.3. The largest source of emissions is from products used as substitutes for ozone depleting substances, followed by the metal, mineral and chemical industries.

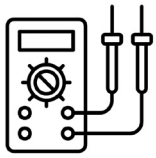
Figure 4.3 Industrial Process and Product Use emissions by subsector, 1989–90 to 2023–24



Changes in emissions by industrial processes and product use subsector since 1989–90, 2004–05 and the last prior financial year are shown in Figure 4.4. Emissions from the sector have increased 22.8% (5.7 Mt CO_2-e) since 1989–90, driven by increased emissions from HFC refrigerants and increased emissions from manufacturing of chemicals. These increases were offset by reduced emissions in metal manufacturing, driven by lower levels of production of steel together with lower emission rates of PFCs from aluminium production, and reductions in mineral product manufacturing driven by lower production levels of cement. Emissions from the sector declined 2.2 Mt CO_2-e (6.8%) in 2023–24, driven by reductions in all sectors apart from *2.D Non-energy products from fuels and solvent use*.

Figure 4.4 Comparison of 2023–24 emissions with past emissions levels from key industrial processes and product use (IPPU) subsectors, million tonnes of carbon dioxide equivalent (Mt CO_2-e) and percentage change (%)

IPPU Subsectors	2023–24 emissions	Change in 2023–24 emissions since: 1989–90	2004–05	2022–23
 2.A Mineral Industry	5 Mt	-0.3 Mt CO_2-e -6%	-1 Mt CO_2-e -20%	-0.3 Mt CO_2-e -6%
 2.B Chemical Industry	4 Mt	+29% +1 Mt CO_2-e	-1 Mt CO_2-e -21%	-1 Mt CO_2-e -17%
 2.C Metal Industry	10 Mt	-6 Mt CO_2-e -37%	-4 Mt CO_2-e -30%	-1 Mt CO_2-e -7%
 2.D Non-energy Products from Fuels and Solvent Use	0.2 Mt	-0.1 Mt CO_2-e -38%	-0.1 Mt CO_2-e -31%	+3% <+0.1 Mt CO_2-e
 2.E Electronics Industry	NO	–	–	–
 2.F Product Uses as Substitutes for Ozone Depleting Substances	11 Mt	+100% +11 Mt CO_2-e	+200% +7 Mt CO_2-e	-0.3 Mt CO_2-e -3%

IPPU Subsectors	2023–24 emissions	Change in 2023–24 emissions since: 1989–90	2004–05	2022–23
 2.G Other Product Manufacture and Use	0.1 Mt	-0.1 Mt CO_2-e -59%	-0.1 Mt CO_2-e -52%	<-0.1 Mt CO_2-e -29%
 2.H Other	0.2 Mt	+140% +0.1 Mt CO_2-e	+19% +<0.1 Mt CO_2-e	<-0.1 Mt CO_2-e -10%

Note: NO = not occurring. Icons in this figure are sourced from nawicon, smartline, smashicons, iconjam, surang, Freepik, Vectors Tank, GOWI, and Creatype on flaticon.com.

Key categories for Australia in this sector include emissions from cement production, iron and steel production, aluminium production and leakages of HFC refrigerants ('Product uses as substitutes for ODS').

The Australian methodology tiers and EFs are outlined in Table 4.1.

In certain subsectors 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 subsectoral emission estimates in order to preserve confidentiality.

Emissions of CO_2 from *non-metallurgical magnesium 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) are reported under 2.B.10 – *Other.* Emissions of N_2O from the *use of* N_2O in anaesthesia and aerosols (2.G.3) have been aggregated with emissions of N_2O from *nitric acid production* (2.B.2). 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 4.1 Summary of Methods and emission factors: Industrial processes and product use

	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6	
Greenhouse Gas Source and Sink Categories	**Method applied**	**EF**	**Method applied**	**EF**	**Method applied**	**EF**	**Method applied**	**EF**	**Method applied**	**EF**	**Method applied**	**EF**
2. Industrial Processes and Product Use												
A. Mineral Industry												
1. Cement Production	T2	CS, PS										
2. Lime Production	T2	CS										
3. Glass Production	T2	CS										
4. Other Process Uses of Carbonates	T2	CS										
B. Chemical Industry												
1. Ammonia Production	T2/3	CS, PS	NA	NA	NA	NA						
2. Nitric Acid Production					T3	CS, PS						
3. Adipic Acid Production	NO	NO			NO	NO						
4. Caprolactam, Glyoxal and Glyoxal acid Production	NO	NO			NO	NO						
5. Carbide Production	T2	CS	NA	NA								
6. Titanium Dioxide Production	T2	CS										
7. Soda Ash Production	T2	CS										
8. Petrochemical and Carbon Black Production	T1	CS	T2	CS								
9. Fluorochemical Production							T1	D	NA	NA	NA	NA
10. Other[(a)]												
C. Metal Industry												
1. Iron and Steel Production	T2/3	CS	T2	CS	T2	CS						
2. Ferroalloys Production	T2	CS	T2	CS	T2	CS						
3. Aluminium Production	T2/3	CS							T2/3	PS, CS	NA	NA
4. Magnesium Production	NA	NA					NA	NA	NA	NA	T2	CS
5. Lead Production	T2	CS	T2	CS	T2	CS						
6. Zinc Production	T2	CS	T2	CS	T2	CS						
7. Other[(a)]												

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
D. Non-Energy Products from Fuels and Solvent Use												
1. Lubricant Use	T2	CS										
2. Paraffin wax Use	NE	NE										
3. Other												
E. Electronics Industry					NO	NO	NO	NO	NO	NO	NO	NO
F. Product Uses as Substitutes for Ozone Depleting Substances												
1. Refrigeration and Air Conditioning							T2	CS	NA	NA	NA	NA
2. Foam Blowing							T2	D	NA	NA	NA	NA
3. Fire Protection							T2	D	NA	NA	NA	NA
4. Aerosols							T2	D	NA	NA	NA	NA
5. Solvents							T2	D	NA	NA	NA	NA
6. Other Applications							NA	NA	NA	NA	NA	NA
G. Other Product Manufacture and Use												
1. Electrical Equipment							NA	NA	NA	NA	T2	CS
2. SF, and PFCS from Other Product Uses									NA	NA	T1,T2	CS
3. N_2O from Product Uses					T2	CS						
H. Other												
2. Food and Beverage Industry	CS	CS										

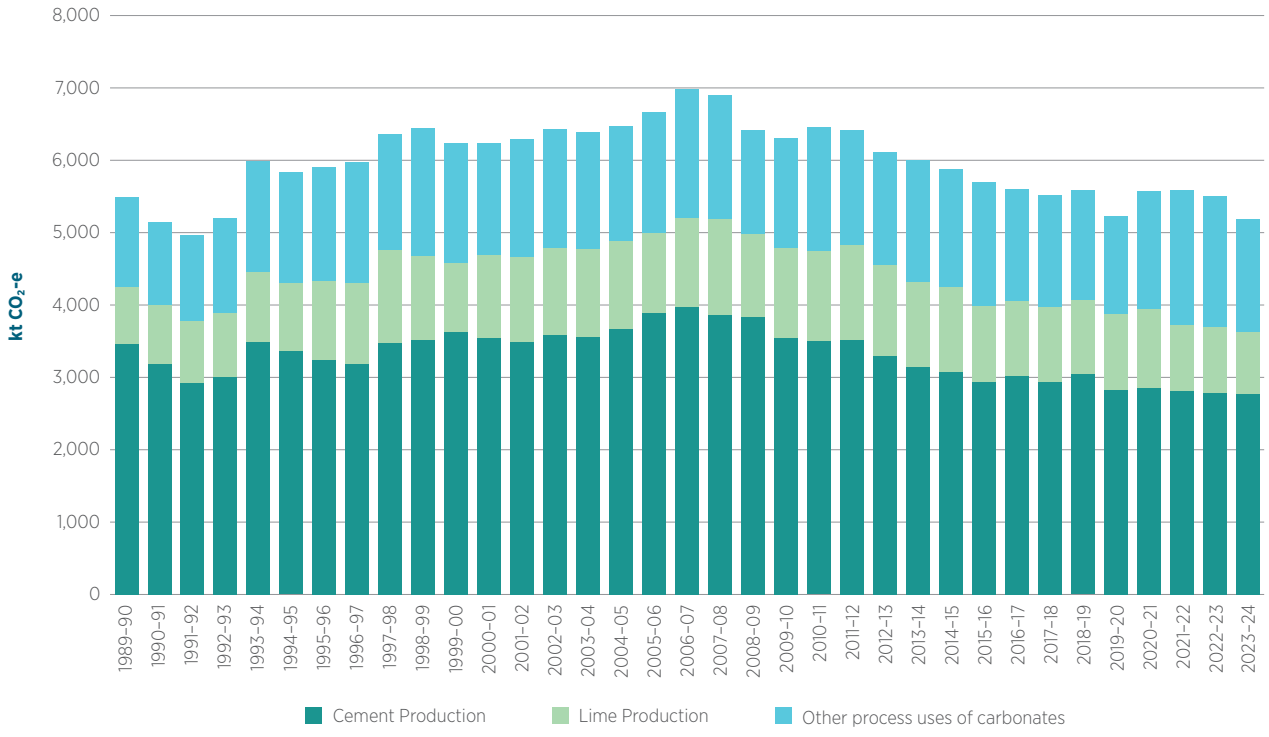
Notes: EF = Emission Factor, T1 = Tier 1,T2 = Tier 2, T3 = Tier 3, CS= country-specific, D= IPCC default, M = model, NE = not estimated, NA= not available, NO = not occurring, IE = included elsewhere, PS = plant-specific, ▢ = key category. Gray shading matches Common Reporting Tables. (a) Confidentialised emissions are reported in 2.B.10 and 2.C.7 ('Other').

4.2 Mineral Industry (CRT category 2.A)

4.2.1 Category description

The mineral industry produces CO_2 emissions due to the use of carbonate-containing minerals. Emissions associated with the mineral industry are shown in Figure 4.5 below.

Figure 4.5 Emissions from the mineral industry, Australia, 1989–90 to 2023–24, kt CO_2



Cement production (2.A.1)

CO_2 is produced during the manufacture of portland clinker, which is an intermediate product in the production of cement. 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 (anhydrous calcium sulphate) added to control the setting time of the cement.

The production of clinker in Australia responds to market conditions. Competition with domestic production from imported clinker has increased in over time (CIF 2022, p. 10). Between 2009–10 and 2014–15, five clinker production facilities ceased operations. Year on year fluctuations in emissions from this category are strongly correlated to fluctuations in cement production. Improvements in industry practices such as the recycling of cement kiln dust have resulted in small reductions in emissions per unit of production.

There are three clinker producers in Australia and their facilities report on their activity and emissions through the National Greenhouse and Energy Reporting (NGER) scheme.

Efforts are underway to reduce emissions from cement clinker production by using supplementary cementitious materials ('SCM') such as unburnt limestone, ground blast furnace slag and fly ash to lower the amount of clinker used per unit of concrete produced (CIF 2022).

Free lime (CaO) released during the curing of concrete from the hydration of clinker materials can potentially and very slowly (years to centuries) re-absorb atmospheric CO_2 through a process called carbonation. In line with the IPCC 2006 Guidelines (Volume 3, Chapter 2, Section 2.2.1.4), Australia does not estimate an emissions sink for this category as it is not considered practical or good practice without further work on a methodology. The IPCC 2019 Refinement (IPCC 2019) does not provide any additional information on this category.

Lime Production (2.A.2)

Lime is an important mineral product with major uses in metallurgy (steel, copper, gold, aluminium and silver), construction (soil stabilisation, asphalt additive and masonry lime) and other industrial applications (water softening, pH control, sewage sludge stabilisation).

The producers of commercial lime in Australia report their activity and emissions through the NGER scheme. One facility produced lime in-house (that is, not for commercial sale) until 2008–09.

Emissions of CO_2 from the production of lime are strongly correlated with production volumes. Production is particularly dependent on the demand for lime within the Australian resources sector- notable decreases in 1998–99 and 1999–2000 were caused by the fall in demand for minerals processing particularly in the gold sector, and in 2008–09 by the global economic downturn.

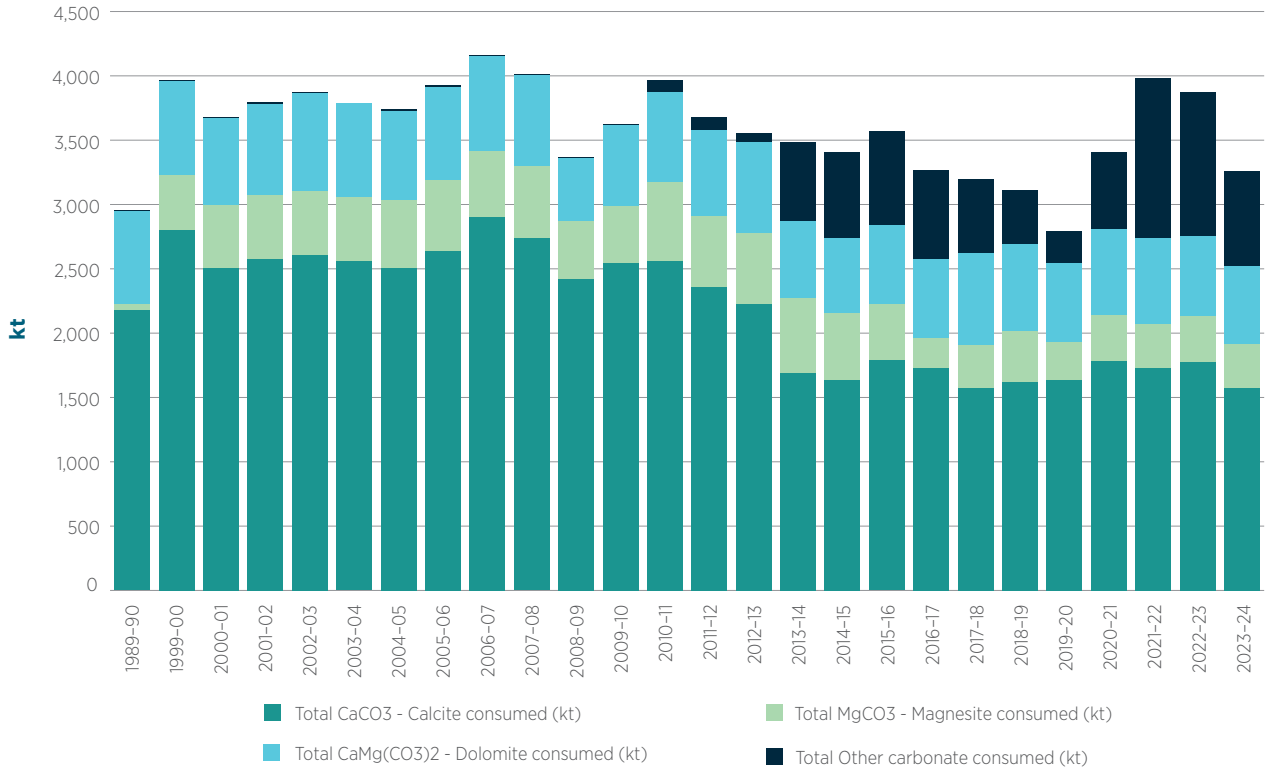
Glass production (2.A.3); Other process uses of carbonates (2.A.4)

In addition to their use in cement and lime production, carbonates (primarily limestone ($CaCO_3$), magnesite ($MgCO_3$) and dolomite ($CaMg(CO_3)_2$) are basic raw materials that have commercial applications in a number of industries including metallurgy (for example, iron and steel, ferroalloys and zinc), glass manufacture, ceramics and clay bricks, agriculture, construction, magnesia production and environmental pollution control. To improve the completeness of the inventory, emissions from other carbonates known to be supplied to the Australian economy have also been included. These are: sodium bicarbonate, potassium carbonate, barium carbonate, lithium carbonate and strontium carbonate.

Emissions from the use of carbonates in glass production are reported in 2.A.3. All CO_2 emissions from the consumption of carbonates other than for cement (2.A.1), lime (2.A.2) or glass (2.A.3) production, are accounted for under Other Process Uses of Carbonates (2.A.4).

The trend in emissions in categories 2.A.3 and 2.A.4 is heavily influenced by the consumption of limestone (calcite) which is consumed in greater quantities than any other carbonate. Year on year growth in carbonate consumption has varied from positive to negative throughout the time series correlating with activity in the broad range of consuming industries.

Figure 4.6 Other process uses of carbonates (2.A.4): Carbonate consumption by type, Australia, 1989–90 to 2023–24, kt



4.2.2 Methodological issues

Cement Production (2.A.1)

Emission factors

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, simply expressed as:

$$CaCO_3 + heat \rightarrow CaO + CO_2$$

Emissions from clinker production are estimated using a Tier 2 Method using the following equation:

$$E_{cl} = A_{cl} \cdot EF_{cl} + A_{ckd} \cdot F_{ckd} \cdot EF_{cl} + (A_{cl} + A_{ckd} \cdot F_{ckd}) \cdot EF_{toc}$$

CO_2 emissions from clinker manufacture E_{cl} are estimated by the application of a country-specific emission factor EF_{cl} to annual clinker production A_{cl}.

A country-specific EF_{cl} was calculated as 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 and the quantity of total organic carbon (TOC) expressed as a proportion of total clinker produced. F_{ckd} is the degree of calcination of cement kiln dust and is assumed to be 100 per cent for the purpose of calculating the country-specific EF following WBCSD 2005 (i.e. $F_{ckd} = 1$). A_{ckd} is the quantity of cement kiln dust (CKD) produced annually. The EF for total organic carbon EF_{toc} is taken from WBCSD 2005 (equivalent to 10kg CO_2 per tonne of clinker).

Under the provisions of the *National Greenhouse and Energy Reporting (Measurement) Determination 2008,* facilities are able to determine facility-specific EFs based on the CaO and MgO contents of their cement clinker according to the following equation:

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

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

0.785 is the molecular weight ratio of carbon dioxide to calcium oxide

1.092 is the molecular weight ratio of carbon dioxide to magnesium oxide

From 2015–16, two cement production facilities have reported facility-specific EFs based on measurement of the CaO and MgO contents of their produced clinker. The remaining facilities continue to use the country-specific factor. The country-specific EF is used for all facilities from 1989–90 to 2014–15 as adopted by all cement producers under the NGER scheme prior to 2015–16.

Activity data

Data for cement production for individual facilities were obtained from the NGER scheme for 2008–09 onwards and the reporting mechanisms of the former Emissions Intensive, Trade Exposed Industries assistance program (EITEI – subsequently known as the Jobs and Competitiveness Program) for 2006–07 and 2007–08. Data for the period 1989–90 to 2005–06 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.

Lime production (2.A.2)

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, according to the following reactions:

$$CaCO_3 \text{ (high calcium lime)} + CO_2$$
$$CaCO_3.MgCO_3 \text{ (dolomite)} + \text{heat} \rightarrow CaO \text{ (high calcium lime)} + CO_2$$

Emissions from lime production are estimated using a Tier 2 Method.

Total CO_2 emissions E_l associated with lime production A_l are estimated as the sum of emissions by facility using emission factors EF_l as described below. Where data is available, allowance is made for the quantity of lime dust lost from the kiln during production A_{lkd}, and its calcination fraction F_{lkd}, according to the following equation:

$$E_l = A_l \times EF_l + A_{lkd} \times F_{lkd} \times EF_l$$

Emission factors

Information important to the derivation of lime production emission factors has been obtained under the former EITEI program and the NGER scheme from 2006–07 onwards, where 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:

$$EF = F_{CaO} \times 0.785 + F_{MgO} \times 1.092$$

Where F_{CaO} is the estimated fraction of produced lime that is calcium oxide derived from carbonate sources

F_{MgO} is the estimated fraction of produced lime that is magnesium oxide derived from carbonate sources

0.785 is the molecular weight ratio of carbon dioxide to calcium oxide

1.092 is the molecular weight ratio of carbon dioxide to magnesium oxide

Where lime producers manufacture lime with a high MgO content, their facility-specific emission factor will be higher than the default.

From 2006–07 onwards, facility-specific emission factor information related to commercial lime production became available. The weighted average (by production quantity) of these emission factors for all facilities producing commercial lime (including those who did not provide facility-specific emission factors) was 0.751 t CO_2/t lime produced in 2006–07. This weighted value applied only to manufacturers of commercial lime and is higher than the commercial lime country-specific EF because it reflects the non-standard specifications of producers with commercial lime with a high MgO content.

Where facility-specific lime product composition information is not available, Australia provides country-specific emission factors for the use of lime manufacturers reporting under the NGER scheme. These are based upon assumed fractional purities of commercial and in-house lime and are calculated according to the equation:

$$EF = F \times (44.01/56.08)$$

Where F is the fractional purity of lime produced

44.01 is the molecular weight of CO_2

56.08 is the molecular weight of CaO

The country-specific emission factors are calculated 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

The following timeline sets out the application of each of the emission factors:

Table 4.2 Emission factor for lime production

	1989–90	2005–06	2006–07	2023–24
Commercial lime	Weighted average (EITEI)		Some facility specific EFs (EITEI, NGER)	
	EF 0.751 t CO_2/ t lime		Default country-specific EF 0.675 t CO_2/t lime	
In-house lime	Default country-specific EF 0.730 t CO_2/t lime			

Source: EITEI; NGER scheme

Fluctuations in the implied emission factor year on year reflect the relative proportions of production of individual lime producers from 2006–07 onwards.

For in-house lime, as facility-specific composition information has not been supplied, the country-specific emission factor is applied for all years where in-house lime production occurred.

Activity data

Data on lime production (including data on the amount of lime produced in-house) have been collected under the NGER scheme for 2008–09 onwards and the reporting mechanisms of the former EITEI Program for 2006–07 and 2007–08. Data for the period 1989–90 to 2005–06 were obtained by industry census undertaken by the National Lime Association up to 1999–00 and various consultants from 2000–01 to 2005–06 (for example, GHD 2009). The census and NGER scheme collection mechanisms have enabled complete coverage of lime producers throughout the time-series. Activity data is reported in table A5.4.1.1.

Glass production (2.A.3); Other process uses of carbonates (2.A.4)

A Tier 2 method is utilised to estimate emissions from other process uses of carbonates.

Total CO_2 emissions, E, are estimated by multiplying the quantity of limestone, A_{ls}, dolomite, A_d, and other carbonate, A_o, used by their respective fractional purities and emission factors using the following equation:

$$E = A_{ls} \cdot F_{ls} \cdot EF_{ls} + A_d \cdot F_d \cdot EF_d + A_o \cdot F_o \cdot EF_o$$

Limestone and dolomite consumption data have been collected under the NGER scheme from 2008–09 and the reporting mechanisms of former EITEI Program for 2006–07 and 2007–08 (EITEI 2007 and 2008). Data for the period 1989–90 to 2005–06 were obtained by a combination of industry survey (for example GHD 2009) and back casting of production based on NGER scheme data.

The CO_2 emission factor per unit of limestone (EF_{ls}), dolomite (EF_d) and other carbonates (EF_o) used is estimated from a consideration of the country-specific purity of raw materials and process stoichiometry. Relevant molecular weights are 44 for CO_2; 100 for limestone; 184 for dolomite, 84 for magnesite, 106 for soda ash and 114 for the remaining carbonates. The fractional purities are country specific and include limestone, F_{ls}, 0.90, dolomite F_d, 0.95, and for all other carbonates, F_o, 1.00. The resulting emission factors are 0.396 t CO_2/t limestone, 0.522 t CO_2/t magnesium carbonate, and 0.453 t CO_2/t dolomite. Only the amount of carbonate material used in an application which generates CO_2 is used in the estimation of CO_2 emitted.

Emissions from the manufacture of clay bricks

Emissions from carbonate consumption associated with the manufacture of clay bricks are based upon the quantities of clay bricks produced annually as recorded by the Australian Bureau of Statistics (ABS 1991, 2000, 2012) and a country-specific emission factor derived from data provided by the peak industry body representing Australian clay brick and paver manufacturers, Think Brick. The ABS discontinued their reporting of clay brick production in 2012 and from that point onwards, brick production has been derived using ABS construction activity as a driver (ABS 2025e).

Soda Ash Consumption

A Tier 2 method is utilised for the Australian inventory. The mass of CO_2 emitted from the use of soda ash E_{sa} may be estimated from a consideration of the consumption data A_{sa} and the stoichiometry of the chemical process, where 0.415 represents the ratio of molecular weights of CO_2 (44.01) and Na_2CO_3 (105.99), according to the following equation:

$$E_{sa} = 0.415 \cdot A_{sa}$$

Data on soda ash consumption were collected under the NGER scheme for 2008–09 onwards and the EITEI Program for 2006–07 and 2007–08. Data for soda ash consumption for the period 1989–90 to 2005–06 were obtained by industry survey (EnerGreen 2009) and data on soda ash imports taken from ABS 2015. Activity data is reported in Table A5.4.1.3.

4.2.3 Uncertainty assessment and time-series consistency

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

Activity data obtained under the NGER scheme (2008–09 onwards) was compared with activity data obtained from the former EITEI Program for each facility and with data obtained from GHD and EnerGreen consulting to ensure the consistent classification of sources and consistency of data.

For lime production, 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 (1989–90 to 2005–06). It is assumed for the years 1989–90 to 2005–06 that lime producers produced lime in the same relative proportions as observed in 2006–07 when facility-level data first became available.

For other uses of carbonates, where facilities were newly identified from NGER scheme data (2008–09 onwards) as emitting facilities, 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 2008–09 for the each of the new facilities.

Where facility-specific EFs were identified from NGER scheme data (2008–09 onwards) 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 1989–90 to 2005–06.

4.2.4 Category-specific QA/QC and verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in Annex 4. Additional source specific quality control checks were undertaken to assess completeness and international comparability.

A summary of use and supply of carbonates tracked by the inventory is shown below. This includes limestone, dolomite, soda ash, magnesite and other carbonates (barium, lithium, potassium, strontium and sodium bicarbonate). Activity data on application of limestone and dolomite to agricultural soils have been held constant since the last available ABS data in 2017 (see section 5.8 Liming). Implied production is calculated as the difference between total use as net imports.

Table 4.3 Summary of carbonate use and supply in the Australian economy, 2023–24

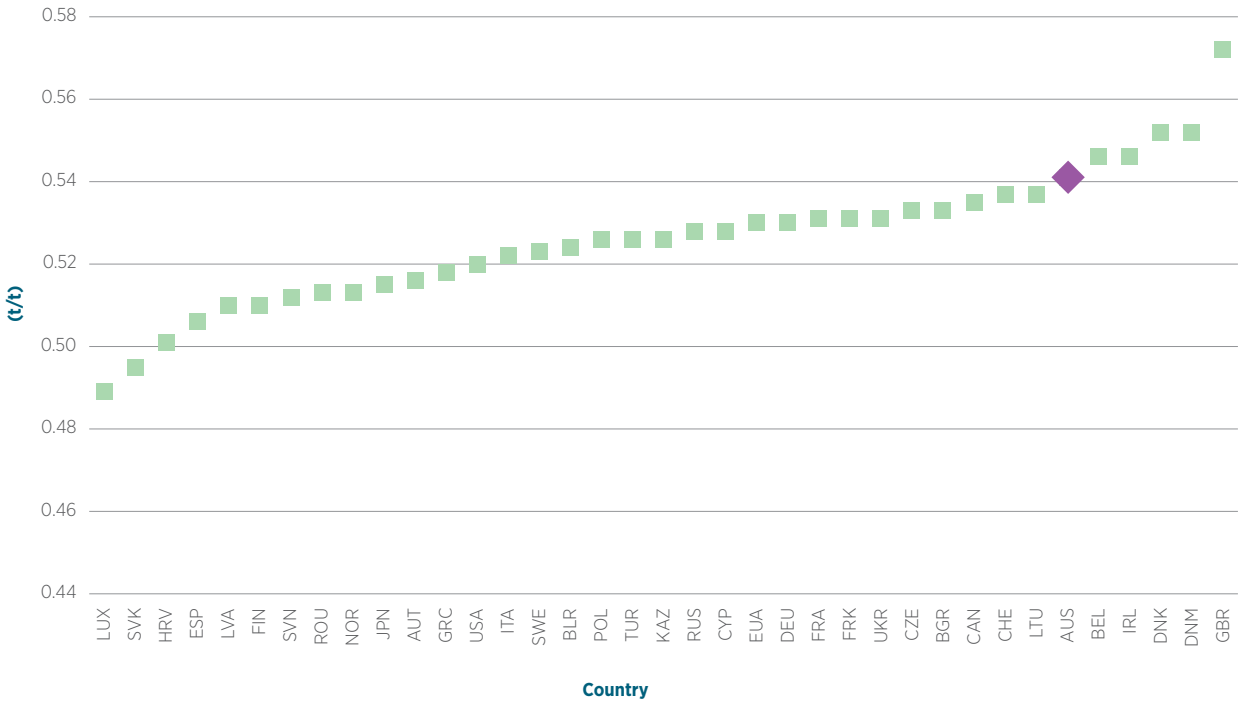
		Carbonate material [(a)] (kt)	Emissions (Gg CO_2)	Carbon (kt)
Use				
2.A.1	Cement production [(b)]	6,270	2,769	756
2.A.2	Lime production	1,914	860	235
2.A.3	Glass Production	129	58	16
2.A.4	Other process uses of carbonates	2,999	1,392	380
3.C.2	Agricultural Liming	4,062	1,617	441
Total Use		**15,374**	**6,696**	**1,827**
Supply				
Net imports		841		
Implied production		14,534		
Total supply		**15,374**		

Source: Customised data on trade of carbonate products supplied by ABS.

(a) 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 4.7 Cement production implied emission factors for developed country Parties (2023 submission) and Australia (2026 submission), tonnes of CO_2 per tonne of cement produced

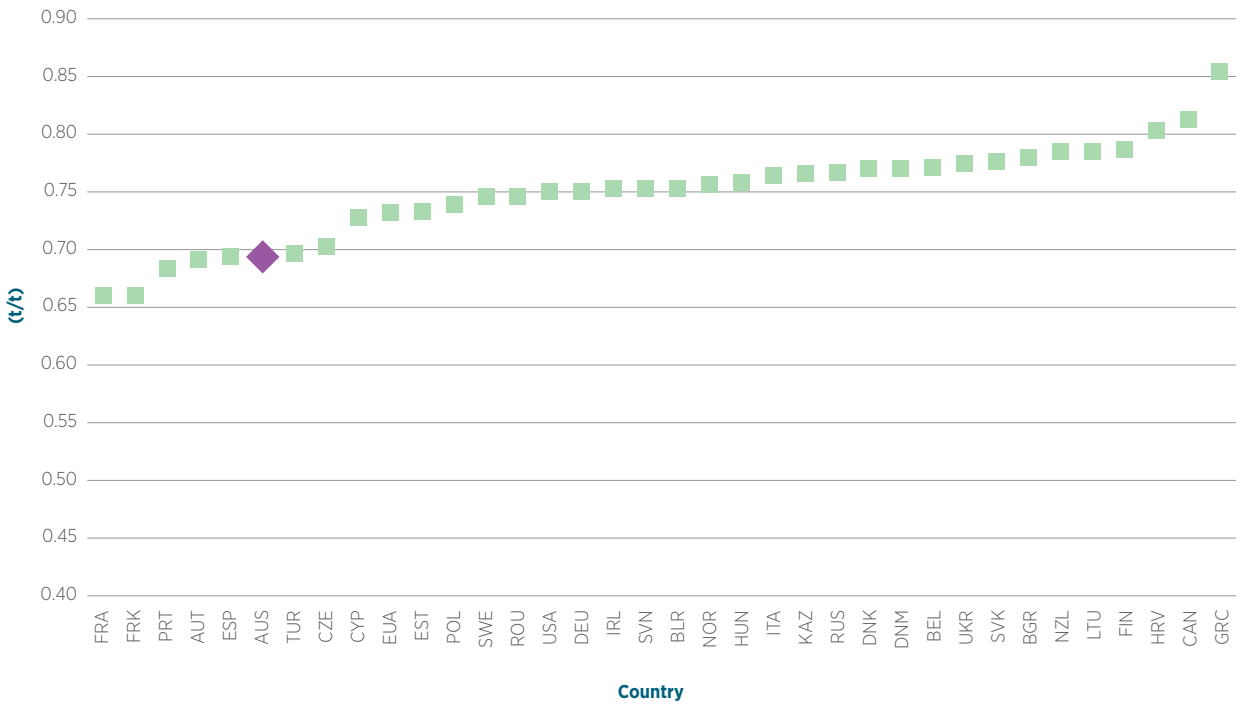


Source: UNFCCC Locator Tool

Australia's IEF for 2.A.1 cement production at the national level has fallen from 0.56 t CO_2/tonne of cement produced in 1994–95 to 0.54 t CO_2/tonne of cement produced in 2023–24. The IEF fluctuates year on year according to the relative contributions of product from each facility with their own particular product specifications.

The IEF for cement clinker production for Australia (above) is within the range reported by other developed country 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 4.8 Lime production implied emission factors for developed country Parties (2023 submission) and Australia (2026 submission), tonnes of CO_2 per tonne of lime produced



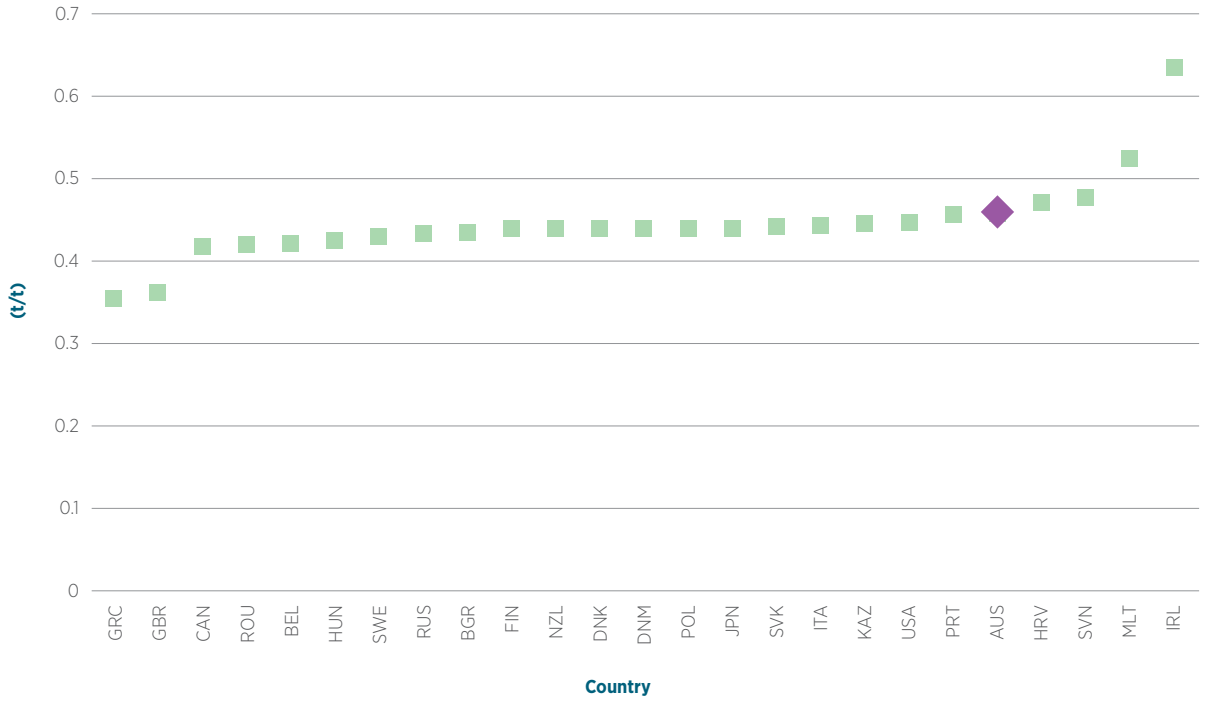
Source: UNFCCC Locator Tool

Note: In the figure above, outliers have been excluded for Japan, the Netherlands and Great Britain.

Australia's IEF for 2.A.2 lime production at the national level has fluctuated year-on-year between 0.68 t CO_2/tonne of lime produced and 0.82 t CO_2/tonne of lime produced according to the relative contributions of product from each facility with their own particular product specifications. This reflects the use of different types of carbonates as well as lime kiln dust recirculation. The IEF reflects relatively low levels of LKD calcination reported under the NGER scheme.

Australia's implied emission factor for lime production is toward the lower end of factors reported by other developed country Parties. Australia's IEF is lower than the IPCC 2006 Tier 1 default EF of 0.75 t CO_2/ tonne 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.

Figure 4.9 Other Process Uses of Carbonates implied emission factors for developed country Parties (2023 submission) and Australia (2026 submission), tonnes of CO_2 per tonne of carbonate used



Source: UNFCCC Locator Tool

Note: In the figure above, outliers have been excluded for Iceland, Lithuania, and Norway.

Australia's IEF for 2.A.4 other process uses of carbonates has ranged between 0.410 and 0.490 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.

The IEF for carbonates use for Australia (above) is toward the higher end of factors reported by other developed country 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.

4.2.5 Category-specific recalculations

The following recalculations have been made in this submission:

- **2.A.1 Cement production CO_2:** recalculations of less than 50 kt CO_2 per year have been made to emissions in this category since last submission due to updated activity data (quantities of cement clinker produced) provided under the NGER scheme for one facility in 2020–21 and two facilities in 2022–23.
- **2.A.4 Other process uses of carbonates CO_2:** minor revisions (less than 0.1 kt CO_2 from 2010–11 to 2018–19 and less than 1 kt CO_2 from 2019–20 to 2023–24) have been made to emissions from 2010–11 onwards due to updated activity data used to estimate emissions from production of bricks.

Table 4.4 Mineral industry (2.A), recalculation of total CO_2-e emissions (Gg), 1989–90 to 2022–23

	2025 Submission	2026 Submission	Change	
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
1989–90	5,489.6	5,489.6	0.0	0.0
1994–95	5,826.3	5,826.3	0.0	0.0
1999–00	6,231.9	6,231.9	0.0	0.0
2004–05	6,478.8	6,478.8	0.0	0.0
2005–06	6,669.0	6,669.0	0.0	0.0
2006–07	6,985.5	6,985.5	0.0	0.0
2007–08	6,898.4	6,898.4	0.0	0.0
2008–09	6,408.1	6,408.1	0.0	0.0
2009–10	6,304.0	6,304.0	0.0	0.0
2010–11	6,454.0	6,453.9	0.0	0.0
2011–12	6,411.5	6,411.4	0.0	0.0
2012–13	6,105.3	6,105.3	0.0	0.0
2013–14	6,004.4	6,004.4	0.0	0.0
2014–15	5,878.5	5,878.5	0.0	0.0
2015–16	5,691.6	5,691.6	0.0	0.0
2016–17	5,599.5	5,599.5	0.0	0.0
2017–18	5,521.9	5,521.9	0.0	0.0
2018–19	5,588.9	5,588.9	0.0	0.0
2019–20	5,230.5	5,230.5	0.1	0.0
2020–21	5,614.0	5,571.6	-42.4	-0.8
2021–22	5,582.4	5,582.4	0.0	0.0
2022–23	5,461.9	5,509.3	47.4	0.9

4.2.6 Category-specific planned improvements

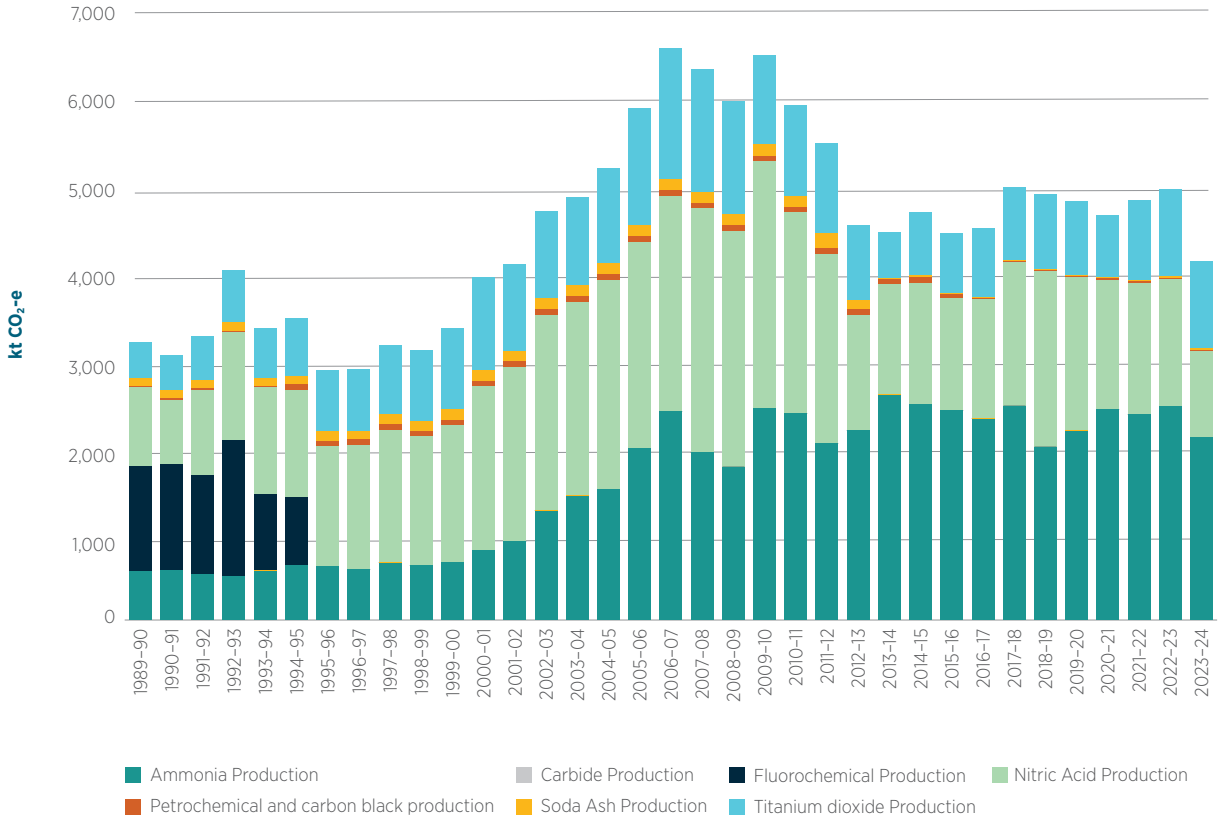
The methodology and emission factors used for the estimation of emissions from *mineral products* are kept under review. Australia has been monitoring the progress of empirical research and the development IPCC guidance material covering mineral carbonation including carbonation that associated with cement. Australia will explore the possibility of including allowance for this chemical process in future inventory submissions.

4.3 **Chemical Industry** (CRT category 2.B)

4.3.1 Category description

Key categories for Australia in the chemicals sector are CO_2 from ammonia production, N_2O from nitric acid production, and (on trend analysis) HFCs from fluorochemical production. Emissions associated with the chemical industry are shown in Figure 4.10.

Figure 4.10 Emissions from the chemical industry, Australia, 1989–90 to 2023–24, kt CO_2-e



Ammonia production (2.B.1)

The production of 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 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 is made in natural gas consumption in the *stationary energy* sector to remove the possibility of double-counting.

Ammonia is produced in six plants operated by five producers in Australia. All companies provide natural gas consumption and CO_2 recovery data (where undertaken) under the NGER scheme.

Nitric acid production (2.B.2)

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 at seven facilities operated by six producers in Australia, all of which report under the NGER scheme.

Adipic acid production (2.B.3)

Adipic acid is used in the manufacture of synthetic fibres, coatings, plastics, urethane foams, elastomers, and synthetic lubricants. There is no known adipic acid production occurring in Australia and therefore no emissions are reported for this category.

Caprolactam, glyoxal and glyoxylic acid production (2.B.4)

Caprolactam, glyoxal, and glyoxylic acid are important sources of N_2O emissions in countries where they are produced. Caprolactam is consumed as the monomer for nylon-6 fibres and plastics used notably in carpet manufacturing. Glyoxal is used as a crosslinking agent for vinyl acetate/acrylic resins, disinfectants, as a gelatine hardening agent, textile finishing agent, and as a wet-resistance additive to paper. Glyoxylic acid is used for the production of synthetic aromas, agrochemicals, and pharmaceutical intermediates. There is no known production of caprolactam, glyoxal or glyoxylic acid occurring in Australia and therefore no emissions are reported for this category.

Carbide production (2.B.5)

The main source of emissions reported in this category arises from the use of acetylene with the combustion of acetylene producing CO_2 emissions.

Silicon carbide and calcium carbide are not produced in Australia. Minor quantities of acetylene have been produced from imported calcium carbide and used in welding applications. Activity data and emissions were previously reported under the NGER scheme by one company, and are therefore confidential. Emissions for this category are reported as 'included elsewhere' and the estimates have been aggregated with emissions from *soda ash production* for reporting in *2.B.10 Other.*

Titanium dioxide production (2.B.6)

Rutile (the most common form of titanium dioxide, TiO_2) is naturally occurring in Australia. Synthetic rutile can be produced from naturally occurring ilmenite using coal reductant. The rutile is then refined using a petroleum coke reductant.

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.

The coal and petroleum coke used as reductants in the synthetic rutile and TiO_2 production processes have been removed from the stationary energy sector to eliminate the possibility of a double-count with this reporting category.

Soda ash production (2.B.7)

The majority of soda ash was produced in Australia by one company located in South Australia using the Solvay process. This facility ceased production in 2012–13 and was 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 use.

Petrochemical and carbon black production (2.B.8)

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.

Estimates 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 for polymers and other chemicals as a whole. Approximately 15 companies producing a large range of polymers and other chemicals in Australia reported through a company census conducted by a EnerGreen Consulting on behalf of the department up to 2008. From 2008 onwards, emissions have been estimated on the assumption that plant capacities have not changed.

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

Fluorochemical production (2.B.9)

From 1990 to 1995, a single company – Pacific Chemicals Industries produced HCFC-22. Fugitive emissions of HFC-23 from this production have been included in the inventory for all relevant years.

4.3.2 Methodological issues

Ammonia production (2.B.1)

A Tier 2/3 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, simply expressed as:

$$3H_2 + N_2 \rightarrow 2NH_3$$

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 A5.3.1.1) to plant specific natural gas consumption data A_i according to the following formula:

$$E_a = \Sigma A_i \,.\, EF_i - R$$

Where A_i is plant-specific natural gas feedstock consumption by feedstock type (i)

EF_i is the plant-specific emission factor for natural gas feedstock type (i)

R is CO_2 captured and sold for use in the food and drink industry and urea production.

CO_2 recovered is deducted from CO_2 emissions from ammonia production and included in reporting under *2.H.2 Food and Drink* and *3.H Urea Application.* The quantity of CO_2 recovered for use is derived from data reported under the NGER scheme. 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.

Emission factors

Facility-specific EFs for the consumption of natural gas are used where reported under the NGER scheme (currently by three facilities).

For the remaining facilities, the country-specific EF for the consumption of natural gas as listed in Table A5.3.1.1 of the NIR was used.

Activity data

Data on fuel consumption, ammonia production and CO_2 capture have been obtained under the NGER scheme for 2008–09 onwards. Data for consumption of fuels were inferred from data on production for the period 1989–90 to 2007–08 provided by EnerGreen 2009 assuming constant consumption to production factors in order to ensure time series consistency. Complete coverage of all ammonia producers has been maintained through the data collection mechanisms utilised throughout the time-series as listed above. Production data is shown in Table A5.4.1.4.

Nitric acid production (2.B.2)

A Tier 3 method is utilised for the Australian inventory. Nitric acid production involves three distinct chemical reactions. These are summarised as follows:

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

Nitric oxide (NO), an intermediate product in the manufacture of nitric acid, readily decomposes to N_2O and nitrogen dioxide (NO2) at high pressures for temperatures in the range of 30 to 50°C.

The emissions of N_2O, E_n, from the manufacture of nitric acid production A_n by a facility is calculated according to the following equation:

$$E_n = A_n \,.\, EF_n$$

Emission factors

The EFs for nitric acid production are facility-specific and obtained under the NGER scheme for 2008–09 onwards. Three nitric acid production plants apply NGER scheme Method 4, which prescribes periodic or continuous measurement of emissions; three plants apply NGER scheme Method 2, which prescribes periodically determined EFs; one plant uses a default factor under Method 1.

For earlier years, incomplete data on facility-specific EFs were available from EnerGreen Consulting 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 Consulting 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 scheme from 2008–09 onwards. Data for nitric acid production for the period 1989–90 to 2007–08 were provided by EnerGreen 2009.

Consistent with IPCC 2006, NGER scheme methods are able to account for operational conditions during a reporting year such as temporary losses of N_2O destruction capability. Nitric acid production is reported in Table A5.4.1.5.

Carbide production (2.B.5)

While calcium carbide is not produced in Australia, acetylene is produced from imported calcium carbide.

The quantity of acetylene use is based on company data supplied to a consultant representing the department up to 2009 (EnerGreen 2009). From 2009 onwards, population data are used as the input to emissions estimation.

A Tier 2 method is used. Emissions from 1989–90 to 2008–09 are estimated based on consultancy work reported. Emissions in subsequent years are estimated using a per capita rate derived from production volumes reported in that work.

Titanium dioxide production (2.B.6)

A Tier 2 method is utilised for the Australian inventory. The processes that are used in the production of TiO_2 in Australia that lead to process greenhouse gas emissions are synthetic rutile production using the Becher process, and rutile TiO_2 production via the chloride route.

The Becher process reduces the iron oxide in ilmenite to metallic iron and then reoxidises it to iron oxide, and in the process separates out the titanium dioxide as synthetic rutile of about 91 per cent to 93 per cent purity. Rutile TiO_2 is produced through the carbothermal chlorination of rutile ore or synthetic rutile to produce titanium tetrachloride ($TiCl_4$) and oxidation of the $TiCl_4$ vapours to TiO_2 according to the following reactions (Kirk-Othmer 1999, p.2017):

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

Based on stoichiometry and assuming complete conversion of the input C to CO_2 through further conversion of CO in excess air, the CO_2 EF cannot be less than 0.826 tonnes of CO_2 per tonne of TiO_2 (based on 1.5 moles of CO_2 per mole of TiO_2).

Emissions from rutile and TiO_2 are calculated by the following equation:

$$E = \Sigma_i F_i \,.\, A_i$$

Where EF_i is the EF for fuel type (i) and Ai is the quantity of fuel type (i) consumed as a reductant.

Emission factors

No facility-specific information on EFs from the NGER scheme 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 are obtained under the NGER scheme from four facilities operated by two companies. For the inventory years 2006–07 and 2007–08, activity data collected under the former EITEI Program was used.

Data for consumption of coal and petroleum coke were derived from data on production for the period 1989–90 to 2005–06 provided by EnerGreen 2009 and constant consumption to production factors in order to ensure time series consistency.

Soda ash production (2.B.7)

A Tier 2 method is utilised for the Australian inventory. To maintain confidentiality, these emissions are aggregated with emissions from *acetylene* under 2.B.10.

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 quantity of coke used as a reductant is deducted from the energy sector as it is a non-energy use of coke and ensures there is no double-counting. Both this use of coke as well as limestone consumed in the manufacture of soda ash are accounted for under this category.

The series of reactions involved in the Solvay process may be simply expressed as:

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

The CO_2 generated in pyrolysis processes is captured, and directed to Solvay precipitating towers for consumption in a mixture of brine (aqueous NaCl) and ammonia. The Solvay process itself is in theory stoichiometrically neutral in relation to CO_2 gas (that is, generation equals uptake), however, in practice a greater amount of CO_2 is generated than can be absorbed in order to optimise the production process.

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 using the following formula.

$$E_s = [\ \Sigma_f\ (CC_f\ .\ A_f + \Sigma_i\ CC_i \times A_i - \Sigma_p\ CC_p\ .\ A_p\ .\ - \Sigma_w\ CC_w \times A_w\ ] \times 3.664$$

Where E_s is the emissions of CO_2 from the production of soda ash and sodium bicarbonate CCf is the carbon content of the fuel consumed Af is the mass of fuel consumed (coke)

CC_f is the carbon content of the carbonate (f) consumed

A_f is the mass of carbonate (f) consumed

CC_i is the carbon content of the fuel input (i)

A_i is quantity of fuel type (i) consumed in the production of soda ash

CC_p is the carbon content of a product (p)

A_p is the mass of product (p) (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 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 slaked lime to form calcium carbonate and sodium hydroxide, expressed simply as:

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

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, expressed simply as:

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

In this way the CO_2 absorbed into the soda ash product is then diverted for use in the brine purification process and the manufacture of sodium hydroxide is converted into calcium carbonate. The carbon in the calcium carbonate formed in these reactions is deducted from the raw materials in the calculation of the emissions estimate. The soda ash product used in the brine purification process and manufacture of sodium hydroxide is essentially a non-emissive use of soda ash and the amount used is not included in the total soda ash produced for sale.

Emission factors

The EFs for limestone consumption and coke consumption are facility-specific and obtained under the NGER scheme for 2008–09 onwards and under the former EITEI Program for 2006–07 and 2007–08.

Activity data

Data on limestone and coke consumption for the purpose of soda ash production were collected under the NGER scheme for 2008–09 onwards and the reporting mechanisms of the former EITEI Program for 2006–07 and 2007–08.

Data for limestone and coke consumption for the period 1989–90 to 2005–06 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 2006–07 to 2008–09.

Petrochemical and carbon black production (2.B.8)

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:

$$E_{ij} = \Sigma_{ij} A_j . EF_{ij}$$

Where E_{ij} is the process emission of gas i from industrial sub-sector j

A_j is the amount of activity (product produced) in industrial sector j (tonnes per year)

EF_{ij} is the EF of gas i per unit of activity in industrial sector j (kg per tonne).

For methanol, 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 kg/t vs 2.0 kg/t for Australia). As this implies a comparable production technology in used, Australia derived CO_2 emissions using the USA CO_2 IEF of 670 kg/t.

Table 4.5 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	670 [c]	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 Consulting 2009. (a) Based on stoichiometry. (b) IPCC 1997. (c) USEPA 2021.

Fluorochemical production (2.B.9)

An emission factor of 0.04 t of HFC-23 per tonne of HCFC-22 has been used for the estimation of emissions from HCFC-22 production (IPCC 2006, Table 3.28).

4.3.3 Uncertainty assessment and time-series consistency

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

Activity data obtained under the NGER scheme was compared with activity data obtained from the former EITEI Program for each facility and with data obtained from GHD and EnerGreen consulting to ensure the consistent classification of sources and consistency of data.

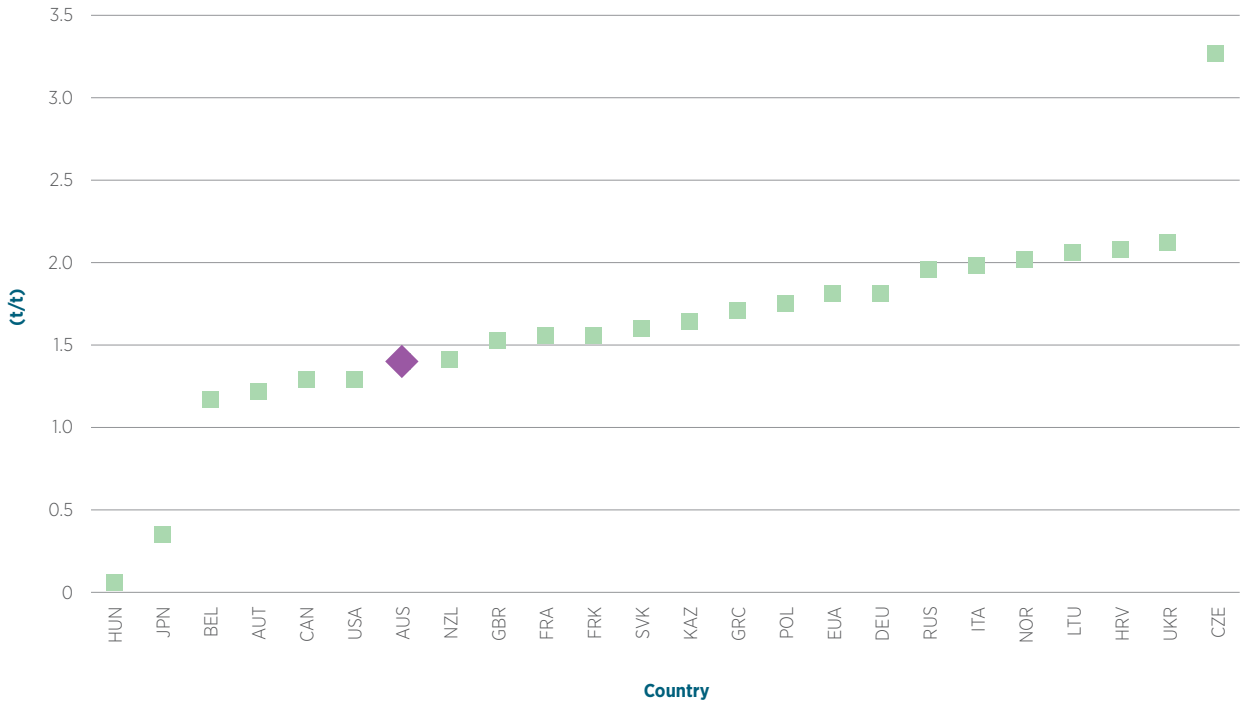
Where facility-specific EFs were identified from the NGER scheme data for particular facilities, in category 2.B.2, the reported EFs for 2006–07, 2007–08 and 2008–09 were interpolated for each facility to the most recent year for which data were available.

4.3.4 Category-specific QA/QC and verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in Annex 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 developed country Parties in the cases of ammonia (Figure 4.11) and nitric acid (Figure 4.12) production are shown below. The factors for Australia were found to be not significantly different to the factors reported by other developed country Parties.

Figure 4.11 Ammonia production implied emission factors for developed country Parties (2023 submission) and Australia (2026 submission), tonnes of CO_2 per tonne of ammonia produced



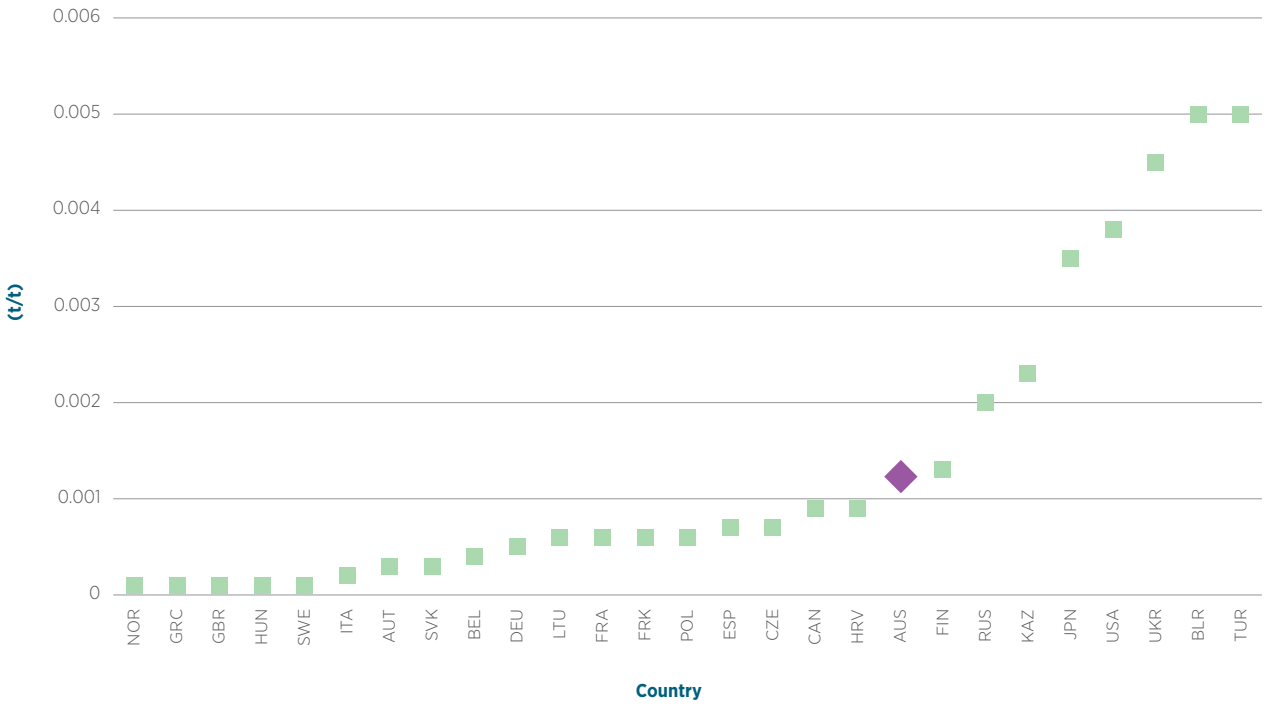
Sources: UNFCCC Locator Tool

The IEF for ammonia production for Australia, excluding captured CO_2, has fluctuated year-on-year between 1.073 t CO_2 generated per tonne of ammonia produced and 1.552 t CO_2 generated per tonne of ammonia produced according to fluctuations in ammonia production levels of individual facilities.

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. IPCC 2006 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 produced. Under the NGER scheme, 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 in this category. Australia's average feedstock fuel requirement has ranged between 21.30 and 30.16 GJ fuel/t NH_3 produced.

This split in activity data between the IPPU and Energy sectors 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.

Figure 4.12 Nitric acid production implied emission factors for developed country Parties (2023 submission) and Australia (2026 submission), tonnes of N_2O per tonne of nitric acid produced



Sources: UNFCCC Locator Tool

The IEF for nitric acid production for Australia has fallen from 10.0 kg N_2O per tonne of nitric acid produced in 1989–90 to 1.2 kg N_2O per tonne of nitric acid produced in 2023–24 with improvements in emissions abatement technology.

In 2011, the Department engaged a consultant to review N_2O emissions control in the nitric acid industry. 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 the 1990s 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.

4.3.5 Category-specific recalculations

No recalculations have been made in this category in this submission.

Table 4.6 Chemicals (2.B), recalculation of total CO_2-e emissions (Gg), 1989–90 to 2022–23

	2025 Submission	2026 Submission	Change	Change
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
1989–90	3,145.4	3,145.4	0.0	0.0
1994–95	3,417.9	3,417.9	0.0	0.0
1999–00	3,301.5	3,301.5	0.0	0.0
2004–05	5,109.3	5,109.3	0.0	0.0
2005–06	5,791.4	5,791.4	0.0	0.0
2006–07	6,468.2	6,468.2	0.0	0.0
2007–08	6,225.2	6,225.2	0.0	0.0
2008–09	5,868.0	5,868.0	0.0	0.0
2009–10	6,389.3	6,389.3	0.0	0.0
2010–11	5,820.8	5,820.8	0.0	0.0
2011–12	5,390.6	5,390.6	0.0	0.0
2012–13	4,463.5	4,463.5	0.0	0.0
2013–14	4,387.4	4,387.4	0.0	0.0
2014–15	4,609.6	4,609.6	0.0	0.0
2015–16	4,371.1	4,371.1	0.0	0.0
2016–17	4,434.5	4,434.5	0.0	0.0
2017–18	4,897.5	4,897.5	0.0	0.0
2018–19	4,813.9	4,813.9	0.0	0.0
2019–20	4,730.7	4,730.7	0.0	0.0
2020–21	4,575.3	4,575.3	0.0	0.0
2021–22	4,750.2	4,750.2	0.0	0.0
2022–23	4,871.3	4,871.3	0.0	0.0

4.3.6 Planned improvements

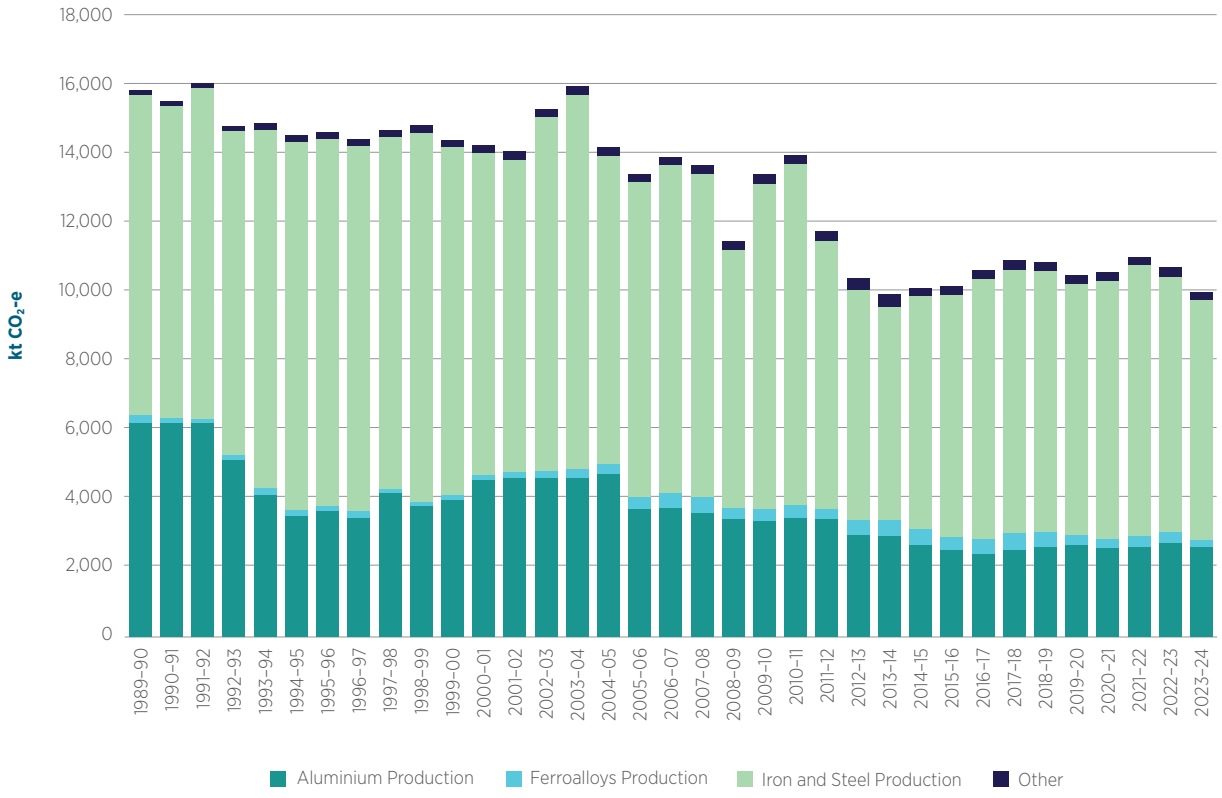
Methods, emission factors and sector coverage is kept under ongoing review.

4.4 Metal Industry

4.4.1 Category description

Key categories in the Australian metals sector are iron and steel and aluminium production.

Figure 4.13 Emissions from the metal industry, Australia, 1989–90 to 2023–24, kt CO_2-e



Iron and steel production (2.C.1)

There are two major producers of iron and steel in Australia, both of which report through the NGER scheme. Integrated iron and steel production occurs at two facilities, located in New South Wales and South Australia. A hot briquetted iron (HBI) plant using natural gas as a reductant operated in Western Australia between 1999–00 and 2004–05. Three steelmaking facilities operated using electric arc furnaces up until the announced closure of one in 2023–24.

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 2002–03, 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 and from the consumption of natural gas are reported in the Energy sector. An assessment of NGER scheme energy data shows 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. Emissions from the use of carbonates in iron and steel production are accounted for under 2.A.2.

Due to confidentiality, emissions from *iron and steel production* are reported as "included elsewhere" (IE) and estimates are aggregated with emissions from *ferroalloys production* and *other metals production* for reporting under *2.C.7 other.*

Decreases have occurred in the Iron and Steel IEF due to the increased use of pulverised coal injection in lieu of coke. A downturn in emissions from this category during 2004–05 occurred due to the blast-furnace re-lining activities at the Whyalla steel works. A notable decline of emissions from iron and steel production occurred in 2011–12 with approximately 20 per cent reduction on 2010–11. This decrease in emissions reflected the closure of the No.6 blast furnace at the Port Kembla steelworks in October 2011.

Ferroalloys production (2.C.2)

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. These emissions are reported under *2.C.7 Other* to protect confidentiality of data.

Aluminium production (2.C.3)

Australia is one of the world's largest producers of bauxite, used in aluminium production, and a significant global producer of alumina and aluminium (AAC 2025). Emissions from the production of aluminium are driven by production levels and the associated consumption of coal tar, petroleum coke and other inputs to the anode production process. 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 expressed simply as:

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

The electrolysis process is conducted in carbon-lined steel pots containing high purity carbon anodes. The cell electrolyte consists of a molten bath of cryolite (Na_3AlF_6) to which varying proportions of aluminium fluoride, calcium fluoride or lithium fluoride may be added to lower the melting point, decrease the density of the electrolyte and improve energy efficiency.

Carbon dioxide is primarily formed by the chemical reaction of oxygen (produced in the electrolysis process) with the carbon anode. During the electrolysis of alumina to aluminium, some of the CO_2 formed at the anode may be reduced to CO by a secondary reaction involving particles of aluminium or sodium.

The perfluorinated carbon compounds (PFC), tetrafluoromethane (CF_4) and hexafluoroethane (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, all of which report through the NGER scheme.

A strong downward trend in emissions per tonne of aluminium produced since the 1990s has occurred as a result of improvements in process control and the resultant reduction in PFC emissions. Fluctuations in implied emissions factors occurring in more recent years are the result of changes in the number of anode effects in the production process occurring due to electricity supply disruptions and potline maintenance. The fall in the PFC implied emission factor between 2004–05 and 2006–07 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.

In Australia, bauxite is refined to alumina in Western Australia (WA), Queensland (Qld) and the Northern Territory (NT). Emissions from the in-house production of lime at in alumina refining are accounted for under 2.A.2.

Magnesium production (2.C.4)

The inventory includes experimental quantities of SF_6 used between 1995–96 and 1999–00 as a cover gas in magnesium foundries preparatory to the development of a commercial magnesium casting plant (which was not, ultimately, commercially viable).

Lead production (2.C.5), zinc production (2.C.6), other (2.C.7)

In Australia the Lead Production, Zinc Production and Other source categories includes emissions from the production of lead, zinc, copper, nickel, and silver.

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 carbonates in the production of other metals are reported under 2.A.4.

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.

4.4.2 Methodological issues

Iron and steel production (2.C.1)

A Tier 2/3 method is utilised, in which CO_2 emissions are calculated on the basis of quantities of fuels consumed and allowance is made for carbon contained in product.

The manufacture of iron involves the high temperature reduction of iron-bearing materials in a blast furnace. The blast furnace is 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) may be summarised as follows:

$2C\ (coke) + O_2 \rightarrow 2CO$

$C + H_2O \rightarrow CO + H_2$

$Fe_y\ O + ZCO \rightarrow YFe + ZCO_2$

$Fe_yOz + ZH_2 \rightarrow YFe + ZH_2O$

$CaCO_3\ (limestone) \rightarrow CaO + CO_2$

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

Data from integrated iron and steel facilities are reported under the NGER scheme using a carbon balance across the whole of the facility. Due to this approach, disaggregations for 2.C.1.a Steel, 2.C.1.b Pig iron, 2.C.1.c Direct reduced iron, 2.C.1 .d Sinter, 2.C.1.e Pellet, and 2.C.1 .f Other (coke and pulverised coal consumption) are not available. As described in CRT Table 9, they are aggregated into the total for 2.C.7 Other (Ferroalloys and other metal production).

Coke

The emissions from the use of coke as a reductant are estimated consistent with those of the Energy sector (Chapter 3.2). A full time series of coke emission factors is provided in Table A5.3.2.20.

The CO_2 EF used to compile the emission estimate for coke consumption (shown in Table 4.7) is derived from a carbon mass balance calculation conducted for the coke oven process. This balance is performed using reported NGER data 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.

Table 4.7 Carbon dioxide emission factors for iron and steel

Fuel Type	Oxidation Factor (%)	CO_2 Emission Factor (Gg/PJ)
Coke	100 [(a)]	107.3 [(b)]
Natural Gas	100	51.4 [(c)]

Notes:

(a) IPCC 2006 default value.

(b) CO_2 EF for coke derived from a carbon balance calculation conducted for the coke oven process.

(c) Natural gas EF provided by the Australian Gas Association.

Table 4.8 Non-carbon dioxide emission factors for iron and steel

	Emission Factors (t/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.

Fugitive Emissions

A process EF was established for CH_4 from integrated iron and steel production (0.44 kg CH_4 / tonne of crude steel produced) to reflect the main sources of fugitive emissions. The estimated CH_4 EF is based on experimental data and engineering calculations conducted at the plant owned by BlueScope Steel by BHP (pers. comm. 2000) for its major Australian integrated iron and steelworks. Process emission sources considered include the in-plant distribution of coke oven gas and natural gas, leakage from coke ovens and the bleeding of unflared blast furnace gas to the atmosphere. By comparison with fugitive emissions from the in-plant distribution of coke oven gas, emissions of CH_4 associated with leakage from coke ovens and the bleeding of unflared gas from blast furnaces are estimated to be of minor significance.

Activity data

Activity data for coke consumption in the production of iron and steel are obtained from the Australian Energy Statistics for inventory years up to 2008–09 and the NGER scheme from 2008–09 onwards. Crude steel production has been sourced directly from companies (EnerGreen Consulting 2009) and the NGER scheme.

Data on pulverised coal consumed in the blast furnace have been obtained from investor reports published by BlueScope Steel. In 2008–09, NGER scheme crude steel production reporting under the NGER scheme was incomplete and was derived by indexing the crude steel production in 2007–08 to the changes in coke consumption in 2008–09.

Complete coverage of all iron and steel production has been maintained through the data collection mechanisms utilised throughout the time-series as listed above. Production and associated data is provided in Table A5.4.1.6

Ferroalloys production (2.C.2)

Emissions from the consumption of reductants in the production of ferroalloy 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 country-specific EFs and oxidation factors consistent with those used for the *Energy* sector manufacturing industries (Chapter 3.2.5) to the quantity of each reductant used.

Data on fuel consumed as reductants for the purpose of production of ferroalloy metals have been collected under the under the NGER scheme from 2008–09 onwards. For the years 1989–90 to 2007–08, this level of fuel consumption has been derived using historical production volumes.

Aluminium production (2.C.3)

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. CO_2 emissions are derived using the equation:

$$E_{al} = A_{al} \cdot EC_{al} \cdot EF_{al}$$

Where A_{al} is the quantity of fuel type (i) consumed in the production of anodes

EC_{al} is the energy content of each fuel type (i)

EF_{al} is the CO_2 EF for each fuel type (i)

Emission factors

CO_2 EFs have been applied to the quantities of fuels used in the production of anodes. One NGER scheme reporting facility 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.

In the case of emissions of perfluorocarbons, facility-specific EFs at all facilities have been estimated and sourced from the NGER scheme from 2008–09 onwards. National average factors for previous years have been supplied by the Australian Aluminium Council based on collected information on individual facility factors.

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) and Hexafluoroethane* (C2F6) *Emissions from Primary Aluminium Production).*

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 scheme since 2008–09. For the years 1989–90 to 2007–08 coal tar and petroleum coke consumption were 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 scheme for 2008–09 onwards and ABARES *Commodity Statistics* (various years) for 1989–90 to 2007–08.

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.

Magnesium production (2.C.4)

Sulphur hexafluoride was used in small quantities for experimental work preparatory to the development of a commercial magnesium casting plant between 1996 and 2000. The data on SF_6 use for this experimental foundry was supplied by the CSIRO to an external consultant (Burnbank 2000).

Lead production (2.C.5), zinc production (2.C.6), other (2.C.7)

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 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 Table 4.9.

Table 4.9 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	2.1

Source: Burnbank 2006

Data on fuel consumed as reductants for the purpose of production of other metals have been collected under the NGER scheme from 2008–09 onwards. For prior years, reductant consumption has been extrapolated backwards using data from the Resources and Energy Quarterly (DISR 2025). The Resources and Energy Quarterly data is used to estimate SO_2 emissions for all years.

4.4.3 Uncertainty assessment and time-series consistency

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

Activity data obtained under the NGER scheme was compared with activity data obtained from the former Emissions Intensive Trade Exposed Industries (EITEI) 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 scheme 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 scheme data for particular facilities, the reported EFs for 2006–07, 2007–08 and 2008–09 were interpolated for each facility between 2005–06 and the most recent year for which data were available.

4.4.4 Category-specific QA/QC and verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in Annex 4. Additional source specific quality control checks were undertaken to assess international comparability.

Iron and steel (2.C.A)

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 scheme and the *Australian Energy Statistics* (DCCEEW 2025). A secondary source of trend comparison is the production of crude steel.

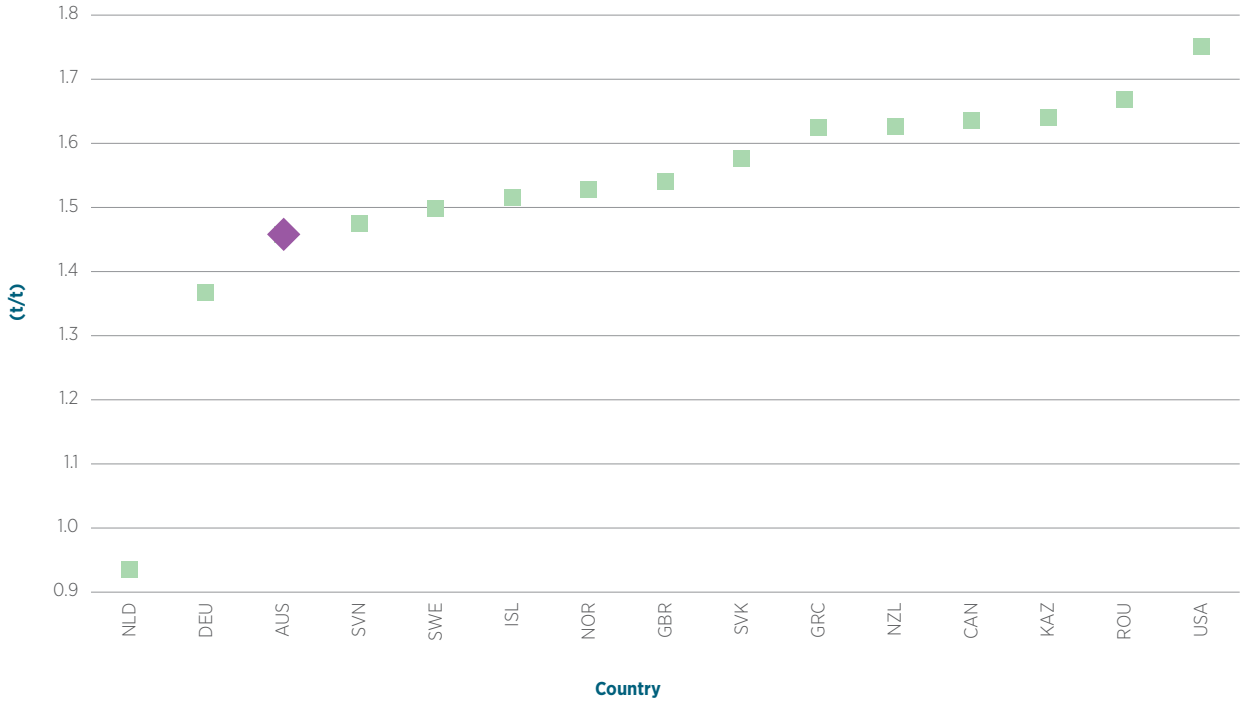
Aluminium (2.C.3)

Emissions of PFCs by the Australian aluminium industry are a key category under both the level and trends analyses. The decline in PFC emissions per unit of aluminium production in Australia since the 1990s (approximately 94 per cent since 1989–90) is consistent with similar declines observed internationally. The International Aluminium Institute (2020) reported a decline of 90 per cent between 1990 and 2019 worldwide.

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.

The quantity of CO_2 per tonne of aluminium produced has been compared with that from other developed country Parties reporting emissions from this source. The results of this comparison are shown in Figure 4.14.

Figure 4.14 Aluminium production implied emission factors for developed country Parties (2023 submissions) and Australia (2026 submission), tonnes of CO_2 per tonne of aluminium produced



Source: UNFCCC Locator Tool

The CO_2 IEF for aluminium production for Australia has fluctuated between 1.40 t CO_2/t aluminium produced and 1.78 t CO_2/ t aluminium produced according to the quantities of carbon-based fuels used to produce anodes. The IEF is within the range reported by other developed country Parties.

4.4.5 Category-specific recalculations

The following recalculations have been made in this submission:

- **2.C.3 Aluminium production PFCs:** Emissions of PFCs from aluminium production were previously calculated on the basis of EFs reported by companies under the NGER scheme. It was however identified during QA/QC that some of these reported factors were not accurate and did not match emissions reported under the scheme. Emissions have been accordingly recalculated in this submission for inventory years from 2008–09 onwards, with a maximum revision magnitude of 86.5 kt CO_2-e in 2019–20.

Table 4.10 Metals (2.C), recalculation of total CO_2-e emissions (Gg)

	2025 Submission	2026 Submission	Change	Change
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
1989–90	15,887.0	15,887.0	0.0	0.0
1994–95	14,577.6	14,577.6	0.0	0.0
1999–00	14,436.9	14,436.9	0.0	0.0
2004–05	14,220.8	14,220.8	0.0	0.0
2005–06	13,452.0	13,452.0	0.0	0.0
2006–07	13,944.7	13,944.7	0.0	0.0
2007–08	13,695.3	13,695.3	0.0	0.0
2008–09	11,535.2	11,489.4	-45.7	-0.4
2009–10	13,476.0	13,445.0	-31.0	-0.2
2010–11	14,035.7	13,990.0	-45.7	-0.3
2011–12	11,834.2	11,796.2	-38.0	-0.3
2012–13	10,439.7	10,437.3	-2.4	0.0
2013–14	9,918.2	9,967.9	49.7	0.5
2014–15	10,107.6	10,132.0	24.5	0.2
2015–16	10,213.6	10,213.1	-0.4	0.0
2016–17	10,655.3	10,675.2	19.9	0.2
2017–18	10,895.7	10,933.0	37.3	0.3
2018–19	10,855.4	10,891.5	36.2	0.3
2019–20	10,428.4	10,514.8	86.5	0.8
2020–21	10,605.2	10,605.2	0.0	0.0
2021–22	10,966.3	11,033.6	67.3	0.6
2022–23	10,692.5	10,750.8	58.3	0.5

4.4.6 Category-specific planned improvements

All activity data, methodologies and emission factors are kept under review.

4.5 Non-Energy Products from Fuels and Solvent Use (CRT category 2.D)

4.5.1 Category description

Lubricant Use (2.D.1)

The use of lubricants in engines is primarily for their lubricating properties and associated emissions are therefore considered as non-combustion emissions to be reported in the IPPU Sector. However, in the case of 2-stroke engines, where the lubricant is mixed with another fuel and deliberately co-combusted in the engine, the emissions should be estimated and reported as part of the combustion emissions in the Energy Sector (IPCC 2006).

Paraffin wax use (2.D.2)

Emissions from paraffin wax use are assessed to be insignificant and are not estimated. There are no activity data to support the preparation of a robust emissions estimate. However, based on the overall average of Annex-1 paraffin use per capita and implied CO_2 EF, emissions from this category are estimated to be approximately 0.7 Gg CO_2 or approximately 0.0001% of total national emissions.

Other (2.D.3)

Surface coating operations involve the application of paint, varnish, lacquer or paint primer for decorative or protective purposes. Thinning solvents are commonly 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 manufacturing 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 blended with petroleum solvents. NMVOC emissions occur during the mixing of bitumen batches, stockpiling, application and curing of the road surface.

4.5.2 Methodological issues

Lubricant Use (2.D.1)

Lubricants, together with bitumen and solvents, are non-fuel products of crude oil, which are included in the Australian Energy Statistics (Annex 5.2). 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 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, and any emissions from incineration are included in the Waste sector.

Other (2.D.3)

Per capita EFs from the *EMEP/EEA air pollutant emission inventory guidebook 2013* (EMEP/EEA 2013) have been adopted for estimating NMVOC emissions from Other Domestic/Commercial products and Consumer Cleaning Products.

EFs for general solvent use and consumer cleaning products are presented below.

Table 4.11 Emission factors for general solvent use and consumer cleaning products

Product	Emission Factor kg NMVOC/capita/year
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* 2013.

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* (Annex 5.2).

4.5.3 Uncertainty assessment and time-series consistency

The Tier 1 uncertainty analysis in Annex II 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.

4.5.4 Category-specific QA/QC and verification

This source category is covered by the general QA/QC of the greenhouse gas inventory in Annex 4.

4.5.5 Category-specific recalculations

In this submission, minor recalculations (with magnitude less than 5 kt CO_2 per year) have been made to emissions in this category in inventory years from 2018–19 to 2021–22 due to updated activity data on lubricant consumption from the Australian Energy Statistics.

4.5.6 Category-specific planned improvements

Activity data, methodologies and EFs are kept under review.

4.6 Electronics Industry (CRT category 2.E)

Electronics industry manufacturing does not occur at scale in Australia.

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, and for which no IPCC guidance on emission estimation could be identified.

4.7 Product Uses as Substitutes for Ozone Depleting Substances (CRT category 2.F)

4.7.1 Category description

This subsector comprises emissions of hydrofluorocarbons (HFCs) occurring as a result of their use in refrigeration and air conditioning (2.F.1), foam blowing (2.F.2), fire extinguishers (2.F.3), aerosols/metered dose inhalers (2.F.4) and solvents (2.F.5).

Use of HFC refrigerants commenced in Australia in 1994 and steadily increased since that time as ozone depleting refrigerants have been phased out under the Montreal Protocol. A phase-down of bulk imports of HFCs commenced on 1 January 2018.

Emissions are estimated for twelve HFC gases: HFC-125, -134a, -143a, -32, -23, -43–10-mee, -227ea, -236fa, -134, -152a, -245fa and -365mfc.

4.7.2 Methodological issues

Emissions in this category are estimated using a model which tracks the import, use, leakage and disposal of HFC gas.

Emissions in the model are calculated on the basis of estimated flows of conceptual quantities of mixed HFC gas across different equipment categories. These quantities of mixed HFC gas are expressed in terms of their carbon dioxide-equivalent global warming potential. Once emissions of mixed HFC gas are calculated on a CO_2-e basis, these are allocated to different HFC gas species using 'speciation factors'.

For years up to 2003-04, speciation factors for all twelve gases were estimated on the basis of analysis of recorded quantities of HFC gases imported into Australia. For 2004-05 and subsequent years, speciation factors for ten gases (HFC-125, -134a, -143a, -32, -23, -227ea, -236fa, -152a, -245fa and -365mfc) have been calculated based on relative proportions (on a CO_2-e basis) of top-down estimates of emissions of each gas made by the CSIRO on the basis of atmospheric measurements and inverse modelling (see section 4.7.4 below and CSIRO 2025). For 2004–05 and subsequent years, the speciation factors for HFC-134 and HFC-10-mee continued to be estimated based on import data, as top-down estimates of emissions of these gases are not produced by the CSIRO. These speciation factors have been applied uniformly across different subcategories within category 2.F.

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 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 and these data are used for emissions estimation.

The methodology uses specified equations to estimate HFC emissions for each equipment type for three separate processes:

1. initial losses that occur at the initial charging of the equipment;
2. emissions from leakages during the life of the equipment; and
3. the emissions from the disposal of the equipment.

Initial losses occur when an amount of bulk imported gas (Mb_{ijkt}) is allocated to a specific equipment type j. Emissions during the life of the equipment depend, in the first year, on the amount of imported bulk gas allocated to the equipment type j and the amount of gas in imports of pre-charged equipment of type j (Mp_{ijkt}) and, for every year thereafter, on the opening stock of gas in the equipment type (S_{ijkt-1}) 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 equipment stock retiring in each year (Z_{jkt}) and the quantity of gas recovered for destruction (D_{ijkt}).

The methodology is summarised by the following equations:

$$E_{ijkt} = Mb_{ijkt} \cdot IL_{ijkt} + (S_{ijkt-1} + Mb_{ijkt} + Mp_{ijkt} + R_{ijkt}) \cdot (EF_{ijkt}) + (Z_{jkt} \cdot S_{ijkt} - D_{ijkt})$$

$$S_{ijkt} = S_{ijkt1} + Mb_{ijkt} + Mp_{ijkt} + R_{ijkt} - E_{ijkt} - D_{ijkt}$$

$$R_{ijkt} = \Sigma_{t-z,\,t}\, E_{ijkt}$$

$$D_{ijkt_base} = Z_{jkt} \cdot S_{ijkt} \cdot DF_{ijk}$$

$$D_{ijkt} = D_{ijkt_base} / \Sigma_j \Sigma_k D_{ijkt_base} \cdot DTOT_t$$

$$E_t = \Sigma_i \Sigma_j \Sigma_k E_{ijkt}$$

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

Mp_{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, the 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

Z_{jkt} is the proportion of the capital stock of equipment type j and vintage k retired in year t

$\Sigma_{t-z,\,t}\, E_{ijkt}$ is the sum of initial and annual emissions from t-z to t where t is the current year and z is the number of years between replenishments

D_{ijkt} is the amount of gas i destroyed from equipment type j and vintage k in year t

D_{ijkt_base} 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

Replenishment and disposal

Commercial equipment is assumed to be replenished to full charge every two years.

Light vehicle air conditioners are assumed to be replenished to full charge once after 6 years of operation.

Sensitivity testing of the impact of these assumptions on emissions is provided in appendices to this chapter.

Average equipment lifetimes are based on country-specific expert assessment for refrigeration and air-conditioning equipment, and on IPCC default values for other equipment classes. A constant proportion of the equipment stock is assumed to be disposed over a period of time centred on the midpoint of the average equipment lifetime.

The charge remaining in equipment at retirement is assumed to be emitted to the atmosphere, subject to reclaim and destruction data reported 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 equipment classes in assumed proportions informed by IPCC default recovery factors. Key assumptions are summarised in Table A5.4.1.9.

Bulk gas activity data allocation

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 4. Methods for each end use category are also identified in Table A5.4.1.9.

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:

$$G_{mv} = G_{prod_mv} + G_{rep_mv}$$

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

Where G_{mv} is total gas demand for production and replenishment for motor vehicle air conditioners

G_{prod_mv} is gas demand for domestic production for motor vehicle air conditioners

G_{rep_mv} is the gas demand for replenishment for motor vehicle air conditioners

New_{mv} is new additions to the motor vehicle stock

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 estimated 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:

$$G_{drac} = G_{prod_drac} + G_{rep_drac}$$

$$G_{prod_drac} = (Exp_{drac} - Imp_{drac} + Ret_{drac} + \Delta S_{drac}) \cdot Shr_{hfc} \cdot Chg_{drac}$$

Where G_{drac} is total gas demand for production and replenishment for domestic refrigerators and air conditioners

G_{prod_drac} is gas demand for domestic production for domestic refrigerators and air conditioners

G_{rep_drac} is the gas demand for replenishment for domestic refrigerators and air conditioners – no replenishment assumed

Imp_{drac} is the imports of pre-charged domestic refrigerators and air conditioners

Exp_{drac} is the exports of domestic refrigerators and air conditioners

Ret_{drac} is the retirements of domestic refrigerators and air conditioners

ΔS_{drac} is the change in stock of domestic refrigerators and air conditioners calculated according to:

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 (G_{tot}) is summed for Method 1 and 2 equipment types as follows:

$$G_{tot} = G_{mv} + G_{drac}$$

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:

$$G_{res} = G_{bulk} - G_{tot}$$
$$G_{res_i} = G_{res} . Shr_i$$

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_{res_i} is the residual gas available to equipment type (i)

Shr_i is the share of residual gas used in equipment type (i) – this value is based upon end use data

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 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 OPSGGM Act.

Quantities of gas imported in bulk and contained in pre-charged equipment by end-use category for the current reporting year are shown in Table A5.4.1.10.

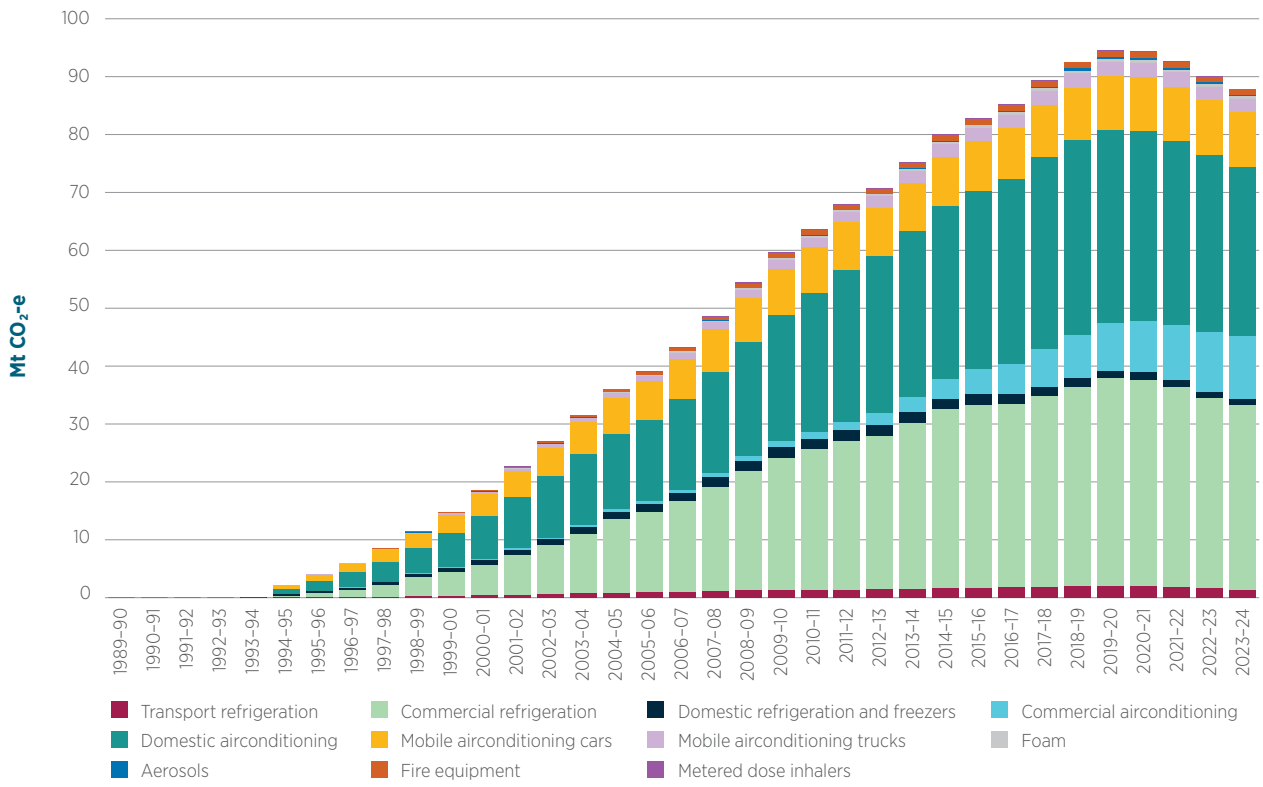
Collection of data on HFC imports under the OPSGGM *Act* commenced in the 2004–05 financial year. There are no data available on the import of HFCs for years prior to this. For each of the end-use categories, information on the transition from the use of CFC refrigerants to HFC refrigerants provided in Burnbank 2002 was used to determine a time series of HFC imports up to 2004–05 when actual import data are available.

The HFC bank

Figure 4.15 shows the growth in the bank of synthetic gas in operating equipment, with stock summary data shown in Table A5.4.1.11.

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 over the time series reflects the transition from CFC to HFC refrigerant use associated with the Montreal Protocol controls on CFC use. The total bank is estimated to have peaked in 2019–20.

Figure 4.15 The bank of HFC gas in operating equipment (Mt CO_2-e)



Product categories

Technical parameters (product lifetimes, leakage rates, replenishment schedules and estimation method) applied to estimate emissions of HFCs from different product categories are summarised in Table A5.4.1.9.

Product stocks of domestic refrigerators, domestic air conditioners and light vehicle air conditioners are shown in Tables 5.4.1.12 and following. Allocations of bulk HFC gas to other product categories are shown in Table 5.4.1.17 and following.

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 was 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 2008b, ABS 2014, Expert Group projections) 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.*

Australia no longer produces household refrigerators domestically, with the last producer closing Australian operations in August 2009. 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.

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 (ABS 2008, ABS 2014, Expert Group projections), and pre-charged equipment import data.

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 BITRE 2025 (formerly the ABS Motor Vehicle Census) have been used to construct a capital stock model. It is assumed that all new units manufactured from 1994–95 onwards contain HFC-134a.

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 number of vehicles imported in that year. In years 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.

Equipment disposals are based on the IPCC default average lifespan of 11.5 years with the first units of each vintage retiring after 5 years of operation.

Mobile air conditioning (heavy vehicles), transport refrigeration and commercial refrigeration and air conditioning

Heavy vehicles are defined as vehicles of over 3.5 tonnes gross mass. Transport refrigeration comprises vehicle and self-powered refrigeration units used in commercial vehicles. Commercial refrigeration comprises stand-alone, medium and large and industrial refrigeration units and is the most significant user of synthetic gases in Australia. Commercial air conditioning covers the use of chiller units used in commercial buildings.

The quantities of imported gas are allocated 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.

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 20.5 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. Imports of gas and stocks are shown in Table A5.4.1.21.

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 Australian Fire Protection Association (FPA) was consulted on the potential use of PFCs in fire extinguishers. They have 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 reported as not occurring.

Aerosols (including 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). 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 2008–09 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 from Burnbank 2002.

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

4.7.3 Uncertainty assessment and time-series consistency

The uncertainty of emissions in this category is estimated to be 27%.

Data on imports of HFC gas became available under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* from 2004–05 onwards. Import quantities for prior years were extrapolated based on Burnbank 2002.

4.7.4 Category-specific QA/QC and verification

Mass-balance quality control

Data are obtained from companies under licensing arrangements established under the *Ozone Protection and Synthetic Greenhouse Gas Management Act* (2003). A mass balance analysis has been completed to ensure that:

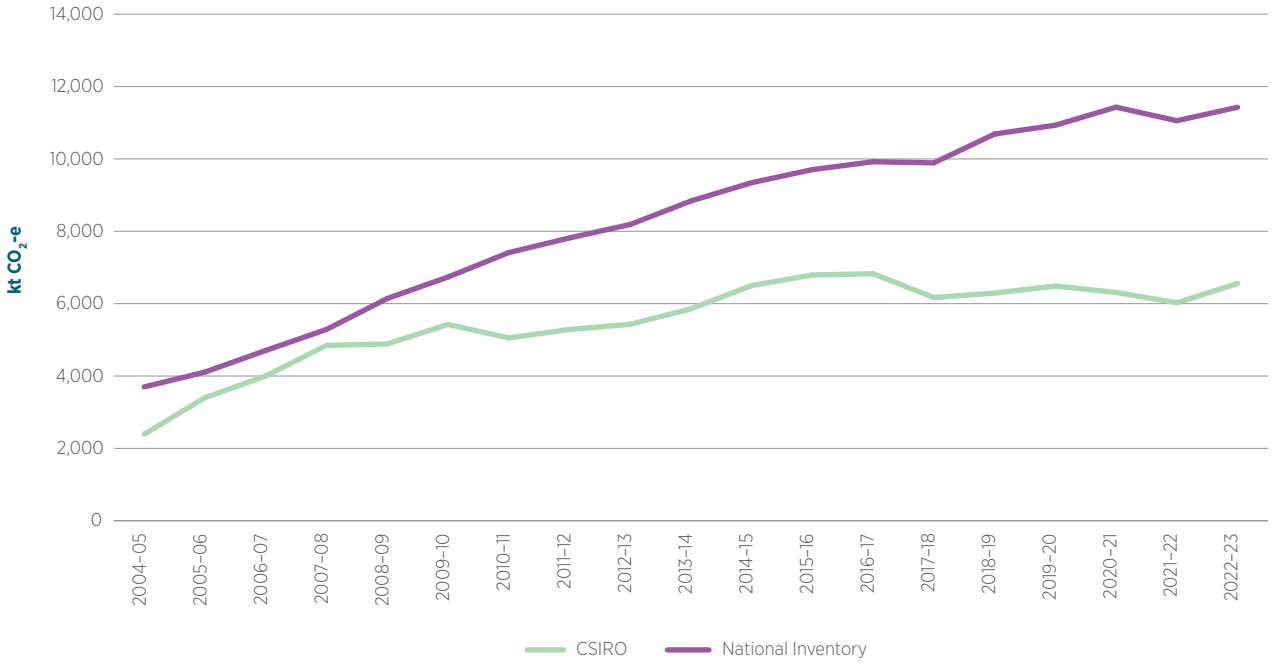
- all imported gas in bulk and pre-charged equipment is assigned to an appropriate end-use category, and
- stock changes and emissions and gas destruction were fully tracked and accounted for.

The results of these allocation and stock balances are presented in Tables A5.4.1.25 and A5.4.1.26.

External verification through atmospheric measurement

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 verification process undertaken independently by CSIRO lags the official inventory submission by one year. CSIRO uses inverse modelling techniques to derive an estimate of national HFC emissions based on atmospheric measurements of HFC concentrations. The comparison of estimates based on Cape Grim measurements with inventory estimates are shown below.

Figure 4.16 Comparison of HFC emission estimates with estimates derived from atmospheric measurement data (kt CO_2-e)



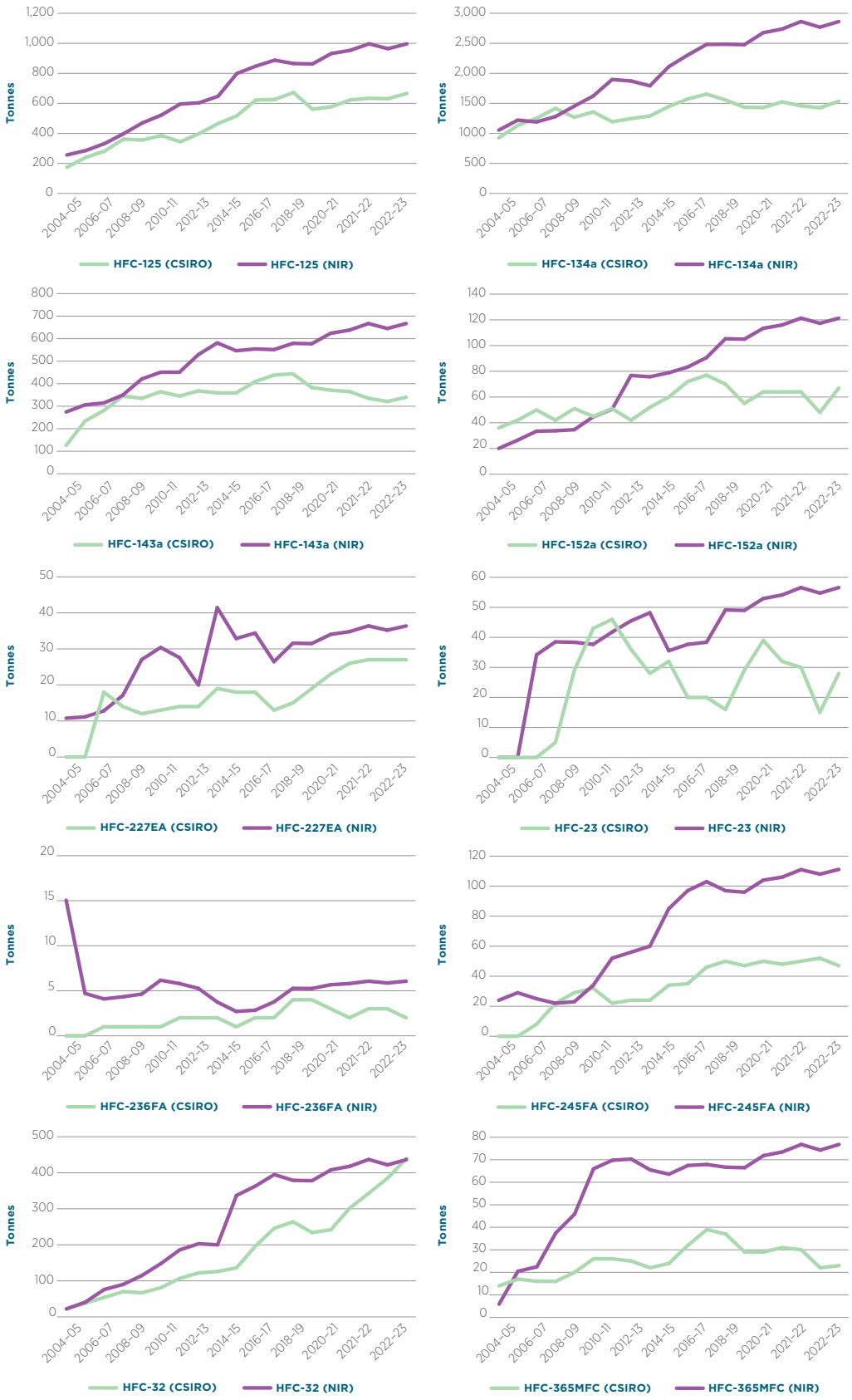
Source: CSIRO 2025

The 2006 IPCC Guidelines (IPCC 2006) (p 6.21) identify fluorinated gases as being among the most suitable for which inverse modelling could provide verification of emissions estimates as they have no natural sources or sinks. The remote location of the Cape Grim monitoring station also reduces the likelihood of measurement error from international sources.

Gas species fluctuations observed at Cape Grim are also used to determine gas speciation in the HFC emissions model.

Comparisons of CSIRO and NIR estimates of individual HFC gas species are shown below.

Figure 4.17 Comparison of HFC emission estimates with estimates derived from atmospheric measurement data – by species (t)



Source: CSIRO 2025

4.7.5 Category-specific recalculations

Minor revisions (with magnitude less than 3 kt CO_2-e) have been made to estimates of emissions in this category due to updated population data used to estimate emissions from metered dose inhalers.

Table 4.12 Product Uses as Substitutes for Ozone Depleting Substances (2.F): recalculation of total CO_2-e emissions (Gg)

	2025 Submission	2026 Submission	Change	
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
1989–90	0.0	0.0	0.0	-
1994–95	100.4	100.4	0.0	0.0
1999–00	1,150.5	1,150.5	0.0	0.0
2004–05	3,699.5	3,699.5	0.0	0.0
2005–06	4,108.7	4,108.7	0.0	0.0
2006–07	4,706.4	4,706.4	0.0	0.0
2007–08	5,286.3	5,286.3	0.0	0.0
2008–09	6,141.5	6,141.5	0.0	0.0
2009–10	6,735.3	6,735.3	0.0	0.0
2010–11	7,409.8	7,409.8	0.0	0.0
2011–12	7,816.4	7,816.4	0.0	0.0
2012–13	8,187.3	8,187.3	0.0	0.0
2013–14	8,837.4	8,837.4	0.0	0.0
2014–15	9,343.5	9,343.5	0.0	0.0
2015–16	9,705.2	9,705.2	0.0	0.0
2016–17	9,922.3	9,922.3	0.0	0.0
2017–18	9,891.6	9,891.5	-0.1	0.0
2018–19	10,688.5	10,688.0	-0.5	0.0
2019–20	10,933.2	10,931.8	-1.5	0.0
2020–21	11,432.4	11,430.2	-2.3	0.0
2021–22	11,058.1	11,056.0	-2.1	0.0
2022–23	11,428.1	11,428.1	-0.1	0.0

4.7.6 Category-specific planned improvements

The department keeps methods and activity data under review.

4.8 Other product manufacture and use (CRT category 2.G)

4.8.1 Category description

This category accounts for the following emissions of greenhouse gases from the manufacture and use of products:

- Sulphur hexafluoride (SF_6) has been commonly used for electrical insulation and current interruption in electricity supply and distribution equipment. Emissions from this use are accounted for under 2.G.1. SF_6 has a number of more minor further uses including eye surgery, tracer gas studies, magnesium casting, plumbing services, tyre manufacture and industrial machinery equipment – emissions from these uses are accounted for under 2.G.2.
- Emissions of N_2O from aerosol products and anaesthesia (2.G.3) are estimated, but are aggregated with emissions of N_2O from nitric acid production and reported in 2.B.2 to maintain historical confidentiality.

4.8.2 Methodological issues

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.

Emissions from leakage of SF_6 may occur at three stages: during product manufacturing, from use during the life of the equipment, and at disposal.

Disposal emissions are included in estimated emissions from equipment use as separate data are not available.

The first recorded destruction of SF_6 in Australia was reported by Refrigerant Reclaim Australia for the year 2023–24. The quantities of gas destroyed have been deducted from emissions estimated from equipment use and disposal in that year.

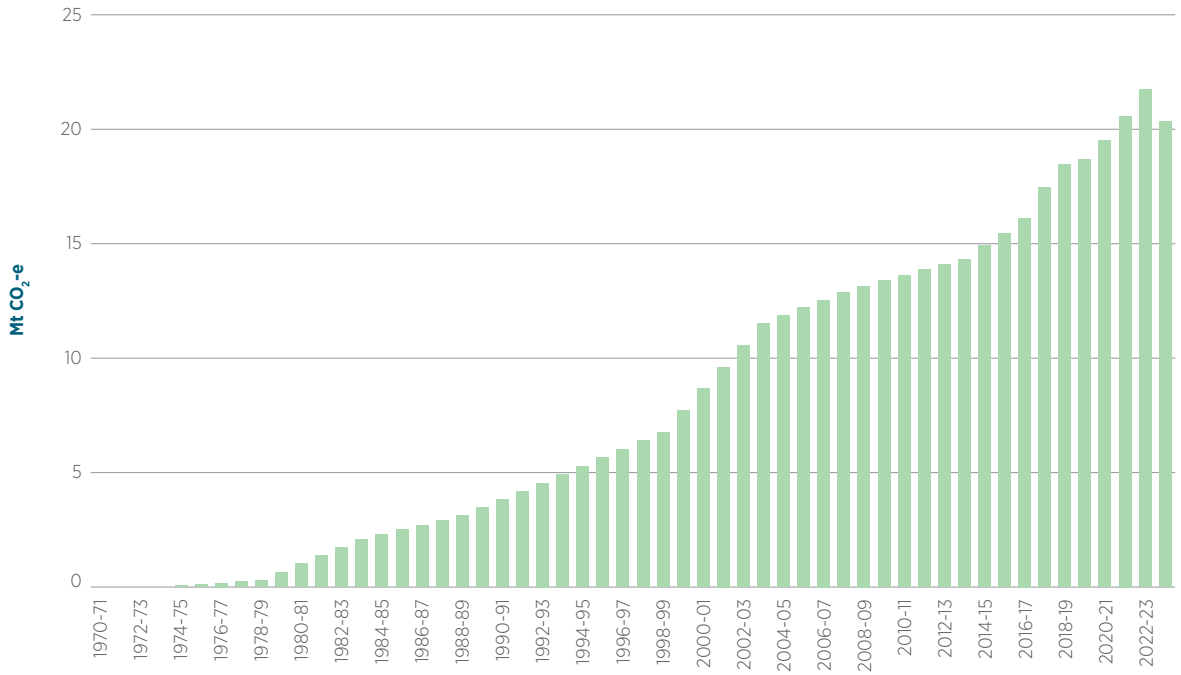
The bank of SF6

Historical stocks of SF_6 were extrapolated backward from first reported data under the NGER scheme in 2008–09 with reference to reported numbers of SF_6-filled circuit breakers reported by the major electricity network operator in the State of New South Wales (see Transgrid 2011, p 45 – 'Circuit Breaker Age Profile', 'SF_6' data series), which indicated that the first time SF_6 was used in equipment in Australia was in the period 1975–79.

From 2008–09 onwards, the national bank of SF_6 is estimated using data reported by companies under the NGER scheme.

The national bank of SF_6 is estimated to have steadily increased over the time series and decreased for the first time in 2023–24.

Figure 4.18 Estimated stock of SF_6 in electrical equipment (Mt CO_2-e)



Source: NGER scheme; backcasting using Transgrid 2011

Product manufacturing emissions

Activity data

Emissions from product manufacturing are estimated by applying assumed leakage rates to estimated quantities of SF_6 locally filled into equipment.

The amount of SF_6 used in domestic manufacturing is inferred from increases in the national bank. It is assumed that all imported SF_6 is used to fill electrical equipment. For years up to 2020–11, in the absence of further information it is assumed that gas entering the country in pre-filled in equipment and in bulk cylinders make equal contributions to increases in the bank. From 2011–12, import data shows that on average approximately 60% of imported SF_6 is contained in pre-charged equipment.

Emission factors

In the absence of country-specific information, Australia has applied the following leakage rates for manufacture or on-site filling of imported electrical equipment, with liner interpolation applied in intervening years:

- 1989–90 5: 15 per cent (IPCC 1997, Table 3.12 – 'Europe – before 1996');
- 1995–96: 8.5 per cent (IPCC 2006, Table 8.3 'Closed pressure electrical equipment (hv switchgear) containing SF_6' – 'Europe').
- 2022–23 and 2023–24: 3.0 per cent, being the average leakage rate reported by other developed country Parties in 2023 inventory submissions (source: UNFCCC Locator Tool).

Product use and disposal emissions

Emissions from the national bank of SF_6 in electrical equipment are estimated on the basis of the following EFs, with linear interpolation applied in intervening years:

- 1989–90 to 1994–95: 5 per cent (IPCC 2000 Table 3.12 'Default emission factors for SF_6 emissions from electrical equipment – Tier 2 (fraction of SF_6/yr)', 'Global – before 1996');
- 1999–00: 2 per cent (IPCC 2000 Table 3.12 'Default emission factors for SF_6 emissions from electrical equipment – Tier 2 (fraction of SF_6/yr)', 'Global – since 1996');
- 2008–09: 0.89 per cent (based on NGER data);
- 2022–23 and 2023–24: 0.49 per cent (based on NGER data).

From 2009–10 NGER scheme allows reporters to estimate their SF_6 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. The approaches are consistent with those set out in the *Electricity Networks Association Industry Guideline for* SF_6 *Management,* ENA Doc 022–2008 (2008).

In the reporting year 2009–10, 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 scheme reports was estimated at 0.0078 tonnes of SF_6 per tonne of stock of SF_6 per year (0.78%). In 2010–11, the average emission rate derived from these 15 NGER scheme reporters (with stocks of 5.2 Mt in 2010–11) was estimated at 0.01 tonnes of SF_6 per tonne of stock of SF_6 per year (1.0%). The fluctuation in leakage rates between the two reporting years is attributed to differing service intervals and equipment retirement and replacement schedules. This fluctuation was 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 (0.89%).

Similar analysis conducted for reporting years 2020–21, 2021–22 and 2022–23 yielded a weighted average emission factor of 0.49 per cent.

The reported EFs obtained from facilities under the NGER scheme incorporates emissions from the operation of equipment and also emissions from disposal. A separate estimate of emissions from disposal is not available.

The decline in leakage rates over time reflects improved awareness and training of personnel in the handling of SF_6 over time.

Summary of stocks and emissions of SF6 from electrical equipment

Stocks and emissions of SF_6 emissions from electrical equipment are presented below.

Table 4.13 Stocks and emissions of SF_6 from electrical equipment

	Stock of SF_6 in electrical equipment				Manufacturing of electrical equipment			
	National stock		Emission factor	Emissions	Quantity	Leakage rate	Emissions	Total Emissions
Year	t CO_2-e	per cent growth	t/t	t CO_2-e	t CO_2-e	t/t	t CO_2-e	t
2004–05	11,859,325	2.97%	1.39%	164,281	253,046	6.52%	16,499	7.93
2005–06	12,201,135	2.88%	1.26%	154,014	247,912	6.30%	15,618	7.44
2006–07	12,542,945	2.80%	1.14%	142,907	242,359	6.08%	14,735	6.91
2007–08	12,884,755	2.73%	1.02%	130,960	236,385	5.86%	13,852	6.35
2008–09	13,152,259	2.08%	0.89%	117,508	192,506	5.64%	10,857	5.63
2009–10	13,400,529	1.89%	0.86%	115,864	182,067	5.42%	9,868	5.51
2010–11	13,629,772	1.71%	0.84%	113,919	171,581	5.20%	8,922	5.39
2011–12	13,859,014	1.68%	0.81%	111,841	136,434	4.98%	6,794	5.20
2012–13	14,088,257	1.65%	0.78%	109,631	135,550	4.76%	6,452	5.09
2013–14	14,317,500	1.63%	0.75%	107,289	134,613	4.54%	6,111	4.97
2014–15	14,905,043	4.10%	0.72%	107,397	277,976	4.32%	12,009	5.24
2015–16	15,449,759	3.65%	0.69%	106,869	260,634	4.10%	10,686	5.16
2016–17	16,123,360	4.36%	0.66%	106,882	312,193	3.88%	12,113	5.22
2017–18	17,440,957	8.17%	0.63%	110,591	571,275	3.66%	20,909	5.77
2018–19	18,454,360	5.81%	0.61%	111,699	450,041	3.44%	15,481	5.58
2019–20	18,683,967	1.24%	0.58%	107,704	134,925	3.22%	4,345	4.91
2020–21	20,124,027	4.50%	0.55%	106,923	379,018	3.00%	11,371	5.19
2021–22	21,210,833	5.40%	0.52%	106,768	464,480	3.00%	13,934	5.29
2022–23	21,725,452	2.43%	0.49%	103,284	241,029	3.00%	7,231	4.85
2023–24	20,955,112	-3.55%	0.49%	99,621	0	3.00%	0	4.37

Other uses of SF6 (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 0.8 kg CO_2-e per person per year has been applied to Australia's total population to derive a time series of emissions from this source.

For consideration of the potential for SF_6 used in military aircraft, enquiries with the Royal Australian Air Force have confirmed that no SF_6 gas is used in Australian aircraft radar systems.

N_2O from product uses (2.G.3)

Emissions in this category were based on data provided by two companies manufacturing or importing N_2O (BOC and Air Liquide) up to the year 2007–08. From 2008–09 onwards, N_2O emissions have therefore been indexed to population growth using the last available per-capita emission rate. These data and the resultant emissions estimates are aggregated with emissions of N_2O from nitric acid production to maintain historical confidentiality and reported under 2.B.2

4.8.3 Uncertainty assessment and time-series consistency

Inventory uncertainty for SF_6 emissions is estimated at ±30 per cent which is comparable with uncertainty estimated for the modelled emissions by CSIRO. Further information on uncertainties is included in Annex II.

Time-series consistency for SF_6 is maintained through the application of linear interpolation of emission factors backward extrapolation of SF_6 stocks in equipment (see Figure 4.18), with an interpolated series of EFs derived from the 2006 IPCC Guidelines.

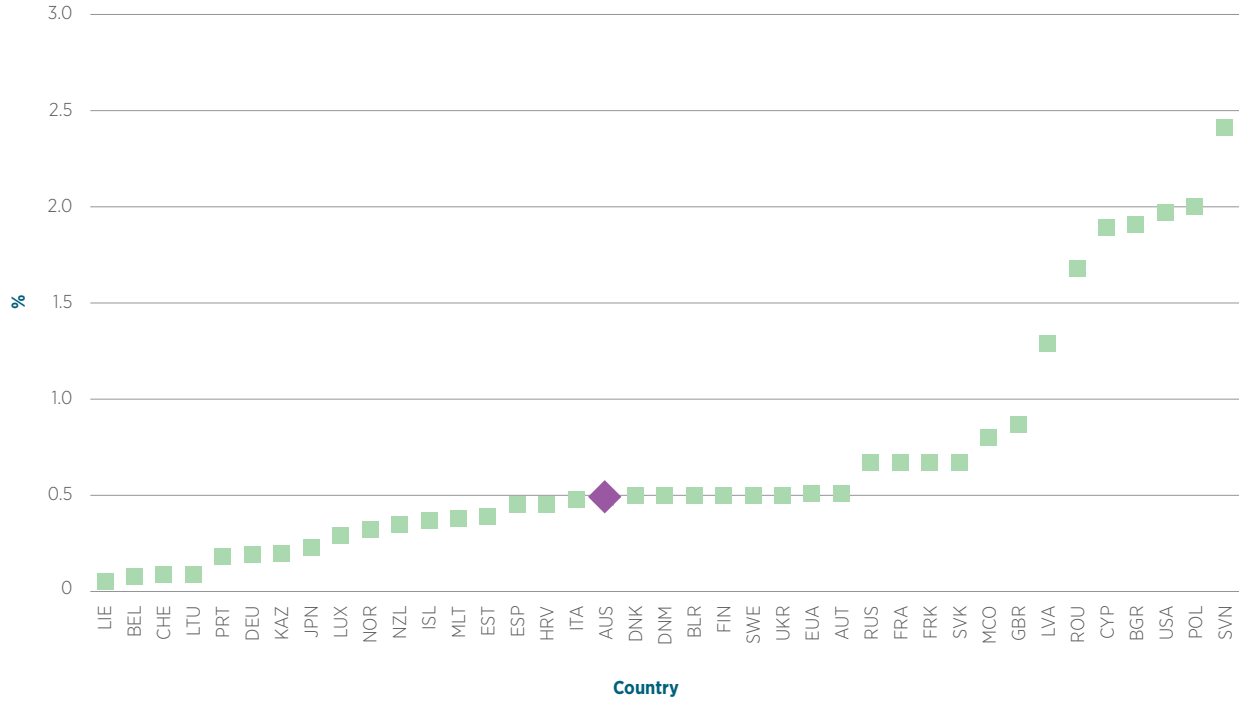
4.8.4 Category-specific QA/QC and verification

Electrical Equipment (2.G.1)

The applied country-specific product use EF for 2008–09 (0.89%) is within the range of default values listed by IPCC 2006 for closed pressure equipment (IPCC 2006, Table 8.3, 'Closed pressure electrical equipment (hv switchgear) containing SF_6: default emission factors').

The applied country-specific product use EF for 2023–24 (0.49%) is in the middle of the range of values reported by other developed country Parties.

Figure 4.19 Electrical equipment product life emission factors for developed country Parties (2023 submission) and Australia (2026 submission), per cent



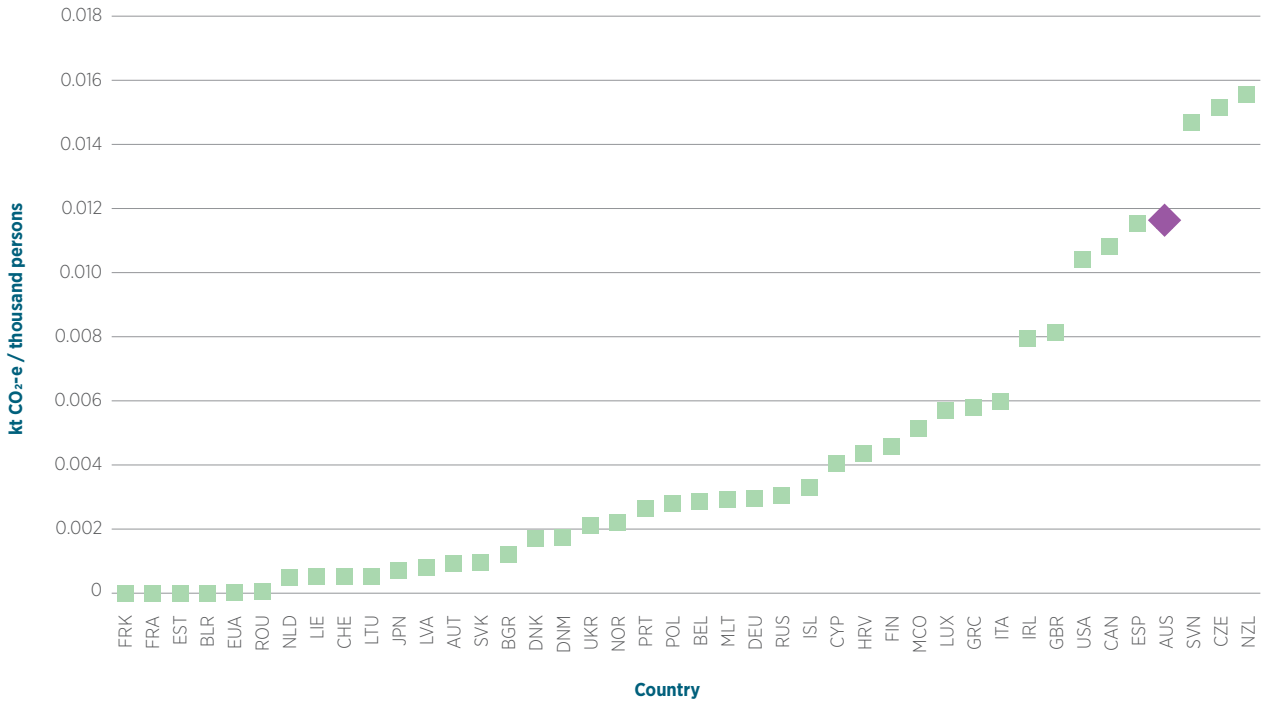
Source: UNFCCC Locator Tool

N_2O from product uses (2.G.3)

Australia's per-capita emission factor for N_2O from product uses is within the range of factors implied by submissions of other developed country Parties.

Figure 4.20 demonstrates it is towards the upper end of the range of per capita factor and therefore likely to lead to a conservative estimate of emissions from N_2O use.

Figure 4.20 N_2O use implied per capita emission factors or developed county Parties (2023 submission) and Australia (2026 submission), kt CO_2-e per thousand persons



Source: UNFCCC Locator Tool

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

4.8.5 Category-specific recalculations

The following revisions were made to estimates of emissions of SF_6 from electrical equipment (2.G.1) in this submission:

- **2.G.1 Electrical equipment SF_6:** emissions for the year 2022–23 have been revised downwards by 11.2 kt CO_2-e as a result of correction of a calculation error identified during QA/QC.

Table 4.14 Other product manufacture and use (2.G), recalculation of total CO_2-e emissions (Gg)

	2025 Submission	2026 Submission	Change	
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
1989–90	227.4	227.4	0.0	0.0
1994–95	308.8	308.8	0.0	0.0
1999–00	211.8	211.8	0.0	0.0
2004–05	197.2	197.2	0.0	0.0
2005–06	186.3	186.3	0.0	0.0
2006–07	174.6	174.6	0.0	0.0
2007–08	162.1	162.1	0.0	0.0
2008–09	146.0	146.0	0.0	0.0
2009–10	143.6	143.6	0.0	0.0
2010–11	141.0	141.0	0.0	0.0
2011–12	137.1	137.1	0.0	0.0
2012–13	134.9	134.9	0.0	0.0
2013–14	132.5	132.5	0.0	0.0
2014–15	138.7	138.7	0.0	0.0
2015–16	137.2	137.2	0.0	0.0
2016–17	139.0	139.0	0.0	0.0
2017–18	151.8	151.8	0.0	0.0
2018–19	147.8	147.8	0.0	0.0
2019–20	132.7	132.7	0.0	0.0
2020–21	139.1	139.1	0.0	0.0
2021–22	141.7	141.7	0.0	0.0
2022–23	143.4	132.3	-11.2	-7.8

4.9 **Other** (CRT category 2.H)

4.9.1 Category Description

The 2.H Other source category includes emissions of CO_2 from the food and beverage industry. The IPCC hierarchy also includes the pulp and paper industry under source category 2.H. While IPCC guidelines suggest that emissions of CO_2 and CH_4 are possible from the pulp and paper industry, no specific section on these categories is provided. Emissions of CO_2 from use of carbonates from the pulp and paper industry is reported under 2.A.3.

Food and beverage industry (2.H.2)

The supply of CO_2 gas for use in the food and drink industry (2.H.2) 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 has also been obtained from two natural CO_2 wells located at Caroline in South Australia (commissioned in 1967 and closed in 2017) 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.H.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.H. 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.

IPCC 1997 indicates the fermentation of sugar by industry is not considered to be a net source of CO_2 emissions. Consistent with IPCC 2006, 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 ABARES.

4.9.2 Methodological issues

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 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 indexed to changes in quantities of soda ash consumption for this plant reported under the NEGR scheme 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. It is assumed that all CO_2 generated is sold for use in food and drink production.

Sodium bicarbonate ($NaHCO_3$) is also produced in the manufacture of soda ash using the Solvay process (see Chapter 4.3.2 (2.B.7)). Uses of sodium bicarbonate in which CO_2 is generated include leavening agents, pharmaceuticals, stock feed buffer and effervescent salts and beverages. EnerGreen 2009 indicated that the proportion of sodium bicarbonate consumption resulting in emissions of CO_2 is 80 per cent. It is assumed that the sodium bicarbonate thermally decomposes in the following reaction:

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

The mass of CO_2 emitted from the use of sodium bicarbonate E_{sb} is estimated using consumption data A_{sb}, 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 $NaHCO_3$) as expressed in the following formula:

$$E_{sb} = 0.8 \times A_{sb} \times 0.262 \text{ kg / tonne } NaCO_3$$

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).

4.9.3 Uncertainties and time series Consistency

The Tier 1 uncertainty analysis in Annex II 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.

4.9.4 Category-specific QA/QC and verification

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

4.9.5 Category-specific recalculations

No recalculations have been made to emissions in this category in this submission.

Table 4.15 Other (2.H), recalculation of total CO_2-e emissions (Gg)

	2025 Submission	2026 Submission	Change	
	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%
1989–90	82.6	82.6	0.0	0.0
1994–95	138.8	138.8	0.0	0.0
1999–00	145.1	145.1	0.0	0.0
2004–05	167.5	167.5	0.0	0.0
2005–06	160.5	160.5	0.0	0.0
2006–07	148.3	148.3	0.0	0.0
2007–08	163.4	163.4	0.0	0.0
2008–09	161.4	161.4	0.0	0.0
2009–10	231.5	231.5	0.0	0.0
2010–11	261.6	261.6	0.0	0.0
2011–12	218.0	218.0	0.0	0.0
2012–13	240.4	240.4	0.0	0.0
2013–14	201.7	201.7	0.0	0.0
2014–15	215.7	215.7	0.0	0.0
2015–16	272.8	272.8	0.0	0.0
2016–17	213.3	213.3	0.0	0.0
2017–18	218.9	218.9	0.0	0.0
2018–19	219.0	219.0	0.0	0.0
2019–20	222.6	222.6	0.0	0.0
2020–21	225.5	225.5	0.0	0.0
2021–22	227.6	227.6	0.0	0.0
2022–23	220.1	220.1	0.0	0.0

4.9.6 Planned improvements

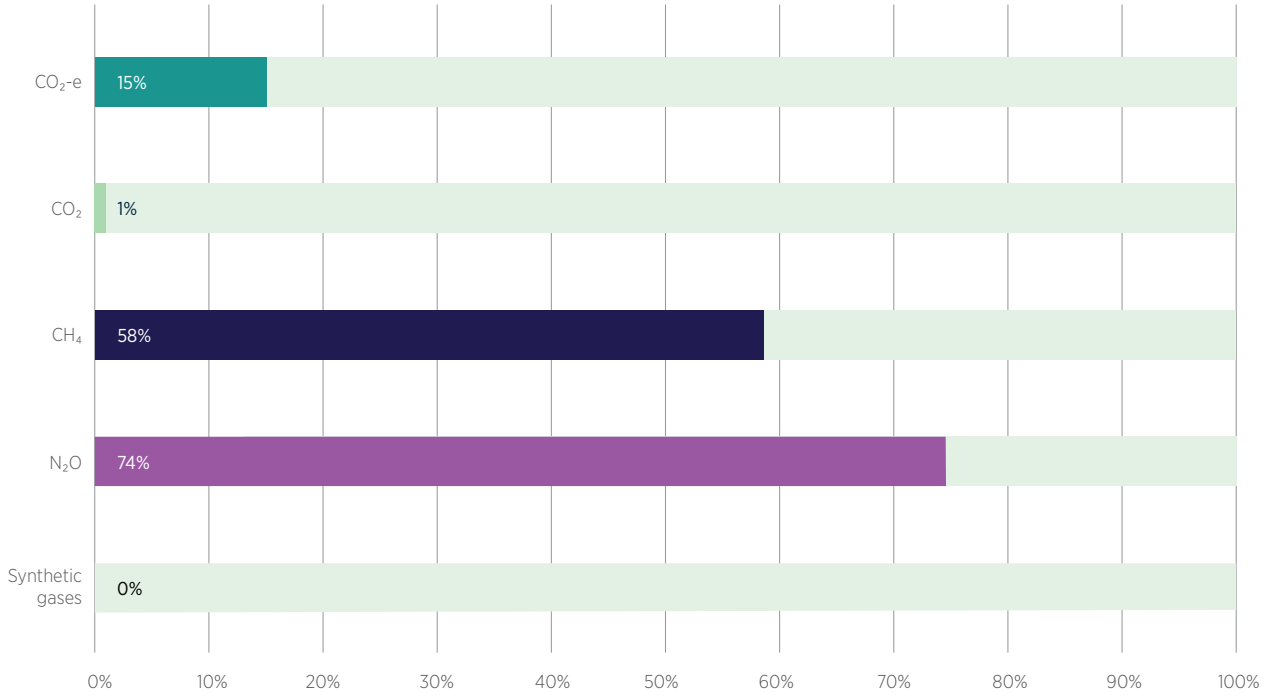
Activity data and EFs will be kept under review.

5. Agriculture

5.1 Overview of the sector and background information

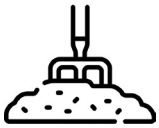
The *Agriculture* sector includes emissions from agricultural activities, including livestock and farm management. The sector as a proportion of total emissions (excluding LULUCF) is presented in Figure 5.1.

Figure 5.1 Share of national emissions (excluding LULUCF) for the Agriculture sector by gas, 2023–24



Enteric fermentation was the main source of *Agriculture* emissions, contributing around 78 per cent of the sector's emissions. The next largest source was *agricultural soils,* followed by *manure management. Liming* and *urea application* contribute a small amount of the sector's emissions with *rice cultivation* and *field burning of agricultural residues* contributing the remainder. Changes in emissions by subsector between 2022–23 and 2023–24 are shown in Figure 5.2.

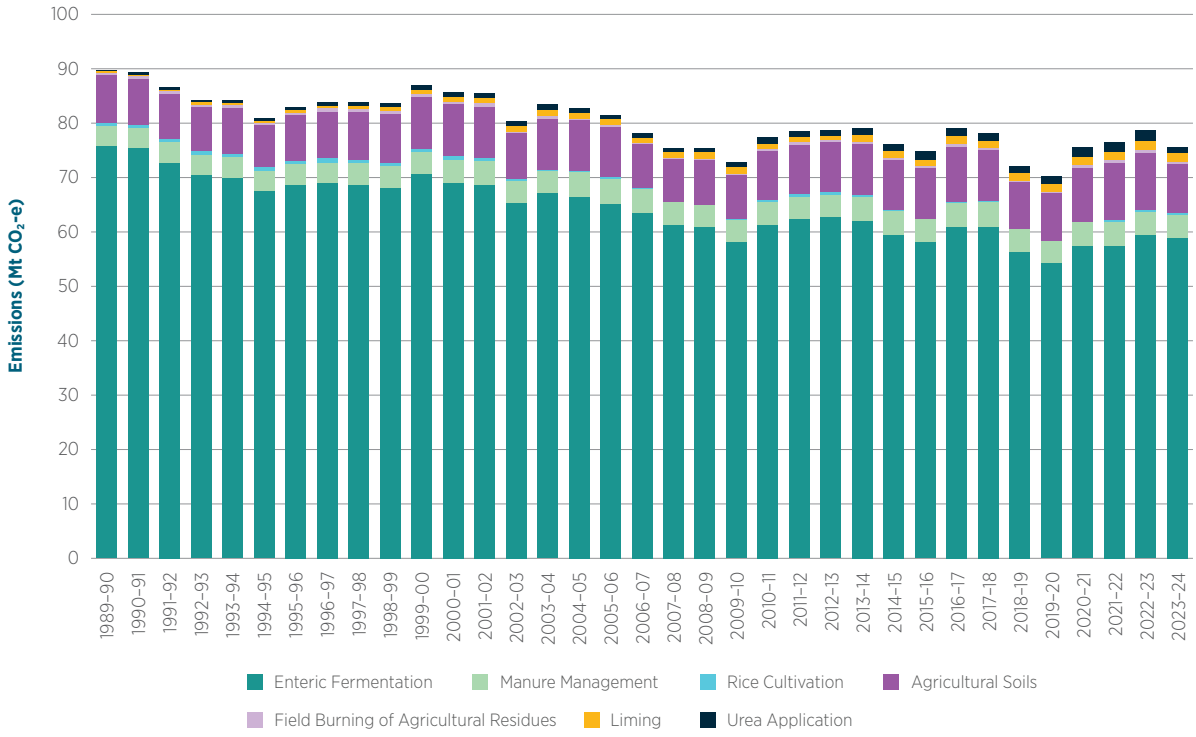
Figure 5.2 Comparison of 2023–24 emissions with past emissions levels from key agriculture subsectors, million tonnes of carbon dioxide equivalent (Mt CO_2-e) and percentage change (%)

Agriculture Subsectors	2023–24 emissions	Change in 2023–24 emissions since: 1989–90	2004–05	2022–23
 3.A Enteric fermentation	59 Mt	-17 Mt CO_2-e -22%	-8 Mt CO_2-e -11%	-0.5 Mt CO_2-e -1%
 3.B Manure management	4 Mt	+14% +0.5 Mt CO_2-e	-0.2 Mt CO_2-e -5%	+0% +0.00 Mt CO_2-e
 3.C Rice Cultivation	0.2 Mt	-0.3 Mt CO_2-e -64%	-0.04 Mt CO_2-e -16%	-0.02 Mt CO_2-e -10%
 3.D Agricultural Soils	9 Mt	+3% +0.3 Mt CO_2-e	-0.20 Mt CO_2-e -2%	-1.64 Mt CO_2-e -15%
 3.E Prescribed burning of savannas	NA	–	–	–
 3.F Field Burning of Agricultural Residues	0.4 Mt	-0.01 Mt CO_2-e -2%	+25% +0.09 Mt CO_2-e	-0.09 Mt CO_2-e -16%

Agriculture Subsectors	2023–24 emissions	Change in 2023–24 emissions since: 1989–90	2004–05	2022–23
3.G Liming and 3.H Urea Application	2.9 Mt	+390% +2.3 Mt CO_2-e	+45% +0.9 Mt CO_2-e	-0.84 Mt CO_2-e -23%
3.I Other carbon-containing fertilisers and 3.J Other	NE	–	–	–

Note: Icons in this figure are sourced from Geotata, adi_sena, Freepik, and Creatype on flaticon.com.

Figure 5.3 CO_2-e emissions from agriculture, by sub-sector, 1990–2024



Livestock industries produce methane (CH_4) and nitrous oxide (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 that of other Annex I countries. Intensive livestock industries also play an increasing role in Australia, specifically for dairy and beef cattle, poultry and swine.

Enteric fermentation emissions are driven by livestock population numbers, in particular, pasture-raised beef cattle. A 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 Australian wool reserve price scheme. The changes in flock and herd numbers reflect changing market conditions in the beef and sheep meat/wool industries and climatic conditions such as drought.

Drought conditions frequently impact Australian livestock numbers, as water availability directly impacts the viability of herds. The national pasture-raised beef cattle herd last peaked in 2012–13 at 28.2 million. These conditions also impact emissions from *manure management.*

Agricultural soils emissions show gradual upward trend over the long term, which is the result of increasing agricultural fertiliser use and an increase in retention of crop residues. Drought conditions, such as between 2016 and 2019, result in a decrease in crop yields and fertiliser use which explains much of the variation in the time series.

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. After a peak in 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. Periodic increases in CH_4 emissions from rice cultivation observed in more recent years occur as a result of increases in the area of rice cultivation outside of drought periods.

Emissions from *field burning of agricultural residues* show a long-term decrease due to a decline in stubble burning practices in Australia as the practice of stubble retention has become 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. The increase in recent years reflects record years of crop production.

The *Agriculture* estimates are compiled on a state and territory basis with 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. These large physical differences lead to significant variability in such things as 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.

5.1.1 Methodological issues

The Australian *Agriculture* methodology consists of both country specific (CS) and IPCC default methodologies and emission factors (EFs) (Table 5.1).

Table 5.1 Summary of methods and emission factors to estimate emissions from Agriculture

Greenhouse Gas Source and Sink Categories Method Applied		CH_4		N_2O	
		Method Applied	Emission Factor	Method Applied	Emission Factor
A	**Enteric Fermentation**				
1. Cattle	a. Dairy cattle	T3	CS		
	b. Beef cattle – pasture	T3	CS		
	c. Beef cattle – feedlot	T3	CS		
2. Sheep		T3	CS		
3. Swine		T2	CS		
4. Other	a. Poultry [(a)]	NE	NE		
	b. Alpacas, buffalo, deer, goats, horses, camels, mules/asses, ostriches and emus	T1	D		
B	**Manure management**				
1. Cattle	a. Dairy cattle	T2	CS	T2	CS
	b. Beef cattle – pasture	T2	CS	NA	NA
	c. Beef cattle – feedlot	T3	CS	T3	CS
2. Sheep		T2	CS	NA	NA
3. Swine		T3	CS	T3	CS
4. Other	a. Poultry	T3	D,CS	T3	CS
	b. Alpacas, buffalo, deer, goats, horses, camels, mules/asses, ostriches and emus	T2	D,CS	NA	NA
5. Indirect emissions				T2	D,CS
C	**Rice cultivation**	T2	D,CS		
D	**Agricultural soils**				
1. Direct emissions	a. Inorganic fertilisers			T2	CS
	b.i. Animal wastes applied to soils			T2	D,CS
	b.ii. Sewage sludge applied to land			T2	CS
	b.iii. Other organic fertilisers [(b)]			NE	NE
	c. Urine and dung deposited by grazing animals			T2	CS
	d. Crop residues			T2	CS
	e. Mineralisation due to loss of soil C			T2	CS
	f. Cultivation of histosols			T1	D
2. Indirect emissions	a. Atmospheric deposition			T1	CS
	b. Leaching and run-off			T2	CS
E	**Prescribed burning of savannas**	IE	IE	IE	IE
F	**Field burning of agricultural residues**	T2	CS	T2	CS
	CO_2				
G	**Liming**	T2	CS		
H	**Urea application**	T1	D		
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, D = IPCC defaults, T1 = tier 1, T2 = tier 2, T3 = tier 3, NE = not estimated, NA = not applicable, IE = included elsewhere.
= Key category

Activity data is mostly sourced from the Australian Bureau of Statistics (ABS) and is supplemented with data from the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES, the science and economics research division of the Department of Agriculture, Fisheries and Forestry), to ensure a nationally-consistent approach and quality control. Additional activity data are sourced from rural Research and Development Corporations (RDCs, government-industry partnerships) and other industry bodies.

A reduced set of agricultural area and production statistics is available for the 2023–24 ABS Agriculture statistics, as the former Agricultural Commodities report has been discontinued and new sectoral reports are being developed on a staged basis. In some cases, this meant that for this inventory year state and territory data were estimated using previous results scaled by national-level changes.

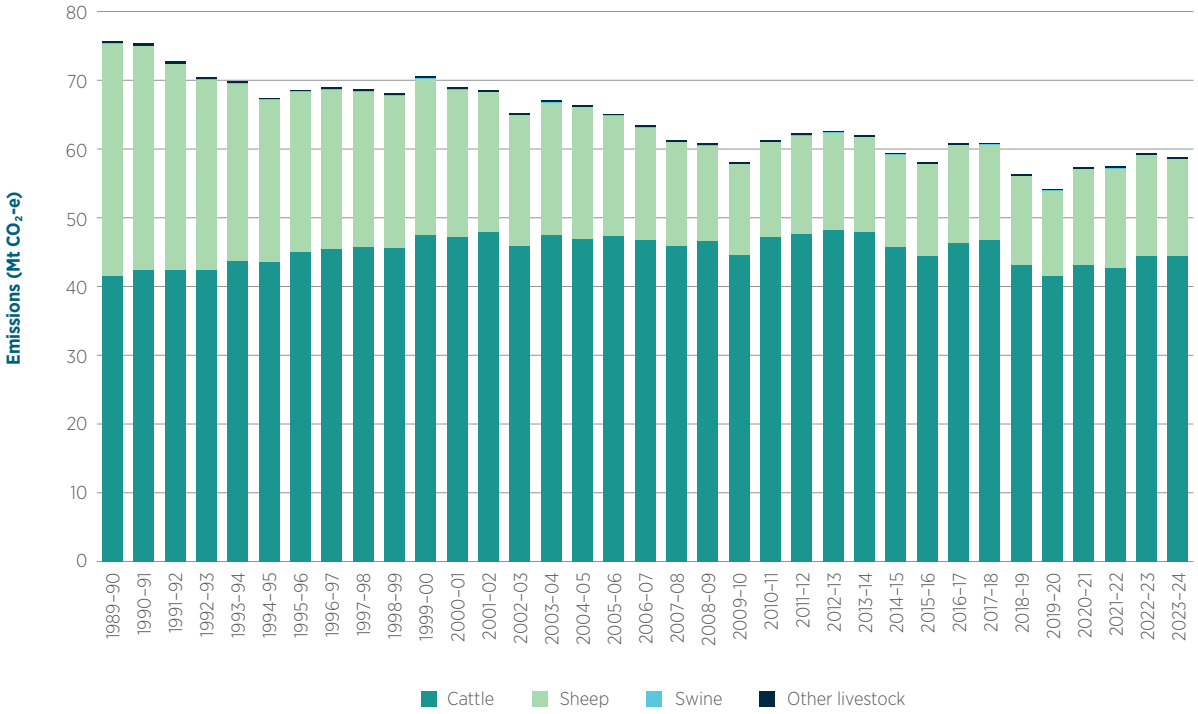
The ABS is modernising the collection and reporting of agricultural statistics. Due to the increasing availability of data other than farm surveys, a commitment to reducing reporting burden and declining survey response rates, it is necessary to change the way in which Australia's official agricultural statistics are produced. This need to modernise the production of agricultural statistics is not unique to Australia and around the world other statistical agencies are making similar changes. The production of the National Greenhouse Accounts is engaged with the ABS throughout this modernisation, to ensure continuity of activity data for the *Agriculture* sector.

5.2 **Enteric Fermentation** (CRT category 3.A)

5.2.1 Category description

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.

Figure 5.4 Enteric Fermentation emissions by livestock category, Australia, Mt CO_2-e



5.2.2 Methodological issues

For activity data, the inventory relies upon the following data sources for livestock numbers:

- ABS Livestock statistics (ABS 2025a) (annual);
- Australian Lot Feeders Association (ALFA 2025) (quarterly);
- Meat & Livestock Australia farm survey data (ABARES) (annual)

This is supported by the following other sources of production statistics:

- Dairy Australia (annual);
- ABARES Agricultural Commodities (ABARES 1999–2023) (quarterly);
- Australian Wool Testing Authority (AWTA 2025) (monthly)

These data sources allow for enhanced livestock characterisation for cattle, sheep, poultry and swine, and therefore allow the use of IPCC tier 2 methods. For dairy cattle, beef cattle on pasture and feedlots, sheep and swine, country-specific information is available for emission factor estimation.

Dairy Cattle (3.A.1.a)

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 feed intake relative to liveweight and liveweight gain of cattle.

The large volume of milk produced by dairy cattle under modern management regimes requires that the lactating cow consumes 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 (Table A5.5.1.10) and the relationships presented by the Standing Committee on Agriculture (SCA 1990).

Table 5.2 Symbols used in algorithms for dairy cattle

State/ territory (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):

$$I_{ij} = (1.185 + 0.00454 \cdot W_{ij} - 0.0000026 \cdot W_{ij}^2 + 0.315 \cdot LWG_{ij})^2 \times MRI_{ij} + MI_{ij} \quad \text{(3.A.1a_1)}$$

Where W_{ij} = liveweight (kg) (Table A5.5.1.1)

LWG_{ij} = liveweight gain (kg/day) (Table A5.5.1.2)

MRI_{ij} = increase in metabolic rate when producing milk (SCA 1990)

= 1.1 for milking and house cows and 1 for all other classes

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

$$MI_{ij} = MP_{ij} \times NE \div (GEC \; x.k \times qm_{ij}) \quad \text{(3.A.1a_2)}$$

Where MP_{ij} = milk production (kg/head/day) from Dairy Australia State statistics (Litres of milk is multiplied by 1.03 to convert to kg of milk)

NE = 3.054 MJ net energy/kg milk (SCA 1990)

GEC= Gross Energy Content, 18.4 MJ/kg dry matter

k = 0.60 efficiency of use of metabolisable energy for milk production (SCA 1990)

qm_{ij} = metabolisability of the diet. This is the ratio of metabolisable energy (ME) to gross energy (GE) in the diet (i.e. ME / GE). Metabolisable energy content is related to digestibility of dry matter (DMD_{ij}). So using the equation of Minson and McDonald (1987), qm_{ij} = 0.00795 DMD – 0.0014; (where DMD is expressed as a per cent)

The total daily production of methane (M_{ij} kg CH_4/head/day) is given by Charmley et al. (2015) as:

$$M_{ij} = 20.7 \times I_{ij} /1000 \quad \text{(3.A.1a_3)}$$

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 ($MPW_{ENTERIC}$) is given in Table A5.5.1.5. Annual Australian methane production (Gg) for all classes of dairy cattle across all states can then be calculated as:

$$E = \Sigma_i \Sigma_j ((N_{ij=1,2,4} \times M_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times M_{ij=3,5} \times 281) + (N_{ij=3,5} \times MPW_{ENTERIC_{ij=3,5}} \times 84)) \times 10^{-6} \quad \text{(3.A.1a_4)}$$

Where N_{ij} = numbers of dairy cattle in each class for each State and season
M_{ij} = methane production (kg/head/day)
$MPW_{ENTERIC_{ij}}$ = methane production for pre-weaned calves (kg/head/day)

Beef Cattle on pastures (3.A.1.b)

Table 5.3 Symbols used in algorithms for beef cattle on pasture

State and territory (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.

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

$$I_{ijkln} = (1.185 + 0.00454W_{ijkln} - 0.0000026\ W_{ijkln}^2 + 0.315\ LWG_{ijkln})^2 \times MA_{ijkl=5} \quad \text{(3.A.1b_1)}$$

Where W_{ijkln} = liveweight in kg (Table A5.5.2.1)
LWG_{ijkln} = live weight gain in kg/head/day (Table A5.5.2.2)

The intake of lactating breeding cattle is 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 ($MA_{i|kl=5}$) is calculated by:

$$MA_{ijkl=5} = (LC_{ijkl=5} \times FA_{ijkl=5}) + (1-LC_{ijkl=5}) \quad \text{(3.A.1b_2)}$$

Where $LC_{ijkl=5}$ = proportion of Cows >2 lactating

$FA_{ijkl=5}$ = feed adjustment (Table A5.5.2.5)

The total daily production of methane (M_{ijk}l kg CH_4/head/day) is given by Charmley et al. (2015) as:

$$M_{ijkl} = 20.7 \times l_{ijkln} \div 1000 \quad \text{(3.A.1b_3)}$$

To calculate emissions from beef cattle on pasture it is necessary to first subtract feedlot cattle numbers from the total 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 (IPCC 2006), 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:

$$N_{ijkl} = N_{ijk}(l = 1,2,3,6) \text{ and } [N_{ijk} \text{ minus feedlot numbers}] (l = 7) \quad \text{(3.A.1b_4)}$$

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

$N_{ijk\ (l = 7)\ -\ total\ feedlot\ numbers}$ = from Table 5.3, l=7 corresponds with steers >1 year old. In order to calculate total beef cattle numbers in this class, total annual equivalent feedlot numbers must be subtracted from l =7. For WA 99 per cent of feedlot cattle are assumed to be sourced from the South-West region and the balance from the Pilbara and Kimberley.

Annual Australian methane production (Gg) for all classes of beef cattle across all seasons can then be calculated as:

$$E = \Sigma_i \Sigma_j \Sigma_k \Sigma_l \Sigma_n (91.25 \times N_{ijkln} \times M_{ijkln}) \times 10^{-6} \quad \text{(3.A.1b_5)}$$

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

Beef cattle in feedlots (3.A.1.c)

Emissions from lot-fed beef cattle are estimated based on the relationship between methane yield and feed intake, and the neutral detergent fibre (NDF) and ether extract (EE) content of the feed, as reported by Almeida et al. (2025). This relationship was derived from a database of respiration chamber measurements taken from beef cattle fed a range of predominantly barley-based diets representative of Australian feedlot operations.

Table 5.4 Symbols used in algorithms for feedlot cattle

State and territory (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	

The Almeida et al. equation to predict daily methane production (M_j kg CH_4/head/day) is:

$$M_j = (5.11 \cdot I_j - 4.00 \cdot EE_j + 2.26 \cdot NDF_j) \times 10^{-3} \quad (3.A.1c_1)$$

Where I_j feed intake (kg dry matter/day) (Table A5.5.3.2)
EE_j = ether extract (as a percentage of I_j) (Table A5.5.3.2)
NDF_j = neutral detergent fibre (as a percentage of I_j) (Table A5.5.3.2)

Methane production (Gg) for all classes of feedlot cattle across all States can then be calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_j) \times 10^{-6} \quad (3.A.1c_2)$$

Where N_{ij} = numbers of feedlot cattle as an annual equivalent in each class in each State
M_j = methane production (kg/head/day)

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, 1964b, 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 corresponds well with intakes reported by state and territory experts for seasonal feed digestibility common in their state and territory. The CS approach to estimating feed intake for sheep takes account of all net energy requirements for activities such as wool production, growth and grazing over large areas.

Table 5.5 Symbols used in algorithms for sheep

State and territory (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* kg DM/head/day) is given by AFRC (1990) as:

$$PI_{ijk} = (104.7 \cdot qm_{ijk} + 0.307 \cdot W_{ijk} - 15.0)\, W_{ijk}^{0.75} \div 1000 \quad \text{(3.A.2_1)}$$

Where W_{ijk} = liveweight (kg) (Table A5.5.4.1)

$qm,_{ijk}$ = metabolisability of the diet. This is the ratio of metabolisable energy (ME) to gross energy (GE) in the diet (i.e. ME / GE). Metabolisable energy content is related to digestibility of dry matter (DMD_{ijk}) so, using the equation of Minson and McDonald (1987), qm_{ijk} = 0.00795 DMD – 0.0014 (DMD is expressed as a per cent)

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*) related to feed availability is given by White et al. (1983) as:

$$RI_{ijk} = 1 - \exp[-2 \times (DMA_{ijk})^2] \quad \text{(3.A.2_2)}$$

Where DMA_{ijk} = dry matter availability (t/ha) (Table A5.5.4.3)

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 kg DM/head/day) of a sheep is thus:

$$I_{ijk} = PI_{ijk} \times RI_{ijk} \times MA_{ijk=4} \quad \text{(3.A.2_3)}$$

Where $MA_{ijk=4}$ additional intake for milk production (dimensionless factor)

The intake of lactating breeding ewes is 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 ($MA_{i|k=4}$) is calculated by:

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

Where LE_{ijk} = 4 = proportion of breeding ewes lactating, calculated as the annual lambing rates x proportion of lambs receiving milk in each season (Table A5.5.4.6)

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):

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

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

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

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

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

91.25 = number of days in each season

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 1987), 0.6 to 0.8 per cent of GE (Moss 1993) and 0.4 per cent of GE (Kirchgessner 1991). A methane conversion of 0.7 per cent of GE intake is used for Australia.

Table 5.6 Symbols used in algorithms for swine

State and territory (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:

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

Where I_{ij} = feed intake (kg DM/day) (Table A5.5.5.2)
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:

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

Where N_{ij} = the number of swine in each class for each State
M_{ij} = methane production (kg/head/day)

Other livestock (3.A.4)

The contribution of other livestock to total methane production is comparatively small. A simplified 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 5.8).

The methane EFs for buffalo and emus/ostriches follow the (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.

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.

Table 5.7 Symbols used in algorithms for other livestock

State and territory (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 and territory, total methane production (Gg) from the enteric fermentation of minor livestock types can be calculated as follows:

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

Where N_{ij} = numbers of other livestock types in each State

M_j = methane EF (kg/head/year) (Table 5.8)

Table 5.8 Other livestock – enteric fermentation EFs (kg CH_4/head/year)

Livestock type	EF	Source
Buffalo	68	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

5.2.3 Uncertainty assessment and time-series consistency

A quantitative assessment of uncertainty was undertaken and uncertainties for enteric fermentation were estimated to be in the order of 25 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.

5.2.4 Category-specific QA/QC and verification

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. The 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.

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 CRT tables and those published by the FAO. The reasons for these differences include recalculations made by the ABS for time series consistency, and adjustments made to ensure that feedlot cattle and chicken numbers are expressed in terms of annual-equivalent populations.

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.

Implied EFs

As tier 3 methods are used to estimate emissions from cattle, sheep and swine, the IEFs have been compared with values in the 2006 IPCC Guidelines (IPCC 2006) and the 2019 Refinement (IPCC 2019)(Table 5.9). The IEF for swine is generally consistent with the IPCC values. The IEFs for pasture-based beef cattle is low, reflecting the predominance of emissions from pasture, rage and paddock in Australian systems.

The dairy cattle IEF is similar to the 2019 IPCC Refinement (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.

Using the methane equation from Almeida et al. (2025) adopted for the first time in this submission, the feedlot cattle IEF is substantially lower than default value. This is due to country-specific feed intakes and breed composition of the feedlot herd, reflecting the increasing dominance of longer-fed animal classes producing higher quality meat.

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

Table 5.9 Implied EFs – enteric fermentation (kg CH_4/head/year)

Livestock type	Australia	IPCC2006	IPCC 2019
Dairy cattle	96.20	90	93
Beef cattle – pasture	50.41	60	63
Beef cattle – feedlot	28.94	60	63
Sheep	6.67	8	5 or 9
Swine	1.57	1.5	1 or 1.5

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

Feed intake

As Australia uses tier 3 methods for estimating feed intakes, these values have been compared with average intakes reported by other Parties.

Cattle

For dairy cattle, average herd feed intakes are within the range reported by other Parties (Table 5.10). 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 are generally not 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 5.10).

Gross energy intake (GEI) for feedlot cattle was predicted using diet composition and the relationship of Jentsch et al. (2003).

Table 5.10 Average herd intake (MJ GEI/head/day)

	Australia	Other Parties	
Livestock type	**Mean**	**Range**	**Mean**
Dairy cows (dairy herd)	237	196–427	314
Non-dairy cattle		104–180	137
Beef cattle – pasture	123		
Beef cattle – feedlot (T2)	181		
Sheep	16	15–31	22

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 5.10). 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 the 2006 IPCC Guidelines (IPCC 2006).

In Australia, actual feed intake is often less than potential intake due to low feed availability on pastures.

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.

Methane conversion rates

As Australia uses tier 3 methods for estimating methane emissions, methane conversion rates (Y_m) have been compared against IPCC values.

Cattle

The 2019 IPCC Guidelines (IPCC 2019) indicate that animals fed diets containing 90 per cent concentrates should use a Y_m of 3.0 per cent. The study by Almeida et al. (2025), whose methane production equation is used in this submission, finds a value of 2.86 per cent for all data included, in good agreement with the default value.

The conversion rates for dairy and beef cattle on pastures (6.1–6.2 per cent) are also consistent with 2019 IPCC Refinement (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 sulphur hexafluoride (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 * DMI – 0.0003) to that reported in Howden et al. (1994) (CH_4 = 0.0188 * DMI + 0.00158).

The herd average Y_m for Australian sheep is 6.2 per cent which is in good agreement with 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. The study of feedlot cattle emissions by Almeida et al. (2025) was reviewed by independent experts for the purpose of this inventory, as well as the peer-review publication process.

5.2.5 Category-specific recalculations

One method improvement required recalculations of enteric fermentation emissions over the full inventory time series. Another resulted in updated activity data for a single year. These recalculations are presented in Table 5.11.

A. Sheep: new herd time series data.

A small recalculation throughout the time series is due to the revised sheep flock numbers published in December 2025 by the Australian Bureau of Statistics (ABS). A new method incorporating several data sources has replaced the previous data based on annual surveys, resulting in revised estimates. Further details of the new method and the wider modernisation of agricultural statistics are available from the ABS.

B. Pasture-fed beef: revision to timeseries.

The new method for estimating the size of the beef herd first published by the ABS in June 2024 has continued to be published as ‘experimental’ values. The 2025 data publication included a small revision to the 2022–23 numbers, resulting in a small downward emissions recalculation.

Table 5.11 Enteric fermentation (3.A): recalculations of total CO_2-e emissions, 1989–90 to 2022–23

	2025 submission	2026 submission	Change		Reasons for Recalculation (Gg CO_2-e)	
Year	Gg CO_2-e	Gg CO_2 -e	Gg CO_2 -e	(Per cent)	A	B
1989–90	75,679	75,690	11	0.0%	11	0
1994–95	67,434	67,444	10	0.0%	10	0
1999–00	70,620	70,628	8	0.0%	8	0
2004–05	66,321	66,390	69	0.1%	69	0
2009–10	58,100	58,091	-8	0.0%	-8	0
2014–15	59,474	59,466	-8	0.0%	-8	0
2019–20	54,319	54,201	-118	-0.2%	-118	0
2022–23	59,102	59,358	256	0.4%	317	-61

5.2.6 Category-specific planned improvements

For enteric fermentation the following areas have been identified for review and/or change:

1. *Sheep methods and parameters* – review methods and parameters used to estimate enteric fermentation emissions from sheep using recent published data.
2. *Feed and animal characteristics* – As these characteristics can change as industry practices change over time, the current values need to be reviewed periodically.
3. *Modernisation of ABS Agricultural Statistics* – as described in section 5.2.4, the department is consulting with the Australian Bureau of Statistics as they modernise the production of agricultural statistics. This may entail changes to the age class information and spatial location of the national herd, including time-series recalculations.
4. *Feedlot cattle activity data* – the time series of animal numbers and the average number of days on feed in each class will be reviewed to integrate new data sources.
5. *Estimation of abatement from feed technologies* – Feed technologies for reducing enteric methane are becoming more prevalent. For some products and livestock systems, there is robust study data and meta-analyses to support estimates of abatement. Inclusion in the inventory depends on the availability of adequate activity data.

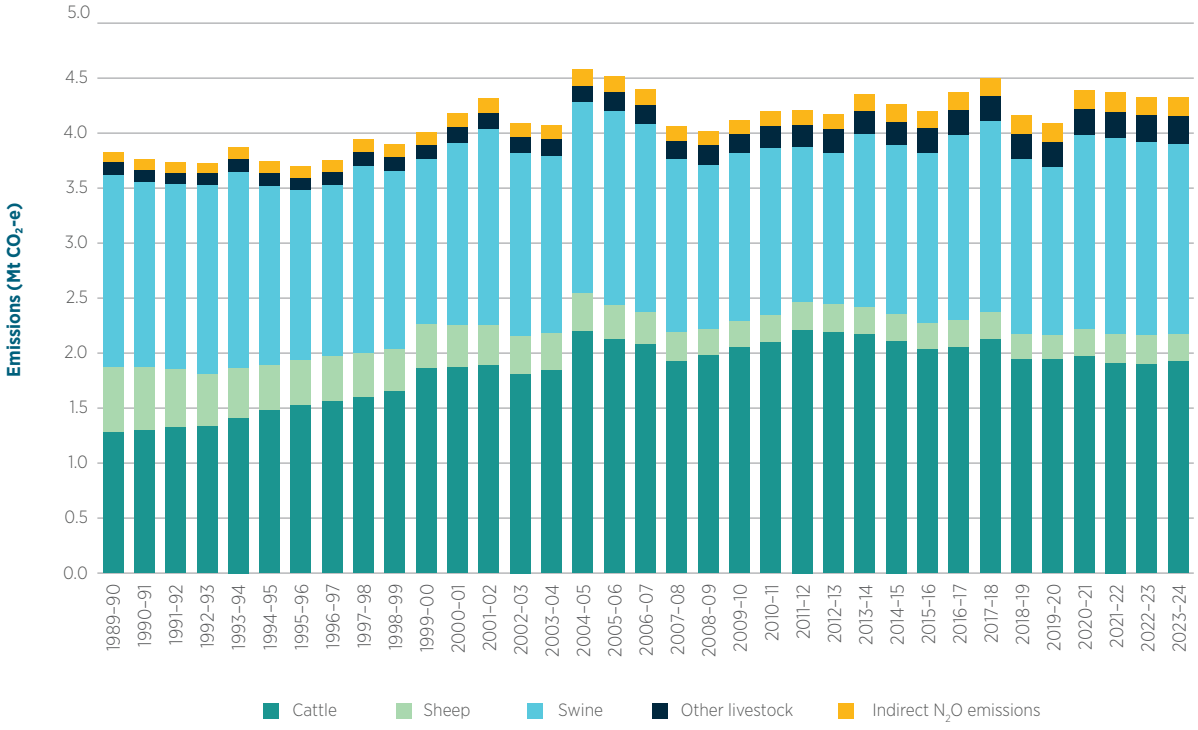
5.3 Manure Management (CRT category 3.B)

5.3.1 Category description

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 manure management systems (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.

Figure 5.5 Manure management emissions by source, Australia, Mt CO_2-e



5.3.2 Methodological issues

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 5.6).

Activity data is the same as used for enteric fermentation. Subscripts for the algorithms are the same as used for calculating enteric fermentation (Table 5.2 to Table 5.7) with an additional MMS component (Table 5.12).

Figure 5.6 Mass flow method of estimating manure management emissions – feedlot cattle example

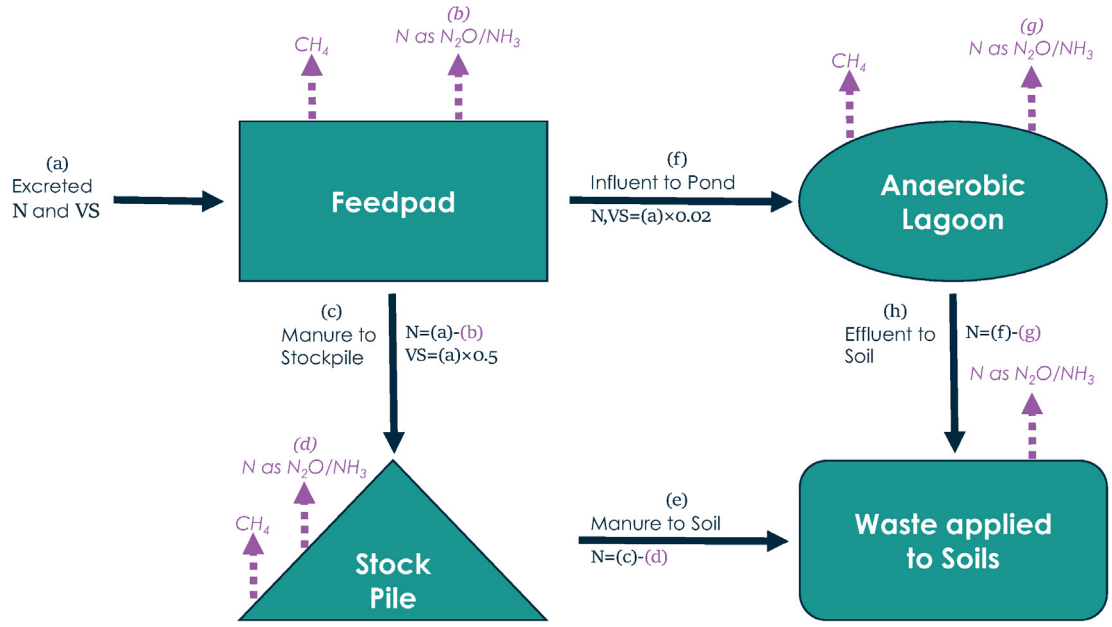


Table 5.12 Additional symbols used in algorithms for manure related emissions

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

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 Annex 5.5.

Manure management emissions for feedlot beef, 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 such as 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

Volatile solid production is estimated from the feed intake, calculated as for the enteric methane estimates. This VS is allocated to the two manure systems using measurements of methane emissions from fenced and unfenced farm dams (Odebiri et al. 2025), and the nationwide AusDams database (Malerba et al. 2021) to develop regional (state, territory or sub-state region) fractions of sheep and beef cattle VS entering farm dams. For nearby dams, the difference in methane emissions is attributed to manure entering the unfenced dams. The amount of VS required to produce this methane can be estimated using equation 3.B.1a_2, and this can be expressed as a fraction of the VS from grazing animals in that statistical area, using the detailed Agricultural Census data from the ABS (2017). Using all the fenced/unfenced paired sites in Odebiri et al. (2025), this allocation can be related to the density of dams in that region. Using this relationship, an allocation between PRP and Farm Dams for the entire country is derived. The details of these allocations are provided in the sections of this report relating to each livestock type.

Methane emissions from the two systems are then calculated as for other livestock, using a temperature-dependent MCF for anaerobic lagoons from IPCC (2006), and the constant MCF of 0.47% for PRP (IPCC 2019).

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 default IPCC and country-specific values depending on the type of livestock.

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 $iFracGASM_{MMS}$ of each system, and N losses from earlier stages in the MMS (see Annex 5.5).

To estimate atmospheric deposition emissions, country-specific EFs are used. As the highest ammonia deposition rates (kg/ha) are found within a few hundred meters of the emission source, the fertiliser EFs of neighbouring production systems were considered to provide a more accurate estimate of emissions than the IPCC default EF. While the majority of volatilised N is advected away from the MMS, it undergoes significant dilution and is deposited to the wider landscape at very low rates (Dr Matt Redding, pers. comm., QLD DAFF, 2014).

A FracLEACH_MS value from the 2019 IPCC Refinement is used to calculate N that is lost through leaching and runoff associated with manure management. The factor in the 2019 IPCC Refinement (IPCC 2019) incorporated results from recent studies in Australia and New Zealand, and is therefore better able to reflect Australia's situation than the defaults in the 2006 IPCC Guidelines (IPCC 2006).

Dairy cattle (3.B.1.a)

Methane

Dairy cattle are generally kept in higher rainfall areas than other Australian livestock. This, and the disposal of excreta washed from milking sheds, gives opportunities for the generation of methane. However, only a small fraction of the potential methane emissions appears to be released. Williams (1993) measured methane production from dairy cattle manure under field conditions in Australia and found that only about 1 per cent of the methane production potential was achieved. This is nevertheless higher than the default 2019 IPCC 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/kg/head/day) was estimated using the data developed to calculate enteric methane production as this included information on intakes and dry matter digestibility. For dairy cattle, volatile solids were calculated as:

$$VS_{ij} = (I_{ij} \times (1 - DMD_{ij}) + (0.04 \times I_{ij})) \times (1 - A) \quad \text{(3.B.1a_1)}$$

Where I_{ij} = dry matter intake calculated as for enteric fermentation
DMD_{ij} = dry matter digestibility expressed as a fraction (Table A5.5.1.4)
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:

$$M_{ij} = VS_{ij} \times B_0 \times iMCF_i \times \rho \quad \text{(3.B.1a_2)}$$

Where B_0 = emissions potential – 0.24m^3 CH_4/kg VS (IPCC 2019)
$iMCF_i$ = integrated methane conversion factor (Table A5.5.1.6)
ρ = density of methane (0.6784 kg/m^3) – Taken from the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*

Methane produced by pre-weaned calves (MPW_{MANURE}) is given in Table A5.5.1.5. The annual methane production (Gg) from manure of dairy cattle is calculated as:

$$Total = \Sigma_i \Sigma_j ((N_{ij=1,2,4} \times M_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times M_{ij=3,5} \times 281) + (N_{ij=3,5} \times MPW_{MANURE_{ij=3,5}} \times 84)) \times 10^{-6} \quad \text{(3.B.1a_3)}$$

Where N_{ij} = numbers of dairy cattle in each State, class and season
M_{ij} = methane production (kg/head/day)
$MPW_{MANURE_{ij}}$ = methane production for pre-weaned calves (kg/head/day) (Appendix 5.A.5)

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:

$$CPI_{ij} = I_{ij} \times CP_{ij} \quad \text{(3.B.1a_4)}$$

Where I_{ij} = dry matter intake (kg/day) as calculated for enteric fermentation

CP_{ij} = crude protein content of feed intake expressed as a fraction (Table A5.5.1.4)

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:

$$NR_{ij} = (0.032 \times MP_{ij} \div 6.38) + \{\{0.212 - 0.008(L_{ij} - 2) - [(0.140 - 0.008(L_{ij} - 2)) \div (1 + \exp(-6(Z_{ij} - 0.4)))]\} \times (LWG_{ij} \times 0.92)\} \div 6.25 \quad \text{(3.B.1a_5)}$$

Where MP_{ij} = milk production in kg/head/day (Table A5.5.1.10)

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 3.A.1a_1)

Z_{ij} = relative size – (liveweight ÷ standard reference weight (Tables A5.5.1.1 and A5.5.1.3))

LWG_{ij} = liveweight gain (kg/day) (Table A5.5.1.2)

Nitrogen excreted (NE_{ij} kg/head/day) is calculated by subtracting NR_{ij}, and dermal protein loss from nitrogen intake such that:

$$NE_{ij} = (CPI_{ij} \div 6.25) - NR_{ij} - [\,(1.1 \times 10^{-4} \times W_{ij}^{0.75}) \div 6.25\,] \quad \text{(3.B.1a_6)}$$

Where W_{ij} = liveweight (Table A5.5.1.1)

Pre-weaned dairy calves are usually removed from their mothers and receive milk or milk replacer and feed pellets. The nitrogen excreted (NPW) by pre-weaned calves is given in Table A5.5.1.5.

The total annual nitrogen excreted (AE_{ij} Gg) is calculated as:

$$AE_{ij} = \Sigma_j\,(\,(N_{ij=1,2,4} \times NE_{ij=1,2,4} \times 365) + (N_{ij=3,5} \times NE_{ij=3,5} \times 281) + (N_{ij=3,5} \times NPW_{ij=3,5} \times 84)\,) \times 10^{-6} \quad \text{(3.B.1a_7)}$$

Where N_{ij} = the number of dairy cattle in each State and class

The annual nitrogen (MN_{ikMMS} Gg) in the different MMS can then be calculated as follows:

$$MN_{ijMMS} = (AE_{ij} \times MMS) \quad \text{(3.B.1a_8)}$$

Where MMS = the fraction of nitrogen that is managed in the different MMS (Table A5.5.1.8)

The total emissions of nitrous oxide from the different MMS can then be calculated as follows:

$$Total_{ijMMS} = (MN_{ijMMS} \times EF_{MMS} \times C_g) \quad \text{(3.B.1a_9)}$$

Where EF_{MMS} = emission factor (N_2O-N kg/ N excreted) for the different MMS (Table A5.5.1.9)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Indirect nitrous oxide emissions – Atmospheric Deposition

The mass of dairy waste volatilised (Gg N) from the MMS is calculated as:

$$MN_{ATMOS_i} = \Sigma_j \Sigma_{MMS} (MN_{ijMMS} \times FracGASM_{MMS}) \quad (3.B.5a_1)$$

Where FracGASM$_{MMS}$ = the fraction of N volatilised for dairy MMS (Table A5.5.1.9)

Atmospheric deposition emissions from dairy MMS are calculated as:

$$E = \Sigma_i (MN_{ATMOS_i} \times EF \times C_g) \quad (3.B.5a_2)$$

Where E = annual emissions from atmospheric deposition (Gg N_2O)
EF = 0.0059 (Gg N_2O-N/Gg N) (Inorganic Fertiliser EF for irrigated pasture – Table 5.21)
C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Indirect nitrous oxide emissions – 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 FracLEACH_MS value for leaching and runoff is used from the 2019 IPCC Refinement (IPCC 2019). The factor in the 2019 IPCC Refinement (IPCC 2019) incorporated results from recent studies in Australia and New Zealand, and is therefore better able to reflect Australia's situation than the defaults in the 2006 IPCC Guidelines (IPCC 2006).

The amount of N available for leaching and runoff (MN$_{LEACH}$) is calculated as:

$$MN_{LEACH} = \Sigma_i \Sigma_j (MN_{ijMMS=4} \times FracWET_{MMSi} \times Frac_{LEACH_MS}) \quad (3.B.5a_3)$$

Where MN_{ijMMS} = 4 = mass of N in solid storage
$FracWET_{MMSi}$ = fraction of N available for leaching and runoff (Table A5.5.10.2)
$Frac_{LEACH_MS}$ = 0.02 (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 are calculated as:

$$E = MN_{LEACH} \times EF \times C_g \quad (3.B.5a_4)$$

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

Beef cattle on pastures (3.B.1.b)

Methane

As described in section 5.3.2, there are two components to methane emission estimates – manure excreted directly onto PRP, and manure that runs-off into natural water sources and farm dams. Methane from manure is formed from the organic fraction of the manure (volatile solids). Volatile solid production for beef cattle on pastures (VS/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 pasture-fed cattle, volatile solids were calculated as:

$$VS_{ijkln} = (I_{ijkln} \times (1 - DMD_{ijk}) + (0.04 \times I_{ijkln})) \times (1 - A) \quad (3.B.1b_1)$$

Where I_{jkln} = dry matter intake calculated as for enteric fermentation

DMD_{ijk} = dry matter digestibility expressed as a fraction (Table A5.5.2.3)

A = ash content of feed intake expressed as a fraction (assumed to be 0.08)

Methane production from manure (M_{ijk} kg/head/day) is then calculated as:

$$M_{ijk} = VS_{ijk} \times B_0 \times MMS_{ijm} \times MCF_{im} \times \rho \quad (3.B.1b_2)$$

Where B_0 = emissions potential – 0.24m^3 CH_4/kg VS (IPCC 2019)

MMS_{ijm} = fraction allocated to each MMS (Table A5.5.2.8)

MCF_{im} = methane conversion factor for each region and MMS (Table A5.5.2.9)

ρ = density of methane (0.6784 kg/m^3) – Taken from the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*

The annual methane production (Gg) from manure of pasture-fed cattle is calculated as:

$$Total = \Sigma_i \Sigma_j \Sigma_k \Sigma_l \Sigma_n (N_{ijkl} \times M_{ijkl} \times 91.25) \times 10^{-6} \quad (3.B.1b_3)$$

Where N_{ijkl} = numbers of pasture-fed cattle in each State, region, class and season

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

91.25 = days in season

Nitrous oxide emissions

As the manure of pasture-based beef cattle is deposited direct to pasture range and paddock (PRP) and anaerobic lagoons (farm dams), 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:

$$NR_{ijkln} = (0.032 \times MP_{ijkln} \div 6.38) + \{ \{ 0.212 - 0.008 (L_{ijkln} - 2) - [(0.140 - 0.008 (L_{ijkln} - 2)) \div (1 + \exp(-6 (Z_{ijkln} - 0.4)))] \} \times (LWG_{ijkln} \times 0.92) \} \div 6.25 \quad (3.B.1b_4)$$

Where MP_{ijkln} = milk production (kg/head/day) calculated as: proportion of cows lactating (LC_{ijkl}) x milk production

In areas where Brahman cross breeds are dominant (NT, Qld and Kimberly WA) milk production is 4 kg/day for cows >2 years old in the first season after calving and 3 kg/day in the second season. In other areas where Hereford or Shorthorn breeds are dominant (all other States) milk production is considered to be 6 and 4 kg/ day respectively (Table A5.5.2.5)

L_{ijkln} = Intake relative to that needed for maintenance. Calculated as actual intake divided by maintenance intake (i.e. intake of non-lactating animal with LWG set to zero calculated by equation 3A.1b_1)

Z_{ijkln} = relative size – (liveweight ÷ standard reference weight (Tables A5.5.2.1 and A5.5.2.6))

LWG_{ijkln} = liveweight gain (kg/day) (Table A5.5.2.2)

Nitrogen excreted (NE_{ijkln} kg/head/day) is calculated by subtracting NR_{ijkl}, and dermal protein loss from the nitrogen intake such that:

$$NE_{ijkln} = (I_{ijkln} \times CP_{ijkl} \div 6.25) + (0.032 \times MC_{ijkl} \div 6.38) - NR_{ijkl} - [(1.1 \times 10^{-4} \times W_{ijkl}^{0.75}) \div 6.25] \quad (3.B.1b_5)$$

Where W_{ijkl} = liveweight (Table A5.5.2.1)

The total annual nitrogen excreted ($AE_{ijkln\ MMS=14}$ Gg) nitrogen excreted to PRP is calculated as:

$$AE_{ijkln\ MMS=14} = (N_{ijkln} \times NE_{ijkln} \times 91.25) \times 10^{-6} \quad \text{(3.B.1b_6)}$$

Where N_{ijkln} = the number of beef cattle adjusted for feedlot cattle in each State, region, season and class

Beef cattle in feedlots (3.B.1.c)

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. 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:

$$VS_j = I_j \times (1 - DMD_j \times (1 - A) \quad \text{(3.B.1c_1)}$$

Where I_j = dry matter intake as calculated for enteric fermentation

DMD_j =DM digestibility expressed as a fraction (Table A5.5.3.2)

A = ash content of manure expressed as a fraction (0.16) – 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 the manure management (M_j kg/head/day) is then calculated as:

$$M_j = VS_j \times B_0 \times iMCF_i \times \rho \quad \text{(3.B.1c_2)}$$

Where B_0 = emissions potential (0.19m^3 CH_4/kg VS (IPCC 2019))

Australia's B_0 value is based on independent research measuring average 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_0 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 (Table A5.5.3.3)

ρ = density of methane (0.6784 kg/m^3) – Taken from the Determination

Annual methane production (Gg) from the manure of beef cattle in feedlots is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_j \times 10^{-6}) \quad \text{(3B.1c_3)}$$

Where N_{ij} = Annual equivalent numbers of beef cattle in feedlots

Mj = methane production (kg/head/day)

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:

$$NI_j = I_j \times CP_j \div 6.25 \quad \text{(3.B.1c_4)}$$

Where I_j = dry matter intake as calculated for enteric fermentation
CP_j = crude protein content of feed expressed as a fraction (Table A5.5.3.2)
6.25 = factor for converting crude protein into nitrogen

Nitrogen excretion NE (kg/head/day) is calculated by:

$$NE_j = NI_j \times (1 - NR_j) \quad \text{(3.B.1c_5)}$$

Where NR_j = nitrogen retention expressed as a fraction of intake (Table A5.5.3.1)

Annual nitrogen excretion (AE_{ij} Gg/year) from feedlot cattle is calculated as:

$$AE_{ij} = N_{ij} \times NE_j \times 365 \times 10^{-6} \quad \text{(3.B.1c_6)}$$

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:

$$Total_{MMS} = \Sigma_i \Sigma_j (AE_{ij} \times iNOF \times C_g) \quad \text{(3.B.1c_7)}$$

Where iNOF = integrated N_2O emission factor (Table A5.5.3.3)
C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Indirect nitrous oxide emissions – Atmospheric Deposition

Integrated $FracGASM_{MMS}$ values (Table A5.5.3.3) based on the IPCC (2006) default and Australian research (Table A5.5.3.7) are used to estimate N volatilisation.

The mass of feedlot waste volatilised (Gg) is calculated as:

$$MN_{ATMOS_{ij}} = \Sigma_i \Sigma_j (N_{ij} \times AE_{ij} \times iFracGASM_{MMS}) \quad \text{(3.B.5c_1)}$$

Where AE_{ij} = mass of nitrogen excreted, calculated in Equation 3.B.1c_6.
$iFracGASM_{MMS}$ = integrated fraction of N volatilised from feedlot cattle (Table A5.5.3.3)

Annual atmospheric deposition emissions (Gg N_2O) from MMS are calculated as:

$$E = MN_{ATMOS} \times EF \times C_g \quad \text{(3.B.5c_2)}$$

Where MN_{ATMOS} = mass of N volatilised (Gg N)
EF = 0.0041 (Gg N_2O-N/Gg N) (Inorganic fertiliser EF for non-irrigated cropping – Table 5.21)
C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Leaching and Runoff

Australian feedlots are managed with strict environmental controls on leaching, requiring the use of an impermeable barrier depending on underlying strata (MLA 2012; Skerman 2000). Leaching is therefore assumed to be zero, while runoff from feedlots is captured in effluent ponds. Emissions associated with waste runoff are therefore included in the direct emission estimates.

Sheep (3.B.2)

Methane

As described in section 5.3.2, there are two components to methane emission estimates – manure excreted directly onto PRP, and manure that runs-off into natural water sources and farm dams. Methane from manure is formed from the organic fraction of the manure (volatile solids). Volatile solid production for sheep (VS/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 sheep, volatile solids were calculated as:

$$VS_{ijk} = (I_{ijk} \times (1 - DMD_{ijk}) + (0.04 \times I_{ijk})) \times (1 - A) \quad \text{(3.B.2_1)}$$

Where I_{ijk} = dry matter intake calculated for enteric fermentation
DMD_{ijk} = digestibility expressed as a percentage (Table A5.5.4.2)
A = ash content of feed intake expressed as a fraction (assumed to be 0.08)

Methane production from manure (M_{ijk} kg/head/day) is then calculated as:

$$M_{ijk} = VS_{ijk} \times B_0 \times MMS_{ijm} \times MCF_{im} \times \rho \quad \text{(3.B.2_2)}$$

Where B_0= emissions potential – 0.24m^3 CH_4/kg VS (IPCC 2019)
MMS_{ijm} = fraction allocated to each MMS (Table A5.5.4.8)
MCF_{im} = methane conversion factor for each region and MMS (Table A5.5.4.9)
ρ = density of methane (0.6784 kg/m^3) – Taken from the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*

The annual methane production (Gg) from manure of sheep is calculated as:

$$Total = \Sigma_i \Sigma_j \Sigma_k (N_{ijk} \times M_{ijk} \times 91.25) \times 10^{-6} \quad \text{(3.B.2_3)}$$

Where N_{ijk} = numbers of sheep in each State, class and season
M_{ijkl} = methane production (kg/head/day)
91.25 = days in season

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:

$$CPI_{ijk} = I_{ijk} \times CP_{ijk} + (0.045 \times MC_{ijk}) \quad \text{(3.B.2_3)}$$

Where I_{ijk} = feed intake (kg DM/head/day) as calculated for enteric fermentation

CPI_{ijk} = crude protein content of feed intake expressed as a fraction (Table A5.5.4.4)

MC_{ijk} = milk intake (kg/head/day) calculated as: proportion of lambs receiving milk in each season x milk intake (Table A5.5.4.6). 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:

$$NR_{ijk} = \{ (0.045 \times MP_{ijk}) + (WP_{ijk} \times 0.84) + \{ [(212 - 4\{[(EBG_{ijk} \times 1000) \div (4 \times (SRW_{ijk})^{0.75})] - 1\}) - (140 - 4\{[(EBG_{ijk} \times 1000) \div (4 \times (SRW_{ijk})^{0.75})] - 1\})] \div \{1 + \exp(-6(Z_{ijk} - 0.4))\}] \times EBG_{ijk} \} \div 1000 \} \div 6.25 \quad \text{(3.B.2_4)}$$

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 Table A5.5.4.7

Z_{ijk}= relative size (liveweight ÷ standard reference weight) (Tables A5.5.4.1 and A5.5.4.7)

Nitrogen excreted (NE_{ijk} kg/head/day) is calculated by subtracting the nitrogen retained (NR_{ijk}) from the nitrogen intake such that:

$$NE_{ijk} = (CPI_{ijk} \div 6.25) - NR_{ijk} \quad \text{(3.B.2_5)}$$

Where 6.25 = factor for converting crude protein into nitrogen

The annual nitrogen excreted (AE_{ijk} Gg) to PRP is calculated as:

$$AE_{ijk\ MMS=14} = (N_{ijk} \times NE_{ijk} \times 91.25) \times 10^{-6} \quad \text{(3.B.2_6)}$$

Where N_{ijk} = the number sheep in each State, season and class

91.25 = days in season

Swine (3.B.3)

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 kg/head/day) in the animal manure (including urine) and waste feed (Annex 5.5).

Using this information, CH_4 production from wastes (M_{ij} kg/head/day) can be calculated as:

$$M_{ij} = VS_{ij} \times B_0 \times iMCF_i \times \rho \quad (3.B.3_1)$$

Where VS_{ij} = volatile solids production (kg/head/day) (Table A5.5.5.4)

B_0 = methane emission potential (0.45m³ CH_4/kg VS – IPCC 2019)

$iMCF_i$ = integrated methane conversion factor based on the proportion of different manure management regimes (Table A5.5.5.5)

ρ = density of methane (0.6784kg/m³) – From the Determination

The annual methane production (Gg) from the wastes of Australian swine is calculated as:

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

Where N_{ij} = numbers of swine in each class for each State

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

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 (Annex 5.5).

Allocations to the different MMS have changed over time (Table A5.5.5.6), 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.

Annual nitrogen (AE_{ij} Gg/year) from swine manure and waste feed is calculated as:

$$AE_{ij} = N_{ij} \times E_{ij} \times 10^{-6} \quad (3.B.3_3)$$

Where N_{ij} = numbers of swine in each class in each State

E_{ij} = nitrogen in waste (kg/head/year) as calculated by PIGBAL (Table A5.5.5.4)

Total emissions of nitrous oxide from the different MMS (Gg) can then be calculated as follows:

$$Total_{MMS} = \Sigma_i \Sigma_j (AE_{ij} \times iNOF \times C_g) \quad (3.B.3_4)$$

Where iNOF = the integrated nitrous oxide emission factor for swine in each state (Table A5.5.5.5)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Indirect nitrous oxide emissions – Atmospheric deposition

Australia has developed integrated $FracGASM_{MMS}$ values (Table A5.5.5.5) for swine based on default IPCC and CS values (Table A5.5.5.9).

The mass of piggery waste volatilised is calculated as:

$$MATMOS = \Sigma_i \Sigma_k (N_{ij} \times AE_{ij} \times iFracGASMMMS) \quad (3.B.5c_1)$$

Where Ae_{ij} = mass of nitrogen excreted, calculated in Equation 3.B.3_3

$iFracGASM_{MMS}$ = the integrated fraction of N volatilised for the swine industry (Table A5.5.5.5)

Annual indirect nitrous oxide production (Gg N_2O) from swine MMS is calculated as:

$$E = MNATMOS \times EF_{ij} \times C_g \quad (3.B.5c_2)$$

Where MN_{ATMOS} = mass of N volatilised (Gg N)

EF_{ij} = 0.0041 (Gg N_2O-N/Gg N) (Inorganic Fertiliser EF for non-irrigated cropping – Table 5.21)

C_g = 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.

$$MNLEACH_{ij} = \Sigma_i \Sigma_k (N_{ij} \times AE_{ij} \times MS_{iMMS=5} \times FracWET_{MMSi} \times FracLEACH_MS) \quad (3.B.5c_3)$$

Where $MNLEACH_{ij}$ = mass of N lost through leaching and runoff (Gg N)

AE_{ij} = mass of nitrogen in waste, calculated in equation 3.B.3_3

$MSi_{MMS=5}$ = fraction of waste handled through drylot (Table A5.5.5.6)

$FracWET_{MMSi}$ = fraction of N available for leaching and runoff (Table A5.5.10.2)

$Frac_{LEACH_MS}$ = 0.22 (Gg N/Gg applied) (CS EF, source IPCC (IPCC 2019) fraction of N lost through leaching and runoff

Annual leaching and runoff emissions (Gg N_2O) from swine MMS are calculated as:

$$E = MNLEACH_{ij} \times EF \times C_g \quad (3.B.5c_4)$$

Where EF = 0.011 (Gg N_2O-N/Gg N) (CS EF, IPCC (IPCC 2019))

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Poultry (3.B.4.g)

Table 5.13 Symbols used in algorithms for poultry

State and territory (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		

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:

$$VS_{ij} = I_{ij} (1 - DMD_{ij}) \times (1 - A) \quad \text{(3.B.4g_1)}$$

Where I_{ij} = dry matter intake (Table A5.5.6.1)
DMD_{ij} = digestibility expressed as a fraction (Table A5.5.6.1)
A = ash content of manure expressed as a fraction (Table A5.5.6.1)

Methane production from poultry manure (M_{ij} kg/head/day) can then be calculated as:

$$M_{ij} = VS_{ij} \times B_0 \times iMCF_{ij} \times \rho \quad \text{(3.B.4g_2)}$$

Where B_0 = emission potential (0.36 m^3 CH_4/kg VS for meat and 0.39 m^3 CH_4 / kg VS for layers (IPCC 2019))
$iMCF_{ij}$ = Integrated methane conversion factor (Table A5.5.6.2)
ρ = density of methane (0.6784 kg/m^3) – From the Determination

Annual methane production (Gg) for poultry is calculated as:

$$E = \Sigma_i \Sigma_j (365 \times N_{ij} \times M_{ij} \times 10^{-6}) \quad \text{(3.B.4g_3)}$$

Where N_{ij} = number of birds in each class and state
M_{ij} = methane production (kg/head/day)

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_j) and retention (NR_j) and from these, the output of nitrogen in manure.

The nitrogen intake NI_j (kg/head/day) of poultry is calculated by:

$$NI_j = I_j \times CP_j \div 6.25 \quad \text{(3.B.4g_4)}$$

Where I_j = dry matter intake in kg/day (Table A5.5.6.1)
CP_j = dietary crude protein expressed as a fraction (Table A5.5.6.1)
6.25 = factor for converting crude protein into nitrogen

Nitrogen excretion (NE_{ij}) (Gg/head/year) is calculated by:

$$NE_{ij} = NI_j (1 - NR_j) \times 365 \times 10^{-6} \quad \text{(3.B.4g_5)}$$

Where NR_j = nitrogen retention as a proportion of intake (Table A5.5.6.1)

Total emissions of nitrous oxide from the different MMS (Gg) can then be calculated as follows:

$$Total_{MMS} = \Sigma_i \Sigma_j (N_{ij} \times NE_j \times iNOF_j \times C_g) \quad \text{(3.B.4g_6)}$$

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 (Table A5.5.6.2)
C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Indirect nitrous oxide emissions – Atmospheric deposition

Integrated FracGASM values (Table A5.5.6.2) based on default IPCC (2006) and CS values (Table A5.5.6.7) are used to estimate N volatilisation from poultry. Mass of poultry waste volatilised (Gg N) is calculated as:

$$M_{ATMOS} = \Sigma_i \Sigma_j (N_{ij} \times NE_{ij} \times iFracGASM_{MMS_j}) \quad (3.B.5d_1)$$

Where NE_{ij} = mass of nitrogen excreted (Gg/head/year), calculated in Equation 3.B.4g_5

$iFracGASM_{MMS_j}$ = the integrated fraction of N volatilised for the meat and layer industries (Table A5.5.6.2)

Annual atmospheric deposition emissions (Gg N_2O) from poultry MMS are calculated as:

$$E = MN_{ATMOS} \times EF_{ij} \times C_g \quad (3.B.5d_2)$$

Where EF_{ij} = 0.0018 (Gg N_2O-N/Gg N) (Meat = inorganic fertiliser EF for non-irrigated pastures)

EF_{ij} = 0.0041 (Gg N_2O-N/Gg N) (Layers = inorganic fertiliser EF for non-irrigated cropping – Table 5.21

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Indirect nitrous oxide emissions – 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.

$$MN_{LEACH} = \Sigma_i \Sigma_j (N_{ij} \times NE_{ij} \times MS_{iMMS=4-5} \times FracWET_{MMSi} \times Frac_{LEACH_MS}) \quad (3.B.5d_3)$$

Where MN_{LEACH} = 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 (Table A5.5.6.3)

$FracWET_{MMSi}$ = Fraction of N available for leaching and runoff (Table A5.5.10.2)

$Frac_{LEACH_MS}$ = 0.02 (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:

$$E = \Sigma_i \Sigma_j (MN_{LEACH_{ij}} \times EF \times C_g) \quad (3.B.5d_4)$$

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

Other livestock (including 3.B.4.a-f, h and i)

Methane

As described in section 5.3.2, there are two components to methane emission estimates – manure excreted directly onto PRP, and manure that runs-off into natural water sources and farm dams. Methane from manure is formed from the organic fraction of the manure (volatile solids).

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 volatile solid production (VS_{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 (Table A5.5.7.1). 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 manure (M_{ij} kg/head/day) is then calculated as:

$$M_{ij} = VS_{ij} \times B_0 \times MMS_{ijm} \times MCF_{im} \times \rho \quad \text{(3.B.4_1)}$$

Where B_0 = emissions potential – 0.24m³ CH_4/kg VS (IPCC 2019)
MMS_{ijm} = fraction allocated to each MMS (Table A5.5.7.4)
MCF_{im} = methane conversion factor for each region and MMS (Table A5.5.7.5)
ρ = density of methane (0.6784 kg/m³) – Taken from the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*

The annual methane production (Gg) from manure of other livestock is calculated as:

$$Total = \Sigma_i \Sigma_j (N_{ij} \times M_{ij}) \times 10^{-6} \quad \text{(3.B.4_2)}$$

Where N_{ij} = numbers of livestock in each State
M_{ij} = methane production (kg/head/day)

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 (Table A5.5.7.2).

The annual nitrogen (AE_{ij} Gg/year) excreted to PRP is calculated as:

$$AE_{ijMMS=14} = (N_{ij} \times E_{ij}) \times 10^{-6} \quad \text{(3.B.4_3)}$$

Where N_{ij} = numbers in each State
$E_{ij\,=\,14}$ = nitrogen excreted (kg/head/year) (Table A5.5.7.2)

5.3.3 Uncertainty assessment 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.

5.3.4 Category-specific QA/QC and verification

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. The ABS has in place a range of procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values.

This source category is also covered by the general QA/QC procedures of the inventory. The QC procedure "ensuring consistency in data between categories" is of specific importance for this category. 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.

Implied EFs

As tier 3 methods are used to estimate emissions from cattle, sheep, pigs and poultry, the IEFs have been compared with IPCC defaults (Table 5.14).

Table 5.14 Implied EFs – Methane manure management (kg/head/year)

Livestock type	Australia	IPCC default (Oceania)
Dairy cattle	14.15	23–31
Beef cattle on pastures	0.93	1–2
Beef cattle in feedlots	3.20	1–2
Sheep	0.12	0.19–0.37
Swine	23.26	11–24
Poultry	0.028	0.02–1.4

Source: IPCC (2006).

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.

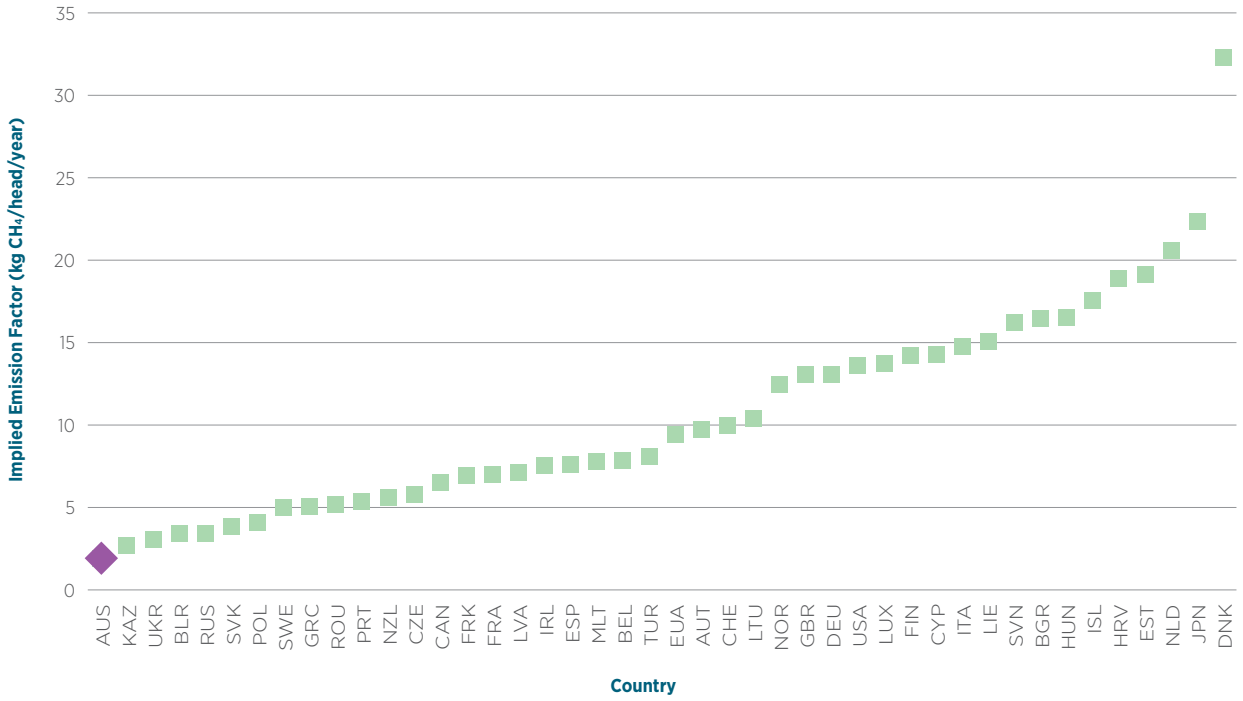
The IEF for beef cattle on pastures is higher than the IPCC default EF range. Reasons for this difference include:

- 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.

The IPCC default B_0 value for North America has been chosen for beef cattle in feedlots 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.

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 5.7). The Australian value is the lowest of reporting countries, reflecting the predominance of grazing livestock on pasture, range and paddock and the low fraction of manure deposited in water bodies (anerobic lagoons) in these environments.

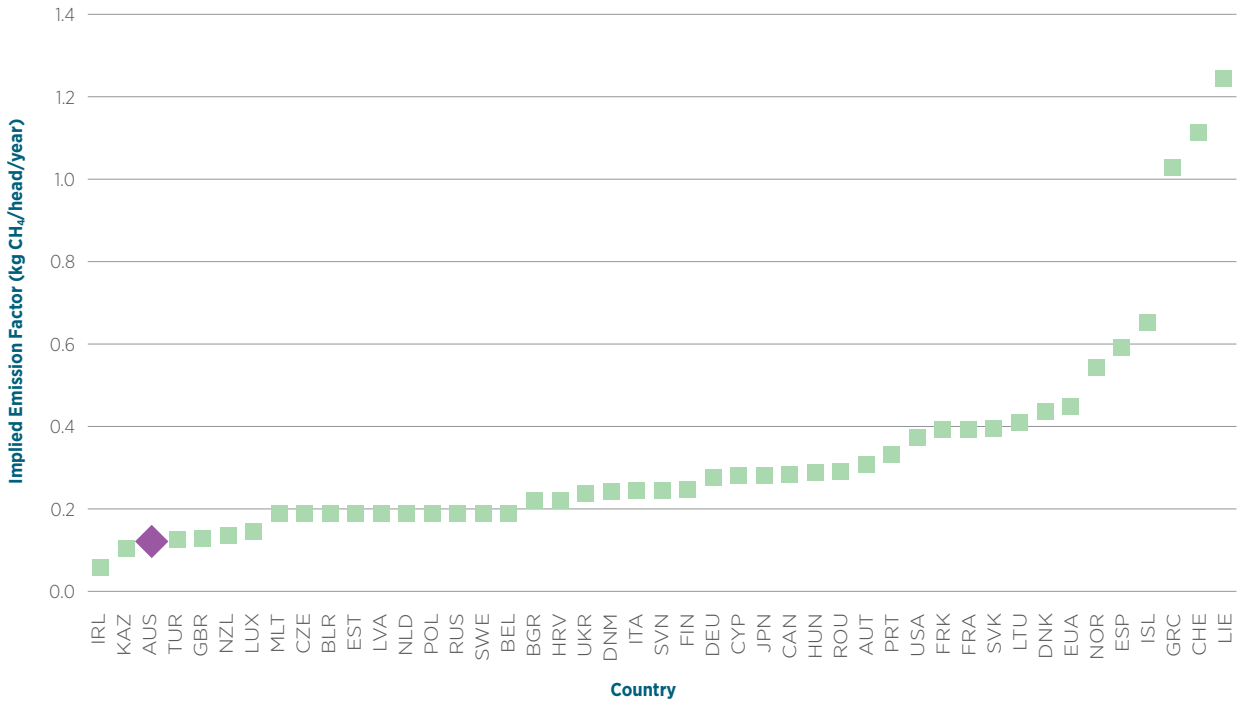
Figure 5.7 Cattle manure management implied emission factors for Annex I countries (2024 submission) and Australia (2026 submission), kg CH_4 per head per year



Source: Other Parties' data from UNFCCC locator tool

Australia's sheep IEF is similarly low compared to other parties, as shown in Figure 5.8, reflecting the dryland grazing environments that prevail.

Figure 5.8 Sheep manure management implied emission factors for Annex I countries (2024 submission) and Australia (2026 submission), kg CH_4 per head per year



Source: Other Parties' data from UNFCCC locator tool

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. The poultry IEF is within the range of the IPCC (2006) default EFs.

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 5.15). 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 5.15 Volatile solids (kg/head/day)

Livestock type	Australia	IPCC 2019
Dairy cows	3.40	2.9–5.4
Beef cattle – Feedlot	1.58	2.3–3.9
Swine		
Breeders	0.40 - 0.55	0.3–0.6
Other pigs	0.39	0.3–0.32
Poultry		
Layers	0.014	0.02
Meat	0.016–0.017	0.01–0.02

Source: IPCC (2019).

Nitrogen excretion

The CS estimates of nitrogen excretion were compared against the IPCC defaults (Table 5.16). 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 5.16 Nitrogen excretion rates (kg/head/year)

Livestock type	Australia	IPCC 2006 default	IPCC 2019
Dairy cattle (455 kg)	127	58–80	42–142
Beef cattle			38–94 (other cattle)
Pasture (378 kg)	35	43–69	43–69
Feedlot (524 kg)	66	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	0.7	0.6–1.0	0.4–0.7

Source: IPCC (2006) and (2019).

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.

5.3.5 Category-specific recalculations

Recalculations of emissions from manure management reported in the current submission are shown in Table 5.17 and are due to:

A. Grazing livestock: new manure management allocation method.

A downward recalculation throughout the time series is due to implementation of a method for calculating methane emissions analogous to that used for intensive livestock, with an allocation of VS to either PRP or farm dams (anaerobic lagoons). The introduction of a method to estimate the allocation nationwide, based on a database of the location of dams, leads to lower allocation to dams over much of the country and hence lower estimated emissions.

Table 5.17 Manure Management (3.B): recalculations of total CO_2-e emissions, 1989–90 to 2022–23

	2025 submission	2026 submission	Change		Reasons for Recalculation (Gg CO_2-e)
Year	(Gg CO_2-e)		(Gg CO_2- e)	(Per cent)	A
1989–90	7,456	3,822	-3,634	-48.7%	-3,634
1994–95	6,849	3,741	-3,109	-45.4%	-3,109
1999–00	7,335	4,014	-3,321	-45.3%	-3,321
2004–05	7,950	4,586	-3,365	-42.3%	-3,365
2005–06	7,996	4,516	-3,480	-43.5%	-3,480
2006–07	7,830	4,409	-3,420	-43.7%	-3,420
2007–08	7,463	4,067	-3,396	-45.5%	-3,396
2008–09	7,399	4,030	-3,369	-45.5%	-3,369
2009–10	7,411	4,119	-3,292	-44.4%	-3,292
2010–11	7,481	4,210	-3,270	-43.7%	-3,270
2011–12	7,717	4,223	-3,495	-45.3%	-3,495

	2025 submission	2026 submission	Change		Reasons for Recalculation (Gg CO_2-e)
Year	(Gg CO_2-e)		(Gg CO_2- e)	(Per cent)	A
2012–13	7,719	4,168	-3,551	-46.0%	-3,551
2013–14	7,877	4,336	-3,541	-45.0%	-3,541
2014–15	7,636	4,255	-3,381	-44.3%	-3,381
2015–16	7,432	4,199	-3,233	-43.5%	-3,233
2016–17	7,787	4,359	-3,428	-44.0%	-3,428
2017–18	7,926	4,495	-3,431	-43.3%	-3,431
2018–19	7,380	4,160	-3,219	-43.6%	-3,219
2019–20	7,127	4,095	-3,032	-42.5%	-3,032
2020–21	7,496	4,376	-3,121	-41.6%	-3,121
2021–22	7,470	4,368	-3,102	-41.5%	-3,102
2022–23	7,593	4,337	-3,257	-42.9%	-3,257

5.3.6 Category-specific planned improvements

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) 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. 2015, 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. *Modernisation of ABS Agricultural Statistics* – as described in section 5.2.4, the department is consulting with Australian Bureau of Statistics as they modernise the production of agricultural statistics. This may entail changes to the age class information and spatial location of the national herd, including time-series recalculations.

5.4 Rice Cultivation (CRT category 3.C)

5.4.1 Category description

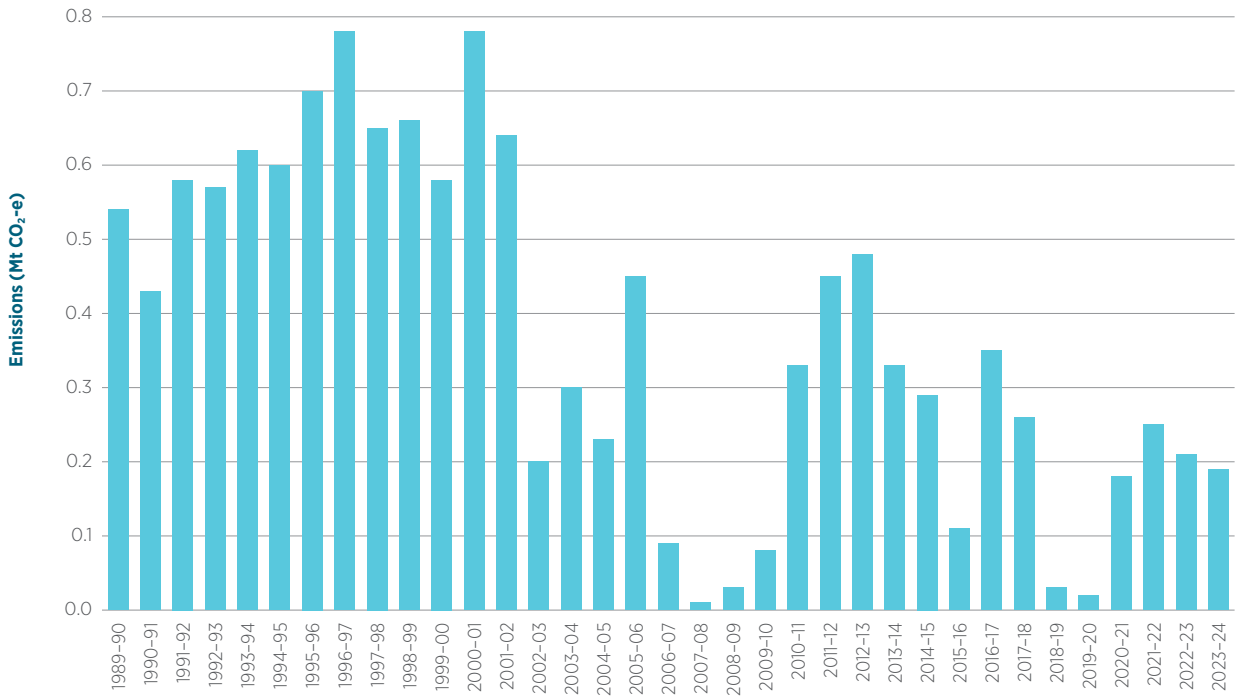
Methane is generated during rice growing from the decomposition of plant residues and other organic carbon material in the soil. This generation occurs through microbial action under anaerobic conditions following flooding of the rice crop.

Methane emission rates vary widely, both diurnally in response to immediate environmental factors such as temperature, and also throughout the season in response to crop development and accompanying changes in soil condition. Emission rates are also dependent on more stable factors including soil type and cultivation method (e.g. irrigation regimes, fertiliser application).

All Australian rice is grown under flooded cultivation and production is highly variable from year to year, reflecting water availability and the prices of alternative crops. 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 northern Victoria. These climates are considered temperate. There have also been very small rice crops grown in the warmer areas of northern Queensland and Northern territory since 2010.

Figure 5.9 Rice cultivation emissions, Australia, 1989–90 to 2023–24, Mt CO_2-e



5.4.2 Methodological issues

A tier 2 method is applied to estimate emissions from rice cultivation, drawing upon updates to default emission factors provided in the 2019 Refinement (IPCC 2019) and applying scaling factors derived from country specific data for sowing practices and flooding duration.

Production data is sourced from the ABS (Agricultural Commodities) and ABARES (Crop Report), and additional information on the usage of aerial and drill sowing methods was provided by the rice industry.

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 (SF_w = 1) and a non-flooded pre-season of >180 days (SF_p = 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.

The average number of days in the growing season was estimated using sowing data from the rice industry. Aerial sown rice is flooded for 152 days on average, while drill sown rice is continuously flooded for 111 days. Drill sowing was introduced in the mid-1990s and has become more prevalent, used in about 60% of the crop in recent years. The average growing season for each year is used to calculate a representative emission rate for Australia using Equation 5.2 in IPCC 2019:

$$\text{Rice EF} = EF_c \times SF_w \times SF_p \times SF_o$$

Where EF_c is the baseline EF for continuously flooded fields without organic amendments (1.19 kg CH_4/ha/day x 150 days)

SF_w is the scaling factor to account for the differences in water regimes during the cultivation period (irrigated, continuously flooded production systems)

SF_p 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)

SF_o is the scaling factor for organic amendments (as fertiliser is used rather than manure, this factor is not applied and set to 1)

The resulting Rice EF has decreased from about 160 kg CH_4/ha in 1990 to around 134 kg CH_4/ha in recent years.

Table 5.18 Symbols used in algorithms for rice cultivation

State and territory (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:

$$E_i = A_i \times EF \times 10^{-6} \qquad (3.C_1)$$

Where A_i = area under rice cultivation (ha)

EF = emission factor integrated over the whole season (kg CH_4/ha)

The area under rice cultivation by State for the entire Inventory time series is provided in Annex 5.5.12.

5.4.3 Uncertainty assessment 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.

5.4.4 Category-specific QA/QC and verification

This source category is covered by the general QA/QC procedures detailed in Annex 4.

5.4.5 Category-specific recalculations

There are recalculations in this submission throughout the time series to emissions from rice cultivation, shown in Table 5.19. The reason for the recalculation is:

A. Modification of the EF to incorporate changing sowing practices.

As described above, the average number of flooded days is varied depending on the prevalence of aerial and drilled sowing. As drill sowing has increased over the inventory time series, and this results in a lower number of flooded days, there is a recalculation throughout the time series, small at the start and then increasingly negative.

Table 5.19 Rice (3.C): recalculations of total CO_2-e emissions, 1989–90 to 2022–23

	2025 submission	2026 submission	Change		Reasons for Recalculation (Gg CO_2-e)
Year	(Gg CO_2-e)		(Gg CO_2- e)	(Per cent)	A
1989–90	533	538	5	1.0%	5
1994–95	599	603	4	0.6%	4
1999–00	583	579	-4	-0.7%	-4
2004–05	230	230	-0	-0.2%	0
2005–06	454	448	-6	-1.3%	-6
2006–07	88	90	1	1.3%	1
2007–08	9	9	0	1.3%	0
2008–09	32	32	0	1.3%	0
2009–10	84	79	-5	-6.2%	-5
2010–11	337	332	-6	-1.6%	-6
2011–12	459	447	-12	-2.5%	-12
2012–13	506	485	-21	-4.1%	-21
2013–14	341	325	-16	-4.7%	-16
2014–15	310	294	-16	-5.2%	-16
2015–16	124	114	-10	-8.2%	-10
2016–17	383	355	-28	-7.3%	-28
2017–18	285	256	-29	-10.1%	-29
2018–19	35	29	-6	-17.1%	-6
2019–20	23	18	-5	-23.3%	-5
2020–21	210	180	-29	-14.0%	-29
2021–22	291	254	-37	-12.7%	-37
2022–23	240	214	-26	-10.8%	-26

5.4.6 Category-specific planned improvements

All data and methodologies are kept under review.

Tier 2 emissions factors are being considered for incorporation into the inventory as time and resources permit. Rice cultivation in Australia is highly responsive to water availability, so the trend in rice area under cultivation and the resultant emissions can be highly variable from year to year. An industry-led research programme is under way to develop country-specific EFs, and when these results are published they will be considered for implementation in the inventory.

5.5 Agricultural Soils (CRT category 3.D)

5.5.1 Category description

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

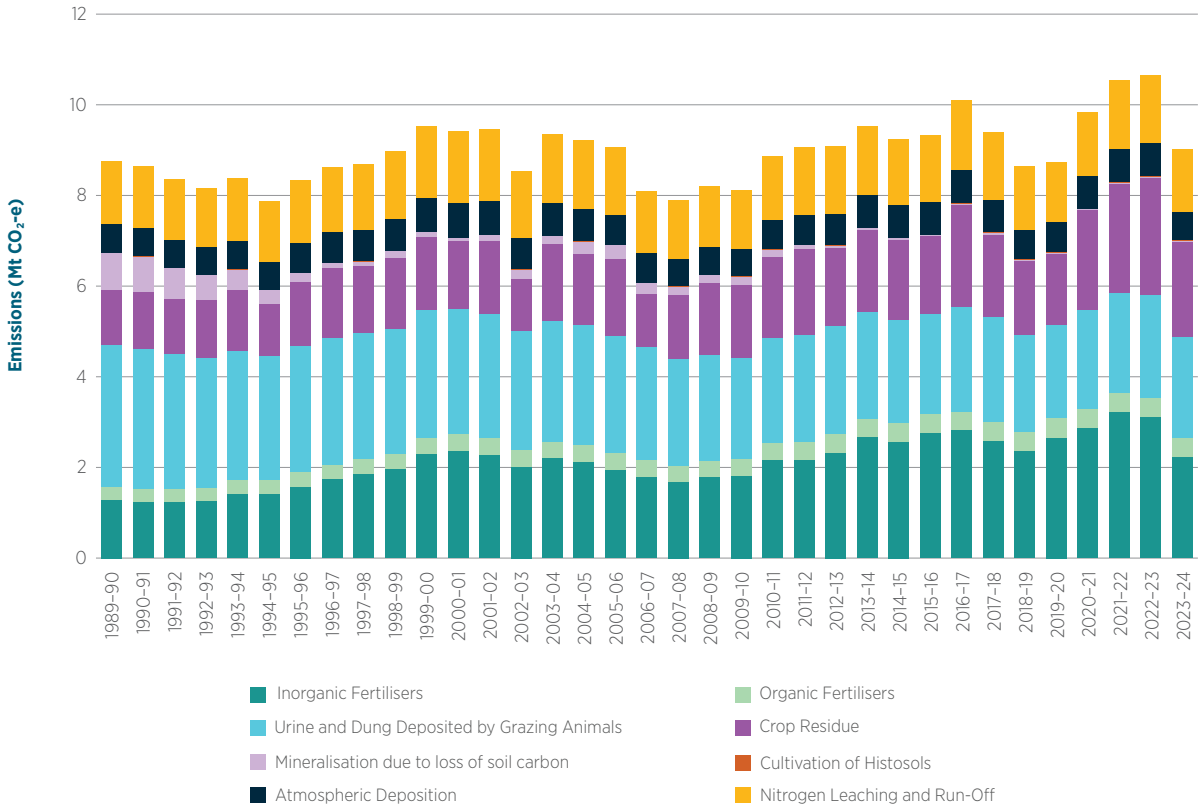
d. mineralisation due to loss of soil carbon

e. mineralisation due to cultivation of organic soils

f. 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.

Figure 5.10 Agricultural Soils emissions by source, Australia, Mt CO_2-e



5.5.2 Methodological issues

Inorganic fertilisers (3.D.a.1)

Activity data is sourced from Fertilizer Australia, and the ABS (Water use in Australia).

A tier 2 method is used to estimate emissions from inorganic fertilisers. The EFs are based on analyses of Australian measurement studies (Grace et al. 2023, 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 research on the application of fertilisers to different production systems and climatic regions in Australia has shown large variations across different classes of crop and pasture systems. The EFs for all production systems except sugar cane fall within the default range provided in IPCC (2019) for N inputs in dry climates, which reflects the climatic conditions of most agricultural land in Australia. The EF for sugar cane is at the upper end of the IPCC (2019) default range for wet climates, also reflecting the climate of the region where cane is grown. The studies compiled in the meta-analyses by Grace et al. (2023) and Scherbak and Grace (2014) are mostly based on urea fertiliser, which represents more than 60 per cent of the nitrogen in inorganic nitrogen fertilisers.

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 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($e^{0.037*N\ application\ rate}$ -1) / N application rate.

The EFs used in the inventory for inorganic fertiliser are provided in Table 5.21.

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 (FNij) 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 (see Table A5.5.8.1) 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 Table A5.5.8.2). Sugar cane fertiliser application rates in QLD have declined significantly over the time series in response to environmental management legislation.

Table 5.20 Symbols used in algorithms for inorganic fertiliser

State and territory (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 5.21 Nitrous oxide EFs for inorganic fertiliser

Production system	Emission factor [(a)] (Gg N_2O-N/ Gg N)
Irrigated pasture	0.0059
Irrigated crop	0.007
Non-irrigated pasture	0.0018
Non-irrigated crop	0.0041 [(b)]
Sugar cane	0.0199
Cotton	0.0053
Horticulture	0.0064

(a) Based on (Grace, et al. 2023).

(b) Weighted EF assuming 77 per cent of non-irrigated crops occur on low rainfall areas. Low rainfall EF = 0.0029 and high rainfall EF = 0.008. The threshold between low and high rainfall areas is annual rainfall = 600 mm.

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 0.18 per cent applied.

The mass of fertiliser applied to soils via crop production systems (M_{ij} Gg N) is calculated as:

$$M_{ij} = TM_{ij} \times FN_{ij} \quad \text{(3.D.A_1)}$$

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:

$$E_{ij} = \Sigma_i \Sigma_j (M_{ij} \times EF_{ij} \times C_g) \quad \text{(3.D.A_2)}$$

Where EF_{ij} = emission factor (Gg N_2O-N/Gg N applied) (Table 5.19)
C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

Organic fertilisers (3.D.a.2)

Direct emissions from organic fertilisers arise from both animal wastes applied to soils and 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.

Inputs to this subsector are calculated using MMS equations in Chapter 5.3 of this report.

Table 5.22 Symbols used in algorithms for animal wastes applied to soils

State and territory (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:

$$MN\ Soil_{ij} = \Sigma_{MMS}\ ((AE_{ij\ MMS=1-13} \times (1 - EF_{MMS=1-13} - FracGASM_{j\ MMS=1-13})) - MNLEACH_{ij\ MMS=1-13}) \quad (3.D.A_3)$$

Where $AE_{ij\ MMS=1-13}$ = mass of N excreted, as calculated for manure management.

$EF_{MMS=1-13}$ = direct nitrous oxide EF from the different MMS (Annex 5.5)

$FracGASM_{j\ MMS=1-13}$ = fraction of animal waste N volatilised from the different MMS (Annex 5.5)

$MNLEACH_{ij\ MMS=1-13}$ = mass of animal waste N from leaching and runoff, as calculated for manure management

Annual nitrous oxide production from animal wastes applied to soils (E_{ij} Gg N_2O) is calculated as:

$$E_{ij} = \Sigma_i \Sigma_j\ (MN\ Soil_{ij} \times EF \times C_g) \quad (3.D.A_4)$$

Where EF = 0.00503 (Gg N_2O-N/Gg N deposited) (weighted average calculated from IPCC 2019)

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

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 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 (NGER) scheme. See Chapter 7.5 for further information.

Table 5.23 Symbols used in algorithms for sewage sludge applied to land

State and territory (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:

$$E_i = \Sigma_i\ (M_i \times EF \times C_g) \quad (3.D.A_5)$$

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

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.

IPCC (2019) provided updated EF values for urine and dung deposited by grazing animals in volume 4, Table 11.1, with separate values for wet climates (0.006 kg N_2O-N per kg N) and dry climates (0.002 kg N_2O-N per kg N). An analysis was conducted using national livestock location data (ABS 2017) and the climate zones from IPCC (2019) to determine a nationally-weighted average EF of 0.0032 kg N_2O-N per kg N which is applied to the whole country.

Table 5.24 Symbols used in algorithms for urine and dung deposited by grazing animals

State and territory (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:

$$E_{ij} = \Sigma_i \Sigma_j ((AE_{ij\ MMS=14} \times EF_j \times C_g)) \quad \text{(3.D.A_6)}$$

Where $AE_{ij\ MMS=14}$ = mass of faecal and urinary nitrogen excreted on pasture range and paddock as calculated for manure management. 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

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 EFs. Activity data is sourced from the ABS (Agricultural statistics) and ABARES (Australian Crop Report). This subsector also includes emissions from pasture residues returned to the soil, based on activity data derived from FullCAM simulations in LULUCF. The climate-zone-dependent IPCC (2019) default EFs for N_2O emissions from crop residues (0.005 in dry zones and 0.006 in wet zones) are used. For each State and crop type, a weighted spatial average EF is calculated based on the production regions and climate zone of each crop. These are provided in Table A5.5. The national weighted average EF is 0.00503, reflecting the dominance of dry climate zones in Australian cropland.

Table 5.25 Symbols used in algorithms for crop residues

State and territory (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:

$$M_{ijk} = (P_{ij} \times R_{AGj} \times (1 - F_{ij} - FFOD_{ij}) \times DM_j \times NC_{AGj}) + (P_{ij} \times R_{AGj} \times R_{BGj} \times DM_j \times NC_{BGj}) \quad (3.D.A_7)$$

Where P_{ij} = annual production of crop (Gg)
R_{AGj} = residue to crop ratio (kg crop residue/kg crop) (Table A5.5.9.1)
R_{BGj} = below ground-residue to above ground residue ratio (kg/kg) (Table A5.5.9.1)
F_{ij} = fraction of crop residue that is burnt (Table A5.5.9.1)
$FFOD_{ij}$ = fraction of the crop residue that is removed (Table A5.5.9.1)
DM_j = dry matter content (kg dry weight/kg crop residue) (Table A5.5.9.1)
NC_{AGj} = nitrogen content of above-ground crop residue (kg N/kg DM) (Table A5.5.9.1)
NC_{BGj} = nitrogen content of below-ground crop residue (kg N/kg DM) (Table A5.5.9.1)

The mass of N in pasture residues returned to soils (M_{ikl} Gg N) is calculated as:

$$M_{ikl} = (A_{ikl} \times Frac_{Renewal} \times (Y_k \div 1000) \times (1 - FFOD_{ik}) \times NC_{AGk}) + (A_{ikl} \times Frac_{Renewal} \times (Y_k \div 1000) \times R_{BGk} \times NC_{BGk} \quad (3.D.A_8)$$

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) (Table A5.5.9.2)
R_{BGk} = below ground-residue: above ground residue ratio (kg/kg) (Table A5.5.9.1)
NC_{AGk} = N content of above-ground crop residue (kg N/kg DM) (Table A5.5.9.1)
NC_{BGk} = N content of below-ground crop residue (kg N/kg DM) (Table A5.5.9.1)
$FFOD_{ik}$ = fraction of pasture yield that is removed (Table A5.5.9.2)

Annual nitrous oxide production from crop residues (E_j Gg N_2O) is calculated as:

$$E_i = \Sigma_i \Sigma_k \Sigma_l (M_{ijkl} \times EF_{ij} \times C_g) \quad \text{(3.D.A_9)}$$

Where M_{ijkl} = mass of N in crop residues (Gg N)
EF_{ij} = emission factor for each crop and State (Gg N_2O-N/Gg N) (Table A5.5.9.5)
C_g = 44/28 factor to convert from elemental mass of N_2O to molecular mass

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 carbon sink there may be no emissions reported in this category. Soil carbon stock changes are estimated in LULUCF using FullCAM simulations.

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 5.21). The EF is based on analyses of Australian measurement studies (Grace et al. 2023, 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 EF applied (0.0041 Gg N_2O-N/Gg N) is a weighted EF assuming 77 per cent of non-irrigated crops occur on low rainfall areas, and falls within the default range provided in IPCC (2019) for N inputs in dry climates, which reflects the climatic conditions of most agricultural land in Australia.

Table 5.26 Symbols used in algorithms for mineralisation due to loss of soil C

State and territory (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 carbon (E_j Gg N_2O) is calculated as:

$$E_j = \Sigma_i (M_i \times NC \times EF \times C_g) \quad \text{(3.D.A_10)}$$

Where M_i = loss of soil carbon in *cropland remaining cropland* (Gg)
NC = nitrogen to carbon ratio for cropland soils
EF = 0.0041 (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

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 area of cultivated histosols used in the estimation of emissions from cultivated organic soils, is crosschecked with those reported in the LULUCF sector to ensure consistency.

The EFs used take into account the different climatic conditions associated with the two isolated areas, using default values from IPCC (2006). A factor of 16 kg N_2O-N/ha is used for Queensland, for tropical organic crop and grassland soils, and 8 kg N_2O-N/ha for Victoria, for temperate organic crop and grassland soils.

Table 5.27 Symbols used in algorithms for cultivation of histosols

State and territory (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_j Gg N_2O) is calculated as:

$$E_j = \Sigma_i (A_i \times EF \times C_g \times 10^{-6}) \quad \text{(3.D.A_11)}$$

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 O to molecular mass

Atmospheric deposition (3.D.b.1)

A Tier 1 method using CS EFs is used to estimate indirect N_2O emissions by atmospheric 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 EFs applied for atmospheric deposition are the same as those applied for direct N_2O emissions (see Table 5.21). The EFs are based on analyses of Australian measurement studies (Scherbak and Grace 2014; Scherbak et al. 2023), 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 across different types of crop and pasture systems, with EFs within the default ranges provided in IPCC (2019).

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.

Default values from for the 2019 IPCC Refinement (IPCC 2019) are used for FracGASMsoil and FracGASF to calculate N volatilised from organic and synthetic fertilisers, and animal waste deposited on soils.

Table 5.28 Symbols used in algorithms for atmospheric deposition

State and territory (i)	Activity (j)
1 = ACT	1 = Inorganic fertilizer
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:

$$M_{ij=1} = TM_{ij=1} \times FracGASF_j \quad \text{(3.D.B_1)}$$

Where $TM_{ij=1}$ = total mass of fertiliser (Gg N), as estimated for inorganic fertilizers
$FracGASF_j$ = 0.11 (Gg N/Gg applied) (IPCC (2019))

The mass of N volatilised from animal waste deposited on or applied to soils ($M_{ij=2}$ Gg N) is calculated as:

$$M_{ij=2} = (MNsoil_{ij}) \times FracGASMsoil_{ij} \quad \text{(3.D.B_2)}$$

Where $MNsoil_{ij}$ = mass of manure N applied to soils (Gg N)
$FracGASMsoil_{ij}$ = 0.21 (kg NH_3-N + NO_x-N) (kg N applied or deposited)$^{-1}$(IPCC (2019))

The mass of N volatilised from sewage sludge applied to soils (M_{ij}=3 Gg N) is calculated as:

$$M_{ij=3} = TM_{ij=3} \times FracGASS_j \quad \text{(3.D.B_3)}$$

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:

$$E = \Sigma_i \Sigma_j (M_{ij} \times EF_{ij} \times C_g) \quad \text{(3.D.B_4)}$$

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

Leaching and runoff (3.D.b.2)

Australia is the driest inhabited 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).

As described in IPCC (2019), areas in Australia which are likely to be susceptible to significant leaching can be identified by comparing the annual precipitation with the sum of evapotranspiration and soil water holding capacity. (Σ(rain) > $\Sigma(ET_0)$ + soil water holding capacity).

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.

Mean annual evapotranspiration has been estimated using the Bureau of Meteorology annual areal actual evapotranspiration over a standard 30-year period, 1961–1990. Soil water holding capacity has been obtained from the CSIRO Soil and Landscape Grid of Australia - Drained Upper Limit Volumetric Water Content (Searle and Somarathna 2022).

In this methodology, we consider leaching to occur where Σ(rain) > $\Sigma(ET_0)$ + soil water holding capacity (Figure 5.11), and where land is irrigated. Regions outside these areas are considered to be 'dryland' and not subject to leaching. The fraction of each crop and livestock class occurring outside the dryland areas (FracWET) were determined by overlaying the dryland area mask onto the spatial map of crops, pastures and livestock stocking density from the 2021–22 Agricultural Commodities census, Australia (ABS 2022b).

Figure 5.11 Map of Australia displaying where soil leaching is likely to occur



Source data: Bureau of Meteorology and CSIRO

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

In the areas subject to leaching, FracLEACH value and N_2O EF values from IPCC (2019) are used to calculate N that is lost through leaching and runoff.

Table 5.29 Symbols used in algorithms for leaching and runoff

State and territory (i)	Activity (j)
1 = ACT	1 = Inorganic fertilizer
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:

$$M_{ij=1} = M_{ij} \times FracWET_{ij} \times Frac_{LEACH} \quad \text{(3.D.B_5)}$$

Where M_{ij} = mass of fertiliser in each production system (Gg N), as calculated for inorganic fertilisers
$FracWET_{ij}$ = fraction of N available for leaching and runoff (Table A5.5.10.1)
$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (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:

$$M_{ij=2} = (MNsoil_{ij} + UNsoil_{ij} + FNsoil_{ij}) \times FracWETsoil_{ij} \times Frac_{LEACH} \quad \text{(3.D.B_6)}$$

Where $MNsoil_{ij}$ = mass of manure N applied to soils (Gg N), as calculated for organic fertilisers
$UNsoil_{ij}$ = mass of urinary N excretion on pasture (Gg N), as calculated for atmospheric deposition
$FNsoil_{ij}$ = mass of faecal N excretion on pasture (Gg N), as calculated for atmospheric deposition
$FracWETsoil_{ij}$ = fraction of N available for leaching and runoff (Table A5.5.10.2)
$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (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:

$$M_{ij=3} = M_{ij} \times FracWET_{ij} \times Frac_{LEACH} \quad \text{(3.D.B_7)}$$

Where M_{ij} = mass of sewage sludge N (Gg N), as calculated for organic fertilisers
$FracWET_{ij}$ = fraction of N available for leaching and runoff = 1.0
$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (IPCC 2019))

The mass of crop residue that is lost through leaching and runoff ($M_{ij=4}$ Gg N) is calculated as:

$$M_{ij=4} = M_{ij} \times FracWET_{ij} \times Frac_{LEACH} \quad \text{(3.D.B_8)}$$

Where M_{ij} = mass of crop residue N (Gg N), as calculated for crop residues
$FracWET_{ij}$ = fraction of N available for leaching and runoff (Table A5.5.10.1)
$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (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:

$$M_{ij=5} = M_{ij} \times FracWET_{ij} \times Frac_{LEACH} \quad \text{(3.D.B_9)}$$

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 (Table A5.5.10.1 – non-irrigated crops)
$Frac_{LEACH}$ = 0.24 (Gg N/Gg applied) (IPCC 2019))

Annual nitrous oxide production from leaching and runoff (E Gg N_2O) is calculated as:

$$E = \Sigma_i \Sigma_j (M_{ij} \times EF \times C_g) \quad \text{(3.D.B_10)}$$

Where M_{ij} = mass of N lost through leaching and runoff (Gg N)
EF = 0.011 (Gg N_2O-N/Gg N) (IPCC 2019)
C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

5.5.3 Uncertainty assessment 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.

5.5.4 Category-specific QA/QC and verification

The Australian Bureau of Statistics (ABS) is the national statistical agency of Australia and is the key provider of activity data for this source category. ABS has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated. Data quality used in the inventory is also kept under review by the Department.

This source category is also covered by the general QA/QC procedures detailed in Annex 4. In particular, 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. 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 Department. These revisions are not reflected in the FAO data.

5.5.5 Category-specific recalculations

Recalculations of *agricultural soils* reported in the current submission are shown in Table 5.30 and are due to:

A: Urine and Dung Deposited by Grazing Animals: new EF

An downward recalculation throughout the time series is due to the adopting a spatially-weighted average EF using the wet and dry climate zone default values from IPCC (2019). Because Australian livestock are mostly raised in dry climate zones, the resulting EF is lower than the previous default value.

B. Reallocation of fertiliser application

As described in section 3.D.a.1, fertilizer is allocated to different production systems using data from the ABS report "water use on Australian Farms". This has not been produced since 2020–21, and a new method was used to allocate fertilizer use based on irrigation statistics from ABARES farm survey data (ABARES 2025).

C. Swine: update to EF for animal waste applied to soils

The EF for animal waste applied to soils for Swine was updated to use the IPCC default value, consistent with all other livestock types.

D. Histosols: disaggregated EFs by climate

Separate EFs were introduced for the histosols in Queensland and Tasmania using default values from IPCC (2006), instead of the previous national average. A factor of 16 kg N_2O-N/ha is used for Queensland, for tropical organic crop and grassland soils, and 8 kg N_2O-N/ha for Victoria, for temperate organic crop and grassland soils.

E. Revisions to soil carbon losses for nitrogen mineralisation

As described in Chapter 6 (LULUCF), the estimates for soil carbon are recalculated for the entire time series in every inventory. This leads to small changes in the estimates of nitrogen mineralisation due to loss of soil carbon.

F. Crop residue EFs: disaggregated by crop and State

Emissions from crop residues are now calculated using individual EFs disaggregated by crop and State to reflect the climate zone where each crop is grown, as described in section 3.D.a.4. The previous weighted average was based on these individual EFs, so the recalculation is small.

G. Indirect emissions: manure management

As described in section 5.3.5, the method for allocating manure from grazing livestock has been improved. This mainly causes a recalculation in sector 3.B, but also a smaller recalculation to the indirect emissions in sector 3.D.

Table 5.30 Agricultural soils (3.D): recalculations of total CO_2-e emissions, 1989–90 to 2022–23

	2025 submission	2026 submission	Change		Reasons for Recalculation (Gg CO_2-e)						
Year	(Gg CO_2-e)		(Gg CO_2- e)	(Per cent)	A	B	C	D	E	F	G
1989–90	9,543	8,754	-789	-8%	-810	0	36	-15	0	0	1
1994–95	8,544	7,855	-689	-8%	-710	0	35	-15	0	1	0
1999–00	10,231	9,519	-713	-7%	-732	0	35	-15	0	-1	0
2004–05	9,871	9,210	-661	-7%	-682	0	36	-15	0	-1	1
2005–06	9,708	9,061	-646	-7%	-667	0	36	-15	0	-1	0
2006–07	8,718	8,094	-624	-7%	-644	0	35	-15	0	0	0
2007–08	8,501	7,906	-596	-7%	-613	0	32	-15	0	0	0
2008–09	8,774	8,184	-590	-7%	-605	0	31	-15	0	-1	0
2009–10	8,672	8,106	-566	-7%	-575	0	25	-15	0	-1	0
2010–11	9,465	8,872	-593	-6%	-601	0	25	-15	0	-1	0
2011–12	9,676	9,064	-611	-6%	-617	0	23	-15	0	-2	0
2012–13	9,701	9,088	-613	-6%	-619	0	23	-15	0	-1	0
2013–14	10,128	9,523	-604	-6%	-613	0	25	-15	0	-1	0
2014–15	9,807	9,224	-583	-6%	-591	0	25	-15	0	-1	0
2015–16	9,886	9,309	-577	-6%	-583	0	25	-15	0	-1	-3
2016–17	10,697	10,094	-603	-6%	-610	0	27	-15	0	-2	-3
2017–18	9,975	9,378	-598	-6%	-607	0	28	-15	0	-1	-3
2018–19	9,174	8,619	-555	-6%	-563	0	26	-15	0	0	-2
2019–20	9,278	8,738	-541	-6%	-544	0	25	-15	-5	1	-2
2020–21	10,660	9,842	-818	-8%	-538	-291	28	-15	-8	-2	8
2021–22	11,255	10,534	-721	-6%	-534	-203	35	-15	-9	-3	9
2022–23	11,495	10,654	-840	-7%	-566	-281	29	-15	-11	-3	7

5.5.6 Category-specific planned improvements

For agricultural soils the following areas have been identified for review and/or change:

1. Use the most recent published information to locate source data to provide information on how inorganic fertiliser EFs are weighted by crop type, climate region, management system and fertiliser type.
2. Consider the disaggregation of inorganic fertiliser EFs into urea and non-urea fertiliser EFs.
3. Investigate using EF values for Urine and dung deposited by grazing animals (3.D.a.3) disaggregated by State, instead of the national weighted average currently used.
4. Investigate using EF values for Animal waste applied to soils (3.D.a.2) disaggregated by State, instead of the national weighted average currently used.
5. Investigate separate reporting of fertiliser emissions from flooded rice soils.

5.6 Prescribed Burning of Savannas (CRT category 3.E)

Non-CO_2 emissions from prescribed burning of savannas are reported under LULUCF category 4(IV) to align Australia's reporting with the categories specified in the 2006 IPCC Guidelines (IPCC 2006). Information on forest and grassland fires is included in Chapter 6.3.2.

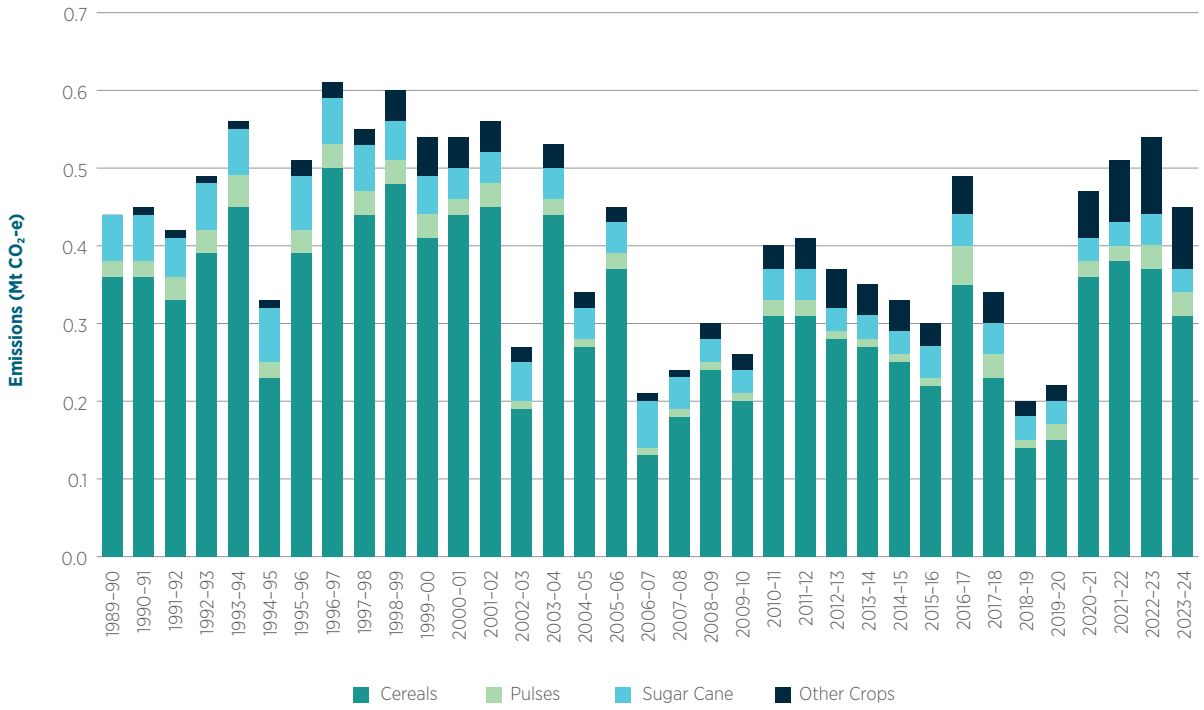
5.7 Field Burning of Agricultural Residues (CRT category 3.F)

5.7.1 Category description

The burning of residual crop material releases CH_4, N_2O, CO, NO_x and NMVOCs into the atmosphere. These gases are formed from carbon and nitrogen in the plant material during the combustion process. As per the IPCC *Guidelines* (IPCC 2006), the CO_2 emissions from burning of agricultural residues are not included in the inventory total since it is assumed that an equivalent amount of CO_2 was removed by the growing crop. 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.

Figure 5.12 Emissions from field burning of agricultural residues, Australia, Mt CO_2-e



5.7.2 Methodological issues

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.

Activity data is sourced from the ABS (Agricultural Commodities), sugar industry associations, and Hop Products Australia.

Table 5.31 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. (1994a), Hurst et al. (1994b).

Table 5.32 Symbols used in algorithms for burning of agricultural residues

State and territory (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:

$$M_{ij} = P_{ij} \times R_j \times S_j \times DM_j \times Z \times F_{ij} \quad \text{(3.F_1)}$$

Where P_{ij} = annual production of crop (Gg)

R_j = residue:crop ratio (kg crop residue/kg crop) (Table A5.5.9.1)

S_j = fraction of crop residue remaining at burning (Table A5.5.9.1)

DM_j = dry matter content (kg dry weight/kg crop residue) (Table A5.5.9.1)

Z = burning efficiency (fuel burnt/fuel load) = 0.96 (Hurst et al. 1994b; Hurst and Cook, 1996)

F_{ij} = fraction of the annual production of crop that is burnt (ha burnt/ ha harvested) (Tables A5.5.9.1 and A5.5.9.3)

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:

$$E_{ij} = M_{ij} \times CC_j \times EF_g \times C_g \quad \text{(3.F_2)}$$

Where E_{ij} = annual emissions from burning of crop residue (Gg)

CC_j = carbon mass fraction in crop residue (Table A5.5.9.1)

EF_g = emission factor (Gg element /Gg burnt) (Table 5.29)

C_g = factor to convert from elemental mass of gas to molecular mass (Table 5.29)

For N_2O and NO_x an additional term in the algorithm, the nitrogen to carbon ratio (NC_j), is required in order to calculate the fuel nitrogen content. Hence:

$$E_{ij} = M_{ij} \times NC_j \times EF_g \times C_g \quad \text{(3.F_3)}$$

Where E_{ij} = annual emissions from burning of crop residue (Gg)

NC_j = nitrogen content in above ground residue (Table A5.5.9.1)

EF_g = emission factor (Gg element /Gg burnt) (Table 5.29)

C_g = factor to convert from elemental mass of gas to molecular mass (Table 5.29)

5.7.3 Uncertainty assessment 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 60 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.

5.7.4 Category-specific QA/QC and verification

The ABS has in place a range of quality assurance-quality control procedures associated with survey design, data input and consistency checks on the survey results and the aggregated values. Sampling errors are also evaluated. Data quality used in the inventory is also kept under review by the Department.

This source category is also covered by the general QA/QC procedures detailed in Annex 4.

5.7.5 Category-specific recalculations

There are no recalculations associated with the field burning of agricultural residues in this submission.

5.7.6 Category-specific planned improvements

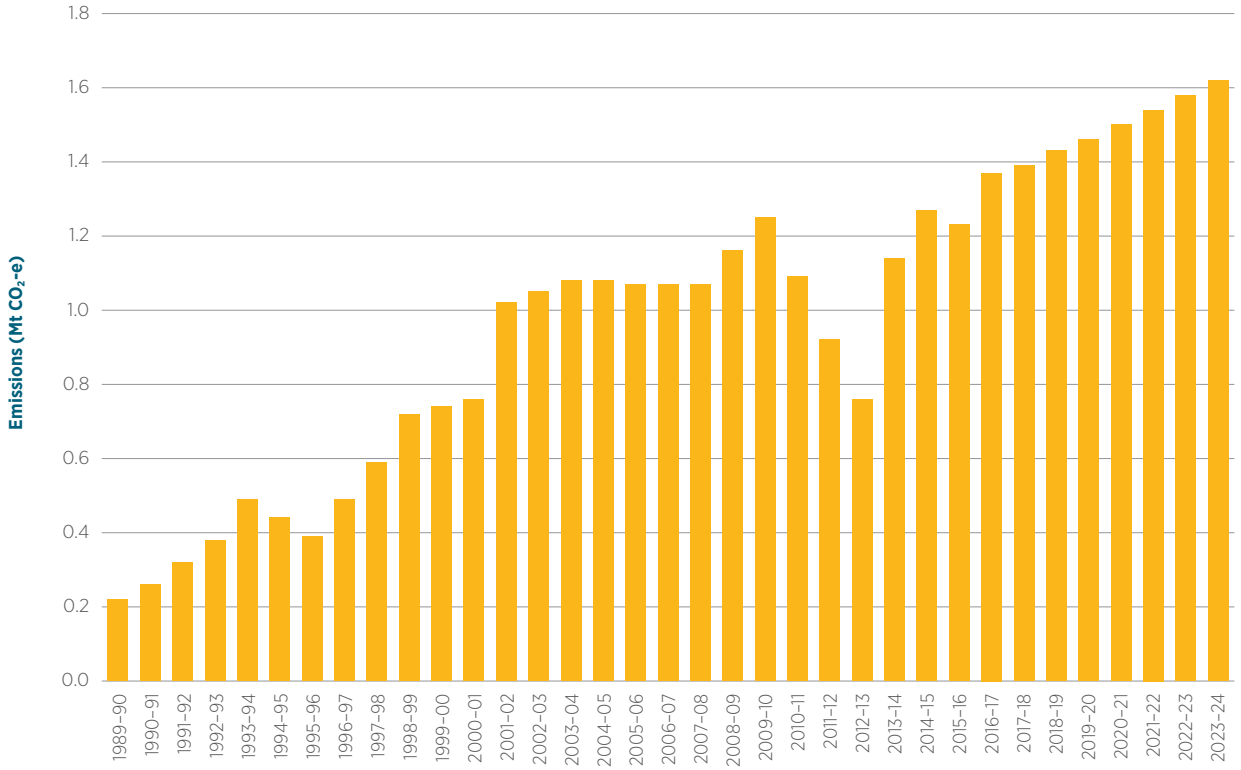
All data and methodologies are kept under review.

5.8 Liming (CRT category 3.G)

5.8.1 Category description

Limestone and dolomite are used in Australia to ameliorate soil acidity, improve soil structure, and improve plant growth in *cropland* and *grassland* and, to a very limited degree, in *forestland.* Adding carbonates to soils in the form of lime (e.g. 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.

Figure 5.13 Emissions from liming, Australia, Mt CO_2-e



5.8.2 Methodological issues

Table 5.33 Symbols used in algorithms for liming

State and territory (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:

$$E_{ij} = ((M_{ij} \times FracLime_{ij} \times P_{j=1} \times EF_{j=1}) + (M_{ij} \times (1-FracLime_{ij}) \times P_{j=2} \times EF_{j=2})) \times C_g \div 1000 \quad (3.G_1)$$

Where M_{ij} = mass of limestone and dolomite applied to soils (tonne)

$FracLime_{ij}$ = fraction of lime as limestone or dolomite, derived from the ABS report "Land Management and Farming in Australia". The values of $FracLime_{ij}$ for each State and year are provided in Appendix 5.K.

$P_{j=1}$ = fractional purity of limestone = 0.9 (DCC 2006)

$P_{j=2}$ = fractional purity of dolomite = 0.95 (DCC 2006)

$EF_{j=1}$ = 0.12 (tonne C/tonne of limestone) – IPCC (2006) default emission factor for limestone

$EF_{j=2}$ = 0.13 (tonne C/tonne of dolomite) – IPCC (2006) default emission factor for dolomite

C_g = 44/12 factor to convert elemental mass of CO_2 to molecular mass

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.

As no data have been reported since 2017, the values have been extrapolated using an ordinary least squares method applied to each State's historical data. Investigation of an alternate source of activity data is a planned improvement.

The use of country-specific purity information on limestone and dolomite amends the emission factors as described in the 2006 IPCC Guidelines (IPCC 2006), making this a Tier 2 method.

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.

5.8.3 Uncertainty assessment 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.

5.8.4 Category-specific QA/QC and verification

This source category is covered by the general QA/QC procedures detailed in Annex 4.

5.8.5 Category-specific recalculations

There are recalculations in this submission throughout the time series to emissions from liming, shown in Table 5.34. The reason for the recalculation is:

A. Extrapolation of activity data

As described above, the ABS has not reported activity data since 2017. Previously, activity data were held constant in the absence of updates, but this is not thought to represent continued increasing use. While an alternative data source is investigated, activity data have been extrapolated, leading to an upward recalculation in years since 2017.

Table 5.34 Rice (3.C): recalculations of total CO_2-e emissions, 1989–90 to 2022–23

	2025 submission	2026 submission	Change		Reasons for Recalculation (Gg CO_2-e)
Year	(Gg CO_2-e)		(Gg CO_2- e)	(Per cent)	A
1989–90	215	215	-	0.0%	0
1994–95	440	440	-	0.0%	0
1999–00	738	738	-	0.0%	0
2004–05	1,076	1,076	-	0.0%	0
2005–06	1,073	1,073	-	0.0%	0
2006–07	1,070	1,070	-	0.0%	0
2007–08	1,066	1,066	-	0.0%	0
2008–09	1,159	1,159	-	0.0%	0
2009–10	1,253	1,253	-	0.0%	0
2010–11	1,088	1,088	-	0.0%	0
2011–12	925	925	-	0.0%	0
2012–13	760	760	-	0.0%	0
2013–14	1,139	1,139	-	0.0%	0
2014–15	1,224	1,272	48	3.9%	48
2015–16	1,153	1,233	80	6.9%	80
2016–17	1,318	1,372	54	4.1%	54
2017–18	1,318	1,387	69	5.2%	69
2018–19	1,318	1,426	107	8.1%	107
2019–20	1,318	1,464	146	11.0%	146
2020–21	1,318	1,502	184	13.9%	184
2021–22	1,318	1,541	222	16.9%	222
2022–23	1,318	1,579	260	19.8%	260

5.8.6 Category-specific planned improvements

All data and methodologies are kept under review.

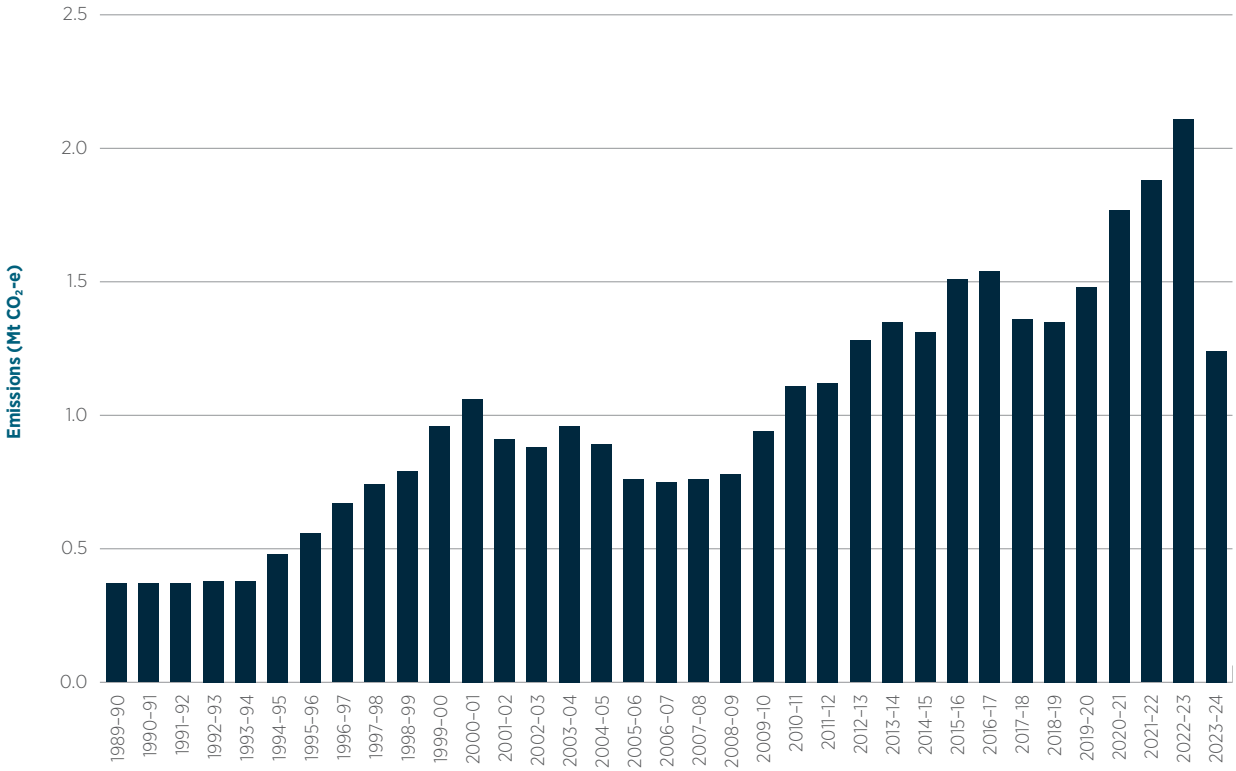
As the ABS have not updated the report of limestone and dolomite application to agricultural soils since 2017, alternative sources of activity data will be investigated.

5.9 Urea Application (CRT category 3.H)

5.9.1 Category description

Adding urea to soils for fertilisation leads to a loss of the CO_2 that was fixed during the manufacturing process. Similar to the reaction following the addition of lime, the bicarbonate that is formed evolves into CO_2 and water.

Figure 5.14 Emissions from urea application, Australia, Mt CO_2-e



5.9.2 Methodological issues

Activity data is sourced from Fertilizer Australia.

For urea application, the annual emissions of CO_2 (E_i Gg) are calculated using the tier 1 approach:

$$E_i = M_i \times EF \times C_g \div 1000 \qquad (3.H_1)$$

Where M_i = mass of urea applied to soils (tonne)

EF = 0.2 (tonne C/tonne urea) (IPCC 2006))

C_g = 44/12 factor to convert elemental mass of CO to molecular mass

5.9.3 Uncertainty assessment 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.

5.9.4 Category-specific QA/QC and verification

This source category is covered by the general QA/QC procedures detailed in Annex 4.

5.9.5 Category-specific recalculations

There are no recalculations associated with urea application in this submission.

5.9.6 Category-specific planned improvements

Country-specific information to estimate emission factors will be investigated.

6. Land Use, Land Use Change and Forestry

6.1 Overview of the sector and background information

The land use, land use change and forestry (LULUCF) sector covers greenhouse gas emissions associated with land management practices that impact the carbon stored in vegetation and soils. Since vegetation can absorb carbon from the atmosphere, this sector has the ability to function as a net sink of emissions. LULUCF emissions by sub-sector for 2023–24 are shown in Figure 6.1.1, with changes since 1989–90, 2004–05 and 2022–23.

The LULUCF sector was a net sink of 52.1 Mt CO_2–e in 2023–24, equivalent to 11.2 per cent of total net emissions (including LULUCF). Between 1989–90 and 2023–24 there was a decrease in emissions of 128.9 per cent (232.3 Mt CO_2–e), with the sector changing from a net source to a net sink. Between 2022–23 and 2023–24 there was a 11.1 Mt CO_2–e increase in the net sink from the LULUCF sector.

Figure 6.1.1 Comparison of 2023–24 emissions with past emissions levels from key LULUCF sub-sectors (Mt CO_2–e)

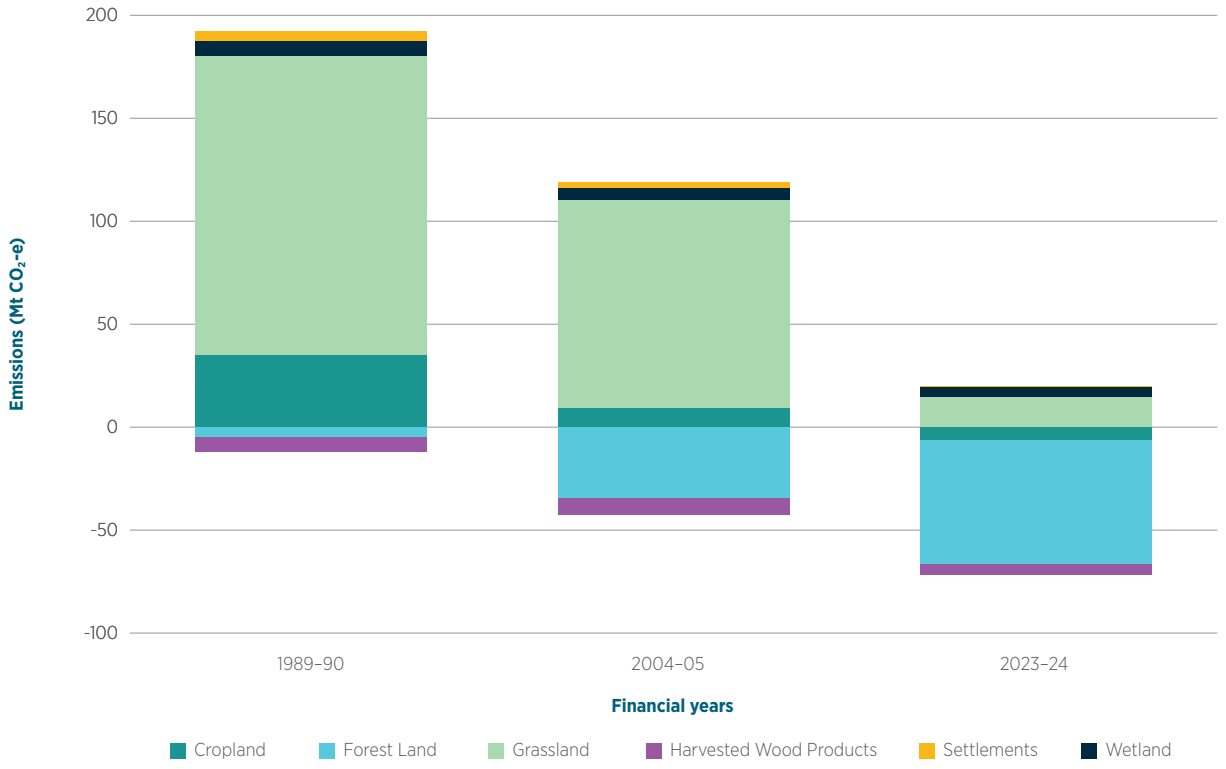
LULUCF Subsectors	2023–24 emissions	Change in 2023–24 emissions since: 1989–90	2004–05	2022–23
 4.A Forest land	-60 Mt	-56 Mt CO_2-e -1152%	-26 Mt CO_2-e -76%	+1% +1 Mt CO_2-e
 4.B Cropland	-6 Mt	-41 Mt CO_2-e -117%	-15 Mt CO_2-e -167%	+17% +1 Mt CO_2-e
 4.C Grassland	14 Mt	-131 Mt CO_2-e -90%	-87 Mt CO_2-e -86%	-12 Mt CO_2-e -46%
 4.D, E Wetlands and Settlements	5 Mt	-6 Mt CO_2-e -54%	-3 Mt CO_2-e -38%	-1 Mt CO_2-e -38%

LULUCF Subsectors	2023–24 emissions	Change in 2023–24 emissions since:		
		1989–90	2004–05	2022–23
4.G Harvested Wood Products	-5 Mt	+26% +2 Mt CO_2-e	+34% +3 Mt CO_2-e	-0.3 Mt CO_2-e -5%

Note: Icons in this figure are sourced from Geotata, adi_sena, Freepik, and Creatype on flaticon.com.

The share of emissions per sub-sector has changed significantly between the base years and the current year, with some sub-sectors changing from a net source to a net sink. Changes in LULUCF emissions by sub-sector in 1989–90, 2004–05, and 2023–24 are shown in Figure 6.1.2.

Figure 6.1.2 LULUCF emissions by sub-sector, 1989–90, 2004–05 and 2023–24 (Mt CO_2–e)



The underlying trend of declining emissions from LULUCF since 1990 has been mainly driven by the decline in emissions from forest land conversions to other land uses and the increase in removals through forest regrowth on previously cleared land (Figure 6.1.3) as well as declining net emissions from the harvest of native forests.

In recent years, in part because of limited activity data updates, the trend has been driven by climate impacts particularly in cropland and grassland, but also lands converted to forest lands. There was significant growth in the net land sink following the 2020–2022 La Niña and associated wetter conditions. These climatic conditions enabled record crop production, elevated forest growth rates which in turn led to increased carbon stocks in vegetation and soils during the La Niña period to 2022. In 2022–23 and 2023–24 the LULUCF emissions moderated back to more typical rates of sequestration with a smaller net sink than 2021–22.

The National Inventory Report 2022 identified planned improvements to the remote sensing program for forest cover change. These improvements include:

- Replacing Landsat imagery with Sentinel satellite data from 2016
- Updating the machine learning forest classification algorithm with new training data including high-resolution imagery and LIDAR data from a range of sources
- Integrating these improvements all the way through the satellite archive by reprocessing the imagery back to 1972
- Visually checking 50 years of new deforestation and reforestation records to identify the human-induced changes

The scale and complexity of transitioning this continental-scale program, developing new data processing pipelines, and ensuring time-series consistency across a composite dataset derived from different satellite technologies has extended the timeframe for data availability. As a result, the updated dataset was not available for inclusion in this inventory submission. The department is continuing to undertake QA/QC of the data received to date. The outcomes of this QA/QC process will inform the next steps for the improved dataset.

For several LULUCF categories that rely on the forest cover monitoring system for activity data, the emissions reported for 2022–23 and 2023–24 are an extrapolation of the validated 2022 results to ensure completeness of reporting.

Updates to climate data, crop and grass yields and forest productivity data, were incorporated to improve estimates of emissions and removals from regenerating forests and emissions on previously cleared lands. These land use categories were updated because climate conditions since 2022 have materially affected emissions in these sectors, robust methods exist to partially update the modelling, and because climate-driven changes are judged unlikely to be significantly revised once new vegetation monitoring data becomes available. The data updates for these land use categories show the moderation of forest growth and sequestration rates on previously cleared croplands and grassland to more typical levels. This is consistent with climate conditions that have transitioned out of the prolonged La Niña period that was associated with elevated rainfall including significant flooding in different regions of Australia in 2020, 2021 and 2022.

This hybrid approach provides the most reliable estimates given current data constraints. It balances the need for completeness and methodological consistency with the opportunity to incorporate category specific updates where supporting data exist.

Other land use categories were not updated because the impacts of climate data and vegetation monitoring activity data were not able to be updated independently, or independent climate updates were considered unlikely to be representative of emissions trends and subject to material revision once activity data becomes available. In these land use categories, holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data, and unsuitability of trend extrapolation given interannual variability of climate drivers. Consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3: Resolving data gaps), emissions for these categories have generally been held constant at 2021–22 levels for 2022–23 and 2023–24.

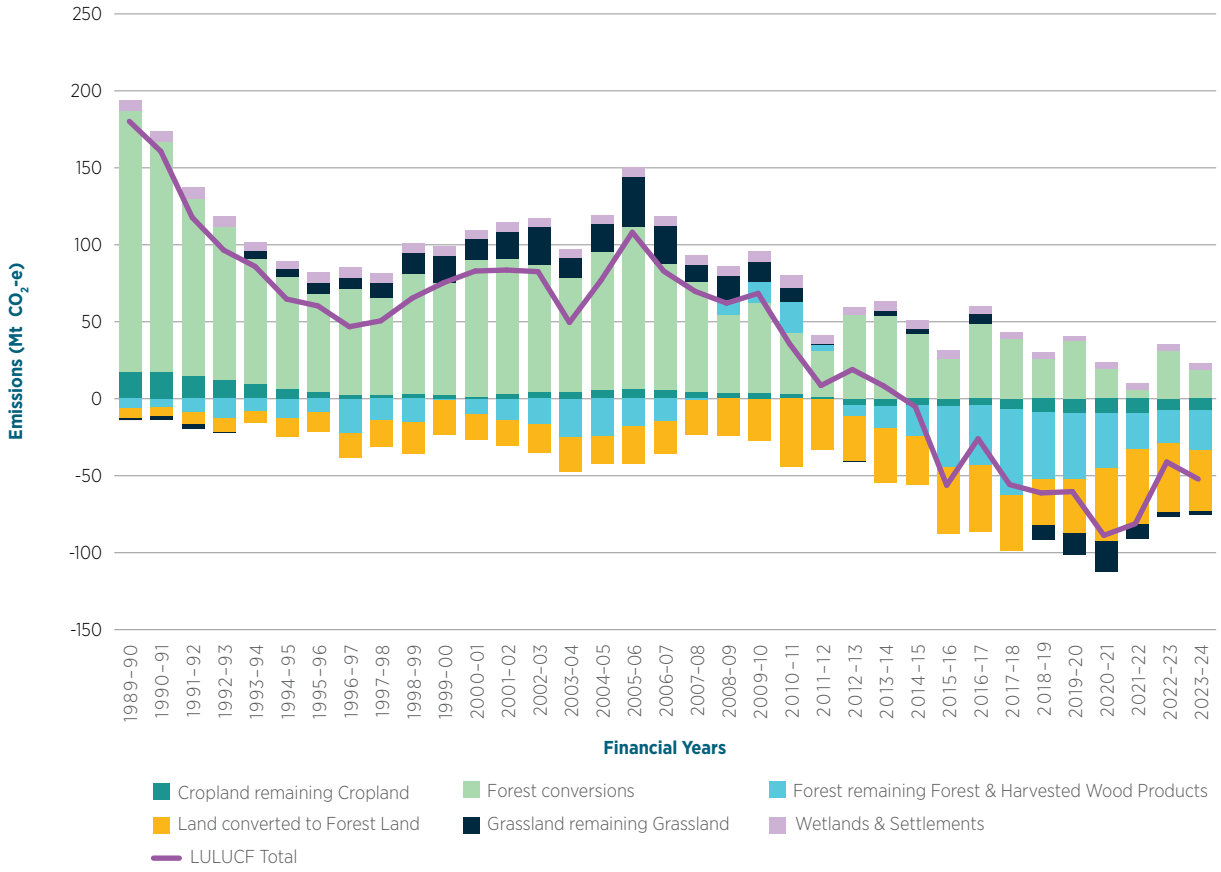
Detailed descriptions of the extrapolation or partial update methods are provided in the methodology description for each of the land use categories in this chapter.

A summary of the approaches used to estimate emissions for each LULUCF land use category for the National Inventory Report 2024 is provided in Table 6.1.1.

Table 6.1.1 Summary of National Inventory Report 2024 updates to LULUCF source and sink categories

Land use category	Source and sink categories	National Inventory Report 2024
Forest land remaining forest land	Harvested native forests	Estimates updated for 2023–24
	Pre-1990 plantations	Held constant at 2021–22 levels
	Other native forests	Estimates updated for 2023–24
	Wildfire and non-temperate fire management	Estimates updated for 2023–24
Land converted to forest land	Regrowth on previously cleared lands	Held constant at 2021–22 levels
	Plantations	Held constant at 2021–22 levels
	Natural forest regeneration	Area converted to forest land held constant at 2021–22 levels Forest productivity data updated to 2023–24 for existing areas of land converted to forest land
	Wildfire and non-temperate fire management	Estimates updated for 2023–24
Cropland remaining cropland	Cropland soils	Estimates updated for 2023–24
	Perennial woody crops	Estimates updated for 2023–24
Land converted to cropland	Forest conversions	Area of forest conversions held constant at 2021–22 levels Updates to climate data and crop and grass yields applied to estimate emissions on previously cleared lands to 2023–24
Grassland remaining grassland	Sparse woody vegetation	Held constant at 2021–22 levels
	Grassland management	Estimates updated for 2023–24
	Non-temperate fire management	Estimates updated for 2023–24
Land converted to grassland	Forest conversions	Area of forest conversions held constant at 2021–22 levels Updates to climate data and crop and grass yields applied to estimate emissions on previously cleared lands to 2023–24
	Non-temperate fire management	Estimates updated for 2023–24
Wetlands remaining wetlands	Established reservoirs	Estimates updated for 2023–24
	Other constructed water bodies	Estimates updated for 2023–24
	Sparse woody vegetation	Held constant at 2021–22 levels
	Non-temperate fire management	Estimates updated for 2023–24
	Seagrass extraction	Estimates updated for 2023–24
	Aquaculture production	Estimates updated for 2023–24
Land converted to wetlands	Forest conversions	Held constant at 2021–22 levels
	New reservoirs	Estimates updated for 2023–24
Settlements remaining settlements	Sparse woody vegetation	Held constant at 2021–22 levels
Land converted to settlements	Forest conversions	Area of forest conversions held constant at 2021–22 levels Updates to climate data and crop and grass yields applied to estimate emissions on previously cleared lands to 2023–24
Harvested Wood Products	Harvested wood products	Estimates updated for 2023–24

Figure 6.1.3 Net CO_2–e emissions from Land Use, Land Use Change and Forestry, by sub-category, 1989–90 to 2023–24



One of the principal drivers of change in carbon fluxes across the Australian landscape relates to losses and gains of woody vegetation. The loss of woody vegetation is mainly reported under three classifications: *forest conversion to other land uses, forest land remaining forest land,* and *grassland remaining grassland.*

Permanent losses of woody vegetation that had previously been classed as *forest land* are reported under forest conversion to other land use classifications.

Temporary losses of woody vegetation on *forest land* are reported under the *forest land remaining forest land* classification. All forests subject to harvest events are monitored over time to ensure that the forest regenerates — if this does not happen, these areas are reported under forest conversion. Most wildfires in Australia are not stand-replacing and do not result in vegetation losses, however where forest cover loss occurs, these temporary losses are also included in monitoring for land use-change or salvage logging (see Chapter 6.4). A regeneration of forest following a harvest event or fire is reported under *forest land remaining forest land* as no change in land use has occurred.

Increases and losses of woody vegetation that are not classed as *forest land* (called sparse woody vegetation) — both permanent and temporary — are reported under *grassland remaining grassland, wetlands remaining wetlands* and *settlements remaining settlements.*

Increases in woody vegetation cover classed as *forest land* are reported under *land converted to forest land.* These changes include new plantations and forest regrowth on land previously cleared for other uses, environmental plantings and the regeneration of forest from natural seed sources including conversion of tidal marsh to mangrove.

Choice of Methods

Predominantly country specific methodologies and Tier 3 models (Table 6.1.2) are used for LULUCF. The methods used in the estimation of the LULUCF categories of the inventory are described in detail in Annex 5.6.

Australia's land sector inventory system integrates spatially referenced data with the Full Carbon Accounting Model (FullCAM), an empirically constrained, mass balance, carbon cycling ecosystem model, to estimate carbon stock changes and greenhouse gas emissions (including all carbon pools, gases, lands and land use activities).

FullCAM has been designed to comply with IPCC Guidelines and to meet the Australian Government's international treaty estimation and reporting commitments. It is designed to fully integrate the estimation of carbon stock changes and related emissions across the Australian landscape. Model parameterisation has been informed by the latest empirical science and is continuously updated.

A comprehensive modelling approach to the estimation of carbon stock changes was originally chosen for the Australian land sector because of the absence of extensive forest inventory or measurement systems, reflecting the circumstance that timber industry activity has been confined in recent times to approximately 15 per cent of Australia's forest.

Spatial datasets for key disturbance events such as land clearing, forest planting and natural regeneration are derived from Landsat satellite imagery held by the Australian Geoscience Datacube (Digital Earth Australia). These datasets are processed by CSIRO Data61 and are informed by land use and vegetation datasets provided by the Australian Bureau of Agricultural and Resource Economics and Sciences and the Department of Climate Change, Energy, the Environment and Water.

Summary information on method and emission factor selection is provided in Table 6.1.2, with key categories identified as highlighted squares.

Table 6.1.2 Summary of methodologies and emission factors – LULUCF sector

Greenhouse Gas Source and Sink	CO_2		CH_4		N_2O	
	Method applied	EF	Method applied	EF	Method applied	EF
4. Land Use, Land Use Change and Forestry						
A. Forest Land						
1. Forest land remaining Forest land						
Harvested native forests	T2, T3	CS, M	4(IV)		4(III) & 4(IV)	
Other native forests	T2, T3	CS, M	4(IV)		4(III) & 4(IV)	
Pre-1990 Plantations	T3	M	4(IV)		4(III) & 4(IV)	
Fuelwood consumed	T2	CS	IE	NA	IE	NA
2. Land converted to Forest land	T3	CS, M	4(IV)		4(III) & 4(IV)	
B. Cropland						
1. Cropland remaining Cropland	T3, T2	CS, M	IE	NA	IE	NA
2. Land converted to Cropland						
Forest converted to cropland	T3	M	4(IV)		4(III) & 4(IV)	
Wetlands converted to cropland	T1	D	NE	NA	NE	NA
C. Grassland						
1. Grassland remaining Grassland	T3, T2	M, CS	4(IV)		4(III) & 4(IV)	
2. Land converted to Grassland						
Forest converted to grassland	T3	M, CS	4(IV)		4(III) & 4(IV)	
Wetlands converted to grassland	T1	D	NE	NA	NE	NA

Greenhouse Gas Source and Sink	CO_2		CH_4		N_2O	
	Method applied	EF	Method applied	EF	Method applied	EF
D. Wetlands						
1. Wetlands remaining Wetlands	T2, T3	CS	4(II)		4(II)	
2. Land converted to Wetlands	T3	M	4(II)		4(II)	
E. Settlements						
1. Settlements remaining Settlements	T2	CS	IE	NA	IE	NA
2. Land converted to Settlements						
Forest converted to settlements	T3	M	4(IV)		4(III) & 4(IV)	
F. Other Lands	NO	NA	NO	NA	NO	NA
G. Harvested wood products	T3	M				
4(I) Direct nitrous oxide (N_2O) emissions from nitrogen (N) Inputs to managed soils [a]					IE	NA
4(II) Emissions and removals from drainage and re wetting and other management of organic and mineral soils [b]	IE	NA	T1,T2	D,CS	NE	NA
4(III) Direct and indirect nitrous oxide (N_2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils [c]					T2	CS
4(IV) Biomass burning [c]	IE,T3	IE,CS	T2,T3	CS	T2,T3	CS
H. Other [d]	T2	CS	NA	NA	T1	D

(a) In accordance with footnote 6 of Common Reporting Table 4(I), Australia reports all N_2O emissions from N inputs to managed soils in the Agriculture sector.

(b) Emissions from reservoirs are discussed in this report under *wetlands*.

(c) Methods for nitrogen mineralisation, nitrogen leaching and run-off, and biomass burning are applied across all land use classifications.

(d) Emissions from seagrass dredging and aquaculture are discussed in this report under wetlands.

EF = emission factor, CS = country specific, D = IPCC default, M = Model, NA = not applicable, NE= not estimated, NO = not occurring, IE = included elsewhere, T1 = Tier 1, T2 = Tier 2 and T3 = Tier 3.

= Key category

Forestry Activities

Harvesting in Australia's native forests, including multiple use forests and private native forests, is the key driver of human-induced emissions and removals in these forests. Over recent years, harvesting in the native forest sector has reached historically low levels (Figure 6.1.4). The annual areas of new plantations are shown in Figure 6.1.5. Note that in Figure 6.1.5, the area of new plantations in 2022–23 and 2023–24 has not been estimated, as the activity data for plantation establishment was not available.

Figure 6.1.4 Area harvested in native forests 1989–90 to 2023–24

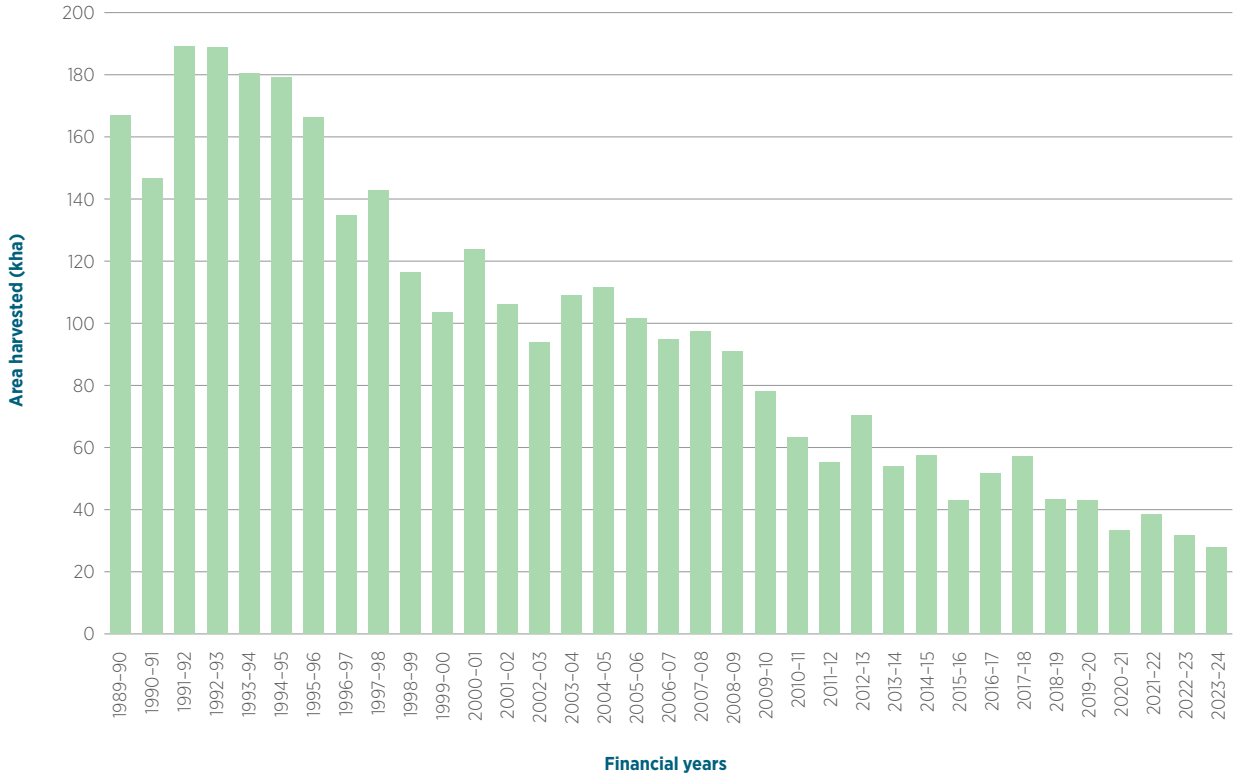
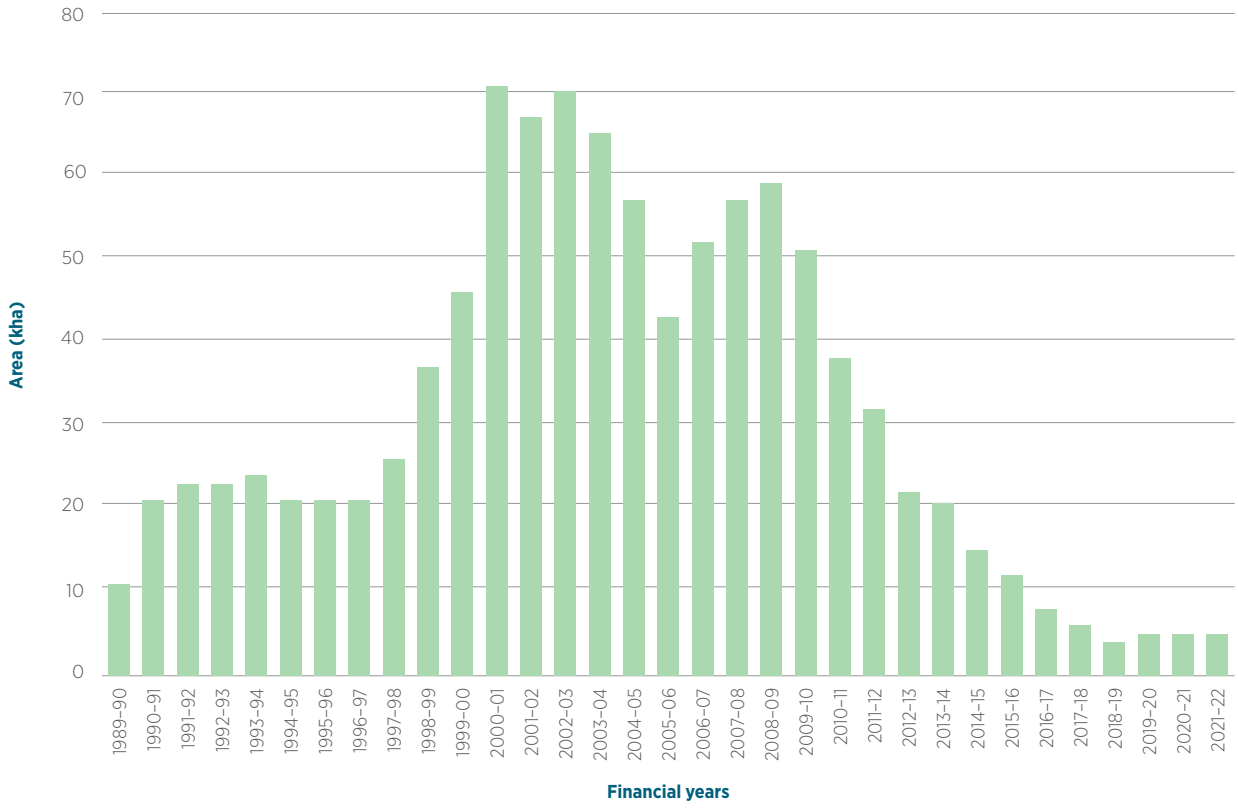


Figure 6.1.5 Area of new plantations 1989–90 to 2021–22



Forest land converted to other land uses

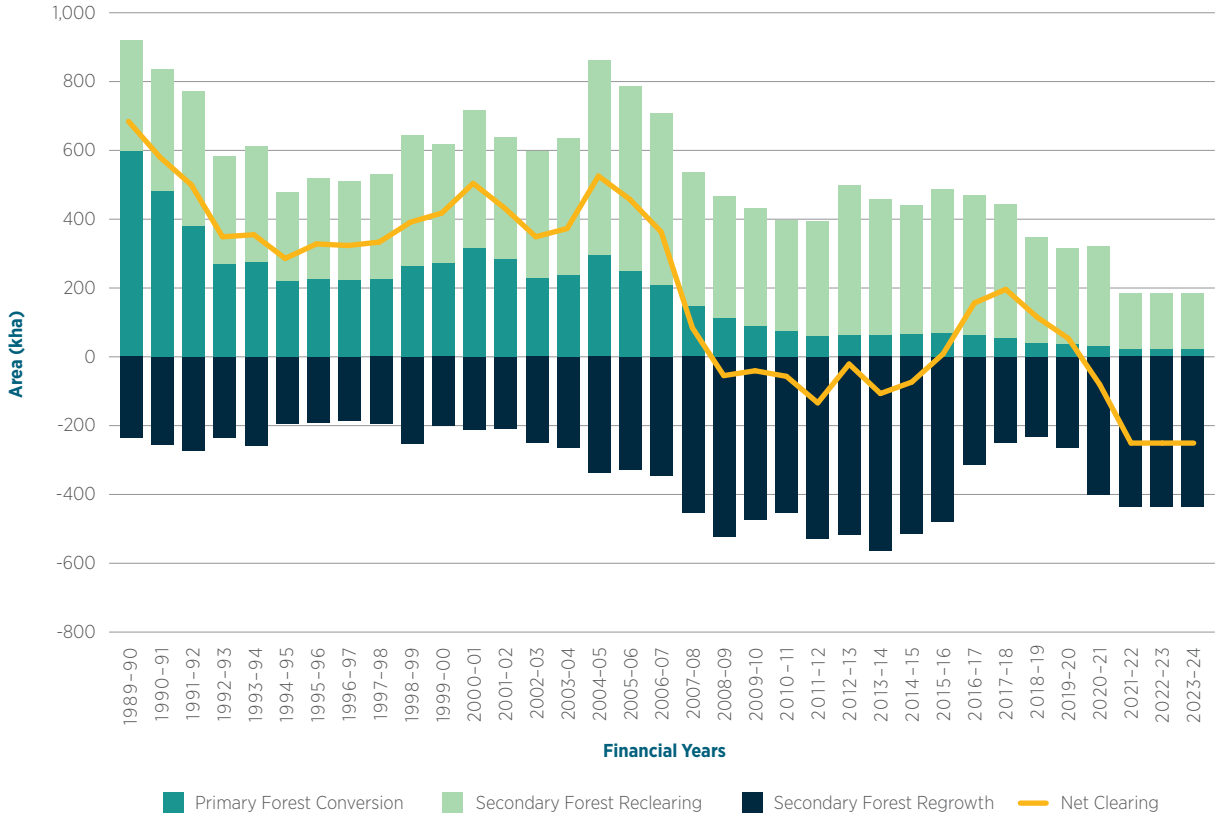
The total emissions associated with the transition from forest to a non-forest land use include the immediate loss of carbon as trees are cleared and burnt, as well as an ongoing loss of soil carbon as it decays to a new equilibrium stock level and other ongoing emissions and removals associated with the new land use. CO_2 removals associated with forest regrowth emerging on previously cleared land are accounted for as part of *land converted to forest land.*

The management of native vegetation and the majority of forest conversion processes in Australia are governed by State Governments in accordance with their own individual circumstances and land management practices and legislative frameworks. Land clearing is also regulated at a national level through the *Environmental Protection and Biodiversity Conservation Act 1999* if the clearing in question is likely to have a significant impact on matters of national environmental significance including threatened or endangered species.

Figure 6.1.6 illustrates the trend in forest land conversion to other land uses in Australia since 1990 and shows the contribution of conversion of mature primary forest and re-clearing of secondary forest cover that has re-grown on previously cleared land. Ongoing re-clearing, including of juvenile forest already converted to grassland and cropland, indicates an ongoing continuing and cyclical need of land managers to re-clear previously cleared areas. This is a common practice in many grazing regions due to regeneration from natural seed sources or resprouting from root masses following pushing of fodder species during droughts. Figure 6.1.6 also shows, for each year, the area on which forest has been observed to re-emerge on previously cleared land.

Activity data on forest clearing, re-clearing of secondary forest, and regrowth on previously cleared land relies on the forest cover monitoring system which was not available for the 2024 report (see Chapter 6.1). Reported areas have been held constant at 2021–22 levels for 2022–23 and 2023–24, while updates to climate and crop and grass yield data were incorporated to improve estimates of emissions on previously cleared lands. These updates were incorporated because climate conditions since 2022 have materially affected emissions in this sector, robust methods exist to partially update the modelling, and because climate-driven changes are judged unlikely to be significantly revised once new vegetation monitoring data becomes available. The data updates show the moderation of sequestration rates on previously cleared croplands and grasslands to more typical levels. This is consistent with climate conditions that have transitioned out of the prolonged La Niña period that was associated with elevated rainfall including significant flooding in different regions of Australia in 2020, 2021 and 2022. This hybrid approach provides the most reliable estimates given current data constraints. It balances the need for completeness and methodological consistency with the opportunity to incorporate category specific updates where supporting data exist.

Figure 6.1.6 Area of primary and secondary forest conversion and regrowth, Australia, 1989–90 to 2023–24



Within this national native vegetation framework, economic considerations remain important drivers of the demand for forest conversion to alternative uses. Most forest land converted in Australia is used for cattle grazing but also for crop production, settlements and mining. For graziers and other landowners, economic considerations are an important driver of forest land conversion. When the prices of agricultural products, for example beef, are high, landowners have a strong incentive to clear land and expand production.

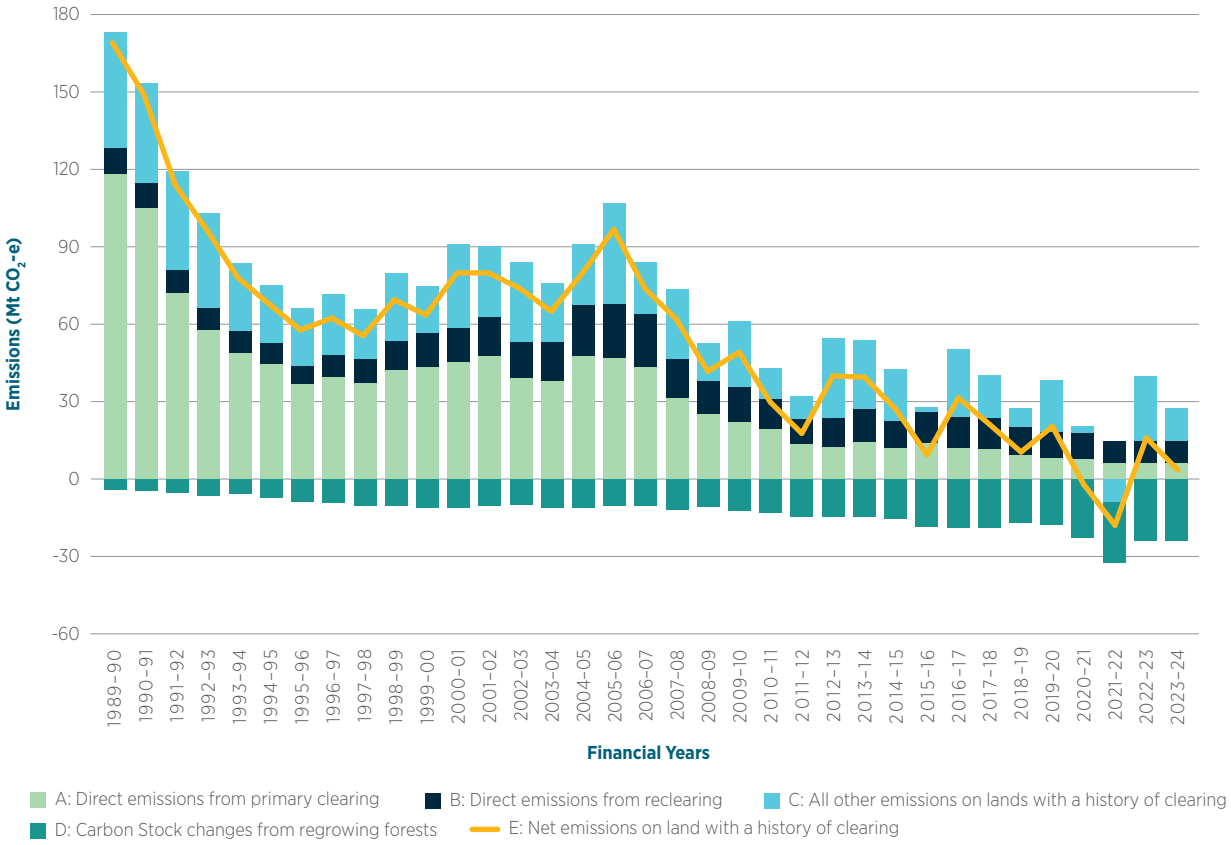
Although economic conditions are a factor, the effects of the more restrictive policy changes implemented in 2007 may be seen in the drop in first-time conversion from 2007–08 onwards (Figure 6.1.6). In addition, the sharpness of the decline may also reflect land managers bringing forward decisions to clear land to the period 2003–04 to 2006–07 – the period between the announcement of new policies and when they came into force.

The shift in the balance between first-time conversion and re-clearing evident in Figure 6.1.6 also contributes to the trend in emissions from *forest land converted to other land uses* in Figure 6.1.7. Where land is re-cleared the biomass stock at clearing will be significantly less than the initial biomass of first-time conversion.

National net forest conversions to cropland, grassland, wetlands (flooded land) and settlements emissions (Figure 6.1.7) are disaggregated as follows:

- Direct emissions from the forest clearing activity, including:
  - the emissions from the primary conversion of land that was forested in 1972; and
  - the emissions associated with secondary clearing (re-clearing) of forest which has regrown on cleared land.
- Indirect emissions from the converted land under the changed land use – subcomponents include the gradual loss of soil carbon and other emissions and removals associated with the new land use.
- Removals of CO_2 from the atmosphere on previously converted land on which forest has re-emerged.

Figure 6.1.7 Disaggregated emissions and removals associated with forest conversions



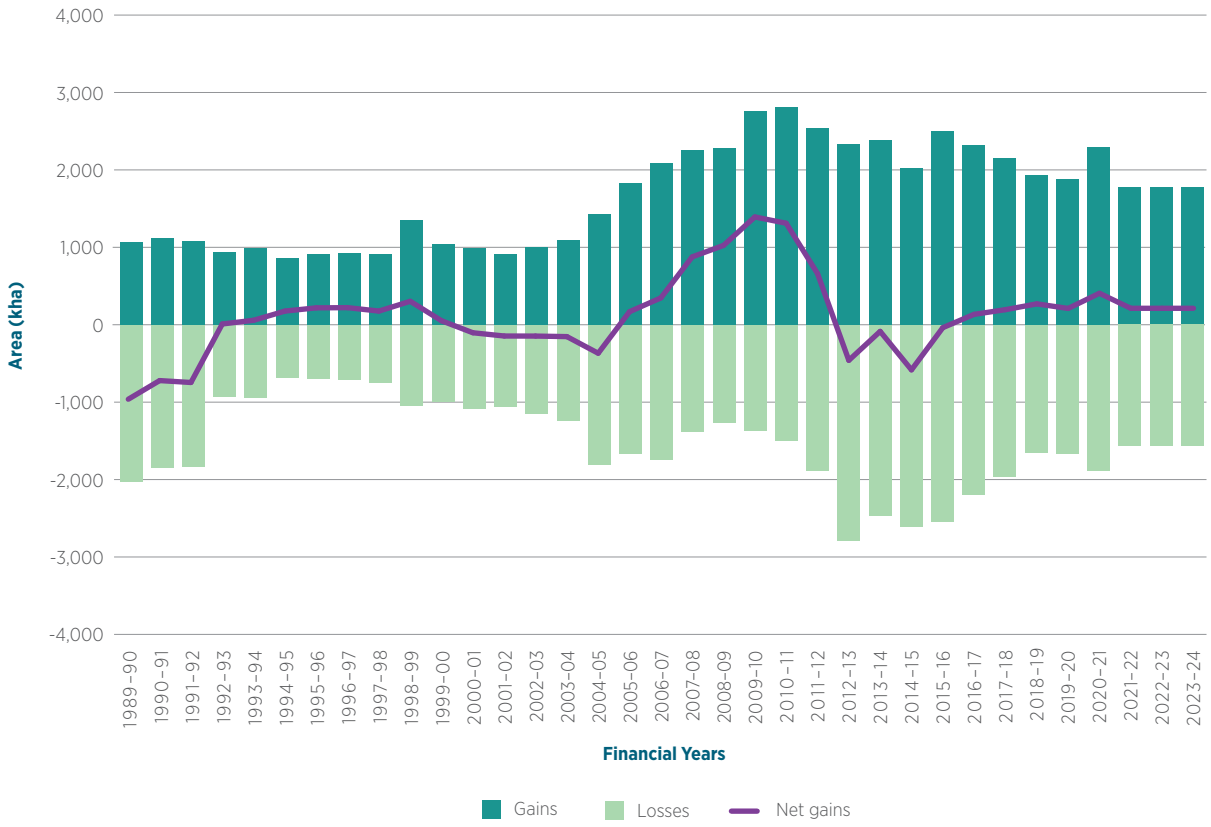
Sparse Woody Vegetation

Where the observed canopy cover does not reach the definition of a forest, it can instead be classified as sparse woody vegetation. Such woody shrubs and sparse woodlands are a key component of grassland ecosystems in semi-arid and arid regions of central Australia. Emissions and removals on these shrublands are driven by land management and transitions between shrubs and grasses.

Net changes in shrub or sparse woody vegetation appear to be strongly correlated with the El Niño Southern Oscillation Index (Bureau of Meteorology) but also reflect the incidence of fire and mechanical clearing activity by land managers. Annual area gains and losses of sparse woody vegetation, aggregated for reporting on grasslands, wetlands and settlements, are shown in Figure 6.1.8.

Activity data on sparse woody vegetation gains and losses relies on data from the land monitoring system, which was not available for use in the 2024 report (see Chapter 6.1). Reported areas and disaggregated emissions have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3 Resolving data gaps).

Figure 6.1.8 Area of sparse woody vegetation gains and losses, kha, 1989–90 to 2023–24



Temperate Fire

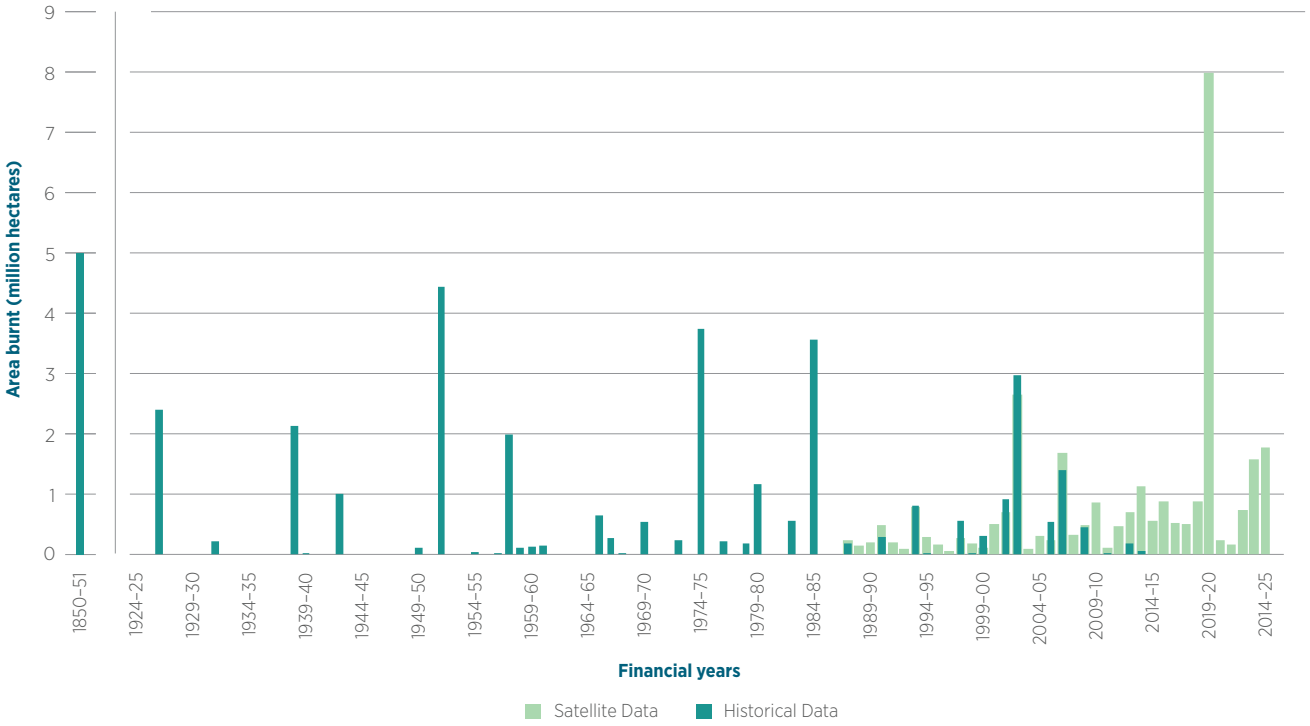
Wildfires are the largest cause of variability in emissions from *forest land remaining forest land.* Wildfires occur annually across Australia's forests with the area burnt varying considerably from year to year (Figure 6.1.9). In addition, *forest land remaining forest land* is subject to significant, non-anthropogenic natural disturbances including wildfires that are beyond control despite extensive efforts of emergency management organisations.

Consistent with guidance in the IPCC 2019 refinement (IPCC 2019) to the 2006 guidelines (IPCC 2006), to ensure transparency, two wildfire estimates are reported: net emissions including inter-annual variability from non-anthropogenic natural disturbances; and the long run trend in net anthropogenic greenhouse gas emissions from the wildfire disturbances and post-fire removals as the forest recovers.

In order to identify emissions from human activity, a statistical approach has been developed to identify non-anthropogenic natural disturbances on *forest land remaining forest land.* For these fires, carbon stock loss and subsequent recovery from non-anthropogenic natural disturbances are modelled to average out over time, leaving greenhouse gas emissions and removals from anthropogenic fires as the dominant result (Figure 6.1.10).

All prescribed fires are considered to be anthropogenic in nature. Disturbance areas are monitored for permanent changes in land use, in which case emissions are reported in the appropriate land conversion category, and salvage logging emissions are reported.

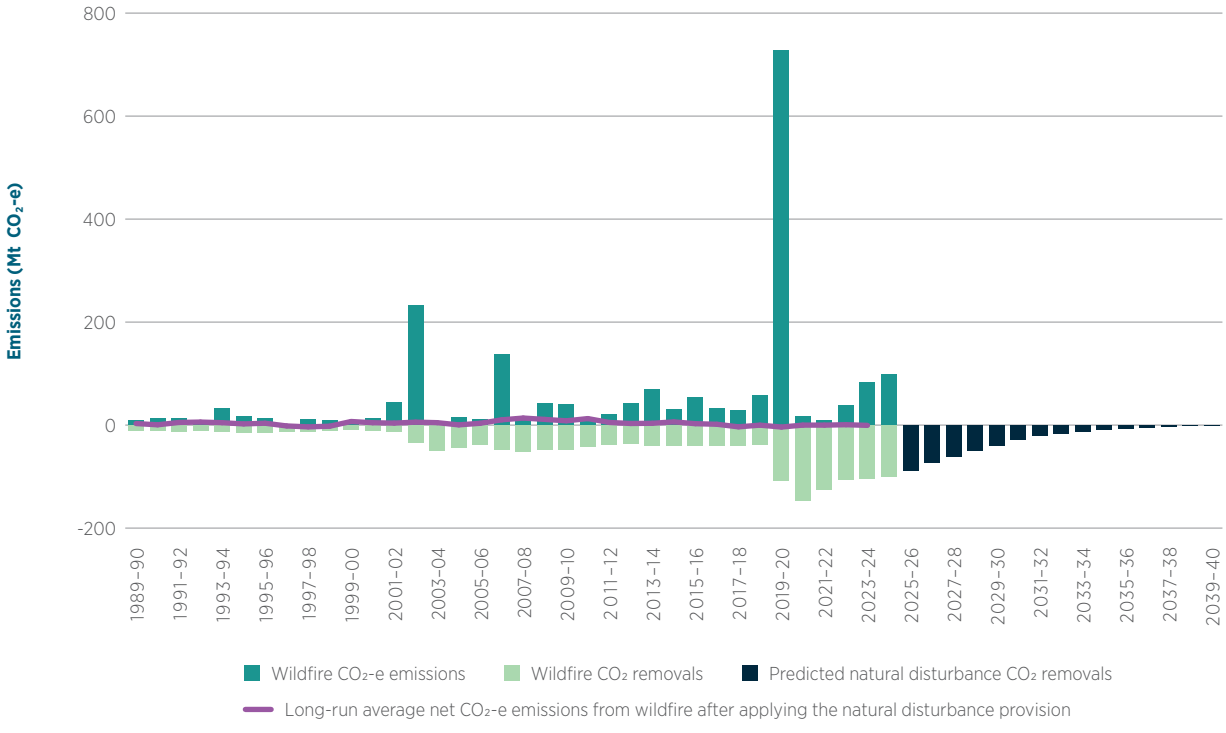
Figure 6.1.9 Annual area burnt by bushfires in Australian temperate forests



Source: Satellite data: DCCEEW using data supplied by Landgate. Note that 2020 areas also include data supplied by Emergency Management Spatial Information Network Australia (EMSINA).

Historical data: based on a range of sources, including a mixture of historical records, anecdotal evidence, and satellite imagery. Updated (with corrections) from (Roxburgh, Volkova, et al. 2015).

Figure 6.1.10 Net emissions from wildfire showing inter-annual variability and long-run trend in carbon impact after applying the natural disturbances provision Savanna Fire



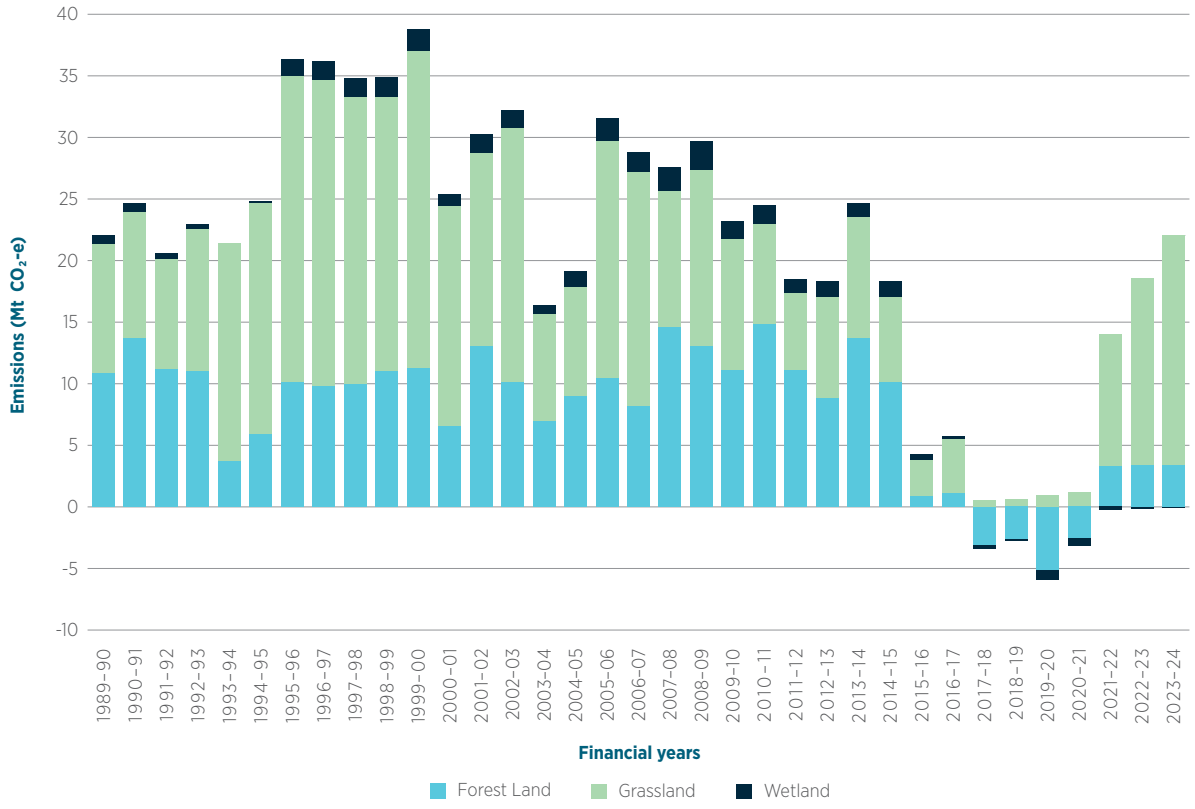
Savanna Fire

Australia reports savanna fire activity in forest land, grasslands, and wetlands based on the land use classification which has been burned by fire or is recovering from the effects of fire.

Tropical savannas represent a large proportion of the total fire affected area each year globally. Australia's tropical savannas cover approximately 26% of the national land mass. Between ~15% and ~35% of the land area in these landscapes can be fire affected each year. Many of these fires are anthropogenic, particularly in the higher rainfall regions where there is ongoing Indigenous and pastoral use of fire as a land management tool. As highly fire prone landscapes, if management fires are not employed the occurrence and extent of naturally ignited wildfires can be severe.

Strategic savanna burning involves lighting fires in the early dry season (EDS) when fine fuel loads, and resulting fire intensities, are low and fires can be controlled. Burning in this way decreases the occurrence and extent of large high intensity late dry season (LDS) fires, which are generally hotter fires that burn more fuel and can be difficult to control. A fire regime that includes strategic EDS fires can decrease greenhouse gas emissions, while the decrease in fire intensity and extent may also result in some sequestration of carbon in pools of dead and live biomass (Paul and Roxburgh (2022)).

Figure 6.1.11 Emissions from Australian tropical savannas by land use category, 1989–90 to 2023–24



Cropland and Grassland management practices

On croplands, the uptake of reduced, minimum and no-till management techniques through the 1980s and 90s is reflected in decreasing emissions during this period as a new soil C state of equilibrium is reached. Further management changes in recent years and their impact on the soil C steady state can be detected in shifts later in the emissions trend.

Changes in carbon stocks in grasslands are largely driven by changes in land management practices and climate. These factors determine the amount of live biomass and dead organic matter (DOM) as well as the amount of residues, root and manure inputs to soil carbon. Management and climatic changes can be detected as the emissions trend moves to new equilibrium levels through time. In the arid and semi-arid rangelands of central Australia, soil carbon stocks under natural grass species are assumed to have reached a steady state.

Wetlands

Separate to emissions associated with forest conversions, emissions from Wetlands includes CH_4 emissions from *reservoirs* and *other constructed waterbodies,* net changes in sparse woody vegetation, loss of seagrass beds due to capital dredging and N_2O emissions from aquaculture operations. CH_4 emissions from *reservoirs* and *other constructed waterbodies* exert the dominant influence on both the level and trend in emissions reported over the time period.

6.2 Land-use definitions and the land representation approaches used and their correspondence to the land use, land-use change and forestry categories

6.2.1 Australia's National Circumstances

Australia has a land area of 769 million hectares containing unique land, water, vegetation and biodiversity resources. Australia is a dry continent where rainfall is highly variable and floods and droughts are a common feature. There are a number of distinct climatic zones, with summer dominant rainfall in the tropics/subtropics in the north, Mediterranean climates in the south, arid and semi-arid regions in the centre, and areas of high rainfall on the coastal fringes and in the ranges of the east (Figure 6.2.1 and Figure 6.2.2).

Figure 6.2.1 Long-term average annual rainfall

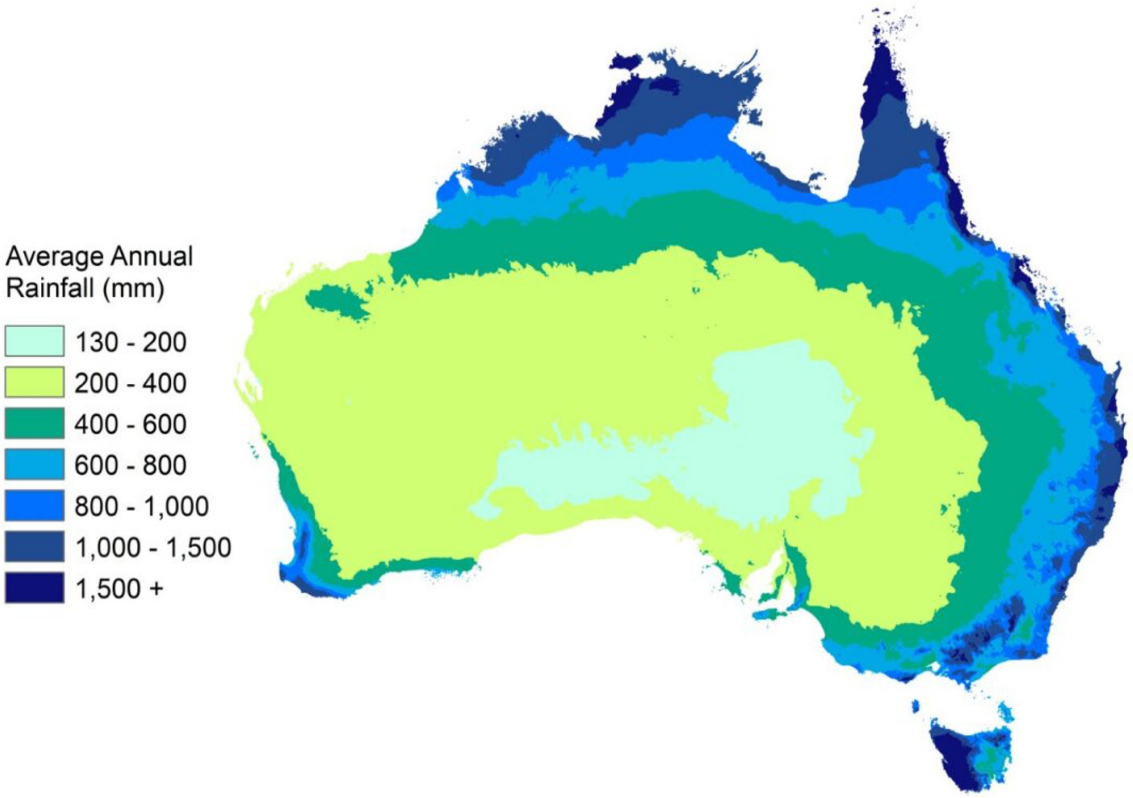
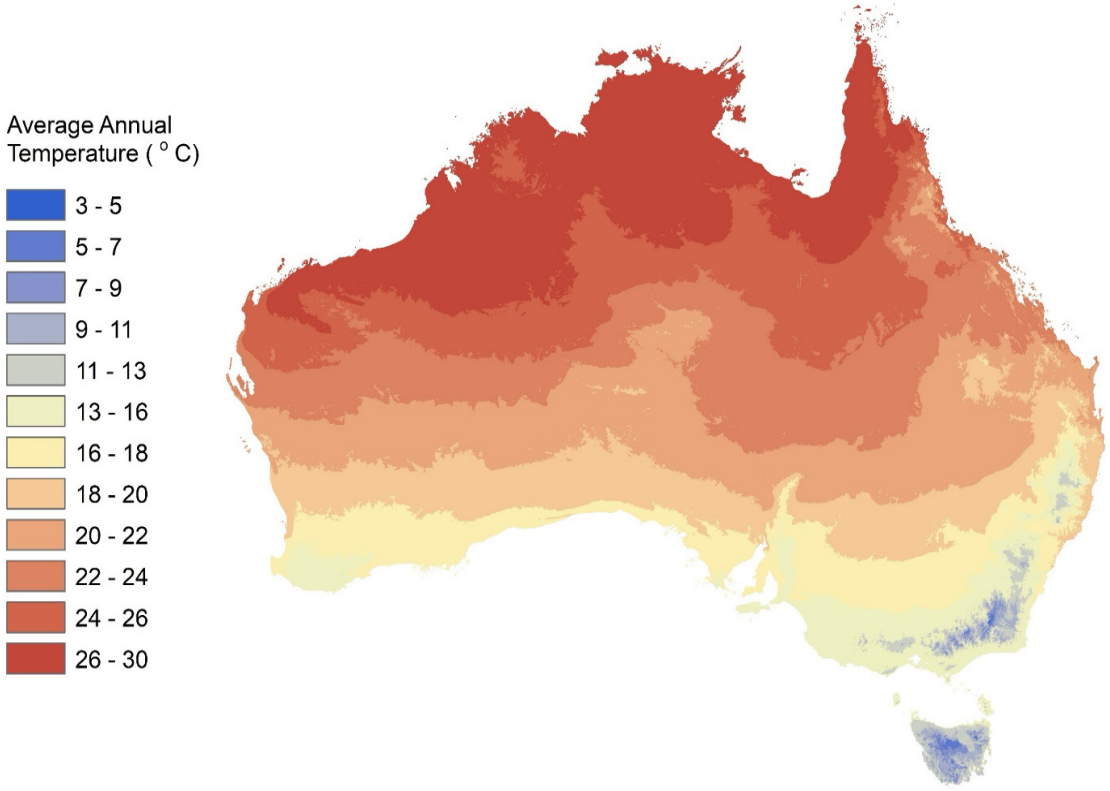


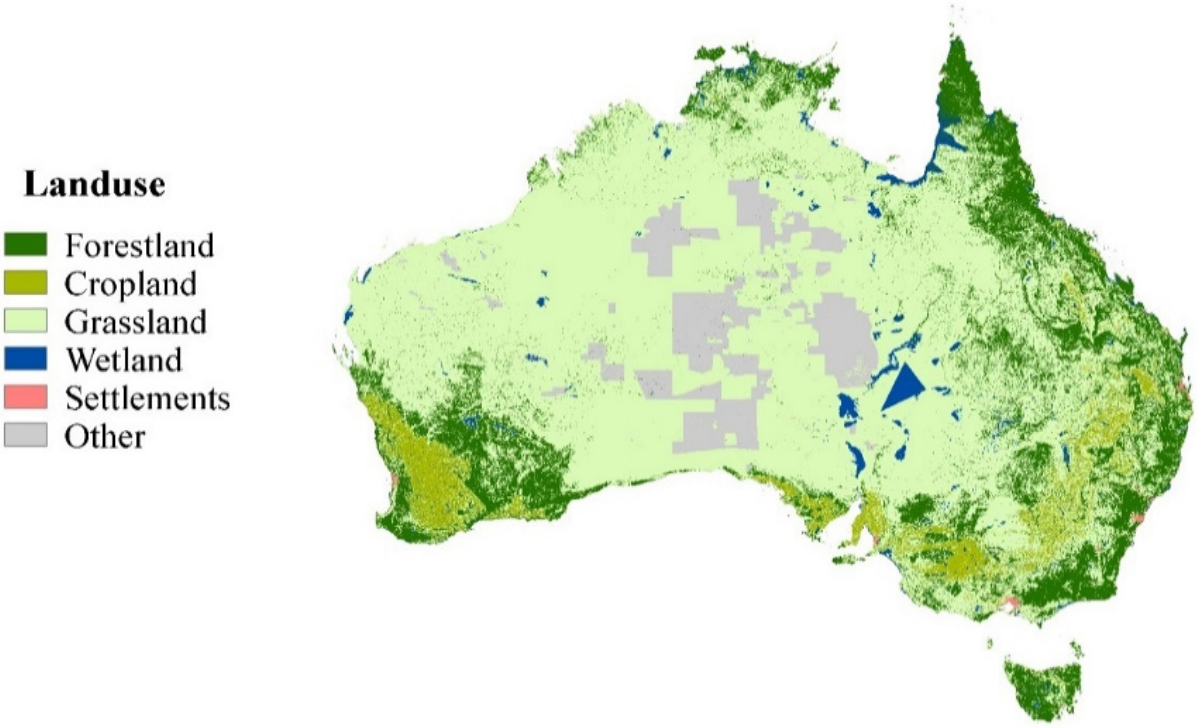
Figure 6.2.2 Long-term average annual temperature



Australia has a diversity of soil types ranging from old, highly weathered and infertile, to younger, more fertile soils derived from volcanic rocks and alluvium. Approximately 50 per cent are dominated by sandy surface soil horizons, 37 per cent are dominated by loam and sandy clay loams in the surface horizon and the remaining 13 per cent are dominated by light to medium clay textured soil in the surface horizon. Most of these soils have low levels of nitrogen, phosphorus and other nutrients.

The areas of the continent under different land uses are shown in Figure 6.2.3. Significant agricultural activities include wool, beef, wheat, cotton and sugar production. Australia is also an exporter of dairy produce, fruit, rice and flowers. Australia's forest resources consist of native forests (primarily dominated by *Eucalyptus* species), which are used for wood production, recreation and conservation, and plantations of native (primarily *Eucalyptus* species) and exotic species (primarily *Pinus* species).

Figure 6.2.3 Land use in Australia



Cropland is generally located along a broad inland fringe across the southern and eastern areas of Australia, with the highest yields commonly obtained in the southwest and eastern regions. In the southern regions, *cropland* is dominated by wheat production, with barley, oats, lupins and canola being the other dominant crops. In the north, wheat, sugarcane, sorghum and cotton production dominate.

The majority of *grassland* areas occur in inland Australia and are used for extensive grazing of both sheep and cattle. In Australia, grazing occurs across very diverse climates, ecosystems and management systems. The pasture types and associated management intensities range from highly improved to extensive rangeland systems in the semi-arid and arid regions of Australia. Native or naturalised pastures are the major pasture type, occupying approximately 17 per cent of Australia's land area with sown and fertilised pastures occupying only 4 per cent of the land area. Sown pastures are represented by mixed annual grasses and legumes as well as mixed perennial grasses and legume species depending upon rainfall and regional location. Irrigated pastures represent about 5 per cent of all pastures and are generally confined to the dairy and feedlot industries.

The three floristically diverse coastal wetland communities covered in the 2013 IPCC Wetlands Supplement (IPCC 2013), namely mangrove forests, tidal marshes and seagrasses are present in Australia's tidal and near coastal zones. Together they cover 8 to 12 million hectares of coastal wetlands around Australia's 60,000 kilometre coastline (mainland plus islands) and store an estimated 3 billion tonnes of carbon, mostly in the soil (mean value, range = 1.4 to 6 billion tonnes Lawrence et al. 2012). Although relatively small in area, this thin veneer of coastal vegetation comprises some of Australia's densest carbon stores.

6.2.2 Land classifications

Forest land (Figure 6.2.4) includes:

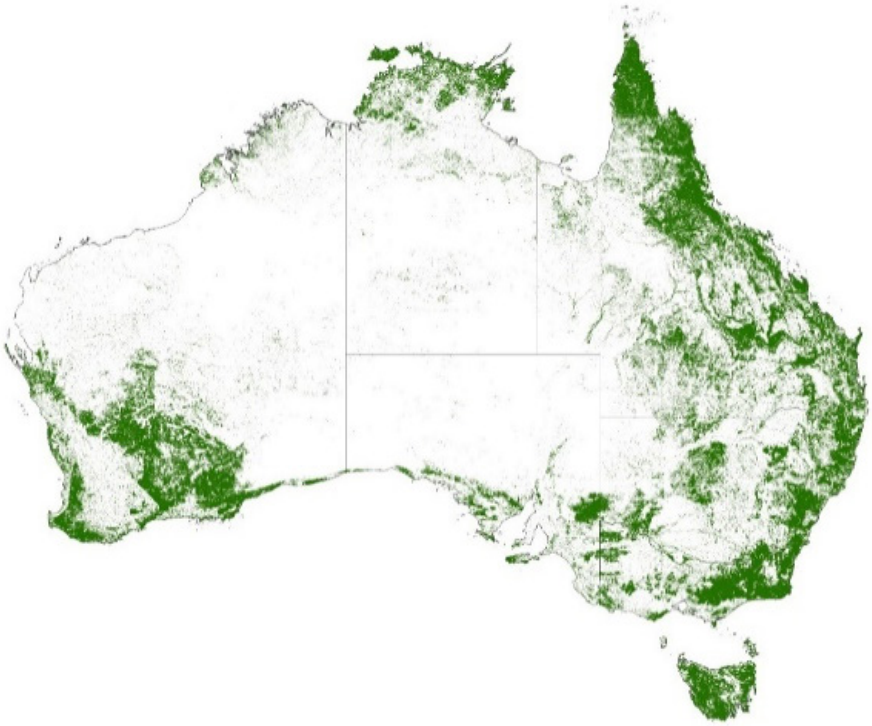
- All lands with a vegetation height of 2 metres or higher and crown canopy cover of 20 per cent or more over an area of at least 0.2 ha; and
- Lands with ecosystems with woody vegetation that currently fall below but which, *in situ,* could potentially[6] reach the threshold values of the definition of *forest land.*

Young natural stands and all plantations and environmental plantings that have yet to reach a crown density of 20 per cent or a tree height of 2 metres are included under *forest land,* as are areas normally forming part of the forest area which are temporarily unstocked as a result of either human intervention (e.g. harvesting) or natural causes, but which are expected to revert to forest.

Forest land does not include woody horticulture that meets the forest threshold parameters; this land is classified as cropland.

Australia has adopted a minimum forest area of 0.2 ha.

Figure 6.2.4 Forest extent in Australia

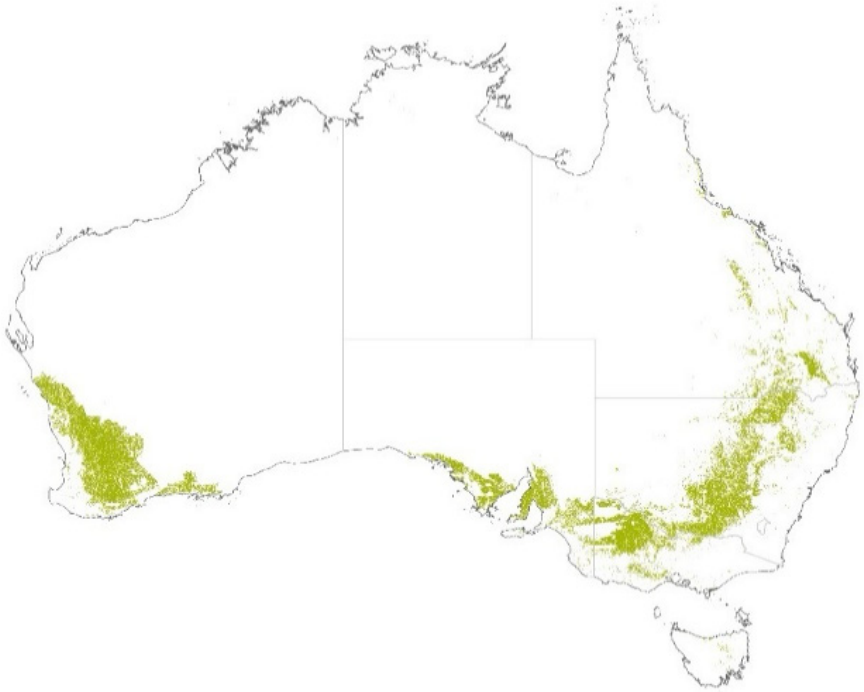


Cropland includes all land that is used for continuous cropping and those lands managed as crop-pasture (grassland) rotations (Figure 6.2.5) (ABARES 2017) as well as perennial woody horticulture that would otherwise reach the forest thresholds.

Non-CO_2 emissions from *cropland remaining cropland* are reported in the *Agriculture* sector.

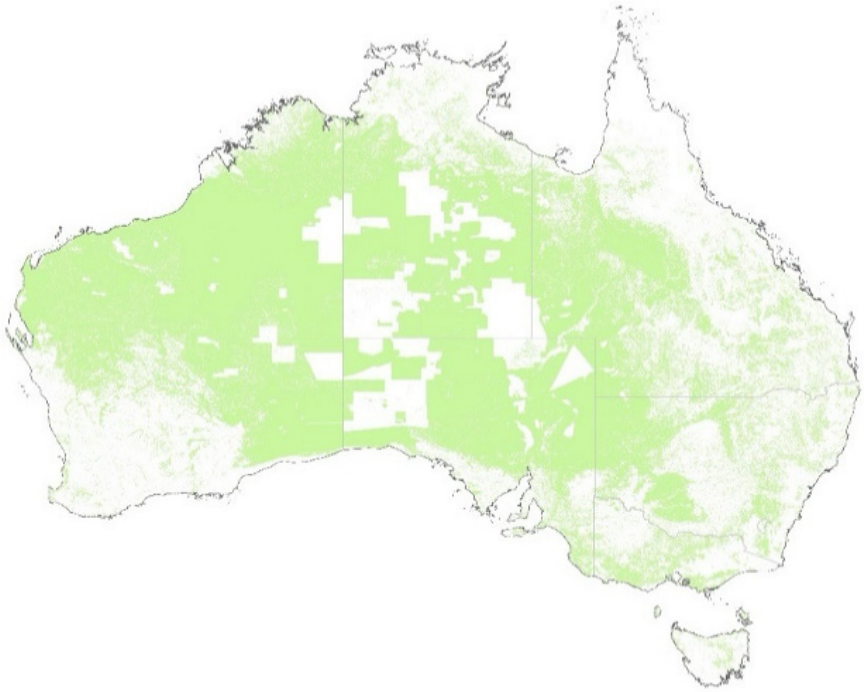
6 This potential is evidenced from the remote sensing series that the land had previously supported forest.

Figure 6.2.5 Cropland remaining cropland distribution in Australia



The *grassland* category represents a diverse range of climate, management and vegetation cover (Figure 6.2.6) (ABARES 2014). The *grassland* category also includes sub-forest forms of woody vegetation (shrubs).

Figure 6.2.6 Grassland remaining grassland distribution in Australia



Settlements include areas of residential and industrial infrastructure, including cities and towns, and transport networks. The area of the *settlements* land use classification is based on information sourced from the 2017 ABARES catchment scale land use data (ABARES 2017). *Settlements* includes additional land use classes such as manufacturing and industry, commercial services, transport and communications including airports.

Wetlands include areas of perennial lakes, reservoirs, swamps and major water course areas derived from the Australian Hydrological Geospatial Fabric (AHGF) data published by the Australian Bureau of Meteorology, all existing wetlands as defined in the Directory of Important Wetlands in Australia (DIWA), and the extensive coastal wetlands of mangrove and tidal marsh ecosystems which circle the Australian continent. Land areas with wetland characteristics that meet the definition of *forest land,* such as mangroves, are reported under the *forest land* category.

The *other land* category includes bare soil, rock and other land areas that do not fall into any of the other five categories according to ABARES' catchment scale land use map of Australia (ABARES 2014).

The allocation of a particular forest conversion area to either *wetland (flooded land), settlement, cropland* or *grassland* is determined using the same criteria as outlined above for the location in which the conversion occurred. Where the regrowth of forest is observed on these lands, the land is re-assigned to the inverse category for conversion to forest.

6.2.3 Land representation matrix

Areas under each land use are reported in Table 6.2.1 and Table 6.2.2 below.

Further detail is included in the Common Reporting Tables which are included with this document as a part of this Report.

Table 6.2.1 Area under land use, land use change and forestry classifications, 1988–89 to 2023–24 (kha)

Year	Forest remaining Forest	Land converted to Forest	Cropland remaining Cropland	Land converted to Cropland	Grassland remaining Grassland	Land converted to Grassland	Wetlands remaining Wetlands	Land converted to Wetlands	Settlements remaining Settlements	Land converted to Settlements	Other land
1988–89	132,708	2,754	37,680	1,843	512,314	6,267	13,226	63	1,148	134	60,692
1989–90	131,939	3,315	37,668	1,927	511,768	6,936	13,015	271	1,147	150	60,692
1990–91	131,080	3,977	37,668	1,982	511,365	7,464	12,993	292	1,147	167	60,692
1991–92	130,289	4,518	37,669	2,012	511,098	7,935	13,052	232	1,147	185	60,692
1992–93	129,806	4,948	37,670	2,028	510,836	8,222	13,094	188	1,147	196	60,692
1993–94	129,282	5,330	37,670	2,048	510,599	8,570	13,094	186	1,147	209	60,692
1994–95	128,899	5,720	37,671	2,065	510,367	8,771	13,114	164	1,147	218	60,692
1995–96	128,506	6,018	37,671	2,089	510,135	9,062	13,103	173	1,147	231	60,692
1996–97	128,108	6,322	37,672	2,115	509,911	9,345	13,100	173	1,147	244	60,692
1997–98	127,734	6,604	37,673	2,137	509,658	9,659	13,095	173	1,147	256	60,692
1998–99	127,222	6,889	37,673	2,157	509,438	10,076	13,084	178	1,147	271	60,692
1999–00	126,751	7,207	37,674	2,170	509,221	10,429	13,082	174	1,147	280	60,692
2000–01	126,211	7,453	37,675	2,189	508,997	10,921	13,078	176	1,147	289	60,692
2001–02	125,742	7,712	37,675	2,204	508,778	11,331	13,079	172	1,147	297	60,692
2002–03	125,354	7,954	37,676	2,219	508,527	11,702	13,080	167	1,147	311	60,692
2003–04	124,973	8,241	37,677	2,232	508,231	12,068	13,076	166	1,147	326	60,692
2004–05	124,439	8,474	37,677	2,251	507,928	12,631	13,076	161	1,147	351	60,692
2005–06	123,957	8,772	37,678	2,264	507,658	13,055	13,081	155	1,147	370	60,692
2006–07	123,538	9,051	37,678	2,276	507,411	13,420	13,074	157	1,147	384	60,692
2007–08	123,277	9,372	37,679	2,282	507,152	13,605	13,095	131	1,147	396	60,692
2008–09	123,098	9,831	37,680	2,285	506,854	13,617	13,089	133	1,147	404	60,692
2009–10	122,963	10,388	37,680	2,284	506,514	13,529	13,084	137	1,147	410	60,692
2010–11	122,789	10,938	37,681	2,285	506,205	13,456	13,086	136	1,147	415	60,692
2011–12	122,653	11,429	37,682	2,285	505,891	13,416	13,079	136	1,147	418	60,692
2012–13	122,513	11,921	37,682	2,288	505,546	13,410	13,073	137	1,147	420	60,692
2013–14	122,356	12,454	37,683	2,289	505,200	13,382	13,068	137	1,147	420	60,692

Year	Forest remaining Forest	Land converted to Forest	Cropland remaining Cropland	Land converted to Cropland	Grassland remaining Grassland	Land converted to Grassland	Wetlands remaining Wetlands	Land converted to Wetlands	Settlements remaining Settlements	Land converted to Settlements	Other land
2014–15	122,258	13,059	37,683	2,285	504,805	13,281	13,060	140	1,147	417	60,692
2015–16	122,045	13,639	37,684	2,285	504,455	13,266	13,053	145	1,147	417	60,692
2016–17	121,808	14,132	37,685	2,280	504,194	13,280	13,050	145	1,147	416	60,692
2017–18	121,644	14,387	37,685	2,279	503,958	13,427	13,045	146	1,147	418	60,692
2018–19	121,540	14,618	37,686	2,280	503,721	13,541	13,042	146	1,147	415	60,692
2019–20	121,581	14,856	37,687	2,281	503,344	13,641	13,038	148	1,147	414	60,692
2020–21	121,600	15,262	37,687	2,281	502,854	13,709	13,032	150	1,147	414	60,692
2021–22	121,359	16,013	37,688	2,275	502,546	13,519	13,028	151	1,147	412	60,692
2022–23	121,359	16,013	37,688	2,275	502,546	13,519	13,028	151	1,147	412	60,692
2023–24	121,359	16,013	37,688	2,275	502,546	13,519	13,028	151	1,147	412	60,692

Table 6.2.2 All land use totals, 1988–89 to 2023–24 (kha)

Year ending June	Forest land	Cropland	Grassland	Wetland	Settlements	Other land
1988–89	135,462	39,522	518,581	13,289	1,282	60,692
1989–90	135,254	39,594	518,704	13,286	1,298	60,692
1990–91	135,057	39,651	518,829	13,285	1,314	60,692
1991–92	134,807	39,681	519,033	13,283	1,332	60,692
1992–93	134,754	39,698	519,058	13,282	1,344	60,692
1993–94	134,612	39,718	519,169	13,280	1,357	60,692
1994–95	134,619	39,735	519,138	13,278	1,366	60,692
1995–96	134,525	39,761	519,197	13,275	1,379	60,692
1996–97	134,430	39,787	519,256	13,272	1,392	60,692
1997–98	134,338	39,809	519,317	13,268	1,404	60,692
1998–99	134,111	39,831	519,514	13,262	1,418	60,692
1999–00	133,958	39,844	519,650	13,257	1,428	60,692
2000–01	133,664	39,863	519,918	13,254	1,436	60,692
2001–02	133,454	39,879	520,109	13,251	1,444	60,692
2002–03	133,308	39,894	520,229	13,247	1,458	60,692
2003–04	133,214	39,909	520,298	13,242	1,474	60,692
2004–05	132,913	39,928	520,559	13,238	1,498	60,692
2005–06	132,729	39,942	520,713	13,235	1,517	60,692
2006–07	132,590	39,954	520,831	13,231	1,531	60,692
2007–08	132,649	39,961	520,757	13,226	1,543	60,692
2008–09	132,928	39,964	520,471	13,222	1,552	60,692
2009–10	133,351	39,965	520,043	13,221	1,557	60,692
2010–11	133,727	39,966	519,661	13,222	1,562	60,692
2011–12	134,082	39,967	519,307	13,216	1,565	60,692
2012–13	134,433	39,970	518,956	13,210	1,567	60,692
2013–14	134,810	39,971	518,583	13,206	1,567	60,692
2014–15	135,318	39,969	518,085	13,201	1,564	60,692
2015–16	135,684	39,969	517,721	13,198	1,564	60,692
2016–17	135,939	39,964	517,475	13,195	1,563	60,692
2017–18	136,031	39,965	517,385	13,191	1,565	60,692
2018–19	136,158	39,966	517,262	13,188	1,563	60,692
2019–20	136,437	39,967	516,986	13,186	1,561	60,692
2020–21	136,862	39,968	516,563	13,182	1,561	60,692
2021–22	137,372	39,962	516,065	13,178	1,559	60,692
2022–23	137,372	39,962	516,065	13,178	1,559	60,692
2023–24	137,372	39,962	516,065	13,178	1,559	60,692

6.3 Country-specific approaches

6.3.1 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

Land monitoring system

Australia uses Approaches 1 and 3 as described in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) to monitor land use, land use change and forestry.

The principal monitoring system is a remote sensing programme used to identify *forest lands* and changes in forest cover (see Annex 5.6.1 for details).

The remote sensing programme is implemented by the Department of Climate Change, Energy, the Environment and Water. The system monitors national forest cover on an annual basis using Landsat satellite data (collected by MSS, TM, ETM+ and OLI sensors). The time series of national maps of forest cover extends from 1972 and has been assembled on an annual basis since 2004. These rasters are able to detect fine-scale changes in forest cover at 25 m by 25 m resolution.

Supplementary spatial information from the Land Use Mapping programme of Australia's Bureau of Agricultural Resource Economics and Sciences (ABARES 2014) is used to identify land areas in the grassland, non-coastal wetlands and other land categories. Cropland and Settlements have been assessed based on the September 2017 revision of these areas (ABARES 2017), with settlements supplemented by spatial data from other unpublished sources. Land categories are expected to be updated over time. This information supports an Approach 1 representation of land, where only total areas are known for the areas under these land categories, not the prior land use. Where the prior land use is not known, emissions and removals associated with conversions to these land uses are estimated using the methods for land remaining in a land category. Further information on reporting of conversions between different land uses is included in Annex 5 (Completeness).

Identified changes in forest area from the remote sensing programme are assessed through a series of automated analytical tools and are quality controlled through inspection by trained operators to determine if these changes are due to human activity and are followed by land use change (e.g. forest clearing for agriculture, mining or urban development). The full details of the remote sensing and attribution analysis are provided in Annex 5.6.1.

The National Inventory Report 2022 identified planned improvements to the remote sensing program for forest cover change. These improvements include:

- Replacing Landsat imagery with Sentinel satellite data from 2016
- Updating the machine learning forest classification algorithm with new training data including high-resolution imagery and LIDAR data from a range of sources
- Integrating these improvements all the way through the satellite archive by reprocessing the imagery back to 1972
- Infilling data gaps in the historical satellite records
- Visually checking 50 years of new deforestation and reforestation records to identify the human-induced changes.

The scale and complexity of transitioning this continental-scale program, development of new data processing pipelines, and ensuring time-series consistency of a composite time-series based on different satellite technologies, has resulted in delays in data availability. Due to delays in this project, the updated dataset was not available to be included in the current inventory submission. The department is continuing to undertake QA/QC of the data received so far which provides partial coverage of Australia. The outcomes of the QA/QC will inform the next steps for incorporating this improvement in the inventory.

Loss of forest cover

Human-induced land-use changes from forest land to other land uses are visually attributed by trained operators. In cases where there is a temporary loss of forest cover, due to a forest harvest or fire, the land remains in the *forest land* category unless a subsequent land use change is identified.

Losses in forest cover due to changes that occur within land tenures where it is expected that the land will revert to forest (e.g. harvested forest) are monitored for a period of time, depending upon the type of forest land use. In the absence of land use change, most of the areas without forest cover that have entered the monitoring system continue to be classified as "forest" provided that the time since forest cover loss is shorter than the number of years within which tree establishment is expected. After that time period, lands that have lost forest cover due to direct human-induced actions, have undergone land use change, and failed to regenerate are classified as converted to the appropriate non-forest land use classification. As an interim estimate for reporting purposes, a small proportion of the area being monitored within plantations is assumed to have undergone a land use change. This proportion is based on historical observations.

In Australia, land remains in the "conversion" sub-category for 50 years, unless specified otherwise for a particular type of conversion (for example, wetlands converted to cropland and grassland). This period is longer than the IPCC default and reflects the long-term impacts of conversion on woody carbon dynamics in Australian systems.

Once classified as a forest conversion event, the land continues to be monitored for subsequent forest cover changes associated with regrowth and re-clearing. Where subsequent forest-cover changes occur within a period shorter than 50 years, the land is reported in each reporting year based on the end-use category of the land in that year (either land *converted to forest land* following regrowth, or to the relevant *"forest land converted to… "* subcategory following re-clearing).

Gain in forest cover

In cases where new forest cover is detected on land previously under another land use (cropland, grassland, wetland or settlement), the land enters the *land converted to forest land* subcategory. Land monitored for this cover gain includes:

- Establishment of new commercial plantations
- Environmental plantings
- Forest emerging through natural regeneration (from seed or rootstock) on previously not forested, protected Lands (i.e. land that has vegetation which is protected or requires a permit to clear under the relevant state's or territory's vegetation management laws, including conservation areas)
- Forest re-emerging on land that has previously been converted from forest to a non-forest land use.

Incorporation of land monitoring data into emissions estimation

The land monitoring system supports Tier 3, Approach 3 spatial enumeration of emissions and removals calculations for the following sub-categories:

- Forest land remaining forest land
- Forest land converted to cropland, wetlands (Flooded Land), grassland, and settlements

- Grassland, cropland, wetland (tidal marsh) and settlements converted to forest land; and
- Cropland remaining cropland and grassland remaining grassland.

Spatial enumeration is achieved through the use of a time-series (since 1972) of Landsat satellite data to determine change in forest and sparse woody vegetation extent at a fine spatial disaggregation. The forest cover change information is coupled with spatially referenced databases of climate and land management practices which allows a comprehensive quantification of emissions (see Annexes 5.6.1 and 5.6.2).

FullCAM can also be configured to operate in a Tier 3, Approach 2 mode where spatially explicit data are unavailable. In this configuration, known as the 'Estate' module, FullCAM uses age-based growth data to estimate living biomass and dead organic matter (DOM) from both turnover and harvest residue. The 'Estate' module of FullCAM is used to scale regional models of carbon stock change by the areas of each forest type (Richards and Evans 2000).

The other principal reporting elements, *wetlands remaining wetlands* and *settlements remaining settlements,* are reported using Tier 2 and Tier 3 methods.

6.3.2 Information on approaches used for natural disturbances

Fire (biomass burning) is the principal form of natural disturbance which impacts carbon stocks on the land in Australia.

Most Australian forests are adapted to fire, and fires, whether wildfires or prescribed fires, are generally not stand-replacing. Many eucalypt species continue growing, with burned leaves and twigs quickly regrowing from epicormic shoots with no effect on stand age-class. In most eucalypt forests, fires do not cause significant changes in the rate of turnover of living biomass to dead biomass, particularly following lower intensity fires which primarily burn only litter and deadwood (Raison and Squire et al. 2008, Bradstock et al. 2012, Fairman et al. 2015). Fire regimes differ widely in regard to fire frequency and intensity across Australia as shown in Figure 6.3.2, with implications for the estimation of carbon stocks.

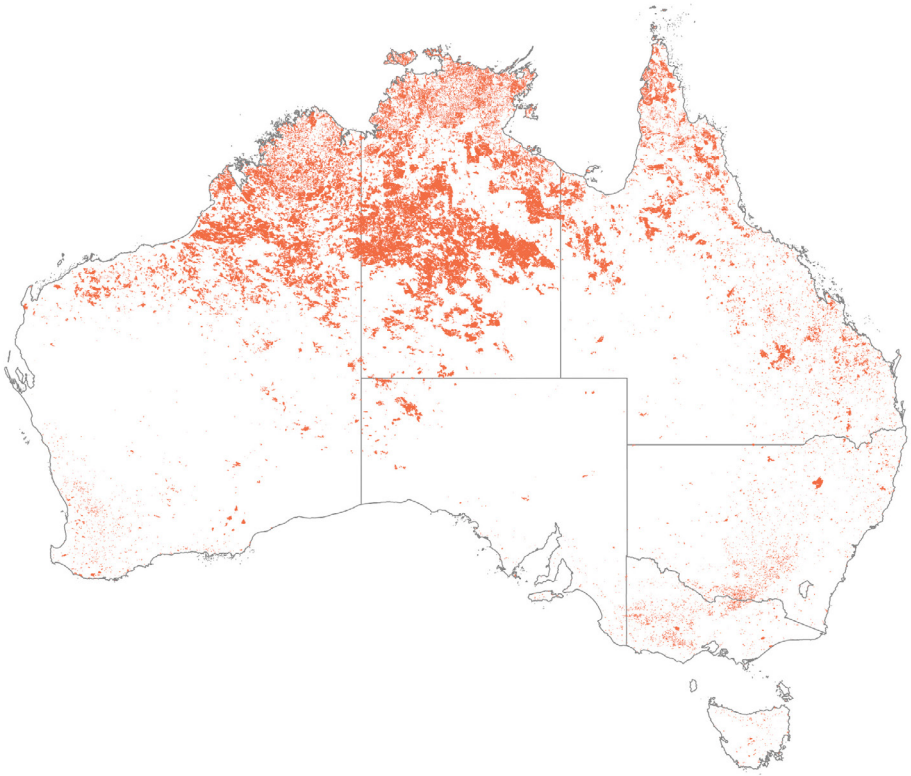
Fire is a very frequent occurrence in the northern and central Australian wet/dry tropical, subtropical and semi-arid forest ecosystems. Many fires are from anthropogenic sources due to ongoing indigenous fire management and the pastoral use of fire as a land management tool.

The seasonality of burning in this region has profound impacts on the fire behaviour and emissions associated with a fire event. Fires in the late dry season (LDS) are typically larger, more intense and consume more fuel than fires that occur during the early dry season (EDS). A primary aim of anthropogenic burning is to encourage more fires in the EDS to mitigate the impacts of the larger, more intense fires in the LDS. These strategic fires in the EDS can decrease net greenhouse gas emissions from these landscapes.

Australia's temperate forests are also highly adapted to fire although do not exhibit the same fire frequency as those in the north of the continent. Instead, the majority of these forests are characterised by fire intervals on the decadal scale.

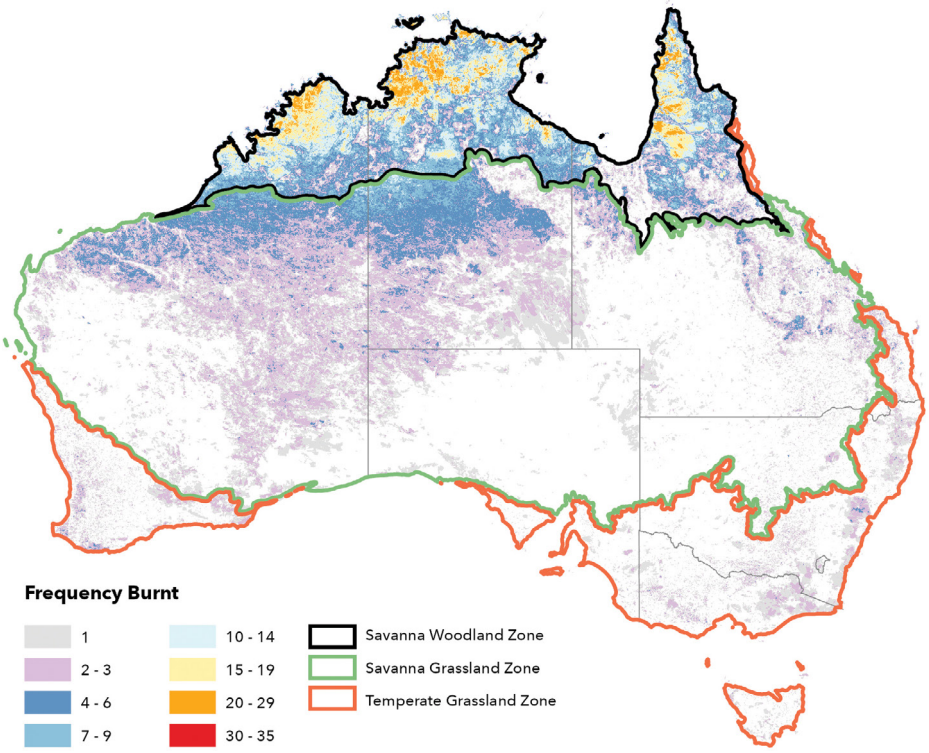
Figure 6.3.1 shows the incidence of fire activity in 2023–24. Figure 6.3.2 shows the reoccurrence of fire events since 1988, highlighting the frequency with which the semi-arid and tropical savannas of Northern Australia are burned and re-burned by fire.

Figure 6.3.1 Fire activity in Australia, 2023–24



Data sourced from Western Australian Land Authority (Landgate)

Figure 6.3.2 Frequency of forest and grassland fires, 1987–88 to 2023–24



Data sourced from Western Australian Land Authority (Landgate)

Prescribed burning in temperate forests involves conducting managed fires that aim to mitigate the risk and severity of wildfires by reducing fuel loads. Prescribed burning is typically low intensity and performed during the cooler and wetter months, consuming only a proportion of the dead organic matter present in the forest.

Wildfires can range from moderate intensity burns through to high intensity wildfire, which can remove most debris as well as understorey vegetation, foliage, and small branches.

Some wildfires constitute non-anthropogenic natural disturbances as they are beyond the control of, and not materially influenced by, Australian authorities and occur despite costly and on-going efforts across regional and national government agencies and emergency services organisations to prevent, manage and control the fires.

In this inventory, in addition to reporting inter-annual variability from natural disturbances, the trend in net emissions from anthropogenic fires (which include prescribed fires and wildfires) is reported. In order to estimate the trend in anthropogenic fires, non-anthropogenic natural disturbances are modelled to average out over time, leaving anthropogenic emissions and removals as the dominant result.

The same methods, factors and data are used to estimate emissions and removals from fire in sparse woody vegetation in *grassland remaining grassland, forest converted to grassland* and *wetland remaining wetland* to ensure consistent estimation of emissions and removals across land classifications.

Stratification of forests

Other native forests are stratified into three geographic/climatic zones where fires demonstrate significantly different behaviour. The boundaries of these zones are shown in Figure 6.3.2.

- Tropical zone forests – the northern part of the Northern Territory (NT), Western Australia (WA) and Queensland (Qld), are characterised by wet/dry tropical woodland and higher rainfall than the arid centre and is known as the 'Top End'. The Top End corresponds to the Interim Biogeographic Regionalisation for Australia (IBRA)[7] version 4.1 zones AEZ 1, AEZ 2 and AEZ 3 which are predominantly woodland with smaller areas of open forest and grassland;
- The open woodlands and grasslands of the arid interior of central Australia ('the Centre') comprise AEZ 5, AEZ 6 and AEZ 11 of the NT, WA, Qld, South Australia (SA) and New South Wales (NSW) and these zones are used as the inventory definition of subtropical and semi-arid zone forests; and
- Temperate forests – comprising forests in zones AEZ4 and AEZ zones 7–10.

Tropical zone forests are further disaggregated into seven vegetation classes (Table 6.3.1). These classes are derived using a combination of validated vegetation, land use and geological data sets (Lynch et al. (2015); Meyer and Cook, (2015)).

7 IBRA is a framework used for sustainable resource management and conservation planning. The 80 IBRA regions in IBRA version 4.1 represent a landscape-based approach to classifying the land surface from a range of continental data on environmental attributes such as vegetation, geology, soils and climate. Background information and a map of the IBRA regions is available at https://www.dcceew.gov.au/environment/land/nrs/science/ibra

Table 6.3.1 Symbols used in algorithms for biomass burning of forest land

State (i)	Vegetation Class (j)	Rainfall Zone (k)	Fire Variant (l)	DOM size class (m)
1 = ACT	1 = Wet/dry tropical zone	1 = High	1 = Early Dry Season (EDS)	1 = Fine
2 = NSW	1.1 = Woodlands (with either hummock or mixed grassland)	2 = Low	2 = Late Dry Season (LDS)	2 = Coarse
3 = NT	1.2 = Shrubland with hummock grasses	3 = NA	3 = Annual	3 = Heavy
4 = SA	1.3 = Open forest with mixed grasses		4 = Temperate prescribed burning	4 = Shrub
5 = TAS	1.4 = Shrubland (heath) with hummock grass		5 = Temperate wildfire	5 = Aggregated
6 = QLD	1.5 = Woodland with tussock, hummock or mixed grasses			
7 = VIC	1.6 = Open woodland with mixed grass			
8 = WA	1.7 = Pindan			
	2 = Subtropical and semi-arid zone			
	3 = Temperate zone			

Carbon stock changes

A time series of monthly satellite data is used to identify the time and location of fires, which are simulated at the 25 m x 25 m resolution for temperate zone fires and 50 m x 50 m for savanna woodland zone fires (Figure 6.3.2). The AVHRR burnt area product produced by the Western Australian Land Authority (Landgate), is tailored to Australian conditions and based on the visual interpretation of fire areas by experienced operators. The data was assessed by the Royal Melbourne Institute of Technology (RMIT, 2014), compared with a range of alternative datasets and was found to be the most suitable and highest quality time series data available.

The AVHRR burnt area product is not used for prescribed burning identification as it is limited in its ability to identify fires where the canopy remains intact. Areas of land where prescribed burns were conducted are identified through digitised, spatially explicit mapping of prescribed burning treatment areas from state or territory fire authorities.

Carbon stock changes in all pools are modelled using the spatially explicit (Approach 3) capabilities of the Tier 3 FullCAM modelling system. FullCAM simulates carbon dynamics in response to fire events, including the following pools; live biomass, heavy woody fuel (including dead trees, shrubs and coarse woody debris - simulated together as standing dead biomass), coarse woody fuel (including on-ground branch and bark litter), fine woody fuel, and fine grass fuel. Impacts on soil carbon in response to fire are not currently modelled as there is insufficient data to confidently estimate the direction or magnitude of the response. These were parameterised for typical fires and not assumed to be highly intense stand-replacing fires which are unusual in most Australian eucalypt and dominated forests. Hence, for both woody and grass live biomass components, it was assumed that fire did not burn roots, with live root biomass assumed to continue at equilibrium conditions of growth and turnover regardless of the fire simulation. A full description of the modelling system is provided in Annexes 5.6.2 and 5.6.4, Waterworth et al. (2007); Waterworth and Richards, (2008); and Paul and Roxburgh, (2019).

Changes in live biomass are estimated using the gain-loss method. The *other native forests* component excludes areas subject to observed harvesting and deforestation, therefore are assumed to represent mature stands in equilibrium conditions, with annual increments in living biomass and soil carbon stocks balanced by annual losses in the absence of disturbances. The main processes leading to emissions and removals in these forests are related to fire management practices. For this reason, the loss of biomass due to wood removals (harvesting) is zero.

Biomass losses due to disturbances (as a percentage of pre-fire biomass) are shown in Annex 5.6.11, Table A5.6.11.6.

Live woody biomass is simulated as mature stands at equilibrium conditions. The model inputs of initial above ground biomass of living woody vegetation were derived from the maximum site carrying capacity (Roxburgh et al. (2019)).

Simulations include short-term fire-induced impacts on the predicted relative allocation of woody biomass due to: (i) fires resulting in only partial burning of live woody biomass components, with the extent of impact varying between components, and; (ii) rates of post-fire re-sprouting or regeneration differing between components, e.g. relatively fast for foliage and relatively slow for stem wood.

Annual increments after fire events are calculated directly as recovery following the loss of live biomass from disturbances using the biomass recovery function described in Annex 5.6.2. Wildfires are not stand-replacing, and typically only affect 10 percent of initial live biomass. A typical time for live biomass recovery following temperate forest wildfires is between 10 and 15 years. For prescribed burning in temperate forests and management fires in savanna woodlands, the impact on live biomass is much lower such that it can take up to 5 years to recover.

Changes in dead organic matter stocks in *other native forests* are calculated in accordance with the gain-loss method in Equation 2.18 of the 2006 IPCC Guidelines (Volume 4) (IPCC 2006) for estimating annual change in carbon stocks in dead wood or litter for areas remaining in a land-use category:

$$\Delta C_{DOM} = \Sigma_{ijklm} (A \times (DOM_{in} - DOM_{out}) \times CF) \quad (6.3.1)$$

Where Subscripts $_{ijklm}$ are the dimensions over which DOM is stratified for the purposes of this estimate (see Table 6.3.1)

ΔC_{DOM} = annual change in carbon stocks in the DOM pools

A = area of land remaining in land-use category

DOM_{in} = average annual transfer of biomass into the dead wood / litter pool due to annual processes and disturbances

DOM_{out} = average annual carbon loss out of dead wood or litter pool

CF = carbon content (Table A5.6.11.8)

DOM stocks are modelled using the spatially explicit (Approach 3) capabilities of the Tier 3 FullCAM modelling system.

Table 6.3.2 Comparison of carbon pools modelled under the previous T2 model and the current T3 FullCAM implementation

Pool type	Fuel pools calculated using previous T2 method	Fuel pools simulated using FullCAM
Live biomass	Shrub	Live Above-Ground Biomass impacted by fire, but which recovers quickly
Fine DOM	Fine-grass	Decomposable grass litter + Resistant grass litter + above-ground biomass of grass
Fine DOM	Fine-woody	Standing Dead foliage + Decomposable foliage litter + Resistant foliage litter
Coarse DOM	Coarse-light	Standing dead bark + Bark litter + Deadwood < 5cm
Coarse DOM	Coarse-heavy	Standing Dead stem + Standing Dead branch + Deadwood > 5cm

FullCAM simulates turnover and decay processes for each pool (or sub-set of pools) based on site conditions (productivity and vegetation type) and monthly climate data, until a fire event is identified based on the Advanced Very High Resolution Radiometry (AVHRR) satellite data. Fire events were individually parameterised for each State (i), Vegetation Class (j), Rainfall Zone (k), Fire Variant / seasonality (l), and DOM size class (m) (Roxburgh et al. (2015), with the resulting fuel dynamics being replicated by FullCAM as described by Paul and Roxburgh (2019).

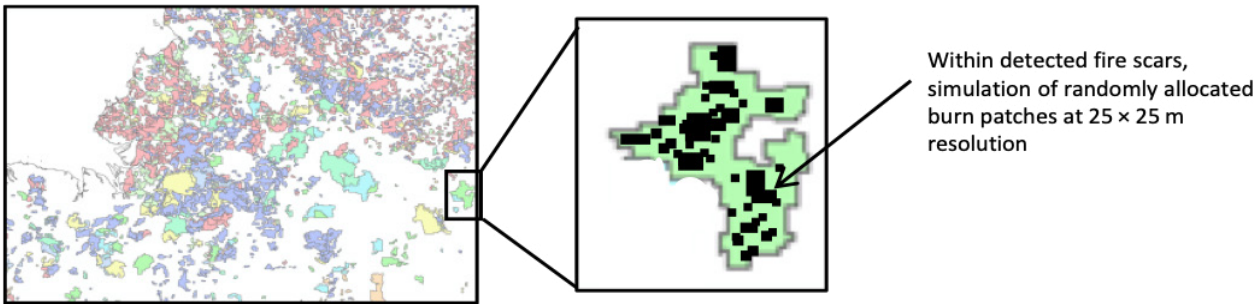
The savanna fire zone applied some differences in approach where there was additional empirical data (Roxburgh and Paul 2024):

- Early Dry Season (EDS) and Late Dry Season (LDS) fire events were calibrated for each vegetation class (j).
- The default IPCC DOM classes of litter and dead wood are further disaggregated into fine (grass live biomass, grass litter, foliage on standing dead material, and foliage litter), coarse-light (standing dead bark, and bark litter), coarse-heavy (standing dead stem and branches, and coarse woody debris) and live woody biomass (Table A5.6.11.4).
- In order to initialise the model ahead of the reporting period, fires prior to 1988 are simulated based on available estimates of typical fire return intervals, time of year fires occur, area of the fire scar, and the proportion of EDS to LDS burns in the savanna fire zone, where available from previous studies and expert opinion (Meyer and Cook 2011; Murphy et al. 2013). To introduce variation in the simulated fire events, uniform probability distribution functions were applied to vary these assumptions between what was deemed to be their upper and lower bounds.
- It was assumed that grasses were a component of the total live biomass within each fire zone. FullCAM has existing default inputs (e.g. yields, allocation of biomass, die-off, decomposition, etc.) for simulation of different perennial grass species (Table A5.6.11.3).

Burning efficiencies and Patchiness

Fires do not uniformly affect the landscape and will leave unburned patches at a finer scale than the resolution of the satellite data. In FullCAM, fire events are only applied to a proportion of model cells within the fire scar in accordance with the assumed Patchiness values *(P)*. Patchiness depends on fire intensity and varies based on State, Vegetation Type and Fire Variant (e.g. seasonality). Figure 6.3.3 shows fire patches (various colours indicate different year in which the fire occurred) in north-west Australia. As indicated in the panel to the right, within each fire scar detected, the patchiness assumption is applied such that a burning event is simulated within only a proportion of pixels within each fire scar.

Figure 6.3.3 Diagrammatic example indicating how spatial fire is implemented within FullCAM



In the wet/dry tropical zone, fires are classified by the season of burning as either early dry season (EDS) or late dry season (LDS). EDS fires are characterised by low intensity or severity, a high degree of patchiness, a greater propensity to extinguish spontaneously and reduced total fuel consumption. LDS fires are characterised by high intensity, low levels of patchiness, a greater propensity to spread and high total fuel consumption.

The average date of transition from EDS to LDS is the last day of July. This date is based on indigenous fire management practices and observations of the seasonal patterns of fire behaviour (C. Meyer, J. Russell-Smith pers. comm.). On average, changes in ambient humidity and wind speed at this time are sufficient to support fire propagation through the night; which allows fires to spread for several days and to reach high intensities (C. D. Haynes 1985; Russell-Smith et al. 1997).

For subtropical and semi-arid forests, burning efficiencies are assumed to be constant from year to year and throughout the year. In temperate forests, while different burning efficiencies are applied for prescribed fires and wildfires, these are not further disaggregated based on seasonality.

Emission factors

FullCAM calculates area burned, the DOM stocks at time t, and the losses due to fire based on the burning efficiency, providing an output in terms of carbon flow to atmosphere due to fire for each State (i), Vegetation Class (j), Rainfall Zone (k), Fire Variant (l), and DOM size class (m). Using these calculations, emission factors derived from direct field measurements from fires across Australia (Meyer and Cook 2015; Roxburgh et al. 2015; Meyer et al. 2012; Hurst et al. 1994) were then applied to calculated non-CO_2 emissions Table A5.6.11.9 to Table A5.6.11.11.

Non-CO_2 emissions

For CH_4, CO, and NMVOCs calculate emissions as:

$$E = \Sigma_{ijklm}\ YSLB\ (A \times DOM_{out\ ijklm}\ YSLB \times CC_{jkm} \times EF_{g,jkm} \times C_g) \quad (6.3.2)$$

and for NO_X, N_2O:

$$E = \Sigma_{ijklm}\ YSLB\ (A \times DOM_{out\ ijklm}\ YSLB \times CC_{jkm} \times NC_{jkm} \times EF_{g,jkm} \times C_g) \quad (6.3.3)$$

Where E = emissions from fires (kt);
A = Area of land remaining in land-use category
$DOM_{out\ ijklm}$ = average DOM losses in fire (kt)
CC_{jkm} = carbon content (Appendix A5.6.11.5)
NC_{jkm} = nitrogen:carbon ratio (Appendix A5.6.11.7)
EF_{gjkm} = emission factor (g N or C emitted as trace species / g DOM N or C emitted) (Tables A5.6.11.9–11)
C_g = elemental to molecular mass conversion factor (Appendix A5.6.11.8)
YSLB = age class of DOM stocks based on the number of years since last burned
Subscripts $_{lm}$ are the dimensions over which DOM is stratified for the purposes of this estimate (see Table 6.3.1)

1. Definition of natural disturbances and types of disturbances identified in the inventory

The fire-adapted ecology of Australian eucalypt-dominated temperate forests leads to infrequent, extreme wildfires. Natural 'background' emissions and removals caused by natural disturbance fires are considered to be caused by non-anthropogenic events and circumstances beyond the control of, and not materially influenced by, Australian authorities and occur despite costly and on-going efforts across regional and national government agencies and emergency services organisations to prevent, manage and control natural disturbances to the extent practicable. These fires are considered to be part of the 'natural background' of non-anthropogenic emissions and removals, which under the Managed Land Proxy (MLP) are understood to average out over time and space[8].

This national definition of natural disturbances applies to wildfires on temperate forests and does not apply to fires reported as controlled burning (e.g. in temperate forests or in wet-dry tropical forests and woodlands). All fires on *land converted to forest land* are treated as anthropogenic.

8 2006 IPCC Guidelines, Volume 4, Chapter 1 (p 1.5) states that, "...while local and short-term variability in emissions and removals due to natural causes can be substantial (e.g. emissions from fire, see footnote 1), the natural 'background' of greenhouse gas emissions and removals by sinks tends to average out over time and space."

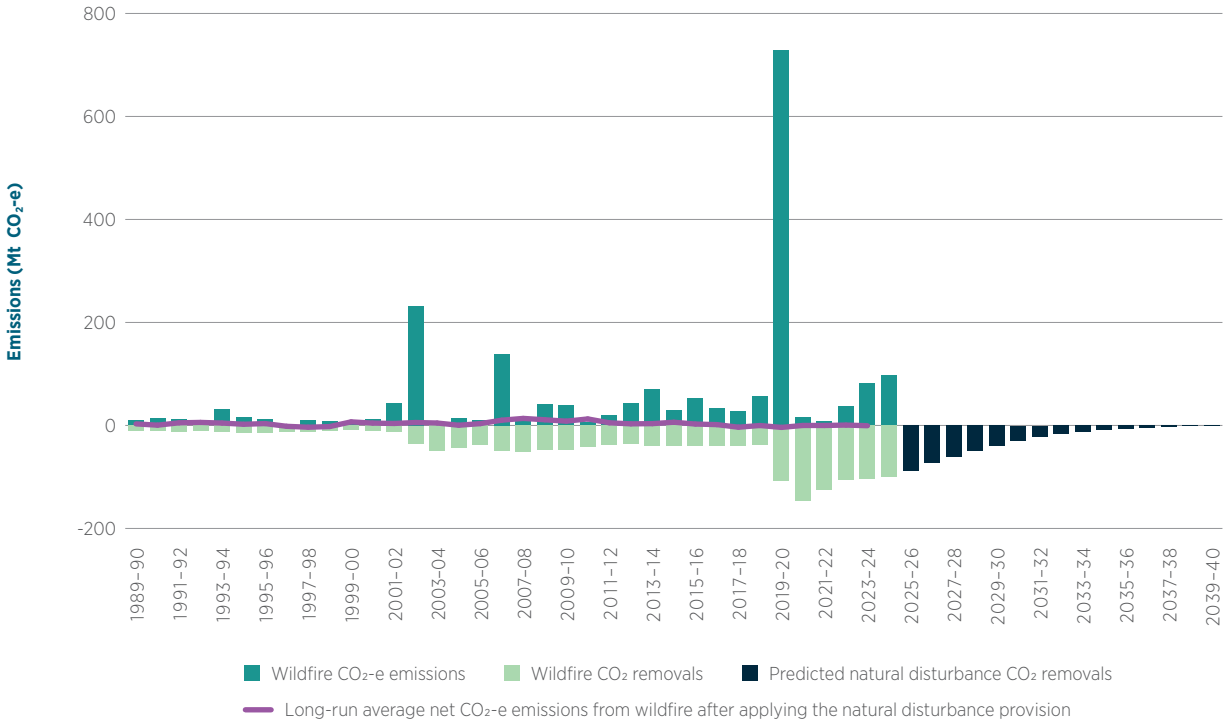
The impacts of human activities (e.g. salvage logging, prescribed burning, deforestation) are excluded from the identification of natural disturbances through the application of an Approach 3 representation of lands which is used to track lands subject to natural disturbances and separately identify and exclude land subject to human activities, as explained in section 6.3.

2. Quantification of inter-annual variability due to all wildfire and natural disturbances (total Managed Land Proxy (MLP) flux)

In Australia, all lands are considered managed lands. All carbon stock changes on managed land from anthropogenic and natural 'background' emissions and removals are reported, consistent with the MLP, including from wildfires.

Inter-annual variability in natural 'background' of emissions and removals is modelled as shown in Figure 6.3.4 below, along with the estimated trend in net emissions and removals associated with human activities.

Figure 6.3.4 Interannual variability from wildfire, including natural 'background' emissions and removals (total MLP flux)



Note: includes preliminary estimates for 2024–25 based on Landgate fire scar data.

3. Methods used for identification and quantification of emissions and removals due to natural disturbances

The quantification of emissions and subsequent removals from natural disturbances is done by identifying fires which meet the definition of natural disturbances both at the total (landscape-level) emissions and regional levels and tracking disturbed areas at fine spatial scales within the Tier 3, Approach 3 FullCAM modelling system.

In order to disaggregate emissions and removals due to natural disturbances under the Tier 3 method applied in this inventory, natural disturbances are explicitly identified in the activity data. Both initial carbon losses and subsequent recoveries in carbon stocks are modelled as part of the disturbance event, and carbon stocks are spatially tracked until pre-disturbance levels are reached to ensure completeness and balance in reporting.

A modelling approach is then applied to ensure that emissions and subsequent removals from non-anthropogenic natural disturbances average out over time, leaving greenhouse gas emissions and removals of anthropogenic fires as the dominant result in the national inventory (IPCC 2006 Volume 4 1.5 (IPCC 2006)), consistent with the Managed Land Proxy (see footnote 10). The approach ensures that Australia's modelled implementation of the MLP is comparable with estimates generated using other methods, such as Tier 3 stock-difference approaches, that tend to average out interannual variability due to natural causes over space (scaling from plots to region) and time (averaging between periodic re-measurements). Natural disturbances evident in the activity data are identified in two steps, summarised in Table 6.3.3.

1. First, at the national level, emissions from the area burned are assessed on a year-by-year basis for extreme fire events where outcomes at the national level were beyond the control of authorities to manage. This is done by comparing each year's data with a threshold level or 'margin' based on two standard deviations above the mean of gross annual emissions from all fires and after iteratively excluding outliers. The national natural disturbance threshold is calculated for the calibration period of 1989–90 to 2019–20.

2. Second, once natural disturbance years are identified at a national level, natural disturbances are spatially identified and the area burnt tracked at the sub-national level. Natural disturbances at the state and territory level were identified where the area burned during their local fire season exceeded a state or territory natural disturbance threshold equal to the average area of the calibration period plus one standard deviation of the non-natural disturbance years.

Natural disturbance areas are identified at the level of each state or territory for a year in which both the area burned exceeds the state or territory natural disturbance threshold and the national emissions from total area burned exceeds the national natural disturbance threshold.

The methodology for identifying natural disturbance events does not preclude long-term changes in fire management practices (such as prescribed burning) affecting trends in anthropogenic emissions and removals.

Table 6.3.3 Calculations for the natural disturbance test in States and Territories, 1989–90 to 2024–25.

	Calibration period	Calculation details	Threshold	Number of natural disturbance years 1989–90 to 2024–25
Step 1: National Level Test	1989–90 to 2019–20	Applied to: gross emissions (not including removals). Threshold calculation: mean plus two standard deviations of calibration period.	63,009 kt CO_2–e	8
Step 2: Regional test	1989–90 to 2019–20	Only applies in national outlier years (following Step 1 test). Applied to: annual area burned. Threshold calculation: mean area burned plus one standard deviation of background (non-outlier) years.		
ACT			0.56 kha	3
NSW			192.01 kha	4
Qld			145.46 kha	3
SA			32.01 kha	3
Tas			30.33 kha	5
VIC			91.44 kha	6
WA			322.50 kha	5

Note: includes preliminary estimates for 2024–25 based on Landgate fire scar data.

All fire areas are monitored for any permanent change in land use, which would trigger reporting of emissions in the appropriate land conversion category. Emissions from salvage logging are reported as part of *harvested native forests.*

4. Disaggregation of emissions and removals due to natural disturbances and identification of the trend in emissions and removals associated with human activity

After identifying lands subject to natural disturbances, and associated emissions and removals, anthropogenic emissions and removals are estimated using the remaining time-series of area burned in anthropogenic fire in each state or territory. The 2019 Refinement (IPCC 2019) to the 2006 IPCC (IPCC 2006) guidelines note that even after disaggregating natural disturbances, "This remaining aggregate of emissions and removals associated with human activities might still include some effects of IAV [inter-annual variability] of natural disturbances and other natural effects on anthropogenic emissions and removals" (IPCC 2019 Refinement, Volume 4, Chapter 2.6.1.1 (IPCC 2019)). In order to control for this remaining inter-annual variability the long-run trend in carbon stocks is reported, reflecting the balance of the carbon lost in the fire and that re-absorbed by regrowth. This information is reported in Table 6.3.4 below.

To ensure transparency and to demonstrate complete reporting of anthropogenic and natural disturbance emissions and removals, the following additional information has been included:

- Identification of lands subject to natural disturbances and monitoring for forest recovery;
- Monitoring for land-use changes to ensure that no land-use change has occurred on lands subject to natural disturbances;
- Demonstrating practicable efforts to prevent, manage and control wildfires in Australia; and
- Inclusion of salvage logging emissions.

Table 6.3.4 Disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity

Forest remaining Forest										
Years	Total MLP flux from wildfires					Natural disturbances component				
	Total area under the MLP (kha)	Annual area of wildfires including natural disturbances, reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)	Annual area of natural disturbances (in reporting year) (kha)	Cumulative area subject to natural disturbances (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989-90	134,543	202	315	1,157	2	0	0	0	0	0
1990-91	134,419	490	-968	1,662	5,213	0	0	0	0	0
1991-92	134,282	199	-128	1,462	1,933	0	0	0	0	0
1992-93	134,220	85	1,778	440	-6,081	0	0	0	0	0
1993-94	134,138	789	-5,833	3,853	25,239	0	0	0	0	0
1994-95	134,130	284	-563	1,912	3,977	0	0	0	0	0
1995-96	134,096	153	706	1,466	-1,124	0	0	0	0	0
1996-97	134,012	44	2,729	233	-9,772	0	0	0	0	0
1997-98	133,897	271	196	1,345	624	0	0	0	0	0
1998-99	133,691	177	601	1,022	-1,181	0	0	0	0	0
1999-00	133,490	111	1,486	459	-4,988	0	0	0	0	0
2000-01	133,239	496	-971	1,567	5,128	0	0	0	0	0
2001-02	133,021	701	-8,462	5,080	36,108	0	0	0	0	0
2002-03	132,848	2,660	-53,834	26,975	224,368	2,623	2,623	-57,030	26,720	235,830
2003-04	132,666	90	11,805	798	-42,486	0	2,617	10,288	0	-37,723
2004-05	132,343	304	7,829	1,783	-26,925	0	2,608	8,533	0	-31,287
2005-06	132,120	223	7,218	1,236	-25,229	0	2,596	6,897	0	-25,289
2006-07	132,013	1,693	-24,401	15,931	105,399	1,299	3,770	-21,186	12,984	90,666
2007-08	132,044	316	9,118	1,997	-31,435	0	3,747	9,650	0	-35,383
2008-09	132,174	484	1,625	4,818	-1,140	0	3,720	8,170	0	-29,958
2009-10	132,489	864	1,992	4,644	-2,659	0	3,690	6,636	0	-24,334
2010-11	132,943	104	9,430	764	-33,812	0	3,654	5,617	0	-20,597
2011-12	133,313	473	4,895	2,320	-15,628	0	3,615	4,555	0	-16,701
2012-13	133,558	701	-2,028	4,930	12,367	0	3,527	3,627	0	-13,300

Forest remaining Forest										
Years	Total MLP flux from wildfires					Natural disturbances component				
	Total area under the MLP (kha)	Annual area of wildfires including natural disturbances, reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)	Annual area of natural disturbances (in reporting year) (kha)	Cumulative area subject to natural disturbances (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
2013–14	133,942	1,123	-8,271	8,067	38,394	862	4,298	-11,065	6,606	47,179
2014–15	134,348	548	2,315	3,532	-4,955	0	4,227	4,522	0	-16,581
2015–16	134,812	872	-3,604	6,131	19,346	772	4,875	-6,924	5,260	30,649
2016–17	135,193	521	1,820	3,866	-2,808	0	4,796	4,820	0	-17,675
2017–18	135,475	496	2,756	3,317	-6,789	0	4,709	4,019	0	-14,735
2018–19	135,666	872	-5,116	6,581	25,340	736	5,271	-9,200	5,894	39,628
2019–20	135,821	7,979	-169,368	84,844	705,862	7,979	11,963	-173,031	84,844	719,292
2020–21	136,098	239	35,118	1,904	-126,862	0	11,917	35,976	0	-131,911
2021–22	136,657	157	31,350	1,079	-113,872	0	11,879	30,112	0	-110,410
2022–23	136,657	730	18,270	4,340	-62,648	0	11,777	24,406	0	-89,487
2023–24	136,657	1,585	5,193	9,562	-9,478	1,585	13,032	1,225	9,562	5,071

Forest remaining Forest										
Years	Inter-annual variability in non-natural disturbance wildfires					Refined MLP flux				
	Remaining area of managed land (kha)	Annual area of wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)	Remaining area of managed land (kha)	Annual area of wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989–90	134,543	202	315	1,157	2	134,543	202	-457	1,499	3,176
1990–91	134,419	490	-968	1,662	5,213	134,419	490	146	1,242	705
1991–92	134,282	199	-128	1,462	1,933	134,282	199	-967	1,715	5,261
1992–93	134,220	85	1,778	440	-6,081	134,220	85	-1,143	1,866	6,056
1993–94	134,138	789	-5,833	3,853	25,239	134,138	789	-808	1,827	4,789
1994–95	134,130	284	-563	1,912	3,977	134,130	284	-237	1,581	2,448
1995–96	134,096	153	706	1,466	-1,124	134,096	153	-553	1,762	3,789
1996–97	134,012	44	2,729	233	-9,772	134,012	44	734	1,196	-1,495
1997–98	133,897	271	196	1,345	624	133,897	271	1,144	905	-3,288

Forest remaining Forest										
Years	Inter-annual variability in non-natural disturbance wildfires					Refined MLP flux				
	Remaining area of managed land (kha)	Annual area of wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)	Remaining area of managed land (kha)	Annual area of wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1998-99	133,691	177	601	1,022	-1,181	133,691	177	808	925	-2,038
1999-00	133,490	111	1,486	459	-4,988	133,490	111	-1,430	1,894	7,138
2000-01	133,239	496	-971	1,567	5,128	133,239	496	-830	1,677	4,721
2001-02	133,021	701	-8,462	5,080	36,108	133,021	701	-647	1,632	4,005
2002-03	132,848	37	3,196	255	-11,462	132,848	37	-1,085	1,896	5,875
2003-04	132,666	90	1,517	798	-4,763	132,666	90	-827	1,830	4,861
2004-05	132,343	304	-703	1,783	4,362	132,343	304	223	1,403	586
2005-06	132,120	223	321	1,236	60	132,120	223	-523	1,752	3,668
2006-07	132,013	393	-3,215	2,946	14,733	132,013	393	-2,135	2,556	10,384
2007-08	132,044	316	-532	1,997	3,948	132,044	316	-2,923	3,128	13,847
2008-09	132,174	484	-6,545	4,818	28,817	132,174	484	-2,225	3,034	11,192
2009-10	132,489	864	-4,645	4,644	21,675	132,489	864	-1,514	2,909	8,460
2010-11	132,943	104	3,813	764	-13,215	132,943	104	-2,539	3,495	12,804
2011-12	133,313	473	340	2,320	1,073	133,313	473	-671	2,824	5,283
2012-13	133,558	701	-5,656	4,930	25,667	133,558	701	-183	2,601	3,273
2013-14	133,942	261	2,794	1,461	-8,785	133,942	261	-282	2,623	3,656
2014-15	134,348	548	-2,207	3,532	11,626	134,348	548	-950	2,932	6,414
2015-16	134,812	100	3,320	871	-11,303	134,812	100	-71	2,609	2,870
2016-17	135,193	521	-3,000	3,866	14,867	135,193	521	187	2,455	1,770
2017-18	135,475	496	-1,262	3,317	7,946	135,475	496	1,361	1,748	-3,242
2018-19	135,666	135	4,084	687	-14,288	135,666	135	525	1,955	29
2019-20	135,821	0	3,663	0	-13,431	135,821	0	1,373	1,398	-3,637
2020-21	136,098	239	-858	1,904	5,049	136,098	239	398	1,602	142
2021-22	136,657	157	1,238	1,079	-3,462	136,657	157	375	1,465	89
2022-23	136,657	730	-6,136	4,340	26,839	136,657	730	161	1,465	875
2023-24	136,657	0	3,968	0	-14,549	136,657	0	484	1,405	-371

5. Identification of lands subject to natural disturbances and monitoring for forest recovery (expectation of balance between emissions and subsequent removals)

The Tier 3, Approach 3, modelling system using FullCAM has been designed to comply with the following safeguard mechanisms:

- the use of geo-located time-series wildfire activity data,
- coverage of all forest lands,
- the ability to monitor if there is a permanent land use change on those lands following a wildfire event
- during the commitment period,
- the inclusion of emissions associated with salvage logging in the accounting, and
- identification of lands where the natural disturbance is followed by another disturbance event, in order to avoid double counting.

FullCAM uses two remote sensing data sources. The Advanced Very High Resolution Radiometer (AVHRR) is used identify and map natural disturbance impacts due to wildfire on forest lands, whereas Landsat data is used to map forest cover changes and identify permanent land-use changes across all forest lands.

FullCAM spatially tracks areas and carbon stocks at the 25m x 25m pixel-level on lands identified as experiencing natural disturbances in a particular year, until another anthropogenic activity occurs (e.g. non-natural disturbance fire, salvage logging or land-use change).

Further information to demonstrate the disaggregation and monitoring of recovery of carbon stocks lost during disturbances is included in Chapter 6.4.1.4 (Category-specific QA/QC for *forest land remaining forest land).*

6. Monitoring for land-use changes to ensure that no land-use change has occurred on lands subject to natural disturbances

All forest land is monitored for harvesting and land-use change events. Where forest cover loss events are identified, these areas visually attributed by experienced operators to either direct, human-induced land-use change, or a temporary forest loss which does not constitute land-use change such as harvesting, fire and other non-anthropogenic disturbance.

7. Demonstrating practicable efforts to prevent, manage and control wildfires in Australia (how the requirements of natural definition of disturbances have been met)

In Australia, wildfires threaten life and property and are addressed in disaster response plans and management arrangements in each state and territory. Common frameworks for national, state and territory fire management policies include reducing the likelihood of fires occurring, for example through fuel reduction burning and fire bans; managing or controlling the fire during its occurrence; monitoring programs and early warning systems; and firefighting operations. In addition to such disaster management policies, there is also a significant research effort into understanding and better managing wildfires, and following many significant fire events, inquests or enquiries are held to assess the disaster response and potential for improvement.

There are fire management policies and plans in place at the national and the state and territory level to control for the risks, events and consequence of wildfire to the extent that this is possible. These policies and plans are periodically updated by jurisdictional governments and set out frameworks for:

- Reducing the likelihood of a wildfire occurring, for example, through the use of prescribed burning;
- Managing or controlling the disturbance during its occurrence;
- Monitoring programs and early warning systems; and
- Firefighting operations.

8. Inclusion of salvage logging emissions

Emissions from salvage logging are included in estimates for *harvested native forests* and *pre-1990 plantations.* Estimates of forest harvesting are based on log production information that includes the products of salvage logging. These production statistics do not differentiate between material sourced from conventional clear felling and salvaging activities following wildfire or other natural disturbances.

A review of salvage harvesting by ABARES (Finn et al. 2015) identified that this is a very minor activity compared to either total harvesting activity or total areas burned. Salvage harvesting is generally opportunistic, determined as much by commercial factors as biophysical factors.

Demonstrating balance of emissions and subsequent removals associated with natural 'background' fires

Over time, average net emissions of CO_2 from non-anthropogenic emissions and subsequent removals will approach zero. Therefore, the disaggregation of natural disturbance emissions will neither over- nor underestimate net emissions in the long term. This can be further demonstrated when simulating a fire event at the plot level – over the long-term the average net carbon dioxide emissions from natural disturbances is zero.

Natural disturbance emissions and removals are not in exact balance over the period since 1989–90 due to a number of recent disturbances from 2006–07 to 2024–25, recovery from which is ongoing. Given the recovery rates for a typical disturbance event, it is projected to take up to 15 years without further disturbance for carbon stocks to fully recover and average net emissions to approach zero as demonstrated in Table 6.3.5. For this reason, a modelling approach is used to ensure that these natural disturbances' net emissions and removals average out within the reporting timeframes.

Net emissions and removals from wildfires prior to 1989–90 are included in reporting. However no natural disturbances have been identified which affect net emissions and removals during the reporting period.

Table 6.3.5 Balancing of natural disturbance CO_2 emissions and removals

Year	Natural disturbance CO_2 emissions	Natural disturbance CO_2 removals
	Mt CO_2	
1989–90	0.00	0.00
1990–91	0.00	0.00
1991–92	0.00	0.00
1992–93	0.00	0.00
1993–94	0.00	0.00
1994–95	0.00	0.00
1995–96	0.00	0.00
1996–97	0.00	0.00
1997–98	0.00	0.00
1998–99	0.00	0.00
1999–00	0.00	0.00
2000–01	0.00	0.00
2001–02	0.00	0.00
2002–03	229.98	-20.87
2003–04	0.00	-37.88
2004–05	0.00	-31.41
2005–06	0.00	-25.34

Year	Natural disturbance CO_2 emissions	Natural disturbance CO_2 removals
	Mt CO_2	
2006–07	112.55	-34.91
2007–08	0.00	-35.45
2008–09	0.00	-30.02
2009–10	0.00	-24.38
2010–11	0.00	-20.64
2011–12	0.00	-16.73
2012–13	0.00	-13.33
2013–14	57.12	-16.56
2014–15	0.00	-16.67
2015–16	45.67	-20.35
2016–17	0.00	-17.79
2017–18	0.00	-14.82
2018–19	50.95	-17.29
2019–20	728.77	-94.45
2020–21	0.00	-133.14
2021–22	0.00	-111.43
2022–23	0.00	-90.23
2023–24	83.34	-88.42
2024–25 *(preliminary)*	98.56	-75.49
2025–26 (projected)	*0.00*	*-80.4*
2026–27 (projected)	*0.00*	*-66.9*
2027–28 (projected)	*0.00*	*-55.6*
2028–29 (projected)	*0.00*	*-45.8*
2029–30 (projected)	*0.00*	*-36.8*
2030–31 (projected)	*0.00*	*-26.1*
2031–32 (projected)	*0.00*	*-18.9*
2032–33 (projected)	*0.00*	*-14.9*
2033–34 (projected)	*0.00*	*-11.5*
2034–35 (projected)	*0.00*	*-8.3*
2035–36 (projected)	*0.00*	*-5.5*
2036–37 (projected)	*0.00*	*-3.6*
2037–38 (projected)	*0.00*	*-2.3*
2038–39 (projected)	*0.00*	*-1.5*
2039–40 (projected)	*0.00*	*-1.1*
Total (1990–2040)	**1406.94**	**-1352.86**
1990–2040 net mean	0.39	
1990–2040 net standard deviation	83.91	

No systematic bias is introduced into the inventory by the disaggregation of natural disturbances from anthropogenic fires. The approach does not introduce any artificial trend in reported emissions and removals (that is, it avoids the expectation of credits or debits).

The approach also improves the quality, accuracy and time series consistency of annual estimates by reducing the high levels of inter-annual variability in the time series.

6.3.3 Information on approaches used for reporting harvested wood products

Australia applies Approach 1 from the 2019 Refinement (IPCC 2019) to the 2006 IPCC Guidelines (IPCC 2006), also known as the stock-change approach. For transparency and comparability, information is also provided regarding estimates under Approach 2, also known as the production approach. Further information is provided in Chapter 6.10.

6.4 **Forest Land** (CRT category 4.A)

6.4.1 Forest Land Remaining Forest Land

6.4.1.1 Category Description

There are four broad sub-divisions to *forest land remaining forest land:* harvested native forests, plantations, other native forests and fuelwood.

Harvested native forests are those forests comprised of native species subjected to harvesting practices and natural regrowth. Various silvicultural techniques may be applied to initiate and promote particular growth characteristics. The areas included in this sub-division include multiple-use public forests and public forest areas which have been available for harvesting at any time since 1990 (Mutendeuzi et al. 2014) and private native forests subject to harvest or regrowing from prior harvest.

Plantations included within *forest land remaining forest land* are commercial plantations (hardwood and softwood) established in Australia up to the end of 1989. Softwood plantations make up the majority of these pre-1990 plantations with hardwood plantations (primarily eucalypt species) making up only a minor part of the plantation estate. Until the mid-1960s, most new areas of softwood plantation were derived from clearing of native forest or scrublands. In later years, some of the hardwood plantations were also established after clearing native forest (Snowdon and James 2008). By the mid-1980s, clearing of native forests for the establishment of plantations had ceased in most states, and most new plantations were established on farmland.

Other native forests include those forests that are comprised of native species, which are not *harvested native forests* or *plantations.* The *other native forests* sub-division includes protected areas (such as wilderness areas and national parks) not previously subject to harvesting and extensive areas of forests including woodlands.

The main processes affecting emissions and removals from these forests include fire management practices and wildfires. Accordingly net emissions are estimated for the following activities:

- prescribed burning of temperate forests;
- wildfire in temperate forests; and
- management fires and wildfire in tropical, sub-tropical and semi-arid forests.

Harvested wood products are not reported in this category. Carbon stocks in wood products are transferred to *harvested wood products* and are discussed further in Chapter 6.10.

As for all forests, the *harvested native forests* sub-category is monitored for forest conversions. Areas that are identified as direct human induced forest conversions are excluded from *forest land remaining forest land* from the time of the conversion event, and any harvesting losses associated with the conversion event are also excluded and reported only under the new land use category to avoid double-counting.

Anthropogenic emissions and removals from forest land remaining forest land are shown in Table 6.4.1.

Table 6.4.1 Emissions and removals from forest land remaining forest land, kt CO_2–e

Year	Harvested native forests	Plantations	Other native forests				Total
			Fuelwood consumed	Wildfires	Prescribed burning of temperate forests	Non-temperate forest fires	
1989–90	-5,710	-7,585	446	3,176	96	10,816	1,239
1994–95	-4,273	-9,355	501	2,448	56	5,880	-4,743
1999–00	-4,558	-4,844	244	7,138	-1,783	11,162	7,359
2004–05	-22,088	-4,931	-419	586	1,522	8,974	-16,355
2005–06	-22,801	-3,063	-491	3,668	1,951	10,434	-10,301
2006–07	-22,058	-5,634	-555	10,384	1,566	8,171	-8,126
2007–08	-21,453	-2,431	-612	13,847	1,493	14,604	5,448
2008–09	-9,119	-1,335	-662	11,192	1,151	13,006	14,233
2009–10	-5,702	3,892	-711	8,460	415	11,026	17,379
2010–11	-8,779	6,134	-757	12,804	467	14,716	24,585
2011–12	-11,924	4,272	-577	5,283	-421	10,998	7,631
2012–13	-14,747	-244	-439	3,273	-348	8,732	-3,773
2013–14	-29,258	1,174	-415	3,656	512	13,614	-10,716
2014–15	-36,055	3,271	-465	6,414	974	10,051	-15,810
2015–16	-38,394	-931	-403	2,870	796	825	-35,237
2016–17	-41,525	3,349	-342	1,770	1,054	1,121	-34,574
2017–18	-47,117	1,885	-304	-3,242	407	-3,083	-51,455
2018–19	-38,264	3,188	-278	29	-226	-2,624	-38,175
2019–20	-33,954	5,003	-249	-3,637	-655	-5,113	-38,605
2020–21	-34,123	7,469	-164	142	-1,270	-2,546	-30,493
2021–22	-28,032	8,726	-110	89	-1,377	3,261	-17,443
2022–23	-28,465	8,738	-7	875	-1,094	3,339	-16,614
2023–24	-30,777	8,727	-237	-371	-1,221	3,318	-20,562

6.4.1.2 Methodological issues

Both spatially explicit and non-spatially explicit models have been implemented in the estimation of emissions and removals from *harvested native forests.* For public forests in Victoria, New South Wales, Tasmania and Queensland, a spatially explicit Tier 3 FullCAM model for *harvested native forests* has been used. The non-spatially explicit estate modelling capability of FullCAM is used for both public and private forests in Western Australia, and for private native forests only in Victoria, New South Wales, Tasmania and Queensland.

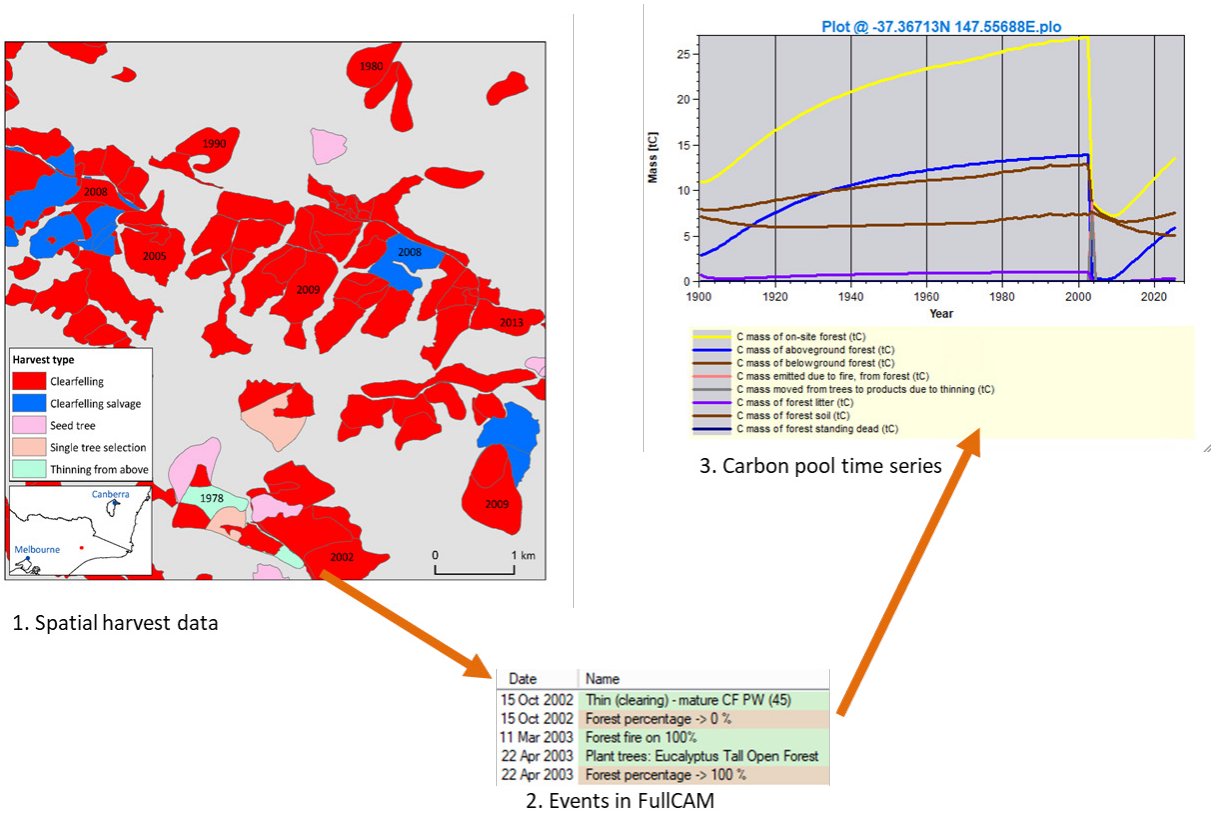
Harvested native forests – Spatial Method

The spatially explicit Tier 3 FullCAM model for *harvested native forests* has been applied to publicly managed forests in the states of Victoria, New South Wales, Tasmania and Queensland.

The FullCAM spatial method for *harvested native forests* simulates carbon stock changes due to tree growth, timber harvesting and associated management, and fire. The general operation of FullCAM spatial simulations is described in Annex 5.6.2. In the spatial method for *harvested native forests,* the type, location and date of timber harvesting activities are drawn from historical harvest data provided by state forestry agencies.

This is illustrated in Figure 6.4.1, in which harvest areas drawn from the spatial harvest data trigger events in the FullCAM simulation and resulting changes to the forest carbon pools. The yellow line represents the on-site carbon mass at one site increasing with tree growth, decreasing with timber harvesting in 2002, and again increasing with regrowth.

Figure 6.4.1 Overview of the spatial method for harvested native forests



Estimating changes in living biomass

The annual change in living biomass in *harvested native forests* is the net result of uptake due to forest growth (above and below ground as determined by the growth models) and losses due to forest harvesting and post-harvest fire where this occurs. Losses occur with the removal of forest products (transferred to *harvested wood products)* and movement of residue material (including belowground biomass) to dead organic matter (DOM) and soils.

Harvested native forests are modelled based on Major Vegetation Groups of the National Vegetation Information System (NVIS, see NLWRA 2001). The changes in carbon stock are estimated using FullCAM for areas defined as Multiple Use Forest (Annex 5.6.5.3), with the model run separately for each 25m x 25m grid cell within these areas. Growth of living biomass in each cell is calculated according to the Tree Yield Formula (TYF), as described in Annex 5.6.3.2, using biomass increments which are defined as a function of the:

- age of the tree stand;
- the maximum aboveground biomass (M), predicted by the model for a mature forest at each location (Annex 5.6.4); and
- estimated constant that determines the rate of biomass accumulation towards M.

Post-harvest regrowth is modelled according to the type of harvest that took place. Areas subject to clearfell harvest regrow from age zero according to the TYF.

After disturbance events which leave living biomass, such as partial harvesting or fire, a biomass recovery function determines the rate of regrowth in the post-disturbance recovery phase. The biomass recovery function is based on the calculated amount of biomass lost from disturbances, which then grows back as an addition to the annual increment over a number of years, until the 'target biomass' is reached (see *Biomass recovery function* in Annex 5.6.2.2).

Partitioning of biomass among tree components

FullCAM calculates below-ground biomass (coarse and fine roots) and the partitioning of above-ground biomass (stems, branches, bark and leaves), using empirically determined proportions of biomass to each component as outlined by Paul et al. (2017). This method allows allocation to vary between tree species based on vegetation classes (Table 6.4.2).

Table 6.4.2 Partitioning of biomass between the tree components in different vegetation groups

	Fraction of biomass allocated to:					
Major Vegetation Group	**Stems**	**Branches**	**Bark**	**Leaves**	**Coarse Roots**	**Fine Roots**
Woodlands <500mm rainfall	0.28	0.22	0.08	0.07	0.27	0.08
Forests >= 500mm rainfall	0.49	0.11	0.09	0.04	0.24	0.03

Carbon fraction of biomass

The carbon fractions of the tree components (Table 6.4.3) are based on studies of Australian vegetation. (Gifford 2000a; Gifford 2000b).

Table 6.4.3 Carbon Fraction of biomass for each tree component based on Gifford (2000a and 2000b)

Tree component	% Carbon
Stems	50
Branches	47
Bark	49
Leaves	52
Coarse roots	50
Fine roots	48

Forest harvest

Harvest events are applied at the locations and dates specified in the spatial data for harvest history provided by state government agencies (currently Victoria, New South Wales, Tasmania and Queensland) which also specifies the harvest type used in each case. The harvest history data is described in Annex 5.6.5.3. The characteristics of each harvest type used in FullCAM, are the proportion of above ground tree biomass harvested, the proportion of tree stem mass which is removed from the site as product, and management associated with the harvest type, such as a post-logging regeneration burn. These harvest characteristics were determined based on advice provided by organisations responsible for managing timber production on public land (VicForests, Forestry Corporation of New South Wales, Sustainable Timber Tasmania and the Queensland Department of Primary Industries). The characteristics of each harvest type are listed in Table 6.4.4.

The amount of carbon affected by each harvest event is determined for each 25 x 25 m pixel by characteristics of the harvest type, and the size of each carbon pool at that location at the time of harvest, resulting from past growth and disturbance over time.

Table 6.4.4 Harvest types used in the spatial model for harvested native forests, and their parameters

State	Harvest type	Major Vegetation Group	Percentage harvested	Pulpwood taken	Percentage of stem to product	Post-harvest fire
Vic	Clearfell (including salvage)	Eucalyptus Tall Open Forest; Eucalyptus Open Forest; Eucalyptus Low Open Forest; Low Closed Forest & Closed Shrublands	100%	Yes	95%	Yes
		Other forest types	100%	No	35%	Yes
Vic	Group (or Gap) selection	Eucalyptus Tall Open Forest	100%	No	67%	No
		Eucalyptus Tall Open Forest	50%	Yes	95%	No
		Other forest types	50%	No	45%	No
		Other forest types	50%	Yes	55%	No
Vic	Regrowth retention harvesting	Eucalyptus Tall Open Forest	100%	Yes	95%	Yes
		All forest types	100%	No	35%	Yes
Vic	Dangerous tree removal / road alignment	Eucalyptus Tall Open Forest; Eucalyptus Open Forest	100%	Yes	95%	No
		All forest types	100%	No	35%	No
Vic	Seed tree	Eucalyptus Tall Open Forest; Eucalyptus Low Open Forest; Low Closed Forest and Closed Shrublands	85%	Yes	90%	No
		All forest types	85%	No	50%	No
Vic	First Shelterwood	Eucalyptus Tall Open Forest; Eucalyptus Open Forest; Eucalyptus Low Open Forest	85%	Yes	55%	No
		All forest types	85%	No	50%	No
Vic	Second Shelterwood	All forest types	100%	-	65%	No
Vic	Single tree selection	All forest types	20%	-	90%	No
Vic	Thinning from above / below	Eucalyptus Tall Open Forest; Eucalyptus Open Woodland	50%	-	90%	No
		Other forest types	40%	-	90%	No
Vic	Variable Retention 1	Eucalyptus Open Forest, Eucalyptus Open Woodland, Eucalyptus Tall Open Forest, Eucalyptus Woodland, Low Closed Forest and Closed Shrublands, Rainforest and vine thickets	75%	No	35%	Yes, usually
				Yes	95%	Yes, usually
Vic	Variable Retention 1 (recovery)	Eucalyptus Open Forest, Eucalyptus Tall Open Forest, Eucalyptus Woodland, Other Forests and Woodlands, Other Shrublands, Rainforest and vine thickets	75%	No	35%	No
				Yes	95%	No

State	Harvest type	Major Vegetation Group	Percentage harvested	Pulpwood taken	Percentage of stem to product	Post-harvest fire
Vic	Variable Retention 2	Eucalyptus Open Forest, Eucalyptus Tall Open Forest, Rainforest and vine thickets	65%	No	35%	Yes, usually
				Yes	95%	Yes, usually
Vic	Variable Retention 2 (recovery)	Eucalyptus Tall Open Forest	65%	No	35%	No
				Yes	95%	No
Vic	Fallen Product Recovery	Acacia Forest and Woodlands, Eucalyptus Open Forest, Eucalyptus Tall Open Forest, Eucalyptus Woodland, Low Closed Forest and Closed Shrublands, Other Forests and Woodlands	100%	No	35%	No
				Yes	95%	No
NSW	Australian group selection	All forest types	25%	-	90%	No
NSW	Plantation clearfell	All forest types	65%	Yes	85%	Yes
NSW	Salvage – roadline & storm	All forest types	100%	-	90%	No
NSW	Salvage – fire & other	All forest types	50%	-	90%	No
NSW	Alternate coupe	All forest types	80%	Yes	90%	Yes
NSW	Miscellaneous	All forest types	10%	No	90%	No
NSW	Non-commercial harvest	All forest types	100%	No	0%	No
NSW	Thinning	All forest types	40%	No	90%	No
NSW	Single tree selection – light	All forest types	20%	No	90%	No
NSW	Single tree selection – mix	All forest types	30%	No	90%	No
NSW	Single tree selection – moderate	All forest types	30%	No	90%	No
NSW	Single tree selection – release	All forest types	30%	No	90%	No
NSW	Single tree selection – heavy	All forest types	40%	No	90%	No
NSW	Single tree selection – regeneration	All forest types	60%	No	90%	No
Tas	Clearfell	All forest types	95%	-	80%	Yes
Tas	Clearfell native for plantation	All forest types	100%	-	80%	Yes
Tas	Salvage – roadline, quarry & dam	All forest types	95%	-	80%	No
Tas	Salvage – fire & other	All forest types	50%	-	65%	No
Tas	Variable retention	All forest types	85%	-	80%	Yes
Tas	Seed tree retention	All forest types	80%	-	80%	Yes
Tas	Advanced growth retention	All forest types	75%	-	80%	No
Tas	Potential sawlog retention	All forest types	70%	-	80%	No

State	Harvest type	Major Vegetation Group	Percentage harvested	Pulpwood taken	Percentage of stem to product	Post-harvest fire
Tas	Commercial thinning	All forest types	60%	-	80%	No
Tas	Shelterwood retention	All forest types	60%	-	80%	No
Tas	Shelterwood removal	All forest types	80%	-	80%	No
Tas	Wattle removal	All forest types	60%	-	35%	No
Tas	Special species sawlogs	All forest types	5%	-	70%	No
Tas	Craftwood	All forest types	5%	-	80%	No
Qld	Carbon Regime 1	All forest types	19%	-	76%	No
Qld	Carbon Regime 2	All forest types	14%	-	76%	No
Qld	Carbon Regime 3	All forest types	8%	-	88%	No
Qld	Carbon Regime 4	All forest types	3%	-	78%	No
Qld	Carbon Regime 5	All forest types	5%	-	65%	No
Qld	Carbon Regime 6	All forest types	40%	-	76%	No
Qld	Carbon Regime 9	All forest types	27%	-	91%	No
Qld	Carbon Regime 10	All forest types	32%	-	91%	No
Qld	Carbon Regime 11	All forest types	36%	-	91%	No
Qld	Carbon Regime 12	All forest types	25%	-	84%	No
Qld	Carbon Regime 21	All forest types	7%	-	76%	No
Qld	Carbon Regime 22	All forest types	5%	-	91%	No
Qld	Carbon Regime 23	All forest types	3%	-	88%	No
Qld	Carbon Regime 24	All forest types	1%	-	78%	No
Qld	Carbon Regime 25	All forest types	2%	-	65%	No
Qld	Carbon Regime 26	All forest types	14%	-	76%	No
Qld	Carbon Regime 29	All forest types	10%	-	91%	No
Qld	Carbon Regime 210	All forest types	12%	-	91%	No
Qld	Carbon Regime 211	All forest types	13%	-	91%	No
Qld	Carbon Regime 212	All forest types	9%	-	84%	No

Pulpwood taken is not specified where it does not affect percentage harvested or percentage stem to product Once harvested, in the model, the removal of products is assumed to result in a transfer of carbon to *harvested wood products* based on production statistics.

Estimating changes in debris

The annual change in DOM in *harvested native forests* is the net result of additions from turnover and harvest residue, and losses due to decay and turnover into soils. Losses are caused by decomposition of both natural accumulation and harvest residue and burning of residues as part of some silvicultural systems. The turnover rates applied for each plant component in the model are shown in Table 6.4.5. The decomposition rates used for standing dead pools are shown in Table 6.4.6, and for debris in Table 6.4.7. Along with the initial amount of forest debris, these values were derived from Paul et al. (2017).

Table 6.4.5 Turnover for tree components

Tree component	Turnover % per month
Branches	0.74
Bark	0.41
Leaves (rainfall >500mm)	2.96
Leaves (rainfall <500mm)	1.28
Coarse Roots	0.87
Fine Roots	12.55

Table 6.4.6 Decomposition rates for standing dead pools used in the harvested native forests model

Standing Dead component	Breakdown % per month
Stems, branches and coarse roots	0.83
Bark	1.25
Leaves and fine roots	1.67

Table 6.4.7 Decomposition rates for debris pools used in the harvested native forests model

	Breakdown % per month	
Debris component	Decomposable	Resistant
Deadwood	-	1.25
Bark litter	-	1.44
Leaf litter	81.2	2.70
Coarse dead roots	-	2.93
Fine dead roots	81.2	81.2

Breakdown rates are not given for decomposable deadwood, bark litter and coarse dead roots because these pools are treated as entirely resistant.

Estimating changes in soil carbon

Soil carbon is estimated using FullCAM with a national soil carbon map (Viscarra Rossel et al. 2014) (Annex 5.6.5) as the base input data. FullCAM simulates changes in soil carbon using Roth-C soil carbon model. Roth-C model computes turnover of organic carbon in soils, taking into account clay content, temperature, moisture content, plant material inputs and plant cover. A mean incremental value for the transitions between SOC near steady states is derived, in this case from the simulated annual data, consistent with the method applied in croplands and grasslands.

Harvested native forests – biomass burning

Wildfires and prescribed fires on *harvested native forests* are modelled in FullCAM as temperate forest fires consistent with *Other native forests.*

The CO_2 emissions associated with slash burning which follows some harvest types (see Table 6.4.4) in *harvested native forests* are similarly modelled in FullCAM as part of the *harvested native forests* model. The mass of carbon burnt annually (FCjk in equations 6.4.1 and 6.4.2) is taken directly from FullCAM and is used to estimate the CO_2 and non-CO_2 gas emissions associated with slash burning.

Harvested native forests – Estate Method

The non-spatially explicit estate method of FullCAM is used for both public and private forests in Western Australia, and for private native forests only, in Victoria, New South Wales, Tasmania and Queensland. For private native forests in New South Wales, an estate model has been developed drawing on the parameters and settings used in spatial modelling of public native forests in that state. For the other estate models for public and private forests, the following methods and parameters apply.

Estimating changes in living biomass

The annual change in living biomass in *harvested native forests* is the net result of uptake due to forest growth (above and below ground as determined from the growth models) and losses due to forest harvesting. Losses occur with the removal of forest products (transferred to *harvested wood products)* and movement of residue material (including belowground biomass) to dead organic matter (DOM) and soils.

Public and private *harvested native forests* in Western Australia, and private harvested native forests in Victoria, Tasmania and Queensland are modelled based on forest types which are consistent with reporting used under the Montreal Process National Forest Inventory (ABARES 2023) and National Vegetation Information System Major Vegetation Groups (NVIS, see NLWRA 2001). A comparison with the inventory forest classes is shown in Table 6.4.8 (Waterworth et al. 2015). Age classes and growth rates (t C ha^{-1} yr^{-1}) for each forest type in multiple-use public forests were reported by Lucas et al. (1997) (Table 6.4.9 and Table 6.4.10).

The changes in carbon stock are estimated using FullCAM, which is configured using the area of each forest type and age class in Table 6.4.9 and biomass increments based on the growth rates reported in Table 6.4.10. Forests of unknown age, or those containing two or more age classes, were assumed to be equivalent to the 'Mature' age class.

Post-harvest growth is modelled according to the type of harvest that took place. Areas subject to clearfell harvest regrow from age zero. Areas subject to partial harvest continue to grow at the same rate as they were growing prior to the harvest (i.e. there is no thinning effect at the stand level, either positive or negative, on the rate of biomass accumulation despite the reduction in stem numbers).

Table 6.4.8 Forest classification comparison table

Inventory forest class (Lucas et al. 1997)	NVIS Major Vegetation Groups	National Forest Inventory (SOFR 2023)
Rainforest	Rainforest and vine thickets	Rainforest
Tall dense eucalypt forest	Eucalyptus tall open forest	Eucalypt tall closed
		Eucalypt tall open
Medium dense eucalypt forest	Eucalyptus open forest	Eucalypt medium closed
		Eucalypt medium open
Low dense eucalypt forest	Low Closed Forests and	Eucalypt low closed
	Tall Closed Shrublands	Eucalypt low open
Tall sparse eucalypt forest	Eucalypt Open Forests	Eucalypt tall woodland
Medium sparse eucalypt forest	Eucalypt medium woodland	
Low sparse eucalypt forest	Eucalyptus woodland	Eucalypt low woodland
	Eucalyptus open woodland	
	Other Open Woodlands	
	Tropical woodlands and grasslands	
	Eucalypt Low Open Forests	
Eucalypt Mallee	Mallee Woodlands and Shrublands	Eucalypt Mallee open
	Mallee Open Woodlands and Sparse Mallee Shrublands	Eucalypt Mallee woodland
Callitris forests	Callitris Forest and Woodlands	Callitris
Acacia forests	Acacia forest and woodlands	Acacia
Other forests	Casuarina Forests and Woodlands	Casuarina
	Melaleuca Forests and Woodlands	Melaleuca
	Mangrove	Mangrove
	Acacia Open Woodlands	
	Eucalypt Woodlands	

Waterworth et al. (2015)

Table 6.4.9 Areas by forest type and age classes in 1989–90 in multiple-use public forests (ha) (Estate method, Australia-wide)

Forest Type	Establishment 1–10yrs	Juvenile 11–30yrs	Immature 31–100yrs	Mature 100–200 yrs	Senescent > 200 yrs	Forests of unknown age [(a)]	Two Aged	Three or More Aged	Total
Rainforests				842,580					842,580
Tall Dense Eucalypt Forests	46,728	95,470	234,898	292,095	230,102	641,646	115,683	388,188	2,044,810
Medium Dense Eucalypt Forests	14,576	97,742	173,424	829,088	168,152	1,659,839	273,720	1,022,136	4,238,677
Medium Sparse Eucalypt Forests					345,153	274,270		663,366	1,282,789
Cypress pine Forests						42,258		144,182	186,440
Other Forests						673,019		141,686	814,705
Totals	**61,304**	**193,212**	**408,321**	**1,963,7633**	**743,407**	**3,291,031**	**389,404**	**2,359,558**	**9,410,000**

(a) The unknown and mixed age classes were represented in the model consistent with the 'Mature' age class.

Table 6.4.10 Aboveground growth rates by forest type and age class (t C ha^{-1} yr^{1})

	Establishment	Juvenile	Immature	Mature	Senescent
Forest Type	**1–10 yrs**	**11–30 yrs**	**31–100 yrs**	**100–200 yrs**	**> 200 yrs**
Rainforests	-	-	-	0.58	0
Tall Dense Eucalypt Forests	6.44	4.41	2.23	0.74	0
Medium Dense Eucalypt Forests	4.24	2.80	0.99	0.18	0
Medium Sparse Eucalypt Forests	0.24	0.24	0.24	0.24	0
Cypress pine Forests	0.25	0.25	0.25	0.25	0
Other Forests	0.23	0.23	0.23	0.23	0

Partitioning of biomass to tree components

The ratios used to partition biomass to the different tree components (Table 6.4.11) are drawn from a synthesis of available data compiled by Snowdon, Eamus, et al. (2000); and the results of Ximenes and Gardner (2005); and Ximenes et al. (2005).

Table 6.4.11 Partitioning of biomass to each of the tree components

	Fraction of biomass allocated to:					
Forest Type	**Stems**	**Branches**	**Bark**	**Leaves**	**Coarse roots**	**Fine roots**
Rainforest	0.60	0.08	0.09	0.03	0.17	0.03
Tall Dense Eucalypt Forest	0.55	0.12	0.10	0.03	0.17	0.03
Medium Dense Eucalypt Forest	0.50	0.15	0.12	0.03	0.17	0.03
Medium Sparse Eucalypt Forest	0.47	0.15	0.12	0.03	0.20	0.03
Cypress pine Forest	0.47	0.15	0.12	0.03	0.20	0.03
Other forest	0.47	0.15	0.12	0.03	0.20	0.03

Carbon fraction of biomass

The carbon fractions of the tree components (Table 6.4.12) are based on studies of Australian vegetation (Gifford 2000a, 2000b).

Table 6.4.12 Carbon fraction of biomass for each tree component based on Gifford (2000a) and (2000b)

Tree component	% Carbon
Stems	52
Branches	47
Bark	49
Leaves	52
Coarse roots	49
Fine roots	46

Forest harvest

The amount of carbon removed as products in a harvest is dependent upon age class, forest type and the type of harvest. The area of *harvested native forests* harvested in each broad forest type and age class was derived from roundwood log volumes removals for each state (ABARES 2025c) using a historical relationship between roundwood removals and harvest area data collated by state agencies.

The broad silvicultural systems applicable to each state are reported in Table 6.4.13. Information on the forest type and silviculture method applied also varied in the level of detail available. Where the information was not explicitly reported, it was inferred from the best available information, including information within the state agency reporting, publications from state agencies (e.g., Forestry Tasmania 2008; FPA 2007; Forests NSW 2008; Vic Forests 2008) and from Raison and Squire (2008). It is assumed that no harvesting occurred in the Establishment (1–10 years) and Juvenile (11–30 years) phases as these are generally too young to produce forest products in Australia's native forests.

Most states began phasing out logging of rainforests in the 1980s, and for the most part, logging was entirely phased out prior to 1990 (Raison and Squire 2008). It was not possible to separate cool temperate rainforest logging from logging in wet temperate eucalypt forests in Tasmania. The harvested area for rainforests in Tasmania was therefore modelled as tall and medium dense eucalypt forests, which are closest to cool temperate rainforests spatially and in successional sequence (Hickey 1994).

Table 6.4.13 Broad silvicultural systems used in the Estate model for harvested native forests

Forest type	Silviculture	% of trees harvested	Post-harvest management
Tall dense eucalypt forest	Clearfell with pulpwood	100%	Regeneration burn
	Clearfell without pulpwood	100%	Regeneration burn
	Partial harvest with pulpwood	35–50%	Slash left on-site
	Partial harvest without pulpwood	25%	Slash left on-site
Medium dense eucalypt forest	Clearfell with pulpwood	100%	Regeneration burn
	Clearfell without pulpwood	100%	Regeneration burn
	Partial harvest with pulpwood	35–75%	Slash left on-site
	Partial harvest without pulpwood	40%	Slash left on-site
Medium sparse eucalypt forest	Partial harvest without pulpwood	30%	Slash left on-site
Callitris forest	Partial harvest without pulpwood	40%	Slash left on-site

Once harvested, in the model, the removal of products at harvest is assumed to result in a transfer of carbon to *harvested wood products* (see Chapter 6.10) based on production statistics.

Estimating changes in debris

The annual change in DOM in *harvested native forests* is the net result of additions from harvest residue and turnover, and losses due to decay and turnover into soils. Losses are caused by decomposition of both natural accumulation and harvest residue and burning of residues as part of some silvicultural systems.

The initial amount of forest debris for each forest type and age class combination is based upon model simulations, cross checked with published estimates of debris in Australian forests. For each forest type, a clearfell event was simulated using initial debris levels. This simulation was then run to equilibrium over 200 years. The final debris pools from this simulation were then used as the initial conditions for a final simulation. The results of the final simulation were used to define the initial debris for each age class for each respective forest type. This method produced debris quantities that are comparable with published estimates of debris in Australian forests (e.g., Woldendorp and Keenan 2005, Hingston, F.J.; Dimmock, G.M.; Turton, A.G. 1980).

The turnover rates applied for each plant component in the model are shown in Table 6.4.14. There is limited information on decomposition rates in the *harvested native forests* of Australia. The decomposition rates for the different debris pools were drawn from the best available information including Mackensen et al. (2003), Mackensen and Bauhaus (1999), O'Connell (1997) and Paul and Polglase (2004). The rates used are shown in Table 6.4.15.

Table 6.4.14 Turnover for tree components

Tree component	Turnover per year
Branches	0.05
Bark	0.07
Leaves	0.50
Coarse Roots	0.10
Fine Roots	0.85

Table 6.4.15 Decomposition rates for debris pools used in the harvested native forests model

	Breakdown per year	
Debris component	**Decomposable**	**Resistant**
Deadwood	0.05	0.05
Bark litter	0.50	0.50
Leaf litter	0.80	0.80
Coarse dead roots	0.40	0.10
Fine dead roots	1.00	1.00

The amount of residue produced by a harvest is also dependent upon the harvest type, forest age and forest type. Information on the production of harvest residue by broad forest type, harvest type and forest age was sourced from Raison and Squire (2008), and studies of residue production from Ximenes and Gardner (2005); and Ximenes et al. (2005).

Estimating changes in soil organic carbon

Soil carbon is estimated using FullCAM operating in estate mode with a national soil carbon map (Viscarra Rossell et al. 2015b) (Annex 5.6.5) as the base input data. FullCAM simulates changes in soil carbon using the Roth-C soil carbon model. The Roth-C model computes turnover of organic carbon in soils, taking into account clay content, temperature, moisture content, plant material inputs and plant cover.

Harvested native forests – biomass burning

Wildfires and prescribed fires on *Harvested native forests* are modelled as temperate forest fires consistent with the methods for natural disturbances described in Chapter 6.3.2.

The CO_2 emissions associated with slash burning in *harvested native forests* are estimated by FullCAM. The mass of carbon burnt annually (FC_k) is taken directly from FullCAM and is used to estimate the CO_2 and non-CO_2 gas emissions associated with slash burning.

There are no direct measurements of trace gas emissions from slash burning in Australia; however it is considered that these fires will have similar characteristics to hot prescribed fires and wildfires (Hurst et al. 1996).

The algorithms for total annual emissions of CH_4, CO and NMVOCs are:

$$E_{ijk} = FC_{jk} \times EF_{ijk} \times C_i \quad (6.4.1)$$

and for total annual emissions for NO and N O are:

$$E_{ijk} = FC_{jk} \times NC_{jk} \times EF_{ijk} \times C_i \quad (6.4.2)$$

Where FC_{jk} = annual carbon burnt in slash burning (obtained from FullCAM) (kt),
EF_{ijk} = emission factor for gas i from vegetation (Tables A5.6.11.10–12),
NC_{jk} = nitrogen to carbon ratio in biomass (Annex 5.6.11.8)
C_j = factor to convert from elemental mass of gas species *i* to molecular mass (Annex 5.6.11.9).

Harvested Native Forests Activity Data

Table 6.4.16 Area of harvesting activity by year and modelling method

	Area harvested (ha)		
Year	Estate method (WA public forests, private native forests in all states)	Spatial method (public forests in Vic, NSW, Tas, Qld)	Total
1989–90	47,442	119,416	166,858
1994–95	55,616	123,544	179,160
1999–00	48,329	55,248	103,576
2004–05	34,371	77,323	111,694
2005–06	25,505	76,183	101,688
2006–07	26,369	68,591	94,960
2007–08	29,092	68,124	97,216
2008–09	24,400	66,605	91,005
2009–10	18,397	59,778	78,174
2010–11	17,416	45,748	63,164
2011–12	12,768	42,584	55,352
2012–13	10,518	59,799	70,317
2013–14	8,648	45,226	53,874
2014–15	8,378	49,024	57,402
2015–16	9,951	33,048	42,999
2016–17	10,694	40,854	51,549
2017–18	9,747	47,255	57,002
2018–19	9,775	33,645	43,420
2019–20	12,857	30,059	42,916
2020–21	12,063	21,313	33,377
2021–22	10,491	28,047	38,539
2022–23	7,583	24,174	31,757
2023–24	6,832	21,012	27,844

Source: Estate method areas derived from Australian Forest and Wood Products Statistics (ABARES 2025c). Spatial method activity data from Department of Jobs, Skills, Industry and Regions Victoria (obtained 2024), Forestry Corporation of New South Wales (2025) Sustainable Timber Tasmania (2025) and the Queensland Department of Primary Industries (2025).

Pre-1990 Plantations

Plantations included within *forest land remaining forest land* are commercial plantations (predominantly softwood) established in Australia up to the end of 1989.

Pre-1990 plantations are simulated using a fully spatial FullCAM simulation. Spatial layers based on information obtained from ABARES are constructed for plantings and harvesting is identified from Landsat satellite imagery. Activity data for plantations relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1). Reported areas and disaggregated emissions have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3 Resolving data gaps). Given the complexity of the Tier 3 modelling system, many factors influence the emissions trend including harvesting data (including commercial and market factors), the age-class of the plantation estate and inter-annual variability due to climate impacts. Emissions trends over recent years would not be suitable for predicting 2023–24 emissions and it was determined that holding emissions constant would be the most appropriate extrapolation method.

The carbon pools considered for *plantations* include above and below ground biomass, DOM and soil.

Estimating changes in carbon stocks

Plantation forest growth and changes in debris in *forest land remaining forest land* is estimated in a manner fully consistent with that described for plantations in *land converted to forest* (Chapter 6.4.2.2).

Fires on *Plantations* are modelled as temperate forest fires consistent with *Other native forests.*

Activity data

Activity data for *plantations* establishment is sourced from the National Plantation Inventory (NPI) (ABARES 2016a), which provides spatial information on areas planted during 1939–40 to 1988–89, years of planting and plant type/species. The plantation area is spread over the 15 NPI regions (Figure 6.4.2) in three broad classes defined as Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW). Table 6.4.17 shows the plantation establishment activity data.

As explained above, the timing of harvesting is based on satellite imagery while the timing of thinning is based on region and species specific management practices.

Figure 6.4.2 The National Plantation Inventory regions

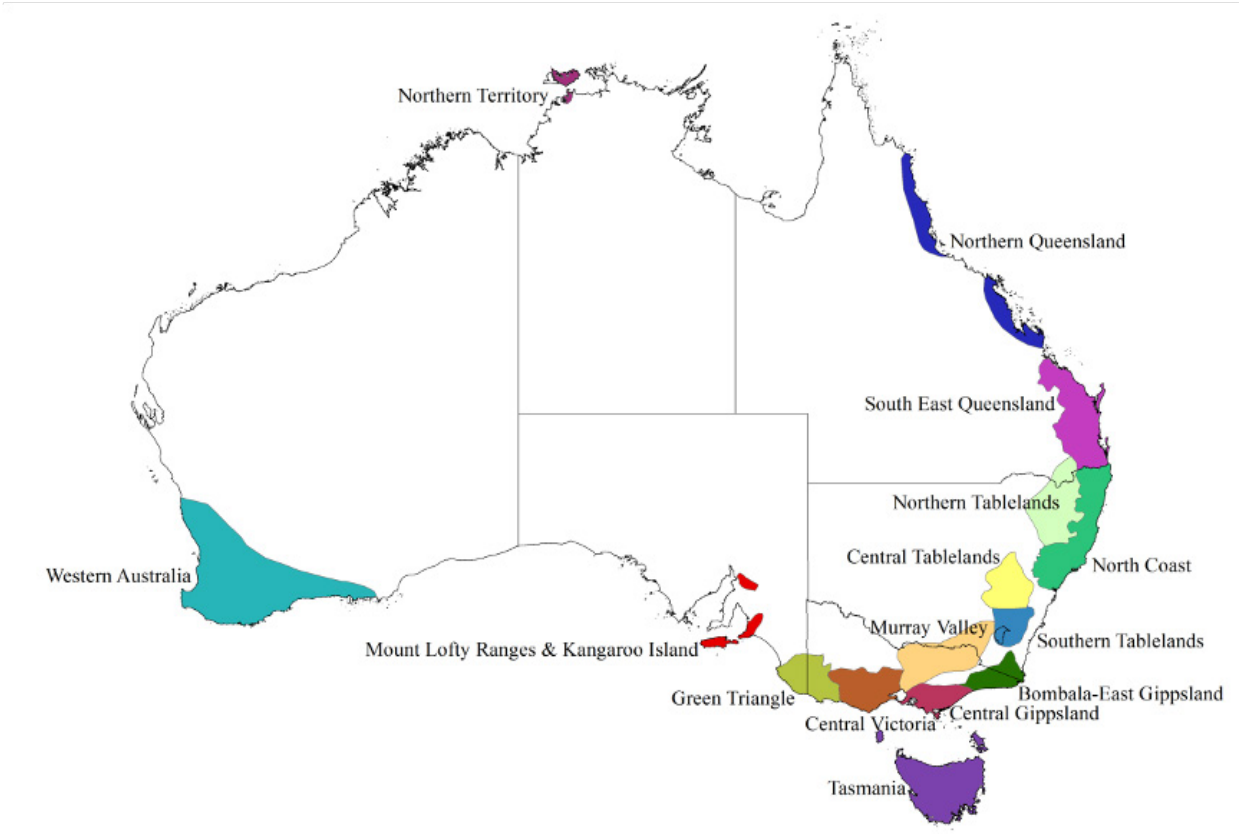


Table 6.4.17 Cumulative area of land converted to plantation from 1939–40 to 1988–89

Year	Area (ha)	Year	Area (ha)
1939–40	818	1964–65	88,111
1940–41	1,476	1965–66	101,189
1941–42	2,440	1966–67	117,217
1942–43	2,977	1967–68	132,600
1943–44	4,126	1968–69	152,958
1944–45	5,946	1969–70	174,337
1945–46	7,756	1970–71	197,355
1946–47	9,945	1971–72	221,677
1947–48	11,876	1972–73	246,389
1948–49	14,600	1973–74	271,855
1949–50	17,184	1974–75	297,202
1950–51	19,837	1975–76	324,016
1951–52	22,484	1976–77	349,761
1952–53	25,204	1977–78	376,550
1953–54	27,926	1978–79	403,158
1954–55	30,686	1979–80	427,484
1955–56	33,588	1980–81	453,817
1956–57	36,493	1981–82	477,122
1957–58	39,580	1982–83	504,146
1958–59	44,191	1983–84	531,896
1959–60	49,777	1984–85	559,649
1960–61	55,519	1985–86	589,023
1961–62	61,354	1986–87	619,993
1962–63	68,662	1987–88	651,390
1963–64	77,839	1988–89	681,460

Other native forests

Wildfire emissions and removals in temperate and tropical zone forests are estimated using a Tier 3, Approach 3 spatial simulation using FullCAM, consistent with the methods described for natural disturbances in Chapter 6.3.2.

Emissions of CO_2 from the consumption of *fuelwood* are estimated using data on the residential consumption of wood and wood-waste obtained from the Australian Energy Statistics. Carbon stocks lost through emissions from consumption of fuelwood from the residential sector are assumed to be collected from DOM in forests.

To ensure no double counting with modelled decay or fires affecting the DOM pool, these instant losses through fuelwood consumption are offset against an Olson fuel accumulation curve (T95 per cent = 11 years).

6.4.1.3 Uncertainty assessment and time-series consistency

Uncertainties for the *forest land remaining forest land* sub-category are estimated to be ±33.5 per cent for CO_2. The majority of this uncertainty is due to the *other native forest* sub-division. Uncertainty in the *plantations* is expected to be less than 10 per cent. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

6.4.1.4 Category-specific QA/QC and verification

Harvested native forests

For the Estate method for *harvested native forests,* data on harvesting is derived from roundwood log volumes for each state. Roundwood log volumes are published by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) in the biannual Australian Forest and Wood Products Statistics report (2025), a comprehensive dataset relating to Australia's forestry sector, including time series data on forest and wood products resources, production, consumption, trade and employment. Historical harvest area data was obtained from a combination of annual reports of Australian state agencies, financial statements, and spatial harvest area data. These datasets have been subject to review processes and financial auditing and are the basis for Australia's reporting to the Food and Agriculture Organisation of the United Nations.

Data on stem to whole tree conversions, carbon content and wood densities are within the ranges published in Gifford (2000a); Gifford (2000b); Ilic et al. (2000); and Snowdon et al. (2000). The estimated slash produced by forest harvesting is in line with independent studies of slash production from forest harvesting for major Australian harvested forests (Snowdon et al. 2000; Ximenes et al. 2008a).

For the Spatial method for *harvested native forests,* data on harvesting is provided directly by state forest management agencies. These data on the location, type and date of harvesting, along with parameters for tree growth, debris and soil processes are used to generate the estimate of net emissions and also of the carbon mass removed from the harvested areas as product. Conversion of this carbon mass to wood volume provides a model output which can be compared directly to the roundwood log volumes published by ABARES.

The overall *harvested native forests* model is verified by comparing the log volume, calculated using the FullCAM harvested native forest model for emissions estimation, with national statistics of round wood production in native forests (ABARES 2025c) (Figure 6.4.3). The log volume from the *harvested native forest* model was estimated by converting the carbon removed from forests as forest products to stem volume, assuming a stemwood carbon percentage of 50 per cent and average wood basic density of 730 kg/m^3. The modelled log volumes closely track the published statistics over time.

Figure 6.4.3 Estimated removals in Harvested Native Forests, FullCAM outputs compared to national harvesting statistics (ABARES 2025c)



Pre-90 Plantations

The calibration and validation of FullCAM, along with the associated quality assurance and quality control program are described in Annex 5.6.2. An independent review of the models used to estimate emissions and removals in the *plantations* category was undertaken by CSIRO in 2001. Recent updates to the parameters for forest plantation used in modelling are provided in Annex 5.6.2.

Other native forests

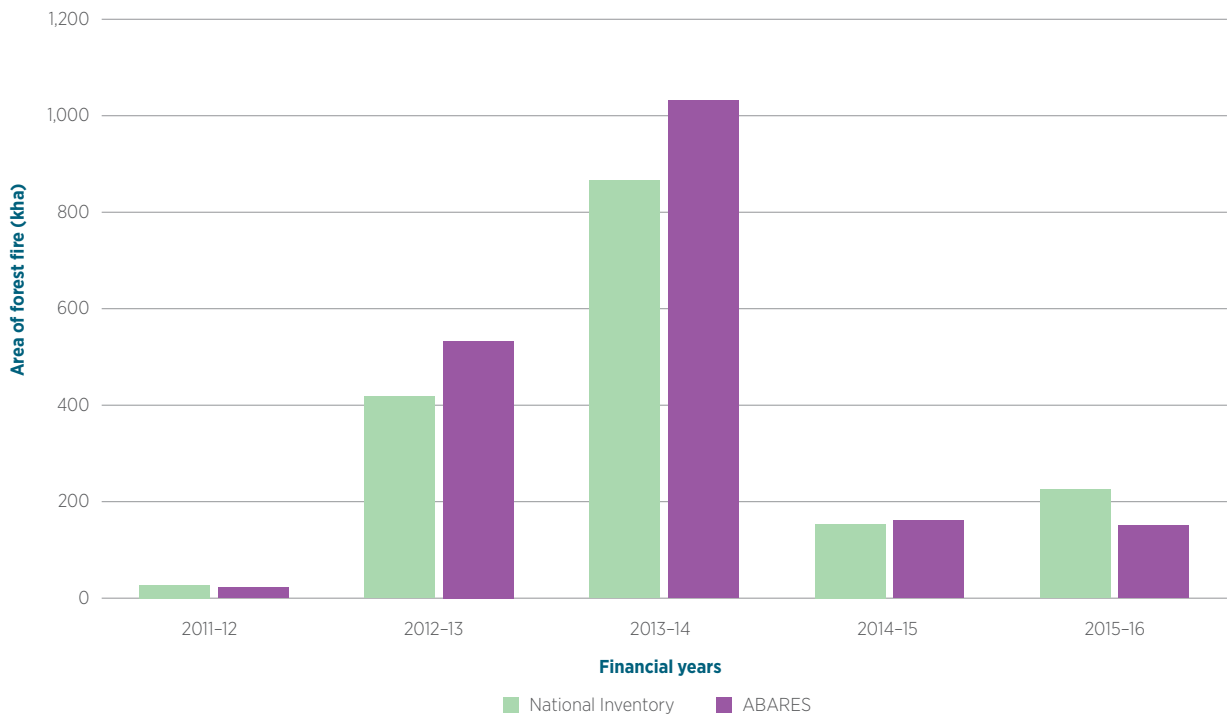
The activity data for wildfire was assessed by the Royal Melbourne Institute of Technology (RMIT) (K. Lowell 2014), and compared with a range of alternative datasets, and was found to be the most suitable and highest quality time series data available. The datasets considered by the RMIT included:

1. Monthly AVHRR burnt area products (1990 to 2014), obtained from the Western Australian Land Information Authority (Landgate);
2. Monthly MODIS burnt area 500m products (2000 to 2013), obtained from the global database maintained by the University of Maryland, USA;
3. Limited coverage of wildfire data from the Landsat series of satellites; and
4. Reference bushfire history data supplied by state agencies.

The overall quality of the post-2000 AVHRR burnt area products had a low commission error (5.4 per cent) which indicates that 94.6 per cent of the wildfire detected in the Landgate AVHRR burnt area product were correctly classified. The omission error was around 11 per cent after accounting for the undetected low-intensity prescribed burns (22 per cent) and smaller fires below the minimum mapping unit (9 per cent) which the 1km resolution AVHRR optical sensors were not expected to detect.

The data reported in the NIR also aligns with reporting to FAO forest resources assessment in the ABARES State of the Forests Report 2018 covering data up to 2016 (Figure 6.4.4).

Figure 6.4.4 Comparison of annual forest area experiencing wildfire, Australia, 2011–12 to 2015–16 (kha)



The reporting of net emissions from *other native forests,* and the identification and disaggregation of non-anthropogenic natural disturbances in temperate forests, results in both carbon dioxide emissions and removals from natural disturbances averaging out over time without impacting anthropogenic net emissions. This methodology and outcomes have been subjected to independent review (Federici 2016a).

6.4.1.5 Category-specific recalculations

The recalculations reported in the current submission are shown in Table 6.4.18 and include:

A. Activity data updates

Emissions have been recalculated as a result of updating the climate, forest harvest, and fire time series and adding an additional year of data.

B. Refinements to the non-temperate fire model

Following independent expert review of the implementation of improvements to the calibrations used to model non-temperate fires reported in the 2022 submission, further refinements to the sub-model in FullCAM were identified. These refinements include a revision to the fire patchiness values for one species type and a revision to the time series of grass yield parameters for monsoonal perennial grass species.

Table 6.4.18 Forest land remaining forest land: recalculation of total CO_2–e emissions, kt CO_2–e

	2025 submission	2026 submission	Change	Reasons for recalculation (kt CO_2–e)	
Year	(kt CO_2–e)	(kt CO_2–e)	(kt CO_2–e)	A	B
1989–90	1,563	1,239	-324	-280	-44
1994–95	-4,687	-4,743	-57	-95	39
1999–00	7,401	7,359	-42	-19	-23
2004–05	-16,297	-16,355	-58	-16	-43
2005–06	-10,254	-10,301	-48	-12	-35
2006–07	-8,122	-8,126	-3	-9	6
2007–08	5,474	5,448	-26	-10	-16
2008–09	14,237	14,233	-4	8	-12
2009–10	17,362	17,379	17	18	-1
2010–11	24,573	24,585	13	36	-23
2011–12	7,645	7,631	-13	34	-48
2012–13	-3,747	-3,773	-26	29	-54
2013–14	-10,774	-10,716	57	117	-60
2014–15	-15,792	-15,810	-18	54	-72
2015–16	-35,319	-35,237	82	107	-25
2016–17	-34,643	-34,574	69	91	-22
2017–18	-51,510	-51,455	55	64	-9
2018–19	-38,117	-38,175	-58	-56	-2
2019–20	-38,650	-38,605	45	14	31
2020–21	-30,775	-30,493	282	269	14
2021–22	-18,822	-17,443	1,380	1,382	-2
2022–23	-16,327	-16,614	-287	-290	3

6.4.1.6 Category-specific planned improvements

Harvested native forests

Australia plans to complete the transition to a comprehensive Tier 3, Approach 3 fully spatial model for the *harvested native forests* sub-category. This approach has already been implemented for four states: Victoria, New South Wales, Tasmania and Queensland. This enables the ongoing incorporation of the most recent empirical research into aboveground biomass, allometrics, turnover and decay factors into the *harvested native forests* sub-category. The inclusion in this method of Western Australian native forest harvesting remains a priority.

The estate model method for private forests will also be updated drawing on data and factors drawn from the spatial model for public forests.

Improved calibrations for forest growth and disturbance

Work is in progress to compile additional field measurements for growth and disturbance in forests and rangelands. This will result in revision of parameters including those relating to tree growth, turnover and decay, loss of biomass due to fire and timber harvesting, and the rate at which biomass recovers from disturbances. A revised vegetation classification in development will refine the association of these parameters to vegetation types.

Forest cover change

The remote sensing programme to detect forest cover change is being updated from the Landsat time series at 25m resolution to use Sentinel 2 satellite imagery at 10m resolution. It is expected that this significant improvement will be included in the next submission.

Systems for the estimation of areas of forest conversion and related assessments of the gains and losses of sparse woody vegetation will continue to be updated to enable consumption of information contained in datasets obtained from the NSW and Queensland State Governments' Statewide Landcover and Trees Study programs and similar products as they develop. The new systems will continue to build on experience gained in the use of these datasets during the finalisation of the area estimates for this inventory.

Specifically, the remote sensing programme is further advancing the methods to enable:

- ongoing improvements and development of rule-based methods for change detection and attribution;
- processing of remaining areas of vegetation monitoring for parts of central Australia to complete the national coverage; and
- estimation of above-ground biomass from remote-sensed canopy cover.

6.4.2 Land Converted to Forest Land

6.4.2.1 Category description

Land converted to forest land includes the sub-categories *grassland converted to forest land, cropland converted to forest land, settlements converted to forest land* and *wetlands converted to forest land.*

Grassland converted to forest land contains forest established on land that was previously non-forest. These conversions include commercial plantations and environmental plantings, forest that has regrown on land that was previously converted from a forest to grassland, and regeneration from natural seed sources on land protected by state or territory vegetation management policies.

Cropland converted to forest land and *settlements converted to forest land* contains forest that has regrown on land that was previously converted from forest land to the land use identified.

Wetlands converted to forest land comprises land on which mangrove forest has been detected to emerge on tidal marshes.

The annual net emissions for the *land converted to forest land* category are shown in Table 6.4.19.

Activity data related to regrowth on previously cleared forest land, commercial plantations and environmental planting and natural regeneration relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1).

A hybrid approach was used to update emissions estimates for the *land converted to forest land* category. For regrowth on previously cleared land, plantations and mangrove forests, reported areas and disaggregated emissions were not updated because the impacts of climate data and vegetation monitoring activity data were not able to be updated independently, or independent climate updates were considered unlikely to be representative of emissions trends and subject to material revision once activity data becomes available. In these categories, holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data, and unsuitability of trend extrapolation given interannual variability of climate drivers. Consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3: Resolving data gaps), emissions for these categories have been held constant at 2021–22 levels for 2022–23 and 2023–24.

For natural regeneration, areas of *land converted to forest land* were held constant for 2022–23 and 2023–24, while updates to climate and forest productivity data updates were incorporated to improve estimates of emissions from regenerating forests. These updates were incorporated because climate conditions since 2022 have materially affected emissions in this sector, robust methods exist to partially update the modelling, and because climate-driven changes are judged unlikely to be significantly revised once new vegetation monitoring data becomes available. The data updates show the moderation of forest growth to more typical levels. This is consistent with climate conditions that have transitioned out of the prolonged La Niña period that was associated with elevated rainfall including significant flooding in different regions of Australia in 2020, 2021 and 2022. This hybrid approach provides the most reliable estimates given current data constraints. It balances the need for completeness and methodological consistency with the opportunity to incorporate category specific updates where supporting data exist.

Activity data updates related to wildfire and non-temperate fire management emissions in *Grassland converted to forest land* were also included in this submission.

Table 6.4.19 Annual net emissions for land converted to forest land, kt CO_2–e

Year	Cropland converted to forest land	Grassland converted to forest land	Settlements converted to forest land	Wetlands converted to forest land	Total
1989–90	-81	-3,240	-18	-2,733	-6,072
1994–95	-166	-8,945	-81	-3,348	-12,540
1999–00	-288	-19,235	-156	-3,506	-23,185
2004–05	-224	-13,567	-217	-3,977	-17,984
2005–06	-225	-20,590	-210	-3,541	-24,565
2006–07	-215	-17,186	-204	-3,701	-21,307
2007–08	-219	-17,840	-185	-4,272	-22,516
2008–09	-202	-20,146	-179	-3,655	-24,182
2009–10	-204	-22,479	-183	-4,168	-27,034
2010–11	-247	-39,397	-159	-4,530	-44,333
2011–12	-286	-28,070	-174	-4,381	-32,911
2012–13	-268	-24,390	-220	-4,197	-29,075
2013–14	-289	-31,360	-253	-4,131	-36,033
2014–15	-324	-27,635	-247	-4,270	-32,476
2015–16	-380	-39,211	-346	-3,874	-43,812
2016–17	-451	-38,628	-326	-4,332	-43,736
2017–18	-435	-30,739	-363	-4,304	-35,841
2018–19	-371	-25,260	-324	-3,931	-29,886
2019–20	-423	-29,991	-335	-4,330	-35,080
2020–21	-544	-42,266	-399	-4,688	-47,897
2021–22	-627	-43,553	-389	-4,643	-49,212
2022–23	-627	-38,966	-389	-4,643	-44,626
2023–24	-627	-34,277	-389	-4,643	-39,936

6.4.2.2 Methodological issues

Plantations

Each individual 25m x 25m pixel identified as being a *plantation* is modelled through time from the time of establishment. Each 25m x 25m model takes into account the age, plantation type, management (including time of harvesting as detected from satellite imagery) and site conditions to estimate emissions and removals. Precise pixel areas are adjusted for the curvature of the earth to ensure the most accurate representation of areas and emissions for each location. Further information on the parameters used in modelling is provided in Annex 5.6.2.

The activity data for plantations in the *grassland converted to forest land* classification is drawn from the remote sensing program (see Annex 5.6.1) (Table 6.4.20). As noted in section 6.4.2.1, the forest cover monitoring system was not available for use in the 2024 report. Reported areas and disaggregated emissions for plantations have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3 Resolving data gaps). As described in relation to plantations in *forest land remaining forest land,* emissions trends over recent years are influenced by age class, harvesting rates, and climatic factors, and emissions trends are subject to significant inter-annual variability. Assuming a continuation of recent trends would not be suitable for predicting 2022–23 and 2023–24 emissions. It was determined that holding emissions constant would be the most appropriate extrapolation method.

Table 6.4.20 Cumulative area of plantations in grassland converted to forest land

Year	Area (ha)
1989–90	19,170
1994–95	195,153
1999–00	380,104
2004–05	740,716
2009–10	1,020,561
2010–11	1,060,663
2011–12	1,090,475
2012–13	1,102,089
2013–14	1,104,707
2014–15	1,119,834
2015–16	1,131,366
2016–17	1,133,720
2017–18	1,132,290
2018–19	1,127,523
2019–20	1,122,412
2020–21	1,124,909
2021–22	1,125,153
2022–23	1,125,153
2023–24	1,125,153

Native Vegetation

The emissions and removals arising due to the regrowth of native vegetation on previously-cleared land, and due to the emergence of forest in protected areas, are estimated using the spatially explicit (Approach 3) capabilities of the Tier 3 FullCAM modelling system. A full description of the modelling system is provided in Annexes 5.6.2 and 5.6.4, and Waterworth et al. (2007), Waterworth and Richards (2008).

Reporting includes carbon in living biomass, dead organic matter (DOM) and soil pools. The areas are drawn from remotely sensed data. As noted in section 6.4.2.1, the forest cover monitoring system was not available for use in the 2024 report. A hybrid approach was used to update emissions estimates for native vegetation. For regrowth on previously cleared land reported areas and disaggregated emissions have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3 Resolving data gaps). For natural regeneration, areas of land converted to forest land were held constant for 2022–23 and 2023–24, while updates to climate and forest productivity data updates were incorporated to improve estimates of emissions from regenerating forests. These updates were incorporated because climate conditions since 2022 have materially affected emissions in this sector, robust methods exist to partially update the modelling, and because climate-driven changes are judged unlikely to be significantly revised once new vegetation monitoring data becomes available. The data updates show the moderation of forest growth to more typical levels. This is consistent with climate conditions that have transitioned out of the prolonged La Niña period that was associated with elevated rainfall including significant flooding in different regions of Australia in 2020, 2021 and 2022. This hybrid approach provides the most reliable estimates given current data constraints. It balances the need for completeness and methodological consistency with the opportunity to incorporate category specific updates where supporting data exist.

Most areas will be classified as *grassland converted to forest land. Cropland converted to forest land* and *settlements converted to forest land* are identified where forest has regrown on land that was previously converted from forest land to the land use in question. These conversions do not always mean that the land has ceased being used for its converted purpose, but that a canopy of trees has been detected as re-emerging above the identified land use. For example, a canopy may emerge due to the urban landscaping of parks and gardens, or the restoration of riparian vegetation along waterways in cropping regions. The re-emergence of sufficient trees as would meet the definition of a forest requires that these lands to be recognised as converted to forest for the purposes of the national inventory.

Table 6.4.21 Cumulative areas of land converted to forest land with native vegetation, ha

Year	Regrowth on grasslands	Regrowth on croplands	Regrowth on settlements	Forest emerging in protected areas
1989–90	782,463	34,281	13,722	2,084,364
1994–95	1,447,497	63,673	32,131	3,429,061
1999–00	1,732,389	63,683	42,150	4,335,240
2004–05	1,788,299	56,619	46,547	5,097,827
2009–10	2,334,598	62,943	50,300	6,038,632
2010–11	2,558,729	68,152	53,111	6,259,184
2011–12	2,752,705	71,944	57,452	6,462,064
2012–13	2,956,345	75,491	60,044	6,676,805
2013–14	3,168,661	79,819	63,055	6,937,365
2014–15	3,429,800	87,743	68,987	7,202,248
2015–16	3,612,734	91,820	71,773	7,528,253
2016–17	3,755,192	99,871	74,875	7,823,713
2017–18	3,750,406	103,534	75,297	8,056,342
2018–19	3,747,062	105,590	78,524	8,264,538
2019–20	3,750,115	106,768	80,672	8,465,848
2020–21	3,777,440	108,626	81,805	8,769,716
2021–22	4,030,737	116,504	85,208	9,163,686
2022–23	4,030,737	116,504	85,208	9,163,686
2023–24	4,030,737	116,504	85,208	9,163,686

Mangrove forests

Australia's continental expanse incorporates a wide range of climate zones and coastal features that together determine the character of its coastal wetlands, including their carbon emissions and removal capacity. Mangrove forests are one of eight native forest types. They are found in the intertidal zones of tropical, subtropical and sheltered temperate coastal rivers, estuaries and bays. They grow in fine sediments deposited by rivers and tides, where they are regularly exposed to tidal inundation and lack of oxygen in the soil. They occupy an estimated 1,110,000 hectares around the Australian coastline (ABARES 2023). Mangroves meet Australia's definition of forests.

Tidal marshes comprise salt tolerant succulent herbs, sedges and grasses covering an estimated area of 1.4 million hectares in Australia. They are typically situated higher in the intertidal zone than mangrove, with the highest areas of tidal marsh only inundated at the highest spring tides (Metcalfe 1999). They are often subject to hypersaline conditions. Tidal marsh species diversity increases with increasing latitude in Australia; an association that appears strongly linked to mean minimum daily temperature 0.

The emergence of mangrove forest is identified using satellite imagery, as for other native forest. Mangrove forests are generally bordered by seawater on the lower side and by salt marsh on the higher side. Most emerging coastal mangrove forest does so on land which was previously tidal marsh or bare tidal flat and is allocated to *wetland converted to forest land.* Re-emergence of mangroves on land previously converted to settlements is allocated to *settlements converted to forest land.*

Carbon dioxide emissions and removals are modelled using FullCAM, a spatially explicit Tier 3 modelling system calibrated, in this model, to mangrove ecosystems around Australia's coastal land area (Annex 5.6.10 with reference to Annexes 5.6.1 and 5.6.2). As noted in section 6.4.2.1, the forest cover monitoring system was not available for use in the 2024 report. Reported areas and disaggregated emissions for mangroves were not updated because the impacts of climate data and vegetation monitoring activity data were not able to be updated independently, or independent climate updates were considered unlikely to be representative of emissions trends and subject to material revision once activity data becomes available. Holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data, and unsuitability of trend extrapolation given interannual variability of climate drivers. Consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3: Resolving data gaps), emissions for this category have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach.

Table 6.4.22 Cumulative area of mangrove establishment, ha

Year	Regrowth on settlements	Regrowth and establishment on wetlands
1989–90	459	94,162
1994–95	686	108,766
1999–00	706	122,995
2004–05	711	134,317
2009–10	725	148,709
2010–11	750	150,992
2011–12	791	154,954
2012–13	816	158,037
2013–14	828	160,157
2014–15	848	162,984
2015–16	870	164,368
2016–17	892	168,885
2017–18	903	171,297
2018–19	914	173,237
2019–20	917	173,348
2020–21	913	172,802
2021–22	918	174,707
2022–23	918	174,707
2023–24	918	174,707

6.4.2.3 Uncertainty assessment and time-series consistency

Uncertainty in the *land converted to forest land* sub-category is expected to be 16.8 per cent. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

Under *wetland converted to forest land* the confidence intervals associated with 2013 IPCC guidance (IPCC 2013) values for parameters associated with land use, land use change involving coastal wetlands are moderate. This inventory applies the spatially explicit FullCAM calibrated to available field data, sourced from scientific literature, to reduce uncertainty. Although a formal uncertainty analysis is not yet available, the level of uncertainty is anticipated to be 30–40% or the lower end of the guidance values and is considered to be within the medium range.

While there is a higher uncertainty in *wetlands converted to forest land* than in *grassland converted to forest land* estimates, the former category makes only a small contribution to the overall uncertainty of *land converted to forest land* due to its lower emissions.

6.4.2.4 Category-specific QA/QC and verification

Tier 1 quality control checks are complimented by an analysis of forest establishment rates, as shown in Figure 6.1.5. Trends in historic establishments provide context to present sequestration rates and provide confidence that the strong sinks being estimated in the most recent years are realistic.

See Annex 5.6 for evaluation of the model processes used for Land Converted to Forest Land.

6.4.2.5 Category-specific recalculations

The recalculation of the *land converted to forest land* time series is presented in Table 6.4.23. Emissions have been recalculated as a result of updating climate, forest productivity and fire time series and adding an additional year of data.

Table 6.4.23 Land converted to forest land: recalculation of total CO_2–e emissions (kt)

	2025 submission	2026 submission	Recalculation
Year	(kt CO_2–e)	(kt CO_2–e)	(kt CO_2–e)
1989–90	-6,057	-6,072	-15
1994–95	-12,528	-12,540	-12
1999–00	-23,178	-23,185	-7
2004–05	-17,961	-17,984	-23
2005–06	-24,542	-24,565	-22
2006–07	-21,270	-21,307	-37
2007–08	-22,487	-22,516	-29
2008–09	-24,166	-24,182	-17
2009–10	-27,049	-27,034	14
2010–11	-44,344	-44,333	11
2011–12	-32,867	-32,911	-45
2012–13	-29,089	-29,075	14
2013–14	-36,045	-36,033	12
2014–15	-32,437	-32,476	-38
2015–16	-43,771	-43,812	-41
2016–17	-43,675	-43,736	-61
2017–18	-35,760	-35,841	-81
2018–19	-29,832	-29,886	-54
2019–20	-35,057	-35,080	-23
2020–21	-47,847	-47,897	-50
2021–22	-49,172	-49,212	-39
2022–23	-49,782	-44,626	5,156

6.4.2.6 Category-specific planned improvements

Improved calibrations for forest growth and disturbance

Work is in progress to compile additional field measurements for growth and disturbance in forests and rangelands. This will result in revision of parameters including those relating to tree growth, standing dead, turnover and decay, loss of biomass due to fire and timber harvesting, and the rate at which biomass recovers from disturbances. A revised vegetation classification in development will refine the association of these parameters to vegetation types.

Improved parameters for soil carbon will also be applied, with a run-in process to begin models with soil at equilibrium for the prevailing conditions.

Forest cover change

The remote sensing programme to detect forest cover change is being updated from the Landsat time series at 25m resolution to use Sentinel 2 satellite imagery at 10m resolution. It is expected that this significant improvement will be included in the next submission.

Systems for the estimation of areas of forest conversion and related assessments of the gains and losses of sparse woody vegetation will continue to be updated to enable consumption of information contained in datasets obtained from the NSW and Queensland State Governments' Statewide Landcover and Trees Study programs and similar products as they develop. The new systems will continue to build on experience gained in the use of these datasets during the finalisation of the area estimates for this inventory.

Specifically, the remote sensing programme is further advancing the methods to enable:

- ongoing improvements and development of rule-based methods for change detection and attribution;
- processing of remaining areas of vegetation monitoring for parts of central Australia to complete the national coverage; and
- estimation of above-ground biomass from remote-sensed canopy cover.

6.5 **Cropland** (CRT category 4.B)

6.5.1 Cropland Remaining Cropland

6.5.1.1 Category Description

The *cropland remaining cropland* sub-category includes continuous cropping lands and lands that are cropped in rotation with pastures. Croplands are considered to be of high land value with a high return on production and moderate to high soil nutrient status and are therefore not generally converted to *forest land* or *grassland* but remain as *cropland.*

Anthropogenic emissions and removals on croplands occur as a result of changes in management practices from changes in crop type and from changes in land use. Permanent changes in management practices generate changes in the levels of soil carbon or woody biomass stocks over the longer term. Changes in carbon stock levels during the transition period to a new stock equilibrium are recorded under croplands.

Emissions and removals from *grassland converted to cropland* are reported under *cropland remaining cropland* because annual variations in area under cropping in Australian agricultural systems do not constitute a permanent land-use change. Activity data for crop-pasture rotations based on Australian national statistical information includes permanent conversions to croplands. This is appropriate for national circumstances and Australian agricultural systems which apply predominantly rain-fed cropping practices and respond to market fluctuations, resulting in seasonal variations in the lands under cropping rather than permanent land-use changes. The 2006 IPCC guidelines (IPCC 2006) permit such an approach where appropriate based on the activity data (for example where prior land use is not known, see *2006 IPCC Guidelines,* Vol 4, Ch 5.3.3 (IPCC 2006).

Anthropogenic emissions and removals from croplands are estimated from changes in specified management practices on croplands including:

- Total cropping area;
- Crop type and rotation (including pasture leys);
- Stubble management, including burning practices;
- Tillage techniques;
- Irrigation; and
- Application of green manures (particularly legume crops).

Conversion of pasture to cropping activities is included within the *cropland remaining cropland* estimates.

Carbon dioxide emissions from the application of lime are reported under *Agriculture.* Nitrous oxide emissions from the application of fertiliser are also reported under *Agriculture.*

Climate has important cyclical effects throughout the time series. The uptake of reduced, minimum and no-till management techniques through the 1980s and 90s is reflected in the tendency towards decreasing emissions during this period as a new soil C state of equilibrium is reached. This downward trend is also inversely correlated with increasing crop production over the same period. Emissions reached their lowest levels in 2020–21 and 2021–22, coinciding with exceptionally high yields under wetter La Niña conditions. The divergence observed in 2022–23 and 2023–24 reflects the weakening influence of La Niña and lower rainfall relative to the preceding two years, resulting in reduced soil carbon gains and a smaller net sink.

Figure 6.5.1 Net CO_2 emissions from cropland remaining cropland

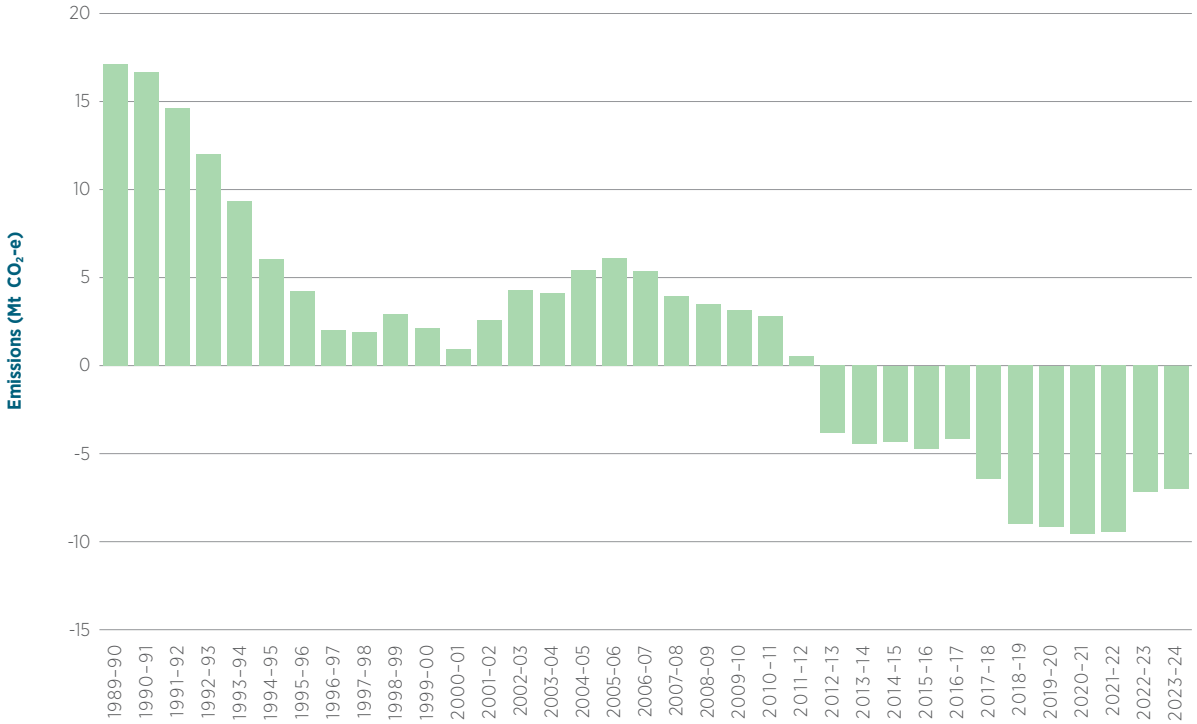


Table 6.5.1 Net emissions and removals from cropland remaining cropland sub-categories (kt CO_2–e)

Year	Soil carbon	Perennial woody crops (biomass)	Total
1989–90	17,160	-58	17,102
1994–95	6,162	-87	6,075
1999–00	2,155	-48	2,106
2004–05	5,609	-170	5,439
2005–06	6,268	-180	6,088
2006–07	5,317	34	5,350
2007–08	4,055	-107	3,948
2008–09	3,642	-146	3,496
2009–10	3,455	-277	3,178
2010–11	3,164	-345	2,819
2011–12	644	-105	539
2012–13	-3,908	93	-3,815
2013–14	-4,480	15	-4,465
2014–15	-4,230	-85	-4,316
2015–16	-4,507	-207	-4,714
2016–17	-3,898	-256	-4,155
2017–18	-6,330	-123	-6,453
2018–19	-8,804	-183	-8,987
2019–20	-8,826	-315	-9,142
2020–21	-9,130	-418	-9,548
2021–22	-8,899	-545	-9,444
2022–23	-6,682	-531	-7,213
2023–24	-6,975	-472	-7,447

6.5.1.2 Methodological issues

Carbon dioxide emissions and removals from the *cropland remaining cropland* soils component are estimated using FullCAM (Annex 5.6.2). The CO_2 emissions and removals associated with changes in the area of perennial woody crops are estimated using a Tier 2 approach outlined below.

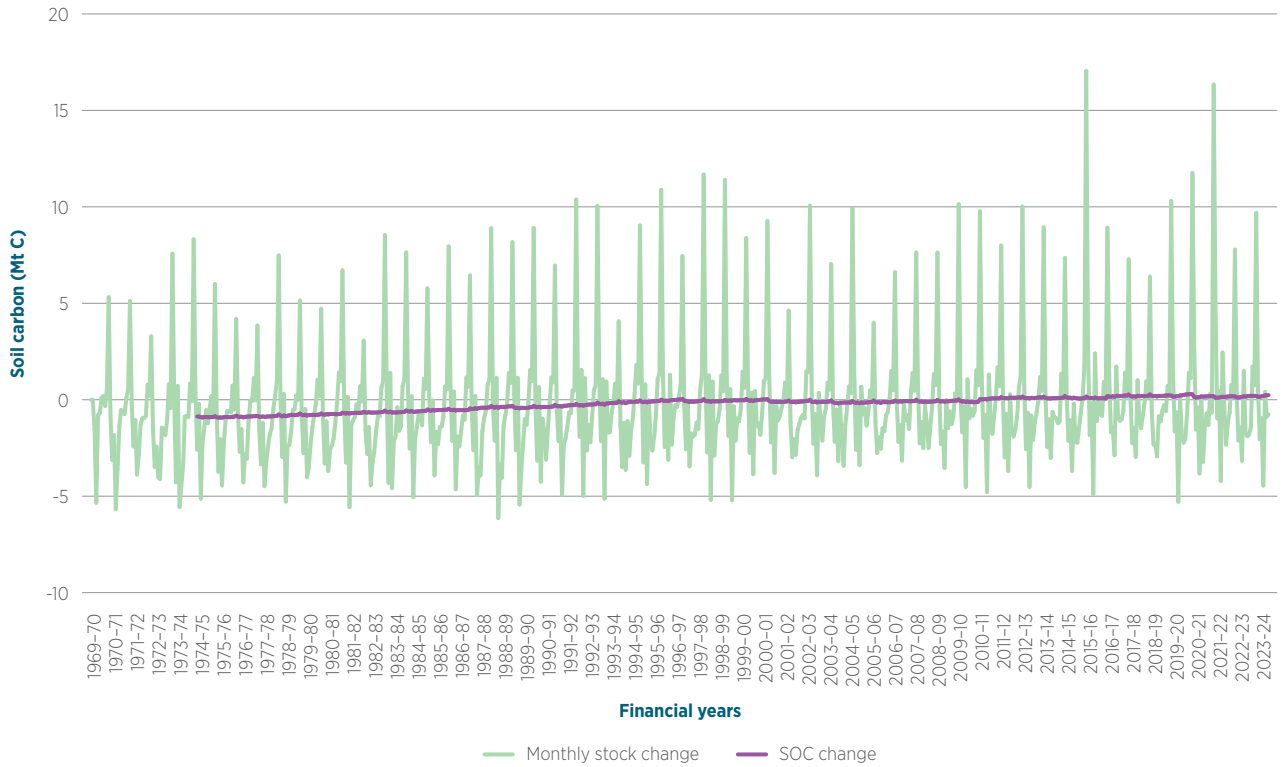
The area of *cropland* is estimated using the Catchment Scale Land Use of Australia dataset provided by ABARES (2017 version) at the mapping scale of 1:5000 to 1:250 000. Where a transition to or from forest within the preceding 50 years has not been identified, these lands are categorised as *cropland remaining cropland.*

Herbaceous crops

FullCAM is simulated in monthly time steps commencing at the time of first planting in 1970. When configured for cropland remaining cropland, FullCAM uses the same climate, site and management datasets as those used in the *forest land converted to cropland* estimates and as described in Annexes 5.6.2 and 5.6.5.

All on-site carbon pools (living biomass, dead organic matter (DOM) and soil) are estimated. For non-woody crops in *cropland remaining cropland* the changes in the soil carbon pool are reported. Carbon stock changes from living biomass and DOM of non-woody annual crops are reported to be zero, consistent with the guidance in the *2006 IPCC Guidelines* (IPCC 2006) that indicates that the increase in biomass stocks in a single crop year may be assumed equal to biomass losses from harvest and mortality in that year – thus there is no net accumulation of biomass carbon stocks (IPCC 2006, p5.7 (IPCC 2006)). In general, croplands will have little or no dead wood, crop residues or litter (IPCC 2006, p5.12 (IPCC 2006)). A mean incremental value for the transitions between soil organic carbon (SOC) near steady states is derived, in this case from the simulated monthly data, as shown in Figure 6.5.2.

Figure 6.5.2 Monthly carbon stock change from cropland remaining cropland



Management practice change has been monitored in the ABS Land Management and Farming (ABS 2017) which provides information on management practices being adopted and utilised by Australian agricultural business. Further details on changes in management practices are provided in Annex 5.6.5.

Perennial woody crops

The carbon dioxide emissions and removals from changes in the area of perennial woody crops are estimated using a country-specific Tier 2 approach. The Tier 2 method retains the basic Tier 1 approach from the *2006 IPCC Guidelines* (IPCC 2006), but with differences to the period over which biomass accumulates (harvest/maturity cycle) and use of more accurate crop-specific coefficients.

Crop-specific coefficients were sourced from literature to calculate CO_2 emissions and removals. The coefficients required are: total biomass carbon stock at harvest (tonnes C ha^{-1}), years to maturity (M), biomass accumulation rate (tonnes C ha^{-1} yr^{-1}) and plot density (trees ha^{-1}). The mathematical relationships between these coefficients are displayed in Table 6.5.2. Additionally, root to shoot ratios were sourced from the literature and biomass accumulations associated with fruit production were excluded from all calculations. Where parameters were derived from other countries, corrections were made to account for local conditions. For example, for olives, carbon accumulation rates were sourced from Spain where plot density was 408 trees per hectare, whereas in Australia plot density of olives is reported to be 250 trees per hectare. The Spanish carbon accumulation rate was adjusted relative to the Australian plot density factor.

Table 6.5.2 Calculations used to develop tier 2 coefficients for perennial woody crops

	total biomass carbon stock at harvest (t C ha^{-1})	harvest cycle (yr)	biomass accumulation rate (t C ha^{-1} yr^{-1})
calculations	M x y	M	y
e.g. (oranges)	5	10	0.5

In total, 27 perennial woody crop types are grouped by major crop-type. The coefficients applied to each group were based on the dominant crop type (Table 6.5.3). The four main crop-types and dominant crops are: 1) citrus, with crop coefficients represented by orange data, 2) Nuts, with crop coefficients represented by macadamia data, 3) pomes, with crop coefficients represented by apple data and 4) stone fruit, with crop coefficients represented by peach data. Other smaller crops modelled included: olives, grapes, kiwifruit, avocados and mangoes. Grape crop coefficients were used to model kiwifruit, and avocado coefficients were used to model mangoes. Regarding nuts, while macadamias were used as the representative crop, almonds were estimated separately as almond-specific coefficients were available.

Estimates of changes in area of perennial woody crops are taken from the *ABS agricultural commodities statistics* (ABS 2022a), which also account for planting and clearing events. Most crop data are provided as tree number values and subsequently were converted to area statistics using crop-specific plot density coefficients.

Table 6.5.3 Perennial woody crop Tier 2 coefficients

Crop type	total biomass carbon stock at harvest (t C ha^{-1})	harvest cycle (yr)	biomass accumulation rate (t C ha^{-1} yr^{-1})	plot density (trees ha^{-1})	root: shoot
Citrus					
Oranges	5	10[n]	0.5[a]	417[b]	0.17[c]
Nuts					
Macadamias	12.3	15[n]	0.82[e]	312[e]	0.25[e]
Almonds	9.6	8[n]	1.2[a]	222[f]	
Pomes					
Apples	4.9[g]	7[n]	0.7	1500[g]	0.17[c]
Stone fruit					
Peaches	5.2	4[n]	1.3[a]	740[h]	0.17[c]
Grapes	1.2	4[n]	0.3[a]	N/A	0.5[c]
Kiwifruits	1.5	5[n]	0.3[a]	N/A	0.5[c]
Olives	6.7	10[n]	0.67[j]	250[k]	0.145[c]
Avocados	6[l]	10[n]	0.6	210[l]	0.125[l]
Mangoes	13[l]	10[n]	1.3	185[m]	0.125[l]
IPCC default	63		2.1		

Source and location of study is: *a* = (Kroodsma and Field 2006) USA California, *b* = (Morgan, et al. 2006) USA Florida, c = (Federal Environment Agency 2013), (Ministerio de Agricultura 2013) *d* = Australian Macadamia Society website, *e* = (Murphy, et al. 2013) Australia, *f* = (Fernandez-Puratich 2013) Spain, *g* = (Haynes and Goh 1980) New Zealand, *h* = (Marini and Sowers 2000) USA, *i* = (San Felipe Olives 2014) USA California, *j* = (Villalobos, et al. 2006) Spain, *k* = (Olives Australia 2014), *l* = (Lovatt 1996) USA California, *m* = (Department of Primary Industries and Regional Development 2017), and *n* = (Department of Agriculture and Fisheries, Queensland 2014). Note that plot density is represented by N/A for Grapes and Kiwifruit as reported in hectares by ABS. All figures not referenced were determined using calculations in Table 6.5.2.

6.5.1.3 Uncertainty assessment and time-series consistency

Based on a qualitative assessment the uncertainties for *cropland remaining cropland* were estimated to be medium. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

There are a number of gaps in the time series of *ABS commodities statistics* (ABS 2022a) for perennial woody crops, in particular for the 2021–22 financial year, the ABS Rural Environment and agricultural commodities survey received a very low response rate and statistics were not available for most perennial woody crops. All data-gaps were filled using extrapolation and interpolation techniques consistent with the *2006 IPCC Guidelines* (IPCC 2006). In the 2023–24 year (this submission), almost no data updates were available, as the ABS is in the process of modernising the collection and reporting of agricultural statistics (as described in section 5.1.1). As recent years have had unusually high rainfall, it was judged that extrapolation would not represent the trend in woody horticulture practices and activity data were held constant at 2021–22 values. When new data are available as the ABS completes its modernisation programme, recalculations may be required.

6.5.1.4 Category-specific QA/QC and verification

Extensive QA/QC of FullCAM shows that the results closely align to the Tier 2 steady-state soil carbon model (T2SSM) provided in Volume 4, Chapter 5 of the *2019 Refinement to the 2006 IPCC Guidelines* (IPCC 2006). This work is described in Annex 5.6.2.

In relation to crop yields, CSIRO Agriculture and Food has tested the performance of the crop growth model against a database of crop yields (see Annex 5.6.5).

The calibration, validation and verification of FullCAM, along with the associated quality assurance and quality control programme are fully described in Annex 5.6.2.

6.5.1.5 Category-specific recalculations

The recalculation of the *cropland remaining cropland* time series is presented in Table 6.5.4, Emissions have been recalculated as a result of updating the climate and fire time series, crop and grass yields and adding an additional year of data.

Table 6.5.4 Cropland remaining cropland: Recalculation of CO_2–e emissions

	2025 submission	2026 submission	Recalculation
Year	kt CO_2 -e	kt CO_2 -e	kt CO_2 -e
1989–90	17,102	17,102	0
1994–95	6,075	6,075	0
1999–00	2,106	2,106	0
2004–05	5,439	5,439	1
2005–06	6,088	6,088	1
2006–07	5,349	5,350	1
2007–08	3,947	3,948	1
2008–09	3,496	3,496	1
2009–10	3,178	3,178	1
2010–11	2,819	2,819	0
2011–12	539	539	0
2012–13	-3,815	-3,815	0
2013–14	-4,466	-4,465	0
2014–15	-4,316	-4,316	0
2015–16	-4,714	-4,714	0
2016–17	-4,154	-4,155	0
2017–18	-6,452	-6,453	0
2018–19	-8,987	-8,987	0
2019–20	-8,663	-9,142	-479
2020–21	-10,174	-9,548	626
2021–22	-10,069	-9,444	625
2022–23	-7,830	-7,213	617

6.5.1.6 Category-specific planned improvements

Refining the spatial allocation of crop species is being investigated. It is envisaged that by incorporating additional covariate data, the accuracy of spatial allocation of crop types can be improved to better reflect national and regional trends.

Investigations into using pixel-based climate data to derive crop yields at finer resolution than statistical area 2 are progressing. It is hoped that this will better reflect the impact of regional differences in climate on crop yields.

The handling of the below-ground debris pool within FullCAM is being investigated to determine the optimal behaviour of the relationship of the Roth-C implementation and changing management practices. Handling of turnover and debris breakdown rates are being investigated. The initialisation of soil carbon pools within FullCAM is being investigated to determine the optimal starting values that more accurately reflect the measured carbon soil fractions at any given period in time.

The calibration of the impact of tillage activities within the FullCAM modelling framework is being refined. This will improve the estimation of the impact that varying tillage practices, such as minimum and no till, have on soil decay functions. Additionally, investigating the timing and parameters associated with pre- and post-harvest management events will enable more accurate modelling of their impacts to better reflect the entry of crop residues into the soil. Stubble management allocations and persistence are being reviewed to ensure they reflect up to date regional practices.

6.5.2 Land converted to cropland

6.5.2.1 Category description

Within the *land converted to cropland* subcategory, Australia reports emissions for *forest land converted to cropland* and *wetlands converted to cropland* subcategories. Net emissions from conversions between croplands and grasslands are included in *cropland remaining cropland* as it is common for cropping systems to include pasture/grazing rotations.

The *wetland converted to cropland* subcategory includes the conversion of wetlands to cropping, irrigated cropping and perennial horticulture, and involves mineral and organic hydrosols.

As Table 6.5.5 below indicates, *forest land converted to cropland* is the dominant contributor to both the level and trend in net emissions in this sub-category.

Table 6.5.5 Net emissions from land converted to cropland by sub-category, kt CO_2–e

Year	Forest land converted to cropland	Wetlands converted to cropland	Total
1989–90	17,450	241	17,691
1994–95	5,149	241	5,390
1999–00	3,104	241	3,345
2004–05	3,297	241	3,538
2005–06	6,512	241	6,753
2006–07	3,225	241	3,466
2007–08	3,164	241	3,405
2008–09	2,326	241	2,567
2009–10	3,439	241	3,680
2010–11	3,333	241	3,574
2011–12	-2,007	241	-1,766
2012–13	6,347	241	6,588
2013–14	3,717	241	3,958
2014–15	3,627	241	3,868
2015–16	1,484	241	1,725
2016–17	1,656	241	1,897
2017–18	106	241	347
2018–19	2,161	241	2,402
2019–20	1,232	241	1,473
2020–21	1,746	241	1,987
2021–22	-193	241	48
2022–23	-342	241	-101
2023–24	1,155	241	1,396

6.5.2.2 Methodological issues

Forest land converted to cropland

The methodology for the subcategory *forest land converted to cropland* is consistent with that used for native vegetation systems in *forest land converted to grassland,* which is described in more detail in Chapter 6.6.2.2. An area of land is identified as being converted to cropland rather than to grassland if it would otherwise fall within cropland areas as identified for *cropland remaining cropland* (see chapter 6.5.1.2). Within the FullCAM framework, a database of cropland-relevant species is used in place of the database of grassland-relevant species for non-forest land use.

The activity data for the *forest land converted to cropland* classification relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1). Reported areas have been held constant at 2021–22 levels for 2022–23 and 2023–24, while updates to climate and crop and grass yield data were incorporated to improve estimates of emissions on previously cleared lands. These updates mean that forest land converted to cropland use consistent inputs as *grasslands remaining grasslands* in 2023 and 2024.

This hybrid approach provides the most reliable estimates given current data constraints. It balances the need for completeness and methodological consistency with the opportunity to incorporate category specific updates where supporting data exist.

Wetlands converted to cropland

Areas of *wetlands converted to cropland* were estimated using IPCC Approach 2 using activity data for 1996 and 2010 acquired from *Australian Collaborative Land Use and Management Program* (ACLUMP) (ABARES 2016b). Spatial information on final land uses, including grazing on native, improved and irrigated pastures, and cropping, irrigated cropping and perennial horticulture, was used in conjunction with available wetlands spatial data to estimate conversions to cropland and grazing land. In addition, expert opinion was provided by C. Meyer (personal communication, 2019) that identified 4,000 ha of histosols associated with cropping or grazing in Queensland and Victoria, based on the CSIRO Australian Soil Classification System (Isbell 2002).

Following IPCC guidance (Volume 1, Chapter 2.2.3) extrapolation and interpolation methods were used to calculate an average annual rate of conversion of wetlands to cropland or grassland over the required time period for each state and territory. The default IPCC time period of 20 years was used for land remaining in transitional categories so that emissions from organic and mineral soils on converted lands continue to be estimated over this time.

With respect to biomass and dead organic matter, only non-woody biomass is assumed to be present in the wetlands prior to conversion – noting that conversions of forested wetlands are already accounted for in the inventory. Therefore, the IPCC tier 1 assumption, that no net change in biomass or dead organic matter stocks from conversion of wetlands to cropland occurs, was applied in this model.

Wetland converted to cropland on organic soils is distributed between Queensland, where 2,250 ha of coastal organic hydrosols were drained for sugar cane farming, and a further 750 ha in Victoria where highland organic hydrosols were drained for cropping. The remaining wetland to cropland conversions involved mineral hydrosols. Several soil-related emission factor values are applied based on stratification with respect to soil type (mineral or organic) and climate zone.

For organic soils, Equation 2.26 from 2006 IPCC Guidelines Vol 4 (IPCC 2006) was used to estimate the annual emissions:

$$L_{organic} = A \times EF \qquad (6.5.1)$$

Where L = emissions from draining organic soils organic
A = area converted
EF = emission factor

The tropical and temperate/boreal IPCC default emission factors were applied based on the tropical north Queensland and Victorian highland locations of the relevant croplands. Emission factor values for tropical and temperate/boreal croplands on drained organic soils are 14 and 7.9 tonnes CO_2–C/ha/year respectively (Table 2.1, 2013 Wetlands Supplement).

Conversions involving wetlands on mineral soils were dispersed over several climate zones. A tier 1 approach was used to estimate annual change in organic carbon stock in mineral soils over a 20–year transition period, based on Equation 2.25 (IPCC 2006) Volume 4, p 2.30. The exact distribution of the conversions within each state and territory was not known. Consequently, averaged climate zone and soil reference values were applied at a state and territory level; Queensland and the Northern Territory comprise Tropical wet and dry climate zones, Tasmania was considered cool temperate moist, and all other states were warm temperate (moist or dry). Australia's soils were generally weathered (Low activity clay), and were long term cultivated with (on average) reduced tillage and medium inputs. Based on these assumptions the following average annual changes in carbon stocks were derived and applied to their respective states to estimate annual emissions:

- Queensland/ Northern Territory: 2.97182 tonnes C / ha / year,
- Tasmania: 0.882 tonnes C / ha / year,
- All other States/Territories: 3.031063 tonnes C /ha / year.

Emissions from each state and territory were calculated, based on area, and then aggregated to give the annual national totals.

Activity data

The activity data for the *forest land converted to cropland* classification is drawn from the remote sensing program (see Annex 5.6.1). As outlined in Chapter 6.5.2.2, the activity data was not available for use in the 2024 report. Reported areas have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3 Resolving data gaps). The method for determining activity data for *wetlands converted to cropland* is described above. Table 6.5.6 below shows the cumulative areas of *forest land* and *wetlands* that were *converted to croplands* over the period since remote sensing commenced in 1971–72.

Table 6.5.6 Cumulative area of land converted to cropland, kha

Year	Forest land converted to cropland	Wetlands converted to cropland	Total
1989–90	1,914	13	1,926
1994–95	2,052	13	2,064
1999–00	2,157	13	2,170
2004–05	2,238	13	2,251
2005–06	2,251	13	2,264
2006–07	2,263	13	2,276
2007–08	2,269	13	2,282
2008–09	2,272	13	2,284
2009–10	2,272	13	2,284
2010–11	2,272	13	2,284
2011–12	2,273	13	2,285
2012–13	2,275	13	2,287
2013–14	2,276	13	2,288
2014–15	2,272	13	2,285
2015–16	2,272	13	2,285
2016–17	2,267	13	2,280
2017–18	2,266	13	2,279
2018–19	2,267	13	2,280
2019–20	2,268	13	2,280
2020–21	2,268	13	2,281
2021–22	2,262	13	2,274
2022–23	2,262	13	2,274
2023–24	2,262	13	2,274

6.5.2.3 Uncertainty assessment and time-series consistency

Uncertainties for *forest land converted to cropland* at the national scale were estimated to be ±27.9 per cent for CO_2. Further details are provided in Annex 2. Time series consistency is ensured using consistent methods and full recalculations in the event of any refinement to the methodology.

The current Tier 1 method for *wetlands converted to cropland* relies on interpolation and extrapolation with respect to two observational years. ABARES does not report on uncertainty about the land use estimates. However, these likely fall in the medium to high range.

While there is a higher uncertainty in *wetlands converted to cropland* than in *forest land converted to cropland,* the former category makes only a small contribution to the overall uncertainty of *land converted to cropland due to its lower emissions.*

6.5.2.4 Category-specific QA/QC and verification

The category specific QA/QC for the subcategory *forest land converted to cropland* is carried out together with that for *forestland converted to grassland* (see Chapter 6.6.2.4).

Quality control measures for *wetlands converted to cropland* involve internal reviews of data entry and model outputs, including a check on the consistency of land use statistics across Australian jurisdictions.

6.5.2.5 Category-specific recalculations

The recalculation of the *land converted to cropland* time series is presented in Table 6.5.7. Emissions have been recalculated as a result of updating the climate and fire time series, crop and grass yields and adding an additional year of data.

Table 6.5.7 Land converted to cropland: Recalculation of CO_2–e emissions (kt)

Year	2025 Submission ($kt\ CO_2$–e)	2026 Submission ($kt\ CO_2$–e)	Recalculation ($kt\ CO_2$–e)
1989–90	17,690	17,690	0
1994–95	5,390	5,390	0
1999–00	3,345	3,345	0
2004–05	3,538	3,538	0
2005–06	6,753	6,753	0
2006–07	3,466	3,466	0
2007–08	3,405	3,405	0
2008–09	2,567	2,567	0
2009–10	3,680	3,680	0
2010–11	3,574	3,574	0
2011–12	-1,766	-1,766	0
2012–13	6,588	6,588	0
2013–14	3,958	3,958	0
2014–15	3,868	3,868	0
2015–16	1,725	1,725	0
2016–17	1,897	1,897	0
2017–18	347	347	0
2018–19	2,402	2,402	0
2019–20	1,473	1,473	0
2020–21	1,986	1,986	0
2021–22	47	47	0
2022–23	47	-102	-149

6.5.2.6 Category-specific planned improvements

Please see Chapter 6.6.2.6 for planned improvements for the subcategory *forest land converted to grassland* which are directly relevant to *forest land converted to cropland.*

Future work will also build on the current spatial and temporal analysis of the relevant activities involved in wetland to cropland conversions and better resolve the distribution of associated organic and mineral hydrosols. This will improve the stratification of the model and therefore the calculation of the regional emission factors applied.

6.6 **Grassland** (CRT category 4.C)

6.6.1 Grassland Remaining Grassland

6.6.1.1 Category description

The *grassland remaining grassland* category includes all areas of *grassland* that are not reported under *land converted to grassland.* Areas that are in rotational use between *grassland* and *cropland* are reported under either *forest land converted to cropland* or *cropland remaining cropland.*

Anthropogenic emissions and removals on grasslands result from changes in management practices on grasslands, particularly from changes in pasture and grazing; changes in savanna fire management practices; and changes in sparse woody vegetation that do not meet the definition of a forest. *Grassland remaining grassland* is reported in three components which align with each of these practices.

Permanent changes in management practices generate changes in the levels of soil carbon or woody biomass stocks over the longer term. As changes occur, carbon may be released as emissions or sequestered to the landscape. These impacts are transitory and are not permanent. After a time, the rate of net emissions or removals associated with the changed management practice will approach an equilibrium of approximately zero emissions until disturbed by another change in management practices.

The distribution of land areas in the *grassland remaining grassland* sub-category is estimated using the ABARES Catchment Scale Land Use of Australia 2017 at the mapping scale of 1:5000 to 1:250 000. The presence of sparse woody vegetation is identified from the remote sensing program (Annex 5.6.1).

Emission estimates for the components of *grassland remaining grassland* are reported in Table 6.6.1.

Table 6.6.1 Emissions and removals from grassland remaining grassland, by sub-category (kt CO_2–e)

Year	Herbaceous grasslands	Perennial woody biomass		Total
	Soil Carbon and Nitrogen mineralisation and run-off	Sparse Transitions	Savanna fire	
1989–90	-9,786	-3,085	10,476	-2,396
1994–95	-14,084	646	18,688	5,250
1999–00	-9,808	1,252	25,635	17,079
2004–05	6,647	2,839	8,735	18,221
2005–06	10,364	2,624	19,157	32,145
2006–07	3,415	2,549	18,903	24,866
2007–08	-2,385	1,831	10,857	10,304
2008–09	1,638	-581	14,254	15,311
2009–10	5,090	-2,740	10,490	12,841
2010–11	5,128	-4,574	7,982	8,537
2011–12	-478	-5,701	6,097	-82
2012–13	-3,755	-5,244	8,089	-910
2013–14	-1,439	-5,128	9,667	3,100
2014–15	790	-4,455	6,844	3,179
2015–16	1,389	-4,217	2,977	150
2016–17	5,722	-4,190	4,348	5,880

Year	Herbaceous grasslands	Perennial woody biomass		Total
	Soil Carbon and Nitrogen mineralisation and run-off	Sparse Transitions	Savanna fire	
2017–18	2,983	-4,242	507	-751
2018–19	-6,564	-4,229	567	-10,227
2019–20	-11,247	-4,382	951	-14,678
2020–21	-16,247	-4,867	1,147	-19,967
2021–22	-15,551	-5,227	10,632	-10,146
2022–23	-13,633	-5,227	14,946	-3,915
2023–24	-16,046	-5,227	18,460	-2,813

6.6.1.2 Methodological issues

Herbaceous Grasslands

Emissions and removals for herbaceous grasslands component are estimated using spatial simulations in the FullCAM framework.

Anthropogenic emissions and removals from grasslands are estimated from changes in specified management practices including:

- the area under grasslands;
- the area under grazing and changes in grazing intensity;
- woody biomass management; and
- fire management.

FullCAM estimates emissions from all on-site carbon pools (living biomass, dead organic matter (DOM) and soil). For the herbaceous grass component only the changes in the soil pool are reported. Carbon stock changes from living biomass and DOM of non-woody annual crops are reported to be zero, consistent with the guidance in *2006 IPCC Guidelines* (IPCC 2006) that indicates that the increase in biomass stocks in a single year may be assumed equal to biomass losses from harvest and mortality in that year – thus there is no net accumulation of biomass carbon stocks for non-woody biomass over the long term.

There are two main agro-ecological categories in grasslands:

- native arid grasslands which may include sparse woody vegetation and woodlands, and remain as primarily native grasses; and
- high-rainfall improved pastures.

The key management practices relevant to estimating changes in carbon stocks in the high rainfall pastures include grazing intensity and pasture composition. For the native arid and semi-arid grasslands, the key drivers include grazing intensity, fire management and the presence of woody vegetation.

Stratification of grasslands is undertaken based on climate and vegetation type. For the high rainfall pastoral regions, where cropping also occurs, the impacts of pasture composition and grazing have been modelled (Annex 5.6.5). In the arid rangelands areas it is assumed that these lands have remained native pastures and as such no stock changes are identified on these lands.

Initial soil carbon values are taken from the baseline map of soil organic carbon (Viscarra Rossel et al. 2015). Management practice change has been monitored in the ABS Land Management and Farming (ABS 2017) which provides information on management practices being adopted and utilised by Australian agricultural business.

Grazing pressure for each ABS Statistical Area 2 region across Australia is derived from the ABS Commodity Statistics. Published beef cattle, dairy cattle, and sheep population and age data from the Australian Bureau of Statistics Agriculture Commodities (ABS 2022a) are used to derive average feed amounts for these livestock types. This data is combined to calculate the grazing pressure for each statistical area 2 (SA2) which is then inserted into FullCAM as a fraction of standing dry matter eaten (t/ha) relative to the amount of dry matter produced (t/ha) each day across grassland areas. For *croplands* the managed grazing method is applied to pasture lands in a crop rotation.

From 2022, almost no data updates were available for grazing pressure, as the ABS is in the process of modernising the collection and reporting of agricultural statistics (as described in section 5.1.1). Grazing-pressure inputs have been held constant at 2021–22 levels for the final years of the time series. When new data are available or as the ABS completes its modernisation programme, recalculations may be required.

Figure 6.6.1 Grazing pressure by animal type Australia

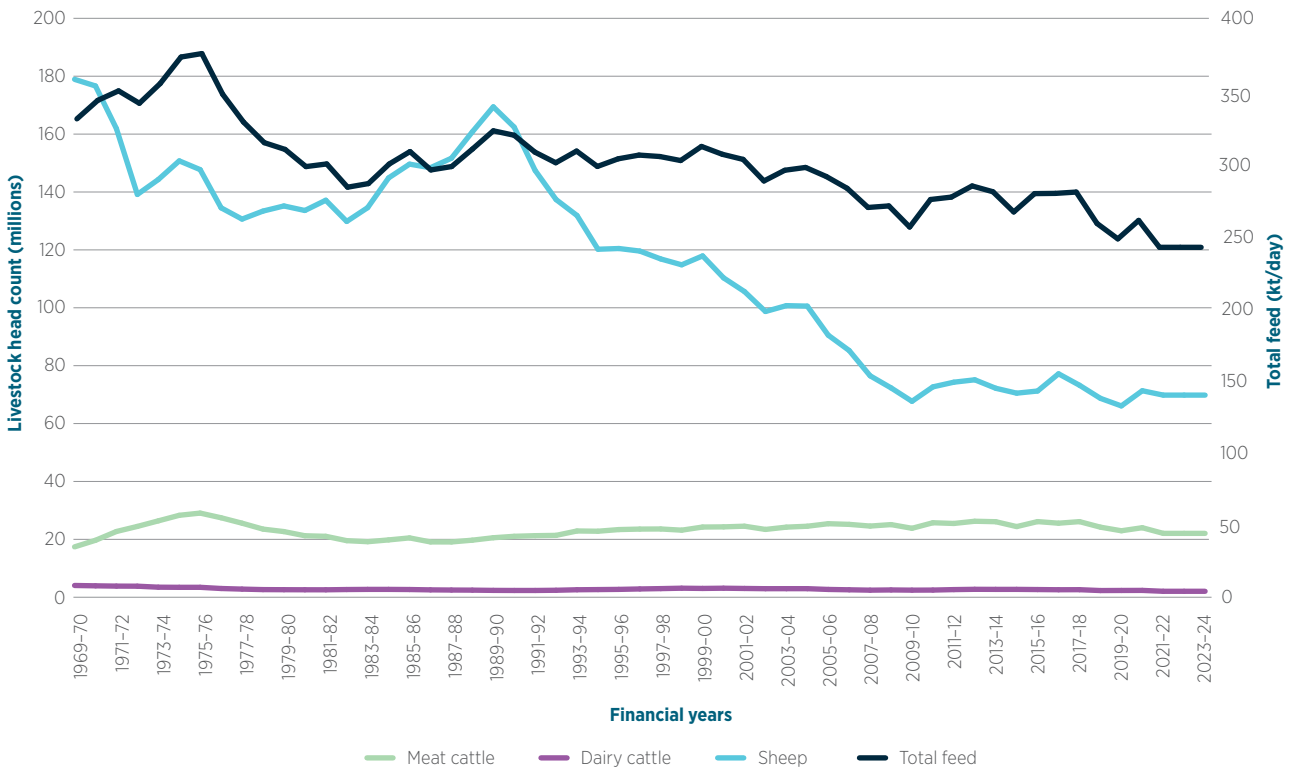
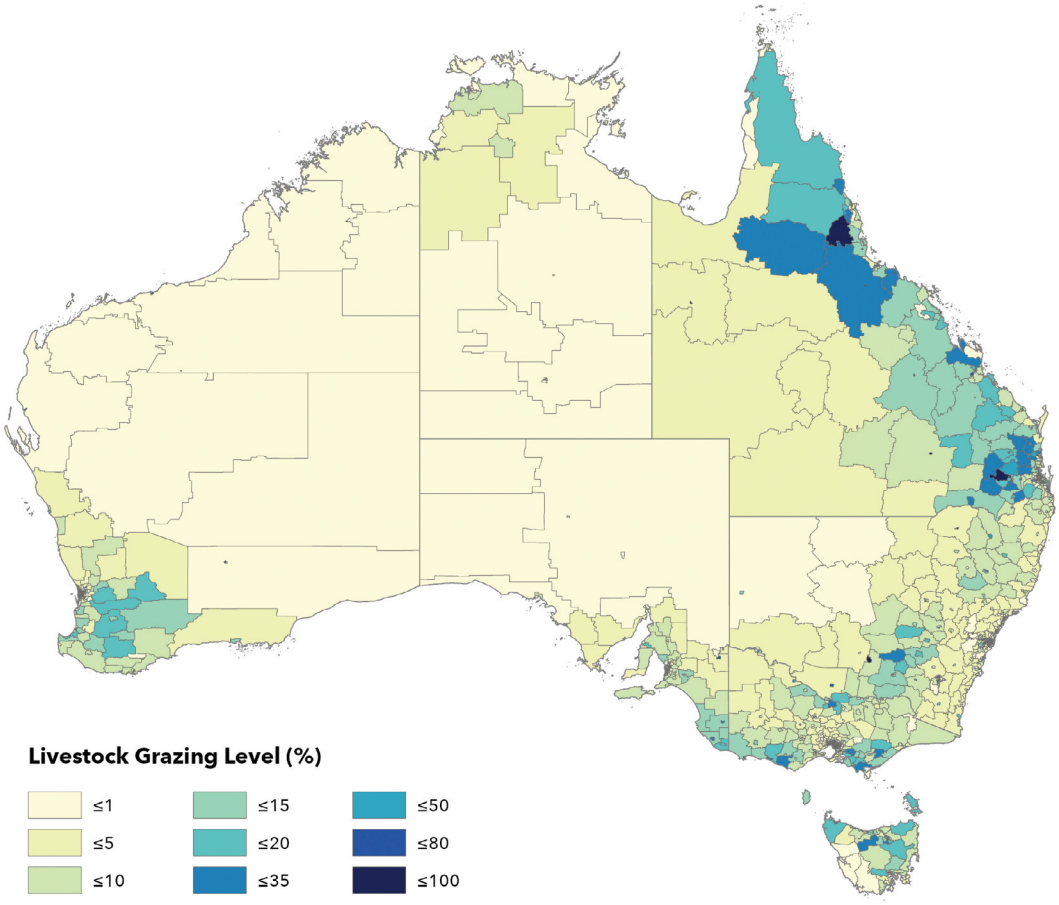


Figure 6.6.2 shows the spatial distribution and levels of biomass eaten.

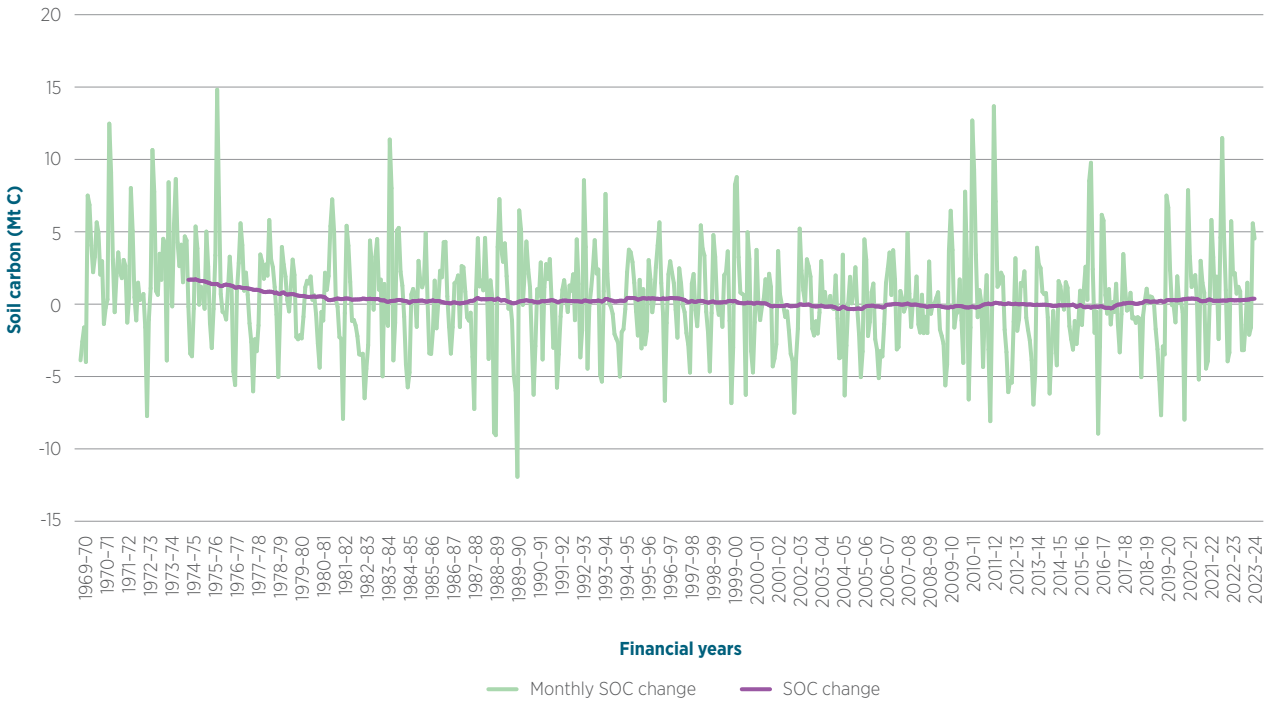
Figure 6.6.2 Livestock grazing pressure levels for Australia (2023–24) at the SA2 level



Additional details on data sources and changes in management practices are provided in Annex 5.6.5.

The estimation of emissions from soil carbon from *grassland remaining grassland* (Figure 6.6.3) is modelled in the same way as for *cropland remaining cropland.* See the discussion on the methodology for herbaceous crops in Chapter 6.5.1.2.

Figure 6.6.3 Monthly carbon stock change from grassland remaining grassland



Sparse woody vegetation

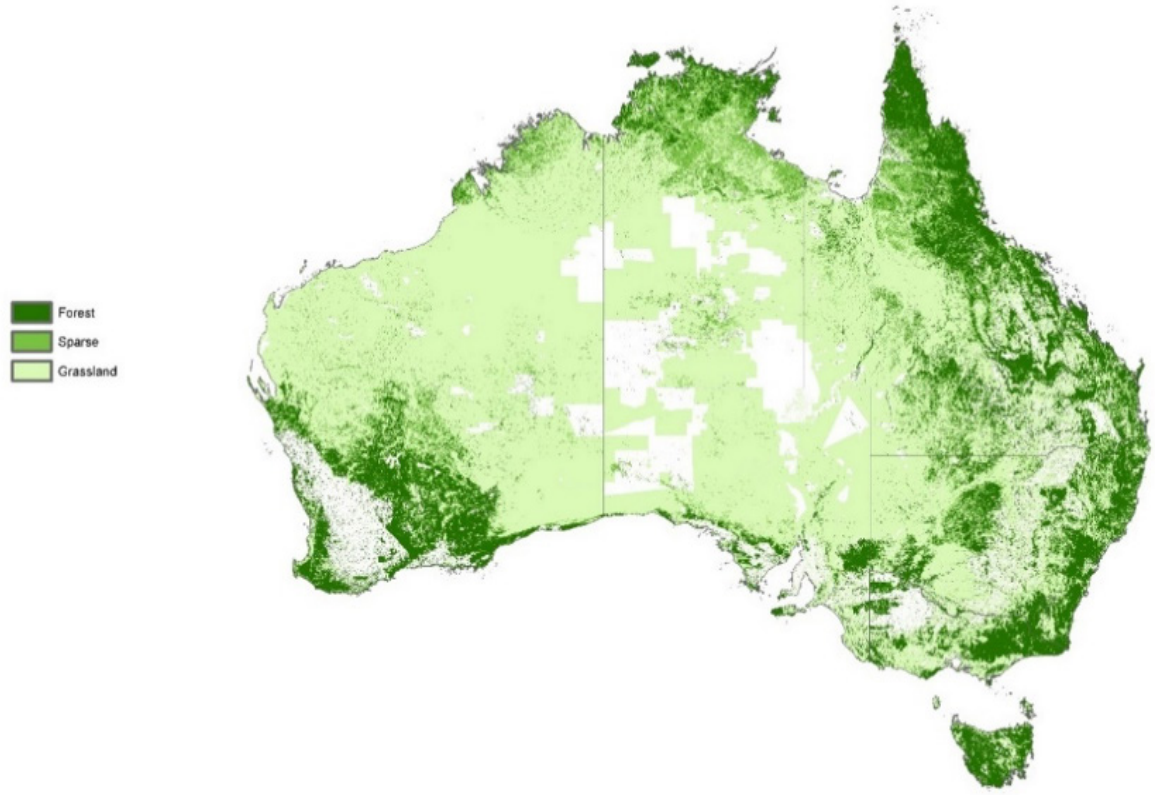
Landsat TM, ETM+ and OLI data for the years from 1988 to 2022 (Caccetta and Furby 2004) are used to detect and map 3 land cover classes for woody vegetation: non-woody (<5% cover), sparse woody vegetation cover (5 per cent to <20 per cent canopy cover) and the forest cover (>20 per cent canopy cover). Activity data on sparse woody vegetation transitions relies on the forest cover monitoring system which was not available for the 2024 report (see Chapter 6.1). Reported areas and disaggregated emissions were not updated because the impacts of climate data and vegetation monitoring activity data were not able to be updated independently, or independent climate updates were considered unlikely to be representative of emissions trends and subject to material revision once activity data becomes available. Holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data, and unsuitability of trend extrapolation given interannual variability of climate drivers. Consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3: Resolving data gaps), emissions for this category have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach.

Figure 6.6.4 shows the extent of sparse vegetation in Australia as distinct from forest vegetation.

Data on sparse woody vegetation extends for the period since 1988. For the period 1970–1985, the net gain in area of sparse woody vegetation has been back-cast using the El Niño Southern Oscillation index (Bureau of Meteorology) as a proxy variable.

To estimate the change in woody biomass due to the change in sparsely woody areas, the net annual change in area was placed in a Tier 2 model. The model uses an average woody biomass of 10 t DM ha^{-1} (Raison et al. 2003) and where vegetation cover is observed to have been lost it presumes a linear loss of that amount over a period of 20 years. Where the area of sparse vegetation increases it is assumed that these will regrow to 10 t DM ha^{-1} over twenty years (i.e. a growth rate of 0.5 t DM ha^{-1} yr^{-1}) (Fensham et al. 2012; Witt et al. 2011).

Figure 6.6.4 Extent of forest and sparse woody vegetation



Savanna Fire

Emissions and removals on *grassland remaining grassland* associated with the burning and subsequent regrowth of biomass and debris are modelled using the same methods, factors and data as described in Chapter 6.3.2.

6.6.1.3 Uncertainty assessment and time-series consistency

Based on a qualitative assessment the uncertainties for *grassland remaining grassland* were estimated to be medium. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

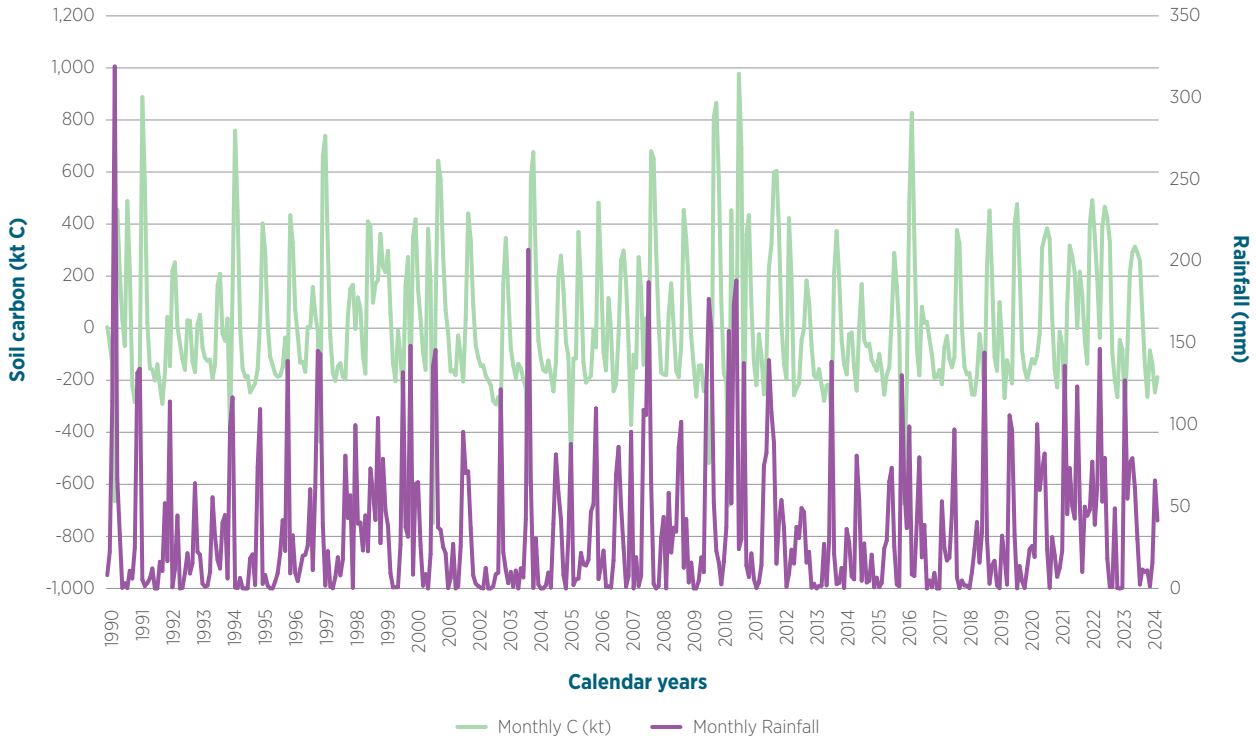
6.6.1.4 Category-specific QA/QC and verification

The calibration, validation and verification of FullCAM, along with the associated quality assurance and quality control programme are fully described in Annex 5.6.2.

Extensive QA/QC of FullCAM shows that the results for grassland remaining grassland closely align to the Tier 2 steady-state soil carbon model (T2SSM) provided in Volume 4, Chapter 5 of the *2019 Refinement to the 2006 IPCC Guidelines* (IPCC 2006). This work is described in Annex 5.6.2.

The impact of climate data on soil carbon change in pasture lands as simulated in FullCAM has been analysed to assure consistency with modelling expectations. The climate inputs (temperature, rainfall and open-pan evaporation) for selected regions and states have been verified against model outputs. An example of this is shown below in Figure 6.6.5 where soil carbon increases align with periods of increased rainfall.

Figure 6.6.5 Barcaldine SA2 region, soil carbon stock change charted against rainfall inputs in FullCAM



The QC of the activity data for detecting gains and losses of woody vegetation is described in Annex 5.6.I.4.

The savanna fire activity data is collated and quality assured by the Western Australian Land Authority (Landgate) before being used in emissions estimation.

6.6.1.5 Category-specific recalculations

Table 6.6.2 below provides the recalculation results, including reasons and quantified impacts.

A. Activity data updates

Emissions have been recalculated as a result of updating the climate and fire time series, crop and grass yields and adding an additional year of data.

B. Refinements to the non-temperate fire model

Refinements to the non-temperate fire model as described in 6.4.1.5.

Table 6.6.2 Grassland remaining grassland: Recalculation of CO_2 emissions

	2025 submission	2026 submission	Change	Reasons for recalculation (Kt CO_2–e)	
	(kt CO_2–e)	(kt CO_2–e)	(kt CO_2–e)	A	B
1989–90	-2,212	-2,396	-183	-111	-72
1994–95	5,301	5,250	-51	20	-71
1999–00	17,219	17,079	-139	-12	-128
2004–05	18,254	18,221	-33	11	-44
2005–06	32,234	32,145	-89	-1	-88
2006–07	24,944	24,866	-78	-1	-77
2007–08	10,325	10,304	-22	12	-34
2008–09	15,326	15,311	-15	3	-18
2009–10	12,839	12,841	1	-2	3
2010–11	8,486	8,537	51	14	37
2011–12	-131	-82	49	3	46
2012–13	-992	-910	82	53	29
2013–14	3,153	3,100	-53	-72	19
2014–15	3,233	3,179	-54	-63	9
2015–16	-56	150	206	176	30
2016–17	5,949	5,880	-68	-73	5
2017–18	-579	-751	-172	-194	22
2018–19	-10,194	-10,227	-33	-51	18
2019–20	-15,454	-14,678	776	726	50
2020–21	-20,001	-19,967	34	3	31
2021–22	-9,983	-10,146	-163	-202	38
2022–23	-5,403	-3,915	1,489	1,455	34

6.6.1.6 Category-specific planned improvements

Planned developments for the grasslands soil carbon model include how FullCAM handles grass growth and grazing, including spatialisation of grass yields, and improvements to the grazing pressure mechanism. Additional updates to the grazing pressure mechanism to reflect the ABS data update will improve and correctly model the grazing pressure.

6.6.2 Land converted to grassland

6.6.2.1 Category description

Within the *land converted to grassland* subcategory, Australia reports emissions for *forest land converted to grassland* and *wetlands converted to grassland* subcategories. Net emissions from conversions between croplands and grasslands are included in *cropland remaining cropland* as it is common for cropping systems to include pasture/grazing rotations.

The activity data for the *forest land converted to grassland* classification relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1). Reported areas have been held constant at 2021–22 levels for 2022–23 and 2023–24, while updates to climate and crop and grass yield data were incorporated to improve estimates of emissions on previously cleared lands. These updates mean that *forest land converted to grassland* use consistent inputs as *grassland remaining grassland* in 2023 and 2024. The data updates show the moderation of sequestration rates on previously cleared croplands and grasslands to more typical levels. This is consistent with climate conditions that have transitioned out of the prolonged La Niña period that was associated with elevated rainfall including significant flooding in different regions of Australia in 2020, 2021 and 2022.

This hybrid approach provides the most reliable estimates given current data constraints. It balances the need for completeness and methodological consistency with the opportunity to incorporate category specific updates where supporting data exist.

Forest conversions to grassland is dominated by the land clearing practices which occur in Australia. Where regrowth is identified, the land is transferred to the *land converted to forest land* category. Cyclical activity of regrowth and re-clearing is common in some parts of Australia and so parcels of land can frequently move between these reporting categories. Over time, the clearing of primary forest with high carbon stocks has become less prevalent, reducing the emissions from this category. Around 88 per cent of clearing activity in 2021–22 was re-clearing of secondary forests on land that has been cleared previously, where graziers are maintaining pasture. Around three quarters of this is regrowth less than 10 years old, which stores far less carbon than primary forests, resulting in lower emissions when it is cleared. The *forest land converted to grassland* category includes emissions from non-temperate fire management for which estimates have been updated for 2023–24.

The net emissions associated with fires or with harvesting of forest for timber are reported under *forest land remaining forest land* (as neither fire nor harvesting constitute a permanent land use change), unless a subsequent land use change or permanent loss of forest cover is identified.

The net emissions associated with the removal of orchards are reported under *cropland remaining cropland.* Orchards are not defined as forests in the Australian inventory. Net emissions from the clearing of sparse woody vegetation are reported under *grassland remaining grassland.*

Areas of *wetlands converted to grassland* were estimated for each state and territory using IPCC Approach 2 and based on land use data from the 1996 and 2010 Land use of Australia surveys (BRS, n.d.; ABARES 2016b). Conversions involved both mineral and organic hydrosols.

Emission estimates for the components of *land converted to grassland* are reported in Table 6.6.3.

Table 6.6.3 Net emissions and removals from land converted to grassland sub-categories, kt CO_2–e

Year	Forest land converted to grassland	Wetlands converted to grassland	Total
1989–90	147,342	466	147,808
1994–95	64,419	466	64,885
1999–00	66,344	466	66,810
2004–05	82,705	466	83,171
2005–06	94,256	466	94,722
2006–07	76,172	466	76,638
2007–08	66,033	466	66,499
2008–09	46,127	466	46,593
2009–10	52,727	466	53,193
2010–11	35,364	466	35,830
2011–12	30,633	466	31,099
2012–13	45,014	466	45,480
2013–14	47,862	466	48,328
2014–15	36,981	466	37,447
2015–16	23,640	466	24,106
2016–17	45,469	466	45,935
2017–18	37,622	466	38,088
2018–19	23,187	466	23,653
2019–20	35,196	466	35,662
2020–21	17,838	466	18,304
2021–22	6,312	466	6,778
2022–23	29,765	466	30,231
2023–24	16,575	466	17,041

6.6.2.2 Methodological issues

Forest land converted to grassland

Emissions and removals from *forest land converted to grassland* (and *other land uses)* are estimated using the Approach 3, Tier 3 Full Carbon Accounting Model (FullCAM) as described in Annex 5.6.2. The reporting includes all carbon pools (living biomass, dead organic matter (DOM) and soil) other than the agricultural debris of perennial grasses. The model runs in a mixed configuration (i.e., both forest and agricultural systems) using the *CAMFor, CAMAg* and *Roth-C* sub-models. Table 6.6.4 below shows the FullCAM configuration for modelling emissions and removals for this sub-category.

N_2O emissions from disturbance associated with land-use conversion to cropland and grassland are estimated using the methods described in Chapter 6.13.

Table 6.6.4 FullCAM configuration used for the forest land converted to cropland and forest land converted to grassland sub-categories

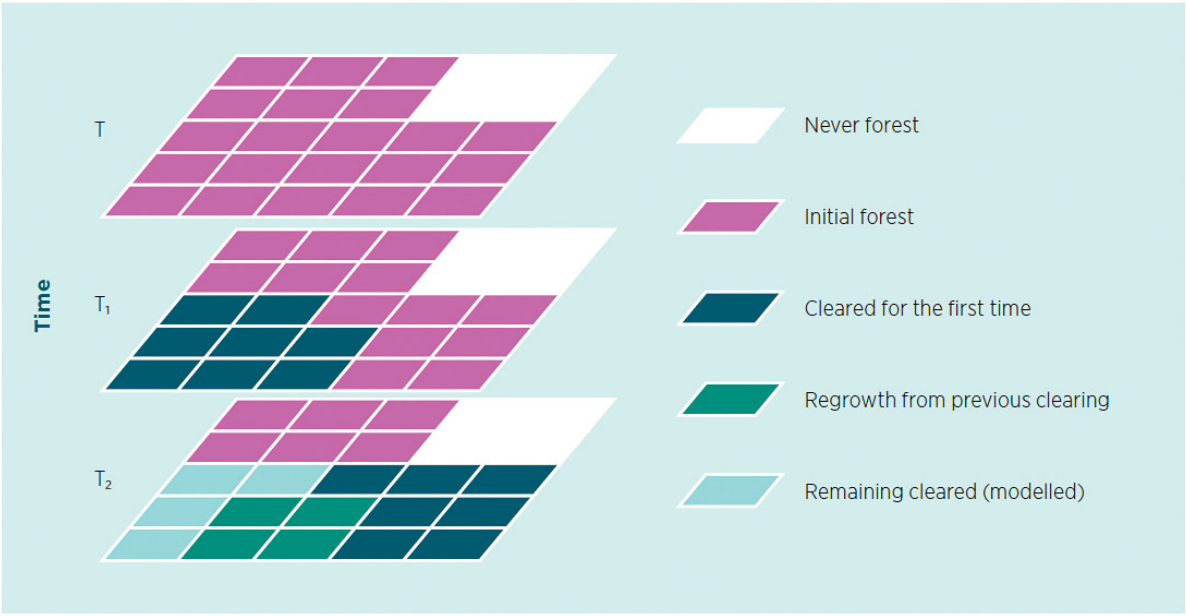
Component	Forest	Agriculture
Living biomass	CAMFor – Forest Productivity Index and Tree Yield Formula	CAMAg – Crop and pasture growth sub-models
Dead organic matter	CAMFor	CAMAg
Soil carbon	Roth-C	Roth-C
Offsite products	NA	NA

Entry of lands into forest land converted to grassland

The fundamental analytic unit of Tier 3, Approach 3 land sector reporting in Australia is the land cover change pixel (25 m x 25 m) derived from the satellite remote sensing programme. Beginning in 1971–72, forest clearing and regrowth events are detected through the remote sensing programme.

In interpreting pixels and events (Figure 6.6.6), the first class of forest pixel is 'initial forest' (pink). This means that the forest cover has not been subject to a forest clearing event since before 1971–72 and is categorised as *forest land remaining forest land.* The second class of forest pixel is 'cleared for the first time'. This means that the forest on that pixel has undergone a forest clearing event in the current year (T1, dark blue). These pixels become categorised as forest converted to grassland, cropland, settlements or wetland (flooded land) depending on the land use at that location. FullCAM simulations are initiated to calculate the emissions and removals on that pixel from the moment that the pixel is observed to have a clearing event and the tracking continues each year into the future (T2, light blue and green). These active pixels may remain cleared (light blue) or may temporarily regrow some forest cover as part of a cyclic clearing/re-clearing management system (green). Where forest regrowth is identified, the pixel will be re-categorised as *land converted to forest* for as long as the forest continues to be observed on the pixel.

Figure 6.6.6 Diagram representing the spatially explicit approach for estimating forest land conversion sub-categories



Modelling emissions and removals

Once lands enter the conversion category through a forest clearing event, based on activity data, FullCAM:

- Randomly allocates a date of clearing between the two dates of satellite images;
- Obtains site, climate, management and initial assumed biomass data (see Annexes 5.6.2 to 5.6.5) for that pixel from a series of spatial grids and databases;
- Begins to model changes in living biomass, debris and soil carbon pools associated with the change in forest cover; and
- Sums the estimates for each pixel each year to estimate the emission/removals.

Where the forest has regrown after clearing as identified from the remote sensing, FullCAM begins to model forest regrowth using the same databases and systems as used for native vegetation in *land converted to forest.*

Where this regrowth is subsequently re-cleared, the biomass at re-clearing is based on what has been modelled to have accumulated at the individual pixel level based on that pixel's history, including site conditions and climate over the period of forest growth. The emissions associated with the re-clearing along with the subsequent emissions and removals on the converted land, including those associated with the decay of DOM and soil carbon, are reported under the *grassland* sub-category.

After 50 years, these forest conversion lands and their associated emissions/removals will be reallocated to the sub-categories for land remaining within its land use.

Estimating changes in carbon stocks

The ratios used to partition biomass to the different tree components are drawn from a synthesis of available data compiled by Paul and Roxburgh (2017), with this partitioning varying as the stand matures, and being different for different forest types based on their typical productivity.

Table 6.6.5 Partitioning of biomass between the tree components under different rainfall zones. Estimates are for mature stands of assumed stand age 100 years

	Fraction of biomass allocated to:					
Rainfall zone	**Stems**	**Branches**	**Bark**	**Leaves**	**Coarse Roots**	**Fine Roots**
>500mm	0.49	0.11	0.09	0.04	0.24	0.03
<500mm	0.28	0.22	0.08	0.07	0.27	0.08

The carbon content of various tree components are drawn from an analysis of a range of species across a range of environments by Gifford (2000a and 2000b).

Table 6.6.6 Carbon content of tree components – forest conversion categories

Tree Component	Carbon Content (fraction of dry matter)
Stems	0.50
Branches	0.47
Bark	0.49
Leaves and Twigs	0.52
Coarse Roots	0.50
Fine Roots	0.48

Turnover rates impact predictions of inputs to DOM under regenerating forests. But under simulations of both permanently cleared and regenerated forests, decomposition of DOM will be important. The rates of turnover and decomposition are based on a review by Paul et al. (2017).

Table 6.6.7 Tree component turnover rates

Tree component	Turnover % per month
Branches	0.74
Bark	0.41
Leaves (rainfall >500mm)	2.96
Leaves (rainfall <500mm)	1.28
Coarse Roots	0.87
Fine Roots	12.55

Table 6.6.8 Decomposition rates for standing dead pools used in the forests model

Standing Dead component	Breakdown % per month
Stems, branches and coarse roots	0.83
Bark	1.25
Leaves and fine roots	1.67

Table 6.6.9 Decomposition rates for debris pools used in the forests model

Debris component	Breakdown % per month
Deadwood	1.25
Bark litter	1.44
Leaf litter, decomposable*	81.20
Leaf litter, resistant*	2.70
Coarse dead roots	2.93
Fine dead roots	81.20

* The fraction of leaf litter that was resistant was 77 per cent.

For each major vegetation group (MVG), initial pools of debris just prior to clearing are based on equilibrium simulations of mature forests, with these simulations being undertaken in regions which typify their productivity. Post-clearing, the pools of live biomass are transferred to the DOM pools.

The principal methods of forest conversion involve the extraction of root material (e.g., tree pulling) to allow for subsequent cultivation for pasture and cropping. Tree pulling usually involves forming 'wind rows' for subsequent burning. Burning of wind rows follows a period of curing (drying), but combustion is still not always complete. FullCAM has been developed to accommodate these processes by implementing a delayed burning, with subsequent decomposition of residual material remaining post-burn. The residual decomposing pool is 'standing dead' of relatively slow decomposition rates (Paul and Roxburgh, 2018b). The standing dead residues burnt is set at 98 per cent, leaving 2 per cent to subsequently decompose on-site. The predictions of post-clearing residues draws upon work by Murphy et al. (2002), Griffin, Verboom and Allen (2002), Harms and Dalal (2003), Harms, Dalal and Cramp (2005) and Mackensen and Bauhus (1999). Of residues burnt post-clearing, combustion efficiencies were set at 90% for deadwood, 95 per cent for bark, 95 per cent for leaf litter, 80 per cent for coarse dead roots, and 70% for fine roots (Paul and Roxburgh 2018b).

A full description of the soil carbon model *(Roth-C)* and the parameterisation of the model are provided in Annex 5.6.2. Parameters governing the input of carbon to the soil following the decomposition of DOM are the fractions of decomposed DOM that is lost as CO_2 to the atmosphere (CO_2–C). The remaining decomposed DOM that is not lost as CO_2–C is predicted to enter the pools of soil C. Values for these parameters calibrated using forest soil carbon studies as described by Paul et al. (2017).

Fires

Carbon dioxide emissions from on-site burning associated with land conversion are estimated using FullCAM and are reported for *forest land converted to cropland, to grassland, to settlements* and *to wetlands (flooded land).* The mass of carbon burnt annually (FC_{jk}) is a FullCAM output and CO_2 emissions associated with biomass burning are therefore included in carbon stock changes, however this FullCAM output is also used to estimate the non-CO_2 gases reported for biomass burning (controlled burning).

There are no direct measurements of trace gas emissions from the burning of cleared vegetation in Australia. However, it is considered that these fires will have similar characteristics to hot prescribed fires and wildfires (Hurst and Cook 1996).

$$\mathbf{E_{ijk}\ FC_{jk} \times EF_{ijk} \times C_i} \qquad \textbf{(6.6.1)}$$

and for total annual emissions for N_2O and NO_x are:

$$\mathbf{E_{ijk} = FC_{jk} \times NC_{jk} \times EF_{ijk} \times C_i} \qquad \textbf{(6.6.1)}$$

Where FC_{jk} = annual fuel carbon burnt in land conversion (kt),
EF_{ijk} = emission factor for gas i from vegetation (Tables A5.6.11.10–12),
NC_{jk} = nitrogen to carbon ratio in biomass (Annex 5.6.11.9)
C = factor to convert from elemental mass of gas species i to molecular mass (Annex 5.6.11.9).

Carbon dioxide emissions and removals associated with the burning and subsequent regrowth of savanna grasslands which occur on *land converted to grassland* are included in reporting and are estimated consistent with the methods described in Chapter 6.3.2.

Wetlands converted to grassland

The methodology for activity data collection and modelling of emissions and removals is similar to that underpinning estimates for *wetlands converted to cropland* as described in Chapter 6.5.2.2. This includes an equivalent analysis of activity data involving wetlands on organic and mineral soils and the use of Emissions factor values appropriate to the climate zones in which the conversions occurred.

Expert opinion provided by C. Meyer (personal communication, 2019) identified 4,000 ha of histosols associated with cropping or grazing in Queensland and Victoria, based on the CSIRO Australian Soil Classification System (Isbell 2002). Wetland transitions recorded elsewhere were considered to involve mineral soils only.

Annual changes in carbon stocks for mineral soils were derived based on climate zone and applied to their respective states to estimate annual emissions:

- Queensland/Northern Territory: 2.12963 tonnes C / ha / year,
- Tasmania: 0.882 tonnes C / ha / year,
- All other States/Territories: 2.7375 tonnes C / ha / year.

Conversions involving organic soils are reported for Queensland and Victoria, which are in the tropical and temperate climate zones respectively. The annual emission factors for drained grassland organic soils in tropical and temperate climate zones are 9.6 and 6.1 tonnes of carbon per hectare per year (IPCC 2013, Table 2.1). Emissions from each state and territory were calculated, based on area, and then aggregated to give the annual national totals for both.

Activity data

The activity data for the *forest land converted to grassland* classification is drawn from the remote sensing program (see Annex 5.6.1). As outlined in Chapter 6.5.2.2, the activity data was not available for use in the 2024 report. Reported areas have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3 Resolving data gaps).

Activity data for the *wetlands converted to grassland* classification comes from the 1996 and 2010 Land use of Australia surveys to which extrapolation and interpolation methods were applied to calculate an average annual rate of conversion. Table 6.6.10 shows cumulative areas for *land converted to grassland* over the period since remote sensing commenced in 1971–72.

Table 6.6.10 Cumulative area of land converted to grassland, Kha

Year	Forest land converted to grassland	Wetlands converted to grassland	Total
1989–90	6,885	49	6,934
1994–95	8,720	49	8,769
1999–00	10,378	49	10,427
2004–05	12,580	49	12,629
2005–06	13,004	49	13,053
2006–07	13,370	49	13,418
2007–08	13,554	49	13,603
2008–09	13,567	49	13,615
2009–10	13,479	49	13,528
2010–11	13,405	49	13,454
2011–12	13,366	49	13,415
2012–13	13,360	49	13,409
2013–14	13,332	49	13,381
2014–15	13,231	49	13,280
2015–16	13,216	49	13,265
2016–17	13,231	49	13,279
2017–18	13,377	49	13,426
2018–19	13,492	49	13,541
2019–20	13,592	49	13,641
2020–21	13,660	49	13,709
2021–22	13,470	49	13,519
2022–23	13,470	49	13,519
2023–24	13,470	49	13,519

6.6.2.3 Uncertainty assessment and time-series consistency

Uncertainties for *forest land converted to grassland* at the national scale were estimated to be ±27.3 per cent for CO_2. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

The current Tier 1 method for *wetlands converted to grassland* relies on interpolation and extrapolation with respect to two observational years. ABARES does not report on uncertainty about the land use estimates. However, these are likely to fall in the medium to high range.

While there is a higher uncertainty in *wetlands converted to grassland* than in *forest land converted to grassland,* the former category makes only a small contribution to the overall uncertainty of *land converted to grassland* due to its lower emissions.

6.6.2.4 Category-specific QA/QC and verification

The QA/QC process includes an overview of the top-level trends in emissions, broken down by jurisdiction, examining their consistency with trends in previous submission reports and reasons for any deviations.

Verification of area of forest clearing estimates

In accordance with the recommendations of an independent review of forest clearing estimates (Federici 2016b), quality control processes were established to compare the remote sensing-based forest change data used in the inventory to similar information published by the Queensland Department of Environment and Science (DES) in order to verify the quality of the remote sensing programme. As reported in Annex 5.6.1, the annual monitoring data from Queensland and NSW Statewide Landcover and Trees Study is also used as an input into the identification and attribution of forests converted to other land uses.

Validation and updates to biomass estimates using empirical data

Following on from a verification study undertaken in 2016 (Roxburgh et al. 2016), CSIRO scientists have utilised a collation of approximately 6,000 new empirical biomass datapoints to update FullCAM's M layer to fine tune the accuracy of predicting biomass, particularly in tall temperate forests (Roxburgh et al. 2017). The simulation of above-ground forest biomass in FullCAM is based on an empirical relationship between model-predicted forest growth (the Forest Productivity Index or FPI) and observations of biomass collected from minimally disturbed stands. This relationship is used to predict M – the maximum attainable site above-ground biomass. In the update by Roxburgh et al. (2019), the original calibration database was augmented with forest biomass observations from the TERN/AusCover National Biomass Library (See Appendix 6.D for details the latest validation and fine-tuning of FullCAM). Further information on FullCAM, along with the associated quality assurance and quality control program, are in Annex 5.6.

Verification using Tier 2 model

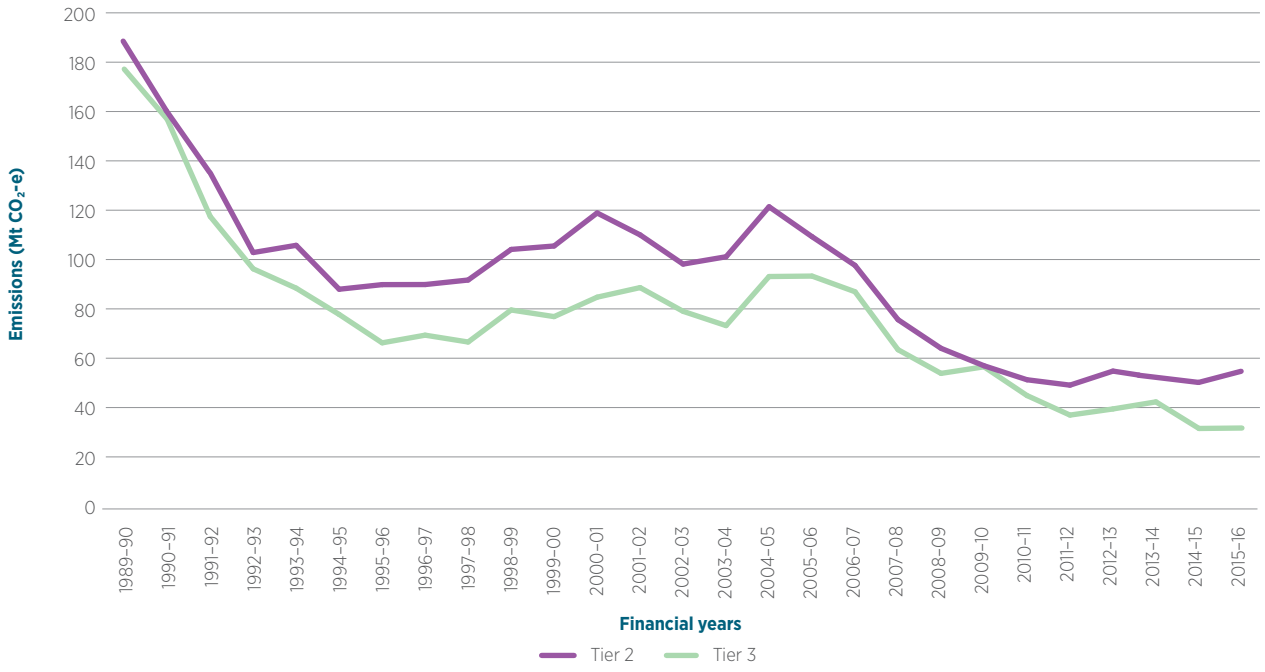
In past submissions, verification of the Tier 3 based emission estimates from this sub-category was performed through comparison with a Tier 2, Approach 2 method (described in Appendix 5.6.8). The Tier 2 method is a spreadsheet model based on country specific biomass data for three broad ecosystem types and uses the areas from the remote sensing analysis, applied using an Approach 2 method (i.e., not fully spatially explicit). The model includes all carbon pools (living biomass, DOM and soil) and emissions from fire.

The results from the two models have been largely consistent and followed a similar trend since 1989–90 (Figure 6.6.7). The emissions output has not varied substantially between the Tier 2 and Tier 3 models; however, the discrepancies between the two model approaches can be explained further.

The Tier 2 method uses country-specific coefficients for three regions differentiated by vegetation class to estimate emissions and removals from deforestation (land use change). It standardises the biophysical (soil, climate, etc.) environment, and hence forest productivity, across Australia. That is, the Tier 2 model does not encompass the finely disaggregated spatial variability relating to soil types (and their characteristics) and climate variability (particularly rainfall) which would have an effect on emission levels. As such, CO_2 emissions and removals could be overestimated or underestimated. The Tier 3, Approach 3 method is spatially explicit, operates at a fine scale (25 m) and incorporates the variability of the biophysical environment (climate and soil) across Australia.

This therefore includes the effects of climate, better represents regrowth and re-clearing cycles and varies emissions based on the site characteristics of the land subject to clearing.

Figure 6.6.7 Emissions from forest land converted to cropland and grassland output from Tier 2 and Tier 3 methodology from 1989–90 to 2015–16



Quality assurance/quality control measures for *wetlands converted to grassland* involve internal reviews of data entry and model outputs, including a check on the consistency of land use statistics across Australian jurisdictions.

6.6.2.5 Category-specific recalculations

Table 6.6.11 shows the overall size of the recalculations applicable to *land converted to grassland and* includes a break-down of the contributions by the main factors influencing these changes.

A. Activity data updates

Emissions have been recalculated as a result of updating the climate and fire time series, crop and grass yields and adding an additional year of data.

B. Refinements to the non-temperate fire model

Refinements to the non-temperate fire model as described in 6.4.1.5.

C. Refinements to the savanna grassland component of the non -temperate fire model

Refinement to estimate emissions using a Tier 2 method on forest land converted to grassland in rangelands regions of Australia using the same methods as the grassland remaining grassland Tier 2 fire model.

Table 6.6.11 Forest land converted to grassland: recalculation of total CO_2–e emissions

Year	2025 submission	2026 submission	Change	Reason for recalculations (Kt CO_2–e)		
	(kt CO_2–e)	(kt CO_2–e)	(kt CO_2–e)	A	B	C
1989–90	147,340	147,342	2	-	2	0
1994–95	64,412	64,419	7	-	7	0
1999–00	66,307	66,344	37	-	37	0
2004–05	82,687	82,705	18	-	18	0
2005–06	94,245	94,256	11	-	11	0
2006–07	76,161	76,172	11	-	11	0
2007–08	66,023	66,033	10	-	10	0
2008–09	46,111	46,127	16	-	16	0
2009–10	52,665	52,727	62	-	62	0
2010–11	35,294	35,364	70	-	70	0
2011–12	30,563	30,633	70	-	70	0
2012–13	44,945	45,014	69	-	70	-1
2013–14	47,795	47,862	67	-	68	-1
2014–15	36,961	36,981	20	-	21	-1
2015–16	23,626	23,640	14	-	14	0
2016–17	45,455	45,469	14	-	14	0
2017–18	37,609	37,622	13	-	13	0
2018–19	23,176	23,187	11	-	11	0
2019–20	35,185	35,196	11	-	11	0
2020–21	17,827	17,838	11	-	11	0
2021–22	6,277	6,312	35	-	35	0
2022–23	6,300	29,765	23,465	23,385	80	0

6.6.2.6 Category-specific planned improvements

The remote sensing programme to detect forest cover change is being updated from the Landsat time series at 25m resolution to use Sentinel 2 satellite imagery at 10m resolution. It is expected that this significant improvement will be included in the next submission.

Systems for the estimation of areas of forest conversion and related assessments of the gains and losses of sparse woody vegetation will continue to be updated to enable consumption of information contained in datasets obtained from the NSW and Queensland Statewide Landcover and Trees Study programs and similar products as they develop. The new systems will continue to build on experience gained in the use of these datasets during the finalisation of the area estimates for this inventory.

Specifically, the remote sensing programme is further advancing the methods to enable:

- ongoing improvements and development of rule-based methods for change detection and attribution;
- processing of remaining areas of vegetation monitoring for parts of central Australia to complete the national coverage; and
- estimation of above-ground biomass from remote-sensed canopy cover.

Improved calibrations for forest growth and disturbance

Work is in progress to compile additional field measurements for growth and disturbance in forests and rangelands. This will result in revision of parameters including those relating to tree growth, standing dead, turnover and decay, loss of biomass due to fire and timber harvesting, and the rate at which biomass recovers from disturbances. A revised vegetation classification in development will refine the association of these parameters to vegetation types.

Improved parameters for soil carbon will also be applied, with a run-in process to begin models with soil at equilibrium for the prevailing conditions.

6.7 Wetlands (CRT category 4.D)

6.7.1 Wetlands Remaining Wetlands

6.7.1.1 Category description

The estimates in this category are guided by the 2013 Wetlands Supplement and the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2006). In this category, the Australian inventory includes estimates for:

- Gains and losses of sparse woody vegetation on wetlands;
- Biomass burning on tropical savannas that are categorised as wetlands;
- Emissions from coastal aquaculture production in Australia;
- Emissions from seagrass removal due to capital dredging projects; and
- Methane emissions from *reservoirs* (over 20 years old) and *other constructed waterbodies* under *flooded land remaining flooded land,* including an estimate for ponded pastures.

Methane emissions from reservoirs up to 20 years in age are reported under *land converted to flooded land.* Continuing CO_2 flux from these younger reservoirs, due to decaying inundated biomass, is also accounted for in this category.

Due to the structure of the Common Reporting Tables for submission to the UNFCCC, which are designed around the premise of LULUCF emissions being associated with activity data on land areas rather than other forms of activity data, emissions for aquaculture activity and seagrass removal as off-shore activities are reported in category 4.H (Other), but are included in this document and in the Australian National Greenhouse Accounts online reporting within *wetlands remaining wetlands* for the purposes of transparency and completeness.

The key input data and estimated net emissions from changes in sparse woody vegetation and biomass burning on wetlands are presented in Table 6.7.1 below: Activity data on changes in sparse woody vegetation relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1). Reported areas and disaggregated emissions have been held constant at 2021–22 levels for 2022–23 and 2023–24.

Table 6.7.1 Area and net emissions of sparse woody vegetation transitions and biomass burning, Wetlands remaining wetlands

	Sparse woody vegetation			Biomass burning	
Year	Area gains kha	Area losses kha	Net emissions kt CO_2–e	Cumulative area kha	Net emissions kt CO_2–e
1989–90	50	71	370	455	802
1994–95	18	26	419	460	167
1999–00	40	26	287	606	1,832
2004–05	76	41	155	726	1,369
2005–06	34	129	241	173	1,867
2006–07	30	78	264	899	1,645
2007–08	28	58	283	985	2,018
2008–09	25	53	244	768	2,276
2009–10	40	67	250	854	1,528
2010–11	35	43	234	606	1,545
2011–12	72	31	89	871	1,206

Year	Sparse woody vegetation			Biomass burning	
	Area gains kha	Area losses kha	Net emissions kt CO_2–e	Cumulative area kha	Net emissions kt CO_2–e
2012–13	57	57	69	1,066	1,256
2013–14	30	76	90	608	1,185
2014–15	31	70	117	1,076	1,246
2015–16	59	57	120	487	411
2016–17	27	94	186	817	248
2017–18	28	76	240	715	-292
2018–19	31	39	268	673	-135
2019–20	37	35	278	723	-804
2020–21	31	46	294	624	-570
2021–22	17	48	324	524	-244
2022–23	17	48	324	503	-102
2023–24	17	48	324	729	-34

The key input data and estimated net emissions from aquaculture and seagrass removal are shown in Table 6.7.2 below.

Table 6.7.2 Annual activity and emissions for coastal aquaculture production and seagrass removal

Year	Annual coastal aquaculture Production – finfish and crustaceans (kt)	N_2O emissions (kt CO_2–e)	Seagrass area removed (ha)	CO_2 Emissions (kt CO_2–e)
1989–90	5	3	0	0
1994–95	13	9	0	0
1999–00	24	17	1	1
2004–05	30	21	26	11
2005–06	36	25	22	10
2006–07	39	27	3	1
2007–08	42	29	235	54
2008–09	46	32	1	0
2009–10	48	34	1	0
2010–11	51	36	0	0
2011–12	60	42	6	1
2012–13	58	41	7	2
2013–14	57	40	76	34
2014–15	66	47	3	1
2015–16	73	52	0	0
2016–17	70	49	0	0
2017–18	79	56	0	0
2018–19	74	52	0	0
2019–20	86	60	0	0
2020–21	108	76	0	0
2021–22	102	72	0	0
2022–23	103	72	0	0
2023–24	93	66	0	0

The key input data and estimated net emissions from *reservoirs* and *other constructed waterbodies,* including ponded pasture, are shown in Table 6.7.3 below.

Table 6.7.3 Annual area and CH_4 emissions from Reservoirs and Other constructed waterbodies under Flooded land remaining flooded land

Year	Reservoir methane emissions (kt CO_2–e)	Reservoir area (kha)	Other constructed waterbody methane Emissions (kt CO_2–e)	Other constructed waterbody area (kha)
1989–90	570	178	372	172
1994–95	975	303	339	159
1999–00	1,185	348	475	209
2004–05	1,036	315	444	193
2005–06	1,058	322	467	200
2006–07	944	289	378	168
2007–08	1,133	331	419	184
2008–09	1,190	342	466	200
2009–10	1,238	359	472	200
2010–11	1,496	429	533	230
2011–12	1,566	451	541	233
2012–13	1,509	438	483	208
2013–14	1,404	412	478	204
2014–15	1,342	396	489	208
2015–16	1,232	362	509	211
2016–17	1,401	412	534	225
2017–18	1,370	406	432	185
2018–19	1,193	361	410	176
2019–20	1,074	332	384	173
2020–21	1,152	352	484	209
2021–22	1,390	412	542	230
2022–23	1,474	432	540	233
2023–24	1,477	433	497	207

6.7.1.2 Methodological issues

Sparse woody vegetation gains/losses

Carbon stock-changes from gains and losses in sub-forest sparse woody vegetation on wetlands have been identified using the same monitoring systems used to identify areas of sparse woody vegetation for grassland systems as described in Chapter 6.6.1.2. Activity data on sparse woody vegetation transitions relies on the forest cover monitoring system which was not available for the 2024 report (see Chapter 6.1). Reported areas and disaggregated emissions were not updated because the impacts of climate data and vegetation monitoring activity data were not able to be updated independently, or independent climate updates were considered unlikely to be representative of emissions trends and subject to material revision once activity data becomes available. Holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data, and unsuitability of trend extrapolation given interannual variability of climate drivers. Consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3: Resolving data gaps), emissions for this category have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach.

Biomass burning

Emissions and removals due to *biomass burning* on savannas that are wetlands are modelled using the same methods, factors and data as described in Chapter 6.3.2.

Aquaculture production

This sub-category accounts for N_2O emissions from the production of finfish and crustaceans in aquaculture systems located in coastal wetland habitats using methods informed by the 2013 Wetlands Supplement.

Australian aquaculture production figures, of the previous financial year, are published annually by the Australian Bureau of Agriculture and Resource Economics (ABARES) in the Australian Fisheries and Aquaculture Statistics report (Tunyman et al. 2025). These statistics are available at the state and territory jurisdiction level. Production data are reported for various broad groups of animals, and the subgroups within those. The two groups of interest are "Fish" and "Crustaceans", both of which contain sub-groups that represent marine and/or freshwater species. Only production figures involving sub-groups that are mostly cultured in coastal wetland-based facilities are included in this analysis. Therefore, fish production data for salmonids, tuna and barramundi are included from "Fish", while prawns is the only sub-group reported from the "Crustacean" group. There are no other groups from the ABARES dataset reported here.

Direct N_2O emissions were estimated using Equation 4.10 in the 2013 Wetlands Supplement. Note that quantities are expressed here in tonnes rather than kg, so that:

$$N_2O\text{-}N_{AQ} = F_F \times EF_F \qquad (6.7.1)$$

Where $N_2O\text{-}N_{AQ}$ = annual direct N_2O-N emissions from aquaculture use; tonnes N_2O-N per year
F_f = annual fish production; tonnes of fish per year
EF_F = emission factor for N_2O emissions from fish produced; 0.00169 tonne N_2O-N per tonne of fish produced

Seagrass removal due to capital dredging

Seagrasses are a diverse group of marine flowering plants adapted to a submerged life. Seagrasses are found along both tropical and temperate Australian coasts, where they may occupy intertidal flats, as well as the sub-tidal near-shore and deeper offshore locations. They cover an estimated area of 5 to 9 million hectares in Australia. Species diversity is greatest in tropical waters, but biomass per unit area increases with increasing latitude in Australia (Butler and Jernakoff 1999).

A report (Kettle 2017) was commissioned to capture the timing and extent of current and historical capital dredging activity in Australia that informs the seagrass excavation model. The seagrass excavation model has a Tier 2 model structure using country-specific parameter values estimated from pooled data collected from the scientific literature and stratified by coastal region.

The timing and extent of capital dredging activity in Australian waters was reported for the period 1988–89 to 2015–16 (Kettle 2017), noting there was no recorded capital dredging activity for 1989–90 to 1994–95, 2010–11 and 2015–16. A review of the Australian Notices to Mariners (Australian Hydrographic Office n.d.) identified almost no stated capital dredging activity after 2015–16. Capital dredging for 22–23 was identified but the dredging location did not intersect with known sea grass sites. An industry report, Dredging Services in Australia (Allday 2021), stated that the dredging industry peaked in 2013–14, but then declined as port expansion programs slowed under reduced natural resource exports and covid-related impacts in the five years to 2020–21. While capital dredging projects declined, maintenance dredging continues to be in demand but is not included in this account.

It is reported in the literature that seagrass habitat takes time to recover after removal or burial, depending on the species involved (Preen et al. 1995; Campbell and McKenzie 2004; Smith et al. 2016; Vanderklift et al. 2017). Some seagrass habitat, including that dominated by temperate, high biomass species, may not re-establish when disturbance is regular, periodic, or catastrophic (Meehan and West 2002; Erftemeijer and Lewis 2006; Wu et al. 2015). As navigational channels also undergo scheduled periodic maintenance dredging it is assumed that seagrass habitat is removed permanently when establishing a channel. In keeping with Tier 1 assumptions, all excavated plant and soil based organic carbon is mineralised in the year of removal. An estimation of the soil organic carbon removed by dredging is based on an excavated depth of one meter.

The model is populated with area estimates for excavated seagrass meadow obtained by spatial modelling. Kettle (2017) provided dredge-related shapefiles that are overlaid on seagrass habitat shapefiles to determine the areas of seagrass and underlying sediment removed by dredging activity. Seagrass habitat shapefiles are sourced from state and territory jurisdictions and the University of Tasmania.

Further information is provided in Annex 5.6.10.

Reservoirs and Other constructed waterbodies

Drawing upon guidance on *flooded lands* from the 2019 Refinement to the IPCC Guidelines (pp 7.1–7.29) (IPCC 2019), Australia reports methane emissions from *reservoirs* older than 20 years and *other constructed waterbodies* as part of *flooded land remaining flooded land.* Carbon dioxide and methane emissions from inundated land associated with newly established reservoirs are reported under *land converted to flooded land* for a period of 20 years from the date the reservoir was completed. After 20 years the reservoir is established and is included in *flooded land remaining flooded land.*

The age of each reservoir included in this account is based on available public records that report the date of completion of dam construction. Activity data, reported as an annual average surface area, is provided by gauge depth to surface area lookup tables established for each reservoir.

For ease of reporting, all *reservoirs* and *other constructed water bodies* methane emissions are reported in *Common Reporting* table 4(11): 4.D.2 *Flooded Lands* (on mineral soils). CO_2 emissions are included in the carbon stock changes of *forest land converted to flooded land.*

The Tier 1 and Tier 2 estimation methods for reservoirs and farm dams respectively are described here, with further information provided in Annex 5.6.10.

For *reservoirs* within a specific climate zone:

$$FCH_4 = EFCH_4 \times A \qquad (6.7.2)$$

Where FCH_4 = Annual emission of CH_4 from all Reservoirs

A = Area of water body water surface

$EFCH_4$ = Emission factor for CH_4 emitted from the water body surface, which is specific for the type of water body and climate zone in which that waterbody is located and, additionally for Reservoirs, its age.

The 2019 Refinement provides default values for methane emission factors ($EFCH_4$) for *reservoirs* that are specific to waterbody age and climate zone (Tables 7.9 and 7.15 in the 2019 Refinement) (IPCC 2019), and which are reproduced in Table 6.7.4. Methane is also emitted from water released downstream of the reservoir, FCH_4 downstream emissions from this source, which under Tier 1 are calculated as 9% of the total reservoir related emissions, are estimated in this account. In higher Tier models, an emission factor adjustment may be applied to account for the influence of eutrophication of reservoir waters. This has a default value of one for Tier 1 models, which is applied here and therefore does not influence the emission estimate.

Activity data for methane emissions from *reservoirs* and *other constructed waterbodies* are reported as the aggregated surface areas (by state and nationally) for each of these categories of water bodies.

Average monthly reservoir surface area is estimated based on the development of water gauge depth to surface area look-up tables for each reservoir included in the account and is described in Annex 5.6.10. Where reservoirs did not have any gauge data, a hybrid model was produced that included annual data to fill the data gaps. This data was extracted by intersecting data from the Bureau of Meteorology (BOM) geofabric data and the Geoscience Australia/Digital Earth Australia (DEA) Waterbodies data to provide the annual average surface area for reservoirs with missing gauge-based activity data. Where there were gaps in gauge data, gaps were filled through linear interpolation. This approach afforded greater timeseries consistency than filling gaps with output from the hybrid model.

The Australian National Committee on Large Dams (ANCOLD) list of dams (2010) names more than 600 dams and their associated reservoirs, a subset of which are included in this account. This subset, which totals 200 reservoirs (Table A5.6.10.12), collectively represents more than 95% of the maximum aggregated surface area of all reservoirs on the ANCOLD list.

Table 6.7.4 $EFCH_4$ and $EFCO_2$ values for Reservoirs

		Reservoirs	
Australian Climate Zone	**AGE (Old > 20 years)**	**$EFCH_4$ (kg CH_4/ha/year)**	**$EFCO_2$ (Tonnes CO_2/ ha/yr)**
Tropical – wet	Young	252	2.77
Tropical – dry	Young	392	2.95
Tropical – moist	Young	196	1.7
Temperate – warm	Young	128	1.46
Temperate – cool	Young	85	1.02
Tropical – wet	Old	141	-
Tropical – dry	Old	284	-
Tropical – moist	Old	151	-
Temperate – warm	Old	151	-
Temperate – cool	Old	54	-

Other constructed waterbodies include freshwater ponds such as stock dams, crop dams and farm tanks that are small to large, shallow impoundments used for crop irrigation and stock watering. These small to medium water bodies (up to 8 ha) comprise a common water source for Australian agriculture and are distributed extensively throughout Australia's rural landscape. They are difficult to identify by satellite, except through high-resolution satellite imagery, so that a remote sensing approach to estimating their annual average surface area at state and national levels is impractical. The prior approach was to use agricultural survey data on water use as a basis for modelling surface area estimates. However recent applications of machine learning to the problems of estimating the distribution, water surface area, and methane emissions of Australia's farm dam population have been applied in developing a new method for estimating Australian annual methane emissions from *other constructed waterbodies.*

The methods employed in constructing this farm dam account were developed by scientists at RMIT University, Deakin University, and the Western Australia Department of Primary Industries and Regional Development. The models used here have been and published in a series of peer-reviewed papers (Malerba et al. 2021; Malerba et al. 2022a; Malerba et al. 2024). A brief overview of the methods is provided here, with a comprehensive summary presented in Annex 5.6.10.

The size and historical and current distribution of Australian farm dams was reported in Malerba et al. (2021). A deep learning convolutional neural network (CNN) was employed to detect farm dams from satellite images. Training of the CNN was based on high-resolution satellite images (~ 0.5 m resolution) of Australian agricultural landscapes containing farm dams.

Malerba et al. (2021) compiled state and national datasets on Australian dams. These datasets are generally incomplete (analysis of lower-res satellite images missed smaller dams) and may be temporally static by providing only a "snapshot" at one time point. The authors employed the trained CNN to verify the existence of each dam from the combined data sources. In addition, the CNN model was given imagery from locations where no dam had previously been recorded. The combination of these enabled the authors to develop better estimates of dam densities and dam water capacity across Australia than could be provided by the original national and state data sets. In addition, they were also able to quantify the rate of new farm dam development for each Australian state and territory.

A second paper (Malerba et al. 2022b) describes the use of satellite images and deep-learning convolutional neural networks to analyse the impacts of local conditions of rain and temperature on the water levels of Australian farm dams over time. This work allowed the authors to develop a predictive model of regional dam level (water surface area and volume), based on climate data. To account for the effects of climate both spatially and temporally over the modelled period, 1989–90 to 2021–22, monthly averages of rainfall and temperature were obtained from weather stations of the Bureau of Meteorology across Australia. Monthly climate surfaces at 1 km resolution for each variable were then derived using ANUSPLIN (Hutchinson and Xu 2013) surface interpolation techniques (Annex 5.6.10). Overall, using climate data to estimate regional farm dam capacity reduced the necessity of expensive and time-consuming satellite image analysis to measure water surface in farm dams.

The emission rate of total methane (diffusive and ebullitive) from agricultural ponds, estimated for different climate zones, is employed in this model. The climate zone-adjusted rates are based on a meta-analysis of data compiled from the scientific literature on methane fluxes from 286 agricultural ponds in subtropical, temperate, semi-arid, and tropical climates (Malerba et al. 2022b). The reported methane fluxes were compared across sites and climate zones by standardising daily emissions to 15°C using the Boltzmann-Arrhenius relationship. A second meta-analysis estimated the ratio of methane diffusion to methane ebullition (bubbling) in freshwater systems were, so that total methane emission rates could be estimated from the published data in which only methane diffusion was reported. The two meta-analyses developed by (Malerba et al. 2022a) were based on the dataset published by Rosentreter et al. (2021).

Annual total methane emissions from agricultural ponds were then estimated by converting the density of pond surface area (pond ha ha^{-1}) into cumulative methane emissions (kg CH_4 $year^{-1}$ ha^{-1}) by re-organising the Boltzmann-Arrhenius relationship and adjusting for local temperature (see Annex 5.6.10). Methane emissions from farm dams are then estimated by multiplying the cumulative methane emissions by the estimated surface area of agricultural ponds (described above) in that climate zone and reporting the results by state and territory.

Many agricultural ponds are ephemeral, and their surface water fluctuates substantially between dry and wet seasons, complicating the calculations on the methane-releasing surface area. As explained in Malerba et al. (2024), the methods to inform Australia's National Greenhouse Gas Inventory uses high-resolution satellite datasets to correct methane emissions for monthly changes in the water surface at each pond. The methods also account for rates of historical accumulation of agricultural ponds and the temperature dependency of methane emissions.

A preliminary review of Australian studies (Grinham et al. 2018; Ollivier et al. 2019) demonstrated that emissions from farm dams not located on grazing land generally have lower methane emissions. This is presumably because these dams are not contaminated with manure, either through direct deposit, or as a component of rain runoff into the dam. Grinham et al. (2018) reported on emissions from freshwater ponds, with primary uses including irrigation, stock watering or urban use. They also recorded the primary land use against each individual pond. A comparison of emission rates between ponds used for stock watering on grazing land (assumed high organic input) against ponds used for irrigation or "urban use" on cropland or settlement land (assumed lower organic inputs) resulted in a mean ratio of 0.4 for crop dams and farm tanks relative to stock dams, upon which the total emissions estimate is based. This ratio is used as a multiplier to estimate the baseline methane emissions for all agricultural ponds reported under *other constructed waterbodies* (0.4 X total CH_4 emissions). The "manure component" of the estimated methane emissions is then (1 - 0.4) X total CH_4 emissions. The manure-related methane emissions are reported elsewhere, in manure management in Agriculture.

Ponded pasture

Ponded pastures are ponds constructed in grazing lands in tropical and subtropical regions that experience distinct wet and dry seasons. The ponds are designed to flood seasonally (during the wet) and are sown with water tolerant grasses. The grasses grow during the wet season and become pasture in the dry season, providing highly nutritious fodder for cattle as the ponds dry out.

Australia has an area of 52,500 ha of certain ponded pastures in Australia's dry tropics and subtropics. An estimate of methane emissions from this source is provided in this submission under *other constructed waterbodies.*

There is no information on the emission rates from these water bodies. However, as they are vegetated, it is likely that methane emissions are high. The full EF values reported in Table 6.7.4 are therefore used in this instance.

The Tier 1 method is briefly described here:

$$FCH_4 = EFCH_4 \times A \times B \quad (6.7.3)$$

Where A = Area of water body water surface (ha)

$EFCH_4$ = Emission factor for CH_4 emitted from the water body surface, which is based on the dry tropical and subtropical climate zone values reported in Table 6.7.4.

B is the proportion of the year that are emissive days (when water is present in the pond)

A total area of 52,500 ha is divided between the dry tropics (35,000ha) and the moist tropics (17,500ha)

The number of emissive days is assumed to be 240 days annually, so that B = 0.66

6.7.1.3 Uncertainty assessment and time-series consistency

Based on a qualitative assessment, the uncertainties for sparse woody vegetation transitions on *wetlands remaining wetlands* is estimated to be medium. Further information is provided in Annex 2. Time series consistency is ensured using a stable method across the time series.

For the subdivision, N_2O from Aquaculture Use, ABARES aquaculture production data is available for the period since 1991 (Tuynman et al. 2025). These data are reported nationally and by state/territory and represent live-weight quantity of aquaculture product that is produced and marketed. The data generally excludes hatchery production. ABARES does not specify a level of uncertainty with its aquaculture and fisheries production figures. Uncertainty regarding annual finfish and crustacean production in coastal facilities is likely to be within the low to medium range.

The confidence intervals associated with 2013 IPCC Wetlands Supplement guidance (IPCC 2013) for parameters associated with coastal wetlands range from 24 per cent to over 200 per cent. For seagrass removal this inventory applies available country-specific values, sourced from the scientific literature, to reduce that level of uncertainty. Although a formal uncertainty analysis is not yet available, the level of uncertainty is anticipated to be towards the lower end of the guidance values and is within the medium range.

Estimates of CH_4 and CO_2 emissions from reservoirs are based on the Tier 1 methodology provided in the 2019 Refinement to the 2006 IPCC Guidelines, combined with refinement in spatial analysis of activity data. Based on the summary of emission factor values published in the 2019 Refinement (IPCC 2019), the 95% confidence interval around the default emission factor values is large. It is anticipated that the level of uncertainty will reduce as research on methane emissions from *reservoirs* continues to be published and the results incorporated into Australia's future modelling efforts.

The overall estimate of uncertainty around quantifying CH_4 emissions from agricultural ponds was produced by applying non-parametric bootstrapping to compound all sources of error. The upper and lower 95% confidence intervals are reported across the time series and for each state in Annex 5.6.10.

Additionally, the coefficient of variation of the mean, a standardised measure of dispersion of a data set, was used to compare the magnitude of each source of uncertainty. The following estimates of CVs are, for pond area (10%), temperature sensitivity (21%), methane flux (22%) and ebullition (27%).

Time series consistency is ensured by using stable, well-defined methods across the time series.

6.7.1.4 Category-specific QA/QC and verification

Quality control measures for *aquaculture and seagrass removal* involve internal reviews of data entry and model outputs, including a check on the consistency of aquaculture production statistics across Australian jurisdictions.

The quality control measures employed in estimating activity data from *reservoirs* include comparing the model derived gauge data to surface area tables used in the model against several official gauge tables supplied by reservoir operators. The model applies IPCC default values for reservoir methane EF values.

Activity data for reservoirs is derived from satellite image analysis to obtain the annual change in their individual surface areas. A subset of these estimates is checked against corresponding water storage levels for major reservoirs as reported annually by each state and territory.

The methods used to develop estimates of methane emissions from Australian agricultural ponds are derived directly from a series of methodologies now published in the scientific literature. Each of the published methods was subject to rigorous peer review prior to publication. The current CH_4 emission estimates for Australian agricultural ponds are the most recent iteration of the published data and modified to distribute those emissions between the base-level methane emissions reported here and the manure-based methane emissions reported in the Agriculture sector.

6.7.1.5 Category-specific recalculations

Recalculations for *wetlands remaining wetlands* are shown in Table 6.7.5 below. Recalculations are due to:

A. Activity data updates

Emissions have been recalculated as a result of updating:

- the climate and fire time series and adding an additional year of data;
- production data for aquaculture; and
- gauge and surface area data for reservoirs.

B. Refinements to the non-temperate fire model

Refinements to the non-temperate fire model as described in 6.4.1.5.

Table 6.7.5 Wetlands remaining wetlands: recalculation of total CO_2–e emissions

	2025 submission	2026 submission	Change	Reason for Recalculation (kt CO_2 -e)	
Year	(kt CO_2–e)	(kt CO_2–e)	(kt CO_2–e)	A	B
1989–90	2,127	2,118	-9	-9	-
1994–95	1,907	1,909	1	-	1
1999–00	3,799	3,797	-3	-	-3
2004–05	3,044	3,036	-8	-	-8
2005–06	3,679	3,668	-11	-	-11
2006–07	3,267	3,259	-8	-	-8
2007–08	3,947	3,938	-9	-	-9
2008–09	4,218	4,209	-10	-	-10
2009–10	3,524	3,523	-1	-	-1
2010–11	3,843	3,844	1	-	1
2011–12	3,451	3,445	-6	-	-6
2012–13	3,369	3,359	-10	-	-10
2013–14	3,242	3,231	-12	-	-12
2014–15	3,256	3,243	-13	-	-13
2015–16	2,336	2,323	-12	-	-12
2016–17	2,426	2,419	-7	-	-7
2017–18	1,809	1,806	-3	-	-3
2018–19	1,789	1,788	-1	-	-1
2019–20	992	993	1	-	1
2020–21	1,434	1,435	1	-	1
2021–22	2,067	2,084	17	2	15
2022–23	2,010	2,309	299	299	-

Note: Recalculations include estimates reported in CRT 4.H (Other)

6.7.1.6 Category-specific planned improvements

In terms of seagrass removal activity data, the capital dredging report (Kettle 2017) has catalogued the capital dredging activity associated with port and related infrastructure projects for the current reporting period 1989–90 to 2017–18. A review of government and industry sources continues with a focus to update data on new and on-going capital dredging activity from 2018–19 onwards.

Modelling of methane emissions associated with *reservoirs* will continue to undergo improvement in step with the developing scientific literature in this area, which will also improve the confidence limits of future submissions.

A process of continuous improvement regarding regionally based seagrass removal parameter values to underpin the emissions model has been established to incorporate updated values acquired in regular surveys of the scientific literature.

6.7.2 Land converted to wetlands

This category comprises the subcategory *forest land converted to wetlands* (flooded land). Forest conversion occurs where forests are cleared as part of the construction of reservoirs and other land categorized in the 2006 IPCC Guidelines (IPCC 2006) as 'flooded lands' under *forest land converted to wetlands,* within the broader *land converted to wetlands source category.* Emissions are reported for land clearing associated with the flooding of the land, and for methane from young reservoirs.

Clearing of mangrove forests to wetland are also included in the subcategory *forest converted to wetlands.* Where mangrove forests are cleared for commercial developments such as marinas, these conversions are categorised as *forest land converted to settlements* within the broader *land converted to settlements* source category (see Chapter 6.8.2).

Activity data on changes in mangrove forest converted to wetlands and forest converted to flooded land relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1). Reported areas and disaggregated emissions were not updated because the impacts of climate data and vegetation monitoring activity data were not able to be updated independently, or independent climate updates were considered unlikely to be representative of emissions trends and subject to material revision once activity data becomes available. Holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data, and unsuitability of trend extrapolation given interannual variability of climate drivers. Consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3: Resolving data gaps), emissions for this category have been held constant at 2021–22 levels for 2022–23 and 2023–24.

The annual area identified, and associated net emissions are in Table 6.7.6 below.

Table 6.7.6 Areas of mangrove forest converted to wetlands, forest land converted to wetlands (flooded land) and reservoirs (up to 20 years old), and associated net annual emissions

Year	Mangrove forest converted to wetlands; Cumulative National Area (kha)	Mangrove forest converted to wetlands; Net Annual Emissions (kt CO_2-e)	Forest Converted to Flooded land: Cumulative National Area (kha)	Forest Converted to Flooded land: Net Annual Emissions (kt CO_2-e)	Young Reservoirs (up to 20 years): Annual area (kha)	Young Reservoirs (up to 20 years): Annual CH 4 emissions (kt CO_2-e)	Young Reservoirs (up to 20 years): Annual CO_2 emissions (kt CO_2)
1989-90	43	2,924	25	721	202	1,116	422
1994-95	62	2,708	32	232	69	353	137
1999-00	70	2,304	35	57	69	373	144
2004-05	79	2,139	37	45	46	266	103
2005-06	81	2,757	38	80	36	211	84
2006-07	82	2,644	38	48	37	228	91
2007-08	82	2,268	38	36	11	47	20
2008-09	83	2,266	39	1	12	56	23
2009-10	84	2,129	41	826	12	62	25
2010-11	87	2,961	45	1,458	4	29	11
2011-12	87	2,821	45	13	5	30	11
2012-13	87	2,449	45	-	5	30	11
2013-14	90	2,632	45	-	3	17	6
2014-15	92	2,520	45	-	4	23	9
2015-16	96	3,170	45	-	4	28	10
2016-17	97	3,335	45	-	3	21	8
2017-18	97	2,687	45	-	3	22	8
2018-19	98	2,698	45	-	3	18	7
2019-20	100	2,658	45	-	2	15	5
2020-21	103	2,661	45	-	2	12	4
2021-22	104	2,572	45	-	2	14	5
2022-23	104	2,572	45	-	3	16	5
2023-24	104	2,572	45	-	2	15	5

6.7.2.1 Methodological issues

Like for areas of forest conversions for cropping and grazing, areas of forest converted to wetland are identified at fine spatial resolution via Australia's Approach 3 remote sensing programme. In this case, the satellite imagery is analysed to identify where forest is cleared for construction of perennial water bodies such as reservoirs.

The method for estimating net emissions is taken from the 2006 IPCC Guidelines (IPCC 2006) as a conversion of land to flooded land. This model is implemented in FullCAM in fully spatial Tier 3 mode considering only fluxes in living biomass, considered using the same methods as for the loss of native vegetation in forest land converted to grassland (Chapter 6.6.2.2). The soil and dead organic matter emissions from conversion of land to flooded land are handled by the reservoir methane method described in Chapter 6.7.1.2 and Annex 5.6.10. Due to the application of Tier 1 emission factors, a transition period of 20 years is applied to this land conversion category rather than the 50–year period used in other categories.

Emissions at the time of land use conversion are reported in CRT 4.D.2. Lagged carbon dioxide and methane emissions are reported in *CRT4(II)* under *flooded land.*

Activity data on changes in mangrove forest converted to wetlands and forest converted to flooded land relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1). Reported areas and disaggregated emissions have been held constant at 2021–22 levels for 2022–23 and 2023–24.

6.7.2.2 Uncertainty assessment and time-series consistency

Uncertainties for *land converted to wetland* at the national scale were estimated to be ±22.8 per cent for CO_2. Further details are provided in Annex 2. Time series consistency is ensured using consistent methods and full recalculations in the event of any refinement to the methodology.

6.7.2.3 Category-specific QA/QC and verification

The category specific QA/QC for the subcategory *forest land converted to wetland* is covered in detail under *forest land converted to grassland* (Chapter 6.6.2.4).

6.7.2.4 Category-specific recalculations

As noted in Chapter 6.1, activity data on forest converted to flooded land and clearance of mangrove forests relies on the forest cover monitoring system which was not available for use in the 2024 report. Reported areas and disaggregated emissions have been held constant at 2021–22 levels for 2022–23 and 2023–24.

There were no recalculations for this category.

Table 6.7.7 Land converted to Wetlands: Recalculation of total CO_2–e emissions

	2025 submission	2026 submission	Recalculation	
	(kt CO_2 -e)	(kt CO_2 -e)	(kt CO_2 -e)	%
1989–90	5,183	5,183	0	0%
1994–95	3,429	3,429	-0	0%
1999–00	2,878	2,878	0	0%
2004–05	2,555	2,555	-0	0%
2005–06	3,132	3,132	0	0%
2006–07	3,011	3,011	0	0%
2007–08	2,371	2,371	0	0%
2008–09	2,346	2,346	0	0%
2009–10	3,042	3,042	0	0%
2010–11	4,458	4,458	0	0%
2011–12	2,876	2,876	0	0%
2012–13	2,491	2,491	-0	0%
2013–14	2,655	2,655	0	0%
2014–15	2,552	2,552	-0	0%
2015–16	3,208	3,208	-0	0%
2016–17	3,364	3,364	-0	0%
2017–18	2,717	2,717	0	0%
2018–19	2,722	2,722	-0	0%
2019–20	2,678	2,678	0	0%
2020–21	2,676	2,676	-0	0%
2021–22	2,591	2,591	-0	0%
2022–23	2,592	2,592	-0	0%

6.7.2.5 Category-specific planned improvements

The category specific planned improvements for the subcategory *forest land converted to wetland* are covered in detail under *forest land converted to grassland* (Chapter 6.6.2.6).

Improvements for the reservoir subcategory are covered in detail under *Wetlands remaining wetlands* (Chapter 6.7.1.6).

6.8 Settlements (CRT category 4.E)

6.8.1 Settlements Remaining Settlements

6.8.1.1 Category Description

The *settlements remaining settlements* subcategory includes urban environments and infrastructure that have not observed a land use conversion. It does not include areas of woody vegetation that constitute a forest to avoid double-counting of lands classified as *forest land.* This subcategory includes only estimates of net emissions from changes in sparse woody vegetation, such as due to changes in urban parks and gardens.

The key input data and estimated net emissions are presented in Table 6.8.1.

Activity data on changes in sparse woody vegetation in settlements relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1). Reported areas and disaggregated emissions were not updated because the impacts of climate data and vegetation monitoring activity data were not able to be updated independently, or independent climate updates were considered unlikely to be representative of emissions trends and subject to material revision once activity data becomes available. Holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data, and unsuitability of trend extrapolation given interannual variability of climate drivers. Consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3: Resolving data gaps), emissions for this category have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach.

Table 6.8.1 Area and net emissions of sparse woody vegetation, settlements remaining settlements

	Area gains	Area losses	Net emissions
Year	kha	kha	kt CO_2 -e
1989–90	5.4	-9.8	-25.4
1994–95	3.4	-4.7	9.6
1999–00	3.8	-4.1	27.3
2004–05	6.4	-9.0	31.6
2005–06	7.5	-7.9	32.3
2006–07	7.5	-8.2	33.1
2007–08	7.0	-9.0	35.0
2008–09	10.0	-9.2	26.1
2009–10	10.2	-8.4	20.4
2010–11	16.8	-5.9	6.9
2011–12	19.4	-5.4	-10.1
2012–13	14.0	-8.5	-16.0
2013–14	15.4	-9.0	-21.5
2014–15	11.9	-8.5	-25.8
2015–16	13.4	-9.1	-32.2
2016–17	19.7	-7.2	-46.2
2017–18	24.3	-5.5	-65.0
2018–19	16.2	-6.0	-75.3
2019–20	10.2	-7.5	-78.1
2020–21	8.6	-9.3	-76.7

	Area gains	Area losses	Net emissions
Year	kha	kha	kt CO_2 -e
2021–22	5.5	-6.6	-75.3
2022–23	5.5	-6.6	-75.3
2023–24	5.5	-6.6	-75.3

6.8.1.2 Methodological issues

Carbon stock-changes from gains and losses in sub-forest sparse woody vegetation on settlements have been identified using the same monitoring and modelling systems used to identify areas of sparse woody vegetation for *grassland remaining grassland* and estimate the associated emissions and removals (see Chapter 6.6.1.2).

Activity data on changes in sparse woody vegetation relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1). Reported areas and disaggregated emissions have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3 Resolving data gaps).

6.8.1.3 Uncertainty assessment and time-series consistency

Based on a qualitative assessment, the uncertainty for *settlements remaining settlements* is estimated to be medium. Further information is provided in Annex 2. Time series consistency is ensured by the use of consistent methods across the time series.

6.8.1.4 Category-specific QA/QC and verification

The QA/QC of the activity data for detecting gains and losses of woody vegetation is described in Annex 5.6.1.

6.8.1.5 Category-specific recalculations

As noted in Chapter 6.1, activity data on *settlements remaining settlements* relies on the forest cover monitoring system which was not available for use in the 2024 report. Reported areas and disaggregated emissions have been held constant at 2021–22 levels for 2022–23 and 2023–24 using an extrapolation approach consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3 Resolving data gaps).

There were no recalculations for this category.

Table 6.8.2 Settlements remaining settlements: recalculation of total CO_2–e emissions

	2025 submission	2026 submission	Change
	(kt CO_2 -e)	(kt CO_2 -e)	(kt CO_2 -e)
1989–90	-25	-25	-
1994–95	10	10	-
1999–00	27	27	-
2004–05	32	32	-
2005–06	32	32	-
2006–07	33	33	-
2007–08	35	35	-
2008–09	26	26	-
2009–10	20	20	-

	2025 submission	2026 submission	Change
	(kt CO_2 -e)	(kt CO_2 -e)	(kt CO_2 -e)
2010–11	7	7	-
2011–12	-10	-10	-
2012–13	-16	-16	-
2013–14	-21	-21	-
2014–15	-26	-26	-
2015–16	-32	-32	-
2016–17	-46	-46	-
2017–18	-65	-65	-
2018–19	-75	-75	-
2019–20	-78	-78	-
2020–21	-77	-77	-
2021–22	-75	-75	-
2022–23	-75	-75	-

6.8.1.6 Category-specific planned improvements

All data and methodologies are kept under review and development.

6.8.2 Land Converted to Settlements

6.8.2.1 Category Description

The land converted to settlements category includes *forest land converted to settlements.*

In reporting net emissions from conversion of forest land to settlements, the emissions and removals from the clearance of terrestrial forests is estimated separately from mangrove forests using FullCAM (see Annex 5.6.10).

The activity data for the *forest land converted to settlements* classification relies on the forest cover monitoring system which was not available for use in the 2024 report (see Chapter 6.1). For mangrove forests, reports areas and disaggregated emissions were not updated because the impacts of climate data and vegetation monitoring activity data were not able to be updated independently, or independent climate updates were considered unlikely to be representative of emissions trends and subject to material revision once activity data becomes available. Holding emissions constant was considered to be the most accurate extrapolation method given the lack of surrogate data, and unsuitability of trend extrapolation given interannual variability of climate drivers. Consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3: Resolving data gaps), emissions for this category have been held constant at 2021–22 levels for 2022–23 and 2023–24.

For terrestrial forest, reported areas have been held constant at 2021–22 levels for 2022–23 and 2023–24, while updates to climate and crop and grass yield data were incorporated to improve estimates of emissions on previously cleared lands. These updates were incorporated because climate conditions since 2022 have materially affected emissions in this sector, robust methods exist to partially update the modelling, and because climate-driven changes are judged unlikely to be significantly revised once new vegetation monitoring data becomes available. The data updates show the moderation of sequestration rates on previously cleared croplands and grasslands to more typical levels. This is consistent with climate conditions that have transitioned out of the prolonged La Niña period that was associated with elevated rainfall including significant flooding in different regions of Australia in 2020, 2021 and 2022.

This hybrid approach provides the most reliable estimates given current data constraints. It balances the need for completeness and methodological consistency with the opportunity to incorporate category specific updates where supporting data exist.

Identified land category transitions and associated annual emissions are in Table 6.8.3 below.

Table 6.8.3 Net emissions from land converted to settlements, kt CO_2–e

	Land converted to settlements		
Year	Mangrove forest	Terrestrial forest	Total
1989–90	14	4,649	4,663
1994–95	8	2,593	2,601
1999–00	8	2,893	2,901
2004–05	9	3,101	3,110
2005–06	13	3,969	3,982
2006–07	12	2,143	2,155
2007–08	12	2,644	2,656
2008–09	12	2,070	2,082
2009–10	10	2,753	2,763
2010–11	10	978	988
2011–12	9	1,678	1,687
2012–13	9	2,598	2,607
2013–14	11	1,953	1,964
2014–15	10	1,230	1,240
2015–16	10	290	300
2016–17	10	1,190	1,200
2017–18	8	875	883
2018–19	8	536	544
2019–20	8	904	912
2020–21	7	-264	-257
2021–22	8	-726	-718
2022–23	8	1,348	1,356
2023–24	8	595	603

6.8.2.2 Methodological issues

While activity data is collected via satellite imagery for both types of clearance, the modelling methods differ, reflecting the significant differences between mangrove and terrestrial forests in terms of their allometrics and carbon fluxes.

Clearance of terrestrial forests for settlement development is modelled using FullCAM, considering fluxes between all five carbon pools using the same methods and approaches as applied for conversions from forest land to grassland (see Chapter 6.6.2). Mangrove forest conversion to settlements is also modelled using FullCAM, calibrated for mangrove species as described in Annex 5.6.10 and Chapter 6.4.2.2 (wetlands converted to forest lands).

Activity data on forest conversions to settlements relies on data from the land monitoring system, which was not available for use in the 2024 Submission (see Chapter 6.1). Reported areas associated with forest conversions have been held constant at the levels reported in the 2024 Submission using an extrapolation approach consistent with the 2006 IPCC Guidelines (Volume 1 Chapter 5.3 Resolving data gaps).

Table 6.8.4 Cumulative area of land converted to settlements, kha

Year	Terrestrial forest converted to settlements	Mangrove forest converted to settlements	Total
1989–90	149.8	0.3	150.1
1994–95	217.9	0.3	218.3
1999–00	280.1	0.4	280.5
2004–05	350.6	0.4	351.0
2005–06	369.3	0.5	369.8
2006–07	383.0	0.5	383.5
2007–08	395.2	0.5	395.7
2008–09	403.9	0.5	404.4
2009–10	409.5	0.5	410.1
2010–11	414.1	0.5	414.6
2011–12	417.1	0.5	417.6
2012–13	419.4	0.5	419.9
2013–14	419.4	0.5	419.9
2014–15	416.5	0.5	417.0
2015–16	416.7	0.5	417.2
2016–17	415.8	0.5	416.3
2017–18	417.1	0.5	417.6
2018–19	415.0	0.5	415.5
2019–20	413.8	0.5	414.3
2020–21	413.8	0.5	414.3
2021–22	411.0	0.5	411.6
2022–23	411.0	0.5	411.6
2023–24	411.0	0.5	411.6

6.8.2.3 Uncertainty assessment and time-series consistency

Uncertainties for *terrestrial forest land converted to settlements* at the national scale were estimated to be ±28.4 per cent for CO_2. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

Under *mangrove forest land converted to settlements* the confidence intervals associated with 2013 Wetlands Supplement guidance for parameters associated with coastal wetlands are moderate. This inventory applies spatially explicit FullCAM modelling calibrated to available, representative field data, sourced from scientific literature, to reduce uncertainty. Although a formal uncertainty analysis is not yet available, the level of uncertainty is anticipated to be 30–50% or towards the lower-mid end of the IPCC guidance values and is considered to be within the medium range. Other uncertainties and time series inconsistencies relevant to FullCAM simulations (Annexes 5.6.1–2) in general also apply here.

6.8.2.4 Category-specific QA/QC and verification

The category specific QA/QC for the subcategory *terrestrial forest land converted to settlements* is covered in detail under *forest land converted to grassland* (Chapter 6.6.2.4).

For *mangrove forest land converted to settlements,* category specific QA/QC was included in general in the approach to designing and calibrating the coastal wetlands sub-model in FullCAM. The mangrove extent has been manually inspected against Google Earth satellite imagery and also overlaid with Digital Earth Australia product (DEA Mangrove; Landsat, mangrove_cover_v2_0_2, Lymburner et al. 2020) and manually compared in numerous regions of Australia that have significant mangrove and tidal marsh vegetation cover. Parameter value estimations governing growth and recovery after clearing included screening field data to obtain a subset of available data representative of different mangrove sites around Australia, prior to model calibration (Annex 5.6.10).

6.8.2.5 Category-specific recalculations

The recalculation of the *land converted to settlements* time series is presented in Table 6.5.7. Emissions have been recalculated as a result of updating climate data and crop and grass yields and adding an additional year of data.

Table 6.8.5 Land converted to settlements: recalculation of total CO_2–e emissions

	2025 submission	2026 submission	Recalculation
	(kt CO_2–e)	(kt CO_2–e)	(kt CO_2–e)
1989–90	4,663	4,663	-
1994–95	2,601	2,601	-
1999–00	2,901	2,901	-
2004–05	3,110	3,110	-
2005–06	3,982	3,982	-
2006–07	2,155	2,155	-
2007–08	2,656	2,656	-
2008–09	2,082	2,082	-
2009–10	2,763	2,763	-
2010–11	988	988	-
2011–12	1,687	1,687	-
2012–13	2,607	2,607	-
2013–14	1,964	1,964	-
2014–15	1,240	1,240	-
2015–16	300	300	-
2016–17	1,200	1,200	-
2017–18	883	883	-
2018–19	544	544	-
2019–20	912	912	-
2020–21	-257	-257	-
2021–22	-718	-718	-
2022–23	-718	1,356	2,074

6.8.2.6 Category-specific planned improvements

Grassland and *cropland converted to settlements* are included within *settlements remaining settlements,* based on land representation Approach 1 (2006 IPCC Guidelines, Volume 4, page 3.10). Work is planned to accommodate the reporting of all conversions to settlements using land representation Approach 3 (spatially explicit land-use conversion data) in future inventory submissions.

The category specific planned improvements for the subcategory of terrestrial *forest land converted to settlements* is described under *forest land converted to grassland* (Chapter 6.6.2.5).

6.9 Other Land (CRT category 4.F)

Australia does not report emissions and removals from the reporting category of *other lands remaining other lands. Other lands* typically occur in regions of central Australia, e.g., deserts, with minimal anthropogenic impacts on biomass, dead organic matter, and soil carbon.

Other lands, by definition, cannot include any land on which a forest has been observed in the Landsat time series since 1972. As a consequence of this definition *land converted to other land* is not observed.

6.10 Harvested Wood Products (CRT category 4.G)

6.10.1 Category Description

Australia applies the stock-change approach for *harvested wood products* (HWP) in use and in solid waste disposal sites (SWDS). The carbon pool is therefore defined as the wood products in service life within Australia —that is, products consumed in Australia, including those imported and excluding those exported. In accordance with the *2006 IPCC Guidelines,* HWP in SWDS are also reported, as the pool exceeds the significance threshold.

To meet transparency requirements of the Paris Agreement, estimates are also provided for HWP in-use using the production approach, which considers the service life of HWP sourced from Australian forests, including where exported and excluding imports.

Table 6.10.1 Net emissions from harvested wood products, kt CO_2–e

Year	HWP in-use (stock-change approach)	HWP in SWDS	Total HWP Emissions	HWP in-use (production approach)
1989–90	-4,012	-3,125	-7,137	-2,577
1994–95	-4,245	-3,250	-7,496	-3,478
1999–00	-4,471	-3,257	-7,728	-5,091
2004–05	-4,361	-3,568	-7,929	-4,711
2005–06	-4,183	-3,323	-7,505	-4,604
2006–07	-3,617	-2,844	-6,461	-4,892
2007–08	-3,878	-2,479	-6,357	-4,745
2008–09	-2,328	-2,253	-4,580	-3,670
2009–10	-2,577	-1,532	-4,110	-3,993
2010–11	-2,706	-1,843	-4,549	-4,259
2011–12	-2,589	-1,323	-3,912	-3,572

Year	HWP in-use (stock-change approach)	HWP in SWDS	Total HWP Emissions	HWP in-use (production approach)
2012–13	-2,689	-1,249	-3,937	-3,211
2013–14	-2,560	-1,176	-3,736	-4,458
2014–15	-2,874	-1,103	-3,977	-4,881
2015–16	-3,089	-1,109	-4,198	-5,589
2016–17	-3,222	-906	-4,128	-6,164
2017–18	-3,792	-1,225	-5,017	-6,110
2018–19	-3,540	-1,383	-4,923	-5,547
2019–20	-3,117	-1,330	-4,447	-4,642
2020–21	-3,732	-1,168	-4,900	-4,367
2021–22	-4,449	-1,180	-5,629	-3,560
2022–23	-3,796	-1,215	-5,011	-3,239
2023–24	-3,388	-1,884	-5,272	-3,136

6.10.2 Methodological issues

The stock of HWP in-use is estimated as the national production plus the imported material, minus exported material and product disposed to the waste system. Transfer of carbon from HWP in-use to landfill is recorded as a loss of carbon stock from the in-use HWP pools and as a gain in the HWP in SWDS pool. HWP in SWDS is tracked using methods consistent with those of the *Waste* sector, which are compatible with the stock-change approach.

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since the 1940s. It is currently maintained as the Australian Forest and Wood Products Statistics (AFWPS) by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES 2025c). This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model.

Model components

Information has been obtained and examined under the following components of the model:

- log flow from the forest: current annual production data were obtained by species groupings, and product classes, e.g., sawlogs, veneer logs, pulp logs, roundwood and other, e.g., sleepers;
- fibre flow from processing: data on the intake of raw materials to the various processing options and the output of products and by-products have been used in the model to estimate the total tonnes of carbon produced each year under various end product classes;
- import and export quantities of wood products;
- recycling;
- entry and decomposition in landfill;
- use for bioenergy; and
- other losses to atmosphere.

Wood flow

The model develops wood flows separately for each pool of wood products within the overall HWP pool and these are integrated to account for cross-linkages. This is particularly important in the accounting for waste or by-products, which are themselves used as resources in production for other wood product pools. In conjunction with the opening carbon stock and life cycle of timber products, this model enables the total and projected carbon stocks in HWP to be estimated.

In broad terms, the components of the models developed for each pool of HWP are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., "x" percentage sawdust, shavings or sander dust for on-site energy generation or compost, "y" percentage woodchips for other manufacturing processes, "z" percentage of sawn timber products, panel products and paper;
- an estimate of the proportion of products by product categories, depending on whether their expected end use is long-term or short-term; e.g., framing timber, dry dressed boards, cases and pallet stock, panel products for use in house construction, panel boards for use in furniture and cabinets, newsprint paper, and writing and printing paper;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon; and
- import and export data obtained via the AFWPS source data by end use categories. Details of the flows are shown in Annex 5.6.9.

Treatment of bark

There has been no accounting for bark. All bark is regarded as being a component of logging slash (harvesting residue) and accounted for as a part of in-forest logging operations.

Basic density and carbon content

Basic wood density and carbon content estimates (Table 6.10.2) are relevant to all processing options, and the choice of values adopted has a significant bearing on the final outcome. In the case of all sawn timber, and treated softwood and hardwood poles, weighted basic densities for the species involved have been applied across each category and the values adopted based on (Ilic, et al. 2000). For board products and paper, which have been subjected to varying amounts of compression during manufacture, their basic densities have been adjusted to that of the finished products.

Carbon content is defined variably throughout the literature, with values ranging from 0.4 to 0.53 of the oven dry (bone dry) weight. A figure of 0.5 has been adopted for use in the model as a median value extracted from (R. Gifford 2000a).

Apart from the assumptions concerning basic density and carbon content, the other manufacturing assumptions were developed from interviews with representatives from the various industry associations and individual sawmilling companies.

Table 6.10.2 Basic densities, moisture and carbon contents

Carbon Fractions	
Description	**Value**
Fraction of softwood sawmilling dry matter that is carbon, by weight	0.50
Fraction of particleboard dry matter that is carbon, by weight	0.40
Fraction of MDF dry matter that is carbon, by weight	0.40
Basic Densities [(a)]	
Description	**Value kg m-3**
Density of softwood sawmilling	460
Density of hardwood sawmilling	630
Density of cypress sawmilling	600
Density of plywood (softwood and hardwood) and veneer	540
Density of particleboard	520
Density of MDF	600
Density of hardboard	930
Density of softboard	230
Density of pulp and paper: Paper	1,000
Density of pulp and paper: Softwood	430
Density of pulp and paper: Hardwood	500
Density of pulp and paper: Waste paper	1,000
Density of pulp and paper: Pulp	1,000
Density of paper and paperboard imports and exports, on average	1,000
Density of chips and logs for export: Softwood logs	415
Density of chips and logs for export: Hardwood logs	630
Density of hardwood poles, sleepers and miscellaneous	790
Moisture Content of Green Wood	
Description	**Value**
Ratio of weight of water to weight of wood substance in softwood chips	1.10
Ratio of weight of water to weight of wood substance in hardwood chips	0.90

(a) Basic density = (mass of oven dry wood in kg) / (volume of green wood in m3)

Wood flows from processing

Wood flows in the various wood products produced in Australia have been developed under the following species/industry headings:

- Softwood sawmilling;
- Hardwood sawmilling;
- Cypress sawmilling;
- Plywood;
- Particleboard and medium density fibreboard (MDF);
- Pulp and paper;
- Preservative treated softwood;
- Hardboard and Softboard;
- Hardwood poles, sleepers and miscellaneous; and
- Export of woodchips and logs.

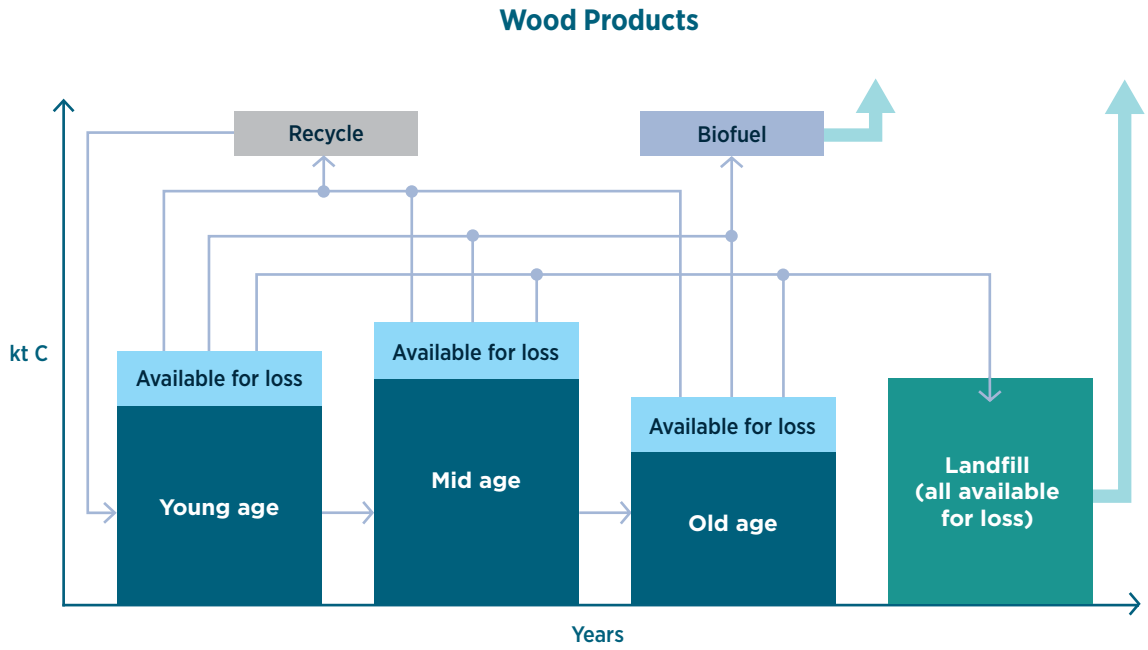
Life span of timber products (recycling and landfill)

The life span of wood products must be taken into account when ascertaining the quantity of carbon stored in timber products. Considerable attention has been given to subdividing the various timber products pools into different classes based on product and decay rates. The decay rates used assume that losses of material from service life will increase with product age. Therefore, the entry and exit of material from production to loss from each product pool is tracked and aged according to three age classes; young, medium and old. The proportion of material lost from each pool may vary (e.g., there may be little loss from young pools (excluding those to the medium age class)). Material is lost at a constant rate and may be placed in landfill, recycled, used for bioenergy or lost to the atmosphere (e.g., burnt with no energy capture) (Figure 6.10.1). The destination of material lost from service life is shown in Table 6.10.3.

Table 6.10.3 Destination of material lost from service life (kt C)

Year	Disposed to Landfill	Recycling and recovery of residues	Fuelwood consumed	Emissions other than biofuel (e.g. Aerobic decay)
1989–90	1,278	1,633	461	527
1994–95	1,363	2,022	531	321
1999–00	1,401	2,323	550	284
2004–05	1,518	2,475	544	422
2005–06	1,459	2,528	536	535
2006–07	1,335	2,527	546	697
2007–08	1,236	2,552	570	836
2008–09	1,170	2,502	444	904
2009–10	969	2,544	420	1,116
2010–11	1,041	2,456	401	1,114
2011–12	890	2,484	427	1,044
2012–13	859	2,417	507	986
2013–14	825	2,438	538	917
2014–15	805	2,509	550	842
2015–16	803	2,517	533	873
2016–17	722	2,667	507	963
2017–18	792	2,646	470	779
2018–19	821	2,691	464	906
2019–20	806	2,664	444	901
2020–21	742	2,738	444	882
2021–22	736	2,782	485	877
2022–23	734	2,823	485	760
2023–24	870	2,616	485	558

Figure 6.10.1 Structure of the Wood Products Model



For shorter-term products, the impact of the size of previous stocks is fairly slight, as the recent additions to the pools have the major impact. For long-term products, an estimate of the size of the initial pool is essential, but difficult. The size of the longest-lived pool representing housing products uses housing starts data.

Life span pools assumed for the Carbon Model

Very short-term products – Pool 1

- Paper and paper products.
- Woodchips and pulp logs for export.
- Age: young = 1; medium = 2; old = 3

Short-term products – Pool 2

- Hardwood – pallets and palings.
- Particleboard and MDF – shop fitting, DIY, miscellaneous.
- Plywood – form board.
- Hardboard – packaging.
- Age: young = 2; medium = 6; old = 10

Medium-term products – Pool 3

- Softwood – pallets and cases
- Plywood – other (noise barriers).
- Particleboard and MDF – kitchen and bathroom cabinets, furniture.
- Preservative treated softwood – decking and palings.
- Age: young = 10; medium = 20; old = 30

Long-term products – Pool 4

- Preservative treated softwood – poles and roundwood.
- Softwood – furniture.
- Roundwood logs for export.
- Age: young = 20; medium = 30; old = 50

Very long-term products – Pool 5

- Softwood – framing, dressed products (flooring, lining, mouldings).
- Cypress – green framing, dressed products (flooring, lining).
- Hardwood – green framing, dried framing, flooring and boards, furniture timber, poles, piles, girders, sleepers and other miscellaneous products.
- Plywood – structural, LVL, flooring, bracing, lining.
- Particleboard and MDF – flooring and lining.
- Softboard and Hardboard – weathertex, lining, bracing, underlay.
- Preservative treated softwood – sawn structural timber.
- Age: young = 30; medium = 50; old =90

A specified proportion of material is lost annually (an exponential loss) from each age class of each in-use product pool. The amount lost from each age class for each product pool can be capped and different proportions can be lost according to age. This feature of the model provides for 'steps' in product loss rather than functioning on either a simple linear or exponential loss applied to a whole product pool, irrespective of the average age of the pool. If inputs vary over time, the average age of products will vary, and this is represented by the amounts of material in each age class of each product pool.

Initial stock assumptions

Input data is available for the model since 1940. This has the benefit of allowing the model to establish equilibrium pools, as the input material may be 'turned-over' several times prior to an equilibrium stock being reached for recent years. Initial stock estimation (for 1940) is more important for Pool 5 as this material may remain in use in housing assets.

Model calibration

Once the data on production inputs, processing flows and initial stocks is determined, other model calibration requirements include:

- the age at which material moves from young to medium and medium to old pools;
- the amount of each age class for each product pool exposed to loss;
- the rate of loss from each age class in each product pool; and
- the fraction of losses from each age class in each product pool to each of land fill recycling, bioenergy and otherwise to the atmosphere.

The model estimates used are presented in Table 6.10.4 and Table 7.6 (in Chapter 7).

Table 6.10.4 Decomposition rates and maximum possible loss

	YOUNG		MEDIUM		OLD	
Pool	Loss Yr^{-1}	Proportion of in use Pool exposed to decay	Loss Yr^{-1}	Proportion of in use Pool exposed to decay	Loss Yr^{-1}	Proportion of in use Pool exposed to decay
1	1.0	0.60	1.0	0.65	1.0	0.90
2	0.50	0.30	0.25	0.50	0.25	0.90
3	0.10	0.15	0.10	0.65	0.10	0.45
4	0.05	0.25	0.10	0.65	0.05	0.80
5	0.033	0.20	0.05	0.55	0.025	0.95

Model results

By integrating the carbon pools and life cycles of wood products, the model enables the total carbon pools and emissions to be estimated (Table 6.10.5).

Table 6.10.5 Carbon stock and emissions outcomes (kt C)

	Domestic Production of Wood Products	Imports of Wood Products	Exports of Wood Products	Increase Due to Wood Products	Carbon Pool (excl. landfill)
Year	kt C	kt C	kt C	kt C	kt C
1989–90	2,905	854	855	2,903	58,188
1994–95	3,503	989	1,190	3,302	63,604
1999–00	4,401	1,063	1,782	3,683	68,776
2004–05	4,937	1,226	2,201	3,962	74,422
2005–06	4,884	1,316	2,173	4,027	75,563
2006–07	5,050	1,198	2,397	3,851	76,550
2007–08	5,142	1,220	2,406	3,956	77,607
2008–09	4,762	1,075	2,333	3,504	78,242
2009–10	4,680	1,144	2,394	3,429	78,945
2010–11	4,743	1,252	2,525	3,471	79,684
2011–12	4,427	1,177	2,203	3,401	80,390
2012–13	4,168	1,186	2,031	3,322	81,123
2013–14	4,637	1,176	2,582	3,231	81,821
2014–15	5,022	1,188	2,884	3,326	82,608
2015–16	5,504	1,144	3,270	3,378	83,452
2016–17	5,929	1,116	3,672	3,374	84,331
2017–18	6,054	1,178	3,743	3,490	85,365
2018–19	5,976	1,121	3,654	3,444	86,330
2019–20	5,330	981	3,071	3,241	87,180
2020–21	4,984	939	2,613	3,310	88,198
2021–22	4,761	1,102	2,354	3,509	89,411
2022–23	4,470	993	2,176	3,287	90,442
2023–24	3,832	1,008	1,746	3,094	91,366

6.10.3 Uncertainty assessment and time-series consistency

A qualitative assessment of uncertainty was undertaken and uncertainties for *harvested wood products* were estimated to be medium. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

6.10.4 Category-specific QA/QC and verification

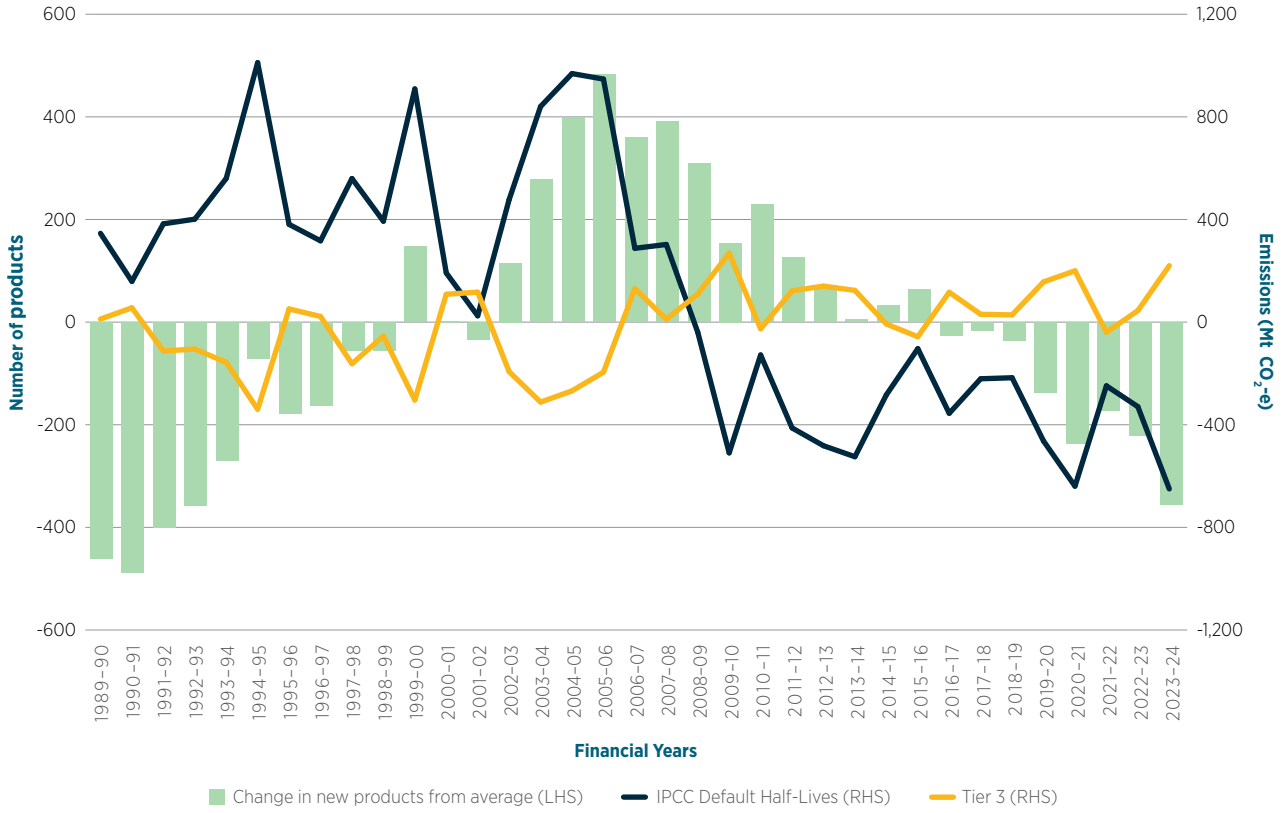
Principal quality control on the Australian Forests Products Statistics is undertaken by the ABARES. Economic data from the Australian Bureau of Statistics on the wood and paper products manufacturing industry is also used as a confrontational data source.

A Tier 2 model using IPCC default half-lives is used to compare Australia's tier 3 method with a tier 2 equivalent. Figure 6.10.2 shows that overall, both approaches yield similar results, with the difference predominantly reflecting how the two models account for declining production in short-lived paper products (see Table 6.10.6). Australia's Tier 3 model relies on country-specific factors and modelling that show young products turn over quicker than products that have been in service for longer periods, and so the emissions results are less influenced by short term variability of fresh inputs than the Tier 2 equivalent (Figure 6.10.3).

Figure 6.10.2 Verification of Tier 3 model for HWP by comparison to IPCC Tier 2 First Order Decay model



Figure 6.10.3 Comparison of the variability in the treatment of paper products by the Tier 3 model and IPCC Tier 2 First Order Decay Model



Decay of other short-term products (Pool 2 in Table 6.10.6) is faster than the default half-lives provided by the IPCC, while the effective loss rate of very long-lived products (Pool 5) is slower, as only a proportion of the pool is considered available for loss in each year in the T3 model. These counteracting differences have little impact on reported net emissions.

Table 6.10.6 Comparison of product pools (note exclusions in IPCC are to avoid double counting)

Pool	Australian Definition	IPCC Definition/equivalent (from 2019 refinement definitions, 12.12)
1 (very short-term products)	Paper and paper products. Woodchips and pulp logs for export. Composite half-life: 0.69	**Paper and paperboard** Aggregate category. The sum of: graphic papers; sanitary and household papers; packaging materials and other paper and paperboard. Excludes manufactured paper products such as boxes, cartons, books and magazines, etc. Default half-life: 2
2 (short-term products)	Hardwood – pallets and palings. Particleboard and MDF – shop fitting, DIY, miscellaneous. Plywood – form board. Hardboard – packaging. Composite half-life: 2.34	**Wood-based panels** An aggregate comprising: veneer sheets, plywood, particle board, and fibreboard Default half-life: 25

Pool	Australian Definition	IPCC Definition/equivalent (from 2019 refinement definitions, 12.12)
3 (medium-term products)	Softwood – pallets and cases Plywood – other (noise barriers). Particleboard and MDF – kitchen and bathroom cabinets, furniture. Preservative treated softwood – decking and palings. Composite half-life: 6.93	
4 (long-term products)	Preservative treated softwood – poles and roundwood. Softwood – furniture. Roundwood logs for export. Composite half-life: 10.35	**Sawnwood** Wood that has been produced from both domestic and imported roundwood, either by sawing lengthways or by a profile-chipping process and that exceeds 6 mm in thickness. It includes: planks, beams, joists, boards, rafters, scantlings, laths, boxboards and "lumber", etc., in the following forms: unplaned, planed, end jointed, etc. It excludes: sleepers, wooden flooring, mouldings (sawnwood continuously shaped along any of edges or faces, like tongued, grooved, rebated, V-jointed, beaded, moulded, rounded or the like) and sawnwood produced by re-sawing previously sawn pieces. Default half-life: 35
5 (very long-term products)	Softwood – framing, dressed products (flooring, lining, mouldings). Cypress – green framing, dressed products (flooring, lining). Hardwood – green framing, dried framing, flooring and boards, furniture timber, poles, piles, girders, sleepers and other miscellaneous products. Plywood – structural, LVL, flooring, bracing, lining. Particleboard and MDF – flooring and lining. Softboard and Hardboard – weathertex, lining, bracing, underlay. Preservative treated softwood – sawn structural timber. Composite half-life: 19.02	

6.10.5 Category-specific recalculations

Recalculations as shown in Table 6.10.7 are due to time-series revisions to the underlying source data on forestry and wood products produced by ABARES, and revisions in the Waste sector, which impact HWP in SWDS.

Table 6.10.7 Recalculations of the HWP inventory

	2025 submission	2026 submission	Recalculation
Year	(kt CO_2–e)	(kt CO_2–e)	(kt CO_2–e)
1989–90	-7,137	-7,137	0
1994–95	-7,495	-7,496	0
1999–00	-7,728	-7,728	-1
2004–05	-7,928	-7,929	-1
2005–06	-7,504	-7,505	-1
2006–07	-6,460	-6,461	-1
2007–08	-6,356	-6,357	-1
2008–09	-4,579	-4,580	-1
2009–10	-4,109	-4,110	-1
2010–11	-4,548	-4,549	-1
2011–12	-3,911	-3,912	-1
2012–13	-3,938	-3,937	0
2013–14	-3,736	-3,736	0
2014–15	-3,977	-3,977	0
2015–16	-4,198	-4,198	0
2016–17	-4,128	-4,128	-1

Year	2025 submission ($kt CO_2$–e)	2026 submission ($kt CO_2$–e)	Recalculation ($kt CO_2$–e)
2017–18	-5,015	-5,017	-2
2018–19	-4,923	-4,923	0
2019–20	-4,443	-4,447	-3
2020–21	-4,901	-4,900	0
2021–22	-5,611	-5,629	-18
2022–23	-4,982	-5,011	-29

6.10.6 Category-specific planned improvements

Australia is investigating the inclusion of biochar in the *harvested wood products* subcategory. Initial inclusion of biochar will likely take the form of biochar sourced from salvage logging activity in bushfire-affected plantations. Parameterisation for carbon storage in biochar will be undertaken in consultation with industry members and scientific expertise.

6.11 N_2O emissions from N fertilisation – 4(I)

Nitrous oxide emissions, associated with nitrogen fertilisers, are reported under the *Agriculture* sector (3D). N_2O released from the application of N fertiliser on forests is reported as Included Elsewhere (IE) in *Agriculture.* The amount of N applied to lands in Australia is obtained from national statistics of the amount of N purchased. It is not possible to disaggregate the use of N fertiliser between agriculture and forestry uses.

N fertilisation of native forests is very rare, if occurring at all. There is a limited amount of N fertiliser applied to forest plantations in Australia. Fertiliser application in plantations is typically done to correct for nutrient deficiencies and trace element correction at establishment. N may be applied on sites where it is shown that it is a significant limiting nutrient, but as most establishments are on pasture systems, background nutrient levels are typically sufficient.

6.12 Emissions and removals from drainage and rewetting and other management of organic and mineral soils – 4(II)

Drawing upon guidance on *Flooded lands* from the 2019 Refinement to the IPCC Guidelines (pp 7.1–7.29) (IPCC 2019), Australia is able to report methane emissions from *Reservoirs* and *Other constructed waterbodies* as part of *flooded land remaining flooded land.* Carbon dioxide emissions from inundated land associated with newly established reservoirs are also reported under *land converted to flooded land* for a period of 20 years from the date the reservoir was completed.

For ease of reporting, all *Reservoirs* and *Other constructed water bodies* emissions (CO_2 and CH_4) are reported in Common Reporting Table 4(11): 4.D.2 *Flooded Lands* (on mineral soils). More information is provided in Chapter 6.7 (Wetlands).

6.13 Direct and Indirect N_2O emissions from managed soils – 4(III) and 4(IV)

N2O emissions from N mineralisation associated with loss of soil organic matter

An increase in N_2O emissions can be expected following a decline in soil organic carbon stocks. This is a consequence of enhanced mineralisation of soil organic matter that takes place as a result of soil disturbance. The conversion not only results in the net loss of soil organic carbon, but the corresponding effects on mineralised nitrogen can result in N_2O emissions from the process of nitrification and denitrification.

The (IPCC 2006) methods are used to calculate N_2O emissions from this source. The amount of nitrogen mineralised is calculated from the C:N ratio of soil. The C:N values used are 18 for *forest land* and forest conversion categories and 10 for *grassland remaining grassland,* reflecting the approximate median value extracted from a survey of national estimates (Snowdon, Ryan and Raison 2005). The country specific emission factor for fertiliser additions to non-irrigated crops and pastures (0.0021 (kt N_2O-N/kt N)) is then applied.

Emissions associated with N mineralisation in *cropland remaining cropland* soils are reported in the Agriculture sector (3.D).

Leaching and run-off

Estimates are made of emissions associated with leaching and run-off of the N mineralised through loss of soil carbon, using country-specific emission factors.

Annual nitrous oxide production from leaching and runoff in state or territory *i* from nitrogen source *j* is calculated as:

$$E_{ij} = M_{ij} \times FracWET_{ij} \times Frac_{LEACH} \times EF \times C_g \quad (6.13.1)$$

Where M_{ij} = mass of N mineralised due to a loss of soil carbon (kt N)
$FracWET_{ij}$ = fraction of N available for leaching and runoff (Annex 5.5.10)
$Frac_{LEACH}$ = 0.24 (kt N/kt applied) IPCC (2019) default fraction of N lost through leaching and runoff
EF = 0.011 (kt N_2O-N/kt N) IPCC (2019) default EF
C_g = 44/28 factor to convert elemental mass of NO to molecular mass

A planned improvement to the calculation of FracWET based on spatial analysis of climate and soils for each land use category based on the IPCC 2019 Refinement, aligned with the method used in the Agriculture sector and described in section 5.5.2, will be incorporated in a future inventory submission.

6.14 Biomass Burning – 4(V)

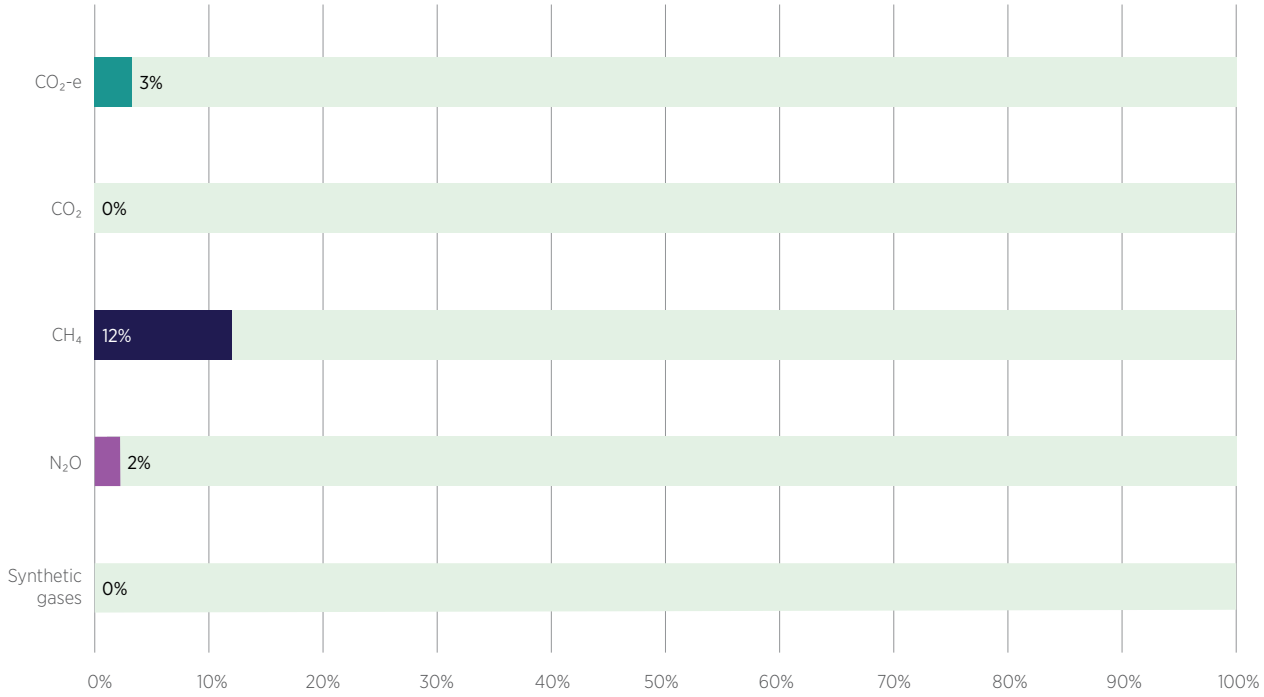
The methods applied to estimate emissions and removals associated with biomass burning are described in Chapter 6.3.2.

7. Waste

7.1 Overview of the sector and background information

The waste sector accounts for greenhouse gas emissions from solid waste disposal, biological treatment of solid waste, waste incineration, and wastewater treatment and discharge. The sector's share of national emissions (excluding LULUCF) by gas is shown in Figure 7.1.

Figure 7.1 Share of national emissions (excluding LULUCF) for the waste sector by gas, 2023–24



The majority of emissions in the waste sector are from *solid waste disposal,* followed by *wastewater treatment and discharge.* Emissions from *waste incineration* and *biological treatment of solid waste* are a relatively small contribution. Waste sector emissions are dominated by methane, which is generated from the anaerobic decomposition of organic matter. Smaller amounts of carbon dioxide are generated through the incineration of solvents and clinical waste, while nitrous oxide is generated during the decomposition of human wastes. Changes in emissions by subsector since 1989–90, 2004–05 and 2022–23 are shown in Figure 7.2.

Figure 7.2 Comparison of 2023–24 emissions with past emissions levels from key waste subsectors, million tonnes of carbon dioxide equivalent (Mt CO_2-e) and percentage change (%)

Waste Subsectors	2023–24 emissions	Change in 2023–24 emissions since:		
		1989–90	2004–05	2022–23
 5.A Solid Waste Disposal	10 Mt	-7 Mt CO_2-e -39%	-2 Mt CO_2-e -15%	-0.1 Mt CO_2-e -1%
 5.B Biological Treatment of Solid Waste	0.3 Mt	+1,285% +0.3 Mt CO_2-e	+107% +0.2 Mt CO_2-e	+2% <+0.1 Mt CO_2-e
 5.C Incineration and Open Burning of Waste	<0.1 Mt	-0.1 Mt CO_2-e -62%	+14% <+0.1 Mt CO_2-e	+0.4% <+0.1 Mt CO_2-e
 5.D Wastewater Treatment and Discharge	3 Mt	-3 Mt CO_2-e -50%	-0.1 Mt CO_2-e -4%	+6% +0.2 Mt CO_2-e
 5.E Other	NE	–	–	–

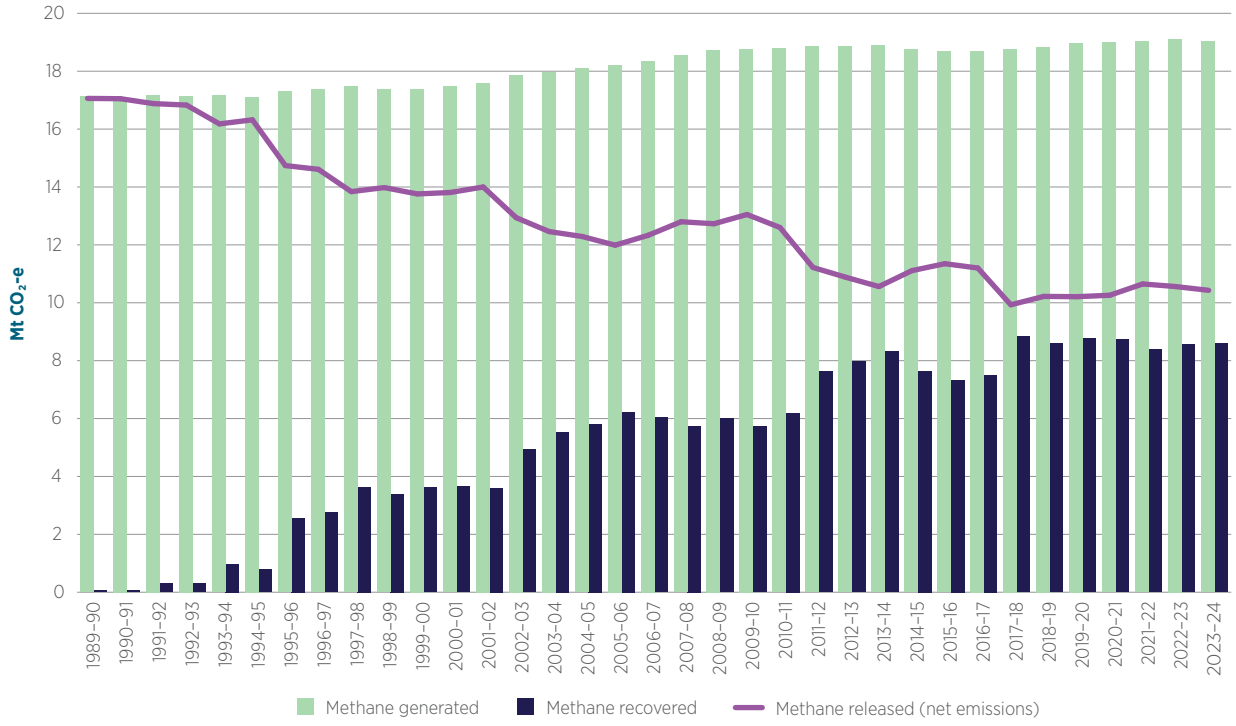
Note: NE = Not Estimated. Icons in this figure are sourced from Uniconlabs, kliwir art, juicy_fish, hindra, and Creatype on flaticon.com.

Total estimated waste emissions have decreased since 1989–90 (Figure 7.2). This decline has been driven by reductions in emissions from *solid waste disposal* and *wastewater treatment and discharge.*

As waste degradation is a slow process, estimates of methane generation from *solid waste disposal* reflect waste disposal levels and composition over several decades. Since 2004–05, as rates of recycling have increased, paper disposal in particular has declined as a share of total waste disposed.

Rates of methane recovery from *solid waste* have improved substantially, increasing from a negligible amount in 1989–90 to almost half of total methane generation in recent years (Figure 7.3).

Figure 7.3 Trends in methane generation, recovery, and emissions from solid waste disposal, 1989–90 to 2023–24



Wastewater treatment and discharge emissions have decreased by almost 50% since 1989–90, largely driven by changes in industry production, population loads on centralised treatment systems and the amount of methane recovered for combustion or flaring.

Table 7.1 Summary of methods and emission factors used to estimate emissions from waste

	CO_2		CH_4		N_2O	
	Method applied	**Emission factor**	**Method applied**	**Emission factor**	**Method applied**	**Emission factor**
5. Waste						
A. Solid waste disposal	NA	NA	T2/3	D	NA	NA
B. Biological treatment of solid waste	NA	NA	T2	CS	T2	CS
C. Incineration and open burning of waste	T2	CS	T2	CS	T2	CS
D. Wastewater treatment and discharge	NA	NA	T2/3	CS, D	T2	CS

T1= Tier 1, T2 = Tier 2, T3 = Tier 3, CS = country specific, M = model, D = default, NE = not estimated, NA = not applicable, = key category

7.2 **Solid Waste Disposal** (CRT category 5.A)

7.2.1 Category description

The anaerobic decomposition of organic matter in a landfill is a complex process that requires several groups of microorganisms to act in a synergistic manner under favourable conditions. Emissions emanate from waste deposited over a long period (in excess of 50 years in the Australian inventory). The final products of anaerobic decomposition are CH_4 and CO_2. Emissions of CO_2 generated from solid waste disposal are considered to be from biomass sources and, therefore, are not included in the waste sector of the inventory. CO_2 produced from the flaring of methane from waste is also considered as having been derived from biomass sources.

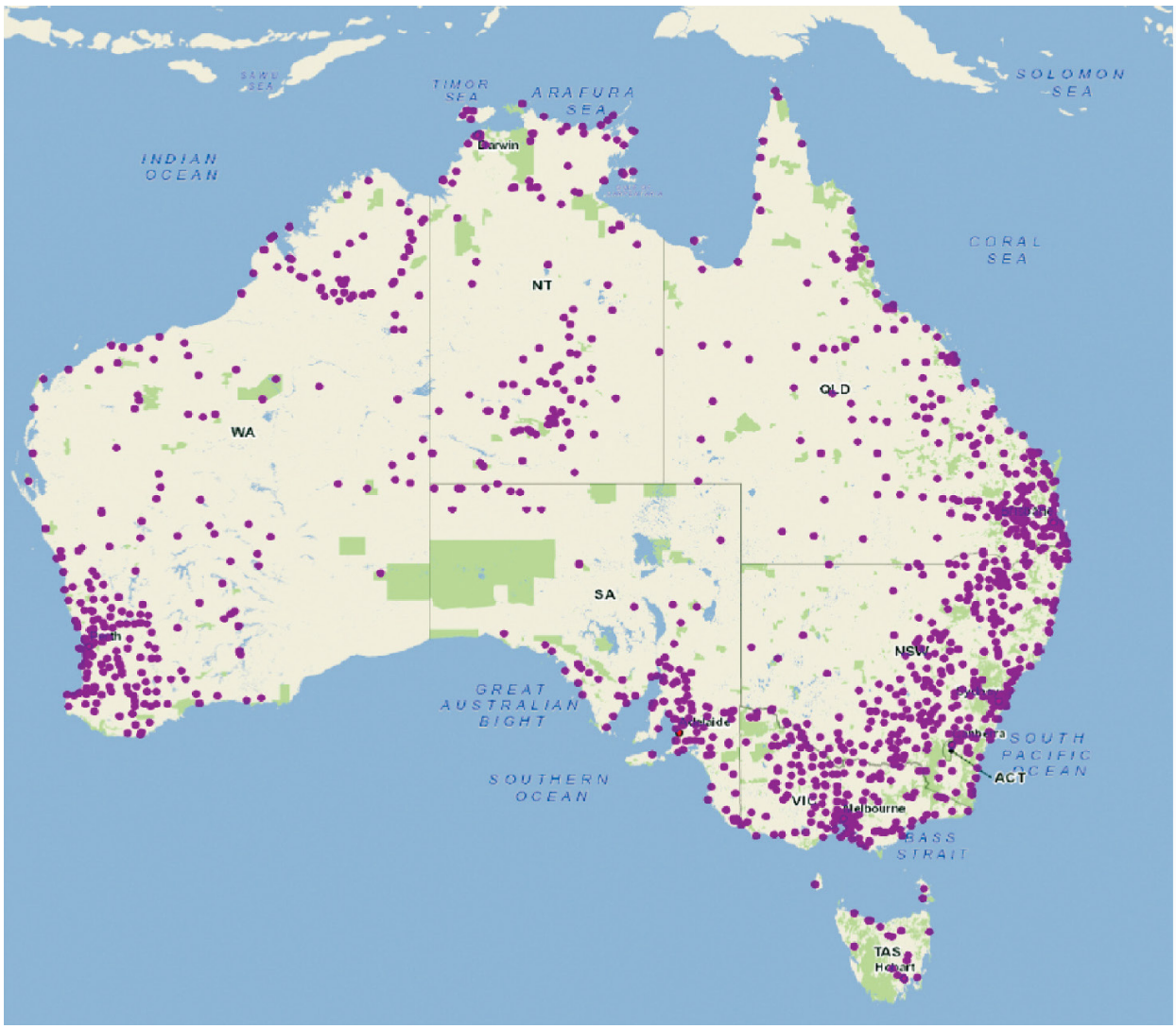
Common with the practice in many other developed economies, solid waste is processed in Australia via four main mechanisms:

- landfill;
- biological treatment/composting;
- incineration; and
- recycling/reuse.

There are approximately 1,275 operating landfills in Australia (disposal facilities). These landfills receive around a third of the estimated total waste generated in Australia with most of the remainder being recycled or reprocessed (including biological treatment/composting and a negligible amount is treated thermally (incinerated). Figure 7.3 shows the physical locations of the major landfills in Australia. The map shows that landfills are clustered around the large population centres around Australia's coastline.

Australia's solid waste management task has become more concentrated in the last decade with many smaller landfills closing and larger centralised landfills taking the bulk of disposed waste. On the basis of the National Greenhouse and Energy Reporting (NGER) scheme data, a relatively small number of sites are responsible for the bulk of the waste received in Australia. Fifty per cent of Australia's waste disposal occurs in the 21 largest landfills. Around 11 per cent of landfills have a landfill gas collection system in place. However, this practice is more common in larger scale landfills, meaning that almost half of the methane generated by solid waste disposal is collected for either flaring or energy generation.

Figure 7.4 Australian landfill locations



Source: DCCEEW – National Waste Reporting Mapping Tool, 2013.

Additions to and losses from the pool of organic carbon in landfills, including both degradable and non-degradable organic carbon from all waste types, are presented in Table 7.2. Half of the carbon losses are assumed to result in the generation of methane (assuming that the share of carbon decay resulting in methane, F, is the IPCC default value of 0.5). The other half is assumed to be carbon dioxide.

The balance of emissions associated with Harvested Wood Products in Solid Waste Disposal Sites is reported in LULUCF (Chapter 6.10). All other CO_2 emissions are assumed to be related to biomass sources, the growth of which are either already accounted for in LULUCF or are assumed to be in equilibrium over the longer term, in accordance with default IPCC-based assumptions.

Table 7.2 Methane generation and emissions, Australia: 1989–90 to 2023–24

Year	Carbon additions to landfill (kt C)	Carbon loss (through emissions) (kt C)	Methane generated (Gg CH_4) [(a)]	Methane captured (Gg CH_4)	Net methane (Gg CH_4)
1989–90	2,270	1,017	679	2	609
1994–95	2,350	1,012	676	28	583
1999–00	2,512	1,011	675	129	491
2004–05	2,673	1,041	695	207	439
2005–06	2,639	1,045	698	222	428
2006–07	2,586	1,055	705	216	440
2007–08	2,542	1,067	713	205	457
2008–09	2,449	1,077	720	215	455
2009–10	2,302	1,081	722	204	466
2010–11	2,378	1,079	721	221	450
2011–12	2,157	1,075	718	272	401
2012–13	2,104	1,072	716	285	389
2013–14	2,124	1,072	716	297	377
2014–15	2,069	1,069	714	273	397
2015–16	2,011	1,067	713	262	405
2016–17	1,946	1,066	712	268	400
2017–18	2,161	1,062	710	316	355
2018–19	2,191	1,067	713	307	365
2019–20	2,171	1,075	718	313	365
2020–21	2,174	1,076	719	312	367
2021–22	2,136	1,080	722	299	380
2022–23	2,125	1,085	725	306	377
2023–24	2,241	1,079	721	307	372

(a) methane generated prior to oxidation.

Source: Department of Climate Change, Energy, the Environment and Water (DCCEEW) estimates.

7.2.2 Methodological Issues

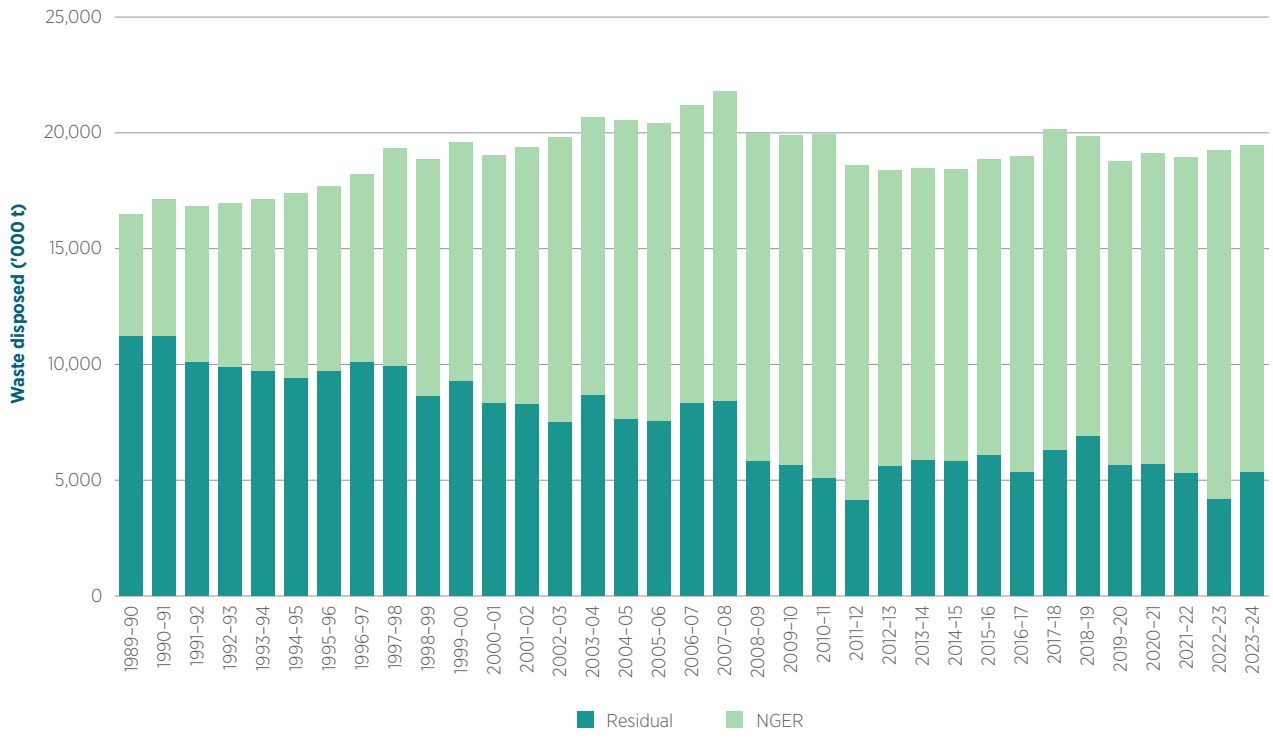
The Australian methodology for calculating greenhouse gas emissions from solid waste is consistent with the IPCC Tier 2 First Order Decay (FOD) Model (IPCC) (2006). This methodology utilises a dynamic model driven by landfill data provided by the relevant State/Territory Government agencies responsible for waste management together with facility-level data obtained under the NGER scheme. Although the structure of the methodology is constant across States, climate-specific parameters introduce variations in estimated emissions depending on location. The model tracks the stock of carbon estimated to be present in the landfill at any given time. Emissions are generated by the decay of that carbon stock and reflects waste disposal activity over many decades. The methodology is fully integrated with the results of the Harvested Wood Products (HWP) model reported in Chapter 6.10, including for the estimation of HWP in SWDS.

Australian waste generation and disposal to landfill

Data on quantities of waste disposed to landfill are collected by State Government agencies (and in most cases also published). Fluctuations in waste disposed to landfill has been observed in Australia's states and territories since the early 1990s reflecting, in part, differences in population growth and the impact of state government policies on waste management (Figure 7.6).

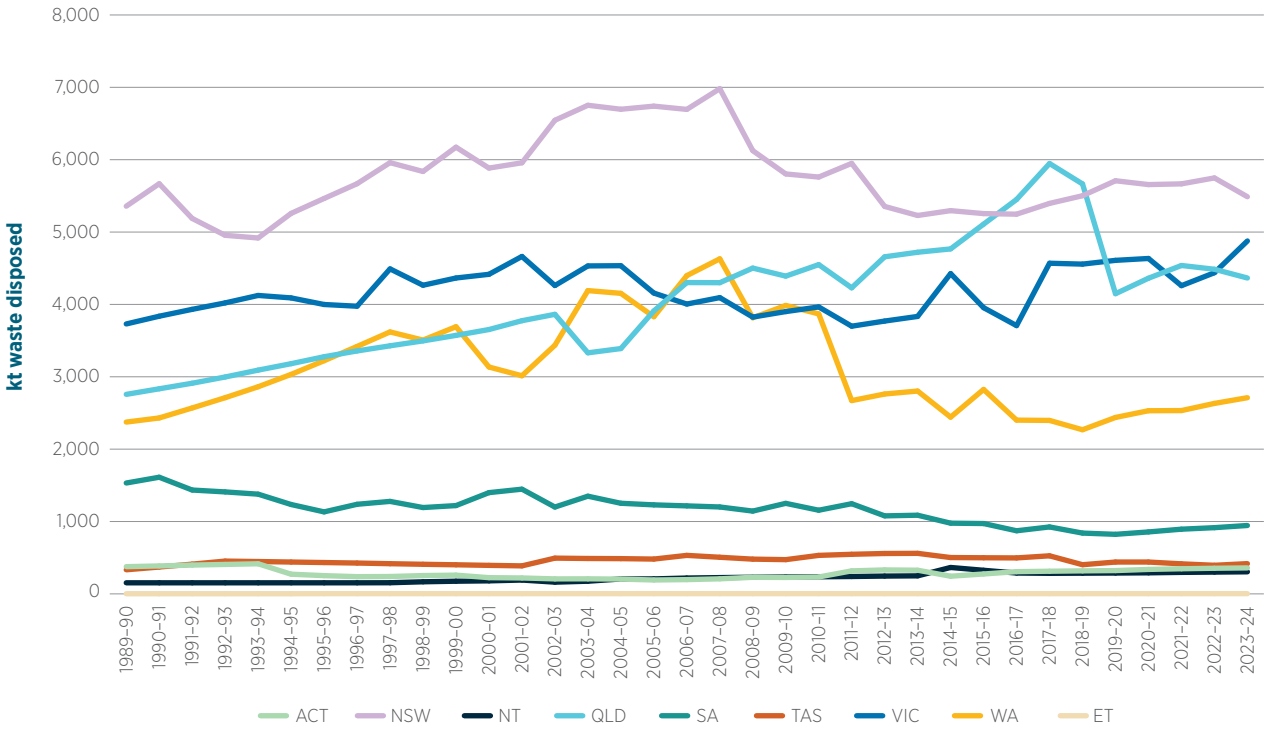
In addition to total disposal in each state and territory, disposal at individual landfills is obtained under the NGER scheme for landfills meeting the reporting thresholds. A majority of total disposal is covered by NGER scheme facility data (see Figure 7.5). The residual disposal not covered by the NGER scheme is calculated as the total disposal reported for each state and territory minus the sum of NGER disposal in each state and territory.

Figure 7.5 NGER scheme waste disposal coverage 1989–90 to 2023–24



Activity data reported in this report and the accompanying Common Reporting Tables are for waste disposal to landfill as opposed to waste generated. State and territory landfill levy schemes are applied specifically to waste disposed and the NGER scheme reporting requirements have also been designed to be consistent with this principle.

Figure 7.6 Solid waste to landfill by state and territory 1989–90 to 2023–24



Waste streams

Total waste to landfill data is disaggregated into three major waste streams, defined according to relevant State and Territory Government legislation and broadly consistent with the following:

- **municipal solid waste** – waste generated by households and local government in their maintenance of civic infrastructure such as public parks and gardens;
- **commercial and industrial waste** – waste generated by business and industry, for example shopping centres and office blocks or manufacturing plants; and
- **construction and demolition waste** – waste resulting from the demolition, erection, construction, alteration or refurbishment of buildings and infrastructure. Construction and demolition waste may also include hazardous materials such as contaminated soil or asbestos.

State/territory and NGER scheme data have been used to determine the stream percentages. Where disaggregated historical data cease, the stream shares have been held constant back to 1940 (Table 7.3).

Table 7.3 Waste streams: municipal, commercial and industrial, construction and demolition: percentages by State: 2023–24

	NSW	VIC	QLD	NT	SA	WA	TAS	ACT
Municipal Solid Waste	32.9%	38.9%	45.4%	43.0%	36.0%	37.1%	37.8%	31.3%
Commercial and Industrial	49.4%	39.0%	37.6%	14.0%	23.7%	39.7%	51.2%	61.9%
Construction and Demolition	17.7%	22.1%	16.9%	43.0%	40.3%	23.2%	11.0%	6.8%

Note: External Territories waste stream breakdown is assumed to be the same as QLD.

Some States include clean fill (uncontaminated inert solid material) in their waste to landfill estimates and this has an influence on the waste stream proportions. As this type of waste is largely inert, there is little effect on the final emissions estimate.

Individual waste types

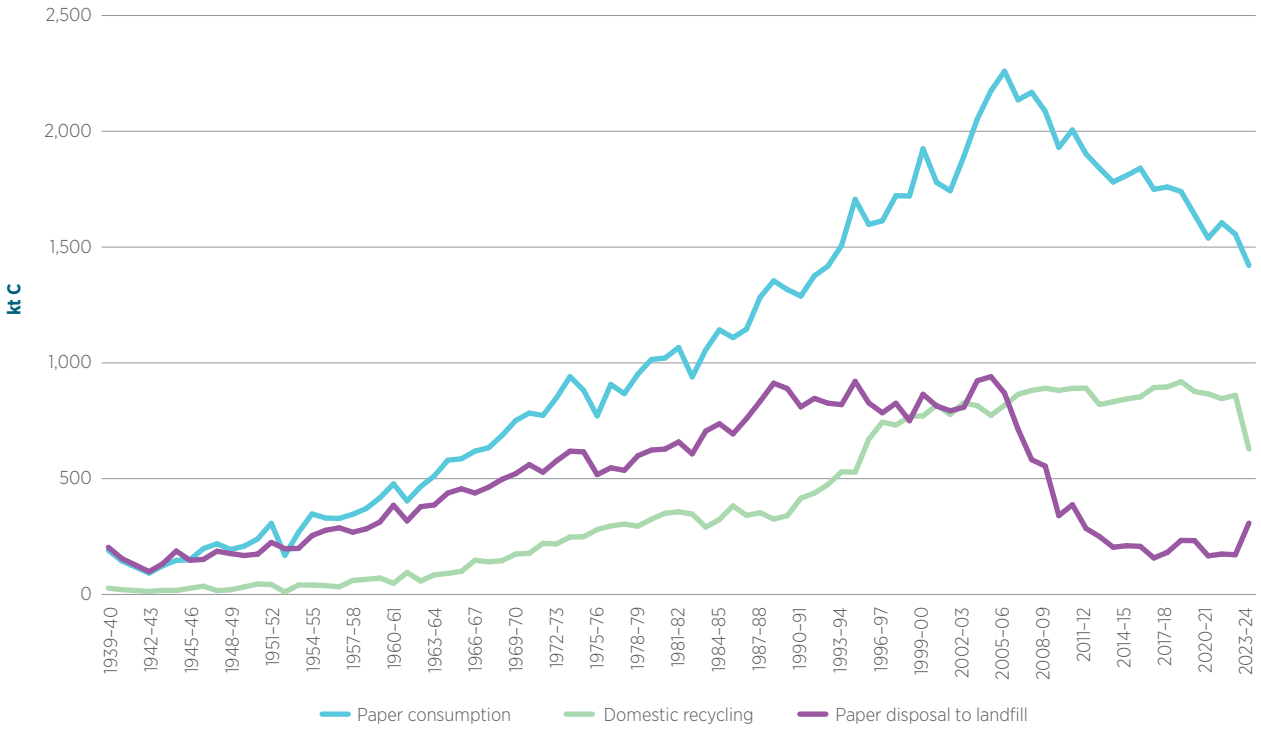
Each waste stream is further disaggregated into a mix of individual waste type categories that contain significant fractions of biodegradable carbon. The categories considered are as follows:

- Food;
- Paper;
- Garden and green;
- Wood;
- Wastes from the production of harvested wood products;
- Textiles;
- Sludge (including biosolids);
- Nappies;
- Rubber and leather; and,
- Inert (concrete, metal, plastics, glass, soil etc).

Harvested wood products – Paper wood and wood waste generation and disposal

The solid waste disposal estimates and composition are integrated with the wood, wood waste and paper disposal estimates output from the harvested wood products model. These quantities of disposal are used to adjust the waste mix percentages for NGER scheme facilities reporting default waste composition and the non-NGER scheme residual proportion of the waste load going to landfill. This adjustment is undertaken to ensure that the total wood, wood waste and paper disposed to all Australian landfills is consistent with the output of the harvested wood products model. This approach also ensures that paper recycling and wood waste diversion practices are reflected in the waste model. Figure 7.7 shows the improvement in paper recycling practices in Australia since 1940.

Figure 7.7 Paper consumption, recycling, and disposal to landfill – Australia: 1939–40 to 2022–23



Source: AFWPS (ABARES), 2025

Back casting of total waste disposed to landfill

The data available from State Government agencies on total waste disposed to landfill does not extend to the period prior to 1989–90, nor are there any possibilities for filling in the gaps with future surveys. The technique chosen to determine the historical time series was a surrogate-data technique where the drivers used to determine total waste to landfill were the amount of waste generated from paper consumption and the estimated amount of waste generated from the production of harvested wood products. These data were chosen because published datasets of production and consumption of these variables, which are closely related to disposal, were available back to 1935–36. The surrogate technique applied was to assume that the total waste to landfill correlates with the sum of paper and wood wastes available for disposal to landfill for years prior to 1989–90. This assumption ensures that the more general underlying influences affecting waste generation impact these estimates since: a) rising per capita incomes and rising population are reflected in rising demand for paper consumption and consequent waste generation and b) changes in production functions over time (improvements in efficiency) are reflected in the amount of waste generated in HWP.

For disposal data reported under the NGER scheme, information is available on the entire operational life of the landfills extending to the period before 1989–90. Where these disposal data are available, they have been used. However, it must be noted that this represents only a small proportion of currently operating landfills.

Waste mixes disposed to landfill

Waste composition is determined in two ways. For landfills covered by the NGER scheme, their reported waste composition is used directly. Where these data are not available, country-specific waste mix percentages are used. Country-specific values are subject to periodic review to ensure they remain representative.

Country-specific waste composition values up to 2013–14 are derived as the simple average of waste mixes reported in studies by GHD (2008) and Hyder Consulting (2008). The validity of these waste mixes was confirmed by a desktop audit of waste composition data undertaken by Anne Prince Consulting (2014). Waste composition values from 2014–15 onwards are based on the findings of a review by Blue Environment (2025). The review recommended minor revisions to the municipal solid waste (MSW) and commercial and industrial (C&I) waste stream compositions, reflecting updated waste audit data. Revised waste mix values were phased in from 2014-15 up to the current inventory year. Table 7.4 shows the waste mix percentages for the current reporting year.

Table 7.4 Individual waste type mix: percentage share of individual waste streams disposed to landfill, 2023–24

	Municipal Solid Waste	Commercial & Industrial	Construction & Demolition
Food	37.9%	20.1%	0.0%
Paper [a]	4.5%	4.7%	1.4%
Garden and Green	15.9%	4.4%	2.0%
Wood [a]	1.1%	10.3%	9.7%
Waste from HWP production [b]	0.0%	0.0%	0.0%
Textiles	3.6%	6.5%	0.0%
Sludge	0.0%	0.7%	0.0%
Nappies	5.9%	0.1%	0.0%
Rubber and Leather	0.3%	2.6%	0.0%
Inert (concrete, metal, plastics and glass, soil etc)	30.1%	49.2%	86.9%

Source: Derived from NGER scheme and Blue Environment (2025).

(a) Proportions vary over time, informed by the HWP model outputs.

(b) Waste generated in the production of HWP is handled at the manufacturing facility.

Table 7.5 Total waste and individual waste types disposed to landfill (kt): Australia

Year	Total waste to landfill	Food	Paper	Garden	Wood and wood waste	Textiles, Sludge, Nappies, Rubber and Leather	Other
	kt	kt	kt	kt	kt	kt	kt
1939–40	10,444	2,403	497	963	680	632	5,269
1989–90	16,615	3,285	2,223	1,382	904	840	7,981
2004–05	20,928	3,684	2,350	1,590	1,344	1,070	10,890
2007–08	22,148	4,188	1,454	1,766	1,521	1,221	11,996
2008–09	20,352	4,104	1,385	1,688	1,433	1,224	10,518
2009–10	20,269	4,278	851	1,774	1,462	1,265	10,639
2010–11	20,305	4,267	968	1,738	1,521	1,313	10,498
2011–12	18,901	4,058	712	1,646	1,407	1,236	9,842
2012–13	18,760	4,015	624	1,613	1,417	1,225	9,866
2013–14	18,812	4,153	510	1,685	1,443	1,286	9,735
2014–15	19,021	4,242	526	1,702	1,381	1,282	9,888
2015–16	19,220	4,074	519	1,698	1,385	1,259	10,285
2016–17	18,773	3,984	393	1,616	1,312	1,241	10,227
2017–18	20,361	4,376	455	1,732	1,419	1,445	10,934
2018–19	19,843	4,483	583	1,676	1,366	1,440	10,295
2019–20	18,781	4,518	581	1,721	1,334	1,422	9,206
2020–21	19,114	4,627	416	1,770	1,337	1,538	9,426
2021–22	18,953	4,580	436	1,700	1,307	1,546	9,384
2022–23	19,272	4,519	429	1,661	1,307	1,558	9,797
2023–24	19,472	4,474	770	1,629	1,307	1,541	9,751

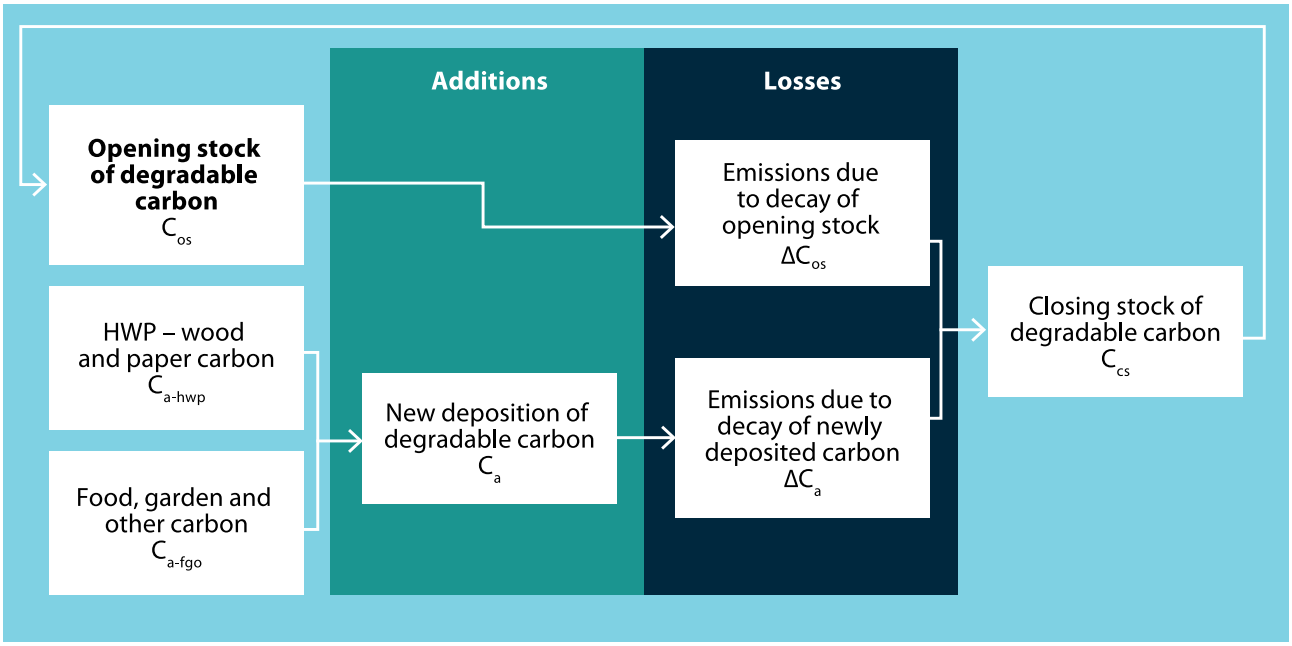
Note: The percentages derived from Table 7.5 will not align with those provided in Table 7.4 as these are based on the entire waste load entering landfill while Table 7.4 presents information by individual waste stream.

Emissions Estimation

The Australian methodology for the estimation of emissions from solid waste disposal utilises the Tier 2 first order decay (FOD) model presented in the 2006 IPCC Guidelines (IPCC 2006).

The key parameters determining the amount of methane emissions are the fraction of degradable organic carbon in each individual waste type (DOC); the rate of decay assumed for each individual waste type (decay function 'k'); the fraction of degradable organic carbon that dissimilates through the life of the waste type (DOC_f); the methane correction factor (MCF); and the amount of methane captured for combustion. The model takes account of the stock of carbon in a landfill by keeping track of additions of carbon through waste disposal and losses due to anaerobic decay. The approach is illustrated in Figure 7.8

Figure 7.8 Carbon stock model flow chart for solid waste to landfill



Carbon enters the landfill system via new deposition of waste (Ca). Deposition is based on wood and paper carbon transferred from the HWP carbon pool (Ca-hwp) and carbon in food, garden and other waste derived from data provided by state and territory waste authorities (Ca-f). A portion of the newly deposited carbon decays in the first year (ACa) and the remainder contributes to the closing stock of carbon (Ccs). Additionally, the opening stock of carbon decays over the year (ACos) with the remainder going to the year's closing stock. The closing stock then becomes the next year's opening stock (Cos). The total change in carbon stock is used to estimate emissions of methane.

$$C_{cs} = C_{os} - \Delta C_{os} + C_a - \Delta C_a$$

In Australia, field work estimating methane generated at particular landfills (Bateman 2009, Dever et al. 2009 and Golder Associates 2009) has demonstrated that there is potentially a wide variation in methane generation rates across Australian landfills. In Australia, this is interpreted as principally reflecting:

- differences in waste composition at landfills, reflecting both the differing values of degradable organic carbon (DOC) of individual waste types and differing values of degradable organic carbon of individual waste types that is dissimilable (DOC_f); and
- differences in the decay rate 'k' reflecting differences in waste composition, management regimes or local climatic conditions.

Values for the degradable organic carbon (DOC) content for each waste mix category used in the model are listed in Table 7.6. The source for these parameters are the defaults provided by the 2006 IPCC Guidelines.

Table 7.6 Key model parameters: DOC values by individual waste type

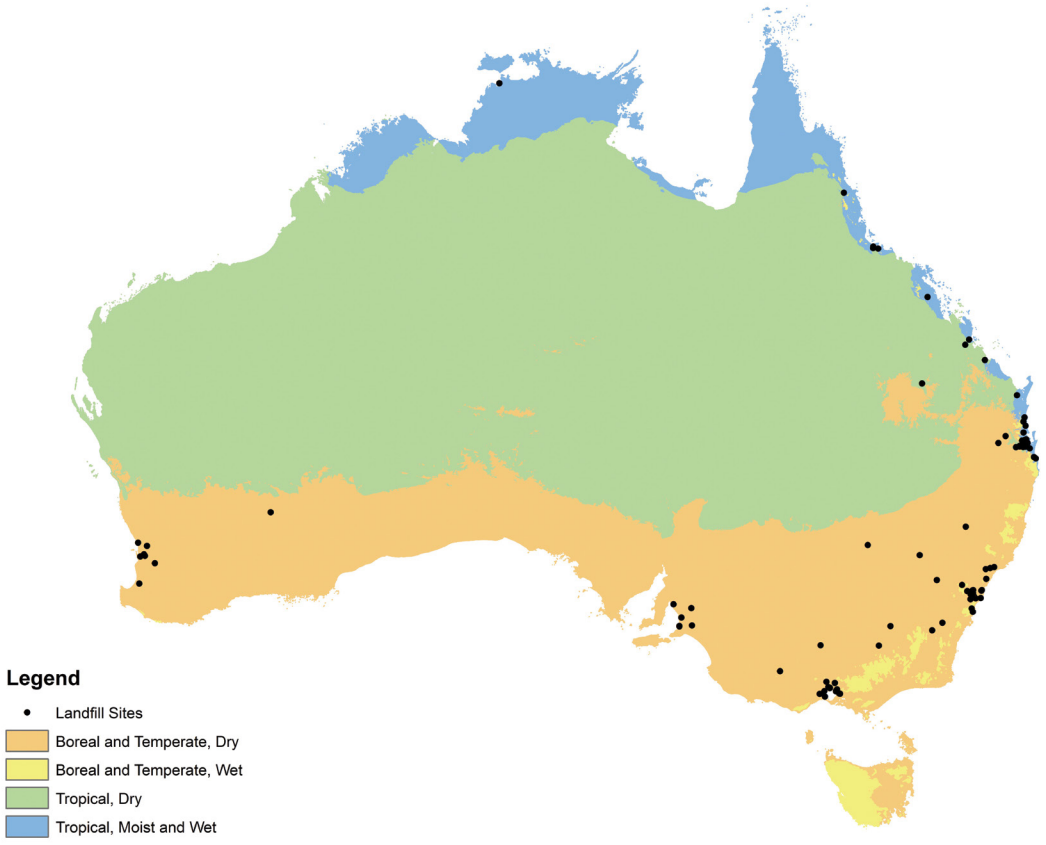
Waste Type (wet)	DOC
Food	0.2
Paper	0.4
Garden and Green	0.2
Wood and waste from HWP production	0.4
Textiles	0.2
Sludge	0.1
Nappies	0.2
Rubber and Leather	0.4
Other	-

The half-lives and associated decay rate constants 'k' values for each waste mix category applied in the FOD model are based on the climate conditions at the landfill location and are also consistent with the defaults provided in the 2006 IPCC Guidelines.

Decay rate constants are applied to disposed waste in two ways. For landfills covered by the NGER scheme, the geographical location of the landfill is used to determine which of the 4 IPCC climatic zones is applicable.

The distribution of the climate zones across Australia is illustrated in Figure 7.9. This map has been produced on the basis of average monthly grids of rainfall, pan-evaporation and average temperature from Bureau of Meteorology records between 1970 and 2010.

Figure 7.9 Australian climate zones and major landfill locations



For the proportion of disposed waste not covered by the NGER scheme, decay rate constants are assigned according to the prevailing climatic conditions at the landfill sites of the principal cities in each state and territory. In each state, average annual temperature and annual rainfall data for the principal landfill sites were taken from data published by the Australian Bureau of Meteorology. The assumptions of climatic conditions for each state/territory and 'k' values for each waste mix category are outlined in Table 7.7.

Table 7.7 Key model parameters: 'k' values by individual waste type and State Capital

	State / Territory and Climate Description		
	NSW	VIC, WA, SA, TAS, ACT	QLD, NT
Waste mix category	Wet Temperate	Dry Temperate	Moist and Wet Tropical
Food	0.2	0.1	0.4
Paper and Textiles	0.1	0.0	0.1
Garden and Green	0.1	0.1	0.2
Wood	0.0	0.0	0.0
Textiles	0.1	0.0	0.1
Sludge	0.2	0.1	0.4
Nappies	0.0	0.0	0.1
Rubber and leather	0.1	0.0	0.1

Source: Derived from Bureau of Meteorology data (BoM).

DOC_f is an estimate of the fraction of carbon in waste that is ultimately degraded anaerobically and released from solid waste disposal site (SWDS) and reflects the fact that some carbon in waste does not degrade or degrades very slowly under anaerobic conditions (IPCC 2006, Vol 5 p3.13) (IPCC 2006).

Values of DOC_f for individual waste types that are appropriate for Australia have been selected based on well documented research on DOC_f values contained in Barlaz 1998, 2005 and 2008 and Wang *etal.* 2011. These estimates provide an upper limit of an appropriate DOC_f value. The approach adopted, while conservative, is based on the recommendations of Guendehou (2010) after consultations with a range of experts in the industry (GHD (2010), Hyder Consulting (2010) and Blue Environment (2010)). The results of the Barlaz work are presented in Table 7. which shows reported values for the initial carbon content and carbon remaining after decomposition and the derived DOC_f value.

Table 7.8 DOC_f values for individual waste types derived from laboratory experiments

Waste type	Initial total organic carbon (kg/dry kg)	Organic carbon remaining after decomposition (kg/dry kg)	DOC_f (A-B)/A
	A	B	
Newsprint	0.49	0.42	0.15
Office paper	0.40	0.05	0.88
Old corrugated containers	0.47	0.26	0.45
Coated paper	0.34	0.27	0.21
Branches	0.49	0.38	0.23
Grass	0.45	0.24	0.47
Leaves	0.42	0.3	0.28
Food	0.51	0.08	0.84

Source: Barlaz (1998, 2005 and 2008).

For paper, the Barlaz work translates into a range of DOC_f values, for four classes of paper types meaning that it is important to understand the types of paper waste entering the landfill waste system to assign the appropriate weights for each of the Barlaz results. Newsprint contains high levels of lignin, which inhibits decomposition in anaerobic conditions, while office paper contains almost no lignin and therefore experiences high levels of decomposition even under anaerobic conditions. In addition, the Barlaz paper classes are not exhaustive of all paper types. Allowance must be made for non-identified paper classes. In these cases, consideration must be given to the possible chemical composition of the paper and theoretical approaches to the estimation of methane potential.

Consequently, it was necessary to make use of available waste audit data to compile a weighted average DOC_f value for the "paper and cardboard" waste mix category. Based on paper waste composition data presented in GHD (2008) and Lamborn (2009), the proportions of paper types corresponding to the Barlaz DOC_f categories have been derived for Australian landfills (Table 7.9).

Given that the classes of paper analysed by Barlaz were not comprehensive, a DOC_f value is also required to be assumed for 'other' paper. One factor important to the analysis of decomposition under anaerobic conditions relates to the amount of cellulose and hemicellulose in the product (see for example, Lamborn 2009). In the case of the paper types analysed with DOC_f values, the reported cellulose and hemicellulose proportions in the product range from 51.7 for coated paper up to 91.3 for office paper (Bariaz) (1998) . For the classification of 'other' paper, the value of cellulose and hemicellulose reported by Lamborn (2009) is 72.0 – which is very much in the middle of the range reported for the waste paper types for which DOC_f values are available.

Consequently, the assumption made is that the DOC_f for the 'other' paper is the weighted average of the paper types for which DOC_f values are available.

Table 7.9 Derivation of a weighted average DOC_f value for paper

Paper type	Composition (% of total paper in analysis) [a]	Cellulose and hemicellulose (%) [b]	DOC_f [c](%)
Newspaper	4.0%	54.6	15.0
Office paper	11.0%	91.3	88.0
Cardboard	58.0%	67.2	450
Coated Paper	1.0%	51.7	21.0
Other paper	25.0%	72.0	49.0
Weighted average of above			49.0

Sources: (a) Lamborn (2009), (b) Barlaz (1998), (c) Hyder consulting (2009), except for 'other paper'.

Micales and Skog (1996) published a range of methane potentials for a comprehensive list of paper types (based on data in Doorn and Barlaz) (1995) which show that methane potentials range between 0.05 g CH_4/g refuse for newspaper and 0.131 g CH_4/g refuse for office paper. These results also suggest that the range of DOC_f values shown in Table 7.9 above derived from Barlaz data encompass the broad range of paper types that may be present in Australian landfills and the degradabilities observed in the experimental data.

For wood products, Australia has selected a value of 0.1 to apply to all wood deposited in landfills in Australia based on the mid-point of observations of DOC_f values for various wood species examined in Wang et al. 2011 which included results for softwood, hardwood, plywood and MDF as well as some Australian wood species. Results from these laboratory-based experiments suggest that, particularly for the Australian wood species examined, very little anaerobic degradation occurs. Follow up studies by Australian researchers (Ximenes et al. 2013) for a range of engineered wood products (particleboard, MDF and high pressure laminate) observed carbon loss factors no higher than 1.6 per cent while previous field studies (Gardner et al. 2008b and Gardner et al. 2004) (Gardner 2004) also indicate that low DOC_f values are likely for timber products.

For food waste the DOC_f value of 0.8 based on the work of Barlaz 1998 has been used. For garden and park waste a DOC_f value of 0.5 based on the work of Barlaz 1998 has been used. This value assumes the upper estimate calculated by Barlaz for "leaves" and "grass". On this assumption, it represents a conservative upper limit on the likely true DOC_f value for this category. For the remaining waste categories in the inventory the IPCC default value of 0.5 has been retained. This includes values for textiles, sludge, nappies, and rubber and leather which require additional research to be undertaken before waste type specific values are adopted. The complete list of DOC_f values for each inventory waste mix type is presented in Table 7.10.

Table 7.10 Key model parameters: DOC_f values by individual waste types

Waste type	DOC_f value
Food	0.8
Paper and paper board	0.5
Garden and park	0.5
Wood	0.1
Wood waste	0.1
Textiles	0.5
Sludge	0.5
Nappies	0.5
Rubber and Leather	0.5
Inert waste (including concrete, metal, plastic and glass)	0.0

Source: Wang et al. (2011), Barlaz (1998).

An important parameter for the emissions calculation is the methane correction factor (MCF) which is intended to represent the extent of anaerobic conditions in landfills. It is assumed that all *solid waste disposal on land* in Australia is disposed to well-managed landfills, hence a methane correction factor of 1.0 has been applied to all years. Data from a Waste Management Association of Australia (WMAA) (2007) survey on waste management practices undertaken in 2007 was reviewed for this inventory and considered to provide strong evidence that the landfills in Australia adopt management practices that are consistent with the IPCC characterisation of well-managed landfills. 71 per cent of landfills, receiving an estimated 95 per cent of waste, operate with some form of permanent cover. The balance of landfills are assumed to operate within the meaning of well-managed landfills, as defined by the IPCC.

The IPCC default delay time of six months (M = 13) has been used to reflect the fact that methane generation does not begin immediately upon deposition of the waste. Under this assumption, and given that all waste is assumed to be delivered at the mid-point of the year, anaerobic decay is set to start, on average, on the first day of the year following deposition.

The IPCC default fraction of decomposition that results in methane (F) of 0.5 is assumed for this inventory, reflecting the assumption that the decomposition of organic carbon under anaerobic conditions is equally split between the generation of methane and the generation of carbon dioxide.

The IPCC default oxidation factor (OF) of 0.1 is assumed for this inventory, reflecting the proportion of methane generated by the decomposition of organic carbon under anaerobic conditions that is oxidised before the gas reaches the surface of the landfill.

Net emissions are derived after accounting for methane recovery undertaken at the landfill site. The quantity of methane recovered for flaring and power is based upon methane capture reported under the NGER scheme for 2008–09 onwards and industry survey for the years 1989–90 to 2007–08. Methane capture reported by landfill gas capture companies is measured according to the gaseous fuels measurement provisions set out in the *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (the Determination). Under these provisions, a range of options are available to reporters including indirect measurement based on invoices or electricity dispatched or direct measurement at the point of consumption using gas measuring equipment operated in accordance with set standards. Under these reporting provisions, landfill gas companies must also specify whether the collected gas is combusted for power generation, flared, or sent offsite for other uses.

Methane recovered (R(t)) is subtracted from the amount generated before applying the oxidation factor, because only landfill gas that is not captured is subject to oxidation in the upper layer of the landfill.

Emissions from the combustion of landfill gas for power generation are reported in the energy sector (1.A.1.a – public electricity and head production).

Small quantities of non-methane volatile organic compounds (NMVOC) are contained in landfill gas emitted from landfills in Australia. Some of these NMVOC are generated by the decomposition process and others are residuals from the types of waste dumped in the landfill. The CSIRO Division of Coal and Energy Technology in Sydney (Duffy et al. 1995) investigated NMVOC emissions from four landfills in the Sydney region. They found significant concentrations, up to 10 parts per million by volume (ppmv), for approximately 60 different compounds. Researchers in the UK (Baldwin and Scott 1991) have found between 2,200 and 4,500 milligrams per cubic metre (mg/m^3) of NMVOC present in landfill gas. In Australian landfills, liquid waste is rarely disposed of with solid waste whereas co-disposal is common practice in the UK. On this basis the lower range of 2,000 mg/m^3 found by the UK researchers is used for NMVOC emissions from Australian landfills unless other site-specific information is available. It is assumed that NMVOC emissions from landfills comprise 0.2 per cent of total landfill gas emissions; the average methane fraction of landfill gas as generated before release to the atmosphere is 0.5. This quantity is a weighted mean for all previous years of waste data used to calculate any inventory year's data and the proportion of methane emitted after oxidation is 0.9.

7.2.3 Uncertainty assessment and time-series consistency

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

The use of NGER scheme data has required careful consideration of time-series consistency issues. Facility-level activity data and emission factors are available from 2008–09 onwards. To preserve time-series consistency, facility-level activity data obtained under the NGER scheme has been back-cast as a fixed proportion of total population serviced in each state. Constant facility level MCF values and the proportion of methane generated that was captured in 2008–09 have been used with the back-cast activity data. This approach to maintaining time series consistency was based on the consideration that the larger-scale facilities covered by the NGER scheme utilise well established infrastructure and treatment processes that have not undergone significant changes since 1989–90.

The residual portion of the sector, for which no NGER scheme facility-specific data is available, has been handled as described above for the entire time-series.

Uncertainty in the waste sector is driven by multiple factors including inconsistencies in data compilation (e.g. varying definitions, standards and reporting formats) and incomplete or uneven data coverage from states and territories. The methodologies applied and the complexity of emissions models, particularly the FOD model which incorporates a large number of parameters, further contributes to the overall uncertainty in the waste sector. While activity data uncertainties are relatively low, uncertainties associated with model parameters and emission factors are much higher.

Understanding the magnitude and sources of uncertainty within the waste sector is critical for interpreting results and prioritising improvements. The DCCEEW continues to prioritise improvements in data completeness, methodological consistency and model refinement.

7.2.4 Category-specific QA/QC and verification

The solid waste sector category is covered by the general QC measures undertaken for inventory preparation. Emissions are estimated subject to the application of carbon balance constraints that ensures completeness; that carbon is tracked from harvest to disposal and that consistency between the harvested wood product and landfill pools is maintained. Estimates of carbon stored in wood products and in landfills are provided in Annex 4.

Quality assurance in relation to key parameters and the overall method for the sector was provided through review by an international external expert not involved in the inventory process (Guendehou) (2009). Independent external review provides assurance that the approach adopted by Australia is consistent with the approaches adopted by other parties.

As part of a systematic quality control process the emission estimates obtained for the Australian inventory are compared with those reported by other parties. Methane generation at landfills in Australia was assessed against the reported estimates of methane generated at landfills across all developed country Parties. It was concluded that the IEF for Australian landfills was not significantly different to the mean IEF for all developed country Parties.

Additionally, methane recovery, utilisation and flaring at landfills is reported under the NGER scheme by landfill operators. Often this methane is subsequently sold to energy companies for utilisation. Under the NGER scheme, such energy companies are also required to report the amount of methane utilised. In this way, two independent reports on the recovery and utilisation of methane are generated. This information is used to verify the amount of methane collected for utilisation.

Key parameters such as waste type fractions have been the subject of consultations with industry and industry experts. External experts have been utilised or review of available waste audit data, MCF, DOC_f and oxidation rates.

The country-specific waste mix percentages used in the inventory were derived from independent analysis undertaken by two external consultants (Hyder Consulting (2008); GHD (2008)). These mixes are subject to periodic review to ensure they remain representative of disposal practices. The most recent reviews were undertaken by Anne Prince Consulting (2014) and Blue Environment (2025). Minor adjustments to waste mix percentages have been made in this submission based on the 2025 review. The updated composition values have been applied from 2014–15 onwards to reflect observed changes in disposal behaviour, including increased diversion of food and garden organics.

The methane correction factor (MCF), which is intended to represent the extent of anaerobic conditions in landfills, was reviewed for this inventory by GHD 2010. The assessment of GHD confirmed that an MCF factor of 1.0 is appropriate for Australian landfills.

Country specific values for DOC_f for individual waste types were selected after consultation with independent consultants (GHD (2010), Hyder consulting (2010), Blue Environment (2010)) and reviewed by an international expert reviewer not involved in the preparation of the inventory (Guendehou (2010)). Guendehou concluded that the approach adopted lead to a significant improvement in the emission estimates.

Oxidation rates were reviewed (GHD (2010)). Following the review, it was decided to retain the IPCC default assumption of 10 per cent until further research can be undertaken.

When NGER scheme data were used for methane capture for the first time in the inventory in 2009–10, it was important to ensure time-series consistency was maintained. To ensure this was the case, the DCCEEW engaged the external consultant who was previously used to collect methane capture information from landfill gas capture companies to undertake a QC analysis of the NGER scheme capture data. Data were assessed for completeness and consistency with previously reported values. Capture estimates were compared with data available from the renewable energy certificate register as well as the NSW Greenhouse Gas Reduction Scheme register. The analysis confirmed that methane capture for energy generation was complete and consistent with previously reported data. For methane flaring, the analysis highlighted a completeness issue with respect to flaring occurring at local council landfills (in general, councils are not required to report under the NGER scheme (2008–09 onwards)). Therefore, this portion of flaring activity data had to be estimated for 2008–09 based on previously reported data. Through this QC project, the former DoEE was able to ensure continuity of expertise and knowledge used in the compilation of previous inventory submissions.

7.2.5 Category-specific recalculations

Recalculations to Solid Waste Disposal are detailed in Table 7.11 and are due to:

A. Revised Activity Data

Activity data relating to methane capture data, population and the harvested wood products model was revised for the years 1990–91 to 2023–24.

B. Revised default waste composition values

Updates to waste composition assumptions were incorporated into the time series from 2014–15 onwards. This resulted in minor downward revisions to emissions estimates from 2014–15 to 2023–24.

Table 7.11 Solid Waste: recalculation of emissions (Gg CO_2-e)

	2025 Submission	2026 Submission	Change		Reason for recalculation (Gg CO_2-e)	
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%	A	B
1989–90	17,064.6	17,064.6	-	0.0	-	-
1994–95	16,304.2	16,320.1	16.0	0.1	16.0	-
1999–00	13,729.9	13,756.6	26.7	0.2	26.7	-
2004–05	12,242.4	12,287.4	44.9	0.4	44.9	-
2005–06	11,941.1	11,991.8	50.8	0.4	50.8	-
2006–07	12,271.7	12,328.0	56.3	0.5	56.3	-
2007–08	12,739.0	12,800.4	61.4	0.5	61.4	-
2008–09	12,661.6	12,727.7	66.1	0.5	66.1	-
2009–10	12,979.5	13,050.2	70.7	0.5	70.7	-
2010–11	12,524.9	12,599.8	74.8	0.6	74.8	-
2011–12	11,145.4	11,224.3	78.9	0.7	78.9	-

	2025 Submission	2026 Submission	Change		Reason for recalculation (Gg CO_2-e)	
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%	A	B
2012–13	10,283.1	10,880.7	597.7	5.8	597.7	-
2013–14	10,246.0	10,559.3	313.2	3.1	313.2	-
2014–15	9,734.8	11,105.6	1,370.8	14.1	1,422.3	-51.5
2015–16	9,863.5	11,352.0	1,488.5	15.1	1,580.3	-91.8
2016–17	10,158.9	11,199.9	1,041.0	10.2	1,173.1	-132.1
2017–18	9,572.5	9,926.9	354.4	3.7	526.7	-172.3
2018–19	10,185.2	10,224.1	39.0	0.4	251.6	-212.6
2019–20	10,166.9	10,206.3	39.3	0.4	292.2	-252.9
2020–21	10,092.9	10,263.1	170.2	1.7	463.4	-293.2
2021–22	10,633.5	10,645.8	12.3	0.1	345.8	-333.5
2022–23	10,479.7	10,557.9	78.3	0.7	452.0	-373.7

7.2.6 Category-specific planned improvements

Facility-level data used in this submission are limited to waste disposal quantities and composition and methane capture for all landfill facilities triggering NGER scheme reporting thresholds. Decay rate constants have been assigned to each landfill based on their individual geospatial coordinates and BOM climate data.

Initial testing of the methods at landfills has demonstrated the value of ensuring that local climate and management practices are explicitly considered. The methods to be used to determine 'k' are provided in the Determination. Under the NGER scheme, operators of landfills are encouraged to undertake audits of waste data received and to collect data on methane generation rates to enable the operator to determine a facility-specific 'k' value so that 'k' will reflect both localised climate and management conditions. However, to date, no landfills have undertaken these measurements. The DCCEEW will continue to review the availability of data and where available these will be used to ensure that the decay functions applied at individual landfills reflect both local climatic conditions and facility management practices. The latter is particularly important as practices can vary considerably – for example, two in every five landfills practice leachate control which would significantly increase the value of 'k' at a landfill facility.

For the residual disposal not covered by the NGER scheme reporting, the DCCEEW will continue to explore methods of aligning state and territory reported data as well as the possibility of estimating emissions at a more spatially disaggregated level. This would enable climatic variation to be accounted for in the residual estimates. The implementation of this planned improvement will depend on the availability of disposal data at a more disaggregated level than is currently available.

The DCCEEW will also continue to review the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019) for supplementary methodologies, parameters and/or guidance applicable to Australia's inventory.

7.3 Biological Treatment of Solid Waste (CRT category 5.B)

7.3.1 Category description

Biological treatment of solid waste through processes such as windrow composting and enclosed anaerobic digestion is considered an emerging treatment pathway in Australia, where a small amount of activity data has become available under the NGER scheme (2008–09 onwards) and annual industry surveys by the University of New South Wales (2003–04 to 2009–10).

Table 7.12 Emissions from biological treatment of solid waste, Australia: 1989–90 to 2023–24

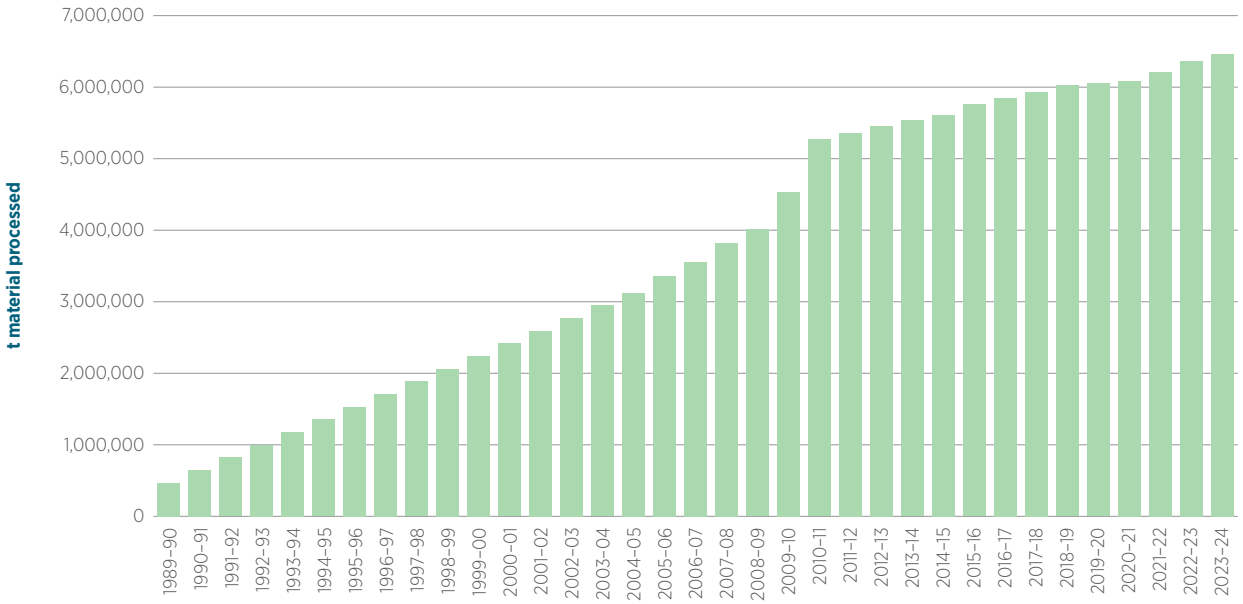
Year	Methane emissions (kt CH_4)	Nitrous oxide emissions (kt N_2O)	Total emissions (kt CO_2-e)
1989–90	9.8	11.9	21.7
1994–95	28.4	34.4	62.8
1999–00	47.0	56.9	103.9
2004–05	65.6	79.5	145.1
2005–06	70.6	85.6	156.2
2006–07	74.6	90.3	164.9
2007–08	80.3	97.3	177.6
2008–09	84.2	102.0	186.3
2009–10	95.3	115.4	210.7
2010–11	110.7	134.1	244.8
2011–12	112.6	136.4	249.0
2012–13	114.5	138.7	253.3
2013–14	116.2	140.8	257.0
2014–15	117.9	142.8	260.6
2015–16	120.9	146.5	267.4
2016–17	122.8	148.7	271.5
2017–18	124.7	151.0	275.7
2018–19	126.5	153.3	279.8
2019–20	127.1	153.9	281.0
2020–21	127.8	154.8	282.6
2021–22	130.5	158.0	288.5
2022–23	133.7	161.9	295.6
2023–24	135.8	164.5	300.3

7.3.2 Methodological issues

Composting

Australia has applied the Tier 2 Method from the 2006 IPCC Guidelines (IPCC 2006) and country-specific emission factors to derive estimates of emissions based upon the total amount of material processed through composting and anaerobic digestion. Activity data are obtained from an annual industry survey undertaken by the Recycled Organics Unit at the University of New South Wales. Survey data cover the years 2003–04 to 2009–10, with extrapolation used to derive activity data for the years 1989–90 to 2002–03. From 2008–09 onwards, activity data are from the NGER scheme. The time-series of quantities of waste material processed via composting is shown in Figure 7.10.

Figure 7.10 Quantities of material processed via composting 1989–90 to 2023–24



Source: University of New South Wales (2004 – 2010); NGER Scheme.

Australia has adopted country-specific emission factors for CH_4 and N_2O emissions from composting based on research conducted by Amlinger (2008) covering the composting of bio-waste, loppings and home composting material. The emission factors are shown in Table 7.13.

Table 7.13 Composting emission factors (t CO_2-e /t material processed) used in the Australian inventory [(a)]

	CH_4 emission factor (t CO_2-e /t material processed)	N_2O emission factor (t CO_2-e /t material processed)
Composting	0.021	0.025

(a) In raw-gas terms, these emission factors are 0.00075 t CH_4/ tonne of material processed and 0.000096 t N_2O/ tonne of material processed.

The country-specific emission factors have been drawn from the document *Update of emission factors for N_2O and CH_4 for composting, anaerobic digestion and waste incineration* (DHV (2010)) which itself cites Amlinger (2008) as the source of its recommended emission factors. DHV (2010) presents a synthesis of all available research data covering emissions from the biological treatment of solid waste.

Anaerobic digestion at biogas facilities

To date, no facilities have reported emissions associated with the anaerobic digestion of solid waste at biogas facilities under the NGER scheme. According to the Australian Clean Energy Finance Corporation, bioenergy projects are not widely deployed in Australia (CEFC 2015). There are three known facilities in operation in Australia that could be classed as anaerobic digestion facilities. The Richgro facility in Jandakot Western Australia became operational in 2015 and has the capacity to process up to 140 tonnes of food waste per day. Another facility known as Earthpower has been operating in Sydney since 2003 and can process up to 130 tonnes of organic waste per day. As with the Richgro facility, emissions of less than 1,000 tonnes of CO_2-e are estimated. A third facility was commissioned in the Yarra valley in Victoria as of May 2017. The facility has the capacity to process around 90 tonnes of food waste per day.

When the IPCC default CH_4 EF of 0.8 g CH_4/kg wet waste treated is applied to the maximum quantity of waste that could be processed at these three facilities, it results in annual emissions of around 2.9 kt of CO_2-e. This is well below the significance threshold for reporting. Accordingly, this source is Not Estimated (NE).

There are several biogas facilities associated with agricultural activities in operation in Australia. Emissions associated with these operations are reported under 3.B manure management or 5.D.2 Industrial wastewater treatment where appropriate.

7.3.3 Uncertainty assessment and time-series consistency

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

7.3.4 Category-specific QA/QC and verification

The composition emission factors are considered suitable for use in Australia's inventory due to the following:

1. Emission factors fall within the IPCC default ranges.

   While the CH_4 and N_2O emission factors chosen are towards the lower end of the default range, it has been concluded by Alminger (2008) that values exceeding 0.065 t CO_2-e / t material processed likely indicate some kind of system mismanagement such as insufficient aeration or mechanical turning. The mid-range IPCC default factors according to this conclusion would suggest a level of system mismanagement not thought to occur in Australia.

2. Waste types considered by Amlinger (2008) are representative of waste types commonly processed via biological treatment in Australia (namely bio-waste and greenwaste). GHD (2010) cites typical materials treated by the various biological processes in Australia:

   - Source separated garden organics;
   - Source separated garden organic organics with biosolids;
   - Source separated garden organics with food waste;

- Source separated garden organics with food waste and biosolids;
- Source separated food waste; and
- Mixed residual waste containing food waste and paper.

3. The technologies examined (windrow composting processes) are reflective of those commonly used in Australia. The Recycled Organics Unit identifies aerobic windrow composting as the dominant form of biological treatment of solid waste currently employed in Australia.

7.3.5 Category-specific recalculations

There are no recalculations to this category in this submission.

7.3.6 Category-specific planned improvements

Australia continues to review the use of population data as a proxy. The DCCEEW will continue to investigate other potential data and asses their applicability as a proxy over the coming year.

7.4 Incineration and Open Burning of Solid Waste (CRT category 5.C)

7.4.1 Category description

Emissions are reported for the incineration of solvents and municipal and clinical waste. Incineration estimates include a quantity of solvent generated through various metal product coating and finishing processes. In this instance, incineration is used as a method to minimize emissions of solvents and volatile organic compounds to the atmosphere and leads to emissions of CO_2.

Between 1989–90 and 1995–96 there were three incinerators receiving municipal solid waste, located in New South Wales and Queensland. All three incinerators ceased operations in the mid-1990s.

In addition to the incineration of municipal solid waste, a quantity of clinical waste is incinerated in four major facilities located in Queensland, New South Wales, South Australia, and Western Australia.

7.4.2 Methodological issues

Data on the incineration of solvents prior to 2003–04 is based on company data, after which emissions from this source have been based on data estimated by the DCCEEW. Carbon dioxide emissions from incineration of solvents are estimated by converting the volume of solvent incinerated (Litres) to the weight of solvent (using specific volume factor of 1,229 L/t), deriving the energy content of the mass of solvent (using the energy content of 44 GJ/t), and using a carbon dioxide emission factor per petajoule of solvent (69.6 Gg/PJ).

Data on the quantities of municipal solid waste incinerated are based upon published processing capacities of the three incineration plants prior to decommissioning. Data on the quantities of clinical waste incinerated have been obtained from a per capita waste generation rate derived from data reported under the NGER scheme, by O'Brien (2006b) and an estimate of State population reported by the Australian Bureau of Statistics.

The quantity of CO_2 emitted as a result of the incineration of municipal and clinical waste is based upon the quantity of waste incinerated, the carbon content of the waste and the proportion of that carbon which is of fossil origin and the efficiency of the combustion process (oxidation factor). The country-specific fossil carbon content of municipal waste of 7 per cent is based upon empirical data presented in NGGIC (1995) for incineration activities occurring in 1989–90. Of this 7 per cent of fossil carbon in municipal waste, it is estimated that 80 per cent of this carbon is combustible (NGGIC (1995)). Emissions of N_2O from the incineration of municipal solid waste are also estimated based on a country-specific emission factor of 0.00015 Gg of N_2O/Gg of waste taken from NGGIC (1995). The carbon content factors used in the emissions estimation are shown in Table 7.14. Emissions of methane from the incineration of municipal solid waste have been calculated based on the energy content of "Non-Biomass municipal materials if recycled and combusted to produce heat or electricity" of 12.2 GJ/t MSW used for the NGER scheme and a CH_4 emission factor of 30 kg CH_4/TJ MSW taken from the 2006 IPCC Guidelines (2006).

The 2006 IPCC guidelines (2006) do not provide default CH_4 and N_2O emission factors for the incineration of clinical waste and solvents. Furthermore, when the highest 2006 IPCC default EFs for CH_4 and N_2O listed for municipal solid and general industrial waste incineration are applied to the AD for clinical waste and solvents incineration, emissions estimates contribute around 0.0001 per cent (0.7 kt CO_2-e) of total emissions from all sectors. Accordingly, emissions of CH_4 and N_2O from this source are not estimated in the inventory on the grounds that they fall below the significance threshold established in paragraph 37(b) of the UNFCCC Reporting Guidelines.

Table 7.14 Parameters used in estimation of waste incineration emissions

	Municipal Solid Waste [a]	Clinical Waste [b]
Proportion of waste that contains fossil carbon	0.07	
Proportion of waste that is carbon		0.60
Proportion of fossil carbon containing products that is carbon	0.80	
Fossil carbon content as a proportion of total carbon		0.40
Oxidation factor	1.00	1.00
Energy content of non-biomass municipal materials if recycled and combusted to produce heat or electricity (GJ/t)	12.20	

Source: (a) NGGIC (1995); NGER scheme; (b) IPCC (2006).

Incineration of waste other than solvents, municipal and clinical waste

Emissions resulting from the incineration of waste other than solvents, municipal and clinical waste are not estimated on the basis that the likely level of emissions is below the significance threshold established in paragraph 37(b) of the UNFCCC Reporting Guidelines. In the absence of suitable AD, analysis was undertaken using data obtained from all Annex-1 parties reporting sewage sludge incineration. A per capita value for sewage sludge was used and a 100% fossil carbon content was assumed. When the highest 2006 IPCC default EFs for CO_2 and N_2O listed for waste lubricant, hazardous waste and biosolids are applied to the AD, emissions are likely to contribute around 52 kt CO_2-e, or 0.01% of total emissions from all sectors.

Accidental Fires at Solid Waste Disposal Sites

Emissions of CO_2, CH_4 and N_2O resulting from unintentional (accidental) fires at solid waste disposal sites (SWDS) are uncommon in Australia, however they have been assessed for significance. Emission estimates were derived using emission factors consistent with those described for the incineration of municipal solid waste. The total amount of waste open-burned was estimated based on population, number of waste fires recorded, waste generation rates and approximate fire duration.

Emissions from this source were estimated to be 16.9 kt CO_2-e, or <0.01% of total national emissions from all sectors. Accordingly, emissions from this source are not estimated in the inventory on the grounds that they fall below the significance threshold established in paragraph 37(b) of the UNFCCC Reporting Guidelines.

7.4.3 Uncertainty assessment and time-series consistency

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

7.4.4 Category-specific QA/QC and verification

The incineration and open burning of solid waste category is subject to general QC measures undertaken during inventory preparation. Activity data is reviewed and compared with other relevant data sources and checked against previous years to ensure consistency over time, including amount of waste incinerated.

7.4.5 Category-specific recalculations

There are no recalculations to this category in this submission.

7.4.6 Category-specific planned improvements

The DCCEEW will continue to investigate methods to improve the accuracy and reporting of emissions from accidental fires at SWDS and will aim to include this in a future submission to enhance completeness.

The DCCEEW will also continue to review the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019) for supplementary methodologies, parameters and/or guidance applicable to Australia's inventory.

7.5 Wastewater Treatment and Discharge (CRT category 5.D)

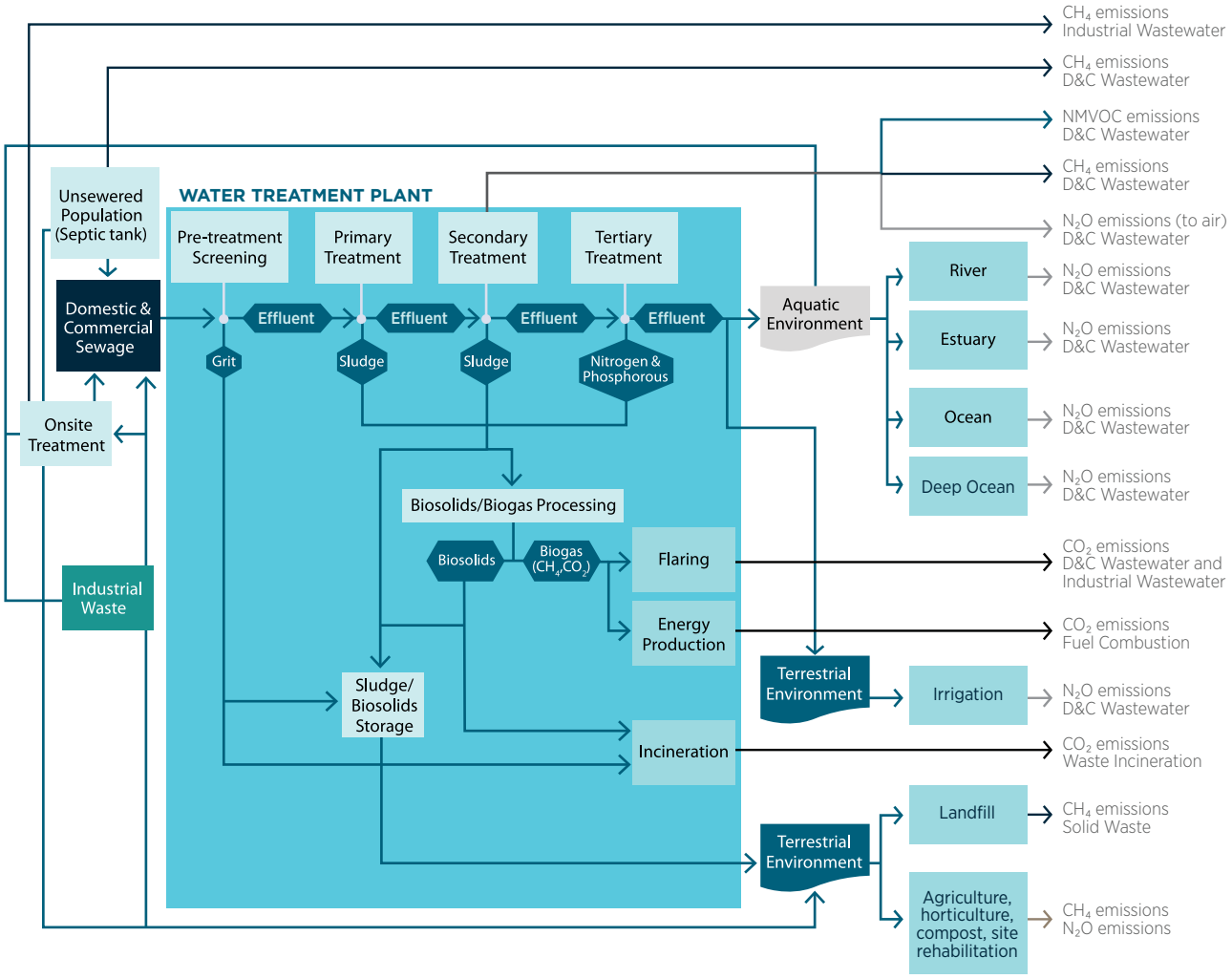
7.5.1 Category description

The anaerobic decomposition of organic matter in wastewater results in emissions of methane while chemical processes of nitrification and denitrification in wastewater treatment plants and discharge waters give rise to emissions of nitrous oxide.

Large quantities of CH_4 are not usually found in wastewater, as even small amounts of oxygen are toxic to the anaerobic bacteria that produce the CH_4. In wastewater treatment plants, however, there are several processes that foster the growth of these organisms by providing anaerobic conditions.

Municipal wastewater treatment plants in Australia treat a major portion of the domestic sewage and commercial wastewater, and a significant part of industrial wastewater. Approximately 5 per cent of the Australian population is not connected to the domestic sewer and instead utilise on-site treatment of wastewater such as septic tank systems (WSAA (2005)). Some industrial wastewater is treated on-site and discharged either to an aquatic environment or to the domestic sewer system which then feeds into a municipal wastewater treatment plant. A schematic diagram of the pathways for the treatment of wastewater in Australia is shown in Figure 7.11.

Figure 7.11 Pathways for Wastewater



Methane emissions from effluent discharge to receiving waters is not reported in the inventory. Similarly, N_2O emissions from any form of industrial wastewater discharge and from discharge of municipal wastewater to ocean and deep ocean waters or used in irrigation are considered negligible and are not reported in the inventory.

Sludge removed from wastewater treatment plants is either disposed to landfill or can be further treated to produce biosolids and then used in a land application such as agriculture, horticulture, composting or site rehabilitation. Emissions of methane from disposal of sludge in a landfill are included in the solid waste sector. Emissions of nitrous oxide from land application are included in the agriculture sector under *3.D Agricultural soils.*

7.5.2 Methodological issues

As methane is generated by the decomposition of organic matter, the principal factor which determines the methane generation potential of wastewater is the amount of organic material in the wastewater stream. This is typically expressed in terms of Chemical Oxygen Demand (COD). COD is a measure of the oxygen consumed during total chemical oxidation (both biodegradable and non-biodegradable) of all material in the wastewater (IPCC (2006)). COD has been used as the data input as this is preferred parameter measured by companies reporting under the NGER scheme. This aligns best with domestic licensing provisions and is consistent with the 2006 IPCC Guidelines (2006), which also provide a default factor in terms of COD.

Nitrous oxide, N_2O, is also generated from municipal wastewater treatment plants. Nitrogen, which is present in the form of urea in urine and as ammonia in domestic wastewater, can be converted to nitrate (NO3). Nitrate is less harmful to receiving waters since it does not take oxygen from the water. The conversion of nitrogen to nitrate is usually done by secondary and tertiary wastewater treatment plants using special bacteria in a process called nitrification. Following the nitrification step some facilities will also use a second biological process, known as denitrification. Denitrification further converts the nitrogen in the nitrates to nitrogen gas, which is then released into the atmosphere. Nitrification and denitrification processes also take place naturally in rivers and estuaries. N_2O is a by-product of both nitrification and denitrification.

Methane generated at wastewater treatment facilities may be captured and combusted for energy purposes or flared. The amount of CH_4 captured or flared is subtracted from the total CH_4 generated. Quantities of sludge biogas combusted to produce energy and the associated non-CO_2 emissions are reported in the *stationary energy* sector.

Discharge of treated effluent to aquatic environments is regulated by state and territory governments. As a result, wastewater treatment facilities in Australia predominantly process wastewater to a secondary or tertiary treatment level before discharging the wastewater into an aquatic environment. As the treatment level increases from primary to secondary to tertiary, the number of unit operations used to treat the wastewater and the amount of organic matter and nitrogen removed before discharge to an aquatic environment increases. Consequently, such aquatic environments are considered unlikely to be sources of CH_4.

Effluent discharged by wastewater treatment plants in Australia enters one of four classes of aquatic environment which are defined as follows:

- River means all waters other than estuarine, ocean or deep ocean waters;
- Estuarine waters means all waters (other than ocean or deep ocean waters):
  - that are ordinarily subject to tidal influence, and
  - that have a mean tidal range greater than 800 mm (being the average difference between the mean high-water mark and the mean low-water mark, expressed in millimetres, over the course of a year);
- Ocean means all waters except for those waters enclosed by a straight line drawn between the low-water marks of consecutive headlands and deep ocean waters; and
- Deep ocean means all waters, except for river and estuarine waters, that are more than 50 metres below the ocean surface.

The type of discharge environment is critical to emissions of N_2O from discharge. Table 7.15 shows the nitrogen discharged to each receiving environment and indicates that the majority of effluent is discharged to either ocean or deep ocean outfalls, typically more than two kilometres from the coastline at a depth of 50 metres or more.

Table 7.15 Effluent discharged from wastewater treatment plants by type of aquatic environment for 2023–24

Type of aquatic environment	Nitrogen discharged (t N)	
River	7,284	32%
Estuary	5,689	25%
Ocean or deep ocean	9,808	43%
Total	**22,781**	**100%**

Source: NGER scheme.

Sludge treatment and disposal practices include transfer to landfill or agricultural land. The proportion sent to each destination are shown in Table 7.16. Emissions from sludge sent to landfills are included in the solid waste sector while emissions from biosolids (treated sludge) used in a land application are included in Agriculture.

Table 7.16 Sludge reuse and disposal in 2023–24

	Nitrogen (t)	% Contribution
Sludge to Landfill	2,183	17%
Sludge Reused in Land Application	10,351	83%
Total	**12,534**	**100%**

Source: NGER scheme.

Methane from municipal wastewater

Methane emissions from the treatment of wastewater at municipal wastewater treatment plants are estimated according to the default method set out in the 2006 IPCC Guidelines (2006), which relates emissions to the total quantity of organic waste treated at the MWTP. The emission factors applied to this quantity of organic waste are derived from a consideration of the type of treatment process used at the MWTP and the degree to which the organic waste is treated anaerobically.

Quantities of organic waste in wastewater treated at individual MWTPs have been obtained under the NGER scheme (2008–09 onwards). Around 80 per cent of facilities reporting under the NGER scheme (numbering 30 in total and servicing around 50 per cent of Australia's population) measured the quantity of COD entering their facility directly. The weighted average per capita COD entering these facilities is 0.0607 tonnes of COD per person per year.

For the remainder of the category's facilities, a country-specific value of 0.0585 tonnes of COD per person per year (NGGIC (1995)) was used for the amount of organic waste in wastewater received at their sites.

Utilities reporting under the NGER scheme are also required to report the quantities of COD leaving their facility in effluent and treated in the form of sludge. As with the COD entering the facilities, NGER scheme facility-specific data on COD sludge leaving the facility has been used where this variable has been measured directly. Where this data was unavailable, a country-specific fraction of COD removed and treated as sludge of 0.54 has been applied (NGGIC (1995)).

To estimate CH_4 emissions generated by the treatment of domestic wastewater, the amount of COD treated separately as sludge, and the amount of untreated COD discharged into aquatic environments, is subtracted from the overall COD entering the treatment facility. This method ensures a balance of organic carbon influent, emissions and effluent.

Emissions generated from the treatment of COD in wastewater are estimated according to the following equation:

$$CH_{4(t)} = (COD_{in} - COD_{sl} - COD_{out}) * EF_t$$

Where $CH_{4(t)}$ is the estimated CH_4 emissions from the treatment of sewage at wastewater plants

COD_{in} is the amount of COD input entering into wastewater treatment plants

COD_{sl} is the amount of COD treated separately as sludge

COD_{out} is the amount of COD effluent discharged from wastewater treatment plants into aquatic environments

EF_t is the emission factor for wastewater treated by wastewater plants

Emissions generated from the treatment of sludge are estimated according to the following equation:

$$CH_{4(t)} = (COD_{sl} - COD_{trl} - COD_{tro}) * EF_{sl}$$

Where $CH_{4(t)}$ is the estimated CH_4 emissions from the treatment of sewage at wastewater plants

COD_{sl} is the amount of COD treated separately as sludge

COD_{trl} is the amount of COD as sludge removed and sent to landfill

COD_{tro} is the amount of COD as sludge removed and sent to a site other than landfill

EF_{sl} is the emission factor for sludge treated by wastewater plants

Under the NGER scheme reporting provisions, wastewater facilities must characterise the type of treatment process used in terms of the fraction of COD (as both sludge and wastewater) treated anaerobically. This parameter is defined as the methane conversion factor (MCF). The 2006 IPCC default MCF values and the definition of the corresponding treatment processes associated with these defaults in Australia are shown in Table 7.17. Facilities reporting under the NGER scheme select the most appropriate MCF value for their operational circumstances.

Table 7.17 MCF values listed by wastewater treatment process

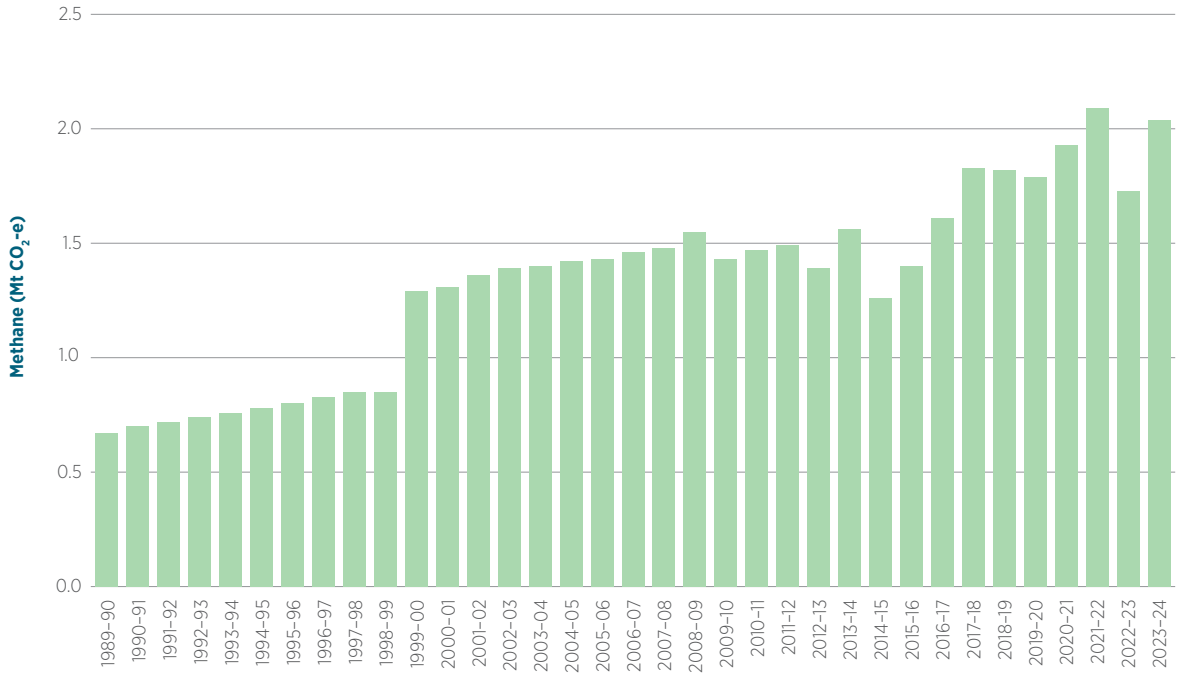
Classes of wastewater treatment in 2006 IPCC Guidelines	MCF Values	Applicable Wastewater Treatment Processes
Managed Aerobic Treatment	0.0	• Preliminary treatment (i.e. screens and grit removal) • Primary sedimentation tanks (PST) • Activated sludge processes, inc. anaerobic fermentation zones and anoxic zones for biological nutrient removal (BNR) • Secondary sedimentation tanks or clarifiers • Intermittently decanted extended aeration (IDEA), intermittently decanted aerated lagoons (IDAL) and sequencing batch reactors (SBR) • Oxidation ditches and carrousels • Membrane bioreactors (MBR) • Mechanically aerated lagoons • Trickling filters • Dissolved air flotation • Aerobic digesters • Tertiary filtration • Disinfection processes (e.g. chlorination inc. contact tanks, ultraviolet, ozonation) • Mechanical dewatering (e.g. centrifuges, belt filter presses)
Unmanaged Aerobic Treatment	0.3	• Gravity thickeners • Imhofftanks
Anaerobic Digester / Reactor	0.8	• Anaerobic digesters High-rate anaerobic reactors (e.g. UASB)
Anaerobic Shallow Lagoon (< 2 m deep)	0.2	• Facultative lagoons • Maturation / polishing lagoons • Sludge drying pans
Anaerobic Deep Lagoon (> 2 m deep)	0.8	• Sludge lagoons • Covered anaerobic lagoons

Source: IPCC 2019 page 6.21 (IPCC 2019), WSAA 2011

Emission factors for each facility for wastewater and sludge are derived using equation 6.2 in the 2006 IPCC Guidelines (2006). The IPCC default maximum methane producing capacity (B0) of 0.25 kg CH_4/kg COD is used for all facilities.

Methane recovered for combustion for energy or flared is deducted from the estimated methane generated and is based on directly measured quantities of methane captured for combustion and flaring reported under the NGER scheme for the years 2008–09 onwards. For 1989–90 to 2007–08, recovery is based upon a consideration of historical changes in methane capture capacity at individual wastewater treatment plants. A capture time-series for each wastewater utility has been established based on capture rates for 1989–90 reported in NGGIC (1995) and on subsequent reported commissioning of cogeneration plants, odour control system upgrades, and general plant capacity upgrades. Figure 7.12 shows the time-series for methane capture from domestic and commercial wastewater treatment. The significant increase in capture from the year 1999–00 corresponds to an improvement in capture capacity due to the commissioning of cogeneration facilities at a number of key wastewater treatment facilities serving particularly large populations. The small decline in capture in 2009–10 reflects a combination of changes to treatment processes (i.e. a shift to aerobic treatment) and reported declines in flaring and combustion of sludge biogas for energy production. The declines in capture in 2014–15 and 2022–23 are due to declines in capture levels reported under the NGER scheme in those years.

Figure 7.12 Methane capture from domestic and commercial wastewater treatment 1989–90 to 2022–23



Source: NGER Scheme.

No data is available on the precise split of methane recovery between wastewater and sludge treatment. For the purposes of reporting in Common Reporting Table 5.B.s1, methane recovery is allocated between wastewater and sludge such that emissions generated from the treatment of sludge are captured and the balance of reported capture is then allocated to wastewater treatment.

EFs by facility are derived according to equation 6.2 in the 2006 IPCC Guidelines (2006), where MCFs by facility are applied to the maximum CH_4 producing capacity (B0) of 0.25 kg CH_4/kg COD.

There is a proportion of the wastewater treatment sector where no facility-specific data is available under the NGER scheme. The choice of parameters applicable to the residual portion of the sector was made in accordance with the decision tree described in Chapter 1.3.1. As treatment processes employed at individual facilities are highly technology specific, it was not considered reasonable to extrapolate the factors obtained from NGER scheme data to the facilities in the residual portion of the sector. Consequently, the per capita COD and region-specific MCF values from NGGIC (1995) were used for 2008–09 for the residual of the category where no facility-specific data under the NGER scheme was available.

Methane from on-site domestic and commercial wastewater treatment

Default methods from the 2006 IPCC Guidelines (2006) are applied. The total unsewered population on a State-by-State basis is calculated according to the Australian Bureau of Statistics (ABS (2020)) and WSAA data (WSAA (2005)). It is assumed that each person in unsewered areas in Australia produces 0.0585 tonnes of COD per person per year (NGGIC (1995)). The amount of COD that settles out as solids and undergoes anaerobic decomposition (MCF) is assumed to be 50 per cent, which is the IPCC default fraction for total urban wastewater (IPCC (2019)). The default emission factor of 0.25 kg CH_4/kg COD is used.

Sludge is also generated by on-site domestic and commercial wastewater treatment. Septic tank systems must be emptied occasionally of the sludge that accumulates inside the system. This sludge is typically transferred to a municipal wastewater treatment facility for further treatment.

Nitrous oxide emissions from domestic and commercial wastewater

The methodology used to estimate N_2O emissions from domestic and commercial wastewater treatment utilises a detailed IPCC 2006 methodology. The methodology comprises estimates of emissions from sewage treatment at a wastewater plant; emissions from discharge of effluent into aquatic environments; and emissions from disposal of treated sludge to land.

$$\text{Total } N_2O\text{-}N = N_2O_{(t)}\text{-}N + N_2O_{(d)}\text{-}N + N_2O_{(l)}\text{-}N$$

Where N_2O-N is the estimated N_2O emissions from domestic and commercial wastewater treatment

$N_2O_{(t)}$-N is the estimated N_2O emissions from sewage treatment at a wastewater plant

$N_2O_{(d)}$-N is the estimated N_2O emissions from discharge of effluent

$N_2O_{(l)}$-N is the estimated N_2O emissions from application of treated sludge to land

The emissions of N_2O from sewage treatment at wastewater treatment plants are estimated using the following equation:

$$N_2O_{(t)}N = (N_{in} - N_{out} - N_{trl} - N_{tro}) \times EF_6$$

Where $N_2O_{(t)}$-N is the estimated emissions from the treatment of sewage at wastewater plants

N_{in} is the amount of nitrogen input entering into wastewater treatment plants

N_{out} is the amount of nitrogen effluent discharged from wastewater treatment plants into aquatic environments

N_{trl} is the amount of nitrogen removed from wastewater treatment plants as sludge and disposed to landfill

N_{tro} is the amount of nitrogen removed from wastewater treatment plants as sludge and disposed at a site other than landfill (reused in land applications) and

EF_6 is the emission factor for sewage treated by wastewater plants

The total nitrogen input entering wastewater treatment plants for Australia is obtained from facility specific measurements under the NGER scheme. In total, facility level data obtained under the NGER scheme covers 146 facilities.

Estimates of the remainder of the nitrogen entering the national system is based on the residual population not covered by the facilities reporting under the NGER scheme and the average nitrogen input received by the wastewater plants per person serviced by the plants derived from the NGER scheme (2008–09 onwards). Together with the IPCC default factor for the fraction of nitrogen in protein, 0.16 kg N/kg protein, the facility level data translates into a per capita protein consumption level of 81.3 g per person per day in 2023–24.

Estimates of nitrogen leaving the system as effluent or as sludge disposed to landfill or to a land application, N, Ntrl and Ntro have also been obtained by facility under the NGER scheme.

The emission factor for the estimation of N_2O emissions from wastewater treatment is the 2006 IPCC Guidelines' (2006) default of 0.01 kg N_2O-N/kg N.

Nitrous oxide emissions from discharge of effluent

The effluent discharged into an aquatic environment may enter directly into a river, estuary, ocean surface waters or deep ocean environment depending on the location of the wastewater outfall of each treatment plant.

The emissions of N_2O from the discharge of effluent are estimated using the following equation:

$$N_2O_{(d)}N = N_{out}rx\ (EF_5r + EF_5e) + N_{out}e \times (EF_5e)$$

Where $N_2O_{(d)}$-N is the emissions from discharge of effluent

$N_{out}r$ is the amount of nitrogen discharged into rivers which then flows into an estuary

$N_{out}e$ is the amount of nitrogen discharged into estuaries

EF_5r is the emission factor for rivers

EF_5e is the emission factor for estuaries

The amount of nitrogen discharged by aquatic environment is obtained by facilities reporting under the NGER scheme.

The default IPCC initial emission factors are 0.0025 kg N_2O-N/kg N for wastewater discharged into rivers (EF_5r) and 0.0025 kg N_2O-N/kg N for wastewater discharged into estuaries (EF_5e) (IPCC 2006 page 11.24). For wastewater discharged into rivers, the final emission factor is cumulative, ($EF_5r + EF_5e$), as it is assumed that the wastewater passes from the river system, through the estuaries and then into the sea. For wastewater discharged directly into an estuary, only (EF_5e) is applied.

While the 2006 IPCC Guidelines state that nitrous oxide emissions resulting from sewage nitrogen are estimated from 'nitrogen discharge to aquatic environment' (IPCC (2006) page 6.25), they only provide an N_2O emission factor based on discharge to rivers and estuaries. Consequently, it is considered that there is no IPCC default method available for the estimation of emissions from effluent discharged directly to ocean waters (as opposed to being passed from river and estuary systems into the sea). Nor is there any empirical literature available on emissions from disposal to ocean waters in Australia – such a study would be prohibitively expensive at this time. It is noted, however, that the 2019 Refinement to the 2006 IPCC Guidelines expands the application of the N_2O emission factor emission to 'freshwater, estuarine and marine discharge' (IPCC (2013) page 6.39). Further discussion of the 2019 Refinement is provided in the planned improvements section of this chapter.

The results of the limited number of studies conducted that relate to ocean bodies outside of Australia are not considered appropriate to Australian marine conditions. They are, nonetheless, reviewed in the QA/QC section of this Chapter.

Ocean waters are defined to include only those bodies of water that are beyond the straight line drawn between the low-water marks of consecutive headlands. Waters within the headlands, such as bays and basins, are included as part of the estuarine waters. Consequently, the delineation of ocean waters is considered conservative.

Table 7.18 IPCC emission factors for disposal of effluent by type of aquatic environment

Type of Aquatic Environment	Emission factor for initial disposal
River (EF_{5-r}).	0.0025 kg N_2O-N/kg N
Estuary (EF_{5-e}).	0.0025 kg N_2O-N/kg N

Source: (a) IPCC (2006) page 11.24

Nitrous oxide emissions from the application of treated sludge to land

The emissions of N_2O from the application of treated sludge to land is estimated using the following equation:

$$N_2O_{(I)}N = N_{tro} \times EF_7$$

Where $N_2O_{(I)}$-N is the emissions from treated sludge applied to the land

N_{tro} is the amount of nitrogen removed as treated sludge and applied to the land

EF_7 is the emission factor for treated sludge applied to land

The amount of nitrogen applied to land is obtained by facility under the NGER scheme (2008–09 onwards). The emission factor for the application of treated sewage to land is 0.009 kg N_2O-N/kg N applied and is consistent with the N_2O emission factors for manure applied to crops and pastures (Bouwman et al. 2002). Emissions from the application of sludge to agricultural land are reported under agricultural soils (3.D) consist with good practice.

Non-methane volatile organic compounds (NMVOC)

There has been little research into the release of NMVOC from wastewater treatment plants. BOD values obtained and used for calculations of methane emissions are used for the calculation of NMVOC from domestic and commercial wastewater and for industrial wastewater. A default value of 0.3 kg NMVOC/ tonne BOD for municipal wastewater treatment plants is used.

Methane from Industrial wastewater

Technologies for dealing with industrial wastewater in Australia are varied. Some industrial wastewater is treated entirely on-site, while a large amount is treated entirely off-site at municipal wastewater treatment plants. Increasingly, industrial wastewater is partially treated on-site before being recycled or discharged to the sewer and treated at municipal wastewater treatment plants. This is due to trade waste discharge licence compliance requirements for a certain quality of wastewater to be achieved prior to sewer discharge.

Most of the industrially produced COD in wastewater comes from the manufacturing industry. Sectors like food and beverage manufacturing produce significant amounts of COD, some of which is anaerobically treated. Some concentrated industrial wastewater is removed from factories in tankers operated by specialised waste disposal services. This wastewater is usually transported to a special treatment facility.

The methodology to determine the amount of CH_4 generated from industrial wastewater is based on the 2006 IPCC Guidelines and focuses on the 9 industrial sectors which are considered to generate the most significant quantities of wastewater in Australia:

- Dairy production;
- Pulp and paper production;
- Meat, poultry and seafood processing;
- Organic chemicals production;
- Sugar production;
- Beer production;
- Wine production;
- Fruit processing; and
- Vegetable processing.

Quantities of organic waste in wastewater treated at industrial facilities have been obtained under the NGER scheme for 2008–09 onwards. Where available, the quantity of COD treated at each facility has been taken from direct measurements reported under the NGER scheme. NGER scheme data are used where coverage is considered sufficient to provide a representative picture of wastewater treatment practices in a given industry. Where facility-specific data under the NGER scheme are unavailable, estimates are based on country-specific wastewater and COD generation rates shown in Table 7.20.

An analysis has been undertaken of the proportions of current production and facility numbers covered by the NGER scheme. Where company/facility coverage is complete or there is robust information about the composition and operational circumstances of the industry, it is possible to conclude that any residual production is not subject to onsite anaerobic wastewater treatment. This is the case for pulp & paper, sugar and beer production. For the remaining commodities considered under industrial, wastewater treatment, NGER scheme coverage is not complete and emissions from residual wastewater are estimated using national statistics on production levels and commodity-specific parameters. Table 7.19 provides further details of the consideration of residual commodity production and associated onsite wastewater treatment.

Table 7.19 Commodity production, coverage and residual wastewater treatment 2023–24

	Total commodity production (litres)	NGER commodity production (tonnes)	% NGER Scheme coverage	Residual treatment
Dairy Production	8,127,000,000	831,797	10%	Residual based on total national production and commodity – specific parameters
Pulp and Paper Production	2,867,000	1,292,560	45%	All facilities covered by NGER scheme. Residual production not subject to onsite WW treatment or aerobic processes
Meat, Poultry and Seafood Production	4,720,176	3,128,078	66%	Residual based on total national production and commodity – specific parameters
Organic Chemicals Production	1,837,591	C	C	Residual based on total national production and commodity – specific parameters
Sugar Production	4,197,185	3,882,068	92%	All facilities covered by NGER scheme. Residual production not subject to onsite WW treatment or aerobic processes

	Total commodity production (litres)	NGER commodity production (tonnes)	% NGER Scheme coverage	Residual treatment
Beer Production	1,811,455,822	861,014	48%	2 of 3 major producers covered by NGER scheme. The remaining producer does not have on-site wastewater treatment.
Wine Production	964,000,000	579,515	60%	Residual based on total national production and commodity – specific parameters
Fruit Processing	2,644,450	C	C	Residual based on total national production and commodity – specific parameters
Vegetable Processing	3,557,595	C	C	Residual based on total national production and commodity – specific parameters

Note: Facility-level parameters obtained for organic chemical, fruit, and vegetable production under the NGER scheme are confidential (C).

Table 7.20 Country-specific COD generation rates for industrial wastewater, 2023–24

Commodity	Wastewater generation rate (m^3 wastewater/t commodity produced)	COD generation rate (kg COD/m^3 wastewater generated)
Dairy	5.7	1.2
Pulp and Paper	26.7	0.7
Meat, Poultry and Seafood	13.7	3.2
Organic Chemicals [(a)]	67.0	C
Sugar	0.4	2.1
Beer	5.3	1.3
Wine	23.0	1.6
Fruit	20.0	0.2
Vegetables [(a)]	20.0	C

Source: NGER (a) facility-level parameters obtained for organic chemical and vegetable production under the NGER scheme are confidential (C).

Emission factors for each facility for wastewater and sludge are derived using equation 6.2 from the 2006 IPCC Guidelines. The IPCC default maximum methane producing capacity (B0) of 0.25 kg CH_4/kg COD is used for all facilities. Under the NGER scheme reporting provisions, industrial wastewater facilities must characterise the type of treatment process used in terms of the fraction of COD (as both sludge and wastewater) treated anaerobically. This parameter is defined as the methane conversion factor (MCF). As with COD, data on facility specific MCF values at industrial wastewater facilities are available for all listed commodities. Country-specific MCF values outlined in Table 7.21 are the weighted average MCF values based on data reported under the NGER scheme and residual treatment not reported under the NGER scheme.

Table 7.21 Methane conversion factors for industrial wastewater emissions, 2023–24

Commodity	MCF wastewater	MCF Sludge
Dairy	0.5	0.7
Pulp and Paper	0.8	0.7
Meat, Poultry and Seafood	0.7	0.3
Organic Chemicals [a]	C	C
Sugar	0.3	0.1
Beer	0.8	0.8
Wine	0.4	0.8
Fruit	1.0	0.8
Vegetables [a]	C	C

Source: NGER scheme (a) facility-level parameters obtained for organic chemical and vegetable production under the NGER scheme are confidential (C).

Note: These values represent weighted averages where facility-level MCF values are reported.

A proportion of the COD generated in the industrial wastewater is ultimately treated as sludge. Quantities of COD treated as sludge have been obtained for the dairy, paper, meat, poultry and seafood, sugar, beer, wine, fruit, and vegetable processing industries from the NGER scheme. For the organic chemicals, a constant fraction of COD of 0.15 is assumed to be treated separately as sludge (NGGIC (1995)).

Estimates of the quantities of methane captured have been obtained from the NGER scheme for dairy, paper, meat, poultry and seafood, sugar, beer, wine, fruit and vegetable processing facilities for 2008–09 onwards and derived from facility-level data in O'Brien (2006) and NGGIC (1995) for the years 1989–90 to 2007–08. For organic chemicals for which NGER scheme data has not been used, the sources are O'Brien (2006) and NGGIC (1995).

As with domestic and commercial wastewater treatment, no data is available on the precise split of methane recovery between wastewater and sludge treatment. For the purposes of reporting in Common Reporting Table 5.B.s1, methane recovery is allocated between wastewater and sludge on the basis of emissions generated from sludge treatment as a proportion of total capture with the balance being allocated to wastewater.

Table 7.22 Methane recovered as a percentage of industrial wastewater treatment 2023–24

Commodity	Fraction of methane recovered/flared (%)
Dairy	39.8
Pulp and Paper	54.7
Meat, Poultry and Seafood	34.8
Organic Chemicals	2.8
Sugar	0.0
Beer	72.3
Wine	79.6
Fruit	0.5
Vegetables	6.0

Source: NGER scheme.

Nitrous oxide emissions from industrial wastewater

Nitrogen generated and discharged to the sewer system is ultimately treated at centralised municipal wastewater treatment plants. As N_2O emissions estimates at these plants are estimated based on the measurement of nitrogen entering the plant, this value is also inclusive of any nitrogen originating from industrial sources. Therefore, emissions of N_2O from *industrial wastewater* are included in the estimate of N_2O emissions from *domestic wastewater.*

7.5.3 Uncertainty assessment and time-series consistency

Facility level data on nitrogen entering the domestic and commercial wastewater system is used for the years 2007–08 onwards, as reported in DCC 2009 and under the NGER scheme (2008–09 onwards). Time-series consistency has been maintained for the estimates of Australia's protein per capita intake through the following assumptions. The protein per capita consumption value for the years 1989–90 to 1992–93 of 99.4 g/day (36.28 kg/year) is sourced from the Australian Institute of Health and Welfare (AIHW) (de Looper and Bhatia 1998). The values for 1993–94 to 1997–98 are based upon data presented in AIHW (2002). Linear interpolation was used to derive values for 1998–99 to 2006–07, which is the period for which no data are available. The following table shows the time series for values used for protein per capita consumption.

Table 7.23 Estimates of implied protein per capita: Australia: 1989–90 to 2023–24

Year	Protein per capita g/capita/day
1989–90	99.4
1994–95	96.6
1999–00	100.0
2004–05	97.6
2005–06	97.1
2006–07	96.6
2007–08	96.1
2008–09	98.3
2009–10	87.3
2010–11	85.2
2011–12	90.6
2012–13	89.7
2013–14	94.4
2014–15	103.6
2015–16	109.0
2016–17	92.8
2017–18	88.8
2018–19	88.9
2019–20	86.0
2020–21	81.7
2021–22	86.7
2022–23	81.5
2023–24	81.3

Source: de Looper and Bhatia 1998 (1989–90 to 1992–93), AIHW (2002) (1993–94 to 1997–98), DCC (2009) (2007–08), NGER scheme 2008–09 onwards. Note: interpolation used for years 1998–99 to 2006–07 inclusive.

Time-series consistency has been maintained through the interpolation of MCF values and proportions of methane captured for pulp and paper, sugar, dairy, meat, poultry and seafood, wine and fruit and vegetables for 1989–90 to 2007–08. For the beer industry, facility specific MCF values and quantities of methane captured were available for the years 2002–03 to 2004–05. For the years 1989–90 to 2001–02 in the beer time series, the 2002–03 values for MCF and proportion of methane generated that was captured have been used. For the years 2005–06 to 2007–08, the 2008–09 NGER scheme MCF and proportion of methane captured have been applied. This introduces a step change in the methane capture estimates for beer in 2005–06 where the amount of methane captured doubles, reflecting a doubling in treatment plant capacity in the beer industry during 2005–06.

For the organic chemicals where NGER scheme data have not been used, time-series consistency is ensured using a consistent methodology and associated parameters.

7.5.4 Category-specific QA/QC and verification

The quality of the data utilised in this report has been assessed against facility data available through the State Government EPA licensing system. The Australian wastewater industry is heavily regulated by State Governments, which administer relevant state legislation such as the *Environmental Protection Act* 1994 in Queensland and the *Protection of the Environment Operations Act* 1997 in New South Wales. Under this legislation the State Governments issue environment protection licences to each premises treating wastewater.

The licences require compliance with strict conditions including limits on odours, noise and organic matter and nutrients (nitrogen and phosphorus) discharged to water catchments. Annual reports must be submitted by wastewater facility operators to their state government to demonstrate their compliance and some of this information is publicly available through public registers, the National Pollutant Inventory and, in some cases, the operator's own website.

The protein per capita consumption for the 2023–24 Inventory is derived from NGER scheme facility data. Facility data received under the NGER scheme for the first 5 years of reporting indicates a degree of volatility associated with this factor. Those facilities reporting the underlying data, however, do undertake frequent sampling and analysis and must also adhere to legislated requirements to ensure the data is representative and free from bias. Nitrous oxide emissions are concentrated in rivers and estuaries where the processes for N_2O production can take place in both the water column and the sediments. N_2O emissions also arise from ocean waters in the continental shelf region; however, while these emissions may occur from human activity, they also occur naturally and are very difficult to isolate empirically.

A good understanding of how N_2O emissions occur in the continental shelf region and the influences of human activity on them is still being formed. Nitrous oxide formation is very dependent on regional conditions and chemistry and location of outfalls. Some studies have been undertaken which attempt to measure or characterise the N_2O in the continental shelf regions of Europe (Bange (2006), Barnes and Owens 1998), Canada (Punshon and Moore (2004)) and North China (Zhang et al. (2008)). A literature survey of four such studies determined an average emission rate for continental shelf/oceanic coastal waters of 0.0018 kg N_2O-N/kg N discharged.

The regions studied, however, are influenced by very different marine conditions to those in Australian waters and also do not consider the effects of treated wastewater discharges (Foley and Lant, (2007)). The regional marine conditions are a major influence on the production of N_2O (Zhang et al. (2008)). An appropriate method and emission factor for estimating N_2O emissions from wastewater discharged to coastal and continental shelf waters would require further research.

The wastewater sector source categories are also covered by the general QA/QC of the greenhouse gas inventory in Annex 4.

7.5.5 Category-specific recalculations

Recalculations to Wastewater Treatment and Discharge are detailed in Table 7.24 and are due to:

A. Revised Activity Data for Industrial Wastewater

Minor revisions to commodity production volumes in some industrial sectors contributed to revisions in emissions estimates for the period 2019–20 to 2022–23.

B. Revised Activity Data for Domestic Wastewater

Minor revisions to activity data contributed to revisions in emissions estimates from 2019–20 to 2022–23 in Domestic Wastewater.

Table 7.24 Wastewater Treatment and Discharge: recalculation of emissions (Gg CO_2-e)

	2024 Submission	2025 Submission	Change		Reasons for Recalculation (Gg CO_2-e)	
Year	Gg CO_2-e	Gg CO_2-e	Gg CO_2-e	%	A	B
1989–90	6,289.5	6,289.5	–	0.0%		
1989–90	5,631.2	5,631.2	–	0.0%		
1994–95	4,707.0	4,707.0	–	0.0%		
1999–00	3,297.5	3,297.5	–	0.0%		
2004–05	3,333.4	3,333.4	–	0.0%		
2005–06	3,385.1	3,385.1	–	0.0%		
2006–07	3,422.4	3,422.4	–	0.0%		
2007–08	3,312.2	3,312.2	–	0.0%		
2008–09	2,818.1	2,818.1	–	0.0%		
2009–10	2,778.1	2,778.1	–	0.0%		
2010–11	2,820.2	2,820.2	–	0.0%		
2011–12	2,702.8	2,702.8	–	0.0%		
2012–13	2,683.9	2,683.9	–	0.0%		
2013–14	2,681.6	2,681.6	–	0.0%		
2014–15	2,906.9	2,906.9	–	0.0%		
2015–16	2,855.0	2,855.0	–	0.0%		
2016–17	2,925.0	2,925.0	–	0.0%		
2017–18	2,759.2	2,759.2	–	0.0%		
2018–19	6,289.5	6,289.5	–	0.0%		
2019–20	2,978.5	2,972.4	-6.0	-0.2%	0.3	-6.3
2020–21	3,182.2	3,179.6	-2.6	-0.1%	2.5	-5.2
2021–22	3,085.7	3,088.9	3.2	0.1%	3.8	-0.6
2022–23	2,984.1	2,982.2	-1.9	-3.4%	2.7	-4.6

7.5.6 Category-specific planned improvements

The DCCEEW will also continue to review the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019) for supplementary methodologies, parameters and/or guidance applicable to Australia's inventory.

The DCCEEW will also keep industrial wastewater model parameters and methods under review based on facility level data reported under the NGER scheme.

We are considering how to respond to previous review recommendation W.8 (2022) on clarifying total organically degradable carbon in wastewater (TOW) removed as sludge to wastewater treatment plant (WWTP) operators. Further information will be provided in a future update.

8. Other (CRT Sector 6)

Australia does not report any emissions under CRT sector 6, 'Other'.

9. Indirect CO_2 and nitrous oxide emissions

For the purpose of paragraph 29 of decision 24/CP.19, Australia has elected not to report indirect CO_2 and nitrous oxide emissions. Information on indirect CO_2 and nitrous oxide emissions in the *Energy* and *Agriculture* sectors can be found in Chapters 3 and 5 respectively.

10. Recalculations and improvements

Emissions processes are complex and, consequently, emissions estimation techniques and data sources for the Australian inventory continue to be refined, updated and improved.

More generally, the development effort behind recalculations is undertaken in line with the *Inventory Improvement Plan* for the Australian inventory. This plan is aimed at improving transparency, accuracy, completeness, consistency and comparability, with a focus on those areas where the Australian community is undertaking efforts to introduce new emissions-reducing approaches and technologies. These generally align with key categories. The improvement plan also responds to international expert reviews and changes in international practice. Some of the elements of the improvement program are set out in this chapter.

10.1 Explanations and justifications for recalculations, including in response to the review process

Key reasons for recalculations in this inventory are given in the sectoral chapters and are summarised in Table 10.1. To ensure the accuracy of the estimates, and to maintain consistency of the series through time, recalculations of past emission estimates are undertaken for all previous years in the time series.

Table 10.1 Recalculations in this Report (NIR 2024), compared with the previous report (NIR 2023)

Sector	Subsector	Category & NIR Chapter	Reason for Recalculation
Energy – Fuel combustion	Energy Industries	Category 1.A.1 Chapter 3.2.4	Australia's official statistics on energy production and use receives periodic updates to support improved understanding of Australia's energy systems, including for time series consistency. These updates are reflected in the inventory. A reallocation of natural gas to unprocessed natural gas has been made in certain conditions. This reallocation has been informed by NGER data. CH_4 EFs for gas have been adjusted in 2023 to correctly align with Zimmerle, et al. Activity data for a petroleum refining facility has been updated in 2023 to align with NGER.
	Public electricity and heat production	Category 1.A.1.a	A change to the application of the AES to derive emissions from small off grid generators has resulted in a recalculation for 2008/09 and 2009/10.
	Manufacturing Industries and Construction	Category 1.A.2 Chapter 3.2.5	Australia's official statistics on energy production and use receives periodic updates to support improved understanding of Australia's energy systems, including for time series consistency. These updates are reflected in the inventory.

Sector	Subsector	Category & NIR Chapter	Reason for Recalculation
	Transport	Category 1.A.3 Chapter 3.2.6	Domestic aviation turbine fuel consumption for 2022–23 was revised in the latest release of the AES. Domestic navigation fuel oil consumption for 2020-21 to 2022–23 was revised in the latest release of the AES. Road transport diesel consumption for 2021–22 and 2022–23 was revised in the latest release of the AES. Road transport LPG consumption for 2020-21 to 2022–23 was revised in the latest release of the AES. Road transport petrol AD for 2018-19 to 2022–23 was revised to align with the AES 2025 and Australian Petroleum Statistics 2025. The distribution of aggregate transport fuel consumption between 1.A.3 Transport, 1.A.4.b.ii Lawnmowers and 1.A.5 Other (Military transport) applications was revised, reflecting revisions to road transport, domestic marine transport and domestic aviation transport activity data as above, as well as the introduction of more disaggregated historical defence fuel consumption data. The split of AES road transport fuel consumption between NSW and the ACT in 2019-20 was revised to correct a minor calculation error. The recalculation of emissions following this revision reflects the different road fleet characteristics of the two jurisdictions.
	Other Sectors	Category 1.A.4 Chapter 3.2.7	Recalculations are a result of minor revisions to the distribution of petrol consumption between 1.A.3 Transport, 1.A.4.b.ii Lawnmowers and 1.A.5 Other (Military transport) applications, reflecting revisions to aggregated road transport activity data.
	Other (Military Transport)	Category 1.A.5 Chapter 3.2.8	Recalculations in this sector are the result of the introduction of more disaggregated historical defence fuel consumption data and revisions to the distribution of petrol consumption between 1.A.3 Transport, 1.A.4.b.ii Lawnmowers and 1.A.5 Other (Military transport) applications.
Energy – Fugitive emissions	Solid Fuels	Category 1.B.1 Chapter 3.3.1	Recalculations in this sector are primarily due to updating the decommissioned mines method to incorporate all data under NGER Method 1. This update has resulted in recalculations across the time series. Other recalculations between 2020-21 and 2022–23 are due to correcting emissions and activity data.

Sector	Subsector	Category & NIR Chapter	Reason for Recalculation
	Oil and Gas	Category 1.B.2 Chapter 3.3.2	Recalculations occurred across 2017-18 to 2022–23 in CRT category *1.B.2.c.ii Flaring* to improve the time series consistency of reported NGER scheme data. Duplicated condensate venting for CRT category *1.B.2.c.i Venting* was removed for 2021–22 and 2022–23 to improve accuracy. Activity data for mud degassing reported under CRT category *1.B.2.c.i Venting* was updated to determine an annual count of wells drilled across the full time series, addressing a time series inconsistency that existed in previous submissions. Emissions factors for well completions and well workovers in *1.B.2.c.i Venting* are defined on a technology-specific basis. In previous submissions, some EFs were applied to activity data that were not aligned with the appropriate technology type. For the 2023–24 inventory, the method was reviewed to ensure EFs were only applied to the corresponding activity data. The flaring destruction efficiency factor for gas flaring from crude oil refining under *1.B.2.c.ii Flaring* was updated to 0.995 from 0.98, in line with IPCC guidance (Section 4.2.2.2, Chapter 4, Volume 2, 2006 IPCC guidelines). This more accurately reflects industry practices at crude oil refineries. The flaring destruction efficiency is no longer applied to the nitrous oxide (N_2O) emissions estimation method, after being applied in previous submissions. These emissions are reported under CRT category *1.B.2.c.ii.2 Gas flaring*. This change improves accuracy by reflecting the understanding that N_2O emissions are minimally dependent on the proportion of gas combusted (i.e. flaring destruction efficiency) and, as such, should not be adjusted to depend on the destruction efficiency. Activity data for crude oil transport in CRT category *1.B.2.b Oil* was updated to include NGER scheme data available from 2011–12 onwards. The surrogate data method was used to establish a time series consistent data set across 1989-90 to 2023–24. This data set more accurately reflects changes in Australia's oil industry across the time series. Minor revisions were also made to the activity data for distribution of oil products, post-meter emissions, and abandoned oil and gas wells. This resulted in small variations to the emissions in these sectors.
Energy – Carbon Dioxide Transport and Storage	CCS Injection and Storage	Category 1.C Chapter 3.4	There are no recalculations to carbon dioxide transport and storage in this submission.
Industrial Processes and Product Use	Mineral Industry	Category 2.A Chapter 4.2	**2.A.1 Cement production CO_2:** recalculations of less than 50 kt CO_2 per year have been made to emissions in this category since last submission due to updated activity data (quantities of cement clinker produced) provided under the NGER scheme for one facility in 2020–21 and two facilities in 2022–23. **2.A.4 Other process uses of carbonates CO_2:** minor (<1 kt CO_2) revisions have been made to emissions from 2010-11 onwards due to updated activity data used to estimate emissions from production of bricks.
	Chemical Industry	Category 2.B Chapter 4.3	Nil.

Sector	Subsector	Category & NIR Chapter	Reason for Recalculation
	Metal Industry	Category 2.C Chapter 4.4	**2.C.3 Aluminium production PFCs:** Emissions of PFCs from aluminium production were previously calculated on the basis of EFs reported by companies under the NGER scheme. It was however identified during QA/QC that some of these reported factors were not accurate and did not match emissions reported under the scheme. Emissions have been accordingly recalculated in this submission for inventory years from 2008–09 onwards, with a maximum revision magnitude of 86.5 kt CO_2-e in 2019–20.
	Non-energy Products from Fuels and Solvent Use	Category 2.D Chapter 4.5	In this submission, minor recalculations (with magnitude less than 5 kt CO_2 per year) have been made to emissions in this category in inventory years from 2018–19 to 2021–22 due to updated activity data on lubricant consumption from the Australian Energy Statistics.
	Product Uses as Substitutes for Ozone Depleting Substances	Category 2.F Chapter 4.7	Minor revisions (with magnitude less than 3 kt CO_2-e) have been made to estimates of emissions in this category due to updated population data used to estimate emissions from metered dose inhalers.
	Other Product Manufacture and Use (Electrical Equipment)	Category 2.G Chapter 4.8	**2.G.1 Electrical equipment SF_6:** emissions for the year 2022–23 have been revised downwards by 11.2 kt CO_2-e as a result of correction of a calculation error identified during QA/QC.
	Other(Food & Beverage Industry)	Category 2.H Chapter 4.9	Nil.
Agriculture	Enteric Fermentation	Category 3.A Chapter 5.2	This submission introduces a new flock time series dataset for sheep from the Australian Bureau of Statistics (ABS), causing small recalculations throughout the time series. A new method incorporating several data sources has replaced the previous data based on annual surveys. The beef herd numbers, using a similar new dataset introduced in the previous submission, were slightly revised for the 2022–23 year. Further details of the new method and the wider modernisation of agricultural statistics are available from the ABS.
	Manure Management	Category 3.B Chapter 5.3	A significant downward recalculation throughout the time series is due to the implementation of a new method for estimating emissions from grazing livestock (pasture-fed beef, sheep, and Other Livestock). The new method is comparable to the approach for intensive livestock, estimating volatile solid production and allocating it between two manure management systems: pasture, range and paddock; and farm dams which are treated as anaerobic lagoons. Previously a constant fraction of manure nationwide was allocated to farm dams. With this change, the allocation is estimated using a spatial map of farm dam locations. This results in lower allocations over much grazing land, and hence lower emissions.
	Rice Cultivation	Category 3.C Chapter 5.4	Recalculations associated with rice cultivation in this submission are due to a refinement of the Tier 1 method, incorporating new data on sowing practices. Drill sowing results is a shorter period of continuous flooding, and as this has become more prevalent over time the emissions estimates have been revised downward more in recent years.

Sector	Subsector	Category & NIR Chapter	Reason for Recalculation
	Agricultural Soils	Category 3.D Chapter 5.5	The main recalculation in this category is due to adoption of new EFs for emissions from Urine and Dung Deposited by Grazing Animals. Previously a single value was used nationwide. Now, livestock location data are combined with the dry- and wet-climate zone EFs from IPCC (2019). As most Australian livestock graze in dry climates, the resulting EF and estimated emissions are lower. Smaller changes are due to the adoption of the IPCC (2019) EF for swine waste applied to soils (upward recalculation); disaggregation of the EF for histosol emissions by climate zone (downward); a new approach to estimating the area of irrigated land from agricultural statistics to calculate fertiliser allocation (downward in recent years); and disaggregation of the crop residue EFs by crop and region (downward). As described in Chapter 6 (LULUCF), the estimates for soil carbon are recalculated for the entire time series in every submission. This leads to small changes in the estimates of nitrogen mineralisation due to loss of soil carbon in all years.
	Field Burning of Agricultural Residues	Category 3.F Chapter 5.7	There are no recalculations associated with the field burning of agricultural residues in this submission.
	Liming	Category 3.G Chapter 5.8	The upward recalculations associated with liming in recent years are due to extrapolating activity data by in recent years when the ABS has not reported it, instead of holding it constant.
	Urea Application	Category 3.H Chapter 5.9	There are no recalculations associated with urea application in this submission.
LULUCF	Cross-cutting	Category 4 Chapter 6	Emissions have been recalculated as a result of updating the climate, forest productivity, crop and grass yields and fire time series and adding an additional year of data. Following independent expert review of the implementation of improvements to the calibrations used to model non-temperate fires reported in the 2022 submission, further refinements to the sub-model in FullCAM were identified. These refinements include a revision to the fire patchiness values for one species type and a revision to the time series of grass yield parameters for monsoonal perennial grass species. These updates have resulted in recalculations in *forest land remaining forest land, grassland remaining grassland, land converted to grassland* and *wetlands remaining wetlands.*
	Forest Land remaining Forest Land	Category 4.A.1 Chapter 6.4.1	Recalculations are limited to the cross-cutting elements.
	Land converted to Forest Land	Category 4.A.2 Chapter 6.4.2	Recalculations are limited to the cross-cutting elements.
	Cropland remaining Cropland	Category 4.B.1 Chapter 6.5.1	Recalculations are limited to the cross-cutting elements.
	Land converted to Cropland	Category 4.B.2 Chapter 6.5.2	Recalculations are limited to the cross-cutting elements.
	Grassland remaining Grassland	Category 4.C.1 Chapter 6.6.1	Recalculations are limited to the cross-cutting elements.
	Land converted to Grassland	Category 4.C.2 Chapter 6.6.2	In addition to the cross-cutting elements, refinements were made to the savanna grassland component of the non-temperate fire model to estimate emissions using a Tier 2 method for forest land converted to grassland in rangeland regions of Australia, applying the same methods as the Grassland Remaining Grassland Tier 2 fire model.

Sector	Subsector	Category & NIR Chapter	Reason for Recalculation
	Wetlands remaining Wetlands	Category 4.D.1 & Category 4.H Chapter 6.7.1	In addition to the cross-cutting elements, emissions have been recalculated as a result of updating production data for aquaculture and gauge and surface area data for reservoirs..
	Land converted to Wetlands	Category 4.D.2 Chapter 6.7.2	There were no recalculations for this category.
	Settlements remaining Settlements	Category 4.E.1 Chapter 6.8.1	There were no recalculations for this category.
	Land converted to Settlements	Category 4.E.2 Chapter 6.8.1	Recalculations are limited to the cross-cutting elements.
	Harvested Wood Products	Category 4.G Chapter 6.10	Recalculations are due to time-series revisions to the underlying source data on forestry and wood products produced by ABARES, and revisions in the Waste sector which impact HWP in SWDS.
Waste	Solid Waste Disposal	Category 5.A Chapter 7.2	Revisions to population data from the ABS and harvested wood products activity data as well as updated default waste composition values contributed to revisions of between -0.02 and 15.09 per cent between 1989-90 and 2023–24.
	Wastewater Treatment and Discharge	Category 5.D Chapter 7.5	**Domestic and commercial wastewater:** Minor revisions to activity and population data contributed to revisions of between -0.36 and -0.03 per cent between 2019-20 and 2022–23. **Industrial wastewater:** Minor revisions to activity data in domestic and commercial wastewater contributed to revisions of between -02 and 0.32 per cent from 2019-20 to 2022–23.

10.2 Implications for emission and removal levels

Table 10.2 gives the recalculations for this submission for each category for 1989–90, 2004–05 and the past ten years.

Table 10.2 Recalculations for this submission (compared with last year's submissions 1989–90, 2004–05, 2013–14 to 2022–23)

Sector	1989–90	2004–05	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23
	Emissions (Mt CO_2-e)											
1.A Fuel Combustion	0.0	0.0	0.0	0.0	0.0	0.0	0.1	-0.2	1.2	1.7	3.6	1.4
1.A.1, 2, 4, 5 Stationary Energy	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.7	0.8	0.8	-0.2
1.A.3 Transport	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.7	0.5	0.9	2.7	1.6
1.B Fugitives	0.0	-0.2	0.0	0.0	0.1	0.2	0.4	0.7	0.8	1.0	0.8	0.6
2 Industrial Processes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
3 Agriculture	-4.4	-4.0	-4.2	-3.9	-3.9	-4.2	-4.1	-3.8	-3.6	-3.3	-3.1	-3.6
4LULUCF	-0.5	-0.1	0.1	-0.1	0.2	-0.1	-0.2	-0.1	0.3	0.9	1.8	32.6
5 Waste	0.0	0.0	0.3	1.4	1.5	1.0	0.4	0.0	0.0	0.2	0.0	0.1
Total Recalculation	**-5.0**	**-4.2**	**-3.7**	**-2.6**	**-2.1**	**-3.0**	**-3.4**	**-3.4**	**-1.1**	**0.4**	**3.1**	**31.2**

10.3 Implications for emission and removal trends, including time series consistency

The most significant recalculations occur in LULUCF. The overall trend of national emissions is largely unaffected, and the standards of time series consistency are preserved in all recalculations. The full time series of recalculations is set out in Table 10.3.

Table 10.3 Recalculations for this submission (compared with last year's submission 1989-90 to 2022–23)

	Including LULUCF				Excluding LULUCF			
	Previous estimate	Current Estimate	Difference		Previous estimate	Current Estimate	Difference	
	Mt CO_2-e	Mt CO_2-e	Mt CO_2-e	%	Mt CO_2-e	Mt CO_2-e	Mt CO_2-e	%
1989-90	620.9	615.9	-5.0	-0.8%	440.2	435.7	-4.5	-1.0%
1990-91	601.6	596.6	-4.9	-0.8%	440.4	435.9	-4.4	-1.0%
1991–92	562.5	557.6	-4.9	-0.9%	444.1	439.8	-4.3	-1.0%
1992–93	541.4	536.8	-4.6	-0.8%	444.4	440.3	-4.1	-0.9%
1993-94	530.8	526.5	-4.3	-0.8%	444.6	440.6	-4.1	-0.9%
1994-95	518.2	514.3	-3.9	-0.8%	453.4	449.6	-3.8	-0.8%
1995-96	520.0	516.0	-4.0	-0.8%	459.6	455.7	-3.9	-0.8%
1996-97	518.6	514.6	-4.0	-0.8%	471.7	467.8	-3.9	-0.8%
1997-98	536.8	532.8	-4.0	-0.8%	486.1	482.1	-3.9	-0.8%
1998-99	557.5	553.5	-4.0	-0.7%	492.0	488.1	-3.9	-0.8%
1999-00	579.2	575.0	-4.2	-0.7%	503.6	499.6	-4.0	-0.8%
2000-01	594.6	590.3	-4.2	-0.7%	511.5	507.3	-4.1	-0.8%
2001–02	598.9	594.4	-4.5	-0.8%	515.1	510.8	-4.3	-0.8%
2002–03	598.1	594.1	-4.0	-0.7%	515.3	511.5	-3.9	-0.7%
2003-04	579.7	575.4	-4.2	-0.7%	530.0	525.9	-4.1	-0.8%
2004-05	611.9	607.7	-4.2	-0.7%	535.0	530.9	-4.1	-0.8%
2005-06	648.4	644.1	-4.3	-0.7%	540.1	535.9	-4.2	-0.8%
2006-07	630.8	626.8	-4.0	-0.6%	547.8	543.9	-3.9	-0.7%
2007-08	620.8	616.8	-3.9	-0.6%	551.0	547.1	-3.9	-0.7%
2008-09	615.3	611.1	-4.2	-0.7%	553.2	549.0	-4.2	-0.8%
2009-10	616.6	612.8	-3.9	-0.6%	548.2	544.3	-3.9	-0.7%
2010-11	585.6	581.9	-3.7	-0.6%	549.9	546.1	-3.8	-0.7%
2011–12	560.6	556.6	-4.0	-0.7%	552.1	548.0	-4.0	-0.7%
2012–13	563.0	559.5	-3.5	-0.6%	544.1	540.5	-3.6	-0.7%
2013-14	544.8	541.0	-3.7	-0.7%	536.6	532.8	-3.8	-0.7%
2014-15	540.1	537.5	-2.6	-0.5%	545.1	542.6	-2.5	-0.5%
2015-16	496.8	494.8	-2.1	-0.4%	553.3	550.9	-2.3	-0.4%
2016-17	536.7	533.8	-3.0	-0.6%	562.6	559.7	-2.9	-0.5%
2017-18	508.3	504.9	-3.4	-0.7%	563.9	560.7	-3.2	-0.6%
2018-19	496.3	492.9	-3.4	-0.7%	557.3	554.0	-3.2	-0.6%
2019-20	477.7	476.6	-1.1	-0.2%	538.3	536.9	-1.4	-0.3%
2020-21	439.9	440.4	0.4	0.1%	529.6	529.1	-0.5	-0.1%
2021–22	440.6	443.8	3.1	0.7%	523.6	524.9	1.3	0.3%
2022–23	453.4	484.7	31.2	6.9%	527.2	525.7	-1.4	-0.3%

10.4 Areas of improvement and/or capacity building in response to the review process

Priorities for the inventory development process have been set out in the *National Inventory Systems Inventory Improvement Plan* and have been informed by analysis of key sources and key trends. Information on planned improvements are outlined for each sector in the relevant chapter.

More broadly, Australia is progressively implementing updated IPCC methods for sources identified in the *2019 Refinement to the 2006 IPCC Guidelines*, and in the *2013 Wetlands Supplement*. Continued investment in IT software systems including the AGEIS, and for *LULUCF* the FullCAM, is also a critical part of the improvement plan.

New information generated by publicly funded research programs or other sources also provide opportunities to test the validity of existing parameters, to consider changes to model structures, or to develop new methods. Australia is closely following the development of new atmospheric measurement technologies and associated techniques for opportunities to further enhance national inventory system quality assurance processes.

Summary of Responses to the simplified review for the 2023 inventory submission

Australia participated in its first in-country review of its NIR, CRTs, and BTR under the Paris Agreement in 2025. The review was conducted by the secretariat in accordance with paragraphs 7–9 of the conclusions and recommendations from the 2025 joint meeting of lead reviewers and the Review Guidance for BTR Reviews.

During the review, Technical Expert Review Team (TERT) reviewed Australia's 2024 submission of the NIR 2022 and associated CRTs, Common Tabular Formats (CTFs), and First BTR. The review report was not published at the time this document was drafted. Once finalised, it will be published on the UNFCCC website: First Biennial Transparency Reports. Australia has provided responses in the table below based on the latest available version of review's final recommendations and encouragements.

Summary of Responses to UNFCCC ERT Recommendations and Comments

As part of the national inventory development process, all issues identified by the UNFCCC ERT review teams are assessed for their implications for the national inventory. Recommendations from the previous reviews, which are in the process of being addressed, are summarised below.

Table 10.4 Status of areas of improvement (AoI) raised by previous UNFCCC Technical Expert Review Teams

Sector	AoI ID#	TERT AoI	Australian response	NIR or CRT references
General	2.G.1, 2025	The TERT recommends that Australia include more detailed information on the comprehensive procedures for identifying needs to update the data and parameters used within the existing inventory reporting system in order to better reflect changes in the situation of estimating GHG emissions.	Inventory review process and improvement steps 1–5 have been revised and expanded to elaborate on Australia's comprehensive, annual planned improvement processes.	1.2.2.c
General	2.G.2, 2025	The TERT recommends that Australia estimate and report agriculture and LULUCF emissions for its external territories.	National agricultural statistics are based on economic activity and other data, and represent production for the whole of Australia. For the LULUCF sector, we are investigating sources of activity data to estimate and report on emissions. As noted in during the review, external territories are largely uninhabited and managed emissions, if they occur, are expected to be negligible.	
General	2.G.3, 2025	The TERT recommends that Australia include specific information on all relevant thresholds under the NGER scheme, as well as on effect on emission estimates for the energy, IPPU and waste sectors, to further improve transparency.	Information on the NGER scheme were expanded to specify the various applicable facility, corporate group, and materiality thresholds.	A5.1
General	G.2, 2022 (G,5, 2021)	Include the information required by the 2006 IPCC Guidelines (vol. 1, chap. 3, section 3.2.2.3, and vol. 1, chap. 2, section 2.2 and annex 2A.1 on expert elicitation) when using expert judgment in the uncertainty analysis.	We have made substantial progress against this recommendation. We are continuing to review uncertainty values and will provide further details on values determined using expert judgment in future annual submissions.	A2
Energy	3.E.1, 2025	The TERT recommends that Australia provide information on the shares of emissions from the plants covered by the NGER scheme with respect to the total emissions from public electricity and heat production across the time series in order to enhance transparency	Additional information has been added to the NIR on the coverage of generators in data sourced through the NGER scheme.	3.2.4.2
IPPU	4.I.1	The TERT recommends that Australia justify and document the use of the country-specific EF reported under method 1 of the NGER scheme, or alternatively adopt the default EF from the 2006 IPCC Guidelines.	Further information regarding the response to this recommendation will be provided in a future submission.	-
IPPU	4.I.2	The TERT recommends that Australia estimate the uncertainties of the emission estimates for cement and lime production separately.	Emissions uncertainties for cement and lime production have been estimated separately in this submission using data reported by facilities for each category under the NGER scheme. The combined uncertainty values estimated for each category are 4.95% and 6.0% respectively.	NIR vol. 2, Annex II

Sector	AoI ID#	TERT AoI	Australian response	NIR or CRT references
IPPU	4.I.3	The TERT recommends that Australia correct the inconsistency between the AD reported for glass production in the NID and in the CRT by applying the appropriate fractional purity factors to both data sets, as applicable. The TERT also recommends that Australia enhance QC checks for this category to ensure consistency between the data reported by Australia in the NID and in the CRT.	QC checks have been enhanced and this data has been presented consistently in this NIR and the CRT tables of this submission.	NIR section 4.2.4, Table 4.3 CRT Table2(I).A–H
IPPU	4.I.4	The TERT recommends that the Party report, under the IPPU sector, the emissions from fuel use as feedstock as well as the emissions from fuel use for energy purposes in ammonia production, and deduct both from the emissions reported for ammonia production in the energy sector to ensure consistency with the 2006 IPCC Guidelines.	Further information regarding the response to this recommendation will be provided in a future submission.	-
IPPU	4.I.5	The TERT recommends that Australia ensure consistency in time-series in accordance with the 2006 IPCC guidelines when performing recalculations in order to update the information regarding petrochemical and carbon black production for the entire time series, incorporating the data collected under the NGER scheme and information for other facilities not covered by the scheme.	Further information regarding the response to this recommendation will be provided in a future submission.	-
IPPU	4.I.6	The TERT recommends that Australia enhance the transparency of its reporting by clearly explaining how the speciation is applied across gases, subcategories and the time series and clarifying that the AD reported in the CRT are estimated once total emissions have been calculated by the Party using the emission model.	This information has been included in this NIR.	NIR vol. 1, section 4.7.2, p.158
IPPU	4.I.7	The TERT recommends that Australia improve the methodological approach applied for reporting AD and emissions in the CRT for each species of gas by ensuring that only the gases actually used under each subcategory are reported.	Further information regarding the response to this recommendation will be provided in a future submission.	-
Agriculture – Animal manure applied to soils	A.10, 2022 (A11, 2021) (A18, 2020)	Explain in the NIR the estimation of the N_2O EF for animal manure applied to soils.	We note that outstanding concerns from the technical expert review team on this issue relate specifically to manure from swine. The EF for swine manure applied to soils has been reviewed and updated to be consistent with other livestock types.	5.3.2 A5.5.5

Sector	AoI ID#	TERT AoI	Australian response	NIR or CRT references
Agriculture MMS – Anaerobic lagoons; drains to paddocks	A.16, 2022	Either (1) report data on average annual temperature by state/territory for the entire reporting period in the NIR (e.g. in tabular format in an appendix) in order to justify the appropriateness of the current MCFs for anaerobic lagoons and drains to paddocks, which have been selected to estimate CH_4 emissions from swine and dairy cattle MMS or (2) adjust the MCF values of the two M MS anaerobic lagoons and drains to paddocks (the latter of which is assumed to be similar to a liquid/ slurry system) in accordance with the data collected on average annual temperature by state/territory for the entire reporting period and recalculate CH_4 emissions from MMS of swine and dairy cattle, as necessary.	We are considering how to respond to this recommendation and further information will be provided in a future update.	5.3.5
Agriculture Rice cultivation – CH_4	5.A.1, 2025	The TERT notes Australia's ongoing efforts and encourages the Party to implement a higher-tier method once new data become available in order to enhance the accuracy of the estimates and ensure consistency with IPCC good practice.	This encouragement has been addressed with the modification of the EF scaling factors to incorporate country-specific data on sowing practices and flooding duration in the NIR 2024 submission. Additional information on CS EFs is expected from research currently in progress, and this will be considered when it is available.	5.4.2
Agriculture Rice cultivation – CH_4	5.A.2, 2025	The TERT recommends that Australia transparently report the correct uncertainty information for rice cultivation, including the expert judgment applied and references for the data sources used.	Resolved. The uncertainty estimates listed in Annex II have been correctly recorded in the NIR 2024 submission using Approach 1 from IPCC 2006.	A2.3
Agriculture Inorganic N fertilizers – N_2O	5.A.3, 2025	The TERT recommends that Australia report N_2O emissions from flooded rice soils under direct N_2O emissions from managed soils, in line with the 2006 IPCC Guidelines (vol. 4, chap. 11, p.11.7, equation 11.1).	Investigating separate reporting of fertiliser emissions from flooded rice soils for inclusion in a future inventory submission is listed as a planned improvement.	5.5.6
Agriculture Urea application – CO_2	5.A.5, 2025	The TERT recommends that Australia report on its progress in developing country-specific EFs for this category, including on the methodologies, and encourages Australia to incorporate these EFs into a tier 2 method once developed in order to improve the accuracy of the relevant estimates.	Australia is reviewing international practice in relation to reporting of CO_2 from urea application and to find examples of options for methodologies to develop country-specific EFs. We will report on progress once further research and planning activities have been completed.	

Sector	AoI ID#	TERT AoI	Australian response	NIR or CRT references
LULUCF General	L.1, 2022 (L.1, 2021) (L.2, 2020) (L.3, 2019) (L.4, 2017) (L.29, 2016)	Provide separate AD and estimates for the following categories and pools currently reported as "IE": cropland, wetlands and settlements converted to forest land (all pools except organic soils); cropland converted to grassland (all pools); and cropland and grassland converted to settlements (all pools). Until this is done, provide in the NIR an update of the status of efforts to provide estimates for these pools.	Croplands, wetlands and settlements converted to forest land are now reported and previous reviews have assessed these elements as resolved. Previous reviews have agreed that it is reasonable for cropland converted to grassland to be reported as IE on the basis that it is not practical to identify these transitions where mixed cropping and grazing rotations frequently occur as a part of normal farming operations in Australia. Identifying cropland and grassland converted to settlements will require an extension of Australia's Approach 3 land identification systems to distinguish changes in land uses other than forest cover. While it is not mandatory for Australia to extend beyond Approach 1 land representation in this respect, it is nevertheless a planned improvement to do so as competing priorities and resources permit.	6.4.2 6.5.1.1 6.8.2.5
LULUCF Land representation	6.L.1, 2025	The TERT recommends that Australia allow sufficient time for adequate category-specific QC procedures within its inventory preparation process in order to eliminate and discrepancies in land areas reported between CRT 4.1 and CRTs 4.A, 4.B, 4.C and 4.E.	This inconsistency was resolved in the CRT submission associated with the 2023 NIR.	CRT 4.1 and CRTs 4.A, 4.B, 4.C and 4.E.
LULUCF General	6.L.2, 2025	The TERT recommends that Australia provide quantitative estimates of uncertainty for all LULUCF categories. Noting that Australia has initiated a review of its LULUCF uncertainty analysis methodology and expects to begin updating the quantified uncertainty estimates for LULUCF categories as from the 2027 inventory submission, the TERT encourages Australia to report on the progress of that review	An update on the progress of this review will be provided in the 2027 inventory submission.	
LULUCF Natural disturbances	6.L.3, 2025	To increase transparency, the TERT recommends that Australia improve its description of the methodology and assumptions used for estimating emissions from natural disturbances, in particular by being more precise regarding the biomass recovery rates after wildfires on managed land.	The text describing the biomass recovery of forests following natural disturbances has been amended to be more precise regarding the expected time for CO_2 recoveries to balance emissions from natural disturbances.	6.3.2

Sector	AoI ID#	TERT AoI	Australian response	NIR or CRT references
Waste Solid waste disposal	W.7, 2022	Provide in the NIR a more detailed explanation of QA/QC procedures for data on CH_4 recovery, utilization and flaring, including how the amount of CH_4 used for energy generation or flaring is verified, preferably including a table with the results, at an aggregated level, of a comparison of data from landfill operators with those from energy companies.	Additional information has been provided regarding the NGER scheme data collection process and how it supports verification.	7.2.4
Waste Solid waste disposal	7.W.1	Provide a more comprehensive qualitative discussion of uncertainty for the waste sector, including how the uncertainties influence the emission estimates, the assumptions underlying the calculations and inventory quality.	Additional discussion of qualitative uncertainty has been provided in Section 7.2.3, chapter 7.	7.2.3
Waste Wastewater	W.8, 2022	Either: (1) better explain the definition of TOW removed as sludge to WWTP operators and improve the QA/QC procedures for data collected on wastewater treatment and discharge under the NGER scheme to ensure that accurate values of sludge are reported; or, alternatively, (2) recalculate CH_4 emissions from wastewater treatment using data on more common WWTP parameters that are available from the WWTP operators and include a description of the methodology in the NIR.	We are considering how to respond to this recommendation and further information will be provided in a future update.	7.5.6

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