Australian Government
Department of the Environment and Energy

METHODOLOGY FOR THE 2018 PROJECTIONS

Australia's emissions projections incorporate a variety of key data inputs, assumptions and methods. This methodology document outlines how the Department of the Environment and Energy (the Department) has estimated the 2018 projections of greenhouse gas (GHG) emissions.

The projections are prepared at a sectoral level consistent with international guidelines adopted by the United Nations Framework Convention on Climate Change (UNFCCC).

The projections use public data sources, from government agencies and other bodies, to inform production estimates. Emissions factors are consistent with Australia's national greenhouse gas inventory.

Greenhouse gas emission estimates are expressed as the carbon dioxide equivalent (CO_2-e) using the 100 year global warming potentials in the Intergovernmental Panel on Climate Change's *Fourth Assessment Report* (IPCC 2007). As greenhouse gases vary in their radiative activity, and in their atmospheric resistance time, converting emissions into CO_2-e allows the integrated effect of emissions of the various gases to be compared.

Australia's emissions projections include:

- historical emissions data taken from the *National Inventory Report*, released in April 2018 (DoEE 2018)
- sector-specific emissions estimation processes.

Reporting years for all sectors are financial years, consistent with Australia's national greenhouse gas inventory. For instance, '2030' refers to financial year 2029–2030.

The 2018 projections have been scaled to the *National Greenhouse Gas Inventory, June Quarter 2018* (DoEE 2018b). Scaling is done as shown below:

Scaled value E_t = Inventory value $E_{(2018)}$ x Modelled value E_t / Modelled value $E_{(2018)}$

Where E_t = emissions in year t from the given subsector (Mt CO_2-e)

$E_{(2018)}$ = emissions in the base year (2018).

Sector specific methodologies are discussed in greater detail below.

The methodology document does not include all the data and processes involved in producing Australia's emissions projections due to constraints and sensitivities relating to specific inputs. For example, facility level information, has not been included due to commercial-in-confidence company data considerations.

Electricity

The *electricity sector* emissions projections have been prepared using external modelling by ACIL Allen for the National Electricity Market (NEM) and Wholesale Electricity Market (WEM) and the Department's internal modelling for the smaller grids and off-grid electricity generation.

Modelling approach

NEM and WEM

ACIL Allen's proprietary market simulation model – PowerMark – was used to project emissions in the NEM and WEM to 2030. PowerMark is a simulator that emulates the settlements mechanism. PowerMark uses a linear program to settle the market, as does the Australian Energy Market Operator's (AEMO) Dispatch Engine in its real-time settlement process. PowerMark is part of an integrated suite of models including models of the market for Renewable Energy Certificates and the wholesale gas market. Demand is included in the model as an exogenous assumption and presented to the market. Generator portfolios compete against this demand for dispatch.

PowerMark accounts for the economic relationships between generating plants in the system. In particular, the model calculates production of each power station given the availability of the station, the availability of other power stations and the relative costs of each generating plant in the system.

Small grids and off-grid

The Department undertook modelling of emissions from Australia's small grid and off-grid electricity networks.

The electricity networks classified as small grids are:

- North West Interconnected System;
- Darwin-Katherine Interconnected System; and
- Mount Isa.

Off-grid refers to all other locations where small electricity networks operate.

For the small grids and off-grid electricity generation, emissions are calculated by

$$E_t = \sum([G_{it} \cdot EI_{ijt}])$$

Where:
E_t = annual emissions in year t (kt CO_2-e)
G_{it} = electricity generation by fuel$_i$, in year t (GWh)
EI_{ij} = the emissions intensity of generation by fuel$_i$ at grid$_j$, in year t (t CO_2-e/MWh coal)

Electricity demand

NEM and WEM

Forecasts of electricity demand are a key input into the electricity sector emissions projections. The Department has sourced data from the AEMO's Electricity Statement of Opportunities (ESOO) reports (AEMO 2018; AEMO 2018a) to inform electricity demand projections for the

NEM and the WEM. The demand scenario that was included in the projections was the ESOO 2018 neutral scenario.

The electricity emissions projections include consumption of electricity from electric vehicles consistent with estimates in the *transport sector*.

Small grids and off-grid

Data and information from the Utilities Commission of the Northern Territory (NT Utilities Commission 2018), electricity generation data from the National Greenhouse and Energy Reporting scheme, liquefied natural gas (LNG) production estimates have been used to inform electricity demand forecasts and the emission intensity of generation for the smaller grids and off-grid electricity generation.

Table 1. Data source for electricity demand projections

Grid	Data source for electricity demand
National Electricity Market	AEMO Electricity Statement of Opportunities for the NEM
Wholesale Electricity Market	AEMO Electricity Statement of Opportunities for the WEM
Small grids: Darwin Katherine interconnected system North West interconnected system Mt Isa	Utilities Commission of the Northern Territory National Greenhouse Energy Reporting scheme (NGERS)electricity generation data
Off-grid	LNG production consistent with production assumptions in the *fugitives sector*, electricity use factor from NGERS where available.

Direct combustion

Emissions from the *direct combustion sector* are projected using modelling processes developed within the Department. Projections are aggregated from six subsectors: energy, mining, manufacturing, buildings, agriculture, forestry and fishing and other (which is solely fuel used by military vehicles within Australia).

Modelling approach

Direct combustion models are a combination of facility-specific and top-down models, depending on the nature of the emission source and the availability of data. The models are maintained and updated within the Department. The structure of these models is provided in Table 2.

The production data for LNG is estimated at the facility-level as each facility has a different emissions intensity. Where sufficient historical data is available, emissions intensity is calculated based on emissions reported through the National Greenhouse and Energy Reporting System. For new LNG projects, information provided in environmental impact statements is used to calculate the emissions intensity. Emissions intensity is updated yearly for each facility where data is available, and they are assumed to be constant across the projections period.

Activity data

Activity data used in the direct combustion subsectors is presented in Table 2.

Emissions projections in the *direct combustion sector* are estimated using activity data from a range of sources including, Office of the Chief Economist's (OCE) commodity forecasts (OCE 2018; OCE 2018a), Australian Energy Update (DoEE 2018a), AME Group's industry analysis, IBISWorld industry reports and AEMO's Gas Statement of Opportunities (GSOO) (AEMO 2018b; AEMO 2018c).

Table 2. Summary of activity data and calculation methods for each direct combustion subsector

Emissions subsector	Activity data	Calculation method
Energy		
LNG (facility level model)	Production data from the *fugitives sector* and emissions intensity from NGER, various Environmental Impact Studies	*$E_t = \sum([EI_{it} . P_{it}])$* *Where:* *$E_t$ = emissions in year t (Mt CO_2-e)* *EI_{it} = facility-specific emissions intensity in year t* *P_{it} = production at facility$_i$ in year t*
Other oil and gas extraction (top down model)	Western Australia Gas demand from AEMO 2018c, East Coast gas demand from AEMO 2018d, crude and condensate oil demand from OCE 2018a.	*$E_t = E_{t-1} . \Delta$ Production* *Where:* *E_t = emissions in year t (Mt CO_2-e)* *E_{t-1} = emissions in the previous year* *Δ Production = percentage change in production between year t and year t-1*
Manufacture of solid fuels (top down model)	Iron and steel growth rates from OCE 2018[1], OCE 2018a and AME Group's industry analysis	
Domestic gas production and distribution (top down model)	Western Australia Gas demand from AEMO 2018c, East Coast gas demand from AEMO 2018d	
Petroleum refining (top down model)	Total refinery output from OCE 2018a	
Mining		
Coal mining (facility level model)	Production data from the *fugitives sector*	*$E_t = E_{t-1} . \Delta$ Production* *Where:* *E_t = emissions in year t (Mt CO_2-e)* *E_{t-1} = emissions in the previous year* *Δ Production = percentage change in production between year t and year t-1*
Other mining (iron ore; gold; copper; nickel; zinc; bauxite and manganese) (top down model)	Production data from OCE 2018, OCE 2018a, AME Group's industry analysis and derived proportion of the base year from NGER data	

[1] Production data for most commodities are sourced from the OCE which goes out to 2023. Growth rates from AME Group's industry analysis have been used for 2024 and beyond.

Emissions subsector	Activity data	Calculation method
Manufacturing *(top down model)*		
Non-ferrous metals (alumina; aluminium and refined nickel)	Production data from OCE 2018, OCE 2018a, AME Group's industry analysis and derived proportion of the base year from NGER data	$E_t = E_{t-1} . \Delta\ Production$ *Where:* *E_t = emissions in year t (Mt CO_2-e)* *E_{t-1} = emissions in the previous year* *Δ Production = percentage change in production between year t and year t-1*
Non-metallic minerals (cement, lime, plaster and concrete; ceramics; glass and glass products and other)	IBISWorld industry reports analysis and derived proportion of the base year from NGER data	
Iron and steel	Production data from OCE 2018, OCE 2018a, and AME Group's industry analysis	
Pulp, paper and print	IBISWorld industry reports analysis	
Chemicals (other petroleum and coal product and basic chemical, chemical and plastic)	IBISWorld industry reports analysis and derived proportion of the base year from NGER data	
Food processing, beverages and tobacco	IBISWorld industry reports analysis	10 year historical average emissions growth
Other manufacturing	n/a	
Buildings *(top down model)*		
Residential and commercial	AEMO 2018b for annual gas consumption, DoEE 2018a for wood and woodwaste fuel use, DoEE 2018c for derived proportion of emissions from wood biomass and others	$E_t = \sum([U_{jyt} . EC_j . EF_j])$ *Where:* *E_t = emissions in year t (Mt CO_2-e)* *U_{jyt} = the use of $fuel_j$ in $State_y$ in year t* *EC_j = the energy content of $fuel_j$* *EF_j = the emissions factor of $fuel_j$*
Construction	Activity data from ACIF 2018	$E_t = E_{t-1} . \Delta\ Activity$ *Where:* *E_t = emissions in year t (Mt CO_2-e)* *E_{t-1} = emissions in the previous year* *Δ Activity = percentage change in activity between year t and year t-1*
Agriculture, forestry and fishing (top down model)	Australian Energy Statistics - Diesel use data, agriculture forestry and fishing classification. Final data point held constant.	

Emissions subsector	Activity data	Calculation method
Other (military) (top down model)	DoEE2018	10 year average of historical emissions

Transport

The Department commissioned the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to undertake modelling of the *transport sector*.

The transport projections have been developed to reflect current policies and measures. The policies impacting the *transport sector* that were included are:

1. Commonwealth fuel excise,
2. New South Wales and Queensland biofuels mandates, and
3. Commonwealth Emissions Reduction Fund.

Modelling approach

Modelling of transport emissions involves three models:

- the Adoption model
- the Demand model
- the Australian-TIMES (Aus-TIMES) model.

The Adoption model

The Adoption model takes vehicle costs together with demographic information to determine the future share of electric, fuel cell and autonomous vehicles. The model assumes that investment decisions are driven by a combination of price and non-price drivers so that adoption will broadly follow the consumer technology adoption curve. The adoption curve is calibrated to appropriate spatial scales (due to differing demographic characteristics and travel needs) and across different customer segments (fleet purchasing behaviour and vehicle utilisation).

The Demand model

The Demand model uses information around Gross Domestic Product, population, mode share and the cost of travel to determine projected activity for passenger and freight transport. Future mode share assumptions are developed based on observation of historical trends and consideration of the future of cities in Australia. This includes specific government programs to extend airports, rail and road infrastructure.

The Aus-TIMES model

The activity and sales of alternative vehicle projections from the Adoption and Demand models are then provided to the Aus-TIMES model which calculates least cost fuel and vehicle fleet changes to meet activity. Aus-TIMES is a partial equilibrium ('bottom-up') model, implemented as a linear program optimisation. The model has a robust economic decision making framework that incorporates the cost of alternative fuels and vehicles, as well as detailed characterisation of fuel and vehicle technical performance, including fuel efficiencies and emission factors by transport mode, vehicle type, engine type and age.

The Aus-TIMES transport model includes:

- Coverage of all states and territories

- Four broad transport modes: road, rail, aviation and shipping
- Ten road transport modes: motorcycles; small, medium and large passenger cars; small, medium and large commercial vehicles; rigid trucks; articulated trucks and buses
- Five road engine types: internal combustion; hybrid electric/internal combustion; hybrid plug-in electric/internal combustion; fully electric and fuel cell
- Fourteen road transport fuels: petrol; diesel; liquefied petroleum gas (LPG); natural gas (compressed (CNG) or liquefied (LNG)); petrol with 10% ethanol blend; diesel with 20% biodiesel blend; ethanol and biodiesel at high concentrations; gas to liquids diesel; coal to liquids diesel with upstream CO_2 capture; shale to liquids diesel with upstream CO_2 capture, hydrogen (from renewables) and electricity
- All road vehicles are assigned a vintage based on when they were first purchased or installed in annual increments
- Time is represented in annual frequency (2015, 2016 etc.).

. **Table 3. Input and data sources for the transport sector model**

Input	Data source
Fuel consumption	Table F of the Australian Energy Update 2018 (DoEE 2018a)
Oil prices	The oil price projections are informed by the Office of the Chief Economist and the United States Energy Information Administration (EIA 2018)
Gross Domestic Product	Department of the Treasury consistent with the Australian Government's 2018-19 Budget (Australian Government 2018)

Key outputs of the modelling include:

- Fuel and engine technology uptake
- Fuel consumption
- Greenhouse gas emissions
- Demand for transport services.

Fugitives

Emissions from the *fugitives sector* are projected using emission estimation models maintained and updated by the Department using external inputs. The models are a combination of facility specific and top down models depending on the nature of the emission source and the availability of data.

Coal fugitives

Operating coal mines

Modelling approach

The Department maintains a mine-by-mine model of fugitive emissions from operating coal mines. A mine-by-mine model takes account of the emissions intensity of each mine which is dependent on the operational and geological characteristics of the mine.

$$E_t = \sum([P_{it} \cdot EI_i]) - ERF_t$$

Where:
E_t = annual emissions from operating coal mines in year t (Mt CO_2-e)
P_{it} = coal production at $mine_i$, in year t (kt)
EI_i = the emissions intensity of production at $mine_i$, (Mt CO_2-e/kt coal)
ERF_t = abatement from forthcoming ERF projects in year t (Mt CO_2-e)

The emissions intensity of coal mines includes all sources of fugitive emissions from vented methane and carbon dioxide, flaring and post mining. For operating mines the emissions intensity is sourced from the latest national greenhouse gas inventory data which is based on company data reported under the NGER scheme. For prospective coal mines emissions intensity is sourced from Environmental Impact Statements or is the average for currently operating mines in the same coal basin.

The Emissions Reduction Fund has contracted abatement from coal mine waste gas capture projects. Abatement from projects are subtracted from the coal fugitives projection.

Activity data

Mine-by-mine production estimates for existing and new mines are informed by the OCE and AME Group estimates. Production is separately calculated for thermal and coking coal production at each mine.

Production from prospective new mines is scaled down so that total Australian production is equal to International Energy Agency (IEA) estimates. The IEA supplies the Department with projections of Australian thermal and coking coal production consistent with the New Policies Scenario in the *2018 World Energy Outlook* (IEA 2018). All prospective coal mines are scaled back at an equivalent rate, the projections do not make decisions on which prospective mines would and would not proceed. Scaling is undertaken for thermal and coking coal separately.

Production from brown coal mines is sourced from the *electricity sector* model.

<u>Abandoned coal mines</u>

Modelling approach

Methane emissions occur under certain conditions following the closure of underground coal mines. Emissions are estimated using a mine-by-mine model developed for the national greenhouse gas inventory. The model is extended to include projected closures of underground coal mines to 2030.

$$E_t = \sum ((ED_i \,.\, EF_i \,.\, (1 - F_{it})) - ER_{it})$$

Where:
E_t = emissions from abandoned coal mines in year t (Mt CO_2-e)
EDi = annual emissions of mine i in the year before decommissioning d (Mt CO_2-e)
EFi = emission factor for the mine i at a point in time since decommissioning. It is derived from the Emissions Decay Curves (see DoEE 2017).
Fit = fraction of mine i flooded at a point in time since decommissioning.
ERit = quantity of methane emissions avoided by recovery at mine i in year t (Mt CO_2-e).

The model requires the emissions at the time of closure, the mine type, mine void size and mine water inflow rates. Emissions at the time of closure and mine void volume are sourced from the operating coal mines model. Emission decay curves are calculated from the formulas published in the *National Inventory Report* (DoEE 2018). Mine flooding rates are estimated based on the mine's water production region consistent with the national greenhouse gas inventory.

Activity data

Closure timing is informed by mine-by-mine projections provided by the OCE and AME Group and is consistent with the operating coal mines model.

Oil and gas fugitives

<u>Oil</u>

Oil fugitive emissions are separated into five subsectors:

1. Refining;
2. Flaring;
3. Production;
4. Exploration; and
5. Transport.

Modelling approach

Oil fugitive emissions projections are calculated using the following algorithm:

$$E_t = E_{t-1} \,.\, Pr_t / Pr_{t-1}$$

Where:
E_t = emissions in the year t (Mt CO_2-e)
E_{t-1} = emissions in the year t-1 (Mt CO_2-e)
Pr_t = proxy indicator in the projection year
Pr_{t-1} = proxy indicator in the year t-1

Activity data

Activity data used to estimate emissions from oil and gas fugitives is provided in Table 4.

Table 4. Summary of sources for oil and gas fugitive emissions

Fugitive emissions source	Proxy indicator	Source
Oil refinery	Refinery output	OCE 2018a
Oil - flaring	Crude oil and condensate production	OCE 2018a, BREE 2014
Oil - production	Crude oil and condensate production	OCE 2018a, BREE 2014
Oil - exploration	Historical 10-year average	DoEE 2018
Oil - transport	Crude oil and condensate production	OCE 2018a, BREE 2014

Oil exploration emissions are small (<0.03 Mt CO_2-e) and volatile from year-to-year. A consistent link to a proxy indicator was not found. Therefore historical emissions levels have been used to project future emissions from this source.

Fugitive emissions from LNG

Modelling approach

The Department maintains a facility-by-facility model of fugitive emissions from LNG. Emissions depend on the operation of the plant, the carbon dioxide concentration and source of the feed gas, abatement actions and annual production.

$$E_t = \sum (P_{ti} . (EI_{vi} + EI_{fi} + EI_{oi})) - CCS_{ti}$$

Where:
E_t = LNG fugitive emissions in year t (Mt CO_2-e)
P_{ti} = production at facility i in year t (Mt LNG)
EI_{vi} = venting emissions intensity at facility i (Mt CO_2-e/Mt LNG)
EI_{fi} = flaring emissions intensity at facility i (Mt CO_2-e/Mt LNG)
EI_{oi} = other leaks emissions intensity at facility i (Mt CO_2-e/Mt LNG)
CCS_{ti} = CO_2 captured and stored at facility i in year t (Mt CO_2)

Emissions intensities for venting, flaring and other fugitive leaks at operating facilities are based on NGER data. For new facilities emissions intensities are sourced from Environmental Impact Statements or other sources. The projected emissions intensities take account of changes in feed gas.

The projections include abatement from the carbon dioxide injection project at Gorgon assumed to commence in the first half of 2019.

Activity data

Production projections of each facility are informed by estimates from the OCE (OCE 2018a), AME Group, Wood Mackenzie and Lewis Grey Advisory (Lewis Grey Advisory 2017). The projections consider committed and prospective additions and removals in capacity given the global outlook for LNG.

Other fugitive emissions from gas

Other fugitive emissions from gas include gas exploration, extraction, processing, storage and transport. Emissions are separated into twenty subsectors. Proxy indicators are used to project the growth in emissions from the sectors as listed below.

$$E_t = E_{t-1} \, . \, Pr_t / Pr_{t-1}$$

Where:
E_t = emissions in the year t (Mt CO_2-e)
E_{t-1} = emissions in the year t-1 (Mt CO_2-e)
Pr_t = proxy indicator in the projection year
Pr_{t-1} = proxy indicator in the year t-1

Table 5. Summary of sources for gas fugitive emissions

Fugitive emissions source	Proxy indicator	Source
Distribution	Unaccounted for gas losses	AEMO 2018b
Exploration - flared	Total gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Exploration - leakage - conventional	Conventional gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Exploration - leakage - unconventional	Unconventional gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Exploration - venting - completions - conventional	Conventional gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Exploration - venting - completions - unconventional	Unconventional gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Exploration - venting - workovers	Unconventional gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Processing	Total gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG,

Fugitive emissions source	Proxy indicator	Source
		electricity and direct combustion
Production - offshore platforms	Number of shallow and deep offshore platforms	AME Group, Company Reports
Production - onshore gathering and boosting - conventional gas	Conventional gas production (excluding LNG)	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Production - onshore gathering and boosting - unconventional gas	Unconventional gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Production - onshore wells - conventional gas	Conventional gas production (excluding LNG)	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Production - onshore wells - unconventional gas	Unconventional gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Production - onshore wells - water production	Unconventional gas production	OCE 2018a, AEMO 2018b, AEMO 2018c, emission projections models for LNG, electricity and direct combustion
Transmission and storage - LNG terminals	Number of LNG terminals operating	AME Group, company reports
Transmission and storage - storage - LNG	Number of LNG storage stations operating	AME Group, company reports
Transmission and storage - storage - natural gas	Number of gas storage stations operating	AME Group, company reports
Transmission and storage - transmission	Total pipeline length	AEC 2018, company reports, Department of the Environment and Energy expert advice
Venting and flaring - flaring - gas	Domestic gas consumption	AEMO 2018b, AEMO 2018c, emission projections models for electricity and direct combustion
Venting and flaring - venting - gas	Domestic gas consumption	AEMO 2018b, AEMO 2018c, emission projections models for electricity and direct combustion

Industrial Processes and Product Use

Emissions from the *industrial processes and product use sector* (IPPU) are projected using bottom-up models developed within the Department. Where possible, emissions are projected by estimating fuel use at the facility-level, to account for different fuel types and emissions intensity of production across facilities.

Modelling approach

A summary of data sources and model frameworks applied are provided in Table 6.

Unless otherwise specified, the emissions intensity of production is assumed to be constant across the entire projections period and is based on the emissions reported in Australia's *National Inventory Report 2016* (DoEE 2018).

Activity Data

For the major chemical industry subsectors the growth in the final demand for these products is used as the driver for production growth, as outlined below.

Ammonia is primarily used in the production of explosives used by the mining industry and in fertilisers. Projections of natural gas use in the manufacture of ammonia are estimated at the facility level. They are informed by:

- coal mining estimates prepared for the *fugitives sector* for east coast explosive manufacturers,
- iron ore mining estimates prepared for the *direct combustion* sector for west coast explosives manufacturers, and
- fertiliser use estimates prepared for the *agriculture sector* for fertiliser producers.

Nitric acid is primarily used in the production of explosives used by the mining industry. Projections of nitric acid emissions are estimated at the facility level. They are informed by:

- coal mining estimates prepared for the *fugitives sector* for east coast explosive manufacturers, and
- iron ore mining estimates prepared for the *direct combustion* sector for west coast explosives manufacturers.

Facility-specific capacity constraints are applied to these estimates.

Synthetic rutile is used to produce titanium dioxide. **Titanium dioxide** is a white pigment used in paint manufacture, paper, plastics, rubber, ceramics, fabrics, floor covering, printing ink and other miscellaneous uses. Approximately 75 per cent of Australia's titanium dioxide is exported. Projections of the use of fuels in the production of titanium dioxide and synthetic rutile are estimated at the facility level. They are informed by projections of gross world product, as well as facility-specific capacity constraints.

Emissions from the Product uses as Substitutes for Ozone Depleting Substances and Other Product Manufacture and Use subsectors are estimated by extrapolating models used in the preparation of the National Inventory Report. A detailed methodology for these subsectors is available in the National Inventory Report (DoEE 2018).

Table 6. Summary of sources and formula for each IPPU subsector

Emissions subsector	Data source	Formula
Chemical industry		
Ammonia	DoEE estimates based on projected iron ore, coal production and fertiliser use	$E_t = \sum([U_{ji} . EC_j . EF_j])$ *Where:* E_t = annual emissions in year t (Mt CO_2-e) $U_{j,i}$ = natural gas consumption at facility$_i$, in year t EC_j = the energy content of natural gas EF_j = the emissions factor of natural gas
Nitric acid	DoEE estimates based on projected iron ore and coal production	$E_t = \sum([EF_i . P_{it}])$ *Where:* E_t = annual emissions in year t (Mt CO_2-e) EF_i = facility-specific emissions factor P_{it} = annual nitric acid production at facility$_i$ in year t
Titanium dioxide	World GDP growth from the Organisation for Economic Co-operation and Development (OECD 2018a)	$E_t = \sum([U_{jit} . EC_j . EF_j])$ *Where:* E_t = annual emissions in year t (Mt CO_2-e) $U_{jit,}$ = the use of fuel j at facility$_i$ in year t EC_j = the energy content of fuel $_j$ EF_j = the emissions factor of fuel $_j$
Synthetic rutile		
Acetylene	Australian Government 2018	$E_t = E_{t-1} . \Delta$ Population *Where:* E_t = annual emissions in year t (Mt CO_2-e) $E_{,t-1}$ = emissions in the previous year Δ Population = percentage change in population between year t and year t-1
Petrochemical and carbon black	n/a	$E_t = E_{t-1}$ *Where:* E_t = annual emissions in year t (Mt CO_2-e) E_{t-1} = emissions in the previous year
Metal Industry		
Aluminium production	Production data from OCE 2018, OCE 2018a, and AME Group's industry analysis	$E_t = \sum([EF_i . P_{it}])$ *Where:* E_t = annual emissions in year t (Mt CO_2-e) EF_i = facility-specific emissions factor P_{it} = annual production at facility$_i$ in year t
Iron and steel production		
Ferroalloys production	Company statements	$E_t = \sum([U_{jit} . EC_j . EF_j])$ *Where:* E_t = annual emissions in year t (Mt CO_2-e) $U_{jit,}$ = the use of fuel j as a reductant at facility$_i$ in year t EC_j = the energy content of fuel $_j$ EF_j = the emissions factor of fuel $_j$
Other metal production (copper, nickel and silicon)	Production data from OCE 2018, OCE 2018a, and AME	$E_t = \sum([U_{jit} . EC_j . EF_j])$ *Where:* E_t = annual emissions in year t (Mt CO_2-e)

Emissions subsector	Data source	Formula
	Group's industry analysis	*$U_{jit,}$ = the use of fuel j as a reductant at facility$_i$ in year t* *EC_j = the energy content of fuel j* *EF_j = the emissions factor of fuel $_j$*
Mineral Industry		
Cement Lime	Contextual production forecast from IBISWorld industry report	*$E_t = \sum([EF_i \, . \, P_{it}])$* *Where:* *$E_t$ = annual emissions in year t (Mt CO_2-e)* *EF_i = facility-specific emissions factor* *P_{it} = annual production at facility$_i$ in year t*
Limestone and dolomite and other carbonates	DoEE estimates based on projected ceramics, ferroalloy production, glass production, iron and steel production and zinc production	*$E_t = E_{t-1} * \Delta$ Production* *Where:* *E_t = emissions in year t (Mt CO_2-e)* *E_{t-1} = emissions in the previous year* *Δ Production = percentage change in production between year t and year t-1*
Non-energy products from fuel and solvent use		
Lubricant use	n/a	*$E_t = E_{t-1}$* *Where: E_t = annual emissions in year t,* *E_{t-1} = emissions in the previous year*
Product uses as a substitute for ozone depleting substances	DoEE 2018	Based on *National Inventory Report* methodology
Other product manufacture and use		
Electrical equipment	DoEE 2018	Based on *National Inventory Report* methodology
SF_6 and PFCs from other product uses N_2O from product uses	Australian Government 2018	*$E_t = E_{t-1} \, . \, \Delta$ Population* *Where:* *E_t = annual emissions in year t (Mt CO_2-e)* *$E_{,t-1}$ = emissions in the previous year* *Δ Population = percentage change in population between year t and year t-1*
Other production	DoEE estimates based on projected ammonia production and food, beverages & tobacco production	*$E_t = E_{t-1} * \Delta$ Production* *Where:* *E_t = emissions in year t (Mt CO_2-e)* *E_{t-1} = emissions in the previous year* *Δ Production = percentage change in production between year t and year t-1*

Agriculture

Emissions from the *agriculture sector* are projected using bottom-up modelling developed by the Department. The model is maintained and updated within the Department using external inputs.

Modelling approach

Emissions from agricultural activity is calculated as:

$$E_t = \sum_j \sum_l \sum_k \sum_i (N_{ki} . EF_{kjil}) \times 10^{-3}$$

Where E = Emissions in year t (Mt CO_2-e)

N_{ki} = quantity of activity type in each state, in relevant unit quantity (number of heads, kilotonnes, hectares, etc.)

EF_{kjil} = emissions factors of gas types, by gas source

Emissions factors in: (kt/unit of activity/year)

(Gg/unit of activity/year for rice cultivation)

Table 7. Symbols used in algorithms

Symbol	Variable	Variable categories
K[2]	State	ACT, Northern Territory, Queensland, Tasmania, South Australia, NSW, Victoria, Tasmania
i[3]	Activity type	Grazing beef cattle, grain fed beef cattle, dairy cattle, sheep, wheat, rice, etc.
j[2]	Gas type	Methane, nitrous oxide, carbon dioxide
l[2]	Gas source	Enteric fermentation, manure management, rice cultivation, agricultural soils, field burning of agricultural residues, lime and urea application

[2] Different states, gas types and gas sources are not relevant to all activity types
[3] Activity types may contribute a number of different gas sources

The agriculture projections use emissions factors for activity consistent with the *National Inventory Report*. For formulas on calculating emissions intensity, please see the *National Inventory Report* (DoEE 2018).

Activity data

Emissions are projected by calculating the amount of agricultural activity in Australia each year. This is done by drawing on external data sources that contain activity numbers and activity growth rates as summarised in Table 8.

Where activity data is not available for particular commodities, an appropriate proxy such as production (quantity of end product), or a relevant driver such as growth in another connected commodity (as informed by historical comparisons) is used. For example, nitrogen fertiliser use has increased in line with crop production. The assumption is that greater crop activity requires more nitrogen from fertilisers to support additional plant growth. Historical trends are also used to inform growth where projected activity data is unavailable.

The projections also include a trend towards grain-fed beef cattle, as some farmers seek a more drought resistant feeding system. This trend affects the emissions intensity of beef cattle production. Grain-fed is more emissions intensive than grass-fed, as diets of grain-fed beef cattle are more energy intensive. Animals convert a portion of this additional energy to emissions in the gut.

Units of agricultural activity (e.g. heads of cattle) are multiplied by relevant emissions intensities. Emissions intensity of activities are assumed to be constant across the projections period and equal to that reported in the final year of the *National Inventory Report* (DoEE 2018).

As emissions within agriculture relate to biological processes, as well as manure and residue management, individual commodities can contribute multiple types of emissions under IPCC subsectors.

Table 8. Summary of principle data source for Agriculture

Commodity	Data sources	Unit of activity
Lime and urea	DoEE estimate based on historical trends	Kilotonnes
Fertilisers	DoEE estimate based on historical trends	Kilotonnes
Other animals	Activity held constant at final year of inventory	Heads of animal
Other animals - poultry	ABARES 2018, ABARES 2018a OECD-FAO Agricultural Outlook 2018-2027	Heads of animal
Pigs	ABARES Commodities: March quarter 2018, September quarter 2018 OECD-FAO 2018	Heads of animal
Crops	ABARES 2018, ABARES 2018a CSIRO 2015 (CSIRO Land Use Trade-Offs (LUTO))	Non-rice crops: Kilotonnes of crop Rice: Kilotonnes of rice, Hectares of area under cultivation
Sheep	ABARES 2018, ABARES 2018a	Heads of animal

Commodity	Data sources	Unit of activity
	CSIRO 2015 (CSIRO LUTO)	
Dairy	ABARES 2018, ABARES 2018a CSIRO 2015 (CSIRO LUTO)	Heads of animal
Grain-fed beef	ABARES 2018, ABARES 2018a CSIRO 2015 (CSIRO LUTO)	Heads of animal
Grazing (grass-fed) beef	ABARES 2018, ABARES 2018a CSIRO 2015 (CSIRO LUTO)	Heads of animal

Table 9. Summary of emission subsectors for each agricultural commodity

Commodity	Emissions subsectors
Lime and urea	Liming and urea application
Fertilisers	Agricultural soils
Other animals	Enteric fermentation Manure management Agricultural soils
Other animals - poultry	Manure management Agricultural soils
Pigs	Enteric fermentation Manure management Agricultural soils
Crops	Agricultural soils Field burning of agricultural residues Rice cultivation
Sheep	Enteric fermentation Manure management Agricultural soils
Dairy	Enteric fermentation Manure management Agricultural soils
Grain fed beef	Enteric fermentation Manure management Agricultural soils
Grazing beef	Enteric fermentation Manure management Agricultural soils

Waste

The *waste sector* emissions projections are prepared by the Department, and include three waste subsectors: solid waste, domestic and commercial wastewater, and industrial wastewater.

Modelling approach

The model algorithms used to calculate the waste sector emissions projections are provided in Table 10.

Activity data

Over the period 2018 to 2025, per capita waste generation is assumed to grow at the same average rate of increase observed between 2008 and 2011, which is 1.7 per cent per year. Growth in waste generation is assumed to peak in 2025 as the impact of state and national waste policies, recycling and increased waste conscious products converges with expected population growth. Waste generation is capped at 2025 levels from 2025 to 2030.

The projections of wastewater activity are based on the assumption that the organic content of wastewater, the proportion of wastewater that is treated anaerobically, and the proportion of the population serviced by a sewer will remain at the levels estimated for 2012,[2] over the projections period.

This projection includes state based waste policy frameworks and the National Food Waste Strategy.

Table 10. Summary of sources and formulas for each waste subsector

Emissions subsector	Data sources	Formula
Solid waste	Australian Government 2018 DoEE 2018 DoEE 2018b Hyder Consulting 2014	$E_{SW} = i + c + \left(CH_4^g - CH_4^c\right)$ *Where:* *E_{SW} = solid waste emissions* *i = emissions from solid waste incineration* *c = emissions from composting* *CH_4^g = solid waste methane generated* *CH_4^c = solid waste methane captured*
Domestic and commercial wastewater	Australian Government 2018 DoEE 2018 DoEE 2018b Hyder Consulting 2014	$E_{DC} = (CH_4^t - CH_4^r) + (N_2 0^t + N_2 0^l)$ *Where:* *E_{DC} = domestic and commercial wastewater emissions* *CH_4^t = total domestic and commercial wastewater methane emissions* *CH_4^r = domestic and commercial wastewater methane recovered* *$N_2 0^t$ = total domestic and commercial wastewater nitrous oxide emissions* *$N_2 0^l$ = land application nitrous oxide emissions*

2 The department's estimate of these parameters come from the *Australian National Greenhouse Accounts: National Inventory Report 2012* (DoE 2014), which was used by Hyder Consulting (Hyder Consulting 2014)

Emissions subsector	Data sources	Formula
Industrial wastewater	DoEE 2018 DoEE 2018b	$$E_i = (CH_4^t - CH_4^r)$$ *Where:* *E_i = industrial wastewater emissions* *CH_4^t = total industrial wastewater methane emissions* *CH_4^r = industrial wastewater methane recovered*

Land use, land use change and forestry

Modelling approach

The Full Carbon Accounting Model (FullCAM) provides the modelling framework for estimating land sector emissions in the national greenhouse gas inventory and the emissions projections. FullCAM models the exchange of carbon between the terrestrial biological system and the atmosphere in a full/closed cycle mass balance model which includes all biomass, litter/debris and soil pools. The model uses data on climate, soils and management practices, as well as land use changes observed from satellite imagery to produce estimates of emissions and removals across the Australian landscape. For more information, a detailed description of the model is provided in the *National Inventory Report* (DoEE 2018, Appendix 6.B).

Activity data

Key activity data include:

- The projected rates of primary clearing of forest lands and their conversion to croplands and grasslands are derived by performing a lagged regression using the farmers' terms of trade, as described in the *National Inventory Report* (DoEE 2018, Appendix 6.A.6). Projected rates of clearing of regrowth on previously cleared land - for example, management of bush encroachment on grazing land - are based on historical averages.
- For projections of net emissions from forest lands, log harvest forecasts were adopted from the 'business as usual' scenario published in the *Outlook Scenarios for Australia's Forestry Sector: Key Drivers and Opportunities* (ABARES 2015). The projections utilised the FullCAM modelling framework to estimate emissions, in conjunction with the harvested wood products model as described in section 2.1 of *Australian Land Use, Land Use-Change and Forestry emissions projections to 2035* (DoE 2015). Projected changes in total forest cover, including regrowth on previously cleared land, are based on a gradual return to historical levels.

The projections include abatement from vegetation, soil carbon and savanna burning projects under the Emissions Reduction Fund.

For cropland and grassland emissions projections, management practices are assumed to remain unchanged over the projection period, and emissions assumed to gradually return to long-run average levels.

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