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Department of Climate Change, Energy,
the Environment and Water

National Inventory Report
2022

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

Australian National Greenhouse Accounts

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VOLUME 2

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ANNEX I:
Key category analysis

A *key category* has a significant influence on a country's total inventory of direct greenhouse gases in terms of absolute level of emissions, the trend in emissions, or both. Australia has identified the key sources for the inventory using the tier 1 level and trend assessments as recommended in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006). This approach identifies sources that contribute to 95 per cent of the total emissions or 95 per cent of the trend of the inventory in absolute terms.

When the LULUCF sector is included in the analysis, Australia has identified *public electricity (solid fuel)* and *road transportation (liquid fuels)* as the most significant of the key categories (i.e. contributing more than 10 per cent of the level). The full results for the key source analysis are reported in Tables A.1.1 to A.1.3.

When the LULUCF sector is excluded from the analysis the most significant key categories are also *public electricity (solid fuel)* and *road transportation (liquid fuels).* The results of this latter analysis are presented in Tables A.1.4 to A.1.6.

The Australian analysis has been undertaken using a relatively high degree of disaggregation of sources, as recommended in Table 4.1 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006).

Table A1.1 Key categories for Australia's 2021–22 inventory-level assessment including LULUCF

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate (kt CO_2-e)	Current Year Estimate (kt CO_2-e)	Level Assessment (%)	Cumulative Total (%)
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	117,909	126,484	0.19	0.19
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	52,645	75,944	0.12	0.31
4.A.2	Land converted to Forest Land	CO_2	6,177	50,272	0.08	0.38
3.A.1	Enteric Fermentation \ Cattle	CH_4	38,199	40,516	0.06	0.44
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8,281	26,275	0.04	0.48
4.C.1	Grassland remaining Grassland	CO_2	11,032	23,137	0.04	0.52
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4,577	21,891	0.03	0.55
4.A.1	Forest Land remaining Forest Land	CO_2	6,956	21,835	0.03	0.59
3.A.2	Enteric Fermentation \ Sheep	CH_4	33,743	13,811	0.02	0.61
1.B.1.a.1.i	Mining Activities (underground coal mining)	CH_4	18,597	13,061	0.02	0.63
4.B.1	Cropland remaining Cropland	CO_2	17,641	11,730	0.02	0.64
2.F.1	Refrigeration and air-conditioning	HFC	0	10,540	0.02	0.66
1.B.2.c.1.iii	Venting \ Combined	CO_2	1,967	10,757	0.02	0.68
5.A	Solid Waste Disposal	CH_4	17,065	10,552	0.02	0.69
1.A.2.g.iii	Mining (excluding fuels) and Quarrying \ Liquid Fuels	CO_2	1,759	9,921	0.02	0.71
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	968	9,351	0.01	0.72

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate (kt CO_2-e)	Current Year Estimate (kt CO_2-e)	Level Assessment (%)	Cumulative Total (%)
1.B.1.a.1.ii	Post-mining activities (Underground coal mining)	CH_4	4,636	9,044	0.01	0.74
1.A.4.b	Residential \ Gaseous Fuels	CO_2	4,646	8,450	0.01	0.75
2.C.1	Iron and Steel Production	CO_2	C	C	0.01	0.76
1.A.4.c	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	3,406	7,436	0.01	0.77
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	4,170	6,661	0.01	0.78
1.A.3.a	Domestic Aviation	CO_2	2,615	5,770	0.01	0.79
4.A.1	Forest Land remaining Forest Land	CH_4	6,711	5,769	0.01	0.80
4.C.2	Land converted to Grassland	CO_2	140,984	5,717	0.01	0.81
4.G	Harvested Wood Products	CO_2	7,137	5,611	0.01	0.82
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	4,132	5,508	0.01	0.83
4.C.1	Grassland remaining Grassland	CH_4	4,973	4,969	0.01	0.83
3.B.1	Manure Management \ Cattle	CH_4	3,325	3,953	0.01	0.84
1.B.2.c.2.ii	Flaring \ Gas	CO_2	2,426	3,708	0.01	0.84
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	3,297	3,650	0.01	0.85
1.A.3.c	Railways \ Liquid Fuels	CO_2	1,734	3,609	0.01	0.86
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	2,907	3,122	0.00	0.86
3.D.1.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	1,284	3,087	0.00	0.86
1.A.4.a	Commercial/Institutional \ Liquid Fuels	CO_2	1,246	2,971	0.00	0.87
2.A.1	Cement Industry	CO_2	3,463	2,818	0.00	0.87
5.D	Wastewater treatment and discharge	CH_4	6,154	2,797	0.00	0.88
3.D.1.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N_2O	3,804	2,600	0.00	0.88
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	1,452	2,562	0.00	0.89
1.A.4.a	Commercial/Institutional \ Gaseous Fuels	CO_2	1,824	2,523	0.00	0.89
1.A.2.f	Non-metallic minerals \ Gaseous Fuels	CO_2	2,972	2,421	0.00	0.89
3.D.1.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N_2O	1,232	2,418	0.00	0.90
2.B.1	Ammonia Production	CO_2	544	2,322	0.00	0.90
3.D.2.2	Agricultural Soils \ Indirect Soil Emissions \ Nitrogen Leaching and Run-Off	N_2O	2,033	2,306	0.00	0.90
2.C.3	Aluminium Production	CO_2	2,058	2,274	0.00	0.91
4.D.1	Wetland remaining Wetland	CH_4	1,233	2,205	0.00	0.91
1.A.3.d	Domestic navigation \ Liquid Fuels	CO_2	2,208	2,118	0.00	0.91
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	4,931	2,076	0.00	0.92
1.A.2.g.v	Construction \ Liquid Fuels	CO_2	2,838	1,887	0.00	0.92
3.H	Urea Application	CO_2	367	1,884	0.00	0.92

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate (kt CO_2-e)	Current Year Estimate (kt CO_2-e)	Level Assessment (%)	Cumulative Total (%)
2.A.3	Other process uses of carbonates	CO_2	1,251	1,860	0.00	0.93
4.E.2	Land converted to Settlements	CO_2	7,363	1,830	0.00	0.93
1.A.2.f	Non-metallic minerals \ Solid Fuels	CO_2	2,212	1,736	0.00	0.93
3.B.3	Manure Management \ Swine	CH_4	1,729	1,728	0.00	0.93
1.A.2.e	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	1,255	1,715	0.00	0.94
1.B.2.b.3	Processing (Natural Gas)	CH_4	252	1,690	0.00	0.94
2.B.2	Nitric Acid Production	N_2O	885	1,484	0.00	0.94
1.B.2.c.1.iii	Venting \ Combined	CH_4	2,368	1,435	0.00	0.94
4.C.1	Grassland remaining Grassland	N_2O	1,637	1,427	0.00	0.95
3.G	Liming	CO_2	215	1,318	0.00	0.95
4.A.1	Forest Land remaining Forest Land	N_2O	1,205	1,187	0.00	0.95

Table A1.2 Key categories for Australia’s 2021–22 inventory-trend assessment including LULUCF (kt CO_2-e)

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate (kt CO_2-e)	Current Year Estimate (kt CO_2-e)	Trend Assessment (%)	Contribution to Trend (%)	Cumulative Total (%)
4.C.2	Land converted to Grassland	CO_2	140,984	5,717	0.14	0.19	0.19
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	117,909	126,484	0.06	0.09	0.28
4.A.2	Land converted to Forest Land	CO_2	6,177	50,272	0.06	0.09	0.37
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	52,645	75,944	0.06	0.08	0.45
4.B.1	Cropland remaining Cropland	CO_2	17,641	11,730	0.04	0.05	0.50
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8,281	26,275	0.03	0.04	0.54
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4,577	21,891	0.03	0.04	0.58
3.A.1	Enteric Fermentation \ Cattle	CH_4	38,199	40,516	0.02	0.03	0.61
4.A.1	Forest Land remaining Forest Land	CO_2	6,956	21,835	0.02	0.03	0.64
4.B.2	Land converted to Cropland	CO_2	16,907	17	0.02	0.02	0.66
2.F.1	Refrigeration and air-conditioning	HFC	0	10,540	0.02	0.02	0.68
3.A.2	Enteric Fermentation \ Sheep	CH_4	33,743	13,811	0.01	0.02	0.70
1.B.2.c.1.iii	Venting \ Combined	CO_2	1,967	10,757	0.01	0.02	0.72

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate (kt CO_2-e)	Current Year Estimate (kt CO_2-e)	Trend Assessment (%)	Contribution to Trend (%)	Cumulative Total (%)
4.C.1	Grassland remaining Grassland	CO_2	11,032	23,137	0.01	0.02	0.74
1.A.2.f	Mining (excluding fuels) and Quarrying \ Liquid Fuels	CO_2	1,759	9,921	0.01	0.02	0.76
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	968	9,351	0.01	0.02	0.78
1.B.1.a.1.ii	Post-mining activities (Underground coal mining)	CH_4	4,636	9,044	0.01	0.01	0.79
1.A.4.b	Residential \ Gaseous Fuels	CO_2	4,646	8,450	0.01	0.01	0.80
1.A.4.c	Agriculture/Forestry/ Fisheries \ Liquid Fuels	CO_2	3,406	7,436	0.01	0.01	0.81
1.A.3.a	Domestic Aviation	CO_2	2,615	5,770	0.01	0.01	0.82
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	4,170	6,661	0.01	0.01	0.83
4.G	Harvested Wood Products	CO_2	7,137	5,611	0.01	0.01	0.83
4.E.2	Land converted to Settlements	CO_2	7,363	1,830	0.00	0.01	0.84
4.C.2	Land converted to Grassland	CH_4	5,740	735	0.00	0.01	0.85
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	4,132	5,508	0.00	0.01	0.85
1.A.3.c	Railways \ Liquid Fuels	CO_2	1,734	3,609	0.00	0.00	0.86
1.B.2.b.4	Transmission and Storage (Natural gas)	CH_4	4,834	1,167	0.00	0.00	0.86
2.C.3	Aluminium Production	CH_4	3,404	192	0.00	0.00	0.87
3.D.1.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	CO_2	1,284	3,087	0.00	0.00	0.87
1.A.4.a	Commercial/ Institutional \ Liquid Fuels	CO_2	1,246	2,971	0.00	0.00	0.88
1.B.2.c.2.ii	Flaring \ Gas	CO_2	2,426	3,708	0.00	0.00	0.88
2.B.1	Ammonia Production	CO_2	544	2,322	0.00	0.00	0.88
3.H	Urea Application	CO_2	367	1,884	0.00	0.00	0.89
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	2,849	386	0.00	0.00	0.89
3.B.1	Manure Management \ Cattle	CH_4	3,325	3,953	0.00	0.00	0.89
3.D.1.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N_2O	1,232	2,418	0.00	0.00	0.90

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate (kt CO_2-e)	Current Year Estimate (kt CO_2-e)	Trend Assessment (%)	Contribution to Trend (%)	Cumulative Total (%)
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	1,452	2,562	0.00	0.00	0.90
5.D	Wastewater treatment and discharge	CH_4	6,154	2,797	0.00	0.00	0.90
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	2,397	160	0.00	0.00	0.91
1.B.2.b.3	Processing (Natural Gas)	CH_4	252	1,690	0.00	0.00	0.91
4.C.1	Grassland remaining Grassland	CH_4	4,973	4,969	0.00	0.00	0.91
5.A	Solid Waste Disposal	CH_4	17,065	10,552	0.00	0.00	0.92
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	4,931	2,076	0.00	0.00	0.92
2.C.1	Iron and Steel Production	CO_2	C	C	0.00	0.00	0.92
4.D.1	Wetland remaining Wetland	CH_4	1,233	2,205	0.00	0.00	0.92
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	3,297	3,650	0.00	0.00	0.93
1.A.4.a	Commercial/ Institutional \ Gaseous Fuels	CO_2	1,824	2,523	0.00	0.00	0.93
3.G	Liming	CO_2	215	1,318	0.00	0.00	0.93
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	2,907	3,122	0.00	0.00	0.93
4.A.1	Forest Land remaining Forest Land	CH_4	6,711	5,769	0.00	0.00	0.94
4.D.1	Wetland remaining Wetland	CO_2	641	588	0.00	0.00	0.94
2.A.3	Other process uses of carbonates	CO_2	1,251	1,860	0.00	0.00	0.94
1.A.4.b	Residential \ Biomass	CH_4	2,691	951	0.00	0.00	0.94
1.B.2.b.2	Production (Natural gas)	CH_4	126	976	0.00	0.00	0.94
3.D.2.2	Agricultural Soils \ Indirect Soil Emissions \ Nitrogen Leaching and Run-Off	N_2O	2,033	2,306	0.00	0.00	0.95
2.B.2	Nitric Acid Production	N_2O	885	1,484	0.00	0.00	0.95
2.B.9	Chemical Industry \ Fluorochemical production	HFC-23	1,194	0	0.00	0.00	0.95

Table A1.3 Key categories for Australia's 2021–22 inventory-summary including LULUCF

IPCC Source Categories		Direct Greenhouse Gas	Key Source Category Flag	Criteria for Identification
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	Yes	Level, Trend
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	Yes	Level, Trend
4.A.2	Land converted to Forest Land	CO_2	Yes	Level, Trend
3.A.1	Enteric Fermentation \ Cattle	CH_4	Yes	Level, Trend
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	Yes	Level, Trend
4.C.1	Grassland remaining Grassland	CO_2	Yes	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	Yes	Level, Trend
4.A.1	Forest Land remaining Forest Land	CO_2	Yes	Level, Trend
3.A.2	Enteric Fermentation \ Sheep	CH_4	Yes	Level, Trend
1.B.1.a.1.i	Mining Activities (underground coal mining)	CH_4	Yes	Level
4.B.1	Cropland remaining Cropland	CO_2	Yes	Level, Trend
2.F.1	Refrigeration and air-conditioning	HFC	Yes	Level, Trend
1.B.2.c.1.iii	Venting \ Combined	CO_2	Yes	Level, Trend
5.A	Solid Waste Disposal	CH_4	Yes	Level, Trend
1.A.2.g.iii	Mining (excluding fuels) and Quarrying \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	Yes	Level, Trend
1.B.1.a.1.ii	Post-mining activities (Underground coal mining)	CH_4	Yes	Trend
1.A.4.b	Residential \ Gaseous Fuels	CO_2	Yes	Level, Trend
2.C.1	Iron and Steel Production	CO_2	Yes	Level, Trend
1.A.4.c	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	Yes	Level, Trend
1.A.3.a	Domestic Aviation	CO_2	Yes	Level, Trend
4.A.1	Forest Land remaining Forest Land	CH_4	Yes	Level, Trend
4.C.2	Land converted to Grassland	CO_2	Yes	Level, Trend
4.G	Harvested Wood Products	CO_2	Yes	Level, Trend
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	Yes	Level, Trend
4.C.1	Grassland remaining Grassland	CH_4	Yes	Level, Trend
3.B.1	Manure Management \ Cattle	CH_4	Yes	Level, Trend
1.B.2.c.2.ii	Flaring \ Gas	CO_2	Yes	Level, Trend
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.3.c	Railways \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	Yes	Level, Trend
3.D.1.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	Yes	Level, Trend
1.A.4.a	Commercial/Institutional \ Liquid Fuels	CO_2	Yes	Level, Trend
2.A.1	Cement Industry	CO_2	Yes	Level
5.D	Wastewater treatment and discharge	CH_4	Yes	Level, Trend

IPCC Source Categories		Direct Greenhouse Gas	Key Source Category Flag	Criteria for Identification
3.D.1.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N_2O	Yes	Level
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	Yes	Level, Trend
1.A.4.a	Commercial/Institutional \ Gaseous Fuels	CO_2	Yes	Level, Trend
1.A.2.f	Non-metallic minerals \ Gaseous Fuels	CO_2	Yes	Level
3.D.1.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N_2O	Yes	Level, Trend
2.B.1	Ammonia Production	CO_2	Yes	Level, Trend
3.D.2.2	Agricultural Soils \ Indirect Soil Emissions \ Nitrogen Leaching and Run-Off	N_2O	Yes	Level, Trend
2.C.3	Aluminium Production	CO_2	Yes	Level
4.D.1	Wetland remaining Wetland	CH_4	Yes	Level, Trend
1.A.3.d	Domestic navigation \ Liquid Fuels	CO_2	Yes	Level
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.2.g.v	Construction \ Liquid Fuels	CO_2	Yes	Level
3.H	Urea Application	CO_2	Yes	Level, Trend
2.A.3	Other process uses of carbonates	CO_2	Yes	Level, Trend
4.E.2	Land converted to Settlements	CO_2	Yes	Level, Trend
1.A.2.f	Non-metallic minerals \ Solid Fuels	CO_2	Yes	Level
3.B.3	Manure Management \ Swine	CH_4	Yes	Level
1.A.2.e	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	Yes	Level
1.B.2.b.3	Processing (Natural Gas)	CH_4	Yes	Level, Trend
2.B.2	Nitric Acid Production	N_2O	Yes	Level, Trend
1.B.2.c.1.iii	Venting \ Combined	CH_4	Yes	Level
4.C.1	Grassland remaining Grassland	N_2O	Yes	Level
3.G	Liming	CO_2	Yes	Level, Trend
4.A.1	Forest Land remaining Forest Land	N_2O	Yes	Level
4.B.2	Land converted to Cropland	CO_2	Yes	Trend
1.A.2.f	Mining (excluding fuels) and Quarrying \ Liquid Fuels	CO_2	Yes	Level, Trend
4.C.2	Land converted to Grassland	CH_4	Yes	Trend
1.B.2.b.4	Transmission and Storage (Natural gas)	CH_4	Yes	Trend
2.C.3	Aluminium Production	CH_4	Yes	Trend
3.D.1.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	Yes	Level, Trend
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	Yes	Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	Yes	Trend
4.D.1	Wetland remaining Wetland	CO_2	Yes	Trend
1.A.4.b	Residential \ Biomass	CH_4	Yes	Trend
1.B.2.b.2	Production (Natural gas)	CH_4	Yes	Trend
2.B.9	Chemical Industry \ Fluorochemical production	HFC-23	Yes	Trend

Table A1.4 Key categories for Australia's 2021–22 inventory-level assessment excluding LULUCF

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate (kt CO_2-e)	Current Year Estimate (kt CO_2-e)	Level Assessment (%)	Cumulative Total (%)
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	117,909	126,484	0.24	0.24
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	52,645	75,944	0.15	0.39
3.A.1	Enteric Fermentation \ Cattle	CH_4	38,199	40,516	0.08	0.47
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8,281	26,275	0.05	0.52
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4,577	21,891	0.04	0.56
3.A.2	Enteric Fermentation \ Sheep	CH_4	33,743	13,811	0.03	0.58
1.B.1.a.1.i	Mining Activities (underground coal mining)	CH_4	18,597	13,061	0.03	0.61
2.F.1	Refrigeration and air-conditioning	HFC	0	10,540	0.02	0.63
1.B.2.c.1.iii	Venting \ Combined	CO_2	1,967	10,757	0.02	0.65
5.A	Solid Waste Disposal	CH_4	17,065	10,552	0.02	0.67
1.A.2.g.iii	Mining (excluding fuels) and Quarrying \ Liquid Fuels	CO_2	1,759	9,921	0.02	0.69
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	968	9,351	0.02	0.71
1.B.1.a.2.i	Mining Activities (surface coal mining)	CH_4	4,636	9,044	0.02	0.73
1.A.4.b	Residential \ Gaseous Fuels	CO_2	4,646	8,450	0.02	0.74
2.C.1	Iron and Steel Production	CO_2	C	C	0.02	0.76
1.A.4.c	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	3,406	7,436	0.01	0.77
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	4,170	6,661	0.01	0.78
1.A.3.a	Domestic Aviation	CO_2	2,615	5,770	0.01	0.80
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	4,132	5,508	0.01	0.81
3.B.1	Manure Management \ Cattle	CH_4	3,325	3,953	0.01	0.81
1.B.2.c.2.ii	Flaring \ Gas	CO_2	2,426	3,708	0.01	0.82
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	3,297	3,650	0.01	0.83
1.A.3.c	Railways \ Liquid Fuels	CO_2	1,734	3,609	0.01	0.83
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	2,907	3,122	0.01	0.84
3.D.1.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	1,284	3,087	0.01	0.85
1.A.4.a	Commercial/Institutional \ Liquid Fuels	CO_2	1,246	2,971	0.01	0.85
2.A.1	Cement Industry	CO_2	3,463	2,818	0.01	0.86
5.D	Wastewater treatment and discharge	CH_4	6,154	2,797	0.01	0.86

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate (kt CO_2-e)	Current Year Estimate (kt CO_2-e)	Level Assessment (%)	Cumulative Total (%)
3.D.1.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N_2O	3,804	2,600	0.00	0.87
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	1,452	2,562	0.00	0.87
1.A.4.a	Commercial/Institutional \ Gaseous Fuels	CO_2	1,824	2,523	0.00	0.88
1.A.2.f	Non-metallic minerals \ Gaseous Fuels	CO_2	2,972	2,421	0.00	0.88
3.D.1.4	Agricultural Soils \ Direct Soil Emissions \ Crop Residue	N_2O	1,232	2,418	0.00	0.89
2.B.1	Ammonia Production	CO_2	544	2,322	0.00	0.89
3.D.2.2	Agricultural Soils \ Indirect Soil Emissions \ Nitrogen Leaching and Run-Off	N_2O	2,033	2,306	0.00	0.90
2.C.3	Aluminium Production	CO_2	2,058	2,274	0.00	0.90
1.A.3.d	Domestic navigation \ Liquid Fuels	CO_2	2,208	2,118	0.00	0.90
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	4,931	2,076	0.00	0.91
1.A.2.g.v	Construction \ Liquid Fuels	CO_2	2,838	1,887	0.00	0.91
3.H	Urea Application	CO_2	367	1,884	0.00	0.92
2.A.3	Other process uses of carbonates	CO_2	1,251	1,860	0.00	0.92
1.A.2.f	Non-metallic minerals \ Solid Fuels	CO_2	2,212	1,736	0.00	0.92
3.B.3	Manure Management \ Swine	CH_4	1,729	1,728	0.00	0.93
1.A.2.e	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	1,255	1,715	0.00	0.93
1.B.2.b.3	Processing (Natural Gas)	CH_4	252	1,690	0.00	0.93
2.B.2	Nitric Acid Production	N_2O	885	1,484	0.00	0.94
1.B.2.c.1.iii	Venting \ Combined	CH_4	2,368	1,435	0.00	0.94
3.G	Liming	CO_2	215	1,318	0.00	0.94
1.B.2.b.4	Transmission and Storage (Natural gas)	CH_4	4,834	1,167	0.00	0.94
1.A.4.b	Residential \ Liquid Fuels	CO_2	1,326	1,140	0.00	0.94
1.B.1.a.1.ii	Post-mining activities (Underground coal mining)	CO_2	1,122	1,016	0.00	0.95
1.B.2.b.2	Production (Natural gas)	CH_4	126	976	0.00	0.95

Table A1.5 Key categories for Australia's 2021–22 inventory-trend assessment excluding LULUCF

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate	Current Year Estimate	Trend Assessment (%)	Contribution to Trend (%)	Cumulative Total (%)
3.A.2	Enteric Fermentation \ Sheep	CH_4	33,743	13,811	0.06	0.11	0.11
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4,577	21,891	0.04	0.07	0.18
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8,281	26,275	0.04	0.07	0.25
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	117,909	126,484	0.03	0.06	0.31
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	52,645	75,944	0.03	0.06	0.37
2.F.1	Refrigeration and air-conditioning	HFC	0	10,540	0.03	0.05	0.41
5.A	Solid Waste Disposal	CH_4	17,065	10,552	0.02	0.04	0.45
1.B.1.a.1.i	Mining Activities (underground coal mining)	CH_4	18,597	13,061	0.02	0.04	0.49
1.B.2.c.1.iii	Venting \ Combined	CO_2	1,967	10,757	0.02	0.04	0.53
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	968	9,351	0.02	0.03	0.56
1.A.2.f	Mining (excluding fuels) and Quarrying \ Liquid Fuels	CO_2	1,759	9,921	0.02	0.03	0.60
3.A.1	Enteric Fermentation \ Cattle	CH_4	38,199	40,516	0.01	0.02	0.62
1.B.2.b.4	Transmission and Storage (Natural Gas)	CH_4	4,834	1,167	0.01	0.02	0.64
5.D	Wastewater treatment and discharge	CH_4	6,154	2,797	0.01	0.02	0.66
2.C.3	Aluminium Production	CF4	3,404	192	0.01	0.02	0.67
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	4,931	2,076	0.01	0.02	0.69
1.B.1.a.1.ii	Post-mining activities (Underground coal mining)	CH_4	4,636	9,044	0.01	0.01	0.70
1.A.4.c	Agriculture/Forestry/ Fisheries \ Liquid Fuels	CO_2	3,406	7,436	0.01	0.01	0.72
2.C.1	Iron and Steel Production	CO_2	C	C	0.01	0.01	0.73
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	2,849	386	0.01	0.01	0.74

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate	Current Year Estimate	Trend Assessment (%)	Contribution to Trend (%)	Cumulative Total (%)
1.A.4.b	Residential \ Gaseous Fuels	CO_2	4,646	8,450	0.01	0.01	0.76
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	2,397	160	0.01	0.01	0.77
1.A.3.a	Domestic Aviation	CO_2	2,615	5,770	0.01	0.01	0.78
1.A.4.b	Residential \ Biomass	CH_4	2,691	951	0.01	0.01	0.79
3.D.1.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N_2O	3,804	2,600	0.00	0.01	0.80
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	4,170	6,661	0.00	0.01	0.80
2.B.1	Ammonia Production	CO_2	544	2,322	0.00	0.01	0.81
3.D.1.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	1,284	3,087	0.00	0.01	0.82
1.A.3.c	Railways \ Liquid Fuels	CO_2	1,734	3,609	0.00	0.01	0.82
1.A.2.g.v	Construction \ Liquid Fuels	CO_2	2,838	1,887	0.00	0.01	0.83
1.A.4.a	Commercial/ Institutional \ Liquid Fuels	CO_2	1,246	2,971	0.00	0.01	0.84
3.H	Urea Application	CO_2	367	1,884	0.00	0.01	0.84
2.B.9	Chemical Industry \ Fluorochemical production	HFC-23	1,194	0	0.00	0.01	0.85
1.B.2.b.iii	Natural Gas Processing	CH_4	2,368	1,435	0.00	0.01	0.85
1.B.2.c.1.iii	Venting \ Combined	CH_4	252	1,690	0.00	0.01	0.86
3.B.2	Manure Management \ Sheep	CH_4	1,740	701	0.00	0.01	0.87
2.A.1	Cement Industry	CO_2	3,463	2,818	0.00	0.01	0.87
1.A.2.f	Non-metallic minerals \ Gaseous Fuels	CO_2	2,972	2,421	0.00	0.00	0.88
3.G	Liming	CO_2	215	1,318	0.00	0.00	0.88
3.D.1.5	Mineralisation due to loss of soil carbon	N_2O	824	25	0.00	0.00	0.88
3.D.1.4	Agricultural Soil \ Direct Soil Emissions \ Crop Residue	N_2O	1,232	2,418	0.00	0.00	0.89
1.A.2.e	Food Processing, Beverages and Tobacco \ Solid Fuels	CO_2	1,214	533	0.00	0.00	0.89
1.A.2.f	Non-metallic minerals \ Solid Fuels	CO_2	2,212	1,736	0.00	0.00	0.90

IPCC Source Abbreviation	IPCC Source Category	Direct Greenhouse Gas	Base Year Estimate	Current Year Estimate	Trend Assessment (%)	Contribution to Trend (%)	Cumulative Total (%)
1.B.2.c.2.i	Flaring \ Oil	CO_2	1,217	558	0.00	0.00	0.90
1.A.2.a	Iron and Steel \ Gaseous Fuels	CO_2	1,393	792	0.00	0.00	0.90
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	1,452	2,562	0.00	0.00	0.91
2.C.3	Aluminium Production	C2F6	740	55	0.00	0.00	0.91
1.B.2.b.ii	Production (Natural gas)	CH_4	126	976	0.00	0.00	0.91
1.B.1.c	Other	CO_2	0	818	0.00	0.00	0.92
1.B.2.c.2.ii	Flaring \ Gas	CO_2	2,426	3,708	0.00	0.00	0.92
1.A.2.a	Iron and Steel \ Solid Fuels	CO_2	1,206	670	0.00	0.00	0.92
1.A.4.a	Commercial/ Institutional \ Solid Fuels	CO_2	523	9	0.00	0.00	0.93
1.A.3.e	Other Transportation \ Pipeline transport \ Gaseous Fuels	CO_2	262	905	0.00	0.00	0.93
1.A.3.b	Road Transportation \ Liquid Fuels	CH_4	628	168	0.00	0.00	0.93
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	4,132	5,508	0.00	0.00	0.93
1.A.3.d	Domestic navigation \ Liquid Fuels	CO_2	2,208	2,118	0.00	0.00	0.94
1.A.2.g.i	Other \ Manufacturing of Machinery	CO_2	422	28	0.00	0.00	0.94
1.A.4.b	Residential \ Liquid Fuels	CO_2	1,326	1,140	0.00	0.00	0.94
1.B.2.a.4	Refining / Storage (Oil)	CO_2	392	35	0.00	0.00	0.94
2.F.4	Aerosols	HFC	0	410	0.00	0.00	0.94
2.B.2	Nitric Acid Production	N_2O	885	1,484	0.00	0.00	0.95
2.B.6	Titanium Dioxide Production	CO_2	415	913	0.00	0.00	0.95
1.A.2.d	Pulp, Paper and Print \ Gaseous Fuels	CO_2	823	594	0.00	0.00	0.95

Table A1.6 Key categories for Australia's 2021–22 inventory-summary excluding LULUCF

IPCC Source Categories		Gas	Key Source Category Flag	Criteria for Identification
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	Yes	Level, Trend
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	Yes	Level, Trend
3.A.1	Enteric Fermentation \ Cattle	CH_4	Yes	Level, Trend
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	Yes	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	Yes	Level, Trend
3.A.2	Enteric Fermentation \ Sheep	CH_4	Yes	Level, Trend
1.B.1.a.1.i	Mining Activities (underground coal mining)	CH_4	Yes	Level
2.F.1	Refrigeration and air-conditioning	HFC	Yes	Level, Trend
1.B.2.c.1.iii	Venting \ Combined	CO_2	Yes	Level, Trend
5.A	Solid Waste Disposal	CH_4	Yes	Level, Trend
1.A.2.g.iii	Mining (excluding fuels) and Quarrying \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.4.b	Residential \ Gaseous Fuels	CO_2	Yes	Level, Trend
2.C.1	Iron and Steel Production	CO_2	Yes	Level, Trend
1.A.4.c	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	Yes	Level, Trend
1.A.3.a	Domestic Aviation	CO_2	Yes	Level, Trend
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	Yes	Level, Trend
3.B.1	Manure Management \ Cattle	CH_4	Yes	Level
1.B.2.c.2.ii	Flaring \ Gas	CO_2	Yes	Level, Trend
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	Yes	Level
1.A.3.c	Railways \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	Yes	Level
3.D.1.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	Yes	Level, Trend
1.A.4.a	Commercial/Institutional \ Liquid Fuels	CO_2	Yes	Level, Trend
2.A.1	Cement Industry	CO_2	Yes	Level, Trend
5.D	Wastewater treatment and discharge	CH_4	Yes	Level, Trend
3.D.1.3	Agricultural Soils \ Direct Soil Emissions \ Urine and Dung Deposited by Grazing Animals	N_2O	Yes	Level, Trend
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	Yes	Level, Trend
1.A.4.a	Commercial/Institutional \ Gaseous Fuels	CO_2	Yes	Level
1.A.2.f	Non-metallic minerals \ Gaseous Fuels	CO_2	Yes	Level, Trend

IPCC Source Categories		Gas	Key Source Category Flag	Criteria for Identification
3.D.1.4	Agricultural Soils \ Direct Soil Emissions \ Crop Residue	N_2O	Yes	Level
2.B.1	Ammonia Production	CO_2	Yes	Level, Trend
3.D.2.2	Agricultural Soils \ Indirect Soil Emissions \ Nitrogen Leaching and Run-Off	N_2O	Yes	Level
2.C.3	Aluminium Production	CO_2	Yes	Level
2.C.3	Aluminium Production	CF4	Yes	Trend
2.C.3	Aluminium Production	C2F6	Yes	Trend
1.A.3.d	Domestic navigation \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	Yes	Level, Trend
1.A.2.g.v	Construction \ Liquid Fuels	CO_2	Yes	Level, Trend
3.H	Urea Application	CO_2	Yes	Level, Trend
2.A.3	Other process uses of carbonates	CO_2	Yes	Level
1.A.2.f	Non-metallic minerals \ Solid Fuels	CO_2	Yes	Level, Trend
3.B.3	Manure Management \ Swine	CH_4	Yes	Level
1.A.2.e	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	Yes	Level
1.B.2.b.3	Processing (Natural Gas)	CH_4	Yes	Level
2.B.2	Nitric Acid Production	N_2O	Yes	Level, Trend
3.G	Liming	CO_2	Yes	Level, Trend
1.B.2.b.4	Transmission and Storage (Natural gas)	CH_4	Yes	Level, Trend
1.A.4.b	Residential \ Liquid Fuels	CO_2	Yes	Level, Trend
1.B.1.a.1.ii	Post-mining activities (Underground coal mining)	CO_2	Yes	Level, Trend
1.B.2.c.1.iii	Venting \ Combined	CH_4	Yes	Level, Trend
1.B.2.b.2	Production (Natural gas)	CH_4	Yes	Level, Trend
1.A.2.f	Mining (excluding fuels) and Quarrying \ Liquid Fuels	CO_2	Yes	Level, Trend
1.B.1.a.1.ii	Mining Activities (surface coal mining)	CH_4	Yes	Level, Trend
1.A.3.b	Road Transportation \ Liquid Fuels	CH_4	Yes	Trend
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	Yes	Trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	Yes	Trend
1.A.4.b	Residential \ Biomass	CH_4	Yes	Trend
3.D.1.1	Agricultural Soils \ Direct Soil Emissions \ Inorganic Fertilisers	N_2O	Yes	Level, Trend
2.B.9	Chemical Industry \ Fluorochemical production	HFC-23	Yes	Trend
1.B.2.b.iii	Natural Gas Processing	CH_4	Yes	Trend
3.B.2	Manure Management \ Sheep	CH_4	Yes	Trend
3.D.1.5	Mineralisation due to loss of soil carbon	N_2O	Yes	Trend

IPCC Source Categories		Gas	Key Source Category Flag	Criteria for Identification
1.A.2.e	Food Processing, Beverages and Tobacco \ Solid Fuels	CO_2	Yes	Trend
1.B.2.c.2.i	Flaring \ Oil	CO_2	Yes	Trend
1.A.2.a	Iron and Steel \ Gaseous Fuels	CO_2	Yes	Trend
1.B.2.b.ii	Production (Natural gas)	CH_4	Yes	Level, Trend
1.B.1.c	Other	CO_2	Yes	Trend
1.A.2.a	Iron and Steel \ Solid Fuels	CO_2	Yes	Trend
1.A.4.a	Commercial/Institutional \ Solid Fuels	CO_2	Yes	Trend
1.A.3.e	Other Transportation \ Pipeline transport \ Gaseous Fuels	CO_2	Yes	Trend
1.A.2.g.i	Other \ Manufacturing of Machinery	CO_2	Yes	Trend
1.B.2.a.4	Refining / Storage (Oil)	CO_2	Yes	Trend
2.F.4	Aerosols	HFC	Yes	Trend
2.B.6	Titanium Dioxide Production	CO_2	Yes	Trend
1.A.2.d	Pulp, Paper and Print \ Gaseous Fuels	CO_2	Yes	Trend

ANNEX II:
Uncertainty analysis

Uncertainty is inherent within any kind of estimation. While it is in some cases possible to continuously monitor emissions, it is not usually practical or economical to do so. This leads to estimations based on samples or studies being used which carry a degree of additional uncertainty attached to them. Uncertainty also arises from the limitations of the measuring instruments, and over the complexities of the modelling of key relationships between observed variables and emissions.

The purpose of estimating the uncertainty attached to emissions estimates is principally to provide information on where inventory resources should be allocated to maximise the future improvements to inventory quality.

Assessing uncertainty is a difficult exercise, especially in the absence of quantitative data. Australia has conducted an uncertainty analysis for the individual sectors in line with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006 Guidelines) (IPCC 2006). Monte Carlo and Latin Hypercube approaches were used to estimate emission uncertainty in some sectors, which is equivalent to the IPCC Tier 2 methodology. Companies with large single sources of emissions must annually report through the NGER scheme on the level of uncertainty associated with these emissions. Statistical uncertainty must be estimated and reported by NGER scheme reporters with emissions of more than 25 Gg CO_2-e from the combustion of a fuel type, or an IPPU, fugitive or waste source other than fuel combustion. NGER scheme reporters must follow the methods for assessing uncertainty published in the Determination and report a combined estimate for activity data and emission factor uncertainty. Uncertainty estimates associated with single sources of emissions first became available under the NGER scheme in 2013–14.

NGER scheme uncertainty estimates have been incorporated into the national uncertainty assessment in sectors where there are a limited number of large facilities such as electricity generation, cement production, aluminium production, petroleum refining and coal mining. Estimates for other sectors have been prepared using the judgement of the sectoral expert consultants. These estimates of uncertainty were reviewed in 2005 by independent experts under protocols developed by the Australian CSIRO Atmospheric Research Division. The CSIRO report confirmed that the quantitative judgements made in relation to the uncertainties of inventory estimates had broadly met the standards of the review, with only one or two exceptions. The report also agreed the estimates provided a strong basis for confidence in the assessments reported in this chapter.

The uncertainties for individual sectors are reported in more detail below. The estimated uncertainties tend to be low for carbon dioxide from energy consumption as well as from some industrial process emissions. Uncertainty surrounding estimates from these sources are typically as low as ± 1–5 per cent. Uncertainty surrounding estimates of emissions are higher for agriculture, land use change and forestry, reflecting inherently high uncertainty due to the very nature of the processes involved (e.g. biological processes). A medium band of uncertainty applies to estimates from fugitive emissions, most industrial processes and non-CO_2 gases in the energy sector. The ranges presented are broadly consistent with the typical uncertainty ranges expected for each sector, as identified in the IPCC 2006 Guidelines (IPCC 2006).

In this inventory submission, Australia has included the base year uncertainty assessment as well as the latest inventory year. The base year for uncertainty assessment is 1989–90.

Sections A2.1 to A2.5 present uncertainty method descriptions, results, and summary tables by sector.

Table A2. 1 presents national emissions uncertainties for 1989–90 and 2021–22. At an aggregate level, using IPCC good practice Tier 1 uncertainty methods, the overall uncertainty surrounding the Australian inventory estimate for 2021–22 is estimated at ± 5.4. The reported uncertainty for the trend in total emissions is estimated to be ± 5.1 per cent. When the LULUCF sector is excluded from the analysis, national inventory uncertainty is estimated at ± 3.5 per cent for 2021–22 emissions and ± 3.3 per cent for trend in emissions.

Table A2.1 Summarised reporting for uncertainty in 1989–90 and 2021–22

	1989–90		2021–22	
	Including LULUCF	Excluding LULUCF	Including LULUCF	Excluding LULUCF
Total Emissions (Gg CO_2-e AR5)	615,387	437,120	432,620	520,994
Uncertainty (%)	±7.4	±5.1	±5.4	±3.5
Trend Uncertainty (%)	±4.3	±2.7	±5.1	±3.3

Detailed uncertainty tables are available in an Excel file format, including Tables A2.2, A2.3, A2.4, and A2.5, via this hyperlink: National Inventory Report 2022: uncertainty tables. Table A2.2 shows the estimated uncertainties surrounding the aggregate inventory estimate for the base year and associated trend estimates inclusive of LULUCF, and Table A2.3 shows this excluding LULUCF. Table A2.4 shows the estimated uncertainties surrounding the aggregate inventory estimate for the current inventory year and associated trend estimates inclusive of LULUCF, and Table A2.5 shows this excluding LULUCF. These estimates have been calculated on the assumption that the total uncertainty for parts of agriculture, land use, land use change and forestry, and the waste sectors are uncorrelated through time.

The estimates of uncertainty surrounding the emissions estimates for individual sectors may be combined to present an estimate of the overall uncertainty for the inventory as a whole. The results of the application of the IPCC Tier 1 approach to estimating the uncertainty of the inventory as a whole, which identifies separately estimates of uncertainty for both activity and emission factors where available, and which does not account for correlations between variables (unlike some of the sectoral analyses), are presented in Tables A.2.1 to A.2.4.

As indicated in the IPCC 2006 Guidelines (IPCC 2006), the Tier 1 approach is valid as long as a number of restrictive assumptions are met. An alternative, more flexible approach, which relies on Monte Carlo analysis and a more detailed specification of the sources of uncertainty, is currently under consideration for development by the Department for use in future national inventory reports. This analysis would be equivalent to the IPCC Tier 2 approach and would take into consideration several refinements proposed by the CSIRO independent review.

The overall uncertainty is skewed higher in the current inventory year as a result of higher levels of uncertainty in the specific subsectors of Agricultural Soils, Enteric Fermentation, Forest Remaining Forest, and Land Converted to Grassland. Uncertainty in CO_2 emissions from 4.C.2 Land Converted to Grassland accounts for almost half the uncertainty in the estimates of emissions including LULUCF in both the base and the current year.

A2.1 Energy

A2.1.1 Stationary energy

Uncertainty analyses were conducted for emissions from three sectors: 1.A.1.a. *Electricity,* 1.A.1.b. *Petroleum refining* and 1.A.1.c. *Manufacture of solid fuels and other energy industries* (Table A.2.1.1).

In the electricity generation sector (black coal, brown coal, natural gas and liquid fuels) and petroleum refining sector (liquid fuels and gaseous fuels) the uncertainty associated with most of Australia's emissions in these sectors are derived from NGER scheme data as source specific uncertainty estimates. The reported CO_2-e uncertainties for NGER scheme facilities were combined to derive an overall estimate that has been applied against the sector and fuel.

In the electricity generation sector, CO_2 emissions from the combustion of coal or gas for electricity generation must be estimated using facility specific measurements. The use of facility specific measurements based on sampling and analysis of fuels results in relatively low uncertainty estimates as published in Table A2.1.1.1.

Table A2.1.1.1 Quantified uncertainty values for key stationary energy subcategories

Greenhouse gas source and sink category	Uncertainty (%) (a)			
	CO_2	CH_4	N_2O	Total CO_2-e
1.A.1.a Electricity				
Black coal (b)	±2.1	±50.0	±50.0	±2.2
Brown coal (b)	±1.8	±50.0	±50.0	±2.0
Petroleum	±4.0	±50.0	±50.0	±4.1
Natural gas (b)	±2.6	±50.0	±50.0	±3.2
1.A.1.b Petroleum refining				
Petroleum (b)	±21.4	±52.2	±52.2	±21.4
Gas (b)	±22.4	±52.5	±52.5	±22.5
1.A.1.c Manufacture of solid fuels and other energy industries				
Fossil Fuels	±5.3	±9.0	±12.0	±5.4

(a) Uncertainty reported at 95 per cent confidence limits as per Section 3.1.3 of the IPCC Guidelines (IPCC 2006), estimated using Latin Hypercube (a type of Monte Carlo) analysis and preliminary estimates for electricity incorporating NGER scheme uncertainty estimates.

(b) Derived from NGER scheme data (CER 2022).

As can be seen at Table A2.1.1.1, CO_2 emissions account for the vast majority of fuel combustion emissions, meaning the uncertainty associated with emissions of N_2O and CH_4 has negligible impact on overall uncertainty.

A2.1.2 Transport

Monte Carlo analyses were conducted for all subsectors and fuel types. The uncertainty distributions for emission factors and activity data were developed on the basis of expert judgement.

The reported CO_2-e uncertainties for each NGER scheme reporting transport facility have been combined to derive the 1.A.3. Transport total sector estimate, which is reported in Table A2.1.2.

The largest source of uncertainty is in the emission factors. The estimates also reflect the relatively higher uncertainty attached to the emission estimates for particular vehicle types, which are drawn from ABS data and its survey of motor vehicle use, than for the sector as a whole. This outcome reflects the dependency between activity variables; and because overall transport fuel consumption is more accurately known than the individual segments.

Table A2.1.2 Quantified uncertainty values for key transport subcategories

	Uncertainty (%) [(a)]		
Greenhouse gas source and sink category	**CO_2**	**CH_4**	**N_2O**
I.A.3. Transport	**±4**	**±24**	**±42**
a. Domestic aviation	±9	±52	±52
b. Road transport	±4	±25	±42
i. Passenger cars	±6	±31	±44
ii. Light commercial vehicles	±7	±38	±41
iii. Medium trucks	±9	±41	±60
iv. Heavy trucks	±10	±44	±61
v. Buses	±8	±36	±53
vi. Motorcycles	±10	±43	±61
c. Railways	±5	±39	±39
d. Domestic Navigation	±8	±59	±32
e. Other transportation	±24	±46	±63
International bunkers			
Aviation	±10	±58	±59
Marine	±4	±47	±52

(a) Uncertainty reported at 95 per cent confidence limits as per Section 3.1.3 of the IPCC Guidelines (IPCC 2006).

A2.1.3 Fugitive emissions

In the coal fugitives sector, uncertainty associated with most of Australia's emissions in this sector are derived from NGER scheme data. The reported CO_2-e uncertainties for each large underground and open cut coal mine have been combined to derive a sector estimate which is reported in Table A2.1.3.

In the coal fugitives sector, underground coal mines must directly monitor their CH_4 emissions while open cut coal mines either undertake analysis and measurements or use state based default emission factors. The uncertainty estimates reported in Table A.2.1.3 reflect the uncertainty associated with these measurement approaches.

In the oil and gas fugitives sector, uncertainty is derived from NGER scheme data (CER 2022). NGER facilities report data for their activity data and emissions uncertainties by gas type,. The reported emissions and activity data uncertainties for each gas type at each oil and gas facility have been combined, in line with equation 3.1 of Chapter 3 of Volume 1 of the IPCC Guidelines (IPCC 2006) to derive sector estimates, which are reported in Table A2.1.3.

Table A2.1.3 Quantified uncertainty values for key fugitive emissions subcategories

	Uncertainty (%) [(a)]		
Greenhouse gas source and sink category	**CO_2**	**CH_4**	**N_2O**
1.B.1. Solid fuels	IE	IE	NA
1.B.1.a.i. Underground mines	±10.2	±10.2	NA
1.B.1.a.ii. Surface mining	±33.2	±33.2	NA
1.B.2.a. Oil	±7.1	±45.2	±50.0
1.B.2.b. Natural gas	±10.4	±73.0	±50.0
1.B.2.c. Venting and flaring	±7.1	±39.4	±50.0

(a) Uncertainty reported at 95 per cent confidence limits as per Section 3.1.3 of the IPCC Guidelines (IPCC 2006), estimated using Latin Hypercube analysis. NA references are used where an item is not a key category

(b) Uncertainty derived from NGER scheme data (CER 2022) and (IPCC 2019)

A2.2 Industrial Processes and Product Use

An analysis of uncertainty was conducted using the methods and random sampling techniques described in the IPCC 2006 Guidelines (IPCC 2006). Uncertainties used have been derived from the NGER scheme and are presented in Table A2.2.

As the IPCC Tier 1 approach is not suitable for assessing uncertainty where approximately normal distribution assumptions cannot be sustained, an analysis was undertaken using Latin Hypercube techniques. These techniques can take into account asymmetric probability distributions associated with emission factors.

For example, as the average emission factor for PFCs tends to the minimum limit that is understood to be technically feasible, the probability of the emission factor being lower than estimated is less than the probability of it being higher than estimated.

Table A2.2 Quantified uncertainty values for key industrial processes subsectors using different techniques

	Uncertainty (%) [(a,b)]					
Greenhouse gas source and sink category	**CO_2**	**CH_4**	**N_2O**	**HFC**	**PFC**	**SF_6**
2.A.1 Cement Production	±5.3	NA	NA	NA	NA	NA
2.A.2 Lime Production	±5.3	NA	NA	NA	NA	NA
2.A.4 Other Process Uses of Carbonates	±4.7	NA	NA	NA	NA	NA
2.B Chemicals	±4.7	±50.2	±7.5	±27.0	NA	NA
2.C.1 Iron and Steel Production	±2.3	±50.0	±50.0	NA	NA	NA
2.C.3 Aluminium Production	±4.2	NA	NA	NA	±27.0	NA
2.C.2 Ferroalloys Production	±10.0	±50.5	±50.5	NA	NA	NA
2.C.7 Other	±10.0	±50.5	±50.5	NA	NA	NA
2.D Non-energy Products from Fuels and Solvent Use	±3.6	NA	NA	NA	NA	NA
2.H.2 Food and Beverages Industry	±4.7	NA	NA	NA	NA	NA
2.F Product Uses as Substitutes for Ozone Depleting Substances	NA	NA	NA	±27.0	NA	NA
2.G Other Product Manufacture and Use	NA	NA	NA	NA	NA	±27.0

(a) Uncertainty reported at 95 per cent confidence limits assuming approximately normal distributions as per Section 3.1.3 of the IPCC Guidelines (IPCC 2006). NA references are used where an item is not a key category

(b) Uncertainty derived from NGER scheme data, (Burnbank Consulting 2002), and (IPCC 2019)

A2.3 Agriculture

An uncertainty analysis was undertaken for the *agriculture* subsectors using the approach 1 propagation of error method. The uncertainties applied to activity data and emission factors were based on IPCC (2006) uncertainty estimates and expert judgement (Table A2.3). It is planned in the future to develop approach 2 uncertainty estimates to better reflect data correlations and the complex tier 2 functions used to estimate emissions.

Table A2.3 Uncertainty in emission estimates for agriculture sectors

	Uncertainty (%)[(a)]		
Greenhouse gas source and sink category	**CH_4**	**N_2O**	**CO_2**
A. Enteric fermentation	±24.6	NA	NA
B. Manure management	±54.8	±54.8	NA
C. Rice cultivation	±50.2	NA	NA
D. Agricultural soils	NA	±55.9	NA
E. Agricultural residue burning	±59.6	±59.6	NA
F. Liming	NA	NA	±53.9
G. Urea application	NA	NA	±51

(a) Uncertainty reported at 95 per cent confidence limits assuming approximately normal distributions as per Section 3.1.3 of the IPCC Guidelines (IPCC 2006). NA references are used where an item is not a key category

A2.4 Land Use, Land Use Change and Forestry

Uncertainty analysis for the LULUCF sector was undertaken using the IPCC Approach 1, propagation of error method as described in the IPCC 2006 Guidelines (IPCC 2006). The results are presented in Table A2.4.

Forest land

In the sub-sector *forest land remaining forest land* activity data is derived from national statistics of forest harvesting. The uncertainty of these activity data has not been published and so is estimated to be ±15 per cent. The uncertainties regarding the emission factors used are also unpublished and are estimated to be ±30 per cent. For Victoria, New South Wales and Tasmania, a spatially explicit Tier 3 model is used, with far lower uncertainty surrounding activity data (location and type of harvest), but similar uncertainty over the emission factor.

The sub-sector *land converted to forest land* includes *grassland converted to forest* and *wetlands converted to forest.* The uncertainty associated with the detection of forest cover gains is reported to be ±3.5 per cent. Field sampling results presented by (K. Paul 2015) indicate an uncertainty of ±11.5 per cent for the estimation of standing biomass. As explained in Chapter 6.5.3, the higher uncertainty around *wetland converted to forest land* contributes only a small increment to the overall uncertainty for the sub-sector.

Cropland

Cropland remaining cropland activity data are derived from ABS reporting of agricultural management practices as a regional level (ABS 2017). The uncertainty associated with the reported activity data is estimated to be ±25 per cent and the uncertainty associated with model results is estimated to be ±20 per cent.

The sub-sector *land converted to cropland* includes *forest land converted to cropland* and *wetlands converted to cropland.* For *forest land converted to cropland,* remote sensing-based data are used and the uncertainty in these data is reported to be ±3.5 per cent. The key input variable to the estimation of biomass at the time of forest conversion to other land uses is the initial assumed above ground biomass. Based on data presented by Richards and Brack (2004) uncertainty in this parameter is estimated to be ±25 per cent.

As explained in Chapter 6.7.3, the higher uncertainty around *wetlands converted to cropland* contributes only a small increment to the overall uncertainty for the sub-sector.

Grassland

Grassland remaining grassland activity data are derived from ABS reporting of agricultural management practices as a regional level (ABS 2017), and from remote-sensed area changes in sparse woody vegetation. The uncertainty associated with these reported activity data is estimated to be ±25 per cent and the uncertainty associated with model results is estimated to be ±20 per cent.

The sub-sector *land converted to grassland* includes *forest land converted to grassland* and *wetlands converted to grassland.* The remote-sensing-based activity data and FullCAM modelling of carbon stock changes for *forest converted to grassland* are similar to *forest converted to cropland,* and the activity data and estimation method for *wetlands converted to grassland* is similar to that for *wetlands converted to cropland.* As such, overall uncertainty is also similar to *land converted to cropland.*

Wetlands

Wetlands remaining wetlands data includes sparse woody vegetation cover changes based on satellite imagery and ABARES aquaculture production statistics (2022) with similar levels of uncertainty. Estimation of net emissions from sparse woody vegetation is via a Tier 2 spreadsheet model. The higher overall uncertainty around aquaculture emissions is driven by that of the simple Tier 1 model used to estimate N_2O emissions from aquaculture. The subsector also includes *flooded land remaining flooded land (reservoirs* more than 20 years old, and *other constructed waterbodies)* whose satellite-based activity data collection methods and CH_4 emission estimates, and therefore uncertainty, are similar to *forest land remaining.*

The sub-sector *land converted to wetlands* includes forest land converted to flooded land (e.g. *reservoirs* up to 20 years old). Activity data collection and emissions estimates, and thus uncertainty, are similar to that for *forest converted to grassland.*

Settlements

Settlements remaining settlements data comprises sparse woody vegetation cover changes based on satellite imagery with net emissions estimated via a Tier 2 spreadsheet model. As such, the level of uncertainty is similar to the CO_2 component of *wetlands remaining wetlands.*

The sub-sector land *converted to settlements* includes *forest land* (both terrestrial and coastal mangrove) *converted to settlements* and *wetlands converted to settlements.* Terrestrial forest conversions exert the dominant influence on overall uncertainty. As such, although the uncertainties around emissions from mangrove forest and tidal marsh conversions are greater than for terrestrial forest conversions, their impact is relatively small.

Harvested wood products

The harvested wood products model uses the same source of activity data as the *forest land remaining forest land* model. Uncertainties associated with these activity data are estimated to be ±33.5 per cent. Estimated uncertainty associated with the harvested wood products carbon stock change were derived as reduced form outputs of Monte Carlo analyses (see chapter 6.13) providing an uncertainty of ±22.4 per cent.

Table A2.4 Estimation of uncertainties in components of the land use change and forestry subsectors

	Uncertainty (%) [(a)]		
Greenhouse gas source and sink category	**CO_2**	**CH_4**	**N_2O**
A.1 Forest land remaining forest land	±33.5	±52.2	±52.2
A.2 Land converted to forest land	±16.8	±51.2	±51.2
B.1 Cropland remaining Cropland	±32.0	NA	NA
C.1 Grassland remaining Grassland	±32.0	±55.9	±55.9
B.2 Forest land converted to Cropland	±27.9	±51.2	±51.2
C.2 Forest land converted to Grassland	±27.3	±51.2	±51.2
D.1 Wetlands remaining Wetlands	±22.8	NA	±27.3
D.2 Land converted to Wetlands	±22.8	NA	NA
E.1 Settlements remaining Settlements	±51.3	NA	NA
E.2 Land converted to Settlements	±51.3	±22.4	±54.0
G Harvested wood products	±50.0	NA	NA

(a) Uncertainty reported at 95 per cent confidence limits assuming approximately normal distributions as per Section 3.1.3 of the IPCC Guidelines (IPCC 2006). NA references are used where an item is not a key category

A2.5 Waste

Estimates for uncertainty for emissions from solid waste disposal and wastewater treatment were estimated by Blue Environment (2016). Estimates of uncertainty for biological treatment and incineration were calculated based on sections 8.3 and 8.4 of the (*National Greenhouse and Energy Reporting (Measurement) Determination 2008* (Cwlth) 2008).

Table A2.5 Relative uncertainty in emission estimates for key waste subsectors

	Uncertainty (%) [(a)]		
Greenhouse gas source and sink category	CO_2	CH_4	N_2O
Waste			
A. Solid waste disposal on land [(b)]	NA	±50.0	NA
B. Biological treatment of solid waste	NA	±20.0	±100.0
C. Incineration and open burning of waste	±50.0	NA	±100.0
D. Wastewater treatment and discharge [(b)]	NA	±40.0	±50.0

(a) Uncertainty reported at 95 per cent confidence limits assuming approximately normal distributions, as per Section 3.1.3 of the IPCC Guidelines (IPCC 2006). NA references are used where an item is not a key category

(b) Source: Blue Environment (2016)

ANNEX III:

Detailed description of the reference approach (including inputs to the reference approach such as the national energy balance) and the results of the comparison of national estimates of emissions with those obtained using the reference approach

A3.1 Estimation of CO_2 using the IPCC reference approach

The reference approach estimates CO_2 emissions from *fuel combustion activities* (covering both *stationary energy* and *transport).* It is calculated using a top-down approach based on Australia's energy balance statistics for production, imports, exports and stock change.

Data is obtained from the Australian Energy Statistics (DCCEEW 2023) for solid and gaseous fuels and the *Australian Petroleum Statistics* (DCCEEW 2023) for liquid fuels.

The primary reason for the differences in petroleum fuels relates to the sensitivity of final apparent consumption and emissions to the average density and energy content values used to convert production, exports, imports, and stock changes from volume/mass units into energy units. 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.

A specific reason for the difference in solid fuels lies in the use of NGER scheme data in conjunction with the AES for the sectoral approach whereas the AES forms all the input of the reference approach. In recent years, the APS has become a larger input into the AES thus reducing some of the historic differences seen with liquid fuels.

Being based on receipts for the year, the APS will revise data for up to 12 months from the data of publication but generally does not revise more historical data (DCCEEW 2023). This lack of revised data which underpins the reference approach can lead to historical differences in certain fuels as the sectoral approach undergoes independent recalculations.

A3.2 Comparison of Australian methodology with IPCC reference approach

The reference approach has also been recalculated for 2020–21 due to revised data in the AES.

The full set of results are presented in Table A3.1.

Table A3.1 Reference approach and sectoral approach comparison for 1989–90 to 2021–22

Year	IPCC Reference (CO_2 Mt)	Sectoral (CO_2 Mt)	Difference in %
1990	254	252	1.1
1991	258	254	1.5
1992	259	258	0.2
1993	266	262	1.3
1994	269	265	1.3
1995	277	276	0.3
1996	287	283	1.5
1997	291	291	0.0
1998	306	304	0.5
1999	314	313	0.2
2000	319	319	0.2
2001	324	327	-0.8
2002	331	331	-0.2
2003	337	337	-0.3
2004	349	350	-0.3
2005	356	355	0.3
2006	355	360	-1.3
2007	365	366	-0.1
2008	370	371	-0.4
2009	380	376	1.1
2010	374	372	0.8
2011	373	370	0.9
2012	381	375	1.7
2013	370	369	0.4
2014	361	362	-0.2
2015	370	369	0.4
2016	373	376	-0.8
2017	375	376	-0.3
2018	370	376	-1.5
2019	375	373	0.5
2020	362	360	0.4
2021	349	351	-0.5
2022	344	344	0.0

The overall difference between the reference approach and the sectoral approach is within 2 per cent for all years. The differences between the reference approach and the sectoral approach for specific fuel types exceeds 2 per cent for some years.

ANNEX IV: QA/QC Plan

A4.1 Additional information on the QA/QC Plan

The management of the QA/QC activities relating to the inventory are undertaken by the Department of Climate Change, Energy, the Environment and Water (the Department) and detailed in the *National Greenhouse Accounts: Quality Assurance-Quality Control Plan.* An overview of the quality control system is provided in Chapter 1 while sector-specific information on quality control activities has been included in the QA/QC sections of each chapter. This Annex provides additional information and should be read in conjunction with the relevant chapters of the report.

The objectives of the national inventory quality and assurance system are to support the provision of emissions estimates that meet the UNFCCC criteria of accuracy; time series consistency; transparency, completeness and comparability of estimates with those of other Parties. Key risks to achieving the defined quality objectives are identified at each level of inventory preparation including the measurement of data at the facility level; the collation of activity and other input data by the Department and other Australian government agencies; and the process of emissions estimation. Specified mitigation strategies, measures and routine actions are deployed to control the identified risks.

These strategies range from utilisation of data measurements governed by existing national measurement systems such as the *National Measurement Act* and taxation legislation to the use of automated quality control tools embedded in the Australian Greenhouse Emissions Information System (AGEIS).

Monitoring of the quality measures and evaluation of the results are critical to the goal of maintaining the system's effectiveness. In particular, control measures include the use of mass balance checks for all years to assess completeness and accuracy. All carbon entering the market economy is accounted for – either as emissions or stored in products or stored in wastes. Carbon balances for fuels, biomass, carbonates, synthetic gases and wastewater consumption have been constructed and the results presented as Australia's National Carbon Balance in Annex 4.8.

External review of the inventory is a critical part of the process of ensuring the quality of the estimates. The Australian inventory and associated quality control systems are subject to audit by the Australian National Audit Office (ANAO), and performance audits have been conducted by the ANAO in 2009–10 and 2016–17. A key data input to the inventory, the National Greenhouse and Energy Reporting scheme, is also subject to five-yearly legislated reviews by the independent Climate Change Authority.

A4.2 Tier 1 quality control checks

Emissions estimation is conducted through the use of the AGEIS software (apart from the *LULUCF* sector). Management of AGEIS is conducted in accordance with the Australian Digital Transformation Agency Digital Service Standard (DTADSS), which replaces the Control Objectives for Information and related Technology (COBIT) Framework.

For the inventory and associated time series, there are over 5 million data inputs in the *non-LULUCF* sectors. To facilitate the management of such a large amount of data, AGEIS was specifically developed to play a central role in the quality control of the national inventory. Key tier 1 QC controls have been systematically built into the operation of AGEIS. Auditable checks are undertaken *inter alia* to reduce the risks of errors associated with the input of activity data, missing data, recalculations and the time series consistency of generated emissions estimates.

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

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

Australia's QA/QC Plan is designed to align with the requirements of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006 Guidelines) (IPCC 2006). The set of tier 1 QC procedures for the inventory compilation process specified in the guidelines along with the relevant control measure reference in Australia's QA/QC Plan, are identified in Table A4.1.

Table A4.1 Implementation of tier 1 quality control checks

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

Tier 1 QC activity: Checks [(a)]	Control Measure [(b)]	Implementation / Comment
Movement of inventory data among processing steps is correct	3.A.1–3	Extensive testing during AGEIS development phase and when new methods introduced. Standard reconciliation reports are run to ensure correct aggregation of emission estimates. Cross checking data between FullCAM, AGEIS and CRTs for consistency.
Uncertainties in emissions and removals are estimated or calculated correctly		Uncertainty estimation has been incorporated into AGEIS and independently verified.
Time series consistency/ Methodological and data changes resulting in recalculations	3.C, 3.D	Where changes are made to methods or activity data the full time series of emissions is recalculated. AGEIS and FullCAM ensure consistent use of methods across time series.
Completeness	B.I-2, B.I-4	Assessed using CRTs. Mass balance checks undertaken for fuel, carbonates, biomass and synthetic gases. FullCAM has a mass balance check incorporated at each stage of the model process.
Trend	3.D.1–2	Activity data, emissions and IEFs are compared with the previous year's estimates, and across entire time series, through AGEIS.
Review of internal documentation	3.E 1–3	All activity data, emission factors and algorithms are archived within AGEIS. Past inventories may be reproduced using AGEIS. All bibliographical data references are archived within AGEIS. FullCAM software, simulations and activity data are backed up on a secure system.

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

A4.3 Tier 2 quality control checks

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

Completeness and accuracy are tested through the operation of mass balance checks. The application of mass balance constraints for carbon in fuels, carbonates, biomass wastes, and hydrofluorocarbons and nitrogen balances for domestic and industrial wastewater constitute tier 2 quality control measures. All carbon entering the economy in fuels is accounted for, either as emissions from fuel combustion, emissions from the use of fossil fuels as reductants, non-energy uses, use of biomass sources of energy, or international bunkers. Carbon balances for biomass, carbonates and synthetic gas consumption have also been implemented. Detailed results of the application of these balances are reported in Annex 4.8 below.

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

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

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

A4.4 Source-based quality control checks – NGER Scheme

The principal data source for this inventory is the National Greenhouse and Energy Reporting Scheme (NGER scheme). The quality control system for this data is critical for the quality for the inventory as a whole.

Use of Standards

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

The *National Greenhouse and Energy Reporting Measurement Determination 2008* is supplemented by the referencing of standards for sampling and analysis of key data inputs. For example, for the estimation of facility-specific EFs, NGER scheme methods reference relevant Australian, ISO, and equivalent international standards (EU, US) for sampling and analysis of relevant fuel qualities and characteristics (such as carbon content). These standards provide, *inter alia,* sample handling protocols and tolerance levels for precision (repeatability and reproducibility), as well as for the management of bias.

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

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

Validation of NGER Scheme Data

In order to facilitate accurate reporting of information, the Clean Energy Regulator (CER) provides education and technical support to assist reporting entities to understand and implement their obligations under the NGER scheme. The CER monitors compliance with the NGER scheme through systematic analysis of reported data for qualitative or quantitative errors and through consideration of findings from its annual audit program. Where reporting errors are identified and confirmed, the CER may require that the data is corrected through resubmission.

Independent auditing of NGER scheme data

The *National Greenhouse and Energy Reporting Act 2007* (NGER Act) provides for a risk-based program for the independent verification of NGER scheme data. Under the NGER Act, the CER has the authority to commission, or to require a reporting entity to commission, an external audit on aspects of the entity's compliance with the NGER Act and associated legislative instruments. Sections 73 and 74 of the NGER Act define the circumstances under which a greenhouse and energy audit may be initiated and establishes a mechanism for Registered Greenhouse and Energy Auditors to undertake audit engagements.

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

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

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

Audits may examine:

- the reporting of emission sources, energy consumption and energy production; and
- the effectiveness of internal controls associated with data collection, record keeping and reporting processes. Significant penalties may apply to an entity's Executive Officers for contravention of the NGER Act.

In addition, many companies voluntarily engage external auditors to review their reports prior to submission to the CER.

Time series consistency with audited data

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

Confidential data

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

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

A4.5 Source-based quality control checks – Other data sources

Quality control of official national statistics other than the NGER scheme is managed by the source agencies. The Australian Bureau of Statistics (ABS) publishes assessments of data quality and quantitative estimates of sampling errors for transport and agriculture activity data. National level energy activity data are produced by the Department through its annual *Australian Energy Statistics* (AES) (DCCEEW 2023).

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

Explicit reconciliations of data are also undertaken with respect to emissions estimates on forest conversion. Geospatial data on forest conversion is compared to independent datasets produced by other agencies. Information provided by other state agencies in relation to permits issued for land clearing have also been used in assessing the land cover change data obtained from Landsat.

A4.6 Full list of quality control checks

A full list of quality control checks is provided in Table A4.2.

Table A4.2 Summary of principal mitigation strategies and quality control measures

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
1.A.1 (i)	Accuracy, completeness and time series consistency	Facility-level data for Energy, IP and Waste subject to national measurement system and Australian regulations and international standards as specified in the *National Greenhouse and Energy Reporting Measurement Determination 2008*	Compliance	Department of Climate Change, Energy, the Environment and Water	6.7.2.2, page 6.16
1.A.1 (ii)	Accuracy, completeness and time series consistency	Agriculture and transport data subject to measurement standards of the Australian Bureau of Statistics (ABS)	Compliance	Monitoring through evaluation of NGER (Measurement) Determination 2008	6.7.2.2, page 6.16
1.A.1 (iii)	Accuracy, completeness and time series consistency	Geospatial data	Considered comparable	Department of Climate Change, Energy, the Environment and Water	6.7.2.2, page 6.16
1.A.1 (iv)	Accuracy, completeness and time series consistency	Climate data received by the Department subjected to rigorous visual and quantitative checks based on ensuring 1) no null values 2) coverage of entirety of Australia 3) free of errors while ingesting into FullCAM	Compliance	Department of Climate Change, Energy, the Environment and Water	6.7.2.2, page 6.16

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
1.A.2	Accuracy	Data submitted under the NGER scheme is subject to Clean Energy Regulator Scheme Audit and Assurance unit	Compliance	Clean Energy Regulator Scheme Audit and Assurance unit	6.7.2.2, page 6.16
1.B.1	Comparability	Integration of national and facility estimation method within National Greenhouse Accounts Framework	Compliance	Department of Climate Change, Energy, the Environment and Water	6.7.1.2 page 6.12
1.D.1	Transparency	Company level data published by the Clean Energy Regulator under the *National Greenhouse and Energy Reporting Act 2007*	Compliance	Clean Energy Regulator website	6.5, page 6.8
2.A.1	Accuracy	Comparison of energy data with independent sources of activity data	Reconciliation within <2%	Excel spreadsheet comparison using dataset from AES, NEM review, Coal Services Pty Ltd, Queensland Department of Mines and Energy	6.7.2.1, page 6.15
2.A.2	Accuracy	External consultants operate QC protocol	Compliance	National Inventory Team	6.4, page 6.16
2.A.3	Accuracy	Quality control systems for external data providers	Compliance	Agency Governance Board	6.4, page 6.16
2.B.1	Completeness	Application of standardised rules for use of facility level data in national inventory	Compliance	See Chapter 1.3 of the National Inventory Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (i)	Completeness	Reconciliation of estimates of energy in fuel supplies to the Australian economy and energy contained in data inputs used in the estimation of carbon in emissions; or stored in products; or non-oxidised; or in permanent storage	Compliance with target objective of <0.1%	IPCC Reference Approach	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (ii)	Completeness	Reconciliation of estimates of carbonate supplies to the Australian economy and estimates of carbonates in data inputs used in estimation of emissions; or stored in products; or waste residues or in permanent storage	Compliance with target objective of <1%	Carbonate Balance Table	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (iii)	Completeness	Reconciliation of estimates of carbon in biomass supplies to the Australian economy and carbon contained in data inputs used for estimation of emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <1%	Excel spreadsheet using data from ABARES forestry publication	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (iv)	Completeness	Reconciliation of estimates of carbon in domestic wastewater to the Australian economy and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <1%	AGEIS Automated Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
2.B.2 (v)	Completeness	Reconciliation of estimates of carbon in industrial wastewater to the Australian economy and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <1%	AGEIS Automated Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (vi)	Completeness	Reconciliation of estimates of carbon in synthetic gases supplied to the Australian economy and synthetic gases contained in emissions or stored in products or destroyed	Compliance with target objective of <0.1%	AGEIS Automated Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
2.B.2 (viii)	Completeness	Reconciliation of estimates of land allocated to land use and land use change classifications and aggregated total land supply	Compliance with target objective of <0.1%	National Inventory Report	Table 6.1, page 6.11; section 6.7.2.1, page 6.15
3.A.1 (i)	Accuracy	Selection of emission estimation methodologies should be consistent with IPCC Good Practice and comparable with international practice	Compliance	QAQC Officer	IPCC Good Practice Guidance
3.A.1 (ii)	Accuracy	Tier 2 (3) model parameters should not be significantly different to the mean of NGER scheme facility-specific data	Compliance	Automated AGEIS Report	6.7.1.2, page 6.13
3.A.1 (iii)	Accuracy	Tier 2 (3) model parameters should not be significantly different to results from the public empirical research program that meet specified conditions for quality	Compliance	National Inventory Team	6.7.1.2, page 6.13
3.A.1 (iv)	Accuracy	Tier 2 (3) model parameters should not be significantly different to results from privately measured datasets that meet specified conditions for quality	Compliance	National Inventory Team	6.7.1.2, page 6.13
3.A.2 (i)	Accuracy	AGEIS development in accordance with DTADSS	Compliance	AGEIS and FullCAM Advisory Board	AGEIS Strategic Plan
3.A.2 (ii)	Accuracy	AGEIS operation in accordance with DTADSS	Compliance	AGEIS and FullCAM Advisory Board	AGEIS Strategic Plan
3.A.2 (iii)	Accuracy	Allocation of separate staff roles and responsibilities	Compliance	National Inventory Team Executive	6.4, page 6.7
3.A.2 (iv)	Accuracy	FullCAM development in accordance with DTADSS	Compliance	AGEIS and FullCAM Advisory Board	FullCAM Strategic Plan
3.A.2 (v)	Accuracy	FullCAM operation in accordance with DTADSS	Compliance	AGEIS and FullCAM Advisory Board	FullCAM Strategic Plan

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
3.A.3	Accuracy	Verification of selected AGEIS estimates by sectoral experts	Difference between AGEIS inventory estimates and verification estimates should be less than 0.1%	Data comparison with sector- specific calculation sheets using Excel spreadsheet	6.7.3, page 6.16
3.A.4	Accuracy	The estimated uncertainty of the overall inventory should decline over time	Compliance	Annex 2 of the NIR.	6.9, page 6.18
3.A.5	Accuracy	Number of significant accuracy issues raised by the UNFCCC ERT, and agreed by the Department, should reduce over time	Compliance	UNFCCC Expert Review Team Report	6.8, page 6.18
3.B.1 (i)	Completeness	Reconciliation of fuel data submitted into the AGEIS and carbon contained in emissions or stored in products or non-oxidised or permanent storage	Compliance with target objective of <0.01%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3, page 6.16
3.B.1 (ii)	Completeness	Reconciliation of carbonate data submitted into the AGEIS and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.01%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3, page 6.16
3.B.1 (iii)	Completeness	Reconciliation of biomass data submitted into the AGEIS and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.001%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3, page 6.16
3.B.1 (iv)	Completeness	Reconciliation of carbon in domestic wastewater data submitted into the AGEIS and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.001%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3, page 6.16
3.B.1 (v)	Completeness	Reconciliation of nitrogen in domestic wastewater data submitted into the AGEIS and nitrogen contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.001%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3, page 6.16
3.B.1 (vi)	Completeness	Reconciliation of carbon in industrial wastewater data submitted into the AGEIS and nitrogen contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.001%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3, page 6.16

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
3.B.1 (vii)	Completeness	Reconciliation of HFCs in data submitted into the AGEIS and carbon contained in emissions or stored in products or waste residues or in permanent storage	Compliance with target objective of <0.001%	AGEIS Automated Report	Table 6.1, page 6.10; 6.7.3, page 6.16
3.B.1 (viii)	Completeness	Reconciliation of CO_2 emissions in the LULUCF sector with the results of carbon stock accounting models	Compliance with target objective of <0.001%	ABARES Australia's State of Forests Report	Table 6.1, page 6.10; 6.7.3, page 6.16
3.B.1 (vix)	Completeness	Reconciliation of carbon in fossil fuels, carbonates, biomass, synthetic gases and wastewater in data submitted into the AGEIS and carbon contained in emissions or stored in products or destroyed	Compliance with target objective of <0.01%	QAQC Officer	Table 6.1, page 6.10; 6.7.3, page 6.16
3.B.2 (i)	Completeness	Reconciliation of National Inventory with aggregate of State and Territory inventories	Compliance with target objective of <0.1%	AGEIS OLAP data cube comparison	6.7.2.1, page 6.14
3.B.2 (ii)	Completeness	Reconciliation of the National Greenhouse Gas Inventory with the National Inventory by Economic Sector	Compliance with target objective of <0.1%	AGEIS Automated Report	6.7.2.1, page 6.14
3.B.2 (iii)	Completeness	Reconciliation of the National Greenhouse Gas Inventory with OLAP output from the Australian Greenhouse Emissions Information System	Compliance with target objective of <0.1%	AGEIS Automated Report	6.7.2.1, page 6.14
3.B.3	Completeness	Number of emission sources not estimated, for which IPCC methods exist, comparable with international practice	Consistent with international practice	UNFCCC Expert Review Team Report	6.8, page 6.18
3.B.4	Completeness	Number of significant completeness issues raised by the UNFCCC ERT, and agreed by the Department, should reduce over time	Compliance	UNFCCC Expert Review Team Report	6.8, page 6.18
3.C.1	Comparability	Implied emission factors for key variables should not be significantly different to those of other UNFCCC reporting parties	Compliance	AGEIS Automated Report	6.7.1.2, page 6.13
3.C.2	Comparability	Number of significant comparability issues raised by the UNFCCC ERT, and agreed by the Department, should reduce over time	Compliance	UNFCCC Expert Review Team Report	6.8, page 6.18
3.C.3	Comparability	Recalculation percentages for the national inventory Annex A sectors should not be significantly different to those of other UNFCCC reporting parties over time	Compliance	UNFCCC National Inventory submissions	6.8, page 6.18
3.D.1	Time series	Analysis by category for time series consistency	Compliance	UNFCCC Expert Review Team Report	Table 6.1, page 6.11

Measure No.	Quality objective	Mitigation strategy or control measure	Target	Monitoring mechanism	2006 IPCC Guidelines Vol 1 cross reference
3.D.2	Time series	Number of significant time series consistency issues raised by the UNFCCC ERT, and agreed by the Department, should reduce over time	Compliance	UNFCCC Expert Review Team Report	Table 6.1, page 6.11
3.E.1	Transparency	Publication of assumptions, methodologies, data sources and emission estimates in the National Inventory Report and related products	Compliance	National Inventory Report	6.5, page 6.8
3.E.2	Transparency	Publication of the AGEIS emissions database on the Department website and related products	Compliance	https://greenhouseaccounts.climatechange.gov.au/	6.5, page 6.
3.E.3	Transparency	Number of significant transparency issues raised by the UNFCCC ERT, and agreed by the Department, should reduce over time	Compliance	UNFCCC Expert Review Team Report	6.5, page 6.

A4.7 Inverse modelling of emissions and other verification work

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

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

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

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

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

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

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

More ‘top-down’ empirical work is underway in Australia and all methods will be kept under review as new empirical studies on methane fluxes emerge, including studies utilising satellite detection of methane.

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

Each year, the Department commissions CSIRO to make an independent, ‘top-down’[1] estimate of annual emissions of HFCs from Australia and then compares this information with estimates of HFC emissions using the national inventory ‘bottom-up’ methods as part of its routine quality assurance program. The CSIRO analysis is also used to inform the gas speciation of Australia’s HFC inventory.

The CSIRO analysis is especially valuable because:

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

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

The time profile of these HFC losses is less well-known, however, depending on factors including rates of leakage from a wide variety of equipment and the rate of recycling of gas at the point of equipment disposal in the economy.

Comparison of the CSIRO and NIR estimates of HFC emissions is contained in Chapter 4.7.4.

In addition to supporting the inverse modelling of HFC emissions, the CSIRO Baseline Air Pollution Station at Cape Grim in Tasmania collects and analyses data on the concentrations of other synthetic gases – PFCs and SF_6 – with the aim of providing an independent assessment of emissions of these gases in Australia (see Chapter 4.7.4).

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

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

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

A4.8 Australia's National Carbon Balance

Australia's National Carbon Balance records the supply of carbon entering the domestic economy through the most important channels and tracks the uses or fates of that carbon allocated amongst greenhouse gas emissions, increments to the stock of carbon in products and increments to the stock of carbon in waste residues. The balance is shown in Table A4.3.

Table A4.3 Australia's National Carbon Balance 2021–22

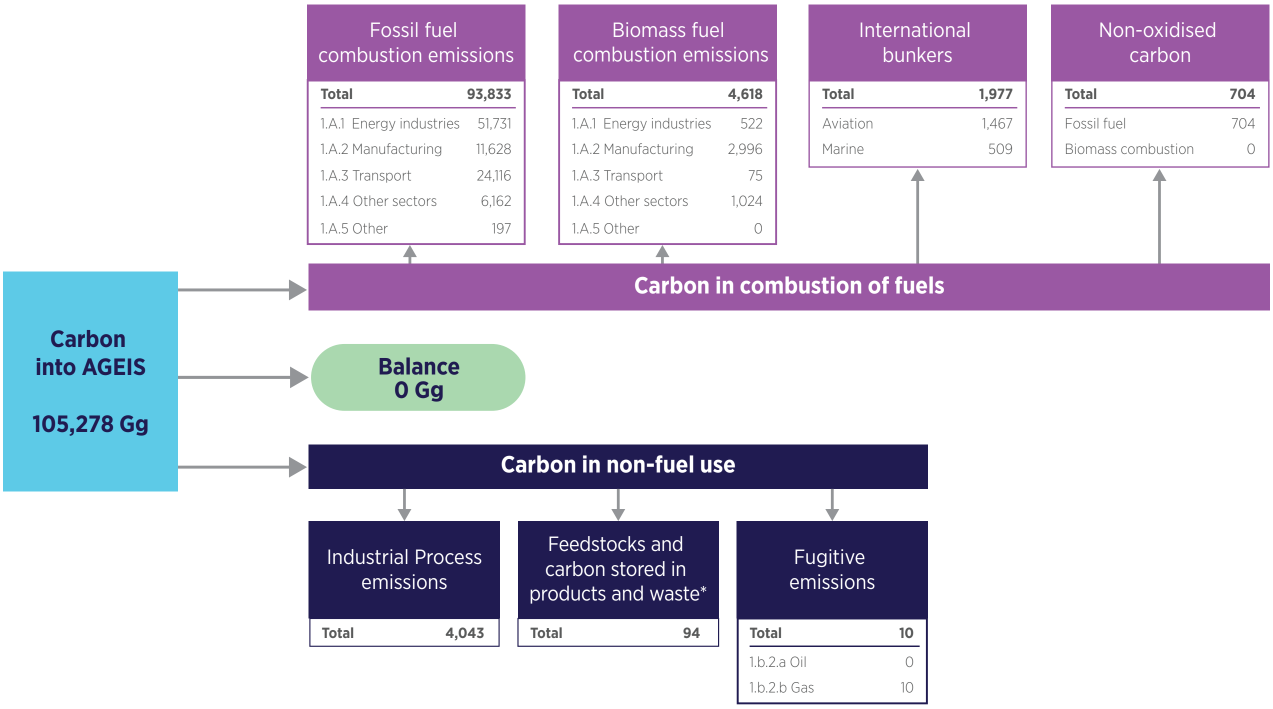
Supply	kt C	Uses	kt C
Fossil fuels for consumption (a)	100,768	*Emissions*	
Carbonate for consumption (a)	1,828	1.A Combustion emissions (fossil fuels)	93,833
Hydrofluorocarbon for consumption (d)	2,979	1.B Fugitive emissions (d)	10
		2.A Industrial process fossil fuel emissions	4,043
		Memo: International bunker fuels	1,977
		2.A Mineral product carbonate emissions	1,811
Biomass products produced		2.F Hydrofluorocarbon emissions (d)	3,181
Wood and paper products (a)	5,188	Memo: Combustion emissions (wood products and waste)	472
Bagasse, ethanol, biogas (b)	2,349	Memo: Combustion emissions (bagasse, ethanol, biogas)	2,349
Firewood collected (b)	1,012	Memo: Combustion emissions (all wood)	2,110
Other wood (b)	1,148	5.A Landfill emissions from HWP	271
		5.A Landfill emissions from non-HWP	819
Waste disposal (food, garden, textiles, rubber – landfill) (c)	1,509	Aerobic treatment processes (paper, wood and wood waste)	1,051
		Increment to product stocks	
		Petrochemical and steel products	94
		Carbonate products	1
		Hydrofluorocarbon products (d)	-474
		Increment to HWP stocks	1,622
		Biomass fibre recycled	1,458
		Increment to waste stocks and residues	
		Carbon dioxide captured for permanent storage	
		Non-oxidised carbon *	704
		Carbonate wastes	15
		Increment to HWP waste in landfill	466
		Increment to non-HWP waste in landfill	699
		Miscellaneous	
		Hydrofluorocarbons destroyed	272
		Residual	6.0
Total supply	**116,781**	**Total uses**	**116,781**

Notes: (a) Entering the domestic economy. (b) Final domestic consumption. (c) Entering waste stream; (d) based on carbon dioxide equivalents. * Coal fuelled electricity generation assumes the NGER scheme oxidation factor of less than 100 per cent oxidation.

Assessments of the total amount of carbon in stock are more difficult to assess and depend critically on starting assumptions. It is estimated that there is approximately 64.5 Mt of carbon stored in harvested wood products in Australia and about 44.9 Mt of carbon stored in waste. The latter estimate relies on the relatively strong assumption that all landfills have been maintained in order to fulfil anaerobic conditions. If the alternative assumption was adopted, such that it was assumed that all landfills were eventually exposed to aerobic conditions, then the amount of carbon stored in landfills would tend to zero over very long time periods. No provision is currently made in this balance for the estimation of carbon stored in geological strata or in forest growing stock. It is assumed that any fossil fuels, carbonates and hydrofluorocarbons consumed were mined, manufactured or imported in the same year as their consumption in the domestic economy. This simplifies the balance assessment by avoiding a need to consider the changes in reserves and storage.

The National Carbon Balance is used as a quality control tool. The Australian inventory utilises a very large number of disaggregated data inputs for energy-related emission calculations (~15,000 per year). Consequently, a carbon balance is undertaken to compare carbon input to carbon output for all years. The carbon input represents the carbon embodied within the total quantity of energy and non-energy fuels which have been consumed in a year and are entered into AGEIS for calculation. The carbon output represents the distribution of the carbon utilised throughout the economy, as determined by the output of the calculations within the AGEIS. The carbon output is distributed as either emissions from fuel combustion, emissions from the use of fossil fuels as reductants, non-energy uses (e.g. feedstocks, bitumen, coal oils and tar), use of biomass sources of energy and international bunkers. While the predominant outcome of carbon entering the economy is emissions, a small portion of the carbon is stored in carbon-containing products or non-oxidised as ash. A flow chart detailing the results of the carbon balance is at Figure A4.1. For 2021–22, the residual in the estimates was 0.005 per cent of total carbon supply, which is within the tolerance level of <0.01 per cent prescribed in the QA/QC Plan.

Figure A4.1 Balance flow chart showing carbon inputs and distribution of outputs for 2021–22



The flows of fugitive methane and carbon dioxide associated with underground and surface coal mines are shown in Figures A4.2 and A4.3. The underground coal mine model demonstrates the effectiveness of methane capture for electricity generation and flaring in reducing net fugitive emissions – capturing 56 per cent of the gross methane generated from underground coal mining.

Figure A4.2 Fugitive gas balance flow chart for underground mines, 2021–22

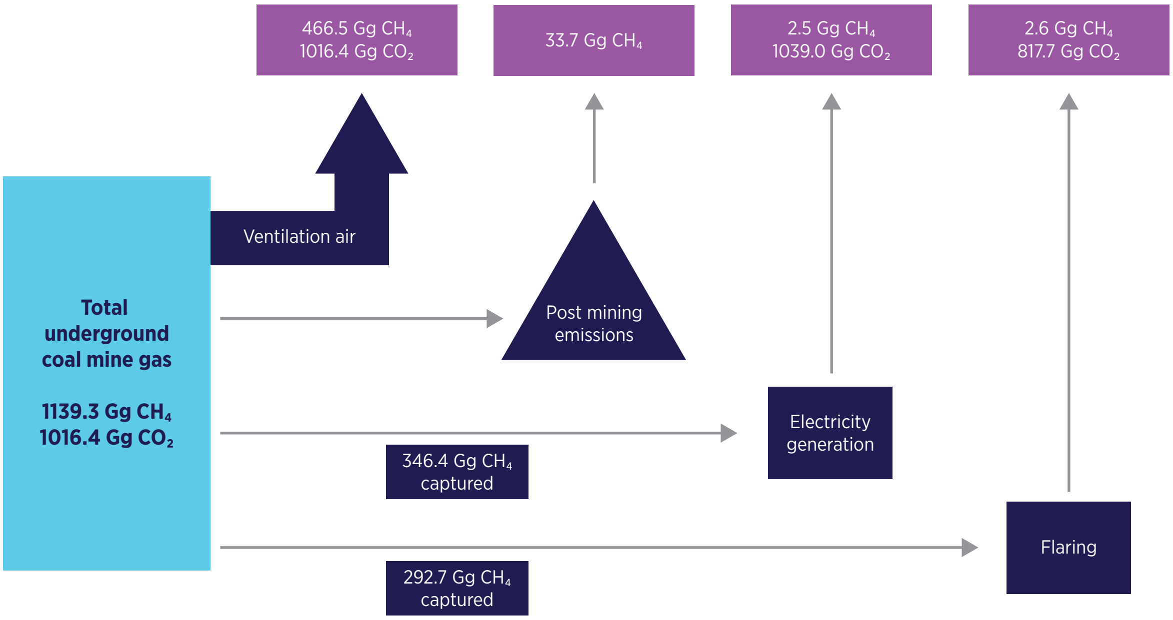
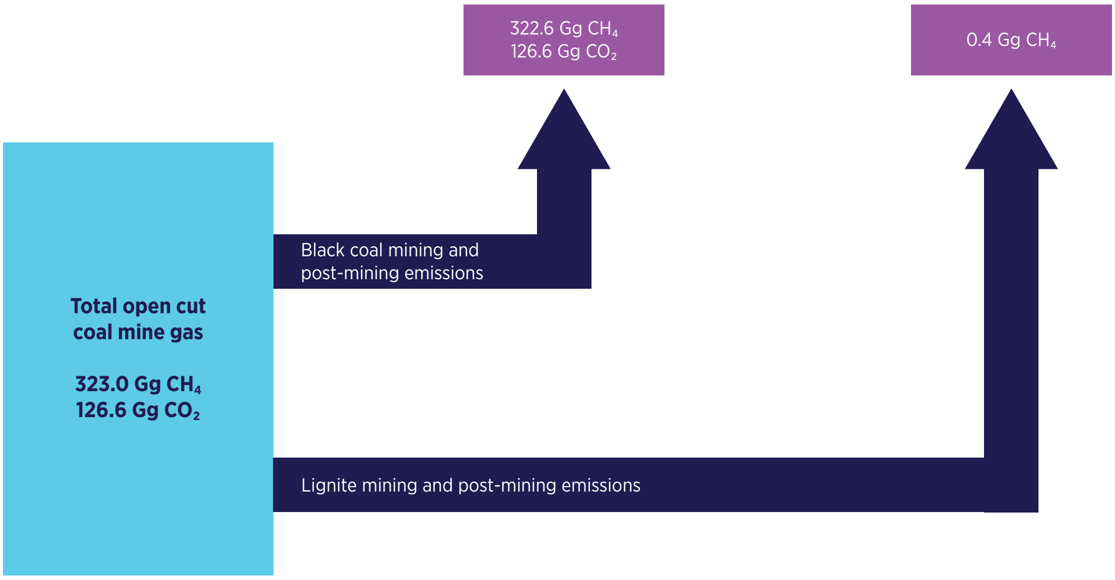


Figure A4.3 Fugitive gas balance flow chart for surface mines, 2021–22



ANNEX V:
Any additional information, as applicable, including detailed methodological descriptions of source or sink categories and the national emission balance

Additional information supporting the information provided throughout the chapters of Volume 1 of this Report are provided here. They are ordered in a manner consistent with the chapters of this Report.

A5.1 National Greenhouse and Energy Reporting (NGER) Scheme

The NGER scheme is an integral element of the national inventory system. NGER scheme data covers approximately 60 per cent of total inventory emissions, and 80 per cent of energy emissions.

The NGER scheme is established by the *National Greenhouse and Energy Reporting Act 2007* (Cwlth) (NGER Act) and 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:

- 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 *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.
- The *National Greenhouse and Energy Reporting (Audit) Determination 2009* (Cwlth) — sets out the requirements for preparing, conducting and reporting on greenhouse and energy audits.
- The *National Greenhouse and Energy Reporting (Auditor Registration) Instrument 2019* (Cwlth) — specifies the qualifications that an auditor must have to be registered under the NGER Act.
- The *National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015* (Cwlth) — sets out the details that establish compliance rules and procedures for administering the safeguard mechanism.

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

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

- **Fuel combustion** emissions from the combustion of fuel for energy (see Chapter 2 of the Determination);
- **Fugitive emissions** from the extraction, production, flaring, processing and distribution of fossil fuels (see Chapter 3 of the Determination);

- **Industrial processes** and product use emissions where a mineral, chemical or metal product is formed using a chemical reaction that generates greenhouse gases as a by-product (see Chapter 4 of the Determination); and
- **Waste emissions** from waste disposal – either in landfill, as management of wastewater or from waste incineration (see Chapter 5 of the Determination).

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

Four estimation methods are provided in the Determination ranging from low-cost simple default methods to higher order methods requiring sampling and analysis of inputs or direct monitoring of emissions.

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

The four Determination estimation methods are:

- **Method 1:** specifies the use of designated EFs in the estimation of emissions against plant-specific activity data (e.g. production, consumption, or throughput of fuels). These EFs can be Australian-specific, state/territory-specific, or an IPCC default where a source is minor and Australian-specific data are not available.

  Australia's national inventory includes activity data or direct-entry emissions from these methods, though different EFs may be applied in the inventory when new information becomes available (such as new research) prior to inclusion in the Determination.

- **Method 2:** a plant-specific method using industry sampling and Australian standards, international standards, or equivalent standards for analysis of fuels and raw materials. This method enables corporations to undertake additional measurements to gain more accurate estimates for emissions for that particular facility. Method 2 draws on the large body of Australian and international documentary standards prepared by standards organisations to provide the benchmarks for procedures for the analysis of, typically, the critical chemical properties of the fuels being combusted. Method 2 was developed using existing technical guidelines used by reporters under the *Generator Efficiency Standards* program (AGO 2000) (AGO 2006).

  Australia's national inventory may use activity data and EFs or other plant-specific parameters collected using this method, depending on the analysis of the quality of the data and in accordance with the decision tree set out in NIR Volume 1, Figure 1.3.

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

- **Method 4:** is a different approach to the estimation of emissions. Rather than using the analysis of the chemical properties of inputs (or in some case, products), method 4 aims to directly monitor greenhouse emissions arising from an activity. This approach can provide a higher level of accuracy in certain circumstances, depending on the type of emissions process. It is likely to be more data intensive than other approaches.

  The national inventory may use emissions data generated using NGER scheme method 4 depending on the analysis of the quality of the data and in accordance with the decision tree set out in NIR Volume 1, Figure 1.3.

- **Other:** incidental reporting provisions are available under NGER scheme Regulation 4.27 for estimating emissions below 12 kt CO_2-e for fuel combustion, and for non-combustion below 3 kt CO_2-e per source or 12 kt CO_2-e per facility. This provision allows reporters to use indicators to estimate emissions for small sources, which must be prepared in accordance with the accuracy and completeness provisions under Section 1.13 of the Determination. These provisions require that emissions are not systemically over- or under- estimated.

The national inventory may use emissions data generated using the other NGER scheme method.

Implementation of the NGER (Measurement) Determination

The NGER scheme has been in operation for over a decade. The majority of carbon dioxide (CO_2) emissions are estimated using method 2 or 3, using analysis of carbon content of fuels or other inputs.

Around a third of CO_2 emissions are estimated using method 1. Less than 1 per cent of CO_2 emissions are estimated using method 4 (Figure A5.1.1). This pattern of NGER scheme method choice reflects the significance of the source and the likely variability in the carbon content of the source. That is, the carbon content of fuels used in Australia are well known, are relatively homogenous, and the associated uncertainties are low (see Tables A2.1.1, A2.1.2). There is, therefore, minimal benefit from direct monitoring. For example, the majority of emissions from the combustion of coal are estimated using method 2, 3 or 4. However, method 1 continues to be used principally for petroleum products, which tend to be homogenous in character and for which the payoff from additional measurement effort is often limited. Choices made by companies for gas lay somewhere between coal and petroleum products.

Figure A5.1.1 2021–22 NGER scheme CO_2 emissions: share of emissions by NGER scheme method

Source: NGER scheme 2021–22 (CER 2022). EF = emissions factor, D = default, CS = country-specific, PS = plant-specific.

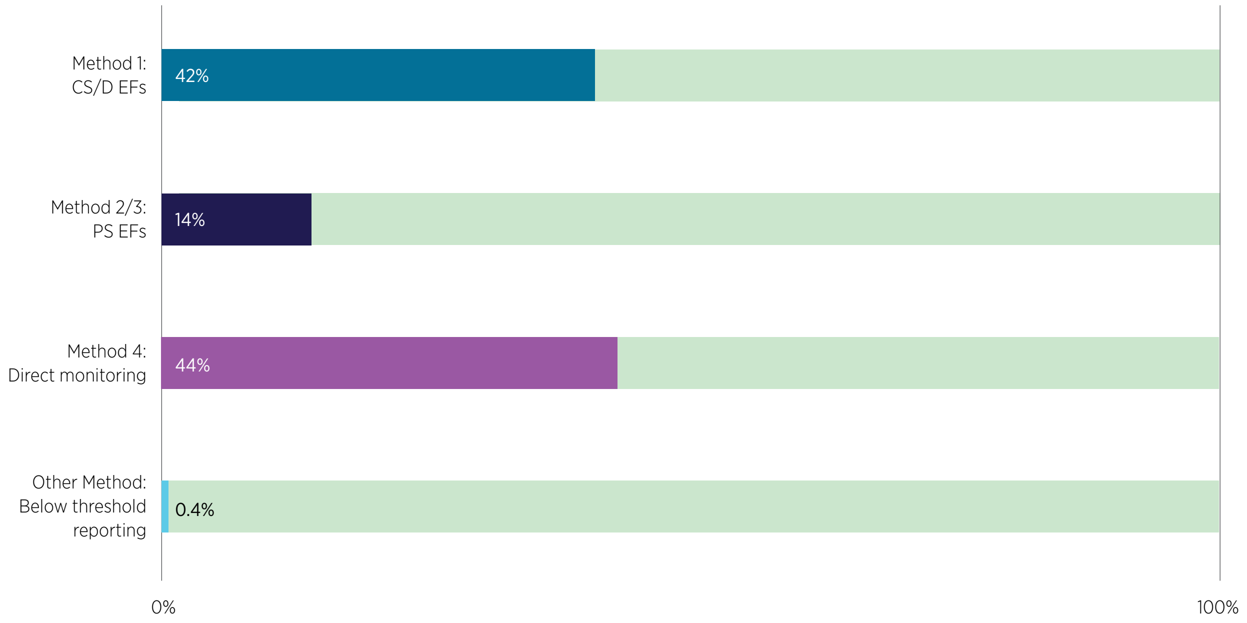
There is a similar story when choices made about estimation methods used for methane are considered (Figure A5.1.2). Almost half of CH_4 emissions were estimated using direct monitoring of emissions while around two fifths of CH_4 emissions were estimated using method 1.

As with CO_2 reporting, the choices available within the NGER scheme have resulted in the use of actual measurements from facilities to determine emissions for major sources of CH_4. This outcome relates principally to reporting by underground coal mines, which are only able to use directly monitored estimates.

Engineering calculation methods in NGER are underpinned by the latest Australian and international research on emissions intensities of different oil, gas, and coal operations and technologies. Australian and international standards are applied, along with industry best practice. The NGER Determination general principles specify that uncertainties in emission estimates, which includes engineering calculations, must be minimised and any estimates must neither be over nor under estimates of the true values at a 95% confidence level.

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

Figure A5.1.2 2021–22 NGER scheme CH_4 emissions: share of emissions by NGER scheme method

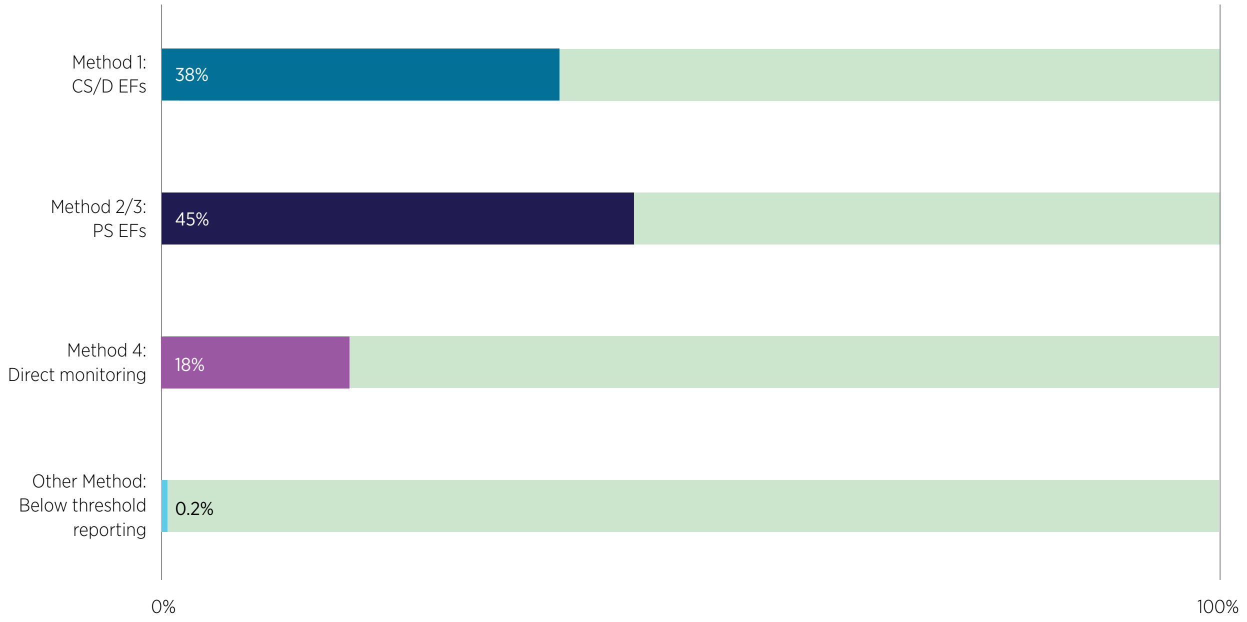


Source: NGER scheme 2021–22 (CER 2022). EF = emissions factor, D = default, CS = country-specific, PS = plant-specific.

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

Methods used for N_2O and synthetic gases are presented in Figure A5.1.3 and Figure A5.1.4.

Figure A5.1.3 2021–22 NGER scheme N_2O emissions: share of emissions by NGER method



Source: NGER scheme 2021–22 (CER 2022). EF = emissions factor, D = default, CS = country-specific, PS = plant-specific.

Figure A5.1.4 2021–22 NGER scheme synthetic gas emissions: share of emissions by NGER method

Source: NGER scheme 2021–22 (CER 2022). EF = emissions factor, D = default, CS = country-specific, PS = plant-specific. Synthetic gases refer to SF_6, NF3, HFCs, and PFCs.

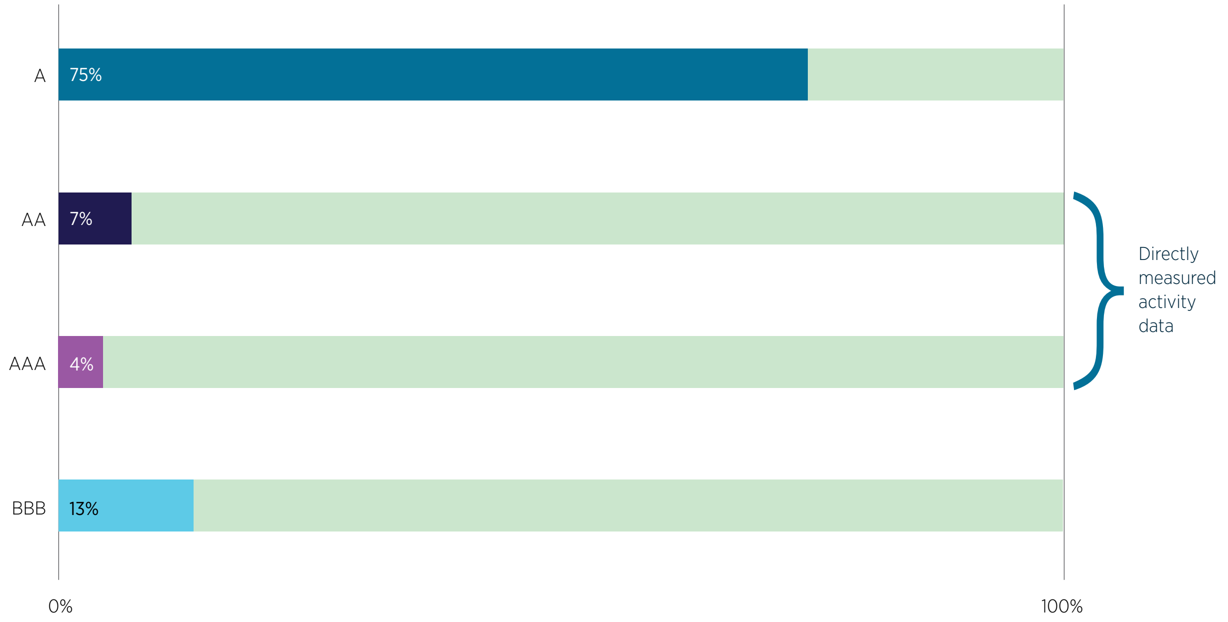
Activity data

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

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

A recent analysis of the choices made by companies with respect to the quality of their activity data inputs is presented in Figure A5.1.5. Of reported activity data points under the NGER scheme, 75 per cent is derived from commercial transactions and requires no new measurements to be undertaken by the company in order to meet reporting requirements.

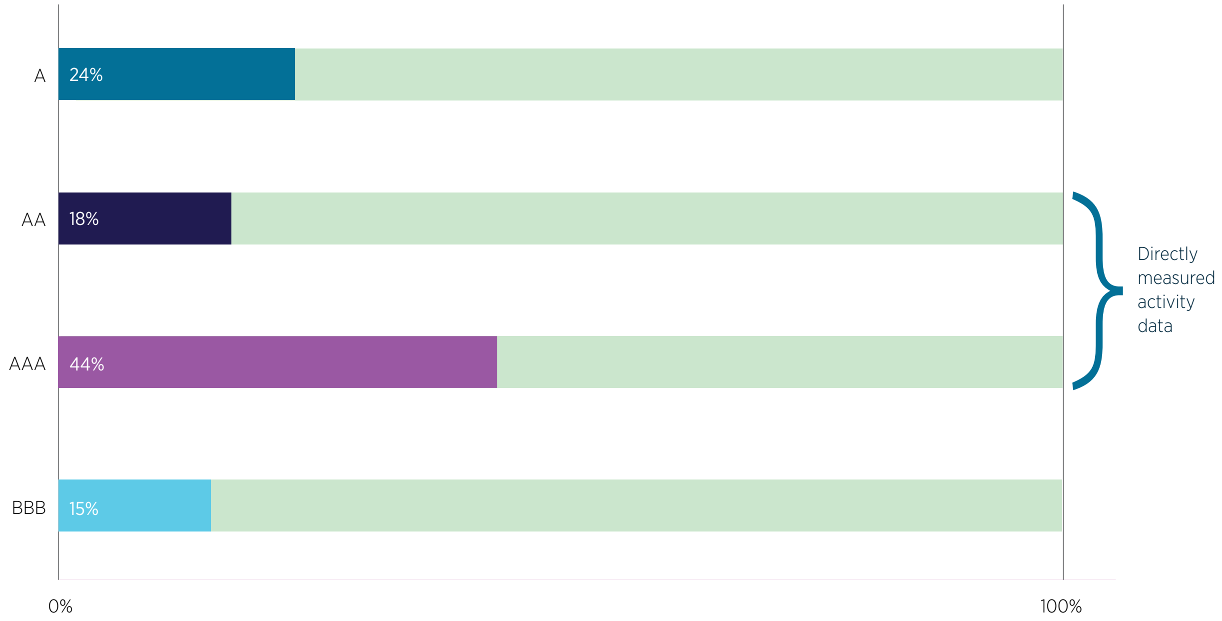
Figure A5.1.5 Activity data selected by NGER scheme reporters for 2021–22 reporting by percentage of data points



Source: NGER scheme 2021–22 (CER 2022). A = commercial transaction, AA = fuel stock change, AAA = direct measurement, BBB = industry best practice.

However, in terms of emissions, companies have tended to choose to use actual measurements of activity to underpin emissions estimates (Figure A5.1.6). The largest share of emissions were estimated using 'AAA' activity data inputs, i.e. estimates of fuel measured at the point of combustion at an accuracy level consistent with standards required to support commercial activity.

Figure A5.1.6 **Activity data selected by NGER scheme reporters for 2021–22 reporting by percentage of emissions**



Source: NGER scheme 2021–22 (CER 2022). A = commercial transaction, AA = fuel stock change, AAA = direct measurement, BBB = industry best practice.

It follows that companies have generally used existing commercial data for relatively minor emissions sources. While commercial data accounted for around three quarters of the data points used in emissions estimation processes, these data points only related to around one quarter of the estimated emissions.

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

Data integrity

Being a key input into Australia's national inventory, data submitted under the NGER scheme are subject to rigorous quality control measures. The UNFCCC and Paris Agreement transparency, accuracy, completeness, comparability, and consistency (TACCC) principles are codified in the NGER scheme under the section 1.13 general principles of the Determination and are important considerations in verification and compliance processes.

Reports submitted under the NGER Act are collected through an online, secure proforma-based system and reviewed by the Clean Energy Regulator (CER), an independent Commonwealth statutory authority, for potential non-compliance with legislative obligations for a period of up to 5 years from the date of submission. Assessment processes compare reported quantities with industry normative values and independent sources of information and are cross-referenced with legislative reporting requirements as set out in the *National Greenhouse and Energy Reporting Regulations 2008* and the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*.

The CER regulates the NGER scheme in accordance with its compliance policy which takes a proportionate approach to mis-reporting. The CERs approach includes helping scheme participants to understand how to comply with their obligations and an overall approach to deter, detect and respond to non-compliance to ensure ongoing scheme integrity.

Education

The CER assists NGER scheme reporters to understand their rights and obligations through education and training programs. It recognises that engagement, education and support, in the first instance, assist participants to meet obligations and avoid inadvertent non-compliance.

A range of calculators, guidelines, frequently asked questions (FAQs), and training videos are published on the CERs forms and resources, webpage. The CER also hosts a series of webinar and presentation events to assist in reporter education.

Monitoring

NGER scheme reports are subject to rigorous monitoring and compliance measures. Monitoring compliance with legislative reporting obligations includes:

- **Desktop reviews:** Officers at the CER examine the information reported by all participants and selects certain reporters for more detailed assessment according to compliance priorities and risk.
- **Greenhouse and energy audits:** The CER uses an external audit program to verify the information reported to it. The audits are typically targeted to areas of particular interest to the CER for example to review implementation of new reporting requirements or in response to previous mis-reporting. These audits are undertaken by auditors accredited through inclusion in the Register of Greenhouse and Energy Auditors.
- **Site visits:** Authorised officers of the CER are empowered to enter any premises for the purposes of determining compliance with the NGER Act.
- **Data analysis:** The CER compares NGER scheme data with data and information from other schemes (e.g. the Australian Carbon Credit Unit Scheme, Renewable Energy Target) or other Government sources (e.g. the Australian Energy Market Operator – AEMO) to identify anomalies and reporting errors.

Compliance and enforcement

When the CER identifies non-compliance, it takes action in the first instance to stop it from continuing, and when required, takes further enforcement actions. Enforcement action is likely to result when:

- there are reasonable grounds to suspect that a serious civil contravention or criminal offence, including fraud, is occurring, or
- the client has not demonstrated sufficient willingness to return to compliance, or
- there are repeated or habitual relapses into non-compliance, or
- conduct that appears to involve deliberate or intentional non-compliance has been displayed.

The CER publishes its compliance and enforcement priorities on its website each year. It has a range of legislated powers giving it compliance and enforcement powers, including imposing penalty provisions for non-compliance under the NGER Act.

Most penalty provisions for non-compliance under the NGER Act impose civil penalties. Civil penalty provisions may lead to financial penalties and are not considered criminal offences. Most civil penalty provisions under the NGER Act relate to a person's failure to meet registration requirements, reporting requirements, record-keeping requirements or auditing requirements. The penalties for non-compliance are described in more detail on the CERs website: Record keeping and compliance.

Where significant inaccuracies are detected in reported data, the CER can seek resubmission of data from the relevant reporting corporation. These compliance actions are completed prior to inventory submission, resulting in the most accurate available data being used in Australia's national inventory.

2021–22 reporting and compliance results

For the 2021–22 NGER scheme reporting period, seven per cent of reporters were required to resubmit their data to return to compliance. 16 per cent of oil and gas reporters were selected for reasonable assurance audit under section 74 of the *National Greenhouse and Energy Reporting Act 2007* to obtain independent verification against extensive new emissions estimation methods. Two reporters entered into Enforceable Undertakings to improve the accuracy and completeness of reporting (CER 2023)

On 28 February 2023, the CER published the annual NGER scheme data for the 2021–22 reporting year.

For the 2021–22 year, corporations reported a total of:

- 310 million tonnes of direct (scope 1) greenhouse gas emissions (carbon dioxide equivalence),
- 84 million tonnes of indirect (scope 2) greenhouse gas emissions (carbon dioxide equivalence), and
- 3,699 petajoules net energy consumed.

More details are available on the CERs 2021–22 published data highlights website.

NGER scheme reviews

As part of its commitment to continuous improvement of the national inventory, DCCEEW is responsible for the development and annual review and update of the NGER scheme's facility-level emissions estimation methods, based on best available science, data, technologies and practices.

Every five years' there is an additional contribution to this review and update process – a review by the independent Climate Change Authority (CCA). NGER scheme legislation requires the CCA to review the operation of the NGER legislation and as part of this process the CCA can make recommendations for improvement.

In December 2023 the CCA published its second review of the NGER Scheme. 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). Most recommendations require further scientific, technical, and economic analysis to determine their implications, and to inform the Government's response to the CCA review. Per legislative requirements, the Australian Government is considering these recommendations and will release its response by mid 2024.

A5.2 The Australian Energy Statistics

The Australian Energy Statistics (DCCEEW 2023) of energy use by economic sector and fuel has been compiled since the 1970s and are published annually. The statistics provide a comprehensive and detailed 'bottom-up' quantification of energy use in Australia. They are reconciled with 'top-down' statistics of all major fuels in Australia, collected from the suppliers of those fuels i.e., the coal, oil, gas and electricity industries.

These statistics have been historically compiled from an annual fuel and electricity survey supplemented by a variety of other sources of information.

The AES utilises data collected under the National Greenhouse and Energy Reporting (NGER) scheme as the primary source of energy consumption data. NGER scheme reporting is compulsory for facilities over specified energy and emissions thresholds and provides greater coverage than was available from the previous voluntary Fuel and Electricity Survey.

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

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

Several re-allocations to the AES are required in order to:

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

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

Revisions are made to the AES to update historical data within the time series. These revisions are made to ensure that the AES presents an accurate picture of Australian energy production and use. Often a revision will reflect changes in source data, such as the NGER scheme or Australian Petroleum Statistics (APS) (DCCEEW 2023). The AES can also be revised to correct errors or to account for changes in estimation techniques. Additional information regarding revisions is available in the Guide to the Australian Energy Statistics published online: Australian Energy Update 2023.

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

Activity data for the Inventory time series, reported by category level and fuel type, is available on the Australian National Greenhouse Accounts website.

Comparison with international data

The Australian Energy Statistics is the common source of energy data for the preparation of the national inventory, as well as the basis for Australia's report to the International Energy Agency (IEA). Some differences occur from year to year between the activity data in the inventory tables, and the data published by the IEA.

A project undertaken by the Department to reconcile the data provided to the IEA with the published Australian Energy Statistics data used in the inventory found that the data reported to the IEA was consistent with the data published in the *Australian Energy Statistics* (in petajoules units).

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

- The energy conversion used by the IEA is a significant cause of the differences, with the data provided to the IEA being processed by methods outside of the control of Australia (including the use of default energy content values as compared to facility specific NGER scheme data); and
- Coal production data reported in the inventory tables are significantly higher (around 13–25 per cent) than those reported to the IEA. The reason for this difference is that the coal production reported to the IEA only comprises black coal production and does not include brown (lignite) coal production. The IEA data does correspond with coal production reported in Australia's inventory tables when brown coal production is included.

During July 2014 the IEA conducted a Statistics Mission to Australia. Officers of the Department responsible for compiling the National Inventory Report had the opportunity to raise with the IEA the issue of differences between data reported by Australia in the inventory tables and data published by the IEA. The IEA observed that at the higher level, the inventory tables fuel consumption was generally in good agreement with the IEA. A better understanding as to why differences exist between the IEA/inventory tables for petroleum fuels was established; Australia submits petroleum data on the 5th of each month to the IEA, whereas the inventory tables are based on the AES which represent Australia's financial year (i.e. 1 July 2020 to 30 June 2021). Therefore, differences will exist due to accounting period inconsistencies and revisions to data published annually in the AES.

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

2004–2005	0.037	0.049	0.037	0.049
1998–2003	0.037	0.025	0.053	0.048

A5.3 Appendices to Chapter 3, Energy

A5.3.1 Emission factors in fuel combustion

This section contains information on the emission factors and estimation methodology used across all elements of the Energy sector for fuel combustion.

CO_2 emissions and emission factors

In general, emissions of CO_2 from the combustion of each fuel, *k,* in each economic sector, *h*, is estimated by:

$$E_{hk} = (F_{hk} . EF_{hk} . P_{hk} / 100) - S_{hk} . 44/12 \qquad \text{(A5.3.1.1)}$$

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

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

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

P_{hk} = the oxidation factor (in per cent) of fuel k

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

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

Solid fuels

Coal

Approximately 90 per cent of all coal consumed in Australia is used by the electricity generation industry. Under the NGER scheme, all electricity generators who consume coal as their primary fuel must sample and analyse their coal and report their facility specific CO_2 EF. After the electricity industry, the largest user of coal in Australia is the steel industry. The steel industry has provided a representative CO_2 EF of 91.8 Gg/PJ for black coal used in iron/steel/coke production (Leung 2001). This EF has been verified using industry data reported under the NGER scheme as being representative. For black coal used in other industries, a representative CO_2 EF of 90.0 Gg/PJ has been derived from NGER scheme data. All EFs are reported in Table A5.3.1.

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

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

Coke

The CO_2 EF for coke is derived from a carbon balance conducted on the coke oven subsector. Carbon input into coke ovens is estimated and balanced against carbon contained in the fuel and product outputs from coke ovens. The carbon content of coke is determined as the carbon content required to achieve a carbon balance for the overall coke oven process. The resulting coke EF varies slightly from year to year depending on the balance of inputs and outputs, in a range between 103.8 and 109.4 Gg/PJ which is comparable to the IPCC default factor (Table A5.4.21). The underlying data used to estimate the coke EF is confidential due to the sector being characterised by a limited number of producers.

Coal By-Products

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

Liquid fuels

Refined Petroleum Products

Australian oil tends to be of the light crude variety and the petroleum products generated by Australian refineries reflect the characteristics of these supplies. The country-specific EFs for marketable petroleum products for this inventory are taken from GHD Australia (GHD 2006), which reports the results of a review of Australian petroleum products. EFs are listed in Table A5.3.1.1. The EFs for petroleum fuels were further validated as being representative in a more recent review of Australia's liquid fuels characteristics conducted by Orbital Australia (Orbital Australia 2011). The Orbital review also confirmed the representativeness of the EF for fuel oil which was obtained from large industrial users of fuel oil (Le Cornu 1996) Bawdin 1996)

Other Petroleum Products

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

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

Solvents and Bitumen

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

Gaseous fuels

Natural Gas

A national EF has been estimated for natural gas using data on the composition of natural gas in each pipeline system, as published by the Australian Gas Association for various years (AGA 1988–2002), weighted by the volumes of gas consumed from each pipeline system (see Table A5.3.1.1).

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

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

Town Gas

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

Biomass fuels

Emissions of CO_2 from biomass fuels are required to be reported as a Memo item. The CO_2 EFs for bagasse, wood and wood waste combusted in commercial and residential sectors are listed in Table A5.3.1.1. A detailed explanation of residential wood heater EFs is provided in section 3.6. Factors for bagasse (95.0 Gg/PJ) and ethanol (67.3 Gg/PJ) are based on IPCC 2006 Guidelines (IPCC 2006).

Table A5.3.1.1 Emission factors for CO_2

Fuel Type	Fuel	CO_2 emission factor ($Gg\ CO_2/PJ$)
Coal derived fuels	Coal used in public electricity generation (a)	85.6–95.9
	Coal used in steel industry (ka)	91.8
	Black coal used by other industry (a)	90.0
	Brown coal used by industry (a)	93.5
	Coke (l)	109.4
	Coal by-products (coke oven gas) (b)	37.0
	Coal by-products (coal tar) (b)	81.8
	Coal by-products (liquefied aromatic hydrocarbons (d)	69.7
	LPG (c)	60.2
Petroleum fuels	Naphtha (d)	69.8
	Automotive gasoline (c)	67.4
	Aviation gasoline (c)	67.0
	Lighting Kerosene (c)	68.9
	Aviation turbine fuel (c)	69.6
	Power Kerosene (c)	68.9
	Heating oil (c)	69.5
	Diesel Oil (c)	69.9
	Industrial Diesel Fuel (c)	69.9
	Petroleum products nec (d)	69.8
	Refinery gas and liquids (d)	54.7
	Refinery coke (d)	92.6
	Fuel oil (m)	73.6
	Tyres (j)	81.6
	Solvents (d)	69.7
	Bitumen (d)	80.7
Gases	Natural gas (including coal seam gas) (e)	51.4
	Natural gas (Basic chemicals sector) (e)	51.4
	Ethane (f)	56.5
	Town gas (c)	60.2
Biomass fuels	Wood and wood waste (g)	94.0
	Wood (for Residential subsector) (h)	77.5
	Ethanol (d)	67.3
	Bagasse (d)	95.0

Source: (a) NGER scheme. (b) Deslandes and Kingston (1997). (c) GHD (2006). (d) IPCC (2006). (e) AGA (1988–2002). (f) ASHRAE (2001). (g) Todd (1993). (h) Todd (2011). (j) GHD (2006). (k) L. Leung BHP (2001). (l) Derived from carbon balance within coke oven/iron and steel subsectors. (m) Industry data confirmed by Orbital (2011).

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

Oxidation Factors for CO_2

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

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

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

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

Non-CO_2 emissions

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

For non-CO_2 gases, emissions are estimated by:

$$E_{hkl} = F_{hk} \cdot E_{fhk} \qquad \text{(A5.3.1.2)}$$

Where E_{hkl} = amount greenhouse gas l emitted from combustion of fuel type k, in economic sector h (in Gg)
F_{hk} = amount of fuel type k combusted in sector h (in PJ)
E_{fhkl} = technology weighted EF (in Gg/PJ) for greenhouse gas l, from fuel type k in sector h

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

The non-CO_2 factors are updated according to the IPCC 2006 Guidelines (IPCC 2006) and US EPA (2005) default values for uncontrolled emissions from various source categories, corrected for control technologies in use in Australia. In Australia, emissions from stationary fuel combustion source are controlled to varying degrees. The EFs for non-CO_2 greenhouse gases for each sector are summarised in Table 5A.4.1. These derived EFs use weightings calculated according to the equipment type shares to reflect the mix of equipment types, including both stationary and mobile equipment, in use for those sectors. In the absence of evidence to differentiate gas variations in measured gas concentrations between boilers, differences cannot be attributed to differences in boiler type – e.g. tangentially-fired, boiler size, boiler load, or combustion modifications – e.g. low NO_x burners, it is assumed that the gas EFs are dependent on fuel type only.

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

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

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

SO_2 emissions

Data on default emission factors was obtained from the following sources:

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

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

Table A5.3.1.2 SO_2 emission factors

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

Source: Australian Institute for Petroleum (1996), National Pollutant Inventory (petroleum refining, (DAWE 1998–2020)), Department of Primary Industries and Energy (pers. comm. 1998) (for default coal values) and Annual Gas Industry Statistics (AGA 1988–2002).

A5.3.2 Additional information on Energy activity data

Table A5.3.2.1 Non-CO_2 Emission Factors: 1.A.1 and 1.A.2

	Emission Factors (Mg / PJ)					
Fuel Type	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
1.A.1.b Petroleum Refining (ANZSIC Class 1701)						
Natural Gas	1.0	0.4	605.1	47.2	1.5	2.3
Crude Oil	1.7	0.5	349.8	49.4	0.8	57.0
Kerosene	2.9	0.6	323.4	49.7	0.7	57.0
Diesel Oil	0.7	0.5	323.4	49.7	0.7	57.0
Fuel Oil	1.7	0.5	349.8	49.4	0.8	1,282.1
LPG	0.9	1.8	325.6	58.1	2.3	2.3
Naphtha	0.7	0.5	323.4	49.7	0.7	57.0
Refinery Gas and Liquids	1.0	0.1	349.8	49.4	0.8	2.3
Refinery Coke	1.0	0.1	349.8	49.4	0.8	370.0
1.A.1.C Coke Oven Operation (ANZSIC Subdivision 21)						
Black Coal	1.0	0.8	425.0	113.6	1.0	370.0
Coke Oven Gas	1.0	0.6	495.5	68.8	1.6	370.0
Fuel Oil	2.0	0.5	217.8	92.2	0.9	1,282.1
Briquette Manufacture (ANZSIC Subdivision 17)						
Brown Coal	1.0	0.7	110.5	88.6	0.8	150.0
Coal Mining (ANZSIC Division B)						
Brown Coal Briquettes	1.0	0.8	307.7	92.1	1.0	150.0
Natural Gas	2.0	0.9	107.1	19.3	1.6	2.3
Automotive Gasoline	47.6	1.9	1,095.2	7,000.0	1,080.0	15.0
Diesel Oil	3.6	3.6	3,681.2	1,132.8	505.6	57.0
LPG	1.2	1.4	902.5	177.0	50.1	2.3
Petroleum products nec	1.1	0.9	901.5	173.3	49.4	57.0
Ethanol	2.9	0.6	667.4	405.4	859.8	0
1.A.1.c.ii Oil and Gas Extraction (ANZSIC Division B)						
Natural Gas	2.0	0.9	107.1	19.3	1.6	2.3
Ethane	1.0	0.1	112.2	20.2	1.6	2.3
Diesel Oil	3.2	3.1	3,227.9	976.4	431.2	57.0
Fuel Oil	1.5	0.8	913.4	173.1	49.4	1,282.1
LPG	1.2	1.4	902.5	177.0	50.1	2.3
Petroleum products nec	1.9	0.9	905.1	299.7	68.5	57.0
Unprocessed Natural Gas	404.6	0.9	107.1	19.3	1.6	2.3
Natural Gas Transmission (ANZSIC Subdivision 50–53)						
Natural Gas	1.0	0.9	65.9	9.6	2.1	2.3
Gas Production and Distribution (ANZSIC Subdivision 27)						
Natural gas	3.4	0.9	120.6	30.0	0.9	2.3
LPG	3.6	1.2	126.1	33.6	1.2	2.3
1.A.2.a Iron and steel (ANZSIC Group 211–12)						
Black coal	1.0	0.8	425.0	113.6	1.0	370.0

	Emission Factors (Mg / PJ)					
Fuel Type	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
Natural Gas	0.9	0.6	499.5	69.4	1.5	2.3
Coke Oven Gas	1.0	0.6	523.2	72.7	1.6	370.0
Diesel Oil	1.8	1.8	1,617.4	522.4	209.1	57.0
LPG	47.6	1.9	2,645.7	3,968.6	3571.4	2.3
1.A.2.b Non-Ferrous Metals (ANZSIC Group 213–14)						
Black Coal	1.0	0.7	191.0	91.2	0.9	370.0
Coke	1.0	0.7	191.0	91.2	0.9	370.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	1.0	0.6	452.7	36.2	1.7	2.3
Diesel Oil	3.3	3.3	3,323.6	1,020.0	453.3	57.0
Fuel Oil	1.7	0.5	355.8	50.6	0.8	1,282.1
Naphtha	0.6	0.5	327.3	51.0	0.7	57.0
Other Petroleum and Coal Product Manufacturing (ANZSIC Class 1709)						
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Natural Gas	0.9	0.9	83.5	10.4	2.1	2.3
Diesel Oil	3.7	3.7	3,809.5	1,177.1	526.7	57.0
Fuel Oil	2.9	0.3	128.6	13.3	0.8	1,282.1
Liquefied Aromatic Hydrocarbons	0.2	0.4	59.0	14.3	0.6	57.0
LPG	47.6	1.9	2,645.7	3,968.6	3,571.4	2.3
1.A.2.c Chemicals (ANZSIC Subdivision 18–19)						
Black Coal	1.0	0.7	110.5	88.6	0.8	370.0
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Natural Gas	1.0	0.5	489.3	38.8	1.5	2.3
Ethane	1.0	0.1	512.6	40.7	1.6	2.3
Diesel Oil	0.6	0.5	302.8	50.7	4.1	57.0
Liquefied Aromatic Hydrocarbons	0.6	0.5	280.0	43.4	0.7	57.0
LPG	11.6	2.0	821.0	945.3	815.8	2.3
Naphtha	0.6	0.5	280.0	43.4	0.7	57.0
Petroleum products nec	0.6	0.5	280.0	43.4	0.7	57.0
1.A.2.d Pulp, Paper and Print (ANZSIC Subdivisions 14–16)						
Black coal	1.0	0.7	110.5	88.6	0.8	370.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	92.8	11.1	2.0	2.3
Diesel Oil	0.5	0.5	101.4	14.8	0.7	57.0
LPG	0.9	2.6	104.9	28.2	3.2	2.3
Petroleum products nec	0.5	0.5	101.4	14.8	0.7	57.0
1.A.2.e Food Processing, Beverages and Tobacco (ANZSIC subdivision 11–12)						
Black coal	1.0	0.7	119.2	92.1	0.8	370.0
Brown coal briquettes	1.0	0.7	119.2	92.1	0.8	150.0
Wood and Wood waste	9.2	5.8	175.8	215.0	6.1	0
Bagasse	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.2	9.1	2.0	2.3

	Emission Factors (Mg / PJ)					
Fuel Type	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
Diesel Oil	3.2	3.2	3,205.1	989.1	441.6	57.0
Fuel Oil	2.6	0.3	133.6	13.6	0.8	1,282.1
LPG	0.9	3.4	78.1	33.5	4.3	57.0
Ethanol	2.9	0.6	667.4	405.4	859.8	2.3
1.A.2.f Non-metallic Minerals (ANZSIC Subdivision 20)						
Black coal	1.0	0.8	343.1	83.0	0.9	370.0
Coke	1.0	0.8	343.1	83.0	0.9	370.0
Natural Gas	1.0	0.2	620.4	48.3	1.2	2.3
Diesel Oil	3.7	3.7	3,809.5	1,177.1	526.7	57.0
Fuel Oil	1.6	0.5	398.8	57.7	0.8	1,282.1
LPG	42.6	1.9	2,401.5	3,548.2	3,187.0	2.3
Petroleum products nec	0.7	0.5	376.5	58.0	0.8	57.0
1.A.2.g.vi Textile, Clothing, Footwear and Leather (ANZSIC Subdivision 13)						
Black Coal	1.0	0.7	110.5	88.6	0.8	370.0
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Natural Gas	0.9	0.8	64.0	9.2	2.0	2.3
Fuel Oil	2.6	0.4	134.9	14.5	0.8	1,282.1
Petroleum products nec	0.5	0.4	79.3	15.3	0.6	57.0
Fabricated Metal Products (ANZSIC Subdivision 22)						
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Diesel Oil	0.8	0.8	586.7	145.7	48.5	1,282.1
LPG	47.6	1.9	2,645.7	3,968.6	3,571.4	2.3
1.A.2.g.i Machinery and Equipment (ANZSIC Subdivision 24)						
Natural Gas	0.9	0.8	169.1	16.5	2.0	2.3
Diesel Oil	3.7	3.7	3,809.5	1,177.1	526.7	57.0
LPG	47.6	1.9	2,645.7	3,968.6	3,571.4	2.3
Furniture and Other Manufacturing (ANZSIC Subdivision 25)						
Natural gas	0.9	0.8	159.4	15.8	2.0	2.3
1.A.2.g.v Construction (ANZSIC Division E)						
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Kerosene	2.9	0.6	59.1	14.3	0.6	57.0
Diesel Oil	3.7	3.7	3,809.5	1,177.1	526.7	57.0
Fuel Oil	2.9	0.6	913.4	173.1	49.4	1,282.1
LPG	1.0	0.1	64.8	36.2	4.8	2.3
Glass and Glass Products (ANZSIC Group 201)						
Natural Gas	1.0	0.1	1,010.0	75.0	1.1	2.3
LPG	0.9	0.8	507.5	76.9	1.0	2.3
Ceramics (ANZSIC Group 202)						
Black coal	1.0	0.8	525.9	78.6	1.0	370.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	1.0	0.1	1,000.5	74.4	1.1	2.3
Diesel Oil	3.7	3.7	3,809.5	1,177.1	526.7	57.0

	Emission Factors (Mg / PJ)					
Fuel Type	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
Fuel Oil	1.0	0.6	515.2	76.7	0.8	1,282.1
LPG	17.0	1.1	1,249.8	1,418.7	1,232.1	2.3
Petroleum products nec	1.0	0.6	515.2	76.7	0.8	57.0
Cement, Lime, Plaster and Concrete (ANZSIC Group 203)						
Black coal	1.0	0.8	525.9	78.6	1.0	370.0
Coke	1.0	0.8	525.9	78.6	1.0	370.0
Tyres	0.7	0.5	323.8	7.6	0.9	57.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	1.0	0.1	953.0	71.1	1.1	2.3
Coke Oven Gas	1.0	0.1	998.4	74.5	1.2	370.0
Diesel Oil	3.5	3.4	3,503.9	1,078.4	480.9	57.0
Fuel Oil	1.3	0.6	307.5	41.1	0.8	57.0
Solvents	0.8	0.6	295.0	41.2	0.8	57.0
LPG	47.0	1.9	2,616.7	3,920.1	3,527.4	2.3
Petroleum products nec	0.8	0.6	295.0	41.2	0.8	57.0
1.A.2.g.iii Mining excluding fuels (ANZSIC subdivisions 08–10)						
Black coal	1.0	0.8	307.7	92.1	1.0	370.0
Coke	1.0	0.8	307.7	92.1	1.0	370.0
Natural Gas	2.0	0.9	107.1	19.3	1.6	2.3
Coke Oven Gas	2.1	0.9	112.2	20.2	1.6	370.0
Diesel Oil	3.6	3.6	3,735.0	1,151.4	514.4	57.0
Fuel Oil	1.5	0.8	913.4	173.1	49.4	1,282.1
LPG	1.2	1.4	902.5	177.0	50.1	2.3
Petroleum products nec	1.1	0.9	901.5	173.3	49.4	57.0

Source: Derived from Table A5.3.2.3.

Table A5.3.2.2 Non-CO_2 Emission Factors: 1.A.4 Other Sectors

	Emission Factors (Mg / PJ)					
Fuel Type	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
281 Water, Sewerage and Drainage						
Natural Gas	0.9	0.9	59.1	14.3	2.1	2.3
Kerosene	2.9	0.6	59.0	14.3	0.6	57.0
Diesel Oil	3.7	3.7	3,809.5	1,177.1	526.7	57.0
50–53 Other Transport, Services and Storage (part)						
Diesel Oil	3.7	3.7	3,809.5	1,177.1	526.7	57.0
Div. F, G Wholesale and Retail Trade						
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Town Gas	0.9	0.9	64.5	9.1	2.1	2.3
Diesel Oil	0.7	0.4	59.0	14.3	0.6	57.0
Fuel Oil	1.3	0.3	128.6	13.3	0.8	1282.1
LPG	0.9	3.8	64.8	36.2	4.8	2.3

	Emission Factors (Mg / PJ)					
Fuel Type	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
Div. H, P, Q Accommodation, Cultural and Personal						
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Diesel Oil	0.7	0.4	59.0	14.3	0.6	57.0
LPG	0.9	3.8	64.8	36.2	4.8	2.3
Div. J Communication						
Natural Gas	1.0	1.0	67.6	9.5	2.2	2.3
Kerosene	2.9	0.6	59.0	14.3	0.6	57.0
Diesel Oil	0.7	0.4	59.0	14.3	0.6	57.0
Div. K, L Finance, Insurance, Property and Business						
Natural Gas	1.0	1.0	67.6	9.5	2.2	2.3
Div. M Government Administration and Defence						
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Kerosene	2.9	0.6	59.0	14.3	0.6	57.0
Diesel Oil	0.7	0.4	59.0	14.3	0.6	57.0
LPG	0.9	3.8	64.8	36.2	4.8	2.3
Div. N, O Education, health and community services						
Black Coal	1.0	0.7	110.5	88.6	0.8	370.0
Brown Coal Briquettes	1.0	0.7	110.5	88.6	0.8	150.0
Wood and Wood Waste	9.2	5.8	175.8	215.0	6.1	0
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Town Gas	0.9	0.9	64.5	9.1	2.1	2.3
Kerosene	2.9	0.6	59.0	14.3	0.6	57.0
Diesel Oil	0.7	0.4	59.0	14.3	0.6	57.0
LPG	0.9	3.8	64.8	36.2	4.8	2.3
Residential						
Wood and Wood Waste (a)						
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Town Gas	0.9	0.9	64.5	9.1	2.1	2.3
Diesel Oil	0.7	0.6	59.0	14.3	0.6	57.0
LPG	1.0	0.6	64.8	36.2	4.8	2.3
1 .A.4.c Agriculture, Forestry & Fisheries: (ANZSIC Division A)						
Natural Gas	0.9	0.9	64.5	9.1	2.1	2.3
Gasoline	47.6	1.9	1,095.2	7,000.0	1,080.0	15.0
Diesel Oil	3.7	3.7	3,809.5	1,177.1	526.7	57.0
LPG	0.9	3.8	64.8	36.2	4.8	2.3

(a) See Table A5.3.3.1 for Residential biomass EFs.

Table A5.3.2.3 Derivation of non-CO_2 emission factors for stationary energy

			Emission Factors (a) (Mass/Gross Energy)				
			CH_4	N_2O (a)	NO_x	CO	NMVOC
Sector	**Fuel**	**Equipment**	MG/ PJ				
Utility excluding Electricity Generation							
1	Residual Fuel Oil	Boiler(b)	0.8	0.3	128.6	13.3	0.8
2	Gas/Diesel Oil	Boiler(c)	0.9	0.4	59.0	14.3	0.6
3	Black Coal	Dry Bottom, Wall Fired Boilers(d)	0.7	0.5	323.8	7.6	0.9
4	Black Coal	Overfeed Stoker Boilers(e)	1	0.7	110.5	88.6	0.8
5	Natural Gas	Boiler(f)	0.9	0.9	71.8	31.8	2.1
6	Gas-Fired Gas Turbines >3MW	NA(g)	3.6	0.9	125.5	31.8	0.8
Industrial							
7	Residual Fuel Oil	Boiler(h)	2.9	0.3	128.6	13.3	0.8
8	Gas/Diesel Oil	Boiler(i)	0.2	0.4	59.0	14.3	0.6
	Large Stationary Diesel						
9	Oil Engines >600 hp (447kW)	NA(j)	3.8	3.7	1,805.7	388.6	142.9
10	Liquefied Petroleum Gases	Boiler(k)	0.9	3.8	64.8	36.2	4.8
11	Black Coal	Dry Bottom, Wall Fired Boilers(l)	0.7	0.5	323.8	7.6	0.9
12	Black Coal	Overfeed Stoker Boilers(m)	1.0	0.7	110.5	88.6	0.8
13	Natural Gas	Boiler(n)	0.9	0.9	64.5	9.1	2.1
14	Gas-Fired Gas Turbines >3MW	NA(o)	3.6	0.9	125.5	31.8	0.8
15	Wood/Wood Waste	Boilers(p)	9.2	5.8	175.8	215	6.1
Kilns, Ovens, and Dryers							
16	Cement, Lime	Kilns – Natural Gas(q)	1.0	0.1	1,010.0	75.0	1.1
17	Cement, Lime	Kilns – Oil(r)	1.0	0.6	525.9	78.6	0.8
18	Cement, Lime	Kilns – Coal(s)	1.0	0.8	525.9	78.6	1.0
19	Coking, Steel	Coke Oven(t)	1.0	0.8	300.7	210.6	1.0
20	Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer – Natural Gas(u)	1.0	0.1	58.0	10.0	1.1
21	Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer – Oil(v)	1.0	0.6	167.6	15.7	0.8
22	Chemical Processes, Wood, Asphalt, Copper, Phosphate	Dryer – Coal(w)	1.0	0.8	225.2	178.1	1.8
Residential							
23	Residual Fuel Oil	Combustors(x)	1.3	0.3	128.6	13.3	0.8
24	Gas/Diesel Oil	Combustors(y)	0.7	0.6	59.0	14.3	0.6

Sector	Fuel	Equipment	Emission Factors (a) (Mass/Gross Energy)				
			CH_4	N_2O (a)	NO_x	CO	NMVOC
			MG/ PJ				
25	Liquefied Petroleum Gases	Furnaces(z)	1.0	0.6	64.8	36.2	4.8
26	Natural Gas	Boilers and Furnaces(aa)	0.9	0.9	64.5	9.1	2.1
Commercial/Institutional							
27	Residual Fuel Oil	Boilers(ab)	1.3	0.3	128.6	13.3	0.8
28	Gas/Diesel Oil	Boilers(ac)	0.7	0.4	59.0	14.3	0.6
29	Liquefied Petroleum Gases	Boilers(ad)	0.9	3.8	64.8	36.2	4.8
30	Black Coal	Dry Bottom, Wall Fired Boilers(ae)	0.7	0.5	323.8	0.9	0.9
31	Black Coal	Overfeed Stoker Boilers(af)	1.0	0.7	110.5	0.8	0.8
32	Natural Gas	Boiler(ag)	0.9	0.9	64.5	2.1	2.1
33	Gas-Fired Gas Turbines >3MW	NA(ah)	3.6	1.3	125.5	31.8	0.8
34	Wood/Wood Waste	Boilers(ai)	9.2	5.8	175.8	215.0	6.1

Source:

(a) IPCC (2006, Volume 2) Net calorific values for CH_4 and N_2O outlined in the IPCC (2006, Volume 2) were converted to gross calorific values by assuming that net calorific values are 5 per cent lower for coal and oil, 10 per cent lower for natural gas and 20 per cent lower for dry wood (Forest Product Laboratory).

(b) USEPA (2005) Pg 1.3–11 to 1.3–14. Uncontrolled emissions of NO_x and CO from residual oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) residual oil (No. 6 oil) fired industrial boilers (normal firing).

(c) USEPA (2005) Pg 1.3–11 to 1.3–14. Uncontrolled emissions of NO_x and CO from distillate oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) distillate oil (No. 6 oil) fired industrial boilers (normal firing).

(d) USEPA (2005) Pg 1.1–16 to 1.1–41 Uncontrolled emissions of NO_x and CO from pulverised coal fired dry bottom configuration (wall fired boiler). NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal fired dry bottom configuration (wall fired boiler).

(e) USEPA (2005) Pg 1.1–16 to 1.1–41 Uncontrolled emissions of NO_x and CO from pulverised coal fired overfeed stoker. NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal overfeed stoker.

(f) USEPA (2005) Pg 1.4–5 and 1.4–6. Uncontrolled emissions for NO_x, CO and NMVOC from natural gas fired large wall fired boilers (>100).

(g) USEPA (2005) Pg 3.1–10 to 3.1–11 Uncontrolled emissions for NO_x, CO and NMVOC from large stationary natural gas fired turbines.

(h) USEPA (2005) Pg 3.1–3 and 3.1–5. Pg 1.3–11 to 1.3–14. Uncontrolled emissions of NO_x and CO from residual oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) residual oil (No. 6 oil) fired industrial boilers (normal firing).

(i) USEPA (2005) Pg 1.3–11 to 1.3–14. Uncontrolled emissions of NO_x and CO from distillate oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) distillate oil (No. 6 oil) fired industrial boilers (normal firing).

(j) USEPA (2005) Pg 3.3–6. Uncontrolled emissions for NO_x, CO and NMVOC from diesel oil industrial engines.

(k) USEPA (2005) Pg 1.5–3 Uncontrolled emissions for NO_x and CO from butane emission factor for industrial boilers. NMVOC emissions estimated from Total Organic Compounds (TOC) from butane emission factor for industrial boilers.

(l) USEPA (2005) Pg 1.1–16 to 1.1–41 Uncontrolled emissions of NO_x and CO from pulverised coal fired dry bottom configuration (wall fired boiler). NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal fired dry bottom configuration (wall fired boiler).

(m) USEPA (2005) Pg 1.1–16 to 1.1–41 Uncontrolled emissions of NO_x and CO from pulverised coal fired overfeed stoker. NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal overfeed stoker.

(n) USEPA (2005) Pg 1.4–5 and 1.4–6. Uncontrolled emissions for NO_x, CO and NMVOC from natural gas fired tangentially fired boilers (all size).

(o) USEPA (2005) Pg 3.1–10 to 3.1–11 Uncontrolled emissions for NO_x, CO and NMVOC from large stationary natural gas fired turbines.

(p) USEPA (2005) Pg 1.6–8 to 1.6–11 Uncontrolled emissions for NO_x and CO from dry wood fired boilers. NMVOC emissions estimated from average emission factor for Volatile Organic Compound (VOC).

(q) Using IPCC good practice, assume 10 per cent increase in natural gas fired kilns EFs for NO_x, CO and NMVOC (USEPA 1995).

(r) Using IPCC good practice, assume 10 per cent increase in fuel oil fired kilns EFs for NO_x, CO and NMVOC (USEPA 1995).

(s) Using IPCC good practice, assume 10 per cent increase in pulverised coal fired kilns EFs for NO_x, CO and NMVOC (USEPA 1995).

(t) Using IPCC good practice, assume 10 per cent increase in pulverised coal fired coke oven EFs for NO_x, CO and NMVOC (USEPA 1995).

(u) Using IPCC good practice, assume 10 per cent increase in natural gas fired dryers EFs for NO_x, CO and NMVOC (USEPA 1995).

(v) Using IPCC good practice, assume 10 per cent increase in fuel oil fired dryers EFs for NO_x, CO and NMVOC (USEPA 1995).

(w) Using IPCC good practice, assume 10 per cent increase in pulverised coal fired dryers EFs for NO_x, CO and NMVOC (USEPA 1995).

(x) USEPA (2005) Pg 3.1–3 and 3.1–5. Pg 1.3–11 to 1.3–14. Uncontrolled emissions of NO_x and CO from residual oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) residual oil (No. 6 oil) fired industrial boilers (normal firing).

(y) USEPA (2005) Pg 1.3–11 to 1.3–14. Uncontrolled emissions of NO_x and CO from distillate oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) distillate oil (No. 6 oil) fired industrial boilers (normal firing).

(z) USEPA (2005) Pg 1.5–3 Uncontrolled emissions for NO_x and CO from butane emission factor for industrial boilers. NMVOC emissions estimated from Total Organic Compounds (TOC) from butane emission factor for industrial boilers.

(aa) USEPA (2005) Pg 1.4–5 and 1.4–6. Uncontrolled emissions for NO_x, CO and NMVOC from natural gas fired tangentially fired boilers (all size).

(ab) USEPA (2005) Pg 3.1–3 and 3.1–5. Pg 1.3–11 to 1.3–14. Uncontrolled emissions of NO_x and CO from residual oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) residual oil (No. 6 oil) fired industrial boilers (normal firing).

(ac) USEPA (2005) Pg 1.3–11 to 1.3–14. Uncontrolled emissions of NO_x and CO from distillate oil (No. 6 oil) fired industrial boilers (normal firing). NMVOC emissions estimated from Non-Methane Total Organic Compounds (NMTOC) distillate oil (No. 6 oil) fired industrial boilers (normal firing).

(ad) USEPA (2005) Pg 1.5–3 Uncontrolled emissions for NO_x and CO from butane emission factor for industrial boilers. NMVOC emissions estimated from Total Organic Compounds (TOC) from butane emission factor for industrial boilers.

(ae) USEPA (2005) Pg 1.1–16 to 1.1–41 Uncontrolled emissions of NO_x and CO from pulverised coal fired dry bottom configuration (wall fired boiler). NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal fired dry bottom configuration (wall fired boiler).

(af) USEPA (2005) Pg 1.1–16 to 1.1–41 Uncontrolled emissions of NO_x and CO from pulverised coal fired overfeed stoker. NMVOC emissions estimated from Total Non-Methane Organic Compounds (TNMOC) for pulverised coal overfeed stoker.

Table A5.3.2.4 Non-CO_2 emission factors for stationary energy – electricity

	Emission Factors (Mg/PJ energy input)				
Basic Technology	CH_4	N_2O	NO_x	CO	NMVOC
Liquid Fuels					
Fuel Oil [(a)]	0.8	0.3	186.0	14.0	2.1
Diesel [(b)]	0.9	0.4	64.0	13.0	1.4
Large diesel Oil Engine [(c)]	3.8	0.9	1,322.0	349.0	45.0
Other Liquids [(d)]	0.8	0.3	54.0	383.8	0.8
LNG [(e)]	234.5	0.9	1,331.0	340.0	80.0
Solid					
Pulverised Wall [(f)]	0.7	0.5	462.0	11.0	1.7
Tangentially Fired (black coal) [(g)]	0.7	1.3	306.0	11.0	1.7
Tangentially Fired (brown coal) [(h)]	0.7	1.3	136.0	17.0	1.7
Fluidised Bed [(i)]	0.9	58.1	54.6	11.0	1.7
Natural Gas					
Boilers [(j)]	0.7	0.5	462.0	11.0	1.7
Gas fired turbine [(k)]	0.7	1.3	306.0	11.0	1.7
Internal Combustion [(l)]	0.7	1.3	136.0	17.0	1.7
Combined cycle [(m)]	0.9	58.1	54.6	11.0	1.7
Biomass					
Wood waste boilers [(n)]	10.5	6.7	75.0	680.0	6.8
Bagasse boiler [(o)]	10.5	6.7	84.0	1,625.0	16.3

(a) CH_4 and N_2O IPCC (2006, Volume 2) value for residual oil boiler. USEPA (1995b) Pg 1.3–2 to 1.3–6. Uncontrolled emissions of CO, NO_x, and NMVOC from residual oil (No. 4–6) fired utility boilers (normal firing).

(b) CH_4 and N_2O IPCC (2006, Volume 2) value for gas/diesel oil boiler. CO, NO_x, NMVOC Distillate oil fired utility boiler data not available. Assume emissions equal those of residual oil fired utility boiler scaled by relative emissions of industrial boiler category (USEPA, 1986, Pg 1.3–2).

(c) CH_4 and N_2O IPCC (2006, Volume 2) value for large diesel oil engine. CO, NO_x, NMVOC USEPA (1995b) Pg 3.4–3

(d) CH_4 and N_2O IPCC (2006, Volume 2) value residual fuel oil/shale oil boiler.

(e) CH_4 and N_2O IPCC (2006, Volume 2) value for residual fuel oil/shale oil. CO, NO_x, NMVOC USEPA (1995) Pg 3.4–3. Assume dual fuel EFs.

(f) CH_4 and N_2O IPCC (2006, Volume 2) value for pulverised coal fired dry bottom configuration CO, NO_x, NMVOC USEPA (1995) Pg 1.1–6 and 1.1–22. Uncontrolled emissions for pulverised coal fired dry bottom configuration.

(g) CH_4 and N_2O IPCC (2006, Volume 2) assume value for pulverised coal fired dry bottom configuration CO, NO_x, NMVOC USEPA (1995) Pg 1.1–6 and 1.1–22. Uncontrolled emissions for pulverised coal fired dry bottom configuration (tangentially fired boiler).

(h) CH_4 and N_2O IPCC (2006, Volume 2) assume value for pulverised coal fired dry bottom configuration. Assume CH_4 and N_2O and NMVOC EFs identical to black coal combustion. CO and NO_x EFs based on average of State Electricity Commission of Victoria data (1994)

(i) CH_4 and N_2O IPCC (2006, Volume 2) assume value for pulverised coal fired dry bottom configuration.

(j) CH_4 and N_2O IPCC (2006, Volume 2) value for natural gas boiler. CO, NO_x, NMVOC USEPA (1995) Pg 1.4–4 to 1.4–6. Uncontrolled emissions of CO, NO_x, and NMVOC from natural gas fired 'commercial' boilers (0.1–2.9 MW).

(k) CH_4 and N_2O IPCC (2006, Volume 2) assume value for natural gas gas-fired turbine>3MW. USEPA (1995) Pg 3.1–3 and 3.1–5. Uncontrolled emissions of CO and NO_x for large stationary natural gas turbines. NMVOC emissions estimated from ratio of NMHC: to Total Organic Compounds for selective catalytic reduction controlled turbines.

(l) CH_4 and N_2O IPCC (2006, Volume 2) assume value for natural gas Large Dual-fuel engine. CO, NO_x, NMVOC USEPA (1995) Pg 3.4–3. Assume dual fuel EFs.

(m) CH_4 and N_2O IPCC (2006, Volume 2) assume value for natural gas combined cycle. CO, NO_x, NMVOC USEPA (1995) Pg 1.4–4 to 1.4–6. Uncontrolled emissions of CO, NO_x and NMVOC from natural gas fired 'commercial' boilers (0.1–2.9 MW).

(n) CH_4 and N_2O IPCC (2006, Volume 2) value for wood/wood waste boiler. CO, NO_x, NMVOC USEPA (1995) Pg 1.6–6 to 1.6–7. Uncontrolled emissions from wood waste combustion in stoker boiler. Assume wood moisture content of 50 per cent as recommended by USEPA.

(o) CH_4 and N_2O IPCC (2006, Volume 2) value for wood/wood waste boiler. CO, NO_x IPCC (IPCC 1997) data for NO_x and CO converted to gross calorific equivalent by dividing by 1.05. NMVOC emission rates estimated by scaling relative to wood boiler data (see (n)).

Table A5.3.2.5 Passenger car and light commercial vehicles (LCV): Zero kilometre CH_4 emissions factors split by urban/non-urban road conditions and hot/cold operation

	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
Fuel type	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
Petrol												
Post-2008	0.001	Orbital Australia 2010	0.029	Orbital Australia 2010	0.001	Orbital Australia 2010	0.002	Orbital Australia 2010	0.073	Orbital Australia 2010	0.003	Orbital Australia 2010
2006–2007	0.002		0.053		0.001		0.002		0.073		0.003	
2004–2005	0.005		0.073		0.002		0.017		0.138		0.013	
1998–2003	0.003		0.098		0.000		0.013		0.155		0.000	
1994–1997	0.076		0.228		0.049		0.054		0.384		0.012	
1985–1993 (3-way cat)	0.052	Orbital Australia 2011[(b)]	0.336	Orbital Australia 2011[(b)]	0.010	Orbital Australia 2011[(b)]	0.000	Orbital Australia 2011[(b)]	0.000	Orbital Australia 2011[(b)]	0.000	Orbital Australia 2011[(b)]
1985–1993 (2-way cat)	0.014		0.207		0.000		0.000		0.000		0.000	
1976–1985	0.125	Carnovale 1991	0.434	USEPA (as cited in IPCC 2006)	0.065	Carnovale 1991	0.140	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.487	USEPA (as cited in IPCC 2006)	0.087	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
Pre-1976	0.133		0.461		0.112		0.150		0.521		0.100	
LPG												
Post-2005	0.080	COPERT IV	0.240	COPERT IV (converted to a per start EF)	0.025	COPERT IV (Highway)	0.080	Petrol LCV EF x Pass car LPG to petrol ratio	0.240	Petrol LCV EF x Pass car LPG to petrol ratio	0.025	Petrol LCV EF x Pass car LPG to petrol ratio
2004–2005	0.080		0.240		0.025		0.080		0.240		0.025	
1998–2003	0.024	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.096	Hot EFx Copert IV (IPCC 2006) cold to hot ratio	0.011	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.024	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.096	Hot EFx Copert IV (IPCC 2006) cold to hot ratio	0.011	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985–1997 (3-way cat)	0.024		0.096		0.011		0.024		0.096		0.011	
1985–1997 (2-way cat)	0.033		0.131		0.014		0.033		0.131		0.014	
1976–1985	0.031		0.125		0.014		0.031		0.125		0.014	
Pre-1976	0.032		0.126		0.014		0.032		0.126		0.014	

	Passenger Car						LCV					
	Urban				Non-urban		Urban				Non-urban	
	Hot		Cold				Hot		Cold			
Fuel type	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
ADO												
Post-2008	0.002	COPERT IV	0.008	COPERT IV (converted to a per start EF)	0.000	COPERT IV (Highway)	0.003	COPERT IV	0.021	COPERT IV (converted to a per – start EF)	0.000	COPERT IV – (Highway)
2006–2007	0.003		0.021		0.000		0.003		0.021		0.000	
2004–2005	0.007		0.018		0.002		0.007		0.018		0.002	
1998–2003	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.003	USEPA (as cited in IPCC 2006)	0.000	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.001	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.003	USEPA (as cited in IPCC 2006)	0.000	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985–1997 (3-way cat)	0.001		0.003		0.000		0.001		0.003		0.000	
1985–1997 (2-way cat)	0.001		0.004		0.001		0.001		0.004		0.001	
1976–1985	0.001		0.004		0.001		0.001		0.004		0.001	
Pre-1976	0.001		0.004		0.001		0.001		0.004		0.001	
Ethanol[a]												
Post-2005	0.037	USEPA (as cited in IPCC 2006) – mid-point of reported range	NA	NA	0.049	Hot EF x Petrol non-urban to Hot Urban ratio	0.037	Passenger car EF x LCV to car ratio	NA	NA	0.049	Ethanol car hot EF x LCV non-urban to petrol hot urban ratio
2004–2005	0.037				0.049		0.037				0.049	
1998–2003	0.037				0.025		0.053				0.048	
1985–1997 (3-way cat)	0.206	Post-97 EF x earlier petrol age class – relativity			0.158		0.211				0.159	
1985–1997 (2-way cat)	0.592				0.331		0.581				0.449	
1976–1985	0.661				0.344		0.740				0.460	
Pre-1976	0.703				0.592		0.793				0.529	

(a) Raw ethanol content of blended fuel.

Source: (as indicated in table): FORS (1996); Carnovale et.al. (1991); IPCC (2006); Orbital Australia (2010); Orbital Australia (2011).

Table A5.3.2.6 Medium and heavy-duty trucks and buses: Zero kilometre CH_4 emission factors split by urban/non-urban road conditions

	Medium Duty Truck				Heavy Duty Truck				Bus			
	Urban		Non-urban		Urban		Non-urban		Urban		Non-urban	
Fuel type	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source
Petrol												
Post-2002	0.078	COPERT IV (x EF reduction per cent)	0.062	COPERT IV (x EF reduction per cent)	0.078	COPERT IV (x EF reduction per cent)	0.062	COPERT IV (x EF reduction per cent)	0.078	COPERT IV (x EF reduction per cent)	0.062	COPERT IV (x EF reduction per cent)
1996–2002	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV	0.140	COPERT IV	0.110	COPERT IV
Pre-1996	0.140		0.110		0.140		0.110		0.140		0.110	
LPG												
Post-2002	0.123	DCC 2006	0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.123	DCC 2006	0.054	Passenger car LPG COPERT IV non-urban to urban ratio	0.067	DCC 2006	0.029	Passenger car LPG COPERT IV non-urban to urban ratio
1996–2002	0.220		0.096		0.220		0.096		0.120		0.053	
Pre-1996	0.220		0.096		0.220		0.096		0.120		0.053	
ADO												
Post-2010	0.0025	COPERT IV (x EF reduction per cent)	0.0051	Hot urban EF x COPERT IV non-urban to urban ratio	0.00525	COPERT IV (x EF reduction per cent)	0.0042	Hot urban EF x COPERT IV non-urban to urban ratio	0.00525	COPERT IV (x EF reduction per cent)	0.0021	Hot urban EF x COPERT IV non-urban to urban ratio
2008–2010	0.0025		0.0051		0.00525		0.0042		0.00525		0.0021	
2003–2007	0.0476		0.07735		0.098		0.0637		0.10325		0.0413	
1996–2002	0.157	COPERT IV	0.037		0.157	COPERT IV	0.07		0.157	COPERT IV	0.0628	
Pre-1996	0.157		0.037		0.157		0.063		0.157		0.0628	

Source: (as indicated in table): FORS (1996); Carnovale et.al. (1991); IPCC (2006); Orbital Australia (2010); Orbital Australia (2011).

Table A5.3.2.7 Passenger car and light commercial vehicles (LCV): Zero-kilometre N_2O emissions factors split by urban/non-urban road conditions and hot/cold operation

	Passenger Car						LCV					
	Urban				Non-urban				Urban		Non-urban	
	Hot		Cold				Hot		Cold			
Fuel type	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
Petrol												
Post-2008	0.001	Orbital Australia 2010	0.020	Orbital Australia 2010	0.002	Orbital Australia 2010	0.003	Orbital Australia 2010	0.144	Orbital Australia 2010	0.001	Orbital Australia 2010
2006–2007	0.001		0.037		0.002		0.003		0.144		0.009	
2004–2005	0.008		0.121		0.004		0.006		0.087		0.009	
1998–2003	0.030		0.332		0.020		0.041		0.156		0.029	
1994–1997	0.037		0.231		0.034		0.025		0.137		0.012	
1985–1993 (3-way cat)	0.057	Orbital Australia 2011[(b)]	0.194	Orbital Australia 2011[(b)]	0.066	Orbital Australia 2011[(b)]	0.002	Orbital Australia 2011[(b)]	0.005	Orbital Australia 2011[(b)]	0.000	Orbital Australia 2011[(b)]
1985–1993 (2-way cat)	0.000		0.000		0.002		0.000		0.000		0.000	
1976–1985	0.004	Weeks et al. 1993	0.041	USEPA (as cited in IPCC 2006)	0.002	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.005	Passenger car EF x USEPA (IPCC 2006) LCV to car EF ratio	0.047	USEPA (as cited in IPCC 2006)	0.005	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
Pre-1976	0.003		0.036		0.002		0.003		0.041		0.002	
LPG												
Post-2005	0.005	COPERT IV	0.027	COPERT IV (converted to a per start EF)	0.001	COPERT IV (Highway)	0.008	Petrol LCV EF x Pass car LPG to petrol ratio	0.081	Petrol LCV EF x Pass car LPG to petrol ratio	0.003	Petrol LCV EF x Pass car LPG to petrol ratio
2004–2005	0.013		0.069		0.002		0.026		0.178		0.018	
1998–2003	0.016	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.048	Hot EF x Copert IV (IPCC 2006) cold to hot ratio	0.006	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.016	Petrol EF x USEPA 2006 LPG to petrol EF ratio	0.048	Hot EFx Copert IV (IPCC 2006) cold to hot ratio	0.006	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985–1997 (3-way cat)	0.006		0.017		0.001		0.006		0.017		0.001	
1985–1997 (2-way cat)	0.003		0.008		0.002		0.003		0.008		0.002	
1976–1985	0.003		0.008		0.000		0.003		0.008		0.000	
Pre-1976	0.002		0.005		0.000		0.002		0.005		0.000	

Fuel type	Passenger Car						LCV					
	Urban				Non-urban				Urban		Non-urban	
	Hot		Cold				Hot		Cold			
	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/start)	Source	EF (g/km)	Source
ADO												
Post-2008	0.005	COPERT IV	0.023	COPERT IV (converted to a per start EF)	0.002	COPERT IV (Highway)	0.009	COPERT IV	0.045	COPERT IV (converted to a per – start EF)	0.004	COPERT IV (Highway)
2006–2007	0.009		0.045		0.004		0.009		0.045		0.004	
2004–2005	0.004		0.045		0.006		0.004		0.045		0.006	
1998–2003	0.003	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.010	USEPA (as cited in IPCC 2006)	0.001	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio	0.003	Petrol EF x USEPA 2006 diesel to petrol EF ratio	0.010	USEPA (as cited in IPCC 2006)	0.001	Hot urban EF x Copert IV (IPCC 2006) non-urban to urban ratio
1985–1997 (3-way cat)	0.001		0.003		0.002		0.001		0.003		0.002	
1985–1997 (2-way cat)	0.001		0.002		0.001		0.001		0.002		0.001	
1976–1985	0.001		0.002		0.000		0.001		0.002		0.000	
Pre-1976	0.000		0.001		0.000		0.000		0.001		0.000	
Ethanol[a]												
Post-2005	0.030	USEPA (as cited in IPCC 2006) – mid-point of reported range	NA	NA	0.015	Post-97 hot EF x Petrol Non-urban to Hot Urban ratio	0.049	Passenger car EF x LCV to car ratio	NA	NA	0.049	Ethanol car hot EF x LCV non-urban to petrol hot urban ratio
2004–2005	0.030				0.007		0.059				0.059	
1998–2003	0.030				0.025		0.082				0.082	
1985–1997 (3-way cat)	0.030	Post-97 EF x earlier petrol age class relativity			0.029		0.049				0.049	
1985–1997 (2-way cat)	0.012				0.011		0.015				0.015	
1976–1985	0.004				0.010		0.005				0.005	
Pre-1976	0.003				0.010		0.002				0.002	

(a) Raw ethanol content of blended fuel.

Source (as indicated in table): Weeks et.al. (1993), IPCC (2006), Orbital Australia (2010); Orbital Australia (2011).

Table A5.3.2.8 Medium and heavy-duty trucks and buses: Zero-kilometre N_2O emissions factors split by urban/non-urban road conditions

	Medium Duty Truck				Heavy Duty Truck				Bus			
	Urban		Non-urban		Urban		Non-urban		Urban		Non-urban	
Fuel type	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source	EF (g/km)	Source
Petrol												
Post-2002	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.006	COPERT IV	0.01	COPERT IV	0.006	COPERT IV
1996–2002	0.006		0.006		0.006		0.006		0.01		0.006	
Pre-1996	0.006		0.006		0.006		0.006		0.01		0.006	
LPG												
Post-2002	0.020	DCC 2006	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.020	DCC 2006	0.020	Hot urban EF x COPERT IV non-urban to urban ratio	0.011	DCC 2006	0.011	Hot urban EF x COPERT IV non-urban to urban ratio
1996–2002	0.020		0.020		0.020		0.020		0.011		0.011	
Pre-1996	0.020		0.020		0.020		0.020		0.011		0.011	
ADO												
Post-2016	0.030	COPERT IV	0.030	Hot urban EF x COPERT IV non-urban to urban ratio	0.00525	COPERT IV	0.017	Hot urban EF x COPERT IV non-urban to urban ratio	0.030	COPERT IV	0.017	Hot urban EF x COPERT IV non-urban to urban ratio
2014–2016	0.030		0.030		0.0075		0.017		0.030		0.017	
2011–2013	0.030		0.030		0.012		0.017		0.030		0.017	
2008–2010	0.030		0.030		0.021		0.030		0.030		0.030	
Pre-2008	0.030		0.030		0.030		0.030		0.030		0.030	

Source (as indicated in table): Weeks et.al. (1993), IPCC (2006), Orbital Australia (2010); Orbital Australia (2011).

Table A5.3.2.9 Vehicle emission factors for indirect gases by year of vehicle manufacture (g/km)

	Passenger Car			LCV			Medium Duty Truck			Heavy Duty Truck			Bus		
Fuel type	NO_x	CO	NMVOC	NO_x	CO	NMVOC	NO_x	CO	NMVOC	NO_x	CO	NMVOC	NO_x	CO	NMVOC
Petrol															
Post 2009	0.023	0.108	0.077	0.139	0.047	0.236	2.52	10.87	1.04	2.52	10.87	1.04	3.91	48.61	3.47
2006–2008	0.044														
2004–2005	0.075	0.399		0.275	0.669										
1998–2003	0.167	0.037		0.820	1.664										
1994–1997	0.498	6.906		1.456	10.108										
1985–93 (3-way cat)	0.669	10.378	0.294	0.000	0.000	0.894									
1985–93 (2-way cat)	0.619	0.083	0.260	0.000	0.000	0.791									
1976–1985	1.400	14.900	1.419	2.853	25.977	4.314									
Pre-1976	2.460	24.000	2.275	5.014	41.842	6.914									
LPG															
Post-97	0.472	2.327	0.199	0.472	2.327	0.199	4.83	24.00	4.21	4.83	10.87	4.21	2.76	24.00	2.41
1985–97 (3-way cat)	0.942	10.305	0.755	0.942	10.305	0.755									
1985–97 (2-way cat)	1.947	14.614	0.669	1.947	14.614	0.669									
1976–1985	2.931	39.881	3.647	2.931	22.875	3.647									
Pre-1976	5.150	64.238	5.846	5.150	36.846	5.846									
ADO															
Post-97	0.250	0.116	0.062	0.250	0.116	0.062	5.20	6.44	1.15	5.20	24.00	1.15	4.90	2.88	1.56
1985–97 (3-way cat)	0.500	0.515	0.237	0.500	0.515	0.237									
1985–97 (2-way cat)	1.034	0.731	0.210	1.034	0.731	0.210									
1976–1985	1.556	1.994	1.144	1.556	1.994	1.144									
Pre-1976	2.734	3.212	1.833	2.734	3.212	1.833									

Note: For light duty vehicles hot urban EFs are reported in the table above.

Table A5.3.2.10 Passenger car and light commercial vehicles: non-CO_2 emission factor deterioration rates (g/km/km)

	Vehicle Age Class							
	Pre-1979(c)	1980–85(c)	1985–93(ac)	1985–93(bd)	1994–97(e)	1998–03(e)	2004–05(e)	2006-current(e)
Passenger Cars								
CH_4	6.35E-07	4.76E-07	3.85E-07	5.85E-07	2.5E-08	1.38E-07	1.52E-07	1.54E-07
N_2O	0	0	0	0	0	0	0	0
CO	1.45E-04	1.27E-04	4.71E-05	1.06E-04	4.31E-06	1.43E-05	5.83E-06	4.74E-06
NO_X	0.00E+00	6.48E-06	1.54E-06	2.98E-06	1.54E-06	1.76E-06	2.73E-07	3.04E-07
NMVOC(d)	9.95E-06	7.45E-06	4.42E-06	7.83E-06	4.42E-06	4.42E-06	4.42E-06	4.42E-06
Light Commercial Vehicles								
CH_4	0	0	0	0	2.35E-07	2.08E-07	1.46E-07	1.55E-07
N_2O	0	0	0	0	0	0	0	0
CO	0	0	0	0	2.22E-05	2.29E-05	1.35E-06	6.23E-06
NO_X	0	0	0	0	1.49E-06	4.46E-06	0	1.08E-07
NMVOC(d)	9.95E-06	7.45E-06	4.42E-06	7.83E-06	4.42E-06	4.42E-06	4.42E-06	4.42E-06

Notes: (a) 3-way catalyst; (b) 2-way catalyst.

Source: (c) EPA NSW (1995) (cl) Orbital Australia (2011) (e) Orbital Australia (2010).

Table A5.3.2.11 Road transport: non-CO_2 emission factors for natural gas road vehicles and petrol motorcycles

Source Category		Emission Factor (g/km)				
Sector	Fuel Type	CH_4 (a)	N_2O (b)	NO_X (c)	CO (c)	NMVOC (c)
Medium Trucks	Natural Gas (e)	0.101	0.001	1.200	0.200	0.010
Heavy Trucks	Natural Gas (e)	0.101	0.001	1.200	0.200	0.010
Buses	Natural Gas (e)	0.101	0.001	1.200	0.200	0.010
Motorcycles	Petrol	0.150	0.002	0.210	19.270	4.580
Passenger Cars	Natural Gas (e)	0.261	0.001	0.190	0.110	0.020
Light Commercial Vehicles	Natural Gas (e)	0.261	0.001	0.190	0.110	0.020

Source: (a) Hoekman (1992); (b) Weeks et.al. (1993); (c) Carnovale et.al. (1991); (cl) EPA NSW (1995); (e) de Maria (1992).

Table A5.3.2.12 Shares used to allocate Australian Energy Statistics fuel consumption to unlisted categories 2021–22

ANZSIC category fuel consumption reported in the AES	General use	Military	Off-road vehicles	Utility engines
Road transport automotive gasoline	99.3 per cent	0.0 per cent	0.1 per cent	0.6 per cent
Road transport ADO	99.9 per cent	0.1 per cent		
Water transport ADO	85.6 per cent	14.4 per cent		
Water transport fuel oil	100 per cent			
Air transport aviation gasoline	99.7 per cent	0.3 per cent		
Air transport aviation turbine fuel	91.2 per cent	8.8 per cent		

Source: Derived from Farrington (1988), ABS (2017) and Department of Defence (2010–2023).

Table A5.3.2.13 Shares used to allocate Australian Energy Statistics road transport fuel consumption to individual vehicle types 2021–22

	Fuel Type			
Vehicle Type	Automotive Gasoline (a)	ADO (a)	LPG (a)	Natural Gas (b)
Passenger cars	89.4 per cent	19.3 per cent	80.0 per cent	2.8 per cent
Light commercial vehicles	9.8 per cent	30.9 per cent	13.6 per cent	4.3 per cent
Medium duty trucks	0.1 per cent	19.7 per cent	0.2 per cent	6.7 per cent
Heavy duty trucks	-	26.8 per cent	-	-
Buses	0.1 per cent	3.3 per cent	6.3 per cent	86.2 percent
Motorcycles	0.6 per cent	-	-	-

Source: (a) ABS (2021). (b) Pekol Traffic and Transport (2022).

Table A5.3.2.14 Australian petrol-fuelled vehicle stock age distribution and fuel consumption rates: 2021–22

	Passenger cars		Light Commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2022[(b)]	271,828	0.104	9,809	0.139	233	0.26	16	0.202	16	0.153
2021	643,807	0.104	21,866	0.139	322	0.260	26	0.202	25	0.153
2020	548,955	0.104	16,462	0.139	163	0.260	12	0.202	18	0.153
2019	649,243	0.104	14,660	0.139	146	0.260	13	0.202	144	0.153
2018	699,980	0.104	14,651	0.139	188	0.260	28	0.202	596	0.153
2017	741,598	0.104	16,085	0.139	183	0.260	48	0.202	503	0.153
2016	727,335	0.104	20,180	0.139	157	0.260	32	0.202	498	0.153
2015	720,987	0.104	19,140	0.139	125	0.260	23	0.202	634	0.153
2014	659,589	0.112	20,213	0.142	151	0.177	25	0.205	617	0.161
2013	687,862	0.112	24,083	0.142	155	0.177	31	0.205	525	0.161
2012	641,718	0.112	26,878	0.142	153	0.177	28	0.205	571	0.161
2011	568,392	0.112	29,505	0.142	147	0.177	21	0.205	827	0.161
2010	595,591	0.112	38,204	0.142	174	0.177	30	0.205	744	0.161
2009	498,473	0.112	42,732	0.142	149	0.177	18	0.205	669	0.161
2008	522,942	0.112	48,583	0.142	221	0.177	27	0.205	958	0.161
2007	532,209	0.112	49,424	0.142	364	0.177	86	0.205	844	0.161
2006	462,972	0.112	44,674	0.142	441	0.177	36	0.205	882	0.161
2005	433,669	0.112	63,961	0.142	279	0.177	36	0.205	556	0.161
2004	370,425	0.121	58,938	0.14	319	0.330	35	0.304	200	0.145
2003	323,034	0.121	52,135	0.14	200	0.330	27	0.304	388	0.145
2002	238,789	0.121	37,637	0.14	400	0.330	22	0.304	319	0.145
2001	191,984	0.121	31,231	0.14	269	0.330	10	0.304	188	0.145
2000	164,912	0.121	27,101	0.14	148	0.330	-	0.304	333	0.145
1999	124,406	0.121	26,161	0.14	117	0.330	12	0.304	213	0.145
1998	104,073	0.121	22,147	0.14	154	0.330	16	0.304	188	0.145
1997	73,077	0.121	16,349	0.14	130	0.330	9	0.304	139	0.145
1996	49,965	0.121	13,962	0.14	114	0.330	11	0.304	109	0.145

	Passenger cars		Light Commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
1995	41,057	0.121	12,166	0.14	92	0.330	3	0.304	118	0.145
1994	34,347	0.121	10,939	0.14	104	0.330	19	0.304	65	0.145
1993	27,571	0.121	8,106	0.14	68	0.330	12	0.304	63	0.145
1992	21,106	0.121	7,980	0.14	81	0.330	3	0.304	40	0.145
1991	17,514	0.121	6,168	0.14	86	0.330	3	0.304	41	0.145
1990	18,874	0.121	6,779	0.14	104	0.330	9	0.304	41	0.145
1980–1989(a)	74,327	0.121	31,212	0.14	1,396	0.330	61	0.304	211	0.145
1979 and earlier	176,108	0.121	41,275	0.14	6,265	0.330	151	0.304	218	0.145

Notes: (a) Fuel consumption rates average for period 1980–89. (b) Assumes new cars on road for average of 6 months in the first year.

Table A5.3.2.15 Australian diesel-fuelled vehicle stock age distribution and fuel consumption rates: 2021–22

	Passenger cars		Light Commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2022(b)	60,668	0.110	95,293	0.120	15,250	0.276	3,160	0.531	1,782	0.257
2021	115,945	0.110	236,505	0.120	35,066	0.276	8,005	0.531	4,643	0.257
2020	94,825	0.110	178,793	0.120	23,292	0.276	5,400	0.531	3,813	0.257
2019	113,922	0.110	195,073	0.120	24,058	0.276	5,993	0.531	4,839	0.257
2018	142,741	0.110	228,258	0.120	28,975	0.276	7,209	0.531	4,288	0.257
2017	153,423	0.110	208,976	0.120	25,323	0.276	6,041	0.531	3,893	0.257
2016	165,350	0.110	185,319	0.120	22,917	0.276	4,503	0.531	3,739	0.257
2015	157,971	0.110	172,846	0.120	21,749	0.276	4,575	0.531	3,684	0.257
2014	146,655	0.112	157,529	0.138	19,454	0.291	5,276	0.531	3,930	0.294
2013	156,110	0.112	160,019	0.138	17,564	0.291	5,511	0.531	3,552	0.294
2012	150,850	0.112	155,058	0.138	18,412	0.291	5,059	0.531	4,195	0.294
2011	118,316	0.112	111,113	0.138	14,054	0.291	2,845	0.531	4,350	0.294
2010	110,238	0.112	110,815	0.138	21,436	0.291	4,774	0.531	3,996	0.294

	Passenger cars		Light Commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2009	74,845	0.112	89,139	0.138	16,883	0.291	2,660	0.531	3,360	0.294
2008	74,144	0.112	95,986	0.138	20,545	0.291	3,296	0.531	4,103	0.294
2007	53,072	0.112	72,543	0.138	24,870	0.291	6,537	0.531	2,940	0.294
2006	41,448	0.112	61,655	0.138	18,711	0.291	3,654	0.531	2,550	0.294
2005	30,215	0.112	46,506	0.138	18,805	0.291	3,654	0.531	2,505	0.294
2004	27,095	0.112	39,431	0.138	17,229	0.291	3,501	0.531	1,451	0.294
2003	22,272	0.112	32,075	0.138	11,471	0.291	2,794	0.531	1,286	0.294
2002	17,802	0.112	28,031	0.138	13,373	0.291	2,107	0.531	1,271	0.294
2001	14,151	0.112	20,158	0.138	8,776	0.291	1,460	0.531	1,087	0.294
2000	12,394	0.112	21,882	0.138	8,489	0.291	1,511	0.531	1,319	0.294
1999	9,855	0.112	19,957	0.138	8,513	0.291	1,626	0.531	1,134	0.294
1998	9,002	0.112	17,545	0.138	7,915	0.291	1,824	0.531	1,088	0.294
1997	7,851	0.112	14,239	0.138	6,249	0.291	1,409	0.531	702	0.294
1996	6,789	0.112	12,463	0.138	5,288	0.291	1,155	0.531	568	0.294
1995	6,697	0.112	11,319	0.138	5,623	0.291	1,271	0.531	599	0.294
1994	6,676	0.112	10,826	0.138	6,020	0.291	1,313	0.531	582	0.294
1993	6,022	0.112	9,108	0.138	4,469	0.291	805	0.531	425	0.294
1992	7,269	0.112	7,939	0.138	4,247	0.291	402	0.531	520	0.294
1991	6,179	0.112	5,606	0.138	3,404	0.291	280	0.531	381	0.294
1990	4,950	0.112	6,647	0.138	5,002	0.291	622	0.531	353	0.294
1980–1989(a)	14,072	0.112	25,453	0.138	33,167	0.291	4,359	0.531	1,482	0.294
1979 and earlier	523	0.112	3,807	0.138	6,684	0.291	1,436	0.531	151	0.294

Notes: (a) Fuel consumption rates average for period 1980–89. (b) Assumes new cars on road for average of 6 months in the first year.

Table A5.3.2.16 Australian LPG-fuelled vehicle stock age distribution and fuel consumption rates: 2021–22

	Passenger cars		Light Commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
2022[(b)]	507	0.087	21	0	5	0.166	-	0.53	2	0.119
2021	525	0.087	72	0	25	0.166	3	0.530	7	0.119
2020	509	0.087	54	0	23	0.166	8	0.530	8	0.119
2019	761	0.087	44	0	35	0.166	8	0.530	22	0.119
2018	305	0.087	54	0	34	0.166	10	0.530	30	0.119
2017	246	0.087	41	0	37	0.166	17	0.530	29	0.119
2016	539	0.087	475	0	39	0.166	10	0.530	42	0.119
2015	1,504	0.087	672	0	18	0.166	10	0.530	79	0.119
2014	2,411	0.087	946	0	33	0.166	10	0.530	80	0.119
2013	3,116	0.087	1,410	0	25	0.166	10	0.530	44	0.119
2012	3,431	0.094	2,354	0.185	32	0.210	8	0.640	50	0.306
2011	2,279	0.094	921	0.185	26	0.210	4	0.640	174	0.306
2010	4,782	0.094	3,390	0.185	43	0.210	10	0.640	240	0.306
2009	6,133	0.094	3,833	0.185	30	0.210	7	0.640	303	0.306
2008	6,889	0.094	5,425	0.185	38	0.210	8	0.640	438	0.306
2007	6,170	0.094	4,329	0.185	53	0.210	18	0.640	256	0.306
2006	6,505	0.094	4,995	0.185	66	0.210	10	0.640	185	0.306
2005	6,646	0.094	3,969	0.185	54	0.210	-	0.640	89	0.306
2004	6,670	0.094	3,580	0.185	51	0.210	3	0.640	31	0.306
2003	7,153	0.094	3,484	0.185	40	0.210	3	0.640	16	0.306
2002	5,658	0.146	2,842	0.202	64	0.278	3	0.432	22	0.585
2001	4,633	0.146	2,784	0.202	41	0.278	-	0.432	49	0.585
2000	4,961	0.146	2,453	0.202	23	0.278	6	0.432	30	0.585
1999	5,273	0.146	2,048	0.202	18	0.278	4	0.432	17	0.585
1998	4,668	0.146	1,515	0.202	13	0.278	-	0.432	11	0.585

	Passenger cars		Light Commercial Vehicles		Medium Duty Trucks		Heavy Duty Trucks		Buses	
Year of manufacture	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)	Vehicle numbers	Average Fuel Consumption Rate (L/km)
1997	2,750	0.146	1,293	0.202	13	0.278	3	0.432	6	0.585
1996	2,062	0.146	1,107	0.202	9	0.278	-	0.432	-	0.585
1995	1,862	0.146	954	0.202	-	0.278	-	0.432	6	0.585
1994	2,007	0.146	820	0.202	15	0.278	-	0.432	3	0.585
1993	1,739	0.146	618	0.202	12	0.278	-	0.432	6	0.585
1992	1,111	0.146	564	0.202	3	0.278	-	0.432	9	0.585
1991	765	0.146	485	0.202	12	0.278	-	0.432	9	0.585
1990	856	0.146	558	0.202	3	0.278	-	0.432	3	0.585
1980–1989[(a)]	3,094	0.146	-	0.202	-	0.278	-	0.432	-	0.585
1979 and earlier	3,143	0.146	3,036	0.202	340	0.278	-	0.432	18	0.585

Notes: (a) Fuel consumption rates average for period 1980–89. (b) Assumes new cars on road for average of 6 months in the first year.

Source: DCCEEW estimates derived from ABS 2013, ABS 2014a.

Table A5.3.2.17 Average rate of fuel consumption for Motor Cycles

	Fuel Type		
Vehicle Type	**Automotive Gasoline (L/km)**	**ADO (L/km)**	**LPG / NG (L/km)**
Motor Cycles	0.058	NA	NA

Source: ABS (2017).

Table A5.3.2.18 Evaporative emission factors for road vehicles using automotive gasoline

	Emission Factor (g/km)	
Vehicle Type	**Hot Soak and Diurnal Emissions(FHij)** (a)	**Running Losses(FRij)** (b)
Passenger Cars (c)		
Post-1985	0.38	0.9
1976–1985	0.96	0.9
Pre-1976	1.92	0.9
Light Commercial Vehicles	1.13	0.19
Medium Trucks	2.24	0.26
Heavy Trucks	2.75	0.29
Buses	2.24	0.20
Motorcycles	0.76	0.0

Source: (a) Carnovale et.al. (1991). (b) OECD (1991). (c) Calculated with an RVP (Reid Vapor Pressure) of 11.0 psi (pound-force per square inch).

Table A5.3.2.19 Average Trip Length by State and Territory, by vehicle type, 2021–22

	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Passenger Cars	10.39	9.25	15.92	10.88	9.72	9.47	10.58	9.80
Light Commercial Vehicles	19.19	15.47	24.13	14.06	14.13	10.82	15.61	14.82
Medium Trucks	34.36	22.68	26.79	26.98	20.47	26.79	22.75	14.90
Heavy Trucks	107.01	70.08	113.71	90.19	80.04	60.72	68.09	58.90
Buses	53.63	21.11	33.12	24.42	22.80	15.35	19.99	19.46

Source: Pekol Traffic and Transport (2022).

Table A5.3.2.20 Carbon dioxide emission factor for coke

Year	Emission Factor (CO_2 Gg/ PJ)
1990	103.79
2000	103.83
2005	106.41
2010	106.65
2011	106.50
2012	106.76
2013	106.15
2014	106.91
2015	108.20
2016	108.19
2017	108.63
2018	109.40
2019	109.40
2020	109.40
2021	109.40
2022	109.40

Source: Determined using a carbon balance of the coke oven process (DCCEEW).

Table A5.3.2.21 NMVOC emission factors for service station storage and transfer operations

Region	Population (million) (a)	Emission factor (kg per kL distributed) (b)
Sydney Statistical Region (c)	3.67	0.16
Port Phillip Control Region (d)	3.39	0.16
Other	10.22	1.00
Australia (e)	17.28	0.66

Source: (a) Australian Bureau of Statistics, Census (ABS 1991 b). (b) Filling losses and underground-tank breathing. (c) Environment Protection Authority NSW (EPA 1995). (d) Melbourne, Geelong and Westernport Regions, Environment Protection Authority Victoria (EPA 1991). (e) Population weighted average, all years 1988–1994.

Table A5.3.2.22 NMVOC emission factors for bulk fuel storage facilities

Region	Population (million) (a)	Emission factor (kg per kL distributed) (b)
Melbourne/Sydney Region (c)	7.06	0.48
Other (d)	10.22	1.49
Australia (e)	17.28	1.08

Source: (a) Australian Bureau of Statistics, Census (ABS 1991). (b) Storage and working losses. (c) Assume emission factors in Melbourne (Carnovale, et al. 1991) and Sydney are similar because control regulations are identical. From Australian Environment Council (AEC 1998) data for regions outside Melbourne and Sydney. (e) Population weighted average, all years 1988–1994

Table A5.3.2.23 Proportion of unaccounted for gas (UAG) attributed to fugitive leakage for natural gas distribution

Year	Proportion of UAG attributed to fugitive leakage (%)
1989–90 to 2003–04	55.00
2004–05	55.00
2005–06	55.00
2006–07	53.50
2007–08	52.00
2008–09	50.60
2009–10	49.10
2010–11	47.60
2011–12	46.10
2012–13	44.70
2013–14	43.20
2014–15	41.70
2015–16	40.20
2016–17	38.70
2017–18	37.30
2018–19	37.30
2019–20	37.30
2020–21	37.30

Sources: 1989 to 2005–06, Energy Strategies (2005). 2017–18 onwards, Zincara (2017). 2006–07 to 2015–16, linear interpolation between the two factors, DCCEEW analysis.

Table A5.3.2.24 Percentage of black coal and coke oven gas fuel mix in 1.A.1.c

Year	Per cent of coal	Per cent of coke oven gas
1990	86	14
2000	72	28
2005	66	34
2010	82	18
2011	82	18
2012	81	19
2013	82	18
2014	81	19
2015	78	22
2016	78	22
2017	76	24
2018	59	41
2019	59	41
2020	59	41
2021	59	41
2022	59	41

A5.3.3 Residential Wood Heater Technology

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

The residential wood heater methodology has been developed for Australian conditions (Todd, Gibbons, et al. 2003) (Todd, Gibbons, et al. 2005) (Todd 2011). This methodology was updated (Todd 2011) to account for the latest information and trends. The model was validated against field studies of emissions from wood heaters used in Australian households and resulted in a minor increase to the CH_4 EF over the complete time series along with a small decrease in the CO_2 EF. The methodology incorporates factors such as appliance type and certification, wood type and moisture content and user behaviour. The composition of gaseous and particulate emissions when burning eucalypt firewood in typical Australian appliances is based on Gras (2002). A schematic diagram showing the methodology process is shown in Figure A5.3.3.1, and is also summarised in the algorithm below:

$$E_{kn} = F_n \text{ x } S \text{ x } W \text{ x } f_{nk}\{\Sigma\ PEF_n\} \qquad \text{A5.3.3.1}$$

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

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

S = softwood use correction factor

W = wet wood correction factor

f_{nk} = formula linking the greenhouse gas EF for gas k to the particulate EF.

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

- l(1) certified wood heater correctly operated
- l(2) certified wood heater carelessly operated
- l(3) certified wood heater very badly operated
- l(4) non-certified wood heater correctly operated
- l(5) non-certified wood heater carelessly operated
- l(6) non-certified wood heater very badly operated
- l(7) masonry open fireplace
- l(8) factory built (metal) open fireplace

Description of factors

Certified and non-certified heater

Emission factors

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

A base CH_4 EF of 462.5 Mg/PJ has been applied to non-certified heaters, through the application of a factor of 1.77 to the certified wood heater EF. Todd (2005) based this approach on comparisons between US emission tests of non-certified heaters (referred to as 'Pre-Phase I Non-Catalytic Heaters' in US literature) and certified heaters (referred to as Phase II Non-Catalytic Heaters) (USEPA 1996).

The Australian emission test for wood heaters has differences to the US test (both in test fuel, and testing procedure); however, the Australian Standard was cross-checked with two models of heater that had passed both the US (Phase II) and found to be generally similar. Thus the US ratio has been applied to Australian heaters.

Mix of certified and non-certified heaters and open fireplaces

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

Operator behaviour

Emission factors

Three operator classifications have been adopted for these calculations.

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

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

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

Proportion of well/poorly operated wood heaters

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

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

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

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

Open fireplaces

Emission factors

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

Proportion of open fireplaces

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

Softwood fuel and wet wood

Emission factors

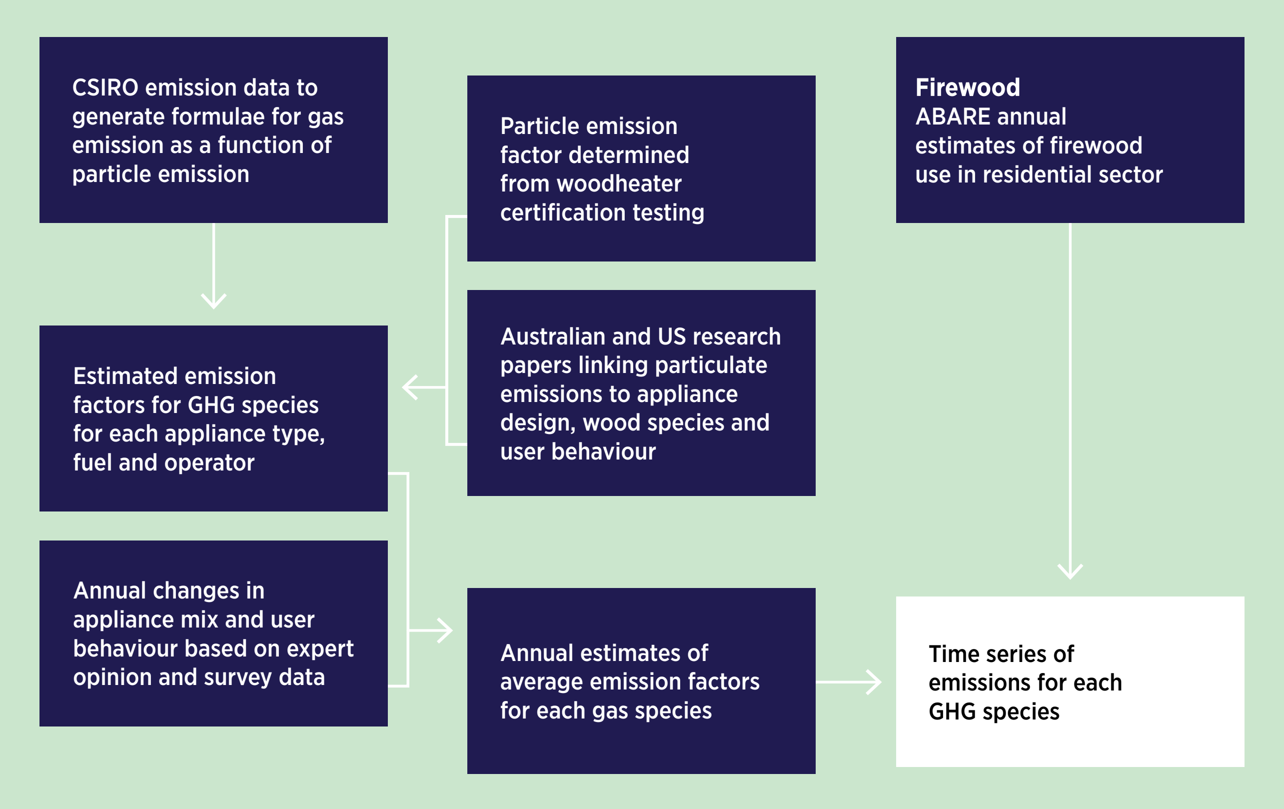
The use of wet firewood is often cited as one of the main reasons for high emissions from wood heaters. However, the CSIRO study, and other Australian studies (Todd, Gibbons, et al. 1989) have consistently shown that only very wet wood (i.e. unseasoned) influences emissions. High burn-rate tests carried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

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

Proportion of wet wood and softwood

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

Figure A5.3.3.1 Schematic diagram of the methodology process for estimation of emissions from wood heaters



The resulting emissions factor trends are shown below in Table A5.3.3.1. With Australian standards for wood heater emissions introduced in 1992, there has been an increasing uptake of certified heaters at the expense of older, non-compliant heaters, as well as open fireplaces. Together with improving user operation, these factors work to produce an overall trend for the more complete and efficient combustion of fuelwood. This is borne out in the increasing CO_2 EF (i.e. more carbon is oxidised under improved combustion conditions) and decreasing CH_4 EF.

As a result, the implied CH_4 EF varies between 1297 Mg/PJ in 1990 and 713 Mg/PJ in 2011. This range is consistent with the 2006 IPCC Guidelines defaults for residential CH_4 EFs for woodstoves (IPCC 2006, Vol. 2, Table 2.9), taking in account the inherent uncertainty of residential combustion CH_4 EFs of 50 to 150 per cent (IPCC 2006, Vol. 2, Table 2.12).

Table A5.3.3.1 Residential biomass emission factors

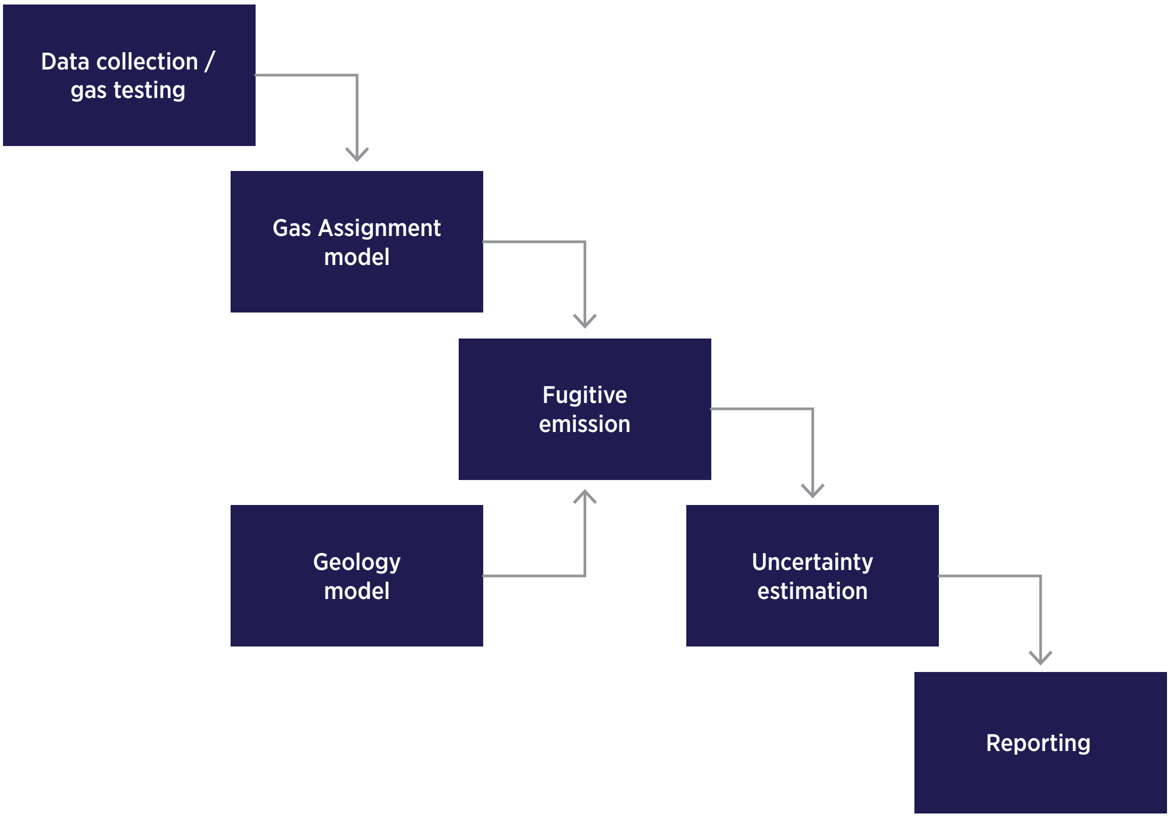
Inventory	Greenhouse Gas Emission Factor (Mg/PJ)						
Year	CO_2	CH_4	N_2O	CO	NO_X	NMVOC	SO_2
1990	66.7	1,297.0	2.5	13,195.8	14.3	1,642.9	1.1
2000	75.1	844.2	2.0	9,874.9	20.3	1,069.3	1.1
2005	76.1	791.3	1.9	9,487.4	21.0	1,002.4	1.1
2010	77.3	725.9	1.9	9,007.8	21.9	919.5	1.1
Post-2010	77.5	712.7	1.9	8,910.4	22.1	902.7	1.1

A5.3.4 Plant-specific methods for estimating Coal Fugitives

Australia has invested in a comprehensive program of measurement technique research and development since 2007 in order 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.

These guidelines have been published by the Australian Coal Association Research Program (ACARP) in December 2011, *Guidelines for the Implementation of NGER Method 2 or 3 for Open Cut Coal Mine Fugitive GHG Emissions Reporting* (ACARP 2011). These guidelines have been incorporated into a legislative instrument, the *National Greenhouse and Energy Reporting (Measurement) Determination 2008,* for the application by mines for the estimation of fugitive emissions under the NGER scheme. As indicated elsewhere, mine estimates are subject to the full audit and compliance processes that apply for other NGER scheme reports.

Figure A5.3.4.1 Surface mines: emissions estimation process flowchart for companies



Source: ACARP (2011).

The key components of the mine-specific method for estimating emissions from surface mines (Figure 3.18) are:

- a framework for data collection, including borehole sampling and gas testing of coal and gas bearing strata, which ensures representative and unbiased sampling;
- guidelines and standards for data analysis and interpretation;
- an approach for estimating gas in near-surface zones characterised by very low gas contents;

- guidelines on utilising the collected data to produce a model of gas distribution describing the gas content and composition with a defined 3 dimensional volume. This is incorporated within the mine's 3-dimensional geological model to establish the *in situ* gas stock residing within the mine strata (e.g. geological models used for JORC Code resource evaluation, or for mine planning where JORC Code[2] compliance is not applicable, are suitable);
- guidelines on estimating the emissions released from the *in situ* gas stock as blocks of strata within the mine are extracted for coal production; and
- minimum qualifications of persons who are permitted to estimate emissions from an surface mine using the higher order method.

The *National Greenhouse and Energy Reporting (Measurement) Determination 2008* sets out requirements for the sampling and analysis to be undertaken by facilities to determine the gas content contained in rock strata within a coal mine; the parameters for the low gas zone, and the application of a gas distribution model to develop an emissions estimate for a surface mine as well as the determination of a low gas zone.

A description of the conceptual framework supporting the plant-specific NGER scheme method is detailed below.

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

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

Where E_j is the fugitive emissions of gas type $_{(j)}$ that result from the extraction of coal from the mine during the year (CO_2-e tonnes)

Υ_j is the factor for converting a quantity of gas type $_{(j)}$ from cubic metres at standard conditions of pressure and temperature to CO_2-e tonnes, as follows:

(a) for methane-6.784 x 10^{-4} x 25

(b) for carbon dioxide-1.861 x 10^{-3}

$\Sigma_z \, (S_{j,z})$is the total of gas type $_{(J)}$ in all gas bearing strata $_{(z)}$ under the extraction area of the mine during the year, in cubic metres

B. For estimating the total gas contained by gas bearing strata for (A) above:

1. For $S_{j,z}$ for gas type $_{(j)}$ contained in a gas bearing strata $_{(z)}$ under the extraction area of the mine during the year, in cubic metres, is:

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

Where M_z is the mass of the gas bearing strata under the extraction area of the mine during the year, in tonnes
y_z is the proportion of the gas content of the gas bearing strata that is released by extracting coal from the extraction area of the mine during the year, as follows:

(a) if the gas bearing strata is at or above the pit floor $y = 1$

(b) in any other case, estimated as a proportion of gas released below the pit floor

GC_{jz} is the content of gas type $_{(j)}$ contained by the gas bearing strata before gas capture, flaring or venting is undertaken at the extraction area of the mine during the year, measured in cubic metres per tonne of gas bearing strata at standard conditions

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

$\Sigma Q_{ij,flared,z}$ is the total quantity of gas type $_{(j)}$ in coal mine waste gas flared from the gas bearing strata (z) at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres

ΣQ_{ijtr} is the total quantity of gas type $_{(j)}$ in coal mine waste gas transferred out of the mining activities at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres

$\Sigma E_{j,vented,z}$ is the total emissions of gas type (vented from the gas bearing strata at any time before coal is extracted from the extraction area of the mine during the year, in cubic metres

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

2. In subsection (1), ΣQ_{ijtr} applies to carbon dioxide only if the carbon dioxide is captured for permanent storage
3. For GC_{lz} in subsection (1), the content of gas type (j) contained by the gas bearing strata (z) – see C below

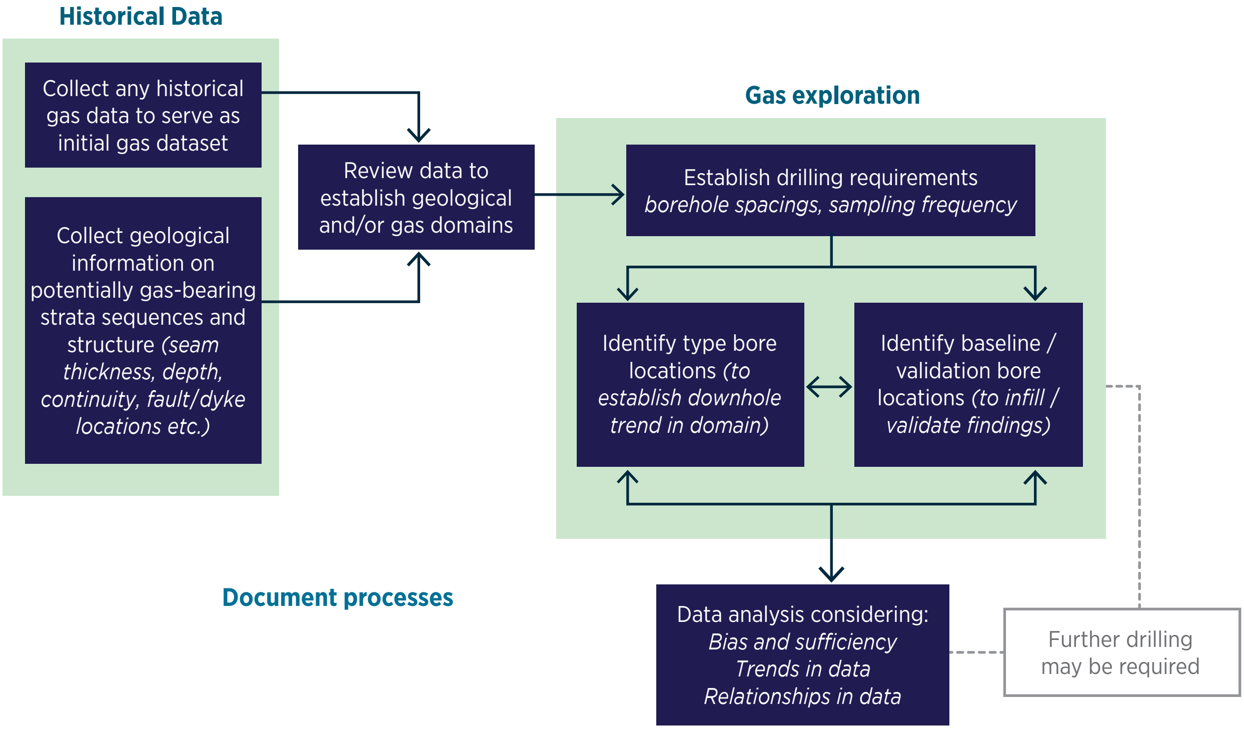
C. For estimating the content of gas type (j) contained by the gas bearing strata (z) total gas contained by gas bearing strata for (B) above:

Data collection and gas testing

A minimum of 3 boreholes that capture the full variance of the gas trends with depth must be located within each gas domain (i.e. area of common gas characteristics). Assessment of the requirement for any additional boreholes is carried out via an iterative process of data review during the gas exploration process to ensure that a sufficient number of unbiased samples have been collected (Figure 3.20).

Sample selection involves the collection of core samples that are representative of the strata that their results will be characterising, and to limit any air contamination both in the field and in the laboratory. Gas testing involves the measurement of each sample's gas content (desorption) and composition according to the Australian Standard AS3980-1999.

Figure A5.3.4.2 Surface mine sample collection process flowchart



Source: ACARP (2011).

The low gas zone

In most mine sites, there is a portion of strata immediately below the surface that is lacking in quantifiable quantities of coal seam gases. Gas properties in strata with no or low gas volumes are difficult to measure accurately due to inherent uncertainties associated with sampling and testing processes.

A gas dataset of over 2,000 samples from New South Wales and Queensland were analysed to provide an alternative method for the estimation of emissions from low gas zones in the subsurface. It was found that there is a 'low' or 'no' gas zone present at most surface coal mines from surface down to a clearly apparent boundary at varying depths. There is a key set of common characteristics observed in these low gas zones:

- over 95 per cent of samples reported gas contents under 0.5 m^3/t;
- over 95 per cent of samples are commonly carbon dioxide (CO_2) and nitrogen (N_2) in gas composition;
- at the horizon where the gas contents increase to over 0.5 m^3/t, the gas compositions simultaneously switch to close to 100 per cent methane (CH_4); and
- this horizon is closely related to the 2 main weathering profiles at the deposit:
  - base of oxidation or water table horizon, and
  - base of weathering (or fresh rock horizon).

Samples within the low gas zone are assigned a default emissions factor. Therefore, all gas bearing strata (i.e. coal and carbonaceous strata with a density less than 1.95 g/cm^3) are assigned the default value, obtained from half the measurable quantities of both components observed in this zone: i.e. 0.25 m^3/t at 50 per cent CO_2 gas composition.

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

NGER scheme emissions for surface mines have been incorporated into the national inventory, having regard to the following procedures and issues:

- Consistency with the IPCC guidelines and comparison with international practice;
- Previous ERT report comments – that have both recommended and encouraged Australia to incorporate NGER scheme emission data for surface mines, when available, into the National Inventory; and
- Inventory quality control procedures for data:
  - NGER scheme data has been subject to quality control procedures specific to inventory purposes, consistent with the national inventory Quality Assurance/Quality Control Plan, as set out in section 1.6 of the NIR.
  - A decision-making process with respect to the use of facility specific EFs is set out in section 1.4.1.

The major issue for which the inventory compilation process must control relates to the question of whether the sample of mines that have estimated emissions using the higher tier methods contains a sampling bias and is not representative of the entire population of coal mines in Australia. At this stage, there is insufficient evidence to indicate that this is the case. This is due to the differing characteristics of individual coal fields, and because companies may select between Method 1 and Method 2/3 when estimating emissions under the NGER scheme. Some mines have not estimated emissions using the higher tier methods (non-reporting mines).

Consequently, the reported plant-specific emissions data has been divided into subgroups based on individual coal basins or coalfields with the use of data and approaches to the treatment of non-reported data set out as below.

In Queensland basins, other than Surat, the number of NGER scheme reporters reporting plant-specific emission estimates using higher order NGER scheme methods is considered to be not sufficient for the sample to be representative of the sub-population of the coal basin. In these cases, the plant-specific NGER scheme emission factors for reporting mines may be incorporated into the inventory but the tail of non-estimating mines is constrained such that the total IEF for the coal field is equal to the pre-existing country-specific emission factors. This means that total emissions for these coal fields are not affected by the inclusion of plant-specific data, for this submission.

In the Western, Surat and Collie coal fields – where previously there has been no empirical data available, the number of reporting mines under NGER scheme is much higher and is considered to be sufficiently representative to be included in the inventory. In these cases, plant-specific NGER scheme data have been incorporated into the inventory, but the emission factors of these reporting mines have, conservatively, not been extrapolated to the non-reporting mines. In the absence of any pre-existing empirical data for these coal fields the pre-existing country-specific emission factors have been used for the tail of non-estimating mines.

In the case of the Gunnedah Basin, the near universal reporting of higher tier facility data has demonstrated the basin to be significantly different from the existing tier 2 country-specific methane emission factor. Therefore, in this case, a Gunnedah Basin-specific methane emission factor has been developed from facility NGER scheme data and applied to mines in the Gunnedah Basin mine for which high tier methane data are not available.

In practice, the use of plant-specific data have been implemented for the Gunnedah, Western, Surat, Collie, Hunter and Newcastle coal fields. The remaining coal fields in Queensland do not use NGER scheme reported data and retain the use of existing tier 2 country-specific methods (see below).

A5.3.5 Emissions Factors and Activity tables for Oil and Gas Fugitives

This section contains information on the emission factors and estimation methodology used across all elements of the Energy sector for oil and gas fugitive emissions. This information supplements section 3.3.2 of Volume 1.

Oil and Gas Exploration (CRT category 1.B.2.a.1, and CRT category 1.B.2.b.1)

Emissions may occur during the process of drilling for oil and gas either during exploration or development drilling, whenever gas or liquid hydrocarbons are encountered. Emission sources include flaring, degassing of drilling muds, and venting during well completions and workovers. Emission factors are reported in Table A5.3.5.1.

Table A5.3.5.1 Oil and gas exploration flaring, venting, and leakage emission factors

		Factor		
Inventory category	**Unit**	**CO_2**	**CH_4**	**N_2O**
Offshore/ Onshore testing[1]	tonnes of emissions / tonne of unprocessed gas flared	2.75	0.035	8.1E-05
	tonnes of emissions / tonne of crude oil flared	3.2	3.3E-04	2.2E-04
Drilling[2]	tonnes of emissions / drill day	0.071 (a)	0.026	NA
Well Completions[3]	tonnes of emissions / event (without fracturing)	0.538 (a)	0.196	NA
	tonnes of emissions / event (with fracturing and venting)	101.03 (a)	36.82	NA
	tonnes of emissions / event (with fracturing and flaring)	13.47 (a)	4.91	NA
	tonnes of emissions / event (with fracturing and green capture)	8.89 (a)	3.24	NA
Well Workovers[3]	tonnes of emissions / event (without fracturing)	0.013 (a)	4.7E-03	NA
	tonnes of emissions / event (with fracturing and venting)	101.03 (a)	36.82	NA
	tonnes of emissions / event (with fracturing and flaring)	13.47 (a)	4.91	NA
	tonnes of emissions / event (with fracturing and green capture)	8.89 (a)	3.24	NA

(a) CO_2 EFs were derived from CH_4 EFs using molecular weights (44.01/16.04).

Source: [1] NGER scheme facility reports (CER 2018) (APPEA 1998–2008)

[2] API Compendium, Table 5.17 (2009)

[3] USEPA NIR Table A-134 (2016)

Crude Oil Production (CRT category 1.B.2.a.ii), and Crude Oil Refining and Storage (CRT category 1.B.2.a.iv)

Emissions of CH_4 and NMVOCs may occur during oil production, including field processing. Crude oil is refined into numerous petroleum products through a variety of physical and chemical processes. Emissions factors for these categories are shown in Table A5.3.5.2.

Table A5.3.5.2 Oil production and refining fugitive emission factors

Inventory Category	Operation/Source	Emissions (t)/throughput(kt)					
		CO_2	CH_4	N_2O	NO_2	CO	NMVOC
Crude Oil Production[1]	Production Leaks		0.057				810
	Internal Floating tank		8.4E-04				
	Fixed roof Tank		4.2E-03				
	Floating tank		0.003				
Flaring of gas at oil refineries[2]	t/kt gas flared	2,695	6.8	0.081	1.5	8.7	12
	Gg/PJ energy flared	47.2	0.12	0.001	0.026	0.15	0.21

Sources:

1 APPEA (1998–2008), E&P Forum (1994)

2 DISER estimates, following methodology of E&P Forum (1994).

Abandoned oil wells (CRT category 1.B.2.a.6.i), and Abandoned Gas wells (CRT category 1.B.2.b.b.vi)

Abandoned wells are defined as wells that are no longer producing petroleum, or where exploration activities have ceased. Emission factors for this category are included in Table A5.3.5.3.

Table A5.3.5.3 Abandoned oil and gas wells emissions factors

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

Source: IPCC (2019, Refinement Table 4.2.4E)

Note: plugged wells are defined as having been capped or sealed, unplugged wells have not been sealed, and thus have a higher emissions factor. "Unknown wells" include wells that are reported to exist but have not had the details of their plugged/unplugged status reported.

Natural gas (CRT category 1.B.2.b)

CRT category 1.B.2.b consists of leakage emissions associated with natural gas systems. Emissions factors for this category are included in Table A5.3.5.4.

Table A5.3.5.4 Fugitive emission factors for natural gas

Inventory category	Unit	Factor		
		CO_2	CH_4	Source
Onshore Natural Gas wells	tonnes of emissions / tonne of gas throughput	1.3E-04 (a)	4.7E-05	Day et al. (2014)
Offshore natural gas platforms (shallow water)	tonnes of emissions / platform	171.8 (a)	62.6	USEPA NIR Table A-134 (2016)
Offshore natural gas platforms (deep water)	tonnes of emissions / platform	1,813.9 (a)	661.1	USEPA NIR Table A-134 (2016)
Onshore coal seam gas wells	tonnes of emissions / tonne of gas throughput	1.3E-04 (a)	4.7E-05	Day et al. (2014)
Produced water	tonnes of emissions / Megalitre of water produced		0.31	(API 2009) Table 627
Gathering and boosting stations	tonnes of emissions / tonne of gas throughput	Modelled	Modelled	Zimmerle et al. (2020)
	tonnes of emissions / pipeline kilometre	0.63 (a)	0.23	(API 2009) Table 745
Gas processing plants	tonnes of emissions / tonne of gas throughput	Modelled	Modelled	Mitchell et al. (2015)
Natural Gas Transmission and Storage	tonnes of emission / kilometre of pipeline	0.02	0.41	(API 2009) Table 745
	tonnes of emission / storage station		370	USEPA NIR Table A-134 (2016)
Natural Gas Distribution	Various	Various	Various	See NIR Volume 2 table A5.3.5.7
LNG storage	tonnes of emission / LNG storage station		921	USEPA NIR Table A-134 (2016)
LNG terminals	tonnes of emission / LNG terminal		1,109	USEPA NIR Table A-134 (2016)
Abandoned gas wells	tonnes of emissions / well		Various	See NIR Volume 2 Table A5.3.5.3
Post-meter leakage	Various	Various	Various	See NIR Volume 2 Table A5.3.5.8

Post-meter emissions (CRT category 1 .B.2.b.vi.1)

Post-meter emissions are a source of emissions that were added in the 2019 IPCC Refinement (IPCC 2019). As per Table 4.2.4K of the 2019 IPCC Refinement (IPCC 2019), this category includes gas leakage emissions from consumer appliances, power plants, and natural gas-fuelled vehicles. Emission factors for this category are included in Table A5.3.5.5.

Table A5.3.5.5 Methane emission factors by natural gas appliance type for residential and commercial sectors

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

Source: Merrin and Francesco (2019)

Natural Gas Distribution (CRT category 1.B.2.b.v)

Plant-specific information is used for the majority of this source, using equipment factors estimated from the API Compendium (API 2009) Table 6-7. Where these data are unavailable, natural gas distribution emissions are calculated by using the proportion of throughput at a facility in a year that is unaccounted for gas (UAG), and then estimating what share of that UAG is actual leakage, rather than being caused by meter inaccuracy, own-use, theft, or the impacts of temperature and pressure variations. The composition of the gas in each distribution network is also reported and combined with the estimated gas leakage to estimate the tonnes of CO_2 and CH_4 that leaks from the network each year. Emission factors for this category are included in Table A5.3.5.6 and Table A5.3.5.7.

Table A5.3.5.6 Proportion of unaccounted for gas (UAG) attributed to fugitive leakage for natural gas distribution

Year	Proportion of UAG attributed to fugitive leakage (%)
1989–90 to 2003–04	55.00
2004–05	55.00
2005–06	55.00
2006–07	53.50
2007–08	52.00
2008–09	50.60
2009–10	49.10
2010–11	47.60
2011–12	46.10
2012–13	44.70
2013–14	43.20
2014–15	41.70
2015–16	40.20
2016–17	38.70
2017–18	37.30
2018–19	37.30
2019–20	37.30
2020–21	37.30

Source: 1989–90 to 2005–06, Energy Strategies (2005). 2017–18 onwards, Zincara (2017). 2006–07 to 2015–16, linear interpolation between the two factors, DCCEEW analysis. IPCC time series consistency has been maintained through the use of the linear interpolation approach under Section 5.3.3.3 of Chapter 5 of Volume 1 of the IPCC Guidelines (IPCC 2006) , as described at page 94 of Volume 1 of the NIR. This table provides the values estimated for the linear interpolation between 2004–05 and 2017–18.

Table A5.3.5.7 Natural gas composition and emissions factors

Pipeline	Longford, Melbourne (Victoria)[3]	Moomba, Sydney (NSW, SA)[3]	Roma, Brisbane (Qld)[3]	Denison, Gladstone (Qld)[3]	Dampier, Perth (WA)[1]	Dongarra, Perth (WA)[1]	Amadeus, Darwin (NT)[3]	Australia (average)[2]
kg CO_2/GJ	0.9	0.8	0.8	0.7	1.0	1.5	0.0	0.88
kg CH_4/GJ	15.5	15.6	15.0	16.0	13.9	16.2	12.6	14.9
kg NMVOC/ GJ	2.5	2.4	3.2	1.8	4.3	1.8	5.8	3.2
Weighted state averages[3]:								
kg CO_2/GJ			0.8		1.1			
kg CH_4/GJ			15.1		14.3			
kg NMVOC/ GJ			3.1		3.9			

Source: 1 (Australian Gas Association 1997)
2 (APA Group 2011)
3 (NGGIC 2007)

Oil and gas production venting and flaring (CRT category 1.B.2.c)

Flaring and venting occurs across the segments of the oil and gas industry. This may include process vents or venting associated with system upsets and accidents. While some sources of emissions such as process vents and flaring systems are engineered or intentional, and therefore well characterised, intermittent events mean the quantity and composition of associated fugitive emissions is often subject to significant uncertainty. Emissions factor for this category are included in Table A5.3.5.8.

Table A5.3.5.8 Venting and flaring emission factors

Inventory category	Unit	Factor		
		CO_2	CH_4	N_2O
Gas vented during oil production[1]	Tonnes of emission/ tonne oil throughput	NA	8.4E-07 – 5.7E-05	NA
Gas vented during onshore gas production[1]	Tonnes of emission/ tonne natural gas throughput	2.0E-07 – 1.3E-04	7.2E-07 – 4.6E-05	NA
Gas vented during offshore gas production[3]	Tonnes of emissions / platform	171.7 – 1,813.9	62.6 – 661.1	NA
Gas vented during condensate production[2]	Tonnes of emission / barrel of condensate	7.0E-03	2.5E-03	NA
Crude oil flared during oil production[4]	Tonnes of emission / tonne of oil flared	3.2	1.4E-03	2.2E-04
Gas flared during oil production[4]	Tonnes of emission / tonne of gas flared	2.9	0.035	8.1E-05
Gas flared during oil refining[1]	Tonnes of emission / tonne of gas flared	2.695	6.8E-03	8.1E-05
Gas flared during gas production[1]	Tonnes of emission / tonne of gas flared	2.7	4.8E-03	9.7E-05

Source: 1 NGER scheme data and API Compendium (API 2009) Tables 5-15, 5-16, 5-17
2 US NIR (2017) Table 3.6-2
3 USEPA (USEPA 2016) Table A-134
3 APPEA (1990–2014)

Activity data source tables

The activity data used to calculate emissions from 1.B.2.a Oil are documented in Table A5.3.5.9.

Table A5.3.5.9 Fugitive emissions from oil extraction activity data sources

Inventory Category	Operation/Source	Activity Data – Type	Activity Data – Source
1.B.2.a.1 Oil Exploration	Gas flared	Tonnes of gas flared	NGER scheme data (CER 2022) and (APPEA 1998–2008)
	Liquids flared	Tonnes of liquids flared	NGER scheme data (CER 2022) and (APPEA 1998–2008)
1.B.2.a.2 Oil production	Wells and well pads leakage	Tonnes of crude oil produced	NGER scheme data (CER 2022) and (APPEA 1998–2008)
1.B.2.a.3 Crude oil transported	Leakage	Petajoules of crude oil transported	Australian Energy Statistics (DCCEEW 2023) and Australian Petroleum Statistics (DCCEEW 2023)
1.B.2.a.4 Refining and storage	Refining leakage	Tonnes of crude oil refined	NGER scheme data (CER 2022) and (APPEA 1998–2008)
	Storage leakage	Tonnes of crude oil stored	NGER scheme data (CER 2022) and (APPEA 1998–2008)
	Gas flared	Tonnes of gas flared	NGER scheme data (CER 2022) and (APPEA 1998–2008)
1.B.2.b.5 Distribution of oil products	Leakage	Petroleum sales	Australian Petroleum Statistics (DCCEEW 2023)
1.B.2.b.6.i Abandoned Oil wells	Leakage	Number of abandoned wells	State and Territory drillhole datasets: (South Australian Department for Energy and Mining 2020), (Resources Queensland 2023), (NSW SEED 2023), (Northern Territory Government 2023), (data WA 2023), (Data Victoria 2023) (Tasmania Department of State Growth 2023)
1.B.2.c Venting and flaring	Gas vented from oil production and condensate production	Tonnes of gas vented	NGER scheme data (CER 2022) and (APPEA 1998–2008)
	Oil and gas flared from oil production	Tonnes of oil or gas flared	NGER scheme data (CER 2022) and (APPEA 1998–2008)

The activity data used to calculate emissions from 1.B.2.b natural gas is documented in Table A5.3.5.10.

Table A5.3.5.10 Fugitive emissions from gas extraction activity data sources

Inventory Category	Operation/Source	Activity Data – Type	Activity Data – Source
1.B.2.b.1 Gas Exploration	Gas flared	Tonnes of gas flared	NGER scheme data (CER 2022) and (APPEA 1998–2008)
	Drilling leakage	Number of drilling days	Derived from NOPTA (NOPTA 1990–2018), state resource agencies, (APPEA 1990–2018) and ABS petroleum investment expenditure (ABS 2023)
	Well completions leakage	Number of wells drilled	(NOPTA 1990–2018), state resource agencies, QLD petroleum production statistics (Business Queensland 2022) and APPEA data (APPEA 1990–2018)
	Well workovers leakage	Number of well workovers	Derived from QLD petroleum statistics (Business Queensland 2022) and APPEA data (APPEA 1990–2018)

Inventory Category	Operation/Source	Activity Data – Type	Activity Data – Source
1.B.2.b.2 Gas production	Wells and well pads leakage	Tonnes of crude oil produced	NGER scheme data (CER 2022) and (APPEA 1998–2008)
	Produced water leakage	Megalitres of water produced	APPEA (APPEA 1990–2018), NGER scheme data (CER 2022), QLD petroleum production statistics (Business Queensland 2022)
	Offshore gas platforms leakage	Number of platforms operating in a year	Geoscience Australia (GA 2022)
	Gathering and boosting compressor stations leakage	Tonnes of gas throughput	NGER scheme data (CER 2022), (APPEA 1990–2018), South Australia Department for Energy and Mining Monthly field production (South Australian Department for Energy and Mining 2020), (EnergyQuest 2017–2023) and Queensland Government CSG production data (Business Queensland 2022)
	Gathering and boosting pipeline leakage	Kilometres of pipeline	Derived using the Australian Energy Statistics (DCCEEW 2023), Table 6 of U.S. GHG Emissions and Sinks (USEPA 2016): Revision to Gathering and Boosting Station Emissions ((USEPA 2016), and miles of pipe per compressor station in the US 2013 National Inventory Report (USEPA 2016)
1.B.2.b.3 Gas processing	Leakage	Tonnes of gas throughput	NGER scheme data (CER 2022) and AES production data (DCCEEW 2023)
1.B.2.b.4 Transmission and storage	Transmission leakage	Length of high-pressure pipeline	Electricity Gas Australia (AEC 2018) Australian Gas Association (AGA 1988–2002)
	Gas storage leakage	Number of gas storage stations operating in a year	NGER scheme data (CER 2022) and Australian Energy Market Operator (Core Energy Group 2015)
	LNG storage leakage	Number of LNG storage stations operating in a year	NGER scheme data (CER 2022) and Australian Energy Market Operator (Core Energy Group 2015)
	LNG terminals leakage	Number of LNG terminals operating in a year	NGER scheme data (CER 2022) and Australian Energy Market Operator (Core Energy Group 2015)
1.B.2.b.5 Distribution	Leakage	Terajoules of gas sales	NGER scheme data (CER 2022) and AES production data (DCCEEW 2023)
1.B.2.b.6.i	Abandoned gas wells Leakage	Number of abandoned wells	State and Territory drillhole datasets: (South Australian Department for Energy and Mining 2020), (Resources Queensland 2023), (NSW SEED 2023), (Northern Territory Government 2023), (data WA 2023), (Data Victoria 2023) (Tasmania Department of State Growth 2023)
1.B.2.b.6.ii Post-meter	Leakage	Number of appliance types `	Residential Baseline Study 2021 (DISER 2022)
		Industrial and power plant gas throughput	AES production data (DCCEEW 2023)
		Number of gas vehicles	(ABS 2019) and NSW State motor vehicle registration statistics (NSWRMS 2018)
1.B.2.c Venting and flaring	Gas vented from gas and condensate production	Tonnes of gas vented	NGER scheme data (CER 2022) and (APPEA 1998–2008)
	Gas flared from gas production	Tonnes of gas flared	NGER scheme data (CER 2022) and (APPEA 1998–2008)

Table A5.3.5.11 Australia's fugitive emissions data for oil, and natural gas extraction activity data, 1989–90 to 2021–22

Activity data by IPCC source and sink categories	Activity data units	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00
1.B.2 Oil and Natural Gas												
Oil												
Exploration	Count of wells	61	74	39	35	55	49	53	99	102	62	34
Crude oil production and upgrading	PJ Crude Oil production	1,184	1,182	1,158	1,136	1,071	1,154	1,119	1,149	1,257	1,032	1,386
Crude oil transport	PJ Crude Oil transported	814	822	801	769	702	764	801	799	845	672	1,146
Crude oil refining and storage	PJ Crude Oil refined	1,386	1,421	1,440	1,495	1,518	1,562	1,624	1,648	1,672	1,675	1,714
Other												
Abandoned wells	Count of wells	1,421.0	1,522.0	1,572.0	1,604.0	1,654.0	1,700.0	1,748.0	1,827.0	1,933.0	1,966.0	2,006.0
Natural Gas												
Exploration	Count of wells	126.1	133.5	101.4	137.4	130.3	154.5	144.3	193.5	188.1	177.2	156.4
Production and gathering												
Well and wellpad production	PJ well and wellpad throughput	2,204.1	3,680.5	4,498.1	3,675.7	2,918.9	2,515.6	4,017.8	4,088.8	2,749.8	2,067.4	1,694.4
Gathering and boosting stations	PJ gathering and boosting station throughput	268.0	264.2	255.9	253.0	246.1	221.9	220.8	225.4	230.3	242.2	234.6
Gathering and boosting pipelines	km gathering and boosting pipelines	97.2	97.2	196.5	322.8	382.4	312.5	478.1	334.9	416.8	518.5	580.0
Offshore facilities	Count of offshore facilities	17.0	17.0	17.0	22.0	22.0	23.0	25.0	28.0	29.0	31.0	31.0
Processing	PJ natural gas processed	1,991.1	1,587.6	1,725.4	1,855.6	1,997.2	2,221.9	2,282.3	2,303.0	2,408.7	2,465.4	2,523.9
Transmission and Storage												
Transmission	Km high-pressure transmission pipeline	10,367	9,900	10,404	10,807	11,381	12,060	13,282	14,093	14,116	17,377	19,043
Storage												
LNG Terminals	Number of facilities	1	1	1	1	1	1	1	1	1	1	1
LNG Storage	Number of facilities	2	2	2	2	2	2	2	2	2	2	2
Natural Gas Storage	Number of facilities	1	1	1	1	1	1	1	2	2	4	5
Distribution	PJ natural gas distributed	294.1	278.4	282.9	286.3	293.0	305.6	305.9	314.2	328.1	299.7	321.3
Other												
Abandoned wells	Count of wells	5,473	5,575	5,681	5,795	5,900	6,065	6,186	6,330	6,492	6,644	6,748
Post meter leakage												
Gas vehicles	Count of vehicles	558	558	558	744	930	1,246	1,233	1,190	1,219	1,063	979
Gas appliance leakage (count)	Count of appliances	7,503,760	7,953,046	8,448,780	8,906,535	9,469,589	9,906,271	10,207,289	10,602,770	11,199,239	11,651,307	12,012,599
Industrial and power plants	mcm gas consumed	11,220	10,277	10,523	10,839	11,485	12,241	11,738	12,081	12,791	13,825	14,248
Venting and Flaring												
Venting	PJ natural gas, crude oil and ORF produced	3,174.9	2,769.9	2,883.8	2,991.6	3,068.2	3,375.9	3,401.6	3,451.8	3,665.3	3,497.6	3,909.4
Flaring	PJ oil and gas flared	76.6	66.9	68.1	63.8	57.6	58.3	47.4	38.4	36.6	41.8	49.1

Activity data by IPCC source and sink categories	Activity data units	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
1.B.2 Oil and Natural Gas												
Oil												
Exploration	Count of wells	38	37	42	54	61	61	99	84	60	25	38
Crude oil production and upgrading	PJ Crude Oil production	1,432	1,380	1,233	1,031	939	900	1,057	954	1,028	946	916
Crude oil transport	PJ Crude Oil transported	1,196	1,132	977	777	712	735	893	799	861	778	785
Crude oil refining and storage	PJ Crude Oil refined	1,695	1,668	1,626	1,528	1,541	1,407	1,504	1,463	1,244	1,251	1,377
Other												
Abandoned wells	Count of wells	2,062.0	2,111.0	2,173.0	2,270.0	2,356.0	2,453.0	2,629.0	2,783.0	2,874.0	2,923.0	2,978.0
Natural Gas												
Exploration	Count of wells	282.7	282.2	289.6	356.1	141.8	382.1	408.6	682.2	637.7	908.0	1,000.3
Production and gathering												
Well and wellpad production	PJ well and wellpad throughput	1,238.3	1,195.8	1,904.9	3,282.9	2,602.1	3,330.1	2,478.7	2,570.6	3,188.2	3,612.9	4,330.9
Gathering and boosting stations	PJ gathering and boosting station throughput	242.6	209.3	198.1	156.7	163.6	164.9	227.5	248.7	273.7	320.6	350.0
Gathering and boosting pipelines	km gathering and boosting pipelines	751.0	639.8	897.1	829.2	832.8	867.1	1,098.1	1,488.4	5,221.4	5,942.0	6,290.3
Offshore facilities	Count of offshore facilities	33.0	36.0	37.0	38.2	39.2	43.2	46.2	48.2	48.2	52.2	52.2
Processing	PJ natural gas processed	2,614.5	2,731.5	2,633.4	2,646.6	2,786.3	2,916.5	3,075.1	3,161.9	3,265.3	3,579.1	4,334.5
Transmission and Storage												
Transmission	Km high-pressure transmission pipeline	19,576	20,109	20,657	21,316	22,168	24,301	25,824	26,946	27,287	28,784	28,203
Storage												
LNG Terminals	Number of facilities	1	1	1	1	1	2	2	2	2	2	2
LNG Storage	Number of facilities	2	2	2	2	2	3	3	3	3	3	3
Natural Gas Storage	Number of facilities	6	6	6	6	6	6	6	6	6	6	7
Distribution	PJ natural gas distributed	339.3	357.3	378.5	383.1	384.5	383.3	395.5	405.8	402.7	398.3	398.5
Other												
Abandoned wells	Count of wells	6,934	7,123	7,307	7,636	7,944	8,272	8,827	9,433	10,207	11,067	11,671
Post meter leakage												
Gas vehicles	Count of vehicles	858	976	969	917	927	1,233	1,230	1,204	1,352	1,481	1,659
Gas appliance leakage (count)	Count of appliances	11,831,702	12,178,326	12,560,517	12,950,112	13,200,489	13,237,571	13,385,470	13,588,193	13,811,708	13,981,175	14,175,753
Industrial and power plants	mcm gas consumed	15,490	15,662	15,995	17,109	17,867	18,214	20,667	21,068	21,540	22,034	22,747
Venting and Flaring												
Venting	PJ natural gas, crude oil and ORF produced	4,046.6	4,111.6	3,866.3	3,678.0	3,725.1	3,816.2	4,131.7	4,116.1	4,293.4	4,525.3	5,250.1
Flaring	PJ oil and gas flared	54.8	49.2	36.1	35.1	33.9	36.1	40.1	40.7	45.2	#VALUE!	36.4

Activity data by IPCC source and sink categories	Activity data units	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
1.B.2 Oil and Natural Gas												
Oil												
Exploration	Count of wells	65	81	71	75	43	34	39	52	27	4	16
Crude oil production and upgrading	PJ Crude Oil production	889	785	745	705	681	597	572	677	677	718	723
Crude oil transport	PJ Crude Oil transported	770	673	632	604	591	511	500	615	615	670	677
Crude oil refining and storage	PJ Crude Oil refined	1,306	1,086	1,229	1,052	884	886	921	924	921	810	473
Other												
Abandoned wells	Count of wells	3,043.0	3,094.0	3,147.0	3,196.0	3,214.0	3,249.0	3,296.0	3,364.0	3,466.0	3,489.0	3,518.0
Natural Gas												
Exploration	Count of wells	659.8	2,165.9	1,685.8	1,552.5	1,223.7	930.7	2,307.7	598.0	2,016.0	2,042.0	1,833.0
Production and gathering												
Well and wellpad production	PJ well and wellpad throughput	3,486.6	3,673.1	3,687.9	4,054.6	5,082.6	6,791.0	7,478.5	9,112.1	9,488.6	9,278.0	7,766.0
Gathering and boosting stations	PJ gathering and boosting station throughput	380.3	413.2	425.6	594.3	1,095.1	1,489.5	1,577.9	1,651.7	1,922.9	1,922.9	3,384.4
Gathering and boosting pipelines	km gathering and boosting pipelines	6,406.5	7,326.6	7,664.8	8,399.2	10,528.6	14,067.6	15,491.8	18,703.0	20,301.4	19,540.4	16,999.5
Offshore facilities	Count of offshore facilities	53.2	53.2	55.2	55.2	55.2	56.2	59.2	50.2	50.2	40.2	40.0
Processing	PJ natural gas processed	3,685.1	3,662.0	3,545.7	3,705.4	5,082.6	6,750.4	7,423.4	9,124.3	9,444.0	9,222.0	10,693.6
Transmission and Storage												
Transmission	Km high-pressure transmission pipeline	28,491	27,841	28,033	29,683	29,774	30,442	30,922	32,706	31,844	31,980	30,219
Storage												
LNG Terminals	Number of facilities	3	3	3	4	7	7	8	10	10	10	10
LNG Storage	Number of facilities	4	4	4	6	9	9	10	12	12	12	12
Natural Gas Storage	Number of facilities	7	7	7	8	8	8	8	8	8	8	8
Distribution	PJ natural gas distributed	386.9	369.5	353.4	358.7	340.5	348.1	339.4	345.9	349.7	354.1	345.9
Other												
Abandoned wells	Count of wells	12,488	13,902	15,553	16,490	17,205	17,780	18,485	19,286	20,110	20,708	21,356
Post meter leakage												
Gas vehicles	Count of vehicles	1,821	2,108	2,225	2,844	3,084	2,822	2,752	2,738	2,142	1,986	2,049
Gas appliance leakage (count)	Count of appliances	14,183,203	14,174,088	14,004,157	13,884,227	13,998,325	14,056,634	14,279,903	14,408,829	14,184,382	14,519,252	14,708,871
Industrial and power plants	mcm gas consumed	23,360	23,876	24,552	24,568	24,518	23,371	23,943	23,462	24,028	22,600	15,152
Venting and Flaring												
Venting	PJ natural gas, crude oil and ORF produced	4,573.6	4,446.9	4,290.8	4,410.7	5,763.2	7,347.4	7,995.4	9,801.1	10,120.8	9,940.4	11,416.5
Flaring	PJ oil and gas flared	59.4	59.0	57.6	80.5	110.6	149.1	154.7	183.7	138.0	107.3	92.7

Sources: Oil and Natural Gas data derived from Australian Energy Statistics (DCCEEW 2023), Resources and Energy Quarterly statistics (DCCEEW 2023), NGER data and Residential Baseline Study for Australia 2000–2040 (DCCEEW, 2021)

Comments: Activity data was updated for oil and gas exploration to provide an estimated count of new wells based on State geospatial data.
Activity data for LNG facility counts were moved to be defined as a subsector of natural gas transmission and storage, in line with IPCC Guidelines.

A5.4 Appendices to Chapter 4, IPPU

A5.4.1 Activity data for industrial processes and product use

Table A5.4.1.1 Lime production, kt

Year	Total Lime production (kt) [(a)]
1990	1,036
2000	1,278
2001	1,535
2002	1,570
2003	1,595
2004	1,625
2005	1,618
2006	1,468
2007	1,633
2008	1,760
2009	1,531
2010	1,633
2011	1,635
2012	1,601
2013	1,641
2014	1,548
2015	1,570
2016	1,543
2017	1,516
2018	1,509
2019	1,489
2020	1,549
2021	1,582
2022	1,328

Source: GHD (2009), DCCEE EITEIs Program (2009), NGER Scheme (CER 2022).

(a) Includes quantities of in-house lime production.

Table A5.4.1.2 Carbonate usage, kt

Year	Limestone Use (kt) [(a)]	Dolomite and Other Carbonate Use(kt) [(b)]
1990	2,176	778
2000	2,800	1,169
2001	2,506	1,170
2002	2,577	1,219
2003	2,606	1,270
2004	2,557	1,235
2005	2,506	1,232
2006	2,641	1,284
2007	2,905	1,255
2008	2,736	1,279
2009	2,420	948
2010	2,548	1,077
2011	2,562	1,404
2012	2,356	1,323
2013	2,223	1,327
2014	1,691	1,792
2015	1,638	1,768
2016	1,788	1,784
2017	1,727	1,539
2018	1,572	1,623
2019	1,623	1,487
2020	1,635	1,158
2021	1,783	1,619
2022	1,726	2,259

Source: EnerGreen Consulting (2008 and 2009), DCCEE EITEIs Program (2009), NGER Scheme (CER 2022).

(a) Excludes limestone consumption for the production of soda ash.

(b) Includes magnesite, barium carbonate, lithium carbonate, potassium carbonate, strontium carbonate and sodium bicarbonate.

Table A5.4.1.3 Soda ash use, kt

Year	Soda ash use (kt)
1990	450
2010	380
2011	361
2012	353
2013	340
2014	317
2015	271
2016	300
2017	277
2018	320
2019	332
2020	262
2021	296
2022	267

Source: EnerGreen Consulting (2008 and 2009), NGER Scheme (CER 2022).

Table A5.4.1.4 Ammonia production, kt

Year	Production (kt)
1990	448
2000	569
2001	677
2002	734
2003	967
2004	1,179
2005	1,231
2006	1,432
2007	1,708
2008	1,395
2009	1,364
2010	1,896
2011	1,855
2012	1,917
2013	2,093
2014	2,037
2015	2,020
2016	1,905
2017	1,924
2018	1,939
2019	1,576
2020	1,816
2021	1,990
2022	1,880

Source: Energreen (2008 and 2009), NGER scheme (CER 2022). DISER (2021).

Table A5.4.1.5 Nitric acid production, kt

Year	Production (kt)
1990	297
2000	536
2001	657
2002	713
2003	748
2004	756
2005	858
2006	915
2007	992
2008	1,082
2009	1,222
2010	1,286
2011	1,269
2012	1,284
2013	1,336
2014	1,466
2015	1,545
2016	1,630
2017	1,630
2018	1,709
2019	1,699
2020	1,815
2021	1,908
2022	1,988

Source: Energreen (2008 and 2009), NGER scheme (CER 2022).

Table A5.4.1.6 Production and aggregated emissions from the production of Iron and Steel, Ferroalloys and Other Metals

Year	Steel production (kt) (a)	Hot Briquetted Iron production (kt) (b)	Natural Gas consumption (PJ) (b)	Refined Lead production (kt) (a)	Refined Nickel production (kt) (a)	Refined Zinc production (kt) (a)	Refined Silver production (kt) (a)	Refined Copper (kt) (a)	Manganese alloy production (kt) (c)	Aggregated emissions from Iron and Steel, Ferroalloys and Other metals production (Gg CO_2-e)
1990	6,223			200	44	295	0.4	265	Not available	9,679
2000	6,345	558	6	233	97	405	0.5	477	Not available	10,455
2001	6,027	1,223	22	215	113	534	0.5	517	Not available	9,733
2002	5,933	1,142	23	275	124	572	0.6	561	Not available	9,507
2003	6,282	1,670	34	267	129	571	0.7	537	Not available	10,739
2004	6,312	1,592	32	247	124	499	0.6	458	Not available	11,387
2005	5,977			234	126	464	0.7	486	Not available	9,502
2006	6,560			234	115	446	0.7	461	Not available	9,740
2007	6,600			191	118	496	0.6	435	Not available	10,214
2008	6,597			203	121	507	0.6	444	Not available	10,105
2009	5,529			213	111	506	0.8	499	Not available	8,071
2010	6,867			189	120	515	0.7	395	Not available	9,996
2011	7,333			190	101	499	0.7	485	Not available	10,462
2012	5,357			174	123	505	0.8	486	Not available	8,285
2013	4,749			159	131	496	1.1	454	Not available	7,407
2014	4,446			183	137	492	1.1	500	387	6,971
2015	4,776			169	145	501	1.0	450	413	7,458
2016	4,945			191	142	459	1.3	514	224	7,671
2017	5,198			172	112	466	1.0	448	220	8,253
2018	5,554			154	111	474	0.9	350	221	8,488
2019	5,393			136	114	480	0.9	409	222	8,340
2020	5,350			107	108	418	0.9	421	223	7,907
2021	5,516			136	105	458	1.0	462	224	8,088
2022	5,654			140	98	435	0.8	368	225	8,501

Sources: (a) Resources and Energy Quarterly (DISER 2021). (b) Energreen (2008 and 2009). (c) South32 Annual Reports (2014–2022).

Table A5.4.1.7 Emission factors: kg per tonne of aluminium production

Year	CO_2 [(a)]	CF4	C_2F_6
1990	1,666	0.416	0.054
2000	1,616	0.082	0.011
2001	1,633	0.112	0.015
2002	1,694	0.106	0.014
2003	1,668	0.101	0.013
2004	1,636	0.102	0.013
2005	1,641	0.106	0.014
2006	1,615	0.040	0.005
2007	1,638	0.033	0.004
2008	1,620	0.025	0.003
2009	1,584	0.020	0.002
2010	1,630	0.017	0.002
2011	1,651	0.018	0.002
2012	1,644	0.017	0.002
2013	1,560	0.012	0.001
2014	1,520	0.012	0.001
2015	1,501	0.012	0.001
2016	1,396	0.015	0.002
2017	1,446	0.012	0.004
2018	1,435	0.017	0.002
2019	1,457	0.016	0.006
2020	1,480	0.019	0.002
2021	1,450	0.017	0.007
2022	1,493	0.019	0.003

Source: NGER scheme (CER 2022), Beyond Neutral (2008), GHD (2009). (a) IEF including production and consumption of anodes.

Table A5.4.1.8 Aluminium production

Year	Aluminium production (kt) (a)
1990	1,235
2000	1,742
2001	1,788
2002	1,809
2003	1,855
2004	1,877
2005	1,890
2006	1,912
2007	1,954
2008	1,965
2009	1,980
2010	1,926
2011	1,943
2012	1,943
2013	1,786
2014	1,778
2015	1,649
2016	1,652
2017	1,520
2018	1,570
2019	1,576
2020	1,576
2021	1,578
2022	1,523

Source: (a) ABARES (1990–2008) and NGER scheme (CER 2022) . (b) Beyond Neutral (2008), GHD (2009).

Table A5.4.1.9 Hydrofluorocarbons: key assumptions concerning average equipment life, initial and annual losses and replenishment rates, by equipment type

End Use Category	Average equipment life [a,b,d]	Loss on initial charge [a]	Annual loss [a,d]	Replenishment [c]	Emissions Estimation Method
	Years	per cent	per cent		
Commercial refrigeration					
Stand-alone commercial applications	12	1.75	7.2	Full replenishment every 2 years	Method 3
Medium and large commercial applications	15	1.75	11.8 – 13.0	Full replenishment every 2 years	Method 3
Industrial commercial applications	23	1.75	15.7 – 17.5	Full replenishment every 2 years	Method 3
Domestic refrigeration	14.5	0.6	1.7	No replenishment	Method 2
Transport refrigeration	7	5.1	15.7 – 20.0	Full replenishment every 2 years	Method 3
Light vehicle air conditioning	11.5	0.4	6.7 – 10.0	Full replenishment at 6 years	Method 1
Heavy vehicle air conditioning	13	0.4	10.8	Full replenishment every 2 years	Method 3
Domestic stationary air conditioning					
Refrigerated portable air conditioners	11.5	0.6	2.5	No replenishment	Method 2
Split system air conditioners	13.5	0.6	3.5 – 4.0	No replenishment	Method 2
Packaged air conditioners	13.5	0.6	2.5 – 4.0	No replenishment	Method 2
Commercial air conditioners	22	5.1	4.5 – 6.0	Full replenishment every 2 years	Method 3
Foams (open and closed cell)	20.5	60.0	2.3	No replenishment	Method 4
Aerosols	2.5	0.0	50.0	No replenishment	Method 4
Fire	10.5	0.4	5.0	Full replenishment every 2 years	Method 4
Metered Dose Inhalers	2	0.0	50.0	No replenishment	Method 3

Source: (a) IPCC (2006). (b) Burnbank (2002). (c) DCCEEW. (d) Expert Group (2013), (2018)

Table A5.4.1.10 End-use allocation of imports of bulk and pre-charged HFC gas, 2022 (Mt CO_2-e)

End Use Breakdown	Bulk Imports (Mt CO_2-e)	Pre-charged imports (Mt CO_2-e)	Total (Mt CO_2-e)
Refrigeration	5.65	0.24	5.90
Transport refrigeration	0.32	0.03	0.35
Commercial refrigeration	5.34	0.19	5.52
Domestic refrigeration and freezers	–	0.02	0.02
Stationary air-conditioning	0.42	2.68	3.11
Chillers	0.38	0.82	1.20
Refrigerated portable	–	0.06	0.06
Split systems	–	1.72	1.72
Packaged systems	0.04	0.09	0.13
Mobile air-conditioning	0.59	0.79	1.38
Cars	0.31	0.71	1.02
Trucks	0.28	0.08	0.36
Foam	–	–	–
Aerosols/solvents	–	0.34	0.34
Fire equipment	0.06	0.00	0.06
Metered dose inhalers	–	0.13	0.13
TOTAL	**6.73**	**4.20**	**10.92**

Source: DCCEEW.

Table A5.4.1.11 Halocarbons: estimated stock, all equipment types

Year	Stock of gas (Mt CO_2-e)
1990	–
1991	–
1992	–
1993	–
1994	0.11
1995	2.10
1996	3.99
1997	5.99
1998	8.49
1999	11.36
2000	14.78
2001	18.57
2002	22.67
2003	27.01
2004	31.61
2005	36.11
2006	39.09
2007	43.29
2008	48.64
2009	54.41
2010	59.65
2011	63.66
2012	68.01
2013	70.70
2014	75.21
2015	80.02
2016	82.78
2017	85.18
2018	89.35
2019	92.59
2020	94.54
2021	94.42
2022	92.68

Table A5.4.1.12 Halocarbons: estimated stock, domestic refrigerator/freezers

Year	Domestic refrigerator stock using HFCs [(a)]	Stock of gas (Mt CO_2-e)
1994	8,382,254	0.11
1995	8,578,471	0.22
1996	8,774,688	0.33
1997	8,970,905	0.44
1998	9,167,123	0.55
1999	9,363,340	0.66
2000	9,538,827	0.76
2001	9,714,313	0.85
2002	9,937,512	0.96
2003	10,226,951	1.07
2004	10,518,356	1.18
2005	10,811,949	1.30
2006	11,045,172	1.36
2007	11,514,381	1.48
2008	11,850,689	1.59
2009	12,182,534	1.69
2010	12,283,818	1.76
2011	12,322,307	1.80
2012	12,372,914	1.83
2013	12,423,522	1.85
2014	12,474,129	1.85
2015	12,474,129	1.89
2016	11,850,423	1.79
2017	11,151,546	1.70
2018	10,410,801	1.58
2019	9,625,030	1.46
2020	8,776,277	1.34
2021	7,871,805	1.24
2022	6,921,298	1.13

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

Table A5.4.1.13 Halocarbons: estimated stock, split system stationary air-conditioners

Year	Split system air conditioner stock [(a)]	Stock of gas (Mt CO_2-e)
1995	664,300	0.34
1996	709,650	0.67
1997	755,000	0.99
1998	800,350	1.30
1999	845,700	1.60
2000	1,146,548	3.07
2001	1,447,395	4.48
2002	1,748,243	5.84
2003	2,075,944	7.27
2004	2,403,645	8.64
2005	2,731,346	9.68
2006	3,062,064	10.82
2007	3,549,559	12.24
2008	3,723,500	13.95
2009	4,106,477	15.64
2010	4,437,195	17.66
2011	4,767,913	19.57
2012	5,098,631	21.83
2013	5,429,349	22.69
2014	5,760,067	24.06
2015	6,090,785	25.14
2016	6,713,882	26.08
2017	7,257,270	27.28
2018	7,715,016	28.62
2019	8,085,303	29.24
2020	8,375,820	29.13
2021	8,598,675	28.64
2022	8,770,800	27.84

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

Table A5.4.1.14 Halocarbons: estimated stock, packaged air conditioners

Year	Packaged air conditioner stock [(a)]	Stock of gas (Mt CO_2-e)
1995	1,582,177	0.53
1996	1,643,545	1.08
1997	1,704,215	1.60
1998	1,764,251	2.11
1999	1,823,714	2.60
2000	1,807,716	2.75
2001	1,791,754	2.90
2002	1,775,404	3.03
2003	1,767,740	3.18
2004	1,759,693	3.34
2005	1,746,587	3.21
2006	1,703,566	3.08
2007	1,660,699	3.15
2008	1,618,530	3.29
2009	1,674,441	3.62
2010	1,730,352	3.73
2011	1,786,263	3.74
2012	1,842,174	3.79
2013	1,898,085	3.83
2014	1,953,995	3.85
2015	2,009,906	3.85
2016	2,009,906	3.73
2017	2,009,906	3.63
2018	2,009,906	3.54
2019	2,009,906	3.44
2020	2,009,906	3.30
2021	2,009,906	3.12
2022	2,009,906	2.95

Source: (a) ABS (2008).

Table A5.4.1.15 Halocarbons: estimated stock, refrigerated portable air conditioners

Year	Refrigerated portable System stock [(a)]	Stock of gas (Mt CO_2-e)
1995	160,971	0.00
1996	155,350	0.00
1997	149,730	0.01
1998	144,109	0.01
1999	138,488	0.02
2000	141,998	0.03
2001	145,508	0.05
2002	149,019	0.06
2003	177,029	0.10
2004	205,040	0.14
2005	233,050	0.16
2006	215,967	0.16
2007	198,883	0.24
2008	181,800	0.31
2009	270,000	0.41
2010	358,200	0.55
2011	446,400	0.65
2012	446,400	0.69
2013	446,400	0.74
2014	446,400	0.81
2015	446,400	0.86
2016	446,400	0.90
2017	446,400	0.94
2018	446,400	0.99
2019	446,400	1.00
2020	446,400	0.99
2021	446,400	0.97
2022	446,400	0.94

Source: (a) ABS (2008).

Table A5.4.1.16 Halocarbons: estimated stock, light vehicle air conditioners

Year	Light vehicle stock [(a)]	Stock of gas in operating equipment ($Mt CO_2$-e)
1995	9,710,640	0.57
1996	10,106,055	1.05
1997	10,249,706	1.53
1998	10,438,519	2.09
1999	10,735,002	2.47
2000	11,103,805	3.14
2001	11,441,871	3.74
2002	11,722,502	4.33
2003	12,017,165	4.98
2004	12,329,726	5.53
2005	12,701,059	6.16
2006	13,168,195	6.57
2007	13,453,049	6.92
2008	13,803,497	7.26
2009	14,121,275	7.52
2010	14,563,421	7.81
2011	14,828,578	7.96
2012	15,194,051	8.13
2013	15,596,290	8.21
2014	15,947,248	8.26
2015	16,248,000	8.42
2016	16,589,084	8.60
2017	16,937,865	8.82
2018	17,251,336	8.97
2019	17,541,397	9.06
2020	18,044,648	9.26
2021	18,352,703	9.38
2022	18,754,331	9.46

Source: (a) ABS (2020); Includes stocks not containing HFC refrigerants.

Table A5.4.1.17 Halocarbons: estimated stock, heavy vehicle air conditioners

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)
1995	0.02	0.02
1996	0.03	0.05
1997	0.04	0.08
1998	0.07	0.14
1999	0.11	0.22
2000	0.09	0.29
2001	0.13	0.38
2002	0.16	0.49
2003	0.18	0.60
2004	0.22	0.74
2005	0.26	0.89
2006	0.20	0.97
2007	0.27	1.11
2008	0.33	1.28
2009	0.36	1.45
2010	0.36	1.60
2011	0.36	1.72
2012	0.38	1.85
2013	0.38	1.94
2014	0.44	2.08
2015	0.49	2.23
2016	0.42	2.29
2017	0.41	2.32
2018	0.48	2.41
2019	0.51	2.51
2020	0.45	2.54
2021	0.44	2.54
2022	0.36	2.47

Source: DCCEEW – HFC import data collected under the Ozone Protection and Synthetic Greenhouse Gas Management Act (2003).

Table A5.4.1.18 Halocarbons: estimated stock, transport refrigeration

Year	Imports of gas ($Mt\ CO_2$-e)	Stock of gas in operating equipment ($Mt\ CO_2$-e)
1995	0.03	0.03
1996	0.04	0.05
1997	0.05	0.09
1998	0.09	0.15
1999	0.15	0.25
2000	0.12	0.31
2001	0.17	0.39
2002	0.22	0.50
2003	0.25	0.59
2004	0.30	0.70
2005	0.37	0.84
2006	0.30	0.89
2007	0.36	0.97
2008	0.44	1.09
2009	0.49	1.21
2010	0.49	1.29
2011	0.47	1.33
2012	0.47	1.37
2013	0.49	1.40
2014	0.58	1.51
2015	0.65	1.65
2016	0.55	1.70
2017	0.55	1.74
2018	0.51	1.76
2019	0.68	1.91
2020	0.70	2.05
2021	0.49	1.96
2022	0.35	1.76

Source: DCCEEW – HFC import data collected under the Ozone Protection and Synthetic Greenhouse Gas Management Act (2003).

Table A5.4.1.19 Halocarbons: estimated stock, commercial refrigeration

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)
1995	0.37	0.34
1996	0.43	0.69
1997	0.60	1.14
1998	1.04	1.95
1999	1.68	3.23
2000	1.34	4.04
2001	1.95	5.26
2002	2.49	6.82
2003	2.80	8.40
2004	3.46	10.36
2005	4.19	12.64
2006	3.45	13.92
2007	4.28	15.68
2008	5.24	18.06
2009	6.01	20.66
2010	5.98	22.84
2011	5.70	24.24
2012	5.95	25.71
2013	5.79	26.60
2014	7.12	28.64
2015	7.82	30.83
2016	6.45	31.58
2017	6.00	31.66
2018	7.24	33.00
2019	7.83	34.49
2020	7.69	35.72
2021	6.72	35.60
2022	5.52	34.56

Source: DCCEEW – HFC import data collected under the Ozone Protection and Synthetic Greenhouse Gas Management Act (2003).

Table A5.4.1.20 Halocarbons: estimated stock, commercial air conditioners

Year	Imports of gas ($Mt CO_2$-e)	Stock of gas in operating equipment ($Mt CO_2$-e)
1995	0.01	0.01
1996	0.01	0.02
1997	0.02	0.03
1998	0.03	0.06
1999	0.04	0.09
2000	0.04	0.12
2001	0.05	0.16
2002	0.06	0.21
2003	0.07	0.26
2004	0.08	0.31
2005	0.11	0.40
2006	0.08	0.45
2007	0.10	0.51
2008	0.22	0.69
2009	0.28	0.91
2010	0.21	1.05
2011	0.23	1.19
2012	0.30	1.40
2013	0.71	1.99
2014	0.79	2.63
2015	1.01	3.45
2016	1.27	4.49
2017	1.06	5.27
2018	1.64	6.61
2019	1.20	7.43
2020	1.15	8.15
2021	1.29	8.95
2022	1.20	9.61

Source: DCCEEW – HFC import data collected under the Ozone Protection and Synthetic Greenhouse Gas Management Act (2003).

Table A5.4.1.21 Halocarbons: estimated stock, foam

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)
1995	0.01	0.00
1996	0.01	0.01
1997	0.02	0.02
1998	0.03	0.03
1999	0.05	0.04
2000	0.03	0.05
2001	0.05	0.07
2002	0.05	0.09
2003	0.06	0.11
2004	0.07	0.13
2005	0.10	0.17
2006	0.05	0.18
2007	0.09	0.21
2008	0.09	0.24
2009	0.12	0.28
2010	0.09	0.30
2011	0.10	0.32
2012	0.07	0.34
2013	0.09	0.36
2014	0.10	0.38
2015	0.15	0.42
2016	0.06	0.43
2017	0.08	0.44
2018	0.08	0.45
2019	0.14	0.48
2020	0.08	0.49
2021	0.09	0.51
2022	–	0.48

Source: DCCEEW – HFC import data collected under the Ozone Protection and Synthetic Greenhouse Gas Management Act (2003).

Table A5.4.1.22 Halocarbons: estimated stock, fire protection equipment

Year	Imports of gas ($Mt\ CO_2$-e)	Stock of gas in operating equipment ($Mt\ CO_2$-e)
1995	0.01	0.01
1996	0.01	0.02
1997	0.02	0.04
1998	0.03	0.07
1999	0.05	0.11
2000	0.03	0.13
2001	0.05	0.18
2002	0.06	0.23
2003	0.07	0.28
2004	0.08	0.34
2005	0.11	0.42
2006	0.07	0.45
2007	0.10	0.52
2008	0.12	0.58
2009	0.15	0.67
2010	0.12	0.73
2011	0.13	0.78
2012	0.11	0.81
2013	0.13	0.85
2014	0.14	0.90
2015	0.19	0.98
2016	0.11	0.99
2017	0.12	1.00
2018	0.13	1.02
2019	0.18	1.08
2020	0.14	1.09
2021	0.13	1.10
2022	0.06	1.03

Source: DCCEEW– HFC import data collected under the Ozone Protection and Synthetic Greenhouse Gas Management Act (2003).

Table A5.4.1.23 Halocarbons: estimated stock, metered dose inhalers

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)
1998	0.01	0.01
1999	0.03	0.03
2000	0.04	0.04
2001	0.06	0.06
2002	0.08	0.08
2003	0.09	0.10
2004	0.11	0.12
2005	0.13	0.14
2006	0.15	0.16
2007	0.17	0.18
2008	0.19	0.20
2009	0.21	0.23
2010	0.21	0.24
2011	0.21	0.24
2012	0.15	0.19
2013	0.14	0.16
2014	0.13	0.15
2015	0.12	0.14
2016	0.12	0.14
2017	0.13	0.14
2018	0.13	0.14
2019	0.13	0.15
2020	0.13	0.15
2021	0.13	0.15
2022	0.13	0.15

Source: DCCEEW Estimates.

Table A5.4.1.24 Halocarbons: estimated stock, aerosols/solvents

Year	Imports of gas (Mt CO_2-e)	Stock of gas in operating equipment (Mt CO_2-e)
1998	0.03	0.03
1999	0.05	0.05
2000	0.03	0.03
2001	0.06	0.05
2002	0.06	0.06
2003	0.07	0.07
2004	0.08	0.07
2005	0.11	0.10
2006	0.06	0.06
2007	0.10	0.09
2008	0.10	0.10
2009	0.14	0.13
2010	0.10	0.10
2011	0.11	0.10
2012	0.08	0.08
2013	0.10	0.09
2014	0.11	0.10
2015	0.17	0.15
2016	0.07	0.08
2017	0.29	0.23
2018	0.27	0.26
2019	0.40	0.35
2020	0.32	0.31
2021	0.27	0.26
2022	0.34	0.31

Source: DCCEEW Estimates.

Table A5.4.1.25 Halocarbons: balance sheet – allocations of imported gas (Mt CO_2-e)

Gas Imported	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Bulk gas imported	0.07	1.93	1.95	2.17	2.78	3.39	3.99	4.60	5.21	5.82	6.42	7.03	6.31	6.01
Gas imported in pre-charged equipment	0.04	0.16	0.22	0.30	0.39	0.48	0.69	0.89	1.07	1.27	1.47	1.48	1.15	3.38
Total gas imported	**0.11**	**2.10**	**2.17**	**2.47**	**3.17**	**3.86**	**4.68**	**5.50**	**6.27**	**7.08**	**7.90**	**8.51**	**7.46**	**9.38**
Allocations to end use														
Transport refrigeration	-	0.03	0.04	0.05	0.09	0.15	0.12	0.17	0.22	0.25	0.30	0.37	0.30	0.36
Commercial refrigeration	-	0.37	0.43	0.60	1.04	1.68	1.34	1.95	2.49	2.80	3.46	4.19	3.45	4.28
Domestic refrigeration and freezers	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.13	0.14	0.16	0.16	0.17	0.13	0.20
Chillers	-	0.01	0.01	0.02	0.03	0.04	0.04	0.05	0.06	0.07	0.08	0.11	0.08	0.10
Refrigerated portable	-	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.02	0.04	0.04	0.03	0.01	0.08
Split systems	-	0.35	0.35	0.35	0.36	0.36	1.58	1.59	1.61	1.75	1.77	1.51	1.72	2.11
Packaged systems	-	0.55	0.58	0.58	0.59	0.59	0.27	0.29	0.31	0.37	0.39	0.14	0.14	0.35
Cars	-	0.61	0.58	0.64	0.76	0.63	0.97	0.96	1.03	1.16	1.13	1.28	1.11	1.16
Trucks	-	0.02	0.03	0.04	0.07	0.11	0.09	0.13	0.16	0.18	0.22	0.26	0.20	0.27
Foam	-	0.01	0.01	0.02	0.03	0.05	0.03	0.05	0.05	0.06	0.07	0.10	0.05	0.09
Aerosols/Solvents	-	0.01	0.01	0.02	0.05	0.08	0.07	0.12	0.14	0.17	0.19	0.24	0.21	0.27
Fire equipment	-	0.01	0.01	0.02	0.03	0.05	0.03	0.05	0.06	0.07	0.08	0.11	0.07	0.10
Total gas allocated	**0.11**	**2.10**	**2.17**	**2.47**	**3.17**	**3.86**	**4.68**	**5.50**	**6.27**	**7.08**	**7.90**	**8.51**	**7.46**	**9.38**
Balance against total gas imported	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Gas Imported	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Bulk gas imported	7.10	8.29	7.84	7.27	7.52	7.52	9.00	10.12	8.03	7.59	8.84	9.79	9.70	8.30	6.73
Gas imported in pre-charged equipment	4.07	4.24	4.87	4.95	5.45	4.47	5.16	5.19	5.43	5.89	6.64	5.54	4.62	4.55	4.20
Total gas imported	**11.17**	**12.53**	**12.70**	**12.22**	**12.96**	**12.00**	**14.16**	**15.31**	**13.46**	**13.49**	**15.49**	**15.33**	**14.32**	**12.85**	**10.92**
Allocations to end use															
Transport refrigeration	0.44	0.49	0.49	0.47	0.47	0.49	0.58	0.65	0.55	0.55	0.51	0.68	0.70	0.49	0.35
Commercial refrigeration	5.24	6.01	5.98	5.70	5.95	5.79	7.12	7.82	6.45	6.00	7.24	7.83	7.69	6.72	5.52
Domestic refrigeration and freezers	0.19	0.19	0.17	0.14	0.14	0.14	0.13	0.17	0.04	0.05	0.02	0.02	0.02	0.03	0.02
Chillers	0.22	0.28	0.21	0.23	0.30	0.71	0.79	1.01	1.27	1.06	1.64	1.20	1.15	1.29	1.20
Refrigerated portable	0.08	0.12	0.17	0.12	0.07	0.09	0.11	0.10	0.10	0.12	0.12	0.10	0.08	0.07	0.06
Split systems	2.55	2.66	3.14	3.17	3.67	2.41	3.04	2.89	2.87	3.26	3.55	2.93	2.32	1.99	1.72
Packaged systems	0.43	0.64	0.44	0.35	0.38	0.39	0.38	0.36	0.23	0.25	0.23	0.22	0.17	0.13	0.13
Cars	1.18	1.16	1.23	1.12	1.21	1.15	1.09	1.19	1.16	1.18	1.08	1.01	1.06	1.06	1.02
Trucks	0.33	0.36	0.36	0.36	0.38	0.38	0.44	0.49	0.42	0.41	0.48	0.51	0.45	0.44	0.36
Foam	0.09	0.12	0.09	0.10	0.07	0.09	0.10	0.15	0.06	0.08	0.08	0.14	0.08	0.09	-
Aerosols/Solvents	0.29	0.35	0.31	0.33	0.23	0.24	0.24	0.29	0.19	0.42	0.40	0.53	0.45	0.41	0.48
Fire equipment	0.12	0.15	0.12	0.13	0.11	0.13	0.14	0.19	0.11	0.12	0.13	0.18	0.14	0.13	0.06
Total gas allocated	**11.17**	**12.53**	**12.70**	**12.22**	**12.96**	**12.00**	**14.16**	**15.31**	**13.46**	**13.49**	**15.49**	**15.33**	**14.32**	**12.85**	**10.92**
Balance against total gas imported	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Table A5.4.1.26 Halocarbons: Supply – use balance sheet (Mt CO_2-e)

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Gas supply	**0.11**	**2.10**	**2.17**	**2.47**	**3.17**	**3.86**	**4.68**	**5.50**	**6.27**	**7.08**	**7.90**	**8.51**	**7.46**	**9.38**
Pre-charged Imports	0.04	0.16	0.22	0.30	0.39	0.48	0.69	0.89	1.07	1.27	1.47	1.48	1.15	3.38
Bulk gas used in production & retrofit	0.07	1.93	1.86	2.09	2.54	3.08	3.13	3.79	3.88	4.50	4.53	5.15	3.69	3.71
Bulk gas used in replenishment	-	-	0.09	0.08	0.24	0.31	0.87	0.81	1.33	1.32	1.89	1.88	2.62	2.29
Gas use/ losses	**0.11**	**2.10**	**2.17**	**2.47**	**3.17**	**3.86**	**4.68**	**5.50**	**6.27**	**7.08**	**7.90**	**8.51**	**7.46**	**9.38**
Emissions	0.00	0.11	0.28	0.46	0.66	0.99	1.25	1.69	2.11	2.65	3.19	3.86	4.27	4.96
Recovery for destruction	-	-	0.00	0.00	0.00	0.01	0.01	0.02	0.06	0.09	0.12	0.16	0.21	0.23
Stock change	0.11	1.99	1.89	2.00	2.50	2.87	3.42	3.79	4.10	4.34	4.60	4.50	2.98	4.20
Balance	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Gas supply	**11.17**	**12.53**	**12.70**	**12.22**	**12.96**	**12.00**	**14.16**	**15.31**	**13.46**	**13.49**	**15.49**	**15.33**	**14.32**	**12.85**	**10.92**
Pre-charged Imports	4.07	4.24	4.87	4.95	5.45	4.47	5.16	5.19	5.43	5.89	6.64	5.54	4.62	4.55	4.20
Bulk gas used in production & retrofit	3.76	5.34	3.58	3.74	2.68	3.57	3.79	5.73	2.23	3.09	2.91	5.16	3.29	3.36	0.06
Bulk gas used in replenishment	3.34	2.95	4.26	3.52	4.84	3.96	5.22	4.38	5.80	4.51	5.93	4.63	6.41	4.94	6.67
Gas use/ losses	**11.17**	**12.53**	**12.70**	**12.22**	**12.96**	**12.00**	**14.16**	**15.31**	**13.46**	**13.49**	**15.49**	**15.33**	**14.32**	**12.85**	**10.92**
Emissions	5.57	6.45	7.07	7.82	8.21	8.57	9.29	9.84	10.25	10.48	10.44	11.29	11.56	12.08	11.66
Recovery for destruction	0.24	0.32	0.39	0.40	0.41	0.73	0.36	0.65	0.45	0.61	0.87	0.81	0.81	0.90	1.00
Stock change	5.35	5.76	5.25	4.01	4.35	2.70	4.51	4.81	2.76	2.40	4.17	3.24	1.95	-0.13	-1.74
Balance	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

A5.4.2 Methodology applied to estimate uncertainty of CSIRO inverse modelled estimates of fluorinated gases (Category 2.F)

While inverse modelled estimates of HFC gas emissions published by the CSIRO (most recent estimates set out in CSIRO (2023)) are no longer used to calibrate leakage rates in Australia's National Inventory estimates for category 2.F, this information is presented here for transparency.

InTEM

The inverse modelling methodology (InTEM: Inversion Technique for Emission Modelling), used by CSIRO to derive independent estimates of Australian HFC emissions, has been developed over the past two decades at the UK Met Office (Manning, O'Doherty, et al. 2011), (Manning, Redington, et al. 2021). InTEM uses a Bayesian statistical technique with a non-negative least squares solver to find the emission distributions that produces the modelled times-series at the Cape Grim Baseline station that has the best statistical match to the observations (Manning, Redington, et al. 2021).

InTEM Uncertainty

InTEM takes into account uncertainties in:

- Observations
- Prior emissions
- The Model

The observation uncertainty (σ_o) is estimated each day by repeatedly measuring the HFCs in the same tank of air. The standard deviation of these measurements is defined as the observation uncertainty for that day's observations for each gas (Manning, Redington, et al. 2021).

InTEM requires the use of a prior emission distribution with associated uncertainties. The prior emissions for the HFCs are based on population distribution and have a large uncertainty (100%) to avoid over-constraining.

The model uncertainty has three parts:

- Background uncertainty (σ_b)
- Meteorological uncertainty (σ_m)
- Atmospheric variability uncertainty (σ_v)

The background uncertainty is estimated during the fitting of the baseline trend to the baseline observations. The meteorological uncertainty of each 4-hour window is proportional to the magnitude of the pollution event, with an imposed minimum uncertainty equal to the median pollution event for that gas and for that year. The third component is the atmospheric variability of the observations within a 12-hour window centred on each 4 hour InTEM sample period.

The overall model and observation uncertainty for each 4 h period (σ_t) is given by the following equation (Manning, et al. 2018) (Manning, Redington, et al. 2021):

$$\sigma_t = \sqrt{\sigma_o^2 + \sigma_b^2 + \sigma_m^2 + \sigma_v^2}$$

This model and observation uncertainty is used to weight each 4-hour observation used by the inversion (i.e. the more uncertain the observations and model are for a particular 4-hour period, the less influence that observation would have on the results). The model and observation uncertainties, as well as the prior uncertainties, are also used by InTEM for calculation of the emission uncertainties.

The inversion for each 2-year inversion window is repeated 24 times omitting roughly 10% of the observations (specifically, 8 randomly-selected 5-day periods per year are omitted). The range from these repeated inversions improves the emissions uncertainty, while helping to prevent any individual pollution events from dominating the estimated emissions.

Table A5.4.2.1 CSIRO InTEM estimates of Australian HFC emissions and uncertainties for entire time series (tonnes)

	2005	unc	2006	unc	2007	unc	2008	unc	2009	unc	2010	unc	2011	unc	2012	unc
HFC-32	23	22	34	24	60	30	80	40	90	40	100	50	120	50	120	50
HFC-125	200	70	270	80	310	100	330	120	370	150	400	140	400	130	400	140
HFC-134a	950	300	1,260	340	1,430	370	1,350	380	1,320	400	1,300	400	1,250	400	1,230	410
HFC-143a	190	70	250	80	310	100	320	100	320	120	340	120	360	120	370	120
HFC-23	60	100	60	100	60	100	60	100	60	100	70	90	50	80	40	60
HFC-152a	30	30	50	30	60	40	50	40	40	50	50	40	40	40	40	40
HFC-227ea	13	13	13	13	13	13	12	14	12	15	11	15	13	15	14	14
HFC-236fa	22	15	6	3	6	3	5	2	5	2	5	2	4	2	4	1
HFC-245fa	41	23	38	16	36	14	28	11	29	11	29	10	39	14	41	14
HFC-365mfc	22	25	22	27	22	29	24	31	22	31	25	30	21	26	23	22

	2013	unc	2014	unc	2015	unc	2016	unc	2017	unc	2018	unc	2019	unc
HFC-32	110	50	140	50	190	60	230	80	240	80	220	80	260	110
HFC-125	460	130	510	130	550	140	570	150	530	160	530	180	560	200
HFC-134a	1,290	370	1,470	380	1,710	400	1,620	410	1,430	400	1,360	420	1,470	490
HFC-143a	360	110	350	110	400	100	430	110	390	110	370	120	380	130
HFC-23	40	60	40	60	40	60	30	60	40	50	40	70	50	90
HFC-152a	50	40	70	30	90	30	80	40	70	30	60	30	60	40
HFC-227ea	15	14	15	14	14	14	16	14	17	14	-	-	-	-
HFC-236fa	3	1	2	1	2	1	2	1	2	1	2	1	2	1
HFC-245fa	45	15	65	22	73	24	60	20	47	16	25	8	40	13
HFC-365mfc	21	18	26	16	24	16	24	16	24	16	24	16	24	16

A5.4.3 Sensitivity testing on Hydroflurocarbons

In addition to the HFC balances documented in Chapter 4.7.4, sensitivity analysis was undertaken to assess the impacts of changes to the allocation of bulk gas to end use as well as changes to the assumptions about replenishment rates in equipment. These two elements of the HFC model are where important assumptions are made about the areas of consumption of imported gas and the servicing/replenishment habits of the consumers of this gas.

The effect of end use allocation on total emissions was tested by altering the percentage of bulk gas allocated to domestic, commercial and transport refrigeration (which is the biggest user of imported bulk gas) by 1 per cent, 5 per cent, 10 per cent and 20 per cent in all years with the residual gas allocated equally among the other end-use categories. In addition to this change in allocation, all gas imports are ceased after 2008–09.

Table A5.4.3.1 Halocarbons: results of sensitivity testing of allocation assumptions (Mt CO_2-e)

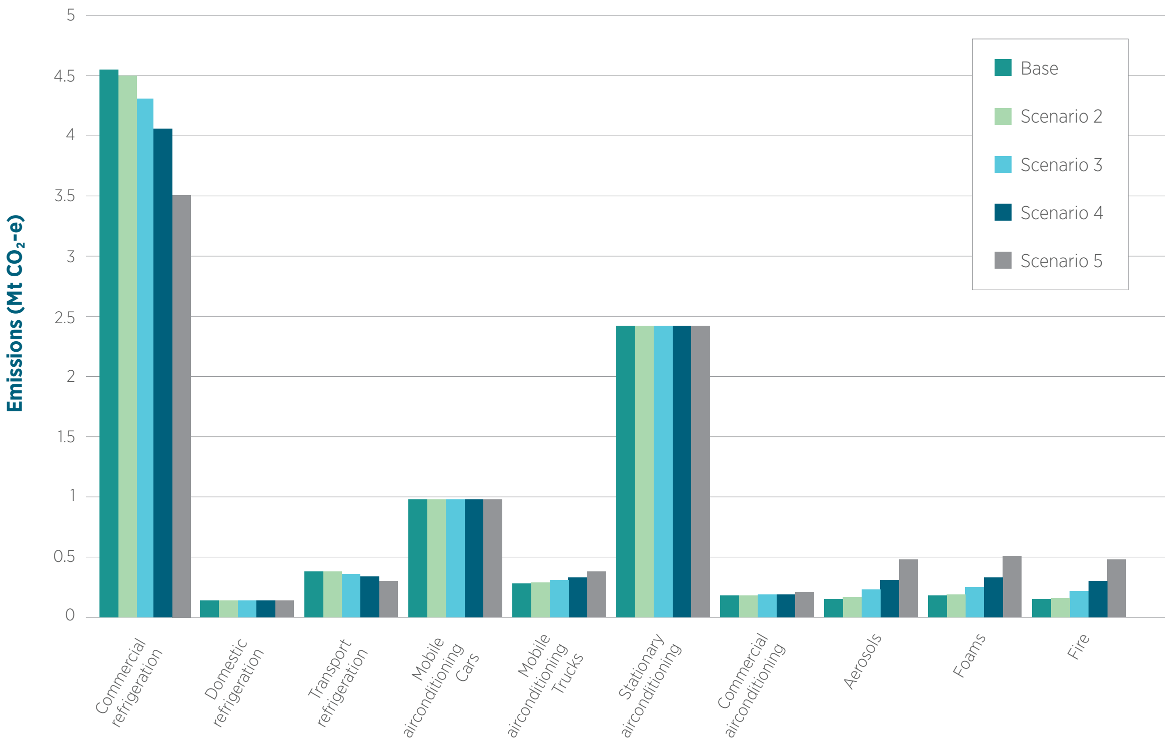
	Allocation assumptions (per cent of total bulk imports)				
End use allocation	**Base**	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Aerosols/solvents	2 %	2 %	3 %	4 %	5 %
Domestic/Commercial/ Transport refrigeration	60 %	59 %	55 %	50 %	40 %
Fire	2 %	2 %	3 %	4 %	5 %
Foam	2 %	2 %	3 %	4 %	6 %
Mobile air conditioning	25 %	25 %	26 %	27 %	28 %
Mobile OEM	1 %	1 %	2 %	3 %	5 %
Stationary air conditioning	8 %	8 %	8 %	9 %	11 %
Emissions in 2007–08 (Mt CO_2-e)					
Commercial refrigeration	3.23	3.19	3.06	2.89	2.50
Domestic refrigeration	0.04	0.04	0.04	0.04	0.04
Transport refrigeration	0.31	0.31	0.30	0.28	0.24
Mobile air conditioning cars	0.86	0.86	0.87	0.87	0.87
Mobile air conditioning trucks	0.19	0.19	0.20	0.22	0.25
Stationary air conditioning	0.62	0.62	0.62	0.62	0.62
Commercial air conditioning	0.06	0.06	0.06	0.06	0.07
Aerosols	0.13	0.15	0.20	0.27	0.43
Foams	0.13	0.14	0.18	0.24	0.37
Fire	0.05	0.06	0.08	0.11	0.18
Metered dose inhalers	0.14	0.14	0.14	0.14	0.14
Total	**5.75**	**5.75**	**5.74**	**5.73**	**5.70**
per cent change in total emissions compared with emissions in the base case		**-0.04 %**	**-0.19 %**	**-0.40 %**	**-0.86 %**

The results show that even with a 33 per cent change in bulk gas allocation from domestic, transport and commercial refrigeration to other end use categories, total emissions in 2007–08 are changed by only 0.9 per cent. This suggests that the estimate of emissions in any given year is relatively insensitive to changes in the allocation of bulk gas.

Figure A5.4.3.1 shows gas imports under the base end use assumption and each of the re-allocation assumptions. It can be seen that the gas diverted from domestic, commercial and transport refrigeration is re-allocated primarily to aerosols, foams, and fire protection. In total however, gas imports are unchanged as a result of the re-allocation.

Under scenario 5 (a 33 per cent re-allocation from domestic, commercial and transport refrigeration), approximately 1 million tonnes is re-directed in equal proportions towards aerosols, foam and fire protection. This results in a reduction in emissions of 0.79 million tonnes CO_2-e in domestic, commercial and transport refrigeration and a corresponding increase of 0.66 million tonnes in aerosols, foams and fire protection. The residual gas is accounted for as gas recovered and destroyed and stock change in the bank of gas in operating equipment.

Figure A5.4.3.1 Halocarbons: sensitivity testing of allocation assumptions: 2007–08 (Mt CO_2-e)



Total cumulative differences in emissions and destruction under each allocation scenario between 1990 and 2050 (where the last of the current stock of operating equipment is retired) are shown in Figure A5.4.3.2. The chart shows that while differences occur in emissions in individual years the total gas either emitted or destroyed is unchanged over the life of each equipment type. The gas end-use re-allocation results in an increase in emissions for years where imports are occurring (up to 2008–09 in the case of this test), followed by a decrease in emissions relative to the base assumption from 2008–09 onwards.

Figure A5.4.3.2 Halocarbons: results of sensitivity testing of allocation assumptions: 1989–90 to 2049–50 (Mt CO_2-e)

As information about servicing and replenishment practices is limited, the replenishment assumptions have been devised by the Department.

The effect of assumptions about gas replenishment was tested by reducing the replenishment rates for all sources where replenishment occurs by 10 per cent, 20 per cent, 30 per cent and 50 per cent.

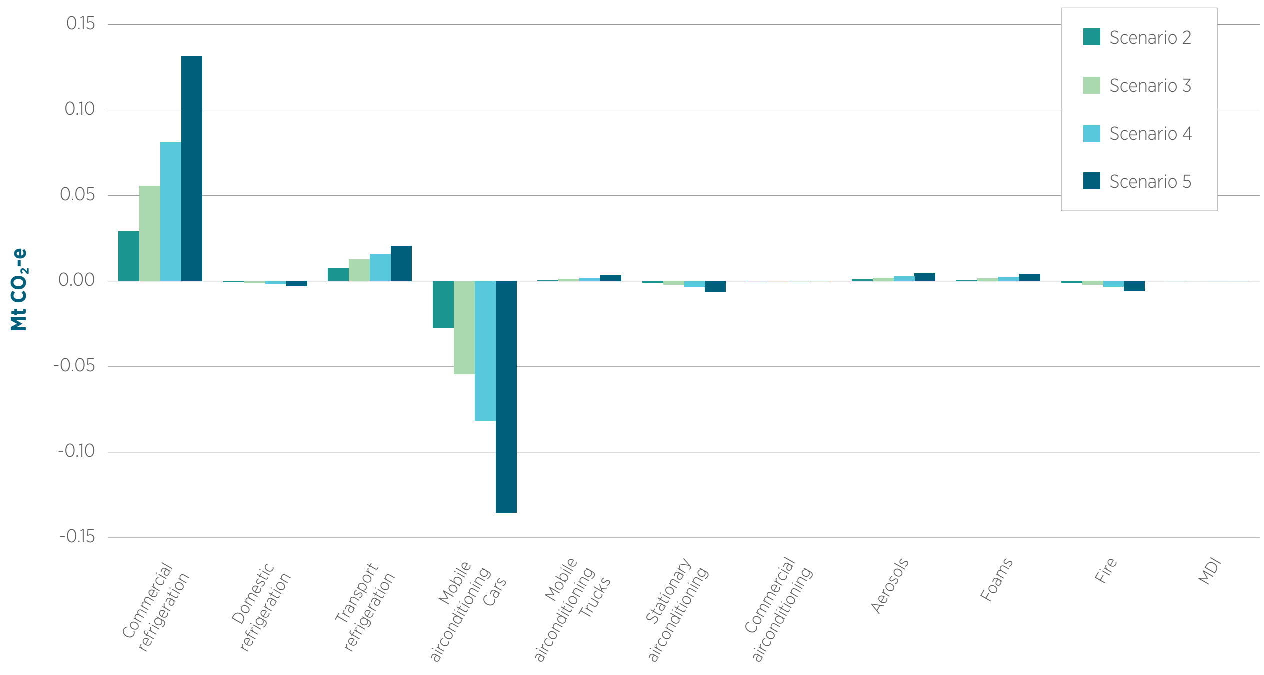
As with bulk gas allocation, the total emissions estimate was found to be insensitive to changes in assumed replenishment rates with a 50 per cent reduction in replenishment resulting in only a 0.25 per cent change in total emissions in 2007–08. The effects of changes to the replenishment assumptions on total emissions within the model, while minimal, are complex. The total gas allocated to equipment is unchanged under these scenarios such that when less gas is allocated to replenishment, more is available to be allocated to new equipment.

Figure A5.4.3.3 shows that emissions from commercial refrigeration increase as a result of a reduction in the general rates of replenishment as more gas is allocated to new equipment for this category. However, for domestic refrigeration, mobile air conditioning in cars and domestic stationary air conditioning the gas stocks are affected by the quantity of gas being replenished and thus, as a result of less gas being replenished, the gas bank and therefore emissions are lower for these categories.

Table A5.4.3.2 Halocarbons: results of sensitivity testing of replenishment assumptions (Mt CO_2-e)

	Replenishment assumptions				
	Base	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Replenishment rate	**100 %**	**90 %**	**80 %**	**70 %**	**50 %**
Emissions in 2007–08 (Mt CO_2-e)					
Commercial refrigeration	3.23	3.26	3.28	3.31	3.36
Domestic refrigeration	0.04	0.04	0.04	0.04	0.04
Transport refrigeration	0.31	0.32	0.32	0.33	0.33
Mobile air conditioning cars	0.86	0.84	0.81	0.78	0.73
Mobile air conditioning trucks	0.19	0.19	0.19	0.19	0.19
Stationary air conditioning	0.62	0.61	0.61	0.61	0.61
Commercial air conditioning	0.06	0.06	0.06	0.06	0.06
Aerosols	0.13	0.14	0.14	0.14	0.14
Foams	0.13	0.13	0.13	0.13	0.13
Fire	0.05	0.05	0.05	0.05	0.05
Metered dose inhalers	0.14	0.14	0.14	0.14	0.14
Total	**5.75**	**5.76**	**5.77**	**5.77**	**5.77**
per cent change on base case		**0.17 %**	**0.24 %**	**0.25 %**	**0.25 %**

Figure A5.4.3.3 Halocarbons: results of sensitivity testing of replenishment assumptions – change in emissions 2007–08 (Mt CO_2-e)



A5.5 Appendices to Chapter 5, Agriculture

A5.5.1 Dairy Cattle

Table A5.5.1.1 Dairy cattle – Liveweight (kg)

Time period	Milking Cows	Heifers >1	Heifers <1 (weaned)	Bulls >1	Bulls <1 (weaned)
1990-1994	520	350	172	600	225
1995-1999	530	360	176	600	225
2000-2004	545	365	178	600	225
2005-2009	550	370	179	600	225
2010-2014	550	370	179	600	225
2015-2019	550	370	179	600	225
2020-2022	550	370	179	600	225

Source: Dairy Technical Working Group (2015).

Table A5.5.1.2 Dairy cattle – Liveweight gain (kg/day)

Time period	Milking Cows	Heifers >1	Heifers <1 (weaned)	Bulls >1	Bulls <1 (weaned)
1990-1994	0.015	0.6	0.53	0.1	0.8
1995-1999	0.016	0.6	0.55	0.1	0.8
2000-2004	0.016	0.6	0.56	0.1	0.8
2005-2009	0.016	0.6	0.57	0.1	0.8
2010-2014	0.016	0.6	0.57	0.1	0.8
2015-2019	0.016	0.6	0.57	0.1	0.8
2020-2022	0.016	0.6	0.57	0.1	0.8

Source: Dairy Technical Working Group (2015).

Table A5.5.1.3 Dairy cattle – Standard reference weights (kg)

Time period	Milking Cows	Heifers >1	Heifers <1 (weaned)	Bulls >1	Bulls <1 (weaned)
1990-1994	555	555	555	770	770
1995-1999	570	570	570	770	770
2000-2004	580	580	580	770	770
2005-2009	590	590	590	770	770
2010-2014	590	590	590	770	770
2015-2019	590	590	590	770	770
2020-2022	590	590	590	770	770

Source: Dairy Technical Working Group (2015).

Table A5.5.1.4 Dairy cattle – Dry matter digestibility and crude protein content of feed intake (per cent)

State	DMD	CP
All	75	20

Source: Christie et al. (2012).

Table A5.5.1.5 Dairy cattle – Data for pre-weaned calves

		CH_4 production	Volatile solids	Faecal N	Urinary N
		(kg/day)			
1990-1994	Heifers<1	0.0180	0.2738	0.0055	0.0084
1995-1999	Heifers<1	0.0178	0.2715	0.0055	0.0083
2000-2004	Heifers<1	0.0177	0.2700	0.0055	0.0082
2005+	Heifers<1	0.0176	0.2685	0.0055	0.0082
All years	Bulls<1	0.0204	0.3003	0.0050	0.0042

Source: Dairy Technical Working Group (2015).

Table A5.5.1.6 Dairy cattle – Integrated MCF

	Milking Cows								Other Dairy Cattle
	ACT	NSW	NT	QLD	SA	TAS	VIC	WA	
1990-1994	0.0295	0.0318	0.0653	0.0548	0.0370	0.0382	0.0512	0.0563	0.01
1995-1999	0.0328	0.0345	0.0699	0.0536	0.0428	0.0415	0.0575	0.0578	0.01
2000-2004	0.0440	0.0456	0.0809	0.0597	0.0524	0.0467	0.0683	0.0619	0.01
2005-2009	0.0743	0.0765	0.0990	0.0819	0.0749	0.0561	0.0871	0.0730	0.01
2010-2014	0.0988	0.1016	0.1032	0.0994	0.0902	0.0670	0.0958	0.0894	0.01
2015-2019	0.0752	0.0771	0.0979	0.0796	0.0766	0.0710	0.0904	0.0835	0.01
2020-2022	0.0781	0.0805	0.1010	0.0799	0.0255	0.0690	0.0892	0.0860	0.01

Table A5.5.1.7 Dairy cattle – MCFs

MMS	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Pasture (a)	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Anaerobic lagoon (b)	0.72	0.76	0.8	0.78	0.74	0.69	0.73	0.76
Sump and dispersal systems (b)	0.005	0.005	0.01	0.005	0.005	0.001	0.005	0.005
Drains to paddocks (bc)	0.15	0.18	0.50	0.24	0.17	0.13	0.17	0.18
Solid Storage (d)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

(a) Williams (1993).

(b) IPCC (2006). Mean over time series.

(c) MCF is assumed to be similar to a liquid/slurry system.

(d) IPCC (2006) cool region values applied as these more closely align with Australian experimental data (Redding, et al. 2015) (201 J. Devereux and M. Redding pers. comm., QDAFF June 2014).

Table A5.5.1.8 Dairy cattle – Allocation of waste to MMS – Milking cows (per cent)

	ACT/NSW	NT/QLD	SA	TAS	VIC	WA
1990-1994						
Pasture	87.7	87.1	87.8	87.9	87.6	88.0
Anaerobic lagoon	1.4	2.0	3.3	3.5	4.8	4.9
Daily Spread: Sump and dispersal	3.0	0.1	5.7	4.4	2.5	0.3
Daily Spread: Drains to paddocks	6.7	9.0	2.1	3.2	3.7	5.8
Solid Storage	1.2	1.8	1.1	1.0	1.3	0.9
1995-1999						
Pasture	87.7	87.1	87.8	87.9	87.6	88.0
Anaerobic lagoon	2.4	2.9	4.2	4.2	6.0	5.6
Daily Spread: Sump and dispersal	4.6	2.8	5.6	5.0	2.9	1.9
Daily Spread: Drains to paddocks	4.2	5.6	1.3	2.0	2.3	3.6
Solid Storage	1.1	1.7	1.0	1.0	1.2	0.9
2000-2004						
Pasture	87.1	86.3	87.5	87.9	87.4	87.7
Anaerobic lagoon	4.2	4.3	5.6	5.1	7.6	6.5
Daily Spread: Sump and dispersal	4.5	3.6	4.8	4.8	2.2	2.4
Daily Spread: Drains to paddocks	2.8	3.7	0.9	1.3	1.5	2.4
Solid Storage	1.5	2.1	1.1	0.8	1.2	1.0
2005-2009						
Pasture	84.0	83.6	84.5	87.5	85.9	86.1
Anaerobic lagoon	8.6	7.4	8.7	6.3	10.4	8.2
Daily Spread: Sump and dispersal	3.0	2.8	3.5	3.4	1.1	2.5
Daily Spread: Drains to paddocks	1.5	3.2	0.7	1.9	0.8	1.5
Solid Storage	2.8	3.1	2.6	0.8	1.8	1.6
2010-2014						
Pasture	79.3	79.4	80.7	85.2	84.3	81.9
Anaerobic lagoon	12.0	9.7	10.8	8.0	11.6	10.4
Daily Spread: Sump and dispersal	2.4	2.6	3.5	3.4	1.1	2.5
Daily Spread: Drains to paddocks	1.2	3.3	0.7	1.4	0.6	1.5
Solid Storage	5.1	5.0	4.3	2.0	2.5	3.7
2015-2019						
Pasture	79.7	78.8	80.6	87.2	83.9	81.4
Anaerobic lagoon	8.9	7.3	8.7	8.8	10.8	9.4
Daily Spread: Sump and dispersal	4.0	3.7	2.8	2.4	0.9	1.4

	ACT/NSW	NT/QLD	SA	TAS	VIC	WA
Daily Spread: Drains to paddocks	0.4	2.5	1.7	0.2	0.6	2.1
Solid Storage	6.9	7.7	6.3	1.4	3.9	5.7
2020-2022						
Pasture	78.6	78.7	80.5	86.5	83.9	79.9
Anaerobic lagoon	9.0	7.3	10.4	8.4	10.8	10.0
Daily Spread: Sump and dispersal	2.0	3.3	1.4	2.4	0.9	1.9
Daily Spread: Drains to paddocks	1.9	2.4	0.8	0.8	0.2	0.9
Solid Storage	8.4	8.4	6.9	2.0	4.2	7.4

Source: Dairy Technical Working Group (2015), Dairy Australia (2020).

Table A5.5.1.9 Dairy cattle – Nitrous oxide EFs and fraction of N volatilised by MMS

MMS	EF (kg N_2O-N/kg N excreted)	FracGASMm (kg N_2O-N/kg N excreted)
Void at Pasture	0 (a)	0
Anaerobic lagoon	0 (a)	0.35
Daily Spread – Sump and Dispersal	0 (a)	0.07
Daily Spread – Drains to Paddock	0 (a)	0.2 (b)
Solid Storage	0.005	0.3

Source: IPCC (2006).

(a) There are no direct emissions from these sources.

(b) Considered similar to a liquid slurry system (0.4), 20 per cent is assumed to be lost by MMS with further 20 per cent loss under agricultural soils.

Table A5.5.1.10 Dairy cattle – Average milk production (kg/head/year)

State	1990	1995	2000	2005	2010	2015	2020	2022
NSW/ACT	3,603	4,519	4,827	4,925	5,329	6,572	7,146	6,831
NT	3,123	3,964	4,349	3,735	5,052	4,388	4,505	4,382
Queensland	3,123	3,964	4,349	3,735	5,052	4,388	4,505	4,382
South Australia	3,934	5,057	6,790	5,862	5,907	7,411	7,007	7,212
Tasmania	3,775	3,781	4,381	4,497	4,640	6,400	5,208	5,112
Victoria	3,920	4,653	4,989	5,101	5,518	5,795	6,289	6,416
Western Australia	4,202	4,609	6,338	5,418	6,641	5,752	6,661	6,519

Source: Dairy Australia (2023).

Table A5.5.1.11 Dairy cattle – Population (1000s)

Year	Population	Bulls greater than one year	Bulls less than one year	Heifers greater than one year	Heifers less than one year	Milking Cows
1990	2561.9	25.7	8.7	448.1	381.9	1697.5
1991	2497.0	23.8	8.1	422.2	360.6	1682.3
1992	2500.5	23.7	8.1	415.2	354.3	1699.2
1993	2531.9	23.7	8.1	423.3	361.0	1715.8
1994	2677.6	26.5	9.1	461.3	394.4	1786.4
1995	2740.1	27.3	9.3	475.8	406.8	1820.9
1996	2808.0	27.5	9.4	477.6	409.4	1884.1
1997	2959.3	29.3	10.0	507.3	435.3	1977.5
1998	3075.7	30.2	10.4	525.0	449.5	2060.6
1999	3219.8	31.8	10.9	550.1	472.1	2154.8
2000	3140.4	28.8	9.8	502.4	427.5	2171.8
2001	3217.3	31.0	10.6	538.5	460.7	2176.4
2002	3135.3	30.2	10.3	521.2	447.5	2126.2
2003	3057.0	29.9	10.2	516.1	444.2	2056.6
2004	3067.7	30.4	10.3	526.3	451.6	2049.1
2005	3073.0	29.4	10.0	507.2	436.7	2089.7
2006	2788.5	27.2	9.3	467.6	404.0	1880.4
2007	2663.7	26.0	8.9	446.6	386.3	1795.9
2008	2537.0	15.9	5.4	637.6	237.7	1640.5
2009	2612.3	47.3	16.1	521.7	351.0	1676.2
2010	2542.4	29.6	9.9	697.0	210.1	1595.7
2011	2570.0	61.9	21.1	485.8	412.5	1588.7
2012	2733.2	43.7	14.8	689.3	285.0	1700.4
2013	2833.9	105.0	22.5	576.7	441.3	1688.3
2014	2807.2	96.7	22.6	602.5	438.8	1646.7
2015	2810.6	83.0	22.0	588.3	427.9	1689.4
2016	2742.9	84.8	22.9	595.4	441.5	1598.4
2017	2681.4	85.6	22.9	579.0	438.0	1555.9
2018	2703.9	83.0	22.9	572.0	442.9	1583.1
2019	2410.2	99.3	19.6	505.5	376.9	1408.9
2020	2428.8	87.9	19.8	512.4	383.2	1425.5
2021	2451.0	86.5	21.4	508.4	414.6	1420.1
2022	2209.4	77.0	19.2	458.3	374.0	1280.9

A5.5.2 Beef Cattle on Pastures

Table A5.5.2.1 Beef cattle – Liveweight (kg)

State	Region	Season	Bulls <1	Bulls >1	Cows <1	Cows 1-2	Cows >2	Steers <1	Steers >1
ACT/NSW		Spring	80	480	75	300	440	75	380
		Summer	170	520	160	360	470	160	420
		Autumn	240	550	220	390	490	220	450
		Winter	280	560	260	410	500	260	460
South Australia		Spring	250	800	220	400	500	230	420
		Summer	320	800	280	420	500	290	420
		Autumn	80	700	70	300	450	75	400
		Winter	160	700	140	350	450	150	400
Tasmania		Spring	105	700	85	300	490	90	480
		Summer	480	750	150	350	530	160	460
		Autumn	250	725	200	360	500	215	490
		Winter	260	700	210	380	460	230	470
Victoria		Spring	250	820	240	410	560	240	510
		Summer	280	850	260	440	550	270	520
		Autumn	100	700	95	300	450	95	410
		Winter	150	720	140	320	470	140	440
Western Australia	South West	Spring	340	800	260	420	550	300	480
		Summer	380	780	300	450	530	340	470
		Autumn	100	680	80	320	480	100	340
		Winter	190	700	150	330	490	170	360
	Pilbara	Spring	80	450	70	260	340	80	370
		Summer	150	500	140	310	360	150	400
		Autumn	230	550	220	330	380	230	420
		Winter	250	500	240	340	360	250	390
	Kimberley	Spring	220	500	180	300	320	210	340
		Summer	110	550	90	220	380	100	390
		Autumn	170	600	140	270	390	160	430
		Winter	200	550	150	280	350	190	400

State	Region	Season	Bulls <1	Bulls >1	Cows <1	Cows 1-2	Cows 2-3	Cows >3	Steers <1	Steers 1-2	Steers 2-3	Steers >3
Northern Territory	Alice Springs	Spring	220	706	208	323	415	467	223	371	493	585
		Summer	110	703	112	256	368	465	108	280	421	543
		Autumn	170	721	169	306	392	464	176	339	470	580
		Winter	200	727	211	338	432	492	222	377	498	590
	Barkly	Spring	220	620	227	319	398	452	216	334	NO	NO
		Summer	110	650	108	262	346	430	111	236	NO	NO
		Autumn	170	670	170	266	363	444	169	282	NO	NO
		Winter	200	660	225	307	398	452	214	326	NO	NO
	Northern	Spring	220	620	177	267	365	406	231	249	324	NO
		Summer	110	650	102	203	299	380	102	218	263	NO
		Autumn	170	670	173	250	336	414	175	243	304	NO
		Winter	200	660	202	272	365	390	208	260	337	NO
Queensland	High	Spring	260	705	215	302	416	519	234	455	551	660
		Summer	153	703	118	277	397	483	111	304	521	547
		Autumn	168	718	191	319	440	506	188	326	520	582
		Winter	235	722	207	352	470	514	209	421	512	605
	Moderate/ High	Spring	230	674	217	344	357	467	242	370	550	620
		Summer	113	669	113	283	361	477	120	273	545	553
		Autumn	172	685	172	309	376	471	238	329	573	620
		Winter	241	692	208	344	364	484	260	350	567	620
	Moderate/ Low	Spring	236	674	178	310	428	466	193	370	519	565
		Summer	120	669	112	250	390	448	115	273	433	556
		Autumn	125	685	140	277	407	455	141	296	445	593
		Winter	180	692	183	316	438	468	189	354	500	553
	Low	Spring	190	617	174	265	371	415	170	272	392	531
		Summer	119	591	140	205	310	405	133	218	315	445
		Autumn	175	610	163	232	351	427	146	242	320	471
		Winter	192	615	162	255	364	420	157	261	342	484

Sources: QLD and NT data from Bray et al. (2015). All other states from NGGIC (2007).

Table A5.5.2.2 Beef cattle – Liveweight gain (kg/head/day)

State	Region	Season	Bulls <1	Bulls >1	Cows <1	Cows 1-2	Cows >2	Steers <1	Steers >1
ACT/NSW		Spring	0.5	0.2	0.5	0.4	0.3	0.5	0.4
		Summer	1.0	0.4	0.9	0.7	0.3	0.9	0.4
		Autumn	0.8	0.3	0.7	0.3	0.2	0.7	0.3
		Winter	0.4	0.1	0.4	0.2	0.1	0.4	0.1
South Australia		Spring	0.99	1.1	0.88	0.55	0.55	0.88	0.22
		Summer	0.77	0.0	0.66	0.22	0.0	0.66	0.0
		Autumn	0.9	-1.1	0.7	0.22	-0.55	0.8	-0.22
		Winter	0.88	0.0	0.77	0.55	0.0	0.82	0.0
Tasmania		Spring	1.0	0.50	1.0	1.0	-0.44	1.0	0.5
		Summer	0.82	0.55	0.71	0.55	0.99	0.77	0.5
		Autumn	0.77	0.50	0.55	0.11	-0.33	0.6	0.33
		Winter	0.11	-0.27	0.11	0.22	-0.44	0.16	-0.22
Victoria		Spring	1.10	1.10	1.10	0.99	0.99	1.10	0.77
		Summer	0.33	0.33	0.22	0.33	-0.10	0.33	0.11
		Autumn	0.50	0.20	0.55	0.44	0.20	0.55	0.20
		Winter	0.55	0.22	0.49	0.22	0.22	0.49	0.33
Western Australia	South West	Spring	1.64	1.10	1.21	0.99	0.66	1.42	1.10
		Summer	0.44	-0.22	0.44	0.33	-0.22	0.44	-0.11
		Autumn	0.60	0.00	0.60	0.22	-0.55	0.60	0.00
		Winter	0.99	0.22	0.77	0.11	0.11	0.77	0.44
	Pilbara	Spring	0.70	-0.55	0.70	0.22	-0.22	0.70	-0.22
		Summer	0.77	0.55	0.77	0.66	0.55	0.77	0.33
		Autumn	0.88	0.55	0.88	0.22	0.22	0.88	0.22
		Winter	0.22	-0.55	0.22	0.11	-0.22	0.22	-0.33
	Kimberley	Spring	0.22	-0.55	0.33	0.22	-0.33	0.22	-0.55
		Summer	0.80	0.55	0.70	0.44	0.66	0.80	0.55
		Autumn	0.66	0.55	0.55	0.55	0.11	0.66	0.55
		Winter	0.33	-0.55	0.11	0.11	-0.44	0.33	-0.55

State	Region	Season	Bulls <1	Bulls >1	Cows <1	Cows 1-2	Cows 2-3	Cows >3	Steers <1	Steers 1-2	Steers 2-3	Steers >3
Northern Territory	Alice Springs	Spring	0.22	-0.23	0.25	0.17	0.18	-0.28	0.32	0.24	0.25	-0.05
		Summer	0.66	0.20	0.62	0.54	0.38	0.27	0.75	0.64	0.55	0.48
		Autumn	0.49	0.13	0.54	0.45	0.35	0.15	0.63	0.54	0.42	0.26
		Winter	0.27	-0.80	0.22	0.09	0.12	0.02	0.25	0.18	0.12	0.03
	Barkly	Spring	0.22	-0.44	0.20	0.21	0.18	0.01	0.12	0.09	NO	NO
		Summer	0.66	0.22	0.68	0.22	0.24	0.25	0.64	0.37	NO	NO
		Autumn	0.49	0.05	0.64	0.25	0.29	0.12	0.57	0.49	NO	NO
		Winter	0.27	-0.27	0.31	0.29	0.19	0.04	0.26	0.28	NO	NO
	Northern	Spring	0.22	-0.44	0.00	0.15	0.08	0.17	0.06	0.02	-0.14	NO
		Summer	0.66	0.22	0.79	0.40	0.38	0.27	0.80	0.16	0.30	NO
		Autumn	0.49	0.05	0.55	0.38	0.36	0.06	0.58	0.23	0.40	NO
		Winter	0.27	-0.27	0.02	0.09	0.16	-0.04	0.21	0.03	0.11	NO
Queensland	High	Spring	0.27	-0.19	0.38	0.25	0.07	0.05	0.52	0.55	0.19	0.60
		Summer	0.16	0.16	0.80	0.57	0.76	0.49	0.84	0.51	0.36	0.17
		Autumn	0.45	0.10	0.49	0.41	0.40	0.17	0.54	0.64	-0.05	0.32
		Winter	0.51	-0.07	0.13	-0.09	-0.13	0.07	0.25	0.71	0.17	0.43
	Moderate/ High	Spring	-0.12	-0.19	0.41	0.09	0.41	-0.19	0.07	1.07	-0.08	0.00
		Summer	0.65	0.19	0.65	0.51	0.18	0.63	1.30	0.48	1.12	0.38
		Autumn	0.70	0.13	0.52	0.34	0.02	0.04	0.77	0.42	0.12	0.74
		Winter	0.32	-0.06	0.25	0.19	-0.10	-0.02	0.02	0.23	-0.13	0.00
	Moderate/ Low	Spring	0.62	-0.19	0.37	0.41	0.06	-0.02	0.47	0.44	0.30	0.13
		Summer	0.05	0.19	0.31	0.54	0.53	0.15	0.28	0.57	0.42	0.40
		Autumn	0.33	0.13	0.39	0.36	0.26	0.11	0.40	0.44	0.37	-0.01
		Winter	0.61	-0.06	0.21	0.18	0.12	0.06	0.29	0.41	0.41	-0.15
	Low	Spring	-0.20	0.02	0.24	0.30	0.23	-0.05	0.34	0.30	0.57	0.52
		Summer	0.62	0.21	0.25	0.32	0.47	0.31	0.14	0.40	0.26	0.43
		Autumn	0.40	0.13	0.12	0.27	0.30	0.08	0.13	0.24	0.15	0.21
		Winter	0.08	0.04	0.06	0.18	0.11	-0.07	0.13	0.16	0.40	0.33

Sources: QLD and NT data from Bray et al. (2015). All other states from NGGIC (2007).

Table A5.5.2.3 Beef cattle – Dry matter digestibility of feed intake (per cent)

		Season			
State	Region	Spring	Summer	Autumn	Winter
ACT/NSW		55	65	60	50
NT		55	61	57	54
QLD		53	57	55	51
SA		70	55	55	75
TAS		75	60	70	75
VIC		80	55	60	76
WA	South West	80	58	50	75
	Pilbara	40	65	55	45
	Kimberley	40	65	55	45

Sources: QLD and NT data from Bray et al. (2015). All other states from NGGIC (2007).

Table A5.5.2.4 Beef cattle – Crude protein content of feed intake (fraction)

		Season			
State	Region	Spring	Summer	Autumn	Winter
ACT/NSW		0.07	0.13	0.1	0.06
NT		0.058	0.092	0.075	0.053
QLD		0.072	0.099	0.078	0.059
SA		0.16	0.07	0.09	0.2
TAS		0.2	0.1	0.16	0.2
VIC		0.25	0.07	0.1	0.21
WA	South West	0.2	0.09	0.06	0.2
	Pilbara	0.04	0.12	0.09	0.06
	Kimberley	0.04	0.12	0.09	0.06

Sources: QLD and NT data from Bray et al. (2015). All other states from NGGIC (2007).

Table A5.5.2.5 Beef Cattle – Feed intake adjustment and milk production and production

State	Region	Season	Feed adjustment	Milk intake / production (kg/day)
ACT/NSW		Spring	1.3	6
		Summer	1.1	4
		Autumn	0	0
		Winter	0	0
Northern Territory		Spring	0	0
		Summer	1.3	4
		Autumn	1.1	3
		Winter	0	0
Queensland		Spring	0	0
		Summer	1.3	4
		Autumn	1.1	3
		Winter	0	0
South Australia		Spring	0	0
		Summer	0	0
		Autumn	1.3	6
		Winter	1.1	4
Tasmania		Spring	1.3	6
		Summer	1.1	4
		Autumn	0	0
		Winter	0	0
Victoria		Spring	0	0
		Summer	0	0
		Autumn	1.3	6
		Winter	1.1	4
Western Australia	South West	Spring	0	0
		Summer	0	0
		Autumn	1.3	6
		Winter	1.1	4
	Pilbara	Spring	1.3	4
		Summer	1.1	3
		Autumn	0	0
		Winter	0	0
	Kimberley	Spring	0	0
		Summer	1.3	4
		Autumn	1.1	3
		Winter	0	0

Source: NGGIC (2007).

Table A5.5.2.6 Beef cattle – Standard reference weights (kg)

State	Bulls <1	Bulls >1	Cows <1	Cows 1-2	Cows >2	Steer <1	Steer >1
ACT/NSW	700	700	600	500	500	500	600
Northern Territory	770	770	660	550	550	550	660
Queensland	770	770	660	550	550	550	660
South Australia	770	770	660	550	550	550	660
Tasmania	770	770	660	550	550	550	660
Victoria	770	770	660	550	550	550	660
Western Australia	770	770	660	550	550	550	660

Source: NGGIC (2007), based on SCA (1990).

Table A5.5.2.7 Beef cattle – Allocation of animals to climate regions

State	Region	Proportion Warm	Proportion Temperate
ACT		0	1
Northern Territory	Alice Springs	0	1
	Barkly	0.5	0.5
	Northern	1	0
Queensland	High	0	1
	Moderate/High	0	1
	Moderate/Low	0	1
	Low	0.8	0.2
South Australia		0	1
Tasmania		0	1
Victoria		0	1
Western Australia	South West	0	1
	Pilbara	1	0
	Kimberly	1	0

Sources: QLD and NT data from Bray et al. (2015). All other states from NGGIC (2007).

Table A5.5.2.8 Beef cattle – Population (1000s)

Year	Total beef cattle population	Bulls <1 year	Bulls >1 year	Cows <1 year	Cows 1-2 years	Cows >2 years	Cows >2 years (Cows 2-3)
1990	21,947.5	111.6	410.5	3010.5	2645.8	4463.9	928.3
1991	22,538.9	106.8	400.0	3091.7	2661.4	4361.3	962.9
1992	22,446.2	102.7	387.8	3069.2	2649.7	4326.3	962.9
1993	22,253.5	100.4	378.5	2983.5	2696.4	4553.5	945.7
1994	22,645.6	102.4	381.0	3029.6	2758.5	4846.3	926.2
1995	22,544.9	101.0	376.1	3123.2	2662.5	4463.8	935.6
1996	23,115.4	100.0	376.4	3140.3	2727.5	4551.3	963.4
1997	23,286.0	99.3	376.0	3235.4	2770.2	4604.8	982.5
1998	23,272.0	98.9	378.0	3250.7	2739.8	4369.5	1013.0
1999	22,812.4	95.0	365.3	3146.7	2694.8	4279.3	1001.5
2000	23,872.2	98.7	384.6	3295.2	2839.7	4353.5	1088.3
2001	23,859.1	107.1	408.6	3252.6	2766.6	4367.2	1052.5
2002	24,180.2	110.2	419.2	3177.4	2832.5	4461.8	1079.2
2003	23,149.0	108.4	405.3	3050.7	2752.5	4499.9	1011.8
2004	24,084.0	110.0	417.2	3042.8	2869.1	4575.0	1080.9
2005	24,389.0	116.2	434.7	3149.3	2921.7	4684.9	1094.7
2006	24,746.8	123.7	454.6	3231.2	2936.2	4802.9	1071.4
2007	24,487.8	134.3	484.8	3195.2	2896.1	4583.0	1095.7
2008	24,098.5	117.2	440.6	2990.9	2995.4	4705.8	1138.0
2009	24,589.5	120.6	453.6	3200.8	2941.8	4544.3	1131.3
2010	23,262.7	117.8	438.5	2951.0	2825.2	4381.2	1091.1
2011	25,156.9	118.8	460.9	3364.0	2953.6	4346.9	1211.0
2012	24,912.8	124.4	466.1	3126.2	3037.4	4754.2	1169.7
2013	25,671.1	143.0	472.0	3437.6	3034.3	4517.7	1220.4
2014	25,484.9	137.6	479.3	3383.4	3003.6	4389.5	1226.6
2015	23,676.5	129.9	460.5	3103.4	2807.8	4362.1	1089.0
2016	23,334.1	135.8	423.8	3163.3	2764.3	4246.9	1070.5
2017	23,971.5	135.9	435.2	3144.6	2850.5	4516.5	1070.6
2018	24,108.3	134.4	426.9	3234.4	2865.5	4235.7	1143.3
2019	22,583.8	123.3	409.3	3009.5	2684.2	3928.9	1080.6
2020	21,227.7	115.6	375.8	2796.3	2569.8	4000.4	978.5
2021	22,719.0	124.9	391.9	2942.0	2696.6	4347.0	991.2
2022	22,969.4	127.2	404.3	2977.0	2708.2	4368.7	993.2

Year	Cows >2 years (Cows >3)	Steers <1 year	Steers >1 year	Steers >1 year (Steers 1-2)	Steers >1 year (Steers 2-3)	Steers >1 year (Steers >3)
1990	3484.9	3170.5	1640.4	1225.2	663.7	192.2
1991	3613.8	3255.4	1922.7	1273.0	690.1	199.9
1992	3613.7	3231.0	1939.8	1273.0	690.2	199.9
1993	3551.2	3138.2	1783.1	1249.4	677.4	196.2
1994	3487.4	3198.4	1853.6	1214.8	657.5	190.0
1995	3476.2	3303.8	2085.0	1203.0	625.1	189.7
1996	3583.4	3317.4	2283.9	1235.8	641.6	194.5
1997	3648.8	3419.6	2029.3	1263.0	657.7	199.2
1998	3763.6	3426.7	2042.3	1303.7	679.8	206.0
1999	3722.5	3313.8	2031.1	1287.6	671.3	203.4
2000	4034.1	3464.8	1944.5	1409.2	736.1	223.5
2001	4045.9	3427.2	2113.0	1360.2	736.2	222.1
2002	4151.6	3335.2	2241.1	1391.9	753.1	227.0
2003	3894.7	3207.1	1998.2	1303.1	704.8	212.4
2004	4156.0	3182.7	2268.7	1397.0	756.4	228.2
2005	4209.0	3300.4	2062.9	1416.3	767.4	231.5
2006	4100.1	3397.3	2264.1	1391.3	753.8	220.1
2007	4198.5	3352.3	2141.8	1416.6	766.1	223.4
2008	4361.0	3110.2	1753.1	1465.6	790.3	230.4
2009	4307.5	3350.5	2008.2	1486.3	807.9	236.6
2010	4193.1	3079.3	1817.3	1396.9	752.2	218.9
2011	4619.6	3513.7	1882.2	1551.9	871.4	262.9
2012	4551.5	3253.1	1947.2	1467.2	778.8	237.0
2013	4741.1	3588.1	1910.6	1538.6	818.4	249.3
2014	4761.3	3527.8	1948.0	1550.5	825.6	251.7
2015	4247.0	3247.5	1927.7	1360.4	721.8	219.5
2016	4141.7	3328.5	1736.1	1365.3	742.4	215.7
2017	4128.7	3298.6	2064.2	1369.1	743.7	213.9
2018	4389.5	3381.7	1773.7	1481.0	808.7	233.5
2019	4161.8	3144.0	1682.6	1387.4	754.9	217.4
2020	3755.4	2926.4	1548.2	1269.2	693.6	199.9
2021	3796.1	3089.2	2133.3	1293.6	708.7	204.6
2022	3790.4	3124.7	2238.2	1309.1	720.0	208.4

(a) adjusted for feedlot animals

A5.5.3 Beef Cattle in Feedlots

Table A5.5.3.1 Feedlot cattle – Animal characteristics

		1990-1994[a]	1995-1999[a]	2000-2004[a]	2005-2009[a]	2010-2014[a]	2015-2019	2020-2022
Domestic								
Days on feed		75	75	70	70	70	70	75
Average daily gain	kg/d	1.5	1.6	1.7	1.7	1.7	1.7	1.7
Mean liveweight	kg LW	356	360	381	400	410	410	410
N retention[b]	per cent of intake	21.4	22.3	22.2	21.1	20.4	20.4	20.4
Mid-fed								
Days on feed		140	120	115	115	115	120	150
Average daily gain	kg/d	1.5	1.5	1.6	1.7	1.7	1.7	1.7
Mean liveweight	kg LW	520	529	534	538	538	538	538
N retention [b]	per cent of intake	11.8	11.6	12.0	12.5	12.7	12.7	12.7
Long-fed								
Days on feed		250	250	250	250	250	250	250
Average daily gain	kg/d	1.1	1.1	1.1	1.2	1.3	1.3	1.3
Mean liveweight	kg LW	598	598	598	600	613	613	613
N retention[b]	per cent of intake	6.4	6.3	6.1	6.6	7.0	7.0	7.0

(a) Productivity data for the period 1990-1994 derived from Tucker et al. (1991) and Watts and Tucker (1994). Data for subsequent periods checked against known industry performance (Dr Rob Lawrence Integrated Animal Production, pers. comm. 2014).

(b) N retention determined using BeefBal (McGahan, et al. 2004).

Table A5.5.3.2 Feedlot cattle – Diet properties

Nutrient analysis	Unit	1990-1994[a]	1995-1999[a]	2000-2004[a]	2005-2009[a]	2010-2014[a]	2015-2019	2020-2022
Domestic and Mid-fed								
Dry matter digestibility	per cent	80	81	81	81	81	81	81
Crude protein	per cent	13.2	13.2	13.2	13.3	13.4	13.4	13.4
Net Energy (NEma)	MJ/kg	8.0	8.0	8.0	8.2	8.4	8.4	8.4
Soluble residue	fraction	0.58	0.61	0.64	0.63	0.62	0.62	0.62
Hemi-cellulose	fraction	0.09	0.09	0.10	0.10	0.10	0.10	0.10
Cellulose	fraction	0.12	0.08	0.05	0.05	0.05	0.05	0.05
Long-Fed								
Dry matter digestibility	per cent	80	80	80	79	79	79	79
Crude protein	per cent	13.2	13.6	14.0	13.6	13.2	13.2	13.2
Net Energy (NEma)	MJ/kg	8.0	8.0	8.1	8.2	8.3	8.3	8.3
Soluble residue	fraction	0.57	0.57	0.57	0.57	0.58	0.58	0.58
Hemi-cellulose	fraction	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Cellulose	fraction	0.06	0.06	0.06	0.07	0.07	0.07	0.07

(a) Feedlot diets for the 1990-1994 period derived from Tucker et al. (1991) and van Sliedregt et al. (2000).

(b) Feedlot diets for subsequent periods reviewed by Integrated Animal Production (Dr Rob Lawrence, pers. comm.) in 2014.

Table A5.5.3.3 Feedlot cattle – Integrated EFs

	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2022
iMCF							
NSW	0.03420	0.03420	0.03345	0.03230	0.03230	0.03230	0.03230
QLD	0.04213	0.04213	0.04138	0.04023	0.04023	0.04023	0.04023
SA	0.03420	0.03420	0.03345	0.03230	0.03230	0.03230	0.03230
VIC	0.03420	0.03420	0.03345	0.03230	0.03230	0.03230	0.03230
WA	0.03460	0.03460	0.03385	0.03270	0.03270	0.03270	0.03270
$iFracGASM_{MMS}$	0.68980	0.68980	0.69790	0.71032	0.71032	0.71116	0.71116
iNOF	0.021656	0.021656	0.021926	0.022340	0.022340	0.019420	0.019420

Note: Integrated factors are derived from the allocation of waste to different MMS (Table 5.5.3.4) and the specific MCF (Table 5. 5.3.5), N_2O EF (Table 5. 5.3.6) and FracGASMMMS (Table 5. 5.3.7) of each MMS.

Table A5.5.3.4 Feedlot cattle – Allocation of waste to MMS (per cent)

	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2022
Primary Systems							
Drylot (Feedpad)	100	100	100	100	100	100	100
Secondary Systems (a)							
Stockpile (Solid storage)	92	92	77	54	54	54	54
Composting (Passive windrow)	0	0	15	38	38	38	38
Direct Application	8	8	8	8	8	8	8
Tertiary System (b)							
Uncovered anaerobic lagoon (Effluent pond)	2	2	2	2	2	2	2

(a) 50 per cent of VS is assumed to be lost during storage in the primary system, predominantly as biogenic CO_2 (McGahan, et al. 2004) (Wiedemann, Sullivan and McGahan, GHG Prediction methods for feedlots, poultry and pigs 2014).

(b) 2 per cent of VS and N from the feed pad is assumed to run-off into effluent ponds (Watts, et al. 2012) (Wiedemann, Sullivan and McGahan, GHG Prediction methods for feedlots, poultry and pigs 2014).

Table A5.5.3.5 Feedlot cattle – MCFs

MMS	NSW	QLD	SA	VIC	WA
Dry lot (Feedpad)	0.01 b)	0.03(a)	0.01(b)	0.01(b)	0.01(b)
Solid Storage (Stockpile) (b)	0.02	0.02	0.02	0.02	0.02
Composting (Passive Windrow) (c)	0.01	0.01	0.01	0.01	0.01
Uncovered anaerobic lagoon (c) (Effluent pond)	0.75	0.77	0.75	0.75	0.77

Source: (a) Redding et al. (2015). (b) IPCC (2006) cool region values applied as these more closely align with Australian experimental data (Redding et al. (2015) and J. Devereux and M. Redding pers.comm., QDAFF June 2014). (c) IPCC (2006).

Table A5.5.3.6 Feedlot cattle – Nitrous oxide EFs (kg N_2O-N / kg N)

MMS	N_2O	Source
Dry lot (Feedpad)	0.0054	Wiedemann & Longworth (2020)
Solid Storage (Stockpile)	0.005	IPCC (2006)
Composting (Passive Windrow)	0.01	IPCC (2006)
Uncovered anaerobic lagoon (Effluent pond)	0	IPCC (2006)

Table A5.5.3.7 Feedlot cattle – Fraction of N volatilised by MMS

MMS	FracGASM	Source
Dry lot (Feedpad)	0.6	DEWR (2007) and Watts et al. (2012)
Solid Storage (Stockpile)	0.25	DEWR (2007) and Watts et al. (2012)
Composting (Passive Windrow)	0.4	Rotz (2004)
Uncovered anaerobic lagoon (Effluent pond)	0.35	IPCC (2019)

Table A5.5.3.8 Feedlot cattle – Population (1000s)

Year	Population	Domestic	Export Mid-fed	Export Long-fed
1990	328.8	30,822	143,836	154,110
1991	345.2	32,363	151,027	161,815
1992	379.7	35,599	166,130	177,997
1993	394.9	48,949	182,743	163,164
1994	434.3	53,844	201,017	179,480
1995	446.2	59,228	189,531	197,428
1996	453.9	77,074	205,531	171,276
1997	450.5	95,563	218,429	136,518
1998	503.7	106,848	244,223	152,639
1999	545.7	115,753	264,578	165,361
2000	575.8	116,732	268,483	190,583
2001	644.2	130,594	300,367	213,215
2002	678.3	137,237	314,452	226,654
2003	695.4	140,678	322,336	232,336
2004	684.6	138,499	317,343	228,737
2005	817.0	165,288	378,727	272,982
2006	858.7	173,731	398,071	286,925
2007	885.5	179,139	410,463	295,857
2008	685.6	138,697	317,799	229,066
2009	705.0	176,098	353,057	175,865
2010	745.1	186,100	373,110	185,853
2011	779.2	194,635	390,223	194,378
2012	772.4	192,930	386,804	192,675
2013	785.8	196,276	393,513	196,017
2014	810.9	202,532	406,055	202,264
2015	925.7	187,676	431,655	306,410
2016	936.6	189,884	436,732	310,014
2017	939.7	197,258	441,858	300,583
2018	1,031.3	217,121	581,574	232,630
2019	1,111.8	240,979	630,178	240,660
2020	1,114.2	224,458	590,513	299,200
2021	1,059.3	169,932	545,939	343,458
2022	1,186.1	159,602	584,446	442,072

A5.5.4 Sheep Parameters

Table A5.5.4.1 Sheep – Liveweight (kg)

		Sheep > 1					Sheep < 1
State	**Season**	**Rams**	**Wethers**	**Maiden Ewes (intended for breeding)**	**Breeding Ewes**	**Other Ewes**	**Lambs & Hoggets**
ACT/NSW	Spring	75	62	44	54	56	20
	Summer	75	55	42	49	51	27
	Autumn	69	55	43	50	50	32
	Winter	69	55	45	50	51	34
Queensland	Spring	58	50	35	40	45	20
	Summer	61	55	40	45	50	25
	Autumn	63	55	40	45	50	20
	Winter	60	50	35	42	48	25
South Australia	Spring	80	70	52	55	55	40
	Summer	70	65	52	55	55	45
	Autumn	70	60	52	55	55	20
	Winter	70	60	52	55	55	30
Tasmania	Spring	90	55	45	50	50	14
	Summer	90	55	45	50	50	24
	Autumn	75	50	45	50	50	36
	Winter	75	45	50	55	50	42
Victoria	Spring	70	60	50	55	50	22
	Summer	65	55	45	50	50	28
	Autumn	65	52	43	48	50	33
	Winter	60	50	40	45	50	35
Western Australia	Spring	75	60	50	55	55	30
	Summer	65	55	45	50	50	30
	Autumn	65	48	40	45	45	10
	Winter	65	48	45	50	50	20

Source: NGGIC (2007).

Table A5.5.4.2 Sheep – Dry matter digestibility of feed intake (per cent)

		Sheep > 1					Sheep < 1
State	**Season**	**Rams**	**Wethers**	**Maiden Ewes (intended for breeding)**	**Breeding Ewes**	**Other Ewes**	**Lambs & Hoggets**
ACT/NSW	Spring	75	75	75	75	75	75
	Summer	61	61	61	61	61	61
	Autumn	64	64	64	64	64	64
	Winter	72	72	72	72	72	72
Queensland	Spring	51	51	51	51	51	51
	Summer	55	55	55	55	55	55
	Autumn	59	59	59	59	59	59
	Winter	58	58	58	58	58	58
South Australia	Spring	70	70	70	70	70	70
	Summer	55	55	55	55	55	55
	Autumn	55	55	55	55	55	55
	Winter	75	75	75	75	75	75
Tasmania	Spring	75	75	75	75	75	75
	Summer	55	55	55	55	55	55
	Autumn	67	67	67	67	67	67
	Winter	70	70	70	70	70	70
Victoria	Spring	70	70	70	70	70	70
	Summer	55	55	55	55	55	55
	Autumn	65	65	65	65	65	65
	Winter	60	60	60	60	60	60
Western Australia	Spring	73	73	73	73	73	73
	Summer	55	55	55	55	55	55
	Autumn	50	50	70	70	50	70
	Winter	76	76	76	76	76	76

Source: NGGIC (2007).

Table A5.5.4.3 Sheep – Feed availability (t/ha)

		Sheep > 1					Sheep < 1
State	**Season**	**Rams**	**Wethers**	**Maiden Ewes (intended for breeding)**	**Breeding Ewes**	**Other Ewes**	**Lambs & Hoggets**
ACT/NSW	Spring	2.9	2.9	2.9	2.9	2.9	2.9
	Summer	2.5	2.5	2.5	2.5	2.5	2.5
	Autumn	1.6	1.6	1.6	1.6	1.6	1.6
	Winter	1.7	1.7	1.7	1.7	1.7	1.7
Queensland	Spring	1.5	1.5	1.5	1.5	1.5	1.5
	Summer	2.0	2.0	2.0	2.0	2.0	2.0
	Autumn	2.2	2.2	2.2	2.2	2.2	2.2
	Winter	1.7	1.7	1.7	1.7	1.7	1.7
South Australia	Spring	4.0	4.0	4.0	4.0	4.0	4.0
	Summer	2.5	2.5	2.5	2.5	2.5	2.5
	Autumn	0.7	0.7	0.7	0.7	0.7	0.7
	Winter	0.9	0.9	0.9	0.9	0.9	0.9
Tasmania	Spring	2.5	2.5	2.5	2.5	2.5	2.5
	Summer	2.5	2.5	2.5	2.5	2.5	2.5
	Autumn	1.3	1.3	1.3	1.3	1.3	1.3
	Winter	0.8	0.8	0.8	0.8	0.8	0.8
Victoria	Spring	3.2	3.2	3.2	3.2	3.2	3.2
	Summer	3.0	3.0	3.0	3.0	3.0	3.0
	Autumn	1.8	1.8	1.8	1.8	1.8	1.8
	Winter	1.0	1.0	1.0	1.0	1.0	1.0
Western Australia	Spring	3.5	3.5	3.5	3.5	3.5	3.5
	Summer	1.5	1.5	1.5	1.5	1.5	1.5
	Autumn	0.7	0.7	0.7	0.7	0.7	0.7
	Winter	1.2	1.2	1.2	1.2	1.2	1.2

Source: NGGIC (2007).

Table A5.5.4.4 Sheep – Crude protein content of feed intake (per cent)

		Sheep > 1					Sheep < 1
State	**Season**	**Rams**	**Wethers**	**Maiden Ewes (intended for breeding)**	**Breeding Ewes**	**Other Ewes**	**Lambs & Hoggets**
ACT/NSW	Spring	20	20	20	20	20	20
	Summer	10	10	10	10	10	10
	Autumn	12	12	12	12	12	12
	Winter	18	18	18	18	18	18
Queensland	Spring	8	8	8	8	8	8
	Summer	10	10	10	10	10	10
	Autumn	9	9	9	9	9	9
	Winter	7	7	7	7	7	7
South Australia	Spring	16	16	16	16	16	16
	Summer	7	7	7	7	7	7
	Autumn	9	9	9	9	9	9
	Winter	20	20	20	20	20	20
Tasmania	Spring	20	20	20	20	20	20
	Summer	7	7	7	7	7	7
	Autumn	14	14	14	14	14	14
	Winter	16	16	16	16	16	16
Victoria	Spring	16	16	16	16	16	16
	Summer	7	7	7	7	7	7
	Autumn	13	13	13	13	13	13
	Winter	10	10	10	10	10	10
Western Australia	Spring	18	18	18	18	18	18
	Summer	6	6	6	6	6	6
	Autumn	6	6	16	16	6	16
	Winter	21	21	21	21	21	21

Source: NGGIC (2007).

Table A5.5.4.5 Sheep – Liveweight gain (kg/day)

		Sheep > 1					Sheep < 1
State	**Season**	**Rams**	**Wethers**	**Maiden Ewes (intended for breeding)**	**Breeding Ewes**	**Other Ewes**	**Lambs & Hoggets**
ACT/NSW	Spring	0.07	0.08	0.07	0.04	0.05	0.16
	Summer	0	-0.08	0.00	-0.05	-0.05	0.08
	Autumn	-0.07	0.00	0.00	0.01	-0.01	0.05
	Winter	0.00	0.00	0.02	0.00	0.01	0.04
Queensland	Spring	-0.02	0.00	0.00	-0.02	-0.03	0.20
	Summer	0.03	0.05	0.05	0.05	0.05	0.05
	Autumn	0.02	0.00	0.00	0.00	0.00	0.20
	Winter	-0.03	-0.05	-0.05	-0.03	-0.02	0.05

		Sheep > 1					Sheep < 1
State	Season	Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
South Australia	Spring	0.11	0.11	0.00	0.00	0.00	0.11
	Summer	-0.10	-0.10	0.00	0.00	0.00	0.05
	Autumn	0.00	-0.10	0.00	0.00	0.00	0.16
	Winter	0.00	0.00	0.00	0.00	0.00	0.16
Tasmania	Spring	0.16	0.11	0.03	-0.02	0.00	0.15
	Summer	0.00	0.00	0.00	0.00	0.00	0.11
	Autumn	-0.20	-0.10	0.00	0.00	0.00	0.13
	Winter	0	-0.10	0.5	0.02	0.00	0.07
Victoria	Spring	0.11	0.11	0.16	0.11	0.00	0.15
	Summer	-0.05	-0.05	-0.05	-0.05	0.00	0.07
	Autumn	0.00	-0.03	-0.02	-0.02	0.00	0.05
	Winter	-0.05	-0.02	-0.03	-0.03	0.00	0.02
Western Australia	Spring	0.11	0.13	0.05	0.05	0.05	0.11
	Summer	-0.11	-0.05	-0.05	-0.05	-0.05	0.00
	Autumn	0.00	-0.08	0.11	-0.05	-0.05	0.11
	Winter	0.00	0.00	0.05	0.05	0.05	0.11

Source: NGGIC (2007).

Table A5.5.4.6 Sheep – Fraction of lambs receiving milk in each season

State	Spring	Summer	Autumn	Winter
ACT/NSW	0.4	0.1	0.2	0.3
Queensland	0.5	0	0.5	0
South Australia	0.15	0.05	0.3	0.5
Tasmania	0.6	0	0.1	0.3
Victoria	0.3	0.1	0.25	0.35
Western Australia	0.15	0.1	0.15	0.6

Source: NGGIC (2007). Based on breed weighted season of joining (+ 2 seasons) as reported in the MLA Lamb Survey (2002). Queensland and Tasmania estimates based on information provided by State experts.

Table A5.5.4.7 Sheep – Standard reference weights (kg)

	Sheep > 1					Sheep < 1
State	Rams	Wethers	Maiden Ewes (intended for breeding)	Breeding Ewes	Other Ewes	Lambs & Hoggets
ACT/NSW	78	62	57	57	57	60
Queensland	70	60	50	50	50	55
South Australia	84	72	60	60	60	66
Tasmania	77	66	55	55	55	60
Victoria	70	60	50	50	50	55
Western Australia	84	72	60	60	60	66

Source: NGGIC (2007), based on SCA (1990).

Table A5.5.4.8 Sheep – Population (1000s)

Year	Population	Rams	Wethers	Maiden Ewes	Breeding Ewes	Other Ewes	Lambs and Hoggets
1990	173,738.0	1,804.9	48,749.1	13,704.5	62,700.5	6,079.6	40,699.5
1991	166,526.4	1,732.6	49,741.2	12,309.4	56,167.0	9,916.9	36,659.3
1992	150,960.8	1,594.7	46,354.3	11,987.1	54,743.4	8,015.7	28,265.7
1993	140,531.0	1,470.7	41,006.3	11,222.1	51,335.0	6,697.6	28,799.2
1994	132,569.2	1,431.9	34,753.7	10,894.6	49,884.1	5,866.2	29,738.7
1995	120,861.7	1,280.3	34,509.9	9,662.1	44,210.9	4,368.8	26,829.7
1996	121,115.9	1,094.1	29,734.7	10,233.6	46,948.3	3,695.5	29,409.5
1997	120,228.1	1,023.9	27,916.1	10,270.0	47,110.4	3,446.7	30,461.1
1998	117,491.5	1,004.8	27,470.6	9,964.9	45,731.0	3,362.8	29,957.4
1999	115,456.1	959.4	26,190.6	9,940.5	45,668.2	3,201.1	29,496.2
2000	118,551.7	1,048.9	28,562.0	9,757.3	44,965.8	3,518.5	30,699.2
2001	110,927.7	930.6	25,513.6	9,530.3	43,894.8	3,089.1	27,969.3
2002	106,056.5	798.2	21,758.6	9,348.9	43,139.4	2,652.8	28,358.7
2003	99,048.8	704.0	19,082.2	9,085.8	42,023.7	2,362.1	25,790.9
2004	100,973.1	663.4	17,916.9	9,122.1	42,207.4	2,253.3	28,810.0
2005	100,705.9	616.7	16,679.5	9,292.1	42,988.2	2,102.8	29,026.7
2006	91,026.0	756.6	20,337.0	7,588.5	35,096.5	2,565.3	24,682.0
2007	85,711.2	665.3	17,867.3	7,371.3	34,146.6	2,240.6	23,420.1
2008	76,937.5	472.2	12,757.4	8,059.9	37,351.4	1,589.7	16,706.8
2009	72,739.7	370.2	10,013.7	7,256.6	33,610.3	1,239.9	20,249.0
2010	68,085.5	299.5	8,120.1	7,502.7	34,762.7	1,010.1	16,390.4
2011	73,096.9	304.3	8,204.2	7,420.7	34,400.8	1,009.5	21,757.4
2012	74,721.6	290.8	7,864.5	7,955.1	36,895.2	970.7	20,745.1
2013	75,547.8	343.2	9,224.4	7,136.1	33,114.2	1,160.5	24,569.5
2014	72,612.3	337.1	9,025.3	7,203.3	33,447.0	1,132.8	21,466.8
2015	70,909.6	321.3	8,535.4	6,970.3	32,380.4	1,064.0	21,638.3
2016	70,866.6	306.4	8,159.5	6,949.8	32,297.7	1,032.3	22,120.8
2017	75,686.6	318.9	8,481.6	7,456.6	34,670.0	1,063.4	23,696.2
2018	74,082.6	295.0	7,878.3	7,452.3	34,669.1	983.3	22,804.6
2019	69,003.2	287.8	7,727.2	7,051.1	32,809.4	977.2	20,150.5
2020	66,670.0	259.0	6,992.5	6,595.8	30,753.8	881.0	21,187.7
2021	71,444.9	263.8	7,088.5	7,029.6	32,718.4	879.0	23,465.5
2022	73,763.6	272.4	7,337.0	7,292.4	33,801.5	904.7	24,155.5

A5.5.5 Swine Parameters

PIGBAL (Skerman, et al. 2013, v4) is a nutrient balance model for intensive piggeries in Australia. By entering typical animal characteristics, intakes, diet compositions and wastage rates (Tables A5.5.5.2 and A5.5.5.3), the model calculates the volatile solids in animal manure and waste feed and the nitrogen retained by the animals (Table A5.5.5.4). Swine industry experts provided information such as average intakes for a typical herd. The model itself is an Excel -based modelling tool available at https://australianpork.com.au/environmentalpractices/waste-management

Supporting documentation is also available from this site. The information required by para 50(a) of decision 24/CP.19 is summarised below.

Table A5.5.5.1 PigBal – Model characteristics

Attribute	Information	location
basis and type of model	The PigBal model uses a mass balance approach to estimate piggery waste production (solids and nutrients) based on detailed dietary data and pig production information entered by the user	Skerman et al. (2013)
application and adaptation	The model is applied and used as provided, without adaptation	n/a
main equations/processes	Annex A of Skerman et al. (2013) (8 pages)	Skerman et al. (2013)
key assumptions	Documented in Table 6 of Skerman et al. (2013). They relate to the nutrient composition of the carcass, placenta, milk and suckers; the gestation period; the litter moisture content; and the shed losses.	Skerman et al. (2013)
domain of application	intensive piggeries in Australia	NIR 5.3.2
how the model parameters were estimated	The animal and feed characteristics data were reviewed and updated by Wiedemann et al. (2014)	Cited in NIR Table A5.5.5.2
description of key inputs and outputs	By entering typical animal characteristics, feed intakes, diet compositions and wastage rates, the model calculates the volatile solids (VSij kg/head/day) in the animal manure (including urine) and waste feed	NIR 5.3.2 and further detail in Annex A5.5.5
details of calibration and model evaluation	replicated metabolic pen trials	Skerman et al. (2013)
uncertainty and sensitivity analysis	None specific to PigBal	
QA/QC procedures adopted	reviewed by Wiedemann et al. (2014)	Cited in NIR 5.3.2 and Annex A5.5.5
references to peer-reviewed literature	Skerman et al. (2013), Wiedemann et al. (2014) and references therein	Cited in NIR 5.4.6 and Annex A5.5.5

Table A5.5.5.2 Swine – Herd characteristics

	Units	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2022
Swine mass and productivity								
Average live weight								
Sows	kg	188	188	198	198	188	188	188
Boars	kg	201	204	206	207	206	206	206
Gilts	kg	115	121	125	127	125	125	125
Slaughter pigs	kg	34	36	34	38	39	39	39
Slaughter pigs at turnoff	kg	85	91	95	94	97	97	97
Avg slaughter pig age at turnoff	weeks	21	21	21	20	21	21	21
Breeder mortality	per cent	10	10	10	10	10	10	10
Slaughter pig mortality	per cent	5	5	5	5	5	5	5
Pigs slaughtered / sow per year	pigs/sow/yr	19	18	19	19	21	21	21
Dressing percentage	per cent	76	77	77	78	78	78	78
FCR (whole herd)	kg feed fed / kg live weight	3	3	3	3	3	3	3
ADG (wean-finish)	g/day/pig	658	690	721	727	730	730	730
Feed intake (ingested as-fed)								
Sows	kg/pig/day	2.98	2.92	3.31	2.58	2.62	2.62	2.62
Boars	kg/pig/day	2.20	2.20	2.20	2.30	2.30	2.30	2.30
Gilts	kg/pig/day	2.20	2.20	2.80	2.50	2.50	2.50	2.50
Slaughter pigs (mean LW)	kg/pig/day	1.49	1.47	1.63	1.65	1.71	1.71	1.71
Feed wastage (per cent)								
Sows	per cent	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Boars	per cent	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Gilts	per cent	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Slaughter pig herd	per cent	11.5	12.1	10.4	12.6	11.0	11.0	11.0

Source: Wiedemann et al. (2014)

Table A5.5.5.3 Pigs – Feed specifications

Diet characteristics		1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2022
Breeder herd								
Dry matter	per cent	90.2	90.2	91.2	91.2	88.8	88.8	88.8
DMD	per cent	82.7	82.5	82.1	82.2	80.3	80.3	80.3
CP	per cent	2.6	2.5	2.4	2.4	2.3	2.3	2.3
Slaughter pig herd								
Dry matter	per cent	90.2	90.2	90.2	90.2	88.8	88.8	88.8
DMD	per cent	86.9	87.0	86.2	85.8	82.5	82.5	82.5
CP	per cent	3.5	3.5	3.1	3.0	2.6	2.6	2.6

Source: Wiedemann et al. (2014)

Table A5.5.5.4 Swine – Manure characteristics derived from PigBAL

Diet characteristics		1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2022
Breeder herd								
Manure ash								
Boars	per cent	26.3	26.3	25.3	25.4	26.7	26.7	26.7
Sows	per cent	27.0	27.1	26.7	26.0	25.5	25.5	25.5
Gilts	per cent	31.4	31.7	25.7	25.4	24.7	24.7	24.7
N retention								
Boars	per cent DM I	24.3	23.2	21.8	23.9	27.6	27.6	27.6
Sows	per cent DM I	7.9	7.7	7.4	10.1	9.7	9.7	9.7
Gilts	per cent DM I	24.3	23.2	21.8	23.9	27.6	27.6	27.6
Volatile solids								
Boars	kg/hd/day	0.37	0.37	0.39	0.40	0.40	0.40	0.40
Sows	kg/hd/day	0.47	0.47	0.55	0.43	0.46	0.46	0.46
Gilts	kg/hd/day	0.41	0.41	0.57	0.51	0.55	0.55	0.55
Nitrogen in waste								
Boars	kg/hd/yr	17.11	17.19	16.47	17.35	16.93	16.93	16.93
Sows	kg/hd/yr	23.37	23.27	25.91	19.24	17.91	17.91	17.91
Gilts	kg/hd/yr	21.84	22.12	22.57	19.69	16.70	16.70	16.70
Slaughter pig herd								
Manure ash	per cent	34.7	34.4	29.5	28.1	21.7	21.7	21.7
N retention	per cent	32.0	33.9	36.8	37.3	42.1	42.1	42.1
Volatile solids	kg/hd/day	0.28	0.27	0.32	0.36	0.39	0.39	0.39
Nitrogen in waste	kg/hd/yr	15.6	15.0	14.0	14.2	11.4	11.4	11.4

Source: PigBal v4 – Skerman et al. (2013).

Table A5.5.5.5 Swine – Integrated EFs

	NT	NSW	QLD	SA	TAS	VIC	WA
1990-1994							
iMCF	0.72623	0.68299	0.72623	0.66132	0.61742	0.65483	0.68924
iFracGASMMMS	0.53068	0.52283	0.53068	0.51433	0.51433	0.51948	0.51853
iNOF	0.00035	0.00105	0.00035	0.00120	0.00120	0.00116	0.00117
1995-1999							
iMCF	0.70229	0.65038	0.70229	0.62570	0.58435	0.62654	0.62798
iFracGASMMMS	0.52280	0.51124	0.52280	0.50154	0.50154	0.50915	0.49734
iNOF	0.00096	0.00178	0.00096	0.00203	0.00203	0.00182	0.00255
2000-2004							
iMCF	0.64298	0.51916	0.64298	0.45333	0.42448	0.47581	0.45708
iFracGASMMMS	0.50266	0.46475	0.50266	0.44051	0.44051	0.45409	0.43856
iNOF	0.00227	0.00470	0.00227	0.00593	0.00593	0.00534	0.00630
2005-2009							
iMCF	0.64598	0.52826	0.64598	0.46862	0.43867	0.48901	0.47428
iFracGASMMMS	0.50406	0.46832	0.50406	0.44630	0.44630	0.46215	0.44490
iNOF	0.00225	0.00454	0.00225	0.00563	0.00563	0.00489	0.00600
2010-2014							
iMCF	0.64598	0.44174	0.61990	0.56080	0.52430	0.45067	0.52871
iFracGASMMMS	0.50406	0.45946	0.50371	0.47860	0.47860	0.45279	0.46465
iNOF	0.00225	0.00517	0.00243	0.00343	0.00343	0.00533	0.00498
2015-2019							
iMCF	0.64598	0.44174	0.61990	0.56080	0.52430	0.45067	0.52871
iFracGASMMMS	0.50406	0.45946	0.50371	0.47860	0.47860	0.45279	0.46465
iNOF	0.00225	0.00517	0.00243	0.00343	0.00343	0.00533	0.00498
2020-2022							
iMCF	0.64598	0.44174	0.61990	0.56080	0.52430	0.45067	0.52871
iFracGASMMMS	0.50406	0.45946	0.50371	0.47860	0.47860	0.45279	0.46465
iNOF	0.00225	0.00517	0.00243	0.00343	0.00343	0.00533	0.00498

Table A5.5.5.6 Swine – Allocation of waste to MMS (per cent)

	NSW	NT	QLD	SA	TAS	VIC	WA
1990-1994							
Outdoor (Dry lot)	3.5	0.0	0.0	4.0	4.0	4.0	4.0
Deep litter (a)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Effluent pond (b) (Uncovered anaerobic lagoon)	90.8	94.1	94.1	87.8	87.8	87.3	89.2
Anaerobic digester / Covered lagoon	0.0	0.0	0.0	0.0	0.0	2.3	0.0
Short HRT tank storage (< 1 month)	1.1	1.1	1.1	3.7	3.7	1.8	2.3
Solid Separation (c)	3.6	3.7	3.7	3.6	3.6	3.6	3.6
1995-1999							
Outdoor (Dry lot)	4.0	2.0	2.0	5.0	5.0	4.5	6.0
Deep litter (a)	5.5	2.5	2.5	5.5	5.5	5.0	8.0
Effluent pond (b) (Uncovered anaerobic lagoon)	86.1	90.8	90.8	82.7	82.7	83.2	80.7
Anaerobic digester / Covered lagoon	0.0	0.0	0.0	0.0	0.0	2.2	0.0
Short HRT tank storage (< 1 month)	1.0	1.1	1.1	3.4	3.4	1.7	2.1
Solid Separation (c)	3.4	3.6	3.6	3.4	3.4	3.4	3.2
2000-2004							
Outdoor (Dry lot)	5.0	2.0	2.0	6.0	6.0	6.0	8.0
Deep litter (a)	25.0	12.0	12.0	32.0	32.0	28.0	32.0
Effluent pond (b) (Uncovered anaerobic lagoon)	67.1	82.4	82.4	57.7	57.7	61.3	56.7
Anaerobic digester / Covered lagoon	0.0	0.0	0.0	0.0	0.0	1.5	0.0
Short HRT tank storage (< 1 month)	0.8	1.0	1.0	2.4	2.4	1.3	1.5
Solid Separation (c)	2.1	2.6	2.6	1.9	1.9	2.0	1.8
2005-2009							
Outdoor (Dry lot)	5.0	2.0	2.0	6.0	6.0	6.0	8.0
Deep litter (a)	24.0	12.0	12.0	30.0	30.0	25.0	30.0
Effluent pond (b) (Uncovered anaerobic lagoon)	68.4	82.8	82.8	59.9	59.9	62.6	59.1
Anaerobic digester / Covered lagoon	0.0	0.0	0.0	0.0	0.0	3.4	0.0
Short HRT tank storage (< 1 month)	0.8	1.0	1.0	2.5	2.5	1.3	1.3
Solid Separation	1.8	2.2	2.2	1.6	1.6	1.7	1.6
2010-2014							
Outdoor (Dry lot)	6.0	2.0	3.0	2.0	2.0	6.0	10.0
Deep litter (a)	27.0	12.0	12.0	20.0	20.0	28.0	20.0
Effluent pond (b) (Uncovered anaerobic lagoon)	51.6	82.8	77.5	73.0	73.0	56.0	66.9
Anaerobic digester / Covered lagoon	13.1	0.0	5.0	0.0	0.0	6.4	0.0
Short HRT tank storage (< 1 month)	0.7	1.0	0.4	3.0	3.0	1.9	1.4
Solid Separation (c)	1.7	2.2	2.1	2.0	2.0	1.7	1.8
2015-2019							
Outdoor (Dry lot)	6.0	2.0	3.0	2.0	2.0	6.0	10.0
Deep litter (a)	27.0	12.0	12.0	20.0	20.0	28.0	20.0

	NSW	NT	QLD	SA	TAS	VIC	WA
Effluent pond [(b)] (Uncovered anaerobic lagoon)	51.6	82.8	77.5	73.0	73.0	56.0	66.9
Anaerobic digester / Covered lagoon	13.1	0.0	5.0	0.0	0.0	6.4	0.0
Short HRT tank storage (< 1 month)	0.7	1.0	0.4	3.0	3.0	1.9	1.4
Solid Separation [(c)]	1.7	2.2	2.1	2.0	2.0	1.7	1.8
2020-2022							
Outdoor (Dry lot)	6.0	2.0	3.0	2.0	2.0	6.0	10.0
Deep litter [(a)]	27.0	12.0	12.0	20.0	20.0	28.0	20.0
Effluent pond [(b)] (Uncovered anaerobic lagoon)	51.6	82.8	77.5	73.0	73.0	56.0	66.9
Anaerobic digester / Covered lagoon	13.1	0.0	5.0	0.0	0.0	6.4	0.0
Short HRT tank storage (< 1 month)	0.7	1.0	0.4	3.0	3.0	1.9	1.4
Solid Separation [(c)]	1.7	2.2	2.1	2.0	2.0	1.7	1.8

Source: Wiedemann et al. (2014)

(a) Secondary MMS for waste from deep litter is solid storage. 5 per cent of VS is assumed to be lost in the primary system (Wiedemann, Sullivan and McGahan, GHG Prediction methods for feedlots, poultry and pigs 2014).

(b) Secondary MMS for waste from covered pond/digester is an uncovered lagoon. 75 per cent of VS is assumed to be lost in the primary system (Wiedemann, Sullivan and McGahan, GHG Prediction methods for feedlots, poultry and pigs 2014).

(c) Separated solids pass directly to the secondary MMS – solid storage.

Table A5.5.5.7 Swine – MCFs

MMS	NSW	QLD/NT	SA	TAS	VIC	WA
Outdoor (Dry lot)	0.01 [(b)]	0.03 [(a)]	0.01 [(b)]	0.01 [(b)]	0.01 [(b)]	0.01 [(b)]
Deep litter [(c)]	0.04	0.04	0.04	0.04	0.04	0.04
Stockpile (Solid storage) [(b)]	0.02	0.02	0.02	0.02	0.02	0.02
Effluent pond (Uncovered anaerobic lagoon)[(d)]	0.75	0.78	0.75	0.70	0.74	0.76
Anaerobic digester / Covered lagoon	0.1	0.1	0.1	0.1	0.1	0.1
Short HRT tank storage (< 1 month)	0.03	0.03	0.03	0.03	0.03	0.03

(a) Redding et al. (2015).

(b) IPCC (2006) cool region values applied as these more closely align with Australian experimental data (Redding et al. (2015) and J. Devereux and M. Redding pers. comm., QDAFF June 2014).

(c) Based on average of international literature (Wiedemann, Sullivan and McGahan, GHG Prediction methods for feedlots, poultry and pigs 2014) (Cabaraux, et al. 2009) (Nicks, Laitat, et al. 2003) (Nicks, Laitat, et al. 2004) (Philippe, Laitat and Canart, et al. 2007) (Philippe, Canart, et al. 2010) (Philippe, Cabaraux and Nicks 2011) (Philippe, Laitat and Nicks, et al. 2012)

(d) IPCC (2006). Average for time series.

(e) IPCC (1997).

Table A5.5.5.8 Swine – Nitrous oxide EFs by MMS (kg N_2O-N / kg N)

MMS	N_2O	Source
Outdoor(Dry lot)	0.02	IPCC (2006)
Deep litter	0.01	IPCC (2006)
Stockpile (Solid storage)	0.005	IPCC (2006)
Effluent pond (Uncovered anaerobic lagoon)	0	IPCC (2006)
Anaerobic digestor / Covered lagoon	0	IPCC (2006)
Short HRT tank storage (< 1 month)	0.002	IPCC (2006)

Table A5.5.5.9 Swine – Fraction of N volatilised by MMS

MMS	FracGASM	Source
Outdoor (Dry lot)	0.3	IPCC (2006) (Other Cattle)
Deep litter	0.125	Wiedemann et al. (2014)
Stockpile (Solid storage)	0.2	FSA Consulting (2007)
Effluent pond (Uncovered anaerobic lagoon)	0.55	Tucker et al. (2010), Wiedemann et al. (2012)
Anaerobic digester / Covered lagoon	0	IPCC (2006)
Short HRT tank storage (< 1 month)	0.25	IPCC (2006)

Table A5.5.5.10 Swine – Population (1000s)

Year	Population 1000s	Boars	Sows	Gilts	Others
1990	2,689.9	21.7	295.7	41.0	2,331.5
1991	2,572.2	21.6	274.2	38.1	2,238.3
1992	2,618.8	21.5	289.4	40.3	2,267.7
1993	2,672.2	20.9	276.4	38.4	2,336.5
1994	2,775.3	21.4	283.2	39.3	2,431.3
1995	2,652.8	21.5	291.6	40.7	2,299.0
1996	2,526.4	20.5	277.7	38.9	2,189.3
1997	2,555.2	20.1	266.3	37.1	2,231.7
1998	2,768.3	19.7	280.9	39.0	2,428.7
1999	2,626.4	16.7	271.3	37.8	2,300.7
2000	2,510.9	15.2	257.4	35.8	2,202.4
2001	2,748.0	16.5	293.1	39.4	2,399.0
2002	2,980.2	17.0	315.6	44.2	2,603.4
2003	2,730.1	14.1	308.2	52.4	2,355.4
2004	2,651.1	12.7	291.8	37.7	2,309.0
2005	2,675.1	11.5	298.5	45.6	2,319.4
2006	2,733.0	12.3	301.9	50.2	2,368.6
2007	2,604.7	11.4	285.6	53.8	2,253.8
2008	2,411.5	10.5	263.0	49.9	2,088.2
2009	2,301.8	8.4	242.2	35.7	2,015.5
2010	2,289.3	10.1	231.7	49.9	1,997.7
2011	2,285.2	8.8	261.2	33.9	1,981.3
2012	2,137.9	8.4	236.6	32.1	1,860.9
2013	2,098.1	8.4	224.5	31.9	1,833.3
2014	2,308.2	8.8	266.2	34.8	1,998.4
2015	2,272.2	8.7	271.1	33.9	1,958.4
2016	2,320.3	9.2	243.4	35.6	2,032.0
2017	2,515.0	9.9	282.5	38.2	2,184.5
2018	2,563.1	10.1	278.8	38.6	2,235.7
2019	2,345.8	9.1	274.1	34.8	2,027.9
2020	2,283.4	9.0	249.8	34.1	1,990.4
2021	2,606.4	10.2	273.2	38.6	2,284.5
2022	2,654.9	10.3	278.2	39.3	2,327.0

A5.5.6 Poultry Parameters

Table A5.5.6.1 Poultry – Diet properties

Nutrient analysis	Layers [(a)]	Meat chicken growers	Meat chicken breeder	Meat other
Dry matter intake (kg/head/day)	0.086	0.093	0.103	0.093
Dry matter digestibility	0.80	0.80	0.80	0.80
Crude protein [(b)]	0.19	0.23	0.19	0.23
Nitrogen retention rate	0.35	0.47	0.32	0.47
Manure ash	0.18	0.15	0.18	0.15

Source: Wiedemann et al. (2014)

(a) Values for layer hens represent the average for hens and pullets over a complete growing cycle.

(b) Crude protein is based on whole diet weighted average, converted to DM basis (K. Bruerton, Protea Park Nutrition Services, pers. comm., 2014).

Table A5.5.6.2 Poultry – Meat and layer chickens – Integrated EFs

	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2022
iMCF							
Meat chickens							
ACT/NSW	0.024830	0.024830	0.024771	0.024711	0.024414	0.024414	0.024414
NT/QLD	0.024870	0.024870	0.024891	0.024911	0.025014	0.025014	0.025014
SA	0.024830	0.024830	0.024771	0.024711	0.024414	0.024414	0.024414
TAS	0.023812	0.023812	0.023757	0.023702	0.023425	0.023425	0.023425
VIC	0.024830	0.024830	0.024771	0.024711	0.024414	0.024414	0.024414
WA	0.024830	0.024830	0.024771	0.024711	0.024414	0.024414	0.024414
Layer chickens							
ACT/NSW	0.029841	0.029887	0.030655	0.031527	0.031702	0.031702	0.031702
NT/QLD	0.029869	0.029927	0.03 0743	0.031687	0.031930	0.031930	0.031930
SA	0.029841	0.029887	0.030655	0.031527	0.031702	0.031702	0.031702
TAS	0.029229	0.029273	0.030009	0.030845	0.031011	0.031011	0.031011
VIC	0.029841	0.029887	0.030655	0.031527	0.031702	0.031702	0.031702
WA	0.029841	0.029887	0.030655	0.031527	0.031702	0.031702	0.031702
iFracGASMMMS							
Meat chickens	0.397064	0.397064	0.395473	0.393881	0.385924	0.385924	0.385924
Layer chickens	0.483880	0.478978	0.413370	0.336948	0.315956	0.315956	0.315956
iNOF							
Meat chickens	0.004277	0.004277	0.004260	0.004242	0.004157	0.004157	0.004157
Layer chickens	0.004327	0.004261	0.004454	0.004675	0.004728	0.004728	0.004728

Table A5.5.6.3 Poultry – Meat chickens allocation of waste to MMS (per cent)

MMS	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2022
Primary system							
Poultry manure with litter (housing)	99.8	99.8	99.4	99.0	97.0	97.0	97.0
Pasture range and paddock (free range)	0.2	0.2	0.6	1.0	3.0	3.0	3.0
Secondary system (a)							
Solid storage (stockpile)	46.0	46.0	46.0	46.0	46.0	46.0	46.0
Composting (passive windrow)	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Direct application to soil	30.0	30.0	30.0	30.0	30.0	30.0	30.0

Source: Wiedemann et al. (2014).

(a) Only housing waste is transferred to the secondary systems. 15 per cent of VS is assumed to be lost in the primary system.

Table A5.5.6.4 Poultry – Layer hens allocation of waste to MMS (per cent)

MMS	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2022
Primary system							
Poultry manure without litter (housing)	98	97.2	93.8	89.0	85.4	85.4	85.4
Belt manure removal	8	9.4	31	55.8	61.6	61.6	61.6
Manure stored in house under cages or slat	90	87.8	62.8	33.2	23.8	23.8	23.8
Poultry manure with litter (housing)	1.86	2.6	5.76	10.2	13.46	13.46	13.46
Pasture range and paddock (free range)	0.14	0.2	0.44	0.8	1.14	1.14	1.14
Secondary System (a)							
Solid storage (stockpile)	76.0	76.0	76.0	76.0	76.0	76.0	76.0
Composting (passive windrow)	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Direct application to soils	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Direct processing	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Anaerobic digester / covered pond	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Source: AECL (2012), G. Runge, Australian Egg Corporation – AECL and E. McGahan, FSA Consulting (pers. comm. 2014).(

a) Only housing waste is transferred to the secondary systems. VS lost in primary system is assumed to be 20 per cent for manure stored in house and 0 per cent for belt removal systems.

Table A5.5.6.5 Poultry – MCFs

MMS	All states	NSW/ACT	QLD/NT	VIC	SA	WA	TAS
Poultry manure with litter	0.015						
Poultry manure without litter	0.015						
Pasture range and paddock [(a)]		0.01	0.03	0.01	0.01	0.01	0.01
Solid storage	0.02						
Composting (passive windrow)		0.01	0.01	0.01	0.01	0.01	0.005
Anaerobic digester / Covered pond	0.1						
Direct processing	0						

Source: IPCC (2006). (a) MCF assumed to be similar to a drylot. QLD/NT based on Redding et al. (2015) and other States based on IPCC (2006) cool region values as these more closely align with Australian experimental data (Redding et al. (2015) and J. Devereux and M. Redding pers. comm., QDAFF June 2014).

Table A5.5.6.6 Poultry – Nitrous oxide EFs by MMS

MMS	N_2O	Source
Poultry manure with litter (housing)	0.001	IPCC (2006)
Poultry manure without litter (housing)	0.001	IPCC (2006)
Pasture range and paddock (free range)	0.02	IPCC (2006)
Solid storage (stockpile)	0.005	IPCC (2006)
Composting (passive windrow)	0.01	IPCC (2006)
Direct processing	0	Wiedemann et al. (2014)
Anaerobic digester / covered pond	0	IPCC (2006)

Table A5.5.6.7 Poultry – Fraction of N volatilised by MMS

MMS	FracGASM	Source
Poultry manure with litter (housing)	0.3	DSEWPC (2013)
Poultry manure without litter (housing)		
Belt manure removal	0.05	DSEWPC (2013)
Manure stored in house under cages or slat	0.4	DSEWPC (2013)
Solid storage (stockpile)	0.2	DSEWPC (2013)
Composting (passive windrow)	0.2	DSEWPC (2013)
Direct processing	0	Wiedemann et al. (2014)
Anaerobic digester / covered pond	0	Wiedemann et al. (2014)

Table A5.5.6.8 Poultry – Population (1000s)

Year	Population (1000s)	Layers	Meat chickens	Ducks	Other
1990	58,982.6	13,090.2	43,926.8	275.9	1,689.6
1991	54,764.0	12,595.6	39,901.8	364.3	1,902.2
1992	56,627.2	9,561.5	44,771.4	413.7	1,880.6
1993	64,472.0	10,886.6	51,688.7	403.9	1,492.8
1994	62,161.0	9,792.9	50,659.4	447.2	1,261.4
1995	68,172.2	11,120.7	54,855.3	429.3	1,766.9
1996	71,475.3	10,119.1	58,646.2	411.4	2,298.6
1997	76,517.5	10,306.1	63,674.1	390.2	2,147.1
1998	82,246.9	9,660.8	70,153.5	455.6	1,977.0
1999	94,159.7	13,608.9	78,472.5	370.1	1,708.1
2000	87,716.2	12,015.6	73,486.8	517.0	1,696.7
2001	93,612.2	14,276.0	77,254.0	769.7	1,312.6
2002	87,368.9	12,857.7	72,739.2	567.4	1,204.6
2003	86,473.0	12,913.4	71,737.9	694.1	1,127.6
2004	85,455.7	12,668.7	70,734.7	953.1	1,099.2
2005	78,196.8	13,174.7	62,728.1	1,309.4	984.6
2006	97,016.9	15,935.7	78,448.4	766.1	1,866.7
2007	100,802.1	15,316.2	82,114.3	905.9	2,465.8
2008	90,900.8	14,759.8	73,869.2	807.8	1,464.0
2009	102,271.2	12,604.2	82,805.1	1,472.8	5,389.0
2010	90,048.5	11,733.8	71,290.1	1,360.6	5,663.9
2011	98,767.3	13,111.2	77,632.8	1,000.0	7,023.3
2012	100,996.2	13,378.6	80,841.7	773.3	6,002.7
2013	105,794.7	14,617.8	84,035.1	953.2	6,188.6
2014	105,927.4	15,332.0	84,035.1	949.7	5,610.6
2015	109,797.5	17,500.2	88,658.8	615.1	3,023.4
2016	111,490.2	15,978.3	92,424.2	658.3	2,429.3
2017	117,556.2	16,498.8	97,491.5	709.2	2,856.7
2018	122,407.6	16,574.0	102,365.6	658.3	2,809.7
2019	136,250.9	16,782.3	114,696.0	872.3	3,900.3
2020	123,567.1	16,500.8	103,431.2	729.3	2,905.8
2021	134,859.1	17,241.6	113,987.3	554.7	3,075.4
2022	135,635.9	14,477.5	117,418.9	571.4	3,168.0

A5.5.7 Other Livestock Parameters

Table A5.5.7.1 Other livestock – Manure production (kg DM/head/year)

Livestock type	Manure production (kg DM/head/year)	Expert Working Group Assumption
Goats, alpacas, emus and ostriches	114	Equivalent to one sheep
Deer, mules and asses	319	One-third of beef cattle – pasture
Horses, buffalo and camels	957	Equivalent to beef cattle – pasture

Table A5.5.7.2 Other livestock – Nitrogen excretion factors (kg N/head/year)

Livestock type	Nitrogen excretion factors (kg N/head/year)	Expert Working Group Assumption
Goats, alpacas, emus and ostriches	7.0	Equivalent to one sheep
Deer, mules and asses	13.2	One-third of beef cattle – pasture
Horses, buffalo and camels	39.5	Equivalent to beef cattle – pasture

Table A5.5.7.3 Other livestock – Allocation of animals to climate regions

State	Fraction warm	Fraction temperate
ACT	0	1
NT	1	0
NSW	0	1
QLD	0	1
SA	0	1
TAS	0	1
VIC	0	1

Table A5.5.7.4 Other livestock – Population (1000s)

Year	Buffalo	Camels	Deer	Goats	Horses	Mules/ asses	Alpacas	Ostriches/ emus
1990	13.4	0.7	61.4	660.6	359.3	2.7	0.3	4.1
1991	18.6	1.0	80.4	530.5	347.0	3.3	0.8	8.6
1992	13.0	1.7	101.7	411.3	334.8	4.0	0.9	14.5
1993	11.4	1.8	130.6	286.1	314.8	2.9	1.8	23.7
1994	11.6	1.5	148.8	231.6	294.4	2.5	3.0	45.1
1995	10.9	1.1	144.3	132.8	237.7	1.6	1.8	32.5
1996	8.9	0.9	136.2	154.5	235.1	1.1	4.3	100.3
1997	9.4	1.1	152.4	176.4	234.0	0.8	6.7	168.1
1998	11.2	1.4	165.8	218.9	233.3	0.4	4.6	170.1
1999	8.5	1.9	127.0	193.5	215.4	0.4	5.7	105.0
2000	6.1	2.0	150.8	327.4	212.1	0.6	12.1	93.9
2001	7.3	2.6	131.9	391.1	224.0	0.9	18.1	82.8
2002	13.6	2.6	101.2	386.7	204.3	0.8	24.4	71.6
2003	8.6	2.5	100.2	485.8	231.2	0.5	30.8	60.5
2004	8.4	2.0	78.7	594.7	219.1	0.3	37.1	49.3

Year	Buffalo	Camels	Deer	Goats	Horses	Mules/ asses	Alpacas	Ostriches/ emus
2005	6.2	1.9	59.5	461.5	221.0	0.3	61.0	38.2
2006	3.2	1.8	68.7	517.7	257.1	0.4	73.7	32.9
2007	2.7	2.0	79.7	518.0	263.3	0.4	98.1	32.9
2008	3.3	2.2	62.4	622.9	259.9	0.5	103.6	22.4
2009	8.6	2.4	46.1	727.7	256.4	0.6	106.5	12.0
2010	6.5	2.8	45.6	513.3	258.0	0.7	122.0	8.5
2011	4.4	3.1	45.1	546.6	259.5	0.8	134.0	9.9
2012	5.1	3.3	38.4	516.1	254.2	0.9	132.0	9.7
2013	5.1	3.3	38.4	516.1	254.2	0.9	132.0	9.7
2014	5.1	3.3	38.4	516.1	254.2	0.9	132.0	9.7
2015	5.1	3.3	38.4	516.1	254.2	0.9	132.0	9.7
2016	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8
2017	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8
2018	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8
2019	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8
2020	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8
2021	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8
2022	5.2	2.8	30.1	460.3	222.5	0.6	133.0	9.8

A5.5.8 Synthetic Fertilizers

Table A5.5.8.1 Crop production areas by State (ha)

New South Wales/ACT							
	Irrigated Pasture	Irrigated crops	Non-irrigated pasture	Non-irrigated crops	Sugar	Cotton	Horticultural vegetable crops
1990	331,322	420,175	3,862,270	5,807,921	19,807	350,628	111,136
2000	331,322	420,175	3,862,270	5,807,921	19,807	350,628	111,136
2010	191,219	172,587	3,862,270	6,202,839	14,162	80,075	193,106
2011	158,892	212,560	3,862,270	6,515,684	13,323	329,665	115,313
2012	172,061	301,511	3,862,270	6,157,818	11,453	358,064	104,236
2013	220,676	357,669	3,862,270	6,059,485	14,882	267,510	125,651
2014	216,939	331,132	3,862,270	5,380,457	13,916	249,834	94,494
2015	217,542	318,554	3,862,270	5,626,940	16,113	125,077	95,295
2016	208,353	266,111	3,862,270	5,607,565	16,055	186,935	123,265
2017	212,650	266,339	3,862,270	6,409,655	15,558	316,214	99,173
2018	215,232	307,961	3,862,270	5,816,820	15,558	229,114	107,576
2019	190,297	219,389	3,862,270	4,106,418	14,413	222,444	110,551
2020	138,223	121,714	3,862,270	4,168,989	14,752	54,755	105,027
2021	165,618	296,577	3,862,270	7,270,707	12,863	167,249	121,652
2022	165,618	296,577	3,862,270	7,270,707	12,863	167,249	121,652

Northern Territory							
	Irrigated Pasture	Irrigated crops	Non-irrigated pasture	Non-irrigated crops	Sugar	Cotton	Horticultural vegetable crops
1990	252	155	40,544	2,051	-	-	3,562
2000	252	155	40,544	2,051	-	-	3,562
2010	347	-	40,544	547	-	-	4,750
2011	533	186	40,544	589	-	-	6,265
2012	274	-	40,544	2,184	-	-	6,283
2013	207	-	40,544	617	-	-	6,337
2014	280	76	40,544	478	-	-	3,284
2015	391	79	40,544	690	-	-	5,639
2016	173	103	40,544	5,965	-	-	4,414
2017	252	494	40,544	1,662	-	-	5,082
2018	20,676	70	40,544	1,546	-	-	6,056
2019	20,329	141	40,544	178	-	4	5,617
2020	446	186	40,544	305	-	300	4,981
2021	1,419	403	40,544	2,771	-	2,873	6,471
2022	1,419	403	40,544	2,771	-	2,873	6,471

Queensland							
	Irrigated Pasture	Irrigated crops	Non-irrigated pasture	Non-irrigated crops	Sugar	Cotton	Horticultural vegetable crops
1990	77,001	57,161	3,149,039	2,120,884	440,058	184,547	97,735
2000	77,001	57,161	3,149,039	2,120,884	440,058	184,547	97,735
2010	89,083	50,952	3,149,039	1,610,912	291,139	73,114	151,243
2011	52,397	37,145	3,149,039	1,797,871	353,072	258,604	95,509
2012	51,819	38,389	3,149,039	1,818,437	345,956	237,613	94,418
2013	56,467	70,812	3,149,039	1,802,124	356,206	170,308	103,528
2014	67,759	69,621	3,149,039	1,495,097	363,341	140,001	96,039
2015	61,099	100,581	3,149,039	1,639,500	366,476	73,162	82,663
2016	68,575	85,262	3,149,039	1,590,841	348,288	96,398	94,253
2017	80,006	62,291	3,149,039	1,647,550	360,127	208,687	57,287
2018	52,643	74,141	3,149,039	1,730,389	362,505	187,818	94,180
2019	53,000	50,013	3,149,039	1,213,434	297,495	83,419	95,578
2020	106,610	55,875	3,149,039	1,042,817	339,023	15,172	99,835
2021	66,960	70,900	3,149,039	2,111,440	328,978	107,679	111,827
2022	66,960	70,900	3,149,039	2,111,440	328,978	107,679	111,827

South Australia

	Irrigated Pasture	Irrigated crops	Non-irrigated pasture	Non-irrigated crops	Sugar	Cotton	Horticultural vegetable crops
1990	62,050	15,662	2,378,602	3,865,677	-	-	100,426
2000	62,050	15,662	2,378,602	3,865,677	-	-	100,426
2010	69,971	6,575	2,378,602	3,825,364	-	-	108,593
2011	66,088	8,910	2,378,602	4,004,962	-	-	113,618
2012	50,135	10,211	2,378,602	3,883,371	-	-	97,963
2013	71,154	9,564	2,378,602	3,745,077	-	-	100,065
2014	59,153	8,529	2,378,602	3,448,592	-	-	99,771
2015	10,615	5,929	2,378,602	3,699,483	-	-	81,692
2016	58,145	34,784	2,378,602	3,235,394	-	-	101,162
2017	20,235	14,383	2,378,602	4,022,424	-	-	97,646
2018	41,616	12,110	2,378,602	761,442	-	-	103,672
2019	38,917	28,083	2,378,602	579,712	-	-	111,086
2020	44,757	17,953	2,378,602	3,530,781	-	-	111,687
2021	54,341	16,561	2,378,602	3,779,047	-	-	115,033
2022	54,341	16,561	2,378,602	3,779,047	-	-	115,033

Tasmania

	Irrigated Pasture	Irrigated crops	Non-irrigated pasture	Non-irrigated crops	Sugar	Cotton	Horticultural vegetable crops
1990	30,174	16,199	768,102	38,845	-	-	23,621
2000	30,174	16,199	768,102	38,845	-	-	23,621
2010	60,203	20,912	773,793	20,995	-	-	20,424
2011	42,666	18,919	773,793	29,227	-	-	19,956
2012	43,816	17,961	773,793	54,046	-	-	20,154
2013	48,556	23,297	773,793	30,779	-	-	17,606
2014	50,693	14,211	773,793	48,546	-	-	25,580
2015	53,760	13,427	773,793	45,766	-	-	16,315
2016	62,725	23,111	773,793	27,516	-	-	17,481
2017	60,270	18,303	773,793	34,669	-	-	21,672
2018	63,281	18,186	773,793	269,028	-	-	17,496
2019	63,080	16,791	773,793	685,160	-	-	17,421
2020	68,521	22,493	773,793	35,235	-	-	16,966
2021	72,297	24,743	773,793	40,382	-	-	20,826
2022	72,297	24,743	773,793	40,382	-	-	20,826

Victoria

	Irrigated Pasture	Irrigated crops	Non-irrigated pasture	Non-irrigated crops	Sugar	Cotton	Horticultural vegetable crops
1990	512,975	41,406	3,971,377	2,892,221	-	-	110,071
2000	512,975	41,406	3,971,377	2,892,221	-	-	110,071
2010	303,437	18,702	3,971,377	3,565,529	-	-	127,882
2011	318,122	33,179	3,971,377	3,655,999	-	-	127,949
2012	387,695	56,989	3,971,377	3,654,583	-	-	125,881
2013	429,984	80,404	3,971,377	3,693,441	-	-	128,929
2014	458,333	101,008	3,971,377	3,502,999	-	-	121,998
2015	442,802	138,089	3,971,377	5,312,785	-	-	112,249
2016	374,564	111,307	3,971,377	3,199,558	-	96	123,265
2017	344,559	109,327	3,971,377	3,538,143	-	-	121,282
2018	413,199	141,138	3,971,377	3,679,073	-	-	121,004
2019	317,945	117,445	3,971,377	7,756,868	-	-	120,798
2020	252,116	65,096	3,971,377	3,789,252	-	-	119,263
2021	301,401	102,170	3,971,377	3,790,128	-	-	134,947
2022	301,401	102,170	3,971,377	3,790,128	-	-	134,947

Western Australia

	Irrigated Pasture	Irrigated crops	Non-irrigated pasture	Non-irrigated crops	Sugar	Cotton	Horticultural vegetable crops
1990	12,176	4,342	5,070,516	7,686,914	3,861	699	34,788
2000	12,176	4,342	5,070,516	7,686,914	3,861	699	34,788
2010	16,786	3,014	5,070,516	8,378,285	-	-	33,466
2011	17,495	5,872	5,070,516	8,007,195	1	26	35,362
2012	12,439	5,717	5,070,516	8,310,655	6	820	32,945
2013	16,489	19,811	5,070,516	8,213,550	-	-	31,429
2014	9,160	11,273	5,070,516	7,610,595	-	-	30,096
2015	15,380	5,887	5,070,516	8,452,322	10	-	31,084
2016	17,275	44,056	5,070,516	7,855,108	10	3	38,740
2017	41,712	85,138	5,070,516	8,545,701	-	-	37,781
2018	11,775	41,078	5,070,516	7,903,533	-	352	36,179
2019	18,423	78,697	5,070,516	7,994,598	-	360	34,953
2020	17,428	21,810	5,070,516	8,180,312	2	190	30,711
2021	15,669	18,172	5,070,516	8,382,591	-	592	38,910
2022	15,669	18,172	5,070,516	8,382,591	-	592	38,910

Source: ABS, Water Use on Australian Farms (2022). No data were reported by ABS for 2021-22, so the values for 2020-21 were used.

Table A5.5.8.2 Sugar cane N fertiliser application rates (kg/ ha)

Year	NSW	QLD
1990-2000 [(a)]	165	205
2001	155	185
2002	150	181
2003	148	175
2004	155	178
2005	148	173
2006	158	177
2007	161	172
2008	97	150
2009	154	180
2010	141	143
2011	176	164
2012	177	161
2013	175	162
2014	183	159
2015	176	160
2016	181	157
2017	183	160
2018	189	161
2019	170	140
2020	174	152
2021	151	149
2022	153	144

Source: Incitec Pivot (2018), Canegrowers Association Queensland (2022) and NSW Sunshine Sugar (2022).
(a) 1990-2000 rates based on the average of 1996-2000A5.5.9 Crop and Pasture Attributes

A5.5.9 Crop and Pasture Attributes

Table A5.5.9.1 Crop attributes

Crop type	Residue: Crop ratio	Below-ground: above-ground residue ratio	Dry matter content	Carbon fraction in dry matter	N content above-ground	N content below-ground	Fraction of residue remaining at time of burning(b)	Fraction burnt	Fraction removed
k	**RAGk**	**RBGk**	**DMk**	**CCk**	**NCAGk**	**NCBGk**	**Sk**	**Fik**	**FFODIk**
Wheat	1.50	0.29	0.88	0.40	0.006	0.010	0.5	Table 5.1.3	Table 5.1.3
Barley	1.24	0.32	0.88	0.40	0.007	0.010	0.5	Table 5.1.3	Table 5.1.3
Maize	0.81	0.39	0.85	0.42	0.005	0.007	1.0	Table 5.1.3	Table 5.1.3
Oats	1.42	0.43	0.88	0.40	0.006	0.010	0.5	Table 5.1.3	Table 5.1.3
Rice(c)	1.31	0.16	0.80	0.42	0.007	0.010	1.0	0.815	0.06
Sorghum	1.50	0.22	0.80	0.40	0.008	0.007	0.5	Table 5.1.3	Table 5.1.3
Triticale	1.50	0.42	0.88	0.40	0.006	0.010	0.5	Table 5.1.3	Table5.1.3
Other cereals	1.46	0.36	0.88	0.40	0.006	0.010	0.5	Table 5.1.3	Table 5.1.3
Pulses	1.37	0.51	0.87	0.40	0.009	0.010	0.5	Table 5.1.3	Table 5.1.3
Tubers and roots	0.34	0.43	0.25	0.40	0.020	0.010	NA	0	1
Peanuts™	1.07	0.20	0.80	0.42	0.016	0.014	0.5	Table 5.1.3	Table 5.1.3
Sugar cane[tel]	0.25	0.45	0.20	0.40	0.005	0.007	1.0	Table 5.1.4	(f)
Cotton[191]	1.90	0.30	0.90	0.40	0.01	0.01	NA	0	0
Hops	1.50	0.29	0.88	0.40	0.006	NA	NA	0	0
Oilseeds	2.08	0.33	0.96	0.40	0.009	0.010	0.5	Table 5.1.3	Table 5.1.3
Forage crops	1.34	0.37	0.88	0.40	0.006	0.010	NA	0	0.8

(a) Sourced from Janzen et al. (2003) unless otherwise specified.
(b) Mulholland et al. (1976) and R Jarvis pers. comm.
(c) Robinson and Kirby (2002).
(d) IPCC (2006).
(e) Root:shoot from Morris and Tai (2004), N content from Fortes et al. (2013).
(f) 0.03 for QLD and zero for WA and NSW.
(g) Rochester pers. comm. (2014) above ground values only.

Table A5.5.9.2 Pasture attributes

	Fraction Renewed		**Average Yield[a]**		**N content[b]**		
Pasture type	**Intensive**	**Other**	**(t DM ha)**	**Below-ground: above-ground residue ratio[b]**	**Above-ground**	**Below-ground**	**Fraction above ground residue removed**
	$Frac_{Renew}$		**Y**	**RBG**	**ncag**	**ncbg**	**FFOD**
Annual grass	0.1	0.03	4.41	0.4	0.015	0.012	0.8
Grass clover mixture	0.1	0.03	8.34	0.8	0.025	0.016	0.8
Lucerne	0.1	0.03	8.62	0.4	0.027	0.019	0.8
Other legume	0.1	0.03	5.62	0.4	0.027	0.022	0.8
Perennial pasture	0.1	0.03	8.35	0.8	0.015	0.012	0.8

(a) Average yields estimated by FullCAM (b) IPCC (2006).

Table A5.5.9.3 Crop residues – Fraction burnt or removed

Year (time-step)	State	Fraction burnt	Fraction removed
1990-1994	NSW	0.37	0.12
	VIC	0.38	0.16
	QLD	0.22	0.12
	SA	0.31	0.19
	WA	0.32	0.24
	TAS	0.16	0.19
	NT	0.30	0.05
	ACT	0.12	0.06
1995-1999	NSW	0.33	0.10
	VIC	0.36	0.15
	QLD	0.17	0.09
	SA	0.29	0.18
	WA	0.23	0.19
	TAS	0.14	0.19
	NT	0.28	0.04
	ACT	0.09	0.05
2000-2004	NSW	0.30	0.09
	VIC	0.32	0.13
	QLD	0.12	0.07
	SA	0.23	0.15
	WA	0.14	0.15
	TAS	0.13	0.18
	NT	0.26	0.03
	ACT	0.06	0.03

Year (time-step)	State	Fraction burnt	Fraction removed
2005-2009	NSW	0.25	0.06
	VIC	0.26	0.10
	QLD	0.06	0.04
	SA	0.17	0.12
	WA	0.08	0.12
	TAS	0.11	0.17
	NT	0.24	0.02
	ACT	0.02	0.01
2010-2014	NSW	0.22	0.05
	VIC	0.21	0.07
	QLD	0.06	0.04
	SA	0.12	0.09
	WA	0.06	0.11
	TAS	0.09	0.16
	NT	0.23	0.01
	ACT	0.00	0.00
2015-2019	NSW	0.22	0.05
	VIC	0.21	0.07
	QLD	0.06	0.04
	SA	0.12	0.09
	WA	0.06	0.11
	TAS	0.09	0.16
	NT	0.23	0.01
	ACT	0.00	0.00
2020-2022	NSW	0.22	0.05
	VIC	0.21	0.07
	QLD	0.06	0.04
	SA	0.12	0.09
	WA	0.06	0.11
	TAS	0.09	0.16
	NT	0.23	0.01
	ACT	0.00	0.00

Source: Estimated by FullCAM

Table A5.5.9.4 Fraction of sugar cane burnt in each State

Year	NSW	QLD	WA
1989	1.000	0.735	NO
1990	0.978	0.686	NO
1991	0.987	0.664	NO
1992	0.987	0.639	NO
1993	0.987	0.641	NO
1994	0.965	0.596	NO
1995	0.949	0.585	NO
1996	0.975	0.505	1.000
1997	0.976	0.430	1.000
1998	0.951	0.405	1.000
1999	0.951	0.307	1.000
2000	0.928	0.346	1.000
2001	0.920	0.390	1.000
2002	0.897	0.357	1.000
2003	0.884	0.331	1.000
2004	0.915	0.329	1.000
2005	0.963	0.306	1.000
2006	0.975	0.282	1.000
2007	0.947	0.434	1.000
2008	0.947	0.271	1.000
2009	0.733	0.263	1.000
2010	0.797	0.287	1.000
2011	0.874	0.359	1.000
2012	0.958	0.374	1.000
2013	0.896	0.265	1.000
2014	0.896	0.265	1.000
2015	0.919	0.250	1.000
2016	0.934	0.278	1.000
2017	0.959	0.278	1.000
2018	0.953	0.278	1.000
2019	0.934	0.278	1.000
2020	0.907	0.273	1.000
2021	0.858	0.283	1.000
2022	0.898	0.275	1.000

Source: Canegrowers Association Queensland (2022) and NSW Sunshine Sugar (2022).
NO – not defined.

A5.5.10 Nitrogen Leaching and Run-off

Table A5.5.10.1 Fraction of fertiliser N available for leaching and runoff (FracWET)

Production system	ACT/NSW	NT	Qld	SA	Tas	Vic	WA
Irrigated pasture	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Irrigated crops	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Non-irrigated pasture	0.334	0.811	0.128	0.708	0.991	0.855	0.508
Non-irrigated crops	0.192	0.777	0.043	0.279	0.985	0.438	0.223
Sugar	0.990		0.656				0.759
Cotton (a)	0.932		0.713				1.000
Horticultural crops	0.599	0.857	0.293	0.667	0.996	0.702	0.911

Source: Stewart et al. (2001).

(a) Weighted average of FracWET for irrigated (1) and non-irrigated (NSW = 0.246, QLD=0.075 and WA=0.759) cotton.

Table A5.5.10.2 Fraction of animal waste available for leaching and runoff (FracWET)

		Dairy	Beef cattle				Poultry		Other
State	Region	cattle (a)	Pasture	Feedlot	Sheep	Pigs	Meat	Layer	categories
ACT		1	0.785		0.812	0.500	0.442	0.396	0.665
NSW		1	0.365	0.192	0.269	0.500	0.442	0.396	0.335
NT		1					0.733	0.733	0.773
NT	Alice Springs								
NT	Barkly								
NT	Northern		0.582						
QLD		1		0.043	0.018	0.250	0.578	0.131	0.107
QLD	High		0.07						
QLD	Moderate/ High								
QLD	Moderate/ Low		0.01						
QLD	Low		0.66						
SA		1	0.691	0.279	0.516	0.750	0.147	0.443	0.415
TAS		1	0.997		0.987	1.000	1.000	1.000	0.995
VIC		1	0.914	0.438	0.873	0.500	0.901	0.858	0.768
WA		1		0.223	0.510	0.400	0.891	0.869	0.668
WA	South West		0.826						
WA	Pilbara								
WA	Kimberley		0.392						

Source: (a) Dairy Technical Working Group (2015). All other fractions from Wiedemann et al. (2014).

A5.5.11 Liming

Table A5.5.11.1 Fraction of lime as limestone (FracLime$_{limestone}$)

	ACT	NSW	NT	QLD	SA	TAS	VIC	WA	Australia
1990	1.00	0.96	0.84	0.86	0.80	0.66	0.94	0.91	0.88
1991	1.00	0.96	0.84	0.86	0.80	0.66	0.94	0.91	0.88
1992	1.00	0.96	0.84	0.86	0.80	0.66	0.94	0.91	0.88
1993	1.00	0.96	0.84	0.86	0.80	0.66	0.94	0.91	0.88
1994	1.00	0.96	0.84	0.86	0.80	0.66	0.94	0.91	0.88
1995	1.00	0.96	0.84	0.86	0.80	0.66	0.94	0.91	0.88
1996	1.00	0.96	0.84	0.86	0.80	0.66	0.94	0.91	0.88
1997	0.99	0.96	0.85	0.81	0.86	0.72	0.94	0.91	0.90
1998	0.99	0.96	0.85	0.81	0.86	0.72	0.94	0.91	0.90
1999	0.99	0.96	0.85	0.81	0.86	0.72	0.94	0.91	0.90
2000	0.99	0.96	0.85	0.81	0.86	0.72	0.94	0.91	0.90
2001	0.97	0.97	0.86	0.77	0.91	0.78	0.95	0.91	0.92
2002	1.00	0.97	0.82	0.86	0.92	0.79	0.95	0.91	0.92
2003	1.00	0.97	0.58	0.85	0.93	0.73	0.96	0.92	0.93
2004	1.00	0.97	0.58	0.85	0.93	0.73	0.96	0.92	0.93
2005	1.00	0.97	0.58	0.85	0.93	0.73	0.96	0.92	0.93
2006	1.00	0.97	0.58	0.85	0.93	0.73	0.96	0.92	0.93
2007	1.00	0.97	0.58	0.85	0.93	0.73	0.96	0.92	0.93
2008	1.00	0.97	0.58	0.84	0.93	0.67	0.96	0.94	0.93
2009	1.00	0.97	0.58	0.84	0.93	0.67	0.96	0.94	0.93
2010	1.00	0.93	0.58	0.88	0.93	0.68	0.98	0.95	0.93
2011	1.00	0.95	0.58	0.85	0.93	0.76	0.96	0.95	0.94
2012	1.00	0.95	0.58	0.85	0.93	0.76	0.96	0.95	0.94
2013	1.00	0.97	0.34	0.83	0.95	0.84	0.95	0.96	0.95
2014	1.00	0.97	0.34	0.83	0.95	0.84	0.95	0.96	0.95
2015	0.97	0.97	0.10	1.00	1.00	0.77	0.97	0.97	0.96
2016	1.00	1.00	1.00	0.86	0.94	1.00	1.05	1.00	1.00
2017	0.98	0.98	0.60	0.86	0.95	0.73	0.97	0.98	0.96
2018	0.98	0.98	0.60	0.86	0.95	0.73	0.97	0.98	0.96
2019	0.98	0.98	0.60	0.86	0.95	0.73	0.97	0.98	0.96
2020	0.98	0.98	0.60	0.86	0.95	0.73	0.97	0.98	0.96
2021	0.98	0.98	0.60	0.86	0.95	0.73	0.97	0.98	0.96
2022	0.98	0.98	0.60	0.86	0.95	0.73	0.97	0.98	0.96

Source:

- data 1990–2007 from the ABS Agricultural Commodities report (2021). Data since 2008 from the ABS Land Management and Farming in Australia report (ABS 2017).
- The fraction of lime as dolomite (FracLime dolomite) = 1-FracLime limestone

A5.5.12 Rice Cultivation

Table A5.5.12.1 Area under rice cultivation, by State (ha)

	New South Wales	Northern Territory	Queensland	Victoria	Western Australia	Australia
1990	114,953	235	4,540	0	0	119,728
1991	92,344	180	4,051	0	0	96,575
1992	128,208	103	1,205	0	0	129,516
1993	127,959	90	0	0	0	128,049
1994	137,921	171	0	0	0	138,092
1995	134,553	48	0	0	0	134,601
1996	155,880	255	0	0	0	156,135
1997	172,520	150	0	783	0	173,453
1998	147,000	5	0	640	0	147,645
1999	148,000	0	0	685	0	148,685
2000	131,000	0	0	0	0	131,000
2001	175,000	0	0	1,840	5	176,845
2002	143,000	0	0	1,564	0	144,564
2003	45,000	0	0	879	0	45,879
2004	66,000	0	0	708	0	66,708
2005	51,200	0	0	516	0	51,716
2006	101,000	0	0	1,063	0	102,063
2007	19,700	0	0	185	0	19,885
2008	2,072	0	0	0	0	2,072
2009	7,194	0	0	0	0	7,194
2010	18,882	0	26	23	0	18,931
2011	74,954	0	369	240	221	75,784
2012	101,933	0	292	806	84	103,115
2013	113,041	0	137	460	0	113,638
2014	74,642	76	1,309	665	0	76,692
2015	69,306	79	6	247	26	69,664
2016	25,872	69	1,650	189	3	27,783
2017	85,834	71	118	0	0	86,023
2018	62,852	70	1,023	0	3	63,948
2019	7,062	108	764	0	0	7,934
2020	4,445	123	637	0	0	5,205
2021	45,952	118	699	374	0	47,143
2022	64,466	200	623	134	0	65,423

Source: Australian Bureau of Statistics and Rice Growers Associations.
There is no record of rice cultivation in South Australia, Tasmania, or the Australian Capital Territory

A5.6 Supplementary information to Chapter 6, Land Use, Land Use Change and Forestry

A5.6.1 Land cover change

The estimation of net emissions for the land sector is supported by the use of remote sensing imagery to determine a time series consistent assessment of land use change in Australia.

The Department has assembled a series of national coverages of Landsat satellite data (MSS, TM, ETM+ and OLI sensors) across time epochs commencing in 1972 which are analysed to identify where and when land use change occurs.

The archive of time series of historic land cover and land cover change information managed by the Department extends as far as possible given the importance of time series consistent data from 1990 to the present. The effects on emissions from land cover change are typically long lasting and estimates of emissions from current activities will be affected by the site history. A current conversion event, for example, will likely generate fewer emissions if the forest cleared is secondary forest (regrowth after a previous deforestation) rather than a primary (mature) forest. Consequently, an extensive record of land management history is a critical input into the preparation of accurate emission estimates.

Monitoring change with remote sensing imagery

Satellite Data Processing

A detailed protocol of remote sensing specifications for land cover change was developed by Furby (2002) through extensive pilot testing (Furby and Woodgate 2002) to ensure time series consistency of methods, and the provision of spatially accurate land cover change data through time. These specifications determine the exact way that images are acquired, processed and classified.

The sequence of data processing stages have been streamlined since the development of the Australian Geoscience Data Cube in 2014 (now referred as Digital Earth Australia). Migration of legacy data processing methods to the Data Cube environment has been completed including use of machine learning algorithms for change detection. The process to produce the assessment of Australia-wide land cover change consists of:

- image compositing of highest quality cloud free pixels acquired during the summer season for the southern tiles and the winter season for the northern tiles, from the Data Cube;
- mosaicing[3] of multiple images to the individual map tiles for each time sequence;
- perform a single-epoch 3–class classification using the Random Forests classifier;
- conditional probability network (CPN) analysis (Kiiveri, Caccetta and Evans 2001), each year over the entire time series; and
- attribution[4] of change to direct human-induced change.

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[3] Mosaicing aggregates images into the map tiles shown in red in Figure A5.6.1.1, removing overlaps in the original 185 km*185 km images and optimising cloud removal.

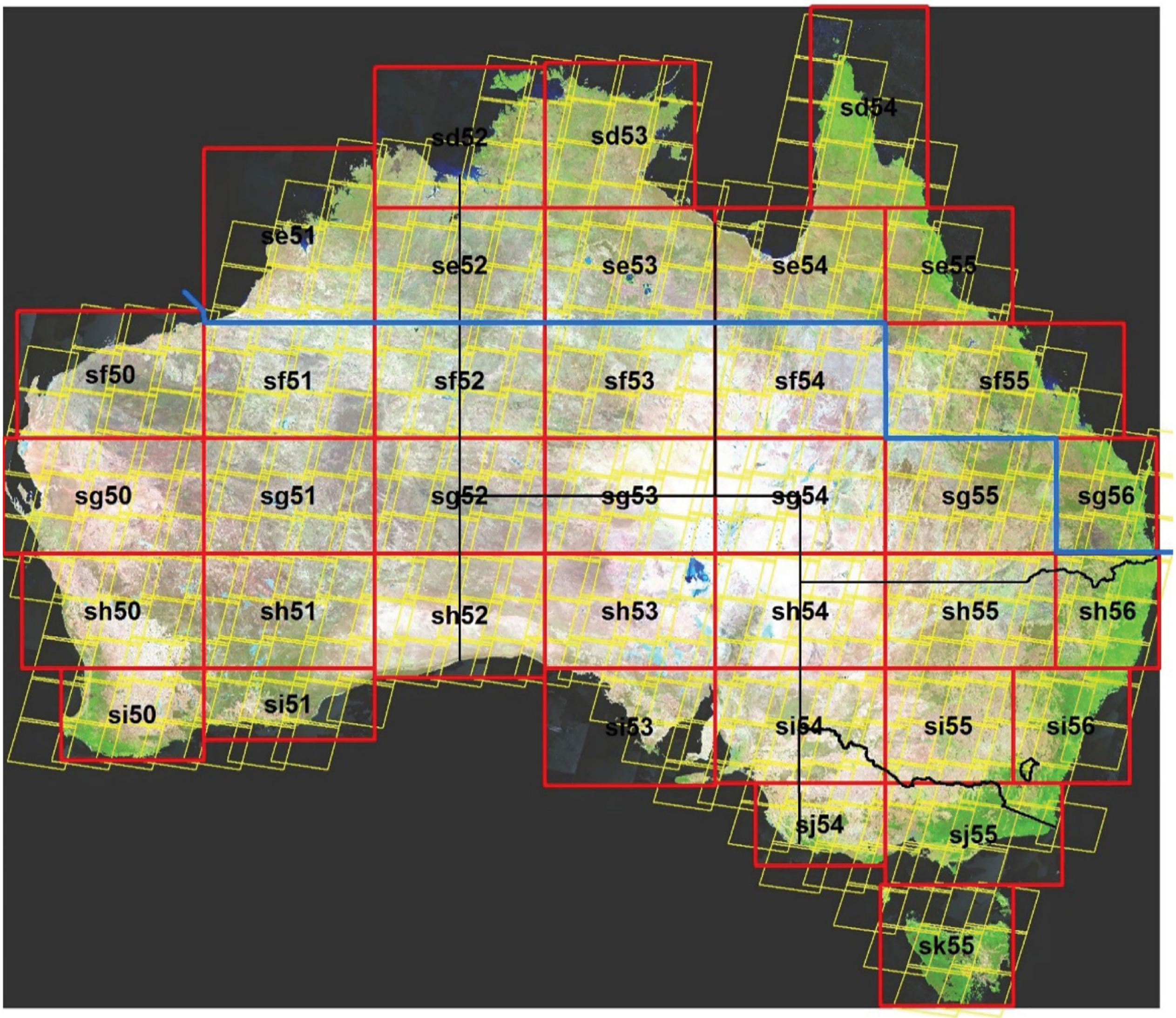
[4] Attribution uses a combination of automation and visual inspection of the image sequence to determine the cause of land cover change and determine subsequent land use.

Image acquisition and selection

The time series of available Landsat images extends from 1972. The selection of periods for analysis, shown in Table A5.6.1.1, was designed to give maximum temporal resolution immediately before and after 1990 and for the period from 2004 onwards to maximise accurate detection of trends in land cover change over time.

Since 2004 imagery has been delivered on an annual basis. Figure A5.6.1.1 shows the 37 map tiles used in the remote sensing programme (red), the north-south seasonal divide used for image capture (blue line) and the paths/rows of Landsat imagery (yellow).

Figure A5.6.1.1 The 37 1:1 million scale map tiles used in the remote sensing programme



Selection of suitable Landsat scenes from the Data Cube is fully automated. For a given location, the season from which the scene should be selected is identified and the best (cloud-free) image is automatically allocated from the stack within the Data Cube. The image selection criteria (S. Furby 2002) require the images to be within three months of the nominated target date. The target dates vary between the north (winter or dry season) and south (summer) of the country and aim to provide the best possible forest discrimination. The precise date allocated to each land cover change (clearing and regrowth) pixel is randomly generated by FullCAM, within the sequence of coverage dates for the relevant map tile. This method provides a random (unbiased over a large sample) distribution of initialisation dates (timing of land cover change event) for the carbon model, within the constraint of the two dates in the overall interval of the image sequence.

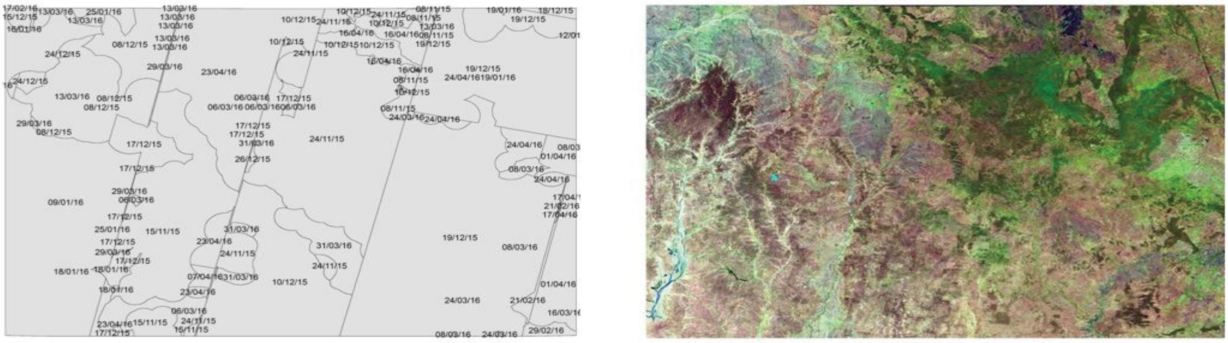
Table A5.6.1.1 Landsat Image sequence

Year	Resolution (m)	Time since previous image (yrs)
1972	50	-
1977	50	5
1980	50	3
1985	50	5
1988 (early)	25/50	3
1989 (end)	25/50	2
1991 (early)	25	1
1992	25	1
1995, 1998	25	3
2000, 2002, 2004	25	2
2005–2022	25	1

Mosaicing

Scene selection and compositing is automated so multiple images can be combined within each path/row to create a cloud free composite (S. Furby 2016). Figure A5.6.1.2 shows how a mosaic is constructed using multiple images within each path and row, resulting in a composite cloud free image. However, in inherently cloudy locations, some gap filling from earlier imagery may be required.

Figure A5.6.1.2 Image selection procedure, to create composite cloud free imagery mosaics



Unit of analysis – spatial resolution of the imagery

The ‘natural’ pixel size of the 1972 to 1985 Landsat MSS (57 m x 79 m) is resampled to a 50 x 50 m pixel.

The 30 x 30 m native resolution of the Landsat TM, ETM+ and OLI data available after 1985 is produced as 25 x25 m pixels. This approach deals with the change in pixel size of the various Landsat sensors over time and supports the need for spatially and temporally consistent integration with other spatial data used in FullCAM.

To apply the pixel-by-pixel analysis over the period where the pixel size changed from 50 m to 25 m, a 50 m MSS equivalent (in both spatial and spectral resolution) is derived from the 1989 TM (25 m) data, and then forest extent is calculated separately from both the 50 and 25 m data sets. Differences in the extents of forest between these two outputs are due to “sensor change”. An overlap technique is used to ensure time-series consistency such that the assessment of land cover change for 1988–89 is then based on a 50 m to 50 m comparison, while the 1989 – 1991 data is a 25 m to 25 m comparison. As part of continuous improvement, processing of 1988 Landsat TM data at 25 m spatial resolution has been completed, replacing the 50 m resolution MSS data for 1988. Consequently, the entire land cover time series data has been recalculated making use of best available data while maintaining time series consistency. This approach is consistent with good practice for ensuring time-series consistency where the instruments used to collect activity data change or degrade through time (IPCC 2003, page 5.58).

All Landsat derived data are used at a consistent 25 m resolution for the full time series analysis by resampling the 50 m pixels (1972–1985 products) into four 25 m pixels. A spatial-temporal model (see the Conditional Probability Network section below) is used to reduce the effect of “mixed” isolated and edge pixels in the overlap period. The ability to determine, from 1988 onwards, the effects of land use change to 0.2 ha minimum areas is robust, given that this area is greater than the pixel resolution and the approach used removes mixed and other pixels which are temporally and spatially inconsistent.

Resampling Landsat TM, ETM+ and OLI sensor data to 25 m pixels is common practice and provides consistency over the multiple resolutions of Landsat sensors while ensuring uniformity across the time series. Quality assurance and validation processes confirm that accurate results are achieved with this resampled data.

Use of Landsat 8 Data

Observations of recent land cover change have been derived from the latest sensor on-board the Landsat 8 satellite, Operational Land Imager (OLI). OLI is an advanced sensor designed to collect improved quality data, ensuring continuity of previous instruments – Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors. Landsat 8 products supplied through the Australian Geoscience Data Cube are in a new format known as the Australian Reflectance Grid (ARG25). ARG25 is a pre-processed product corrected for geometric distortions and calibrated as absolute surface reflectance, hence the specifications of this new product are quite different to the previous Landsat 5 and 7 data products used for the national inventory Land Cover Change Programme (LCCP). To ensure time series consistency and compatibility with the existing LCCP, a detailed technical assessment of the geometric and radiometric consistency and interoperability between these two products was undertaken.

Geometric consistency was assessed by matching about 13,300 ground control points (GCP) drawn from the LCCP scenes held in the national inventory data library and the corresponding ARG25 scenes. Assuming that the correlation matching succeeds in correctly registering each point, the position residuals provide a measure of the accuracy of co-registration of the two datasets. This analysis showed that whilst the temporal geometric accuracy of ARG25 products is highly consistent, several GCPs had residual matching errors ranging from 1, 2 and greater than 2 pixels compared to the LCCP products. The mis-registration, if not accounted for, would result in false change being reported. To resolve this, the mean residual vector for each ground control point (GCP) was calculated and applied to the LCCP scenes to align with the ARG25 product base.

The scene specific transformation coefficients ensure that the two products are aligned and consistent to within a pixel for the entire country.

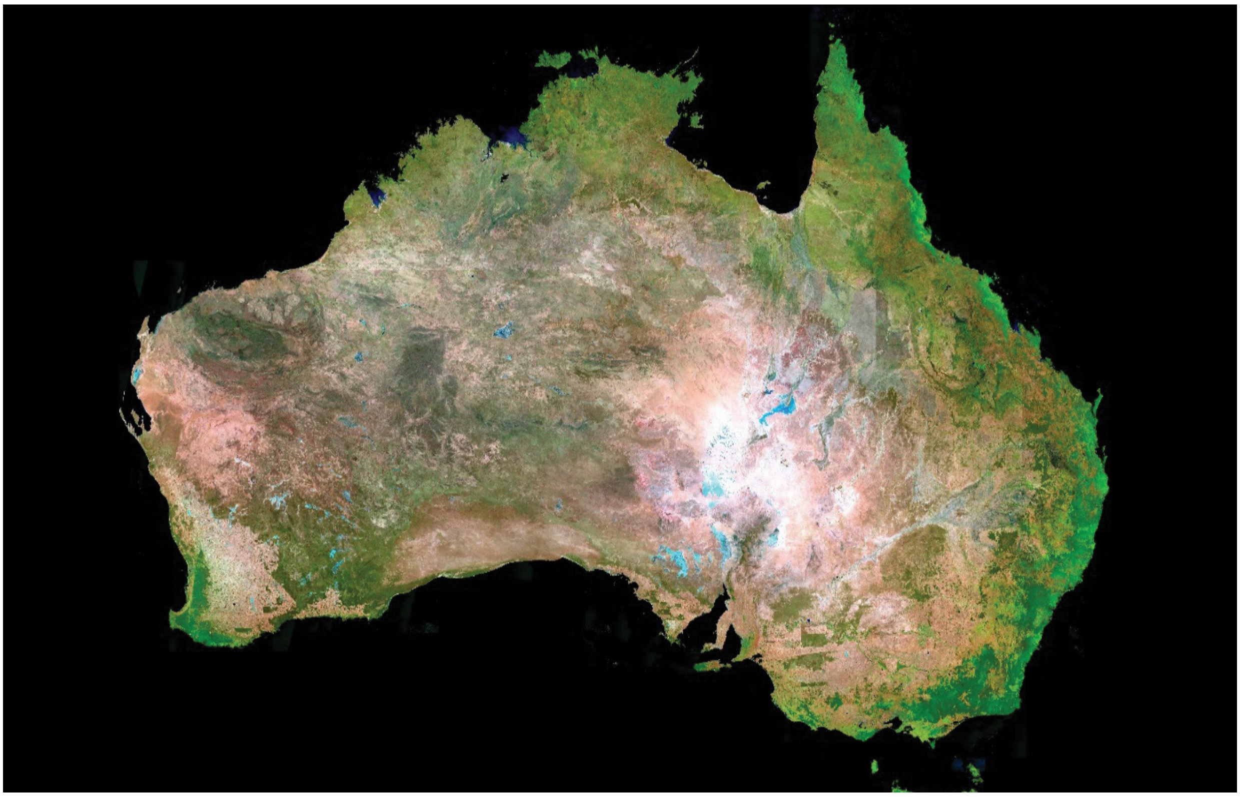
The second step was to assess the radiometric consistency between the ARG25 and LCCP products using 339 image pairs from the 2005 continental coverage. The two products were paired up based on Landsat path and row, and image acquisition date. Null pixels in either image were discarded. Pixels located in very dark or very bright regions in the LCCP images were also excluded from the analysis, since such values may have potentially saturated during the pre-processing. The remaining pixels were linearly regressed against each other, assuming that the relationship will be strongly linear if both products are internally consistent in relation to radiometric characteristics. Correlation values were calculated for each band, gain, and offset combination. The gain and offset values for converting LCCP pixel values into ARG25 pixel values can be expressed as -

ARG25 = gain x LCCP pixel value + offset

The relatively high correlations found in the 2005 coverage confirm that there is a strong linear relationship, across all bands, between the LCCP values and the equivalent ARG25 image values. A scene-specific, linear transformation coefficient for each band was calculated to convert the LCCP calibrated pixel values to be consistent with the ARG25 surface reflectance values (Devereux, Furby and Caccetta 2013). The time series consistency of this method was also assessed for selected sites using eight years of surface reflectance data.

Based on this study, from 2015 the ARG25 Landsat 8 datasets (Figure A5.6.1.3) have been processed to a consistent quality, LCCP compatible tile-based mosaic which are then subjected to image classification to derive forest probability maps.

Figure A5.6.1.3 Landsat 8 surface reflectance image of Australia

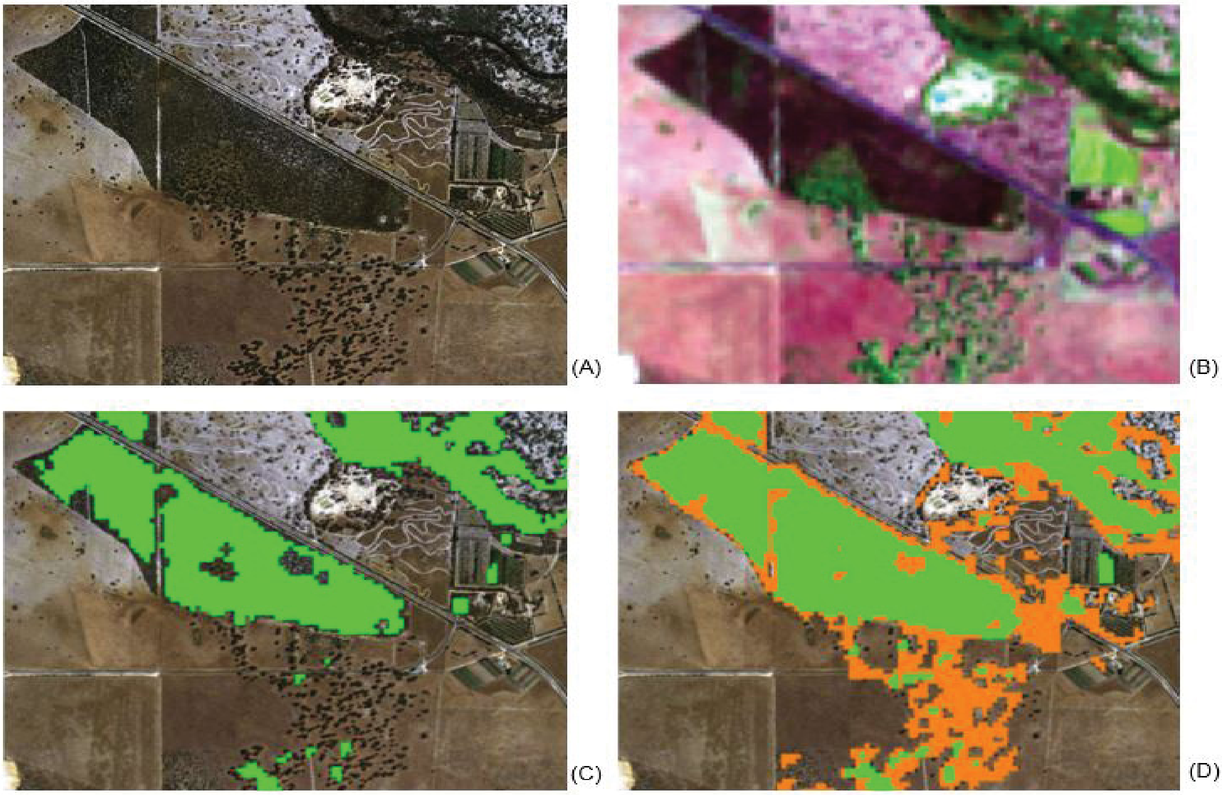


3–class Random Forests classifier

A new method of classifying woody vegetation has been adopted in the National Inventory update since 2019. The method has changed from a thresholding approach using simple decision boundaries, to a Random Forests (RF) classifier (Breiman 2001). The RF classifier uses a sophisticated decision-tree approach, building a large number of trees from samples of training or reference data to create a class prediction. For a given pixel, the average prediction across all the trees is taken. It also allows class membership probabilities to be undertaken concurrently, requires minimal manual intervention and is readily extended to any number of classes of interest.

This method incorporates previous National Inventory innovations such as the move from a 2–class (forest, non-forest) classification to a 3–class classification (forest, sparse, non-woody). Figure A5.6.1.4 compares the previous 2–class product with the current 3–class outputs. Background image is from UrbanMonitorTM 2014 (Figure A5.6.1.4 (A)), and a Landsat false colour composite 2014 (B). Forest is highlighted green and Figure A5.6.1.4 (D) shows sparse vegetation (in orange) that was detected using the 3–class algorithm. As the entire range of woody vegetation needs to be monitored for reporting under the Kyoto Protocol second commitment period and the Paris Agreement, it is essential to create a product that better encompasses all woody vegetation (Figure A5.6.1.5).

Figure A5.6.1.4 Comparison of traditional 2–class forest and non-forest product with the 3–class product



The Random Forests classification was performed on Landsat 8 imagery for the current epoch in a semi-automated manner, to investigate the parameter settings required to optimize the performance of the algorithm. The classifier was fitted independently to each of the stratification zones used in the previous method, which encompass local soil, vegetation and land use types. The relative importance of the individual input variables (i.e. spectral bands 1–6, spectral indices 7–8, texture bands 9–10, texture index 11) are tracked per stratification zone, and results can be used to modify the variables used in future updates.

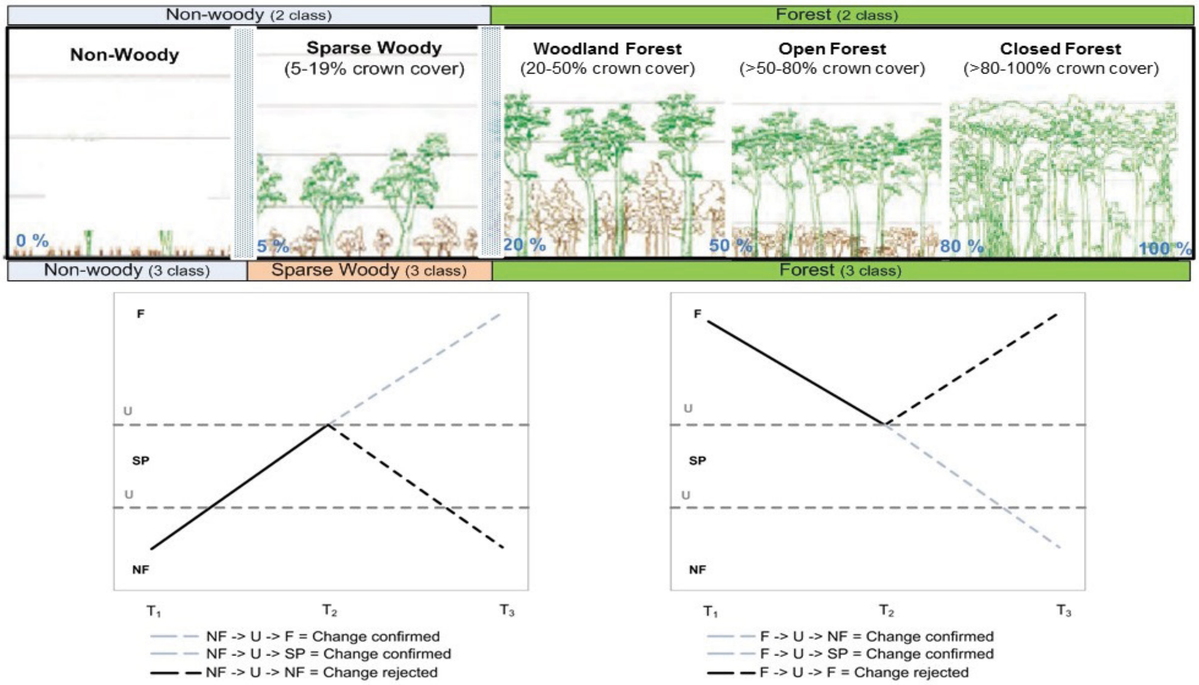
The Conditional Probability Network (CPN) outputs for 2018 were used as the training sample or “base” to train the RF classifier for the new update. Twenty percent of this data is extracted randomly and reserved to calculate an independent accuracy assessment. Early testing indicated that woody extent and change classifications were very sensitive to the choice of training samples, and the RF classifier produced much higher probabilities of class membership than the previous thresholding approach. This is most noticeable in the sparse class, which has historically experienced the greatest uncertainty. As a result, training samples were restricted to more pure examples of each class to enable the classifier to determine the boundary between them.

Early results also showed that the RF classifier could classify an area cleared in the latest epoch as having experienced a reduction in the probability of forest, but not necessarily reduce the probability enough to enable the CPN to correctly identify the change, given multiple years of high forest cover probabilities before the change event. To correct this problem for this update, a change mask was created by comparing the spectral index values between 2019 and 2020. Any pixels that fell under the change mask were excluded from the training sample.

Ultimately a combination of reduced error rates for sparse in 2019 and 2020, the use of a change masks and temporal rules restricting forest to sparse conversion leading up to 2020 were employed, resulting in products more consistent with earlier versions.

In future, the single-epoch classification will be refined to enable a multi-temporal classification to be performed across all epochs, to ensure consistency across the time series. Once all refinements have been made and automation is fully implemented, this should assist in moving towards the planned use of Sentinel 1 and 2 imagery.

Figure A5.6.1.5 3–class algorithm to detect entire range of woody vegetation



Source: Adapted from Australia’s State of the Forests Report (ABARES 2013)

Conditional Probability Network analysis

Remote sensing pilot testing demonstrated the need for time-series consistency in image data pre-processing, analysis and subsequent formation of time-series woody/sparse/non-woody labels. The operational standards (S. Furby 2002) give explicit emphasis through documented rule sets to each of these areas. For time-series classification, these standards also include the use of a joint spatial-temporal model, in this case a Conditional Probability Network (CPN) (P. A. Caccetta 1997) (Kiiveri, Caccetta and Evans 2001) (H. Kiiveri, P. Caccetta, et al. 2003), for determining a time-series of woody/ sparse/non-woody classes. This process produces superior woody extent and change results compared to a process reliant on pair-wise differencing of image pairs. The use of pair-wise differencing methods can lead to change estimates that are affected by errors due to seasonally changing land management effects (introducing large contiguous areas of false change), or by subtle sampling differences where mixed pixels have varying composition of woody/non-woody from year to year (producing many isolated false change pixels or edge effects at woody boundaries).

The land cover change programme uses Conditional Probability Network (CPN) analysis to strengthen confidence in the ‘woody’, ‘sparse woody’ and ‘non-woody’ classification of a pixel (previously ‘forest’ or ‘non-forest’). This is achieved using a series of spatial and temporal rules to create woody vegetation and land cover conversion datasets. The temporal rules bias against unlikely events such as multiple one-year conversions between woody and non-woody, as the CPN empirically assesses the logic of vegetation cover status of a pixel at a point in time, compared to the previous and subsequent images. This helps to eliminate false change from a single image that may be due to anomalies in the data such as unseasonal greenness, wetness or flooding, or missing data. The rules are particularly effective when the time between observations is less than that of a forest growth and harvest cycle.

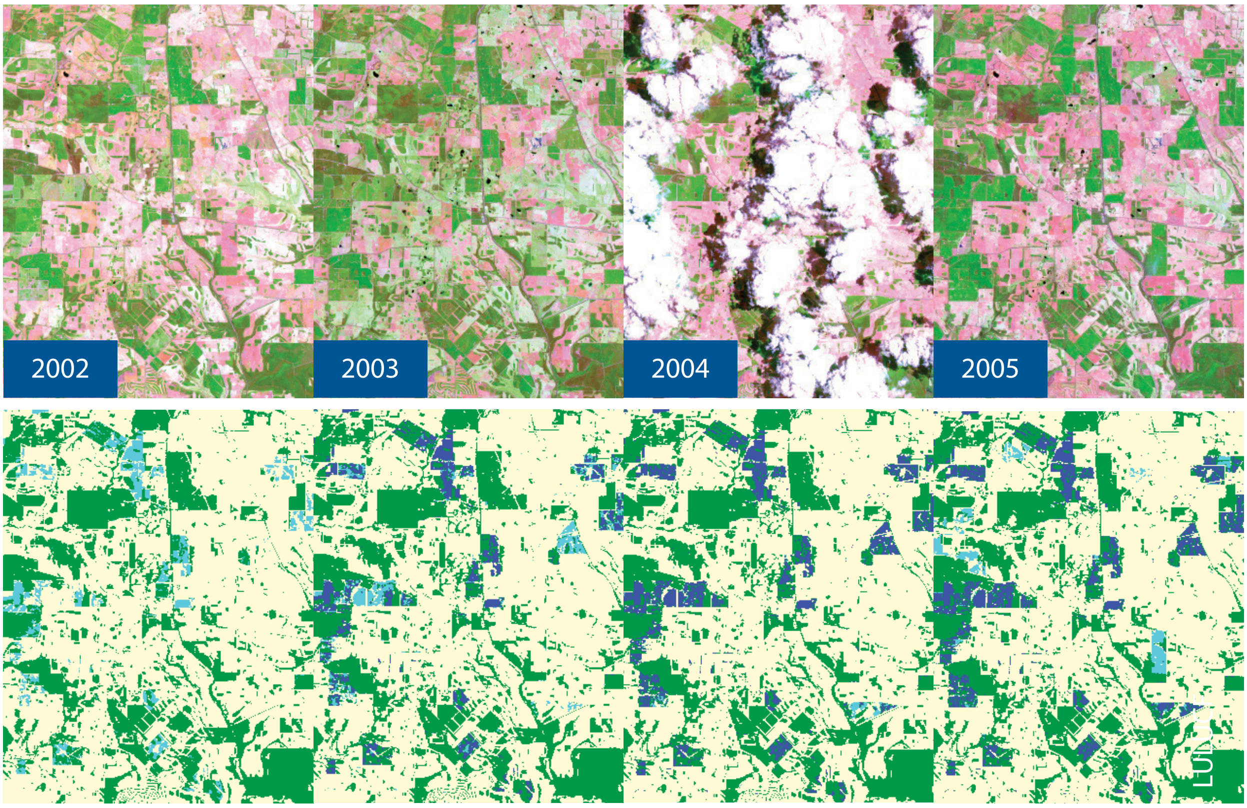
The spatial rules consider the labelling of a pixel in the context of its spatial surroundings, where labels that are consistent with the neighbouring labels are reinforced as opposed to those that are inconsistent (e.g., isolated pixels). This method evaluates the status of adjoining pixels as well as the pixel of interest, which has the effect of reducing ‘flickering’ false change in scattered and edge woody pixels. It also ensures that individual and small clusters of forest pixels have a high classification certainty in relation to their neighbouring pixels and through time, minimising false detection of individual woody pixels and minimising false change in woody classification that would otherwise occur as a result of small changes in the crown cover of isolated pixels. The spatial and temporal rules work together to provide spatial and temporal consistency, minimising temporally varying “mixed pixel” effects (due to spatially varying sampling from independent satellite overpass from year to year) and subsequent error in pixel and change labelling.

This comparative analysis of the same land unit over time was made possible by the accurate and consistent geographic registration and spectral calibration of the image sequences, providing the ability to ‘drill’ through time on a pixel-by-pixel basis. Geographic registration ensures that the same pixel is being looked at through the time sequence. It also avoids incorrect change status determination due to substitution of neighbouring pixels that could have different forest cover status, relative to the correct pixel for that location. Spectral inconsistency can also potentially increase the area attributed to clearing and regrowth events by variable status determination due to image calibration difference. This is addressed by consistent (spectral) calibration, thereby preventing the identification of false clearing or regrowth events and results in a more accurate land cover change map. Consistent registration and calibration are both required to ensure robust multi-temporal change analyses.

The CPN allows areas of missing data, such as those due to cloud cover in the Landsat imagery, to be filled in based on the cover status of the earlier and later images (see Figure A5.6.1.6). With the advent of optimal cloud free image selection from the Data Cube, the amount of missing data is reduced. However, gap filling is still necessary in places due to imperfect automated cloud masks and the lack of available data for locations that are inherently cloudy.

There is also potential for sub-pixel shifts to change the forest/non-forest status on the edges of forest systems where a small edge portion of the pixel may have previously been just over the forest area, but a small shift in geographical registration (e.g., 10 m) would be enough to move the pixel out of the forest area. The spatial rules take the status of adjoining pixels into account and so reduce false change in isolated and edge woody pixels.

Figure A5.6.1.6 Images of forest extent and change, showing how the CPN gap-fills missing data due to cloudy imagery



Green: forest 2000
Blue: new forest 2000-02

Green: forest 2000
Dark Blue: new 2000-02
Light Blue: new 2002-04

Green: forest 2000
Dark Blue: 2000-04
Light Blue: 2004-05

Green: forest 2000
Dark Blue: 2000-05
Light Blue: 2005-06

Forest extent and change analysis

Once the change in forest cover status has been determined for each pixel for a point in time, the spatial relationship of each change pixel to other surrounding or nearby change pixels is assessed to identify isolated pixels with forest cover that do not form part of a forest system. This allows for the identification of pixels that are isolated trees not meeting the minimum canopy criterion defining a forest, as opposed to those pixels that may be part of sparse linear features such as roadsides and riparian zones which do meet the canopy criterion. A minimum mapping unit filter is applied to remove the isolated pixels from the data to be used for attribution.

The area of land cover change is determined as the sum of the changed pixels through time. This approach minimises inclusion of pixels that represent gaps in the forest canopy. An independent study which looked at the implication of the inclusion or exclusion of forest canopy gaps in this way found that the resultant area estimate could vary significantly between approaches (ERIC 2001). The approach used only includes the area of forest canopy loss and not 'gaps' in the forest canopy. This provides a much lower estimate of area cleared than specified in clearing permits, which usually define the area bounded by the clearing, including gaps in forest canopy cover.

Subsequent carbon stock and emissions estimates are computed consistently with the spatial area calculation method. That is, the carbon stock values should reflect the area under canopy and are not an average that includes 'gaps' between areas of tree canopy.

Using the 3–class product allows us to identify six types of land cover changes in the landscape, namely:

- non-woody to sparse
- non-woody to forest
- sparse to forest
- sparse to non-woody
- forest to non-woody, and
- forest to sparse

Land cover changes related to forest cover gain and loss are reported as *land converted to forest* and conversions of forest land to other land classifications, whereas changes in sparse woody cover are reported in the *grassland remaining grassland, wetlands remaining wetlands* and *settlements remaining settlements* categories consistent with the IPCC 2006 Guidelines (IPCC 2006).

Attribution of change

A spatial analysis across the continent identifies land cover change resulting from many causes. For unique identification of conversion to another land use, it is necessary to attribute the identified change event as either direct human-induced and permanent or due to natural, temporary effects or methodological artefacts. Land cover change due to temporary tree dieback, natural dynamics of tree mortality and recruitment, drought and both seasonal and inter-annual variability (causing green 'flushes' of growth with similar spectral signals to regrowth) are also identified and excluded by means of an automated, rule-based monitoring system. This monitors the temporary loss of forest cover for x number of years to determine if a permanent change in land use or deforestation has occurred. Qualified technical staff use visual image backdrops such as Landsat, Google Earth™, and Sentinel Hub™ to differentiate permanent land use change events from those of temporary forest cover loss events such as harvesting or forest fire.

This attribution is achieved by the development of a series of 'masks' to exclude change due to:

- intermittent water features and irrigation areas that may give a false change signal;
- drought and growth flushes; and,
- terrain illumination.

In each national inventory cycle, the method of attribution is continually updated and improved to increase efficiency and reduce the subjectivity of visual attribution of change.

Plantation typing

To allow for more accurate modelling of emissions and removals from newly established forests (under *Grassland converted to Forest Land),* new plantings (reforestation) identified in the remote sensing imagery are mapped into three classes; native forest (environmental plantings), hardwood plantation and softwood plantation. Plantation forests are those that are identified as being due to deliberate human action and are identified by type (e.g., introduction of non-endemic species), evidence of establishment practices (e.g., rip lines) and planting patterns (e.g., rows and stand geometry). The identification of conversion from non-forest to forest follows the same general approach and same remote sensing data as described above. Plantation classes are identified by discrimination against regionally specific ground data. The method uses an automated spectral discrimination and is described in Caccetta and Chia (2004). Currently, only Landsat TM, ETM+ and OLI data is used for plantation classification. The 3–class method has also been applied to plantation typing.

Quality Assurance and Quality Control

Programme implementation

During the initial implementation of the remote sensing programme, pilot tests were used to train and develop industry capacity, refine methods and software and to develop logistical systems to maximise both output and opportunity for quality assurance and quality control (QA/QC). The results of the pilot studies are published in Furby and Woodgate (2002).

The approach to programme administration provides for centralised progress monitoring and QA/QC at each stage in the processing of the Landsat data. Each processing stage is a regionally defined package of work based on 37 1:1,000,000 (1:1 M) map tiles of Australia (Figure A5.6.1.1).

The QA/QC and data validation procedures for each of these items in Australia's land cover change methods are summarised below – see also Furby (2002) (2016). Some of the resource intensive processes undertaken in previous years are no longer valid as multiple steps have been integrated and automated. As a result, QA/QC procedures have also been streamlined, resulting in significant savings and efficiency.

Mosaicing

All mosaiced images (quadrants and time slices) for a particular map sheet are assessed at the same time. Due to the automated processing of imagery in the Data Cube, QA/QC of the mosaiced imagery has been streamlined to a single step since NIR 2016. Each data set is checked to ensure completeness and consistency of the composite images (S. Furby 2016).

3–class Random Forests classifier

The Random Forests classifier is a relatively new process introduced in 2019. The classifier was run in a semiautomated manner as there are a number of variables that can be tuned to optimize the performance of the classification algorithm. In future, the aim is to fully automate the implementation of the classifier.

Semi-automation allowed QA/QC to be undertaken to investigate a number of elements:

- methods of training sample selection, i.e. using default automated settings versus using modified training samples to remove all omission and commission errors
- use of a more 'typical' base year from which to create training samples, for individual stratification zones
- the use of change masks to exclude areas with a change in spectral index values between 2019 and 2020 from the training sample
- setting of suitable probability thresholds of change within indices, per map sheet and stratification zone
- tracking of the relative importance of individual input variables to probabilities for individual map sheets and stratification zones; and
- monitoring of prediction accuracies per stratification zone.

Undertaking all these investigations led to a greater understanding of how the RF classifier performed, and the impact of certain parameters on the probability predictions. As the choice of training sample data was found to greatly influence the results, this remains a major focus of the QA process.

After extensive testing, it was determined that the threshold for inclusion in the training sample should be allowed to vary by class, dependent on the dominant vegetation cover of each map sheet.

CPN products for the current epoch were then compared to the cover class probabilities of previous epochs, to identify the impact from the change in classification methodology. This change has generally resulted in a shift in woody extent and change statistics which has implications for the emission calculations derived from this data.

To compensate for the different nature of the 2019 and 2020 RF probabilities, experiments were performed to adjust the CPN parameters to compensate for the observed shifts and produce a result more consistent with previous updates.

When the probability images have passed assessment and are mosaiced, the resultant images and key intermediate products are assessed for mosaicing accuracy, completeness and standardised formatting.

A final assessment report is completed, detailing the results and whether any further data review is required.

CPN products

When the CPN datasets are supplied to the Department's Geospatial team, they undergo a supplementary QA review process. The purpose of this review is to provide an independent check to ensure supplied products are fit for the purpose.

The review assesses the following components of the CPN products:

- An initial contents check is conducted to ensure the correct number of CPN dataset components have been supplied per tile.
- Check that designated change transitions between neighbouring epoch woody definitions are logical and correct across the time series on a pixel-by-pixel basis.
- Ensure that for each tile the CPN dataset's individual components for the time series contain pixel values that are within the acceptable range for that component.
- Check that for each tile the CPN dataset's individual components for the time series have correct spatial extents, geographic projection, pixel resolution and no null pixel entries.
- Produce a summary of percentage difference between the previous NIRs CPN run with the updated CPN run, to determine any variations which would be considered extreme requiring further investigation
- A sample visual review is undertaken of the distribution of pixel values within the CPN dataset's individual components to ensure they are consistent with the previous NIR and with satellite imagery (e.g., forest classification is consistent with forest shown in associated Landsat imagery for the same year).
- For plant type designations, check they occur over the expected spatial extent when related to the associated forest cover datasets for 1990.

If any issues are found from the above assessment the dataset is returned to the remote sensing specialists for investigation. Only when all aspects of the review are satisfactorily resolved, the CPN datasets are proceeded for spatial attribution prior to submitting to the FullCAM for emissions modelling.

Continuous Improvement and Verification Programme

Periodic review of the CPN products, to ensure human-induced vegetation change is not being omitted, is conducted separately to the NIR. This review is undertaken within a continuous improvement and verification programme (CIVP).

The CPN products identify woody vegetation cover and change and undergo expert geospatial review using high resolution imagery and external datasets to isolate areas of human-induced change. This attribution of human-induced change is a vital part of each NIR. The ongoing verification programme provides an assessment of the CPN products prior to attribution, while attribution by expert operators ensures that errors of omission and commission related to human-induced clearing and regrowth are minimised in the inventory.

Figure A5.6.1.7 shows the history of the CIVP and the relevant details for each iteration. CIVP-3 was established as an extension of CIVP-2 in response to an ERT recommendation, to determine the commission and omission errors associated with using the CPN algorithm to assess land cover change.

Figure A5.6.1.7 The series of continuous improvement and verification programmes

Program:	**CIVP-1**	**CIVP-2**	**CIVP-3**	**CIVP-4**
Year:	2004	2012	2014	2017
Coverage:	**37 tiles**	**19 tiles**	**19 tiles**	**11 tiles**
Number of points:	12,564	7,680	1,214	4,520
Time series:	1972–2000	2002–2010	2001–2012	2011–2014
Products assessed:	Forest & non-forest	Forest & non-forest	Change product only	Forest, sparse & non-woody, change products
Resources used for verification:	Aerial photos, satellite imagery	High resolution satellite imagery	High resolution satellite imagery	Very high resolution satellite imagery

For CIVP-4 the new CPN 3–class woody vegetation product (forest, sparse and non-woody) was assessed across 11 tiles that contribute the most emissions to the national inventory, to determine the accuracy of the product and to identify areas for improvement. The method established during CIVP-2 was followed in CIVP-4, where 400 points were created across each tile using a stratified random sample. The vegetation classification at each point was cross-tabulated against the visual assessment of vegetation type undertaken by experienced operators using very high-resolution satellite imagery (see Table A5.6.1.2).

At points where the CPN identified change in vegetation cover between 2011–2014, an assessment of the likelihood of change during that period was also undertaken. As the CPN algorithm uses data from earlier and later years to determine vegetation change for each pixel, the time period for assessment of change in CIVP-4 was selected to ensure the change classification had stabilized using data from later years. In the latest assessment, the CPN land cover change product was verified using very high-resolution satellite imagery acquired between 2009 and 2014. Imagery earlier than 2011 was consulted in case there was a lag between change being detected by the CPN in 2011 and change occurring prior to that year.

Of the 4520 points assessed across 11 tiles, 88 per cent had experienced no change (NC) across the time period. Based on the CPN classification, these points were identified as forest throughout (FT), sparse throughout (SPT), or non-woody throughout (NWT). The operator determined if these classifications were definitely correct, or probably correct, if imagery was not clear or not available at the right time. Probably non-woody throughout was not assessed as this category was considered to be difficult to distinguish from probably sparse. Table A5.6.1.2 shows the CPN product identified forest and non-woody areas consistently better than the identification of sparse vegetation. Commission errors indicate where the classification is deemed incorrect, while omission errors are where points should have been given the classification but were not.

Table A5.6.1.2 CIVP-4 verification results for the 3–class woody vegetation product where no change was indicated

	CPN classification			
Verification	**Number of points**	**% correct**	**% Commission error**	**% Omission error**
Forest	1546	98	2	2
Sparse	685	66	24	13
Non-woody	1722	96	6	4

As sparse was a new class of woody vegetation and due to the difficulties detecting it remotely using medium resolution data, it was expected that the errors would be moderate. Despite these errors, the 3–class product has improved the prediction of woody and non-woody vegetation when compared to the previous forest and non-forest classes. Forest was predicted as correct for 96 per cent of the points in CIVP-2 compared to 98 per cent in CIVP-4, while non-forest was definitely correct 76 per cent of the time for CIVP-2 compared to 96 per cent for CIVP-4 (Lowell, et al. 2012). Point data records from the verification programme could be used as extra sites to train the CPN algorithm and further improve the woody vegetation product.

The results for the points that had experienced change during 2011–2014 are shown in Table A5.6.1.3, with the number of sample points for each classification cross-tabulated against the operators' assessment. Green cells indicate correct detection of change or no change (NC), red cells are erroneously detected change, lavender cells are undetected deforestation and blue cells are undetected regeneration. Of the points where the CPN had identified change (n = 550), 26 per cent were classified by the CPN as deforestation (DEF), 63 per cent were regeneration (REG) and 11 per cent indicated cyclic change (CYC). In this report DEF and REG refer to all cleared or regeneration pixels as indicated by imagery and associated processing. This is not to be confused with deforestation as used in the Kyoto Protocol that specifically refers to human-induced land conversion. A small number of points were uncertain (U) due to poor imagery available to confirm the classification. Pixels classified as CYC suggest errors in the classification given that rapid change, such as forest to non-woody and back to forest, is unlikely to occur over such a short time.

It is imperative that errors of omission related to human-induced change are minimised to give confidence that the inventory has captured all true clearing and regeneration within the given year.

Results of the operator assessment in Table A5.6.1.3 take into account transitions such as forest to sparse and vice versa. For the purpose of this exercise such transitions were included as the verification programme was undertaken to assess the implications of introducing a new sparse category into the vegetation classification and its impact on the change product. Therefore the 71 DEF points shown in the table are inclusive of these transitions which do not reflect vegetation clearing.

The 27 DEF points and 11 REG points that were incorrectly classified by the CPN in Table A5.6.1.3 were subject to further evaluation by additional operators. Initial investigation indicated that 73 per cent of these points had no evidence of clearing or regrowth, however they reflected the classification and operator uncertainty between the forest-sparse and sparse-non-woody decision boundaries

Combined errors of omission for DEF and REG were 0.4 per cent of the total 4520 points, while errors of commission were 7 per cent. These results are comparable to those of previous verification programmes (see Table A5.6.1.4), with 0.3 per cent omission errors over 7680 points and 3 per cent commission errors. The higher commission errors in CIVP-4 are related to the addition of the sparse category into the woody vegetation product, as almost all points incorrectly identified as change had been classified by the CPN as sparse at some time in the change period. Errors may also be partly explained by the smaller sample size in CIVP-4.

The commission error of 7 per cent within the CPN change products identified by CIVP-4 justifies the continuation of the attribution process by geospatial experts to ensure that non-human induced change (i.e. false positive change) does not enter the inventory accounts.

Once the Random Forests classifier has been extended back through the time series, further verification of the 3-class CPN products produced using this new methodology will be undertaken.

Controls

Omission errors are addressed by using external clearing and revegetation data obtained from state agencies (such as Queensland Statewide Landcover and Trees Study data) and other anecdotal evidence to identify and monitor any areas where change may have been missed. In addition, the CPN algorithm revises the last few years of data each time it is processed, based on the latest probability information. Therefore, pixels with uncertain probabilities are reassessed so omitted change is detected in the following iteration of the process and included in the subsequent NIR submission.

Table A5.6.1.3 Outcomes of operator assessment of CPN classification for CIVP-4

CIVP-4		Operator assessment					
		NC	DEF	REG	CYC	Uncertain	TOTAL
CPN classification	**NC**	3953	10	6	0	1	3970
	DEF	94	44	3	0	0	141
	REG	209	14	121	1	4	349
	CYC	42	3	2	12	1	60
	TOTAL	4298	71	132	13	6	4520

Table A5.6.1.4 Outcomes of operator assessments in previous verification programmes

		Operator assessment					
		NC	DEF	REG	CYC	Uncertain	TOTAL
CPN classification	**NC**	7213	11	12	na	na	7236
	DEF	136	124	0	na	na	260
	REG	87	0	97	na	na	184
	CYC	na	na	na	na	na	Na
	TOTAL	7436	135	109	na	na	7680

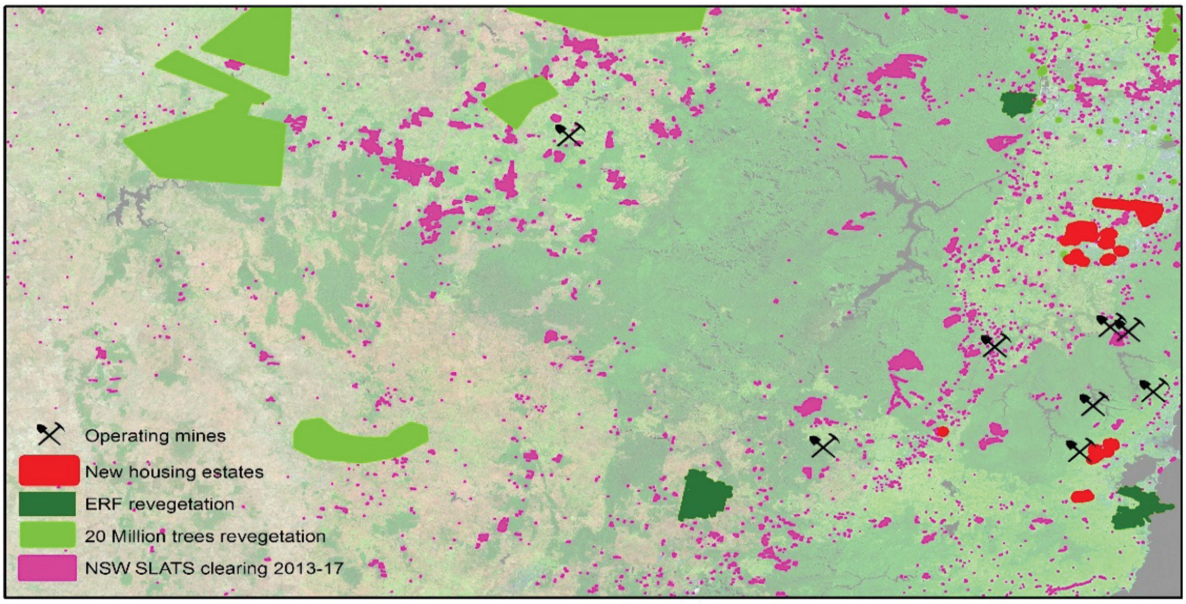
The results of the different verification programmes highlight the continued value of the attribution process, discussed below, which was essentially designed to remove false positive pixels and focus upon human-induced change only. Use of external datasets and rule-based machine learning techniques currently being explored would also reduce the uncertainty in the activity data.

Attribution

The final quality control requires attribution of changes identified in cover change maps by the CPN as either direct human-induced, temporary change or methodological artifacts such as false positive change. The latter effects are well understood and include green flushing in images due to climate, terrain illumination variability, irrigation, water bodies and fire scars. Departmental staff use high resolution imagery such as Landsat, Google Earth™ or Sentinel Hub™ for this discrimination. Results of this discrimination are then quality controlled. This attribution step provides a final quality control process designed to mitigate the risks of errors of commission and omission that were identified in the continuous improvement and verification programme discussed in the previous section.

An ongoing innovation to the attribution process is the development of an Attribution Reference Database (ARD) that captures published information and anecdotal evidence of clearing, land development or reforestation activities such as those funded by state and federal government programmes (see Figure A5.6.1.8). The database is continually being updated and the information is used for attribution and QA/QC of satellite derived activity data. The Department has co-operative arrangements with Queensland and NSW state government agencies to gain access to vegetation monitoring data used to support the current inventory cycle. It is intended that these types of arrangements will be developed with other states and become an integral part of the quality control plan for future national inventories. The use of this information provides further assurance that high quality estimates of areas of land cover change are used for the national inventory and confirms that the national inventory accounts are complete and unbiased.

Figure A5.6.1.8 Example of ancillary datasets in the Attribution Reference Database that are used to confirm human induced changes



Examples of the QA/QC undertaken using external datasets stored in the ARD are outlined below.

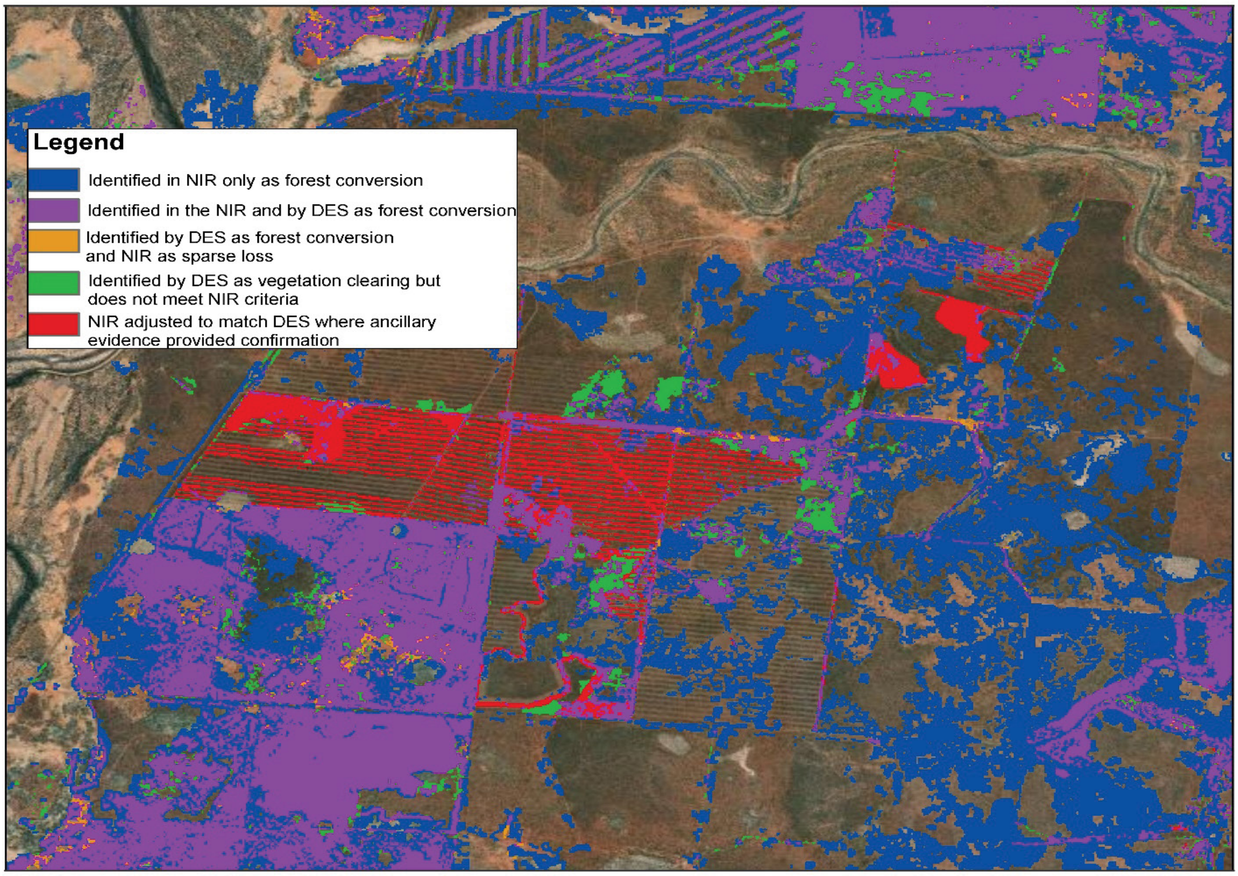
Pixel level comparisons were undertaken of woody vegetation loss between the national inventory data and the Queensland Government Department of Environment and Science (DES) vegetation monitoring system. An assessment was made of the level of agreement between the two datasets for the period 1988 to 2018 (see Figure A5.6.1.9). Using the improved 3–class change data, there is a high level of agreement (within 10 per cent) between the two systems, although at a few places the clearing pattern does not match. The areas reported only in the NIR are mostly pre-1990 clearing, whilst most of the Queensland DES clearing is post-1990. At a few places, clearing is detected only in the DES dataset which is mostly picked up for the National Inventory Report as sparse woody loss reported under the *grassland remaining grassland, wetlands remaining wetlands* and *settlements remaining settlements* accounts.

The main difference between the systems is related to vegetation classification – the national inventory distinguishes between reporting of forest conversion (i.e. clearing in areas where woody vegetation cover meets or exceeds a canopy cover of 20 per cent and a height of 2m); and sparse woody vegetation changes reported under grasslands, whereas the Queensland system reports clearing in all woody vegetation types, independent of tree height, in a single classification. This is a significant factor that explains the majority of the difference in “land clearing” estimates reported by the two systems.

Nevertheless, the analysis showed a high level of agreement between the two systems in the detection of changes in vegetation on forest lands and sparse woody vegetation over the time series. Each area of disagreement was reviewed carefully and the national inventory revised accordingly, where appropriate, using the improved 3–class change product.

Since the review subsequent NIR cycles have utilised the latest Queensland Government SLATS data to confirm areas of observed forest loss as anthropogenic which were unable to be substantiated by other available lines of evidence.

Figure A5.6.1.9 Pixel level comparison of the clearing data of the two systems – National Inventory and Queensland DES

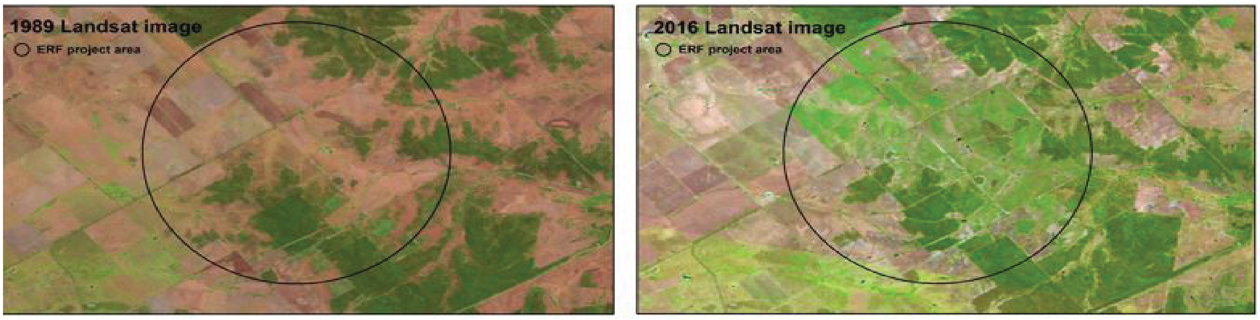


A similar process was also undertaken using vegetation monitoring data for NSW from 1988 to 2014. All areas identified by NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW) as cleared in the past were checked to determine if they were already part of the national inventory. This analysis showed a high level of agreement, and areas of disagreement were carefully reviewed, and the inventory revised, if appropriate. Comparisons showed that the National Inventory Report estimates of primary forest clearing at the time were within 7,000 hectares of clearing reported by NSW DCCEEW . In a similar manner to the Queensland SLATS data, review of the latest NSW DCCEEW vegetation clearing data is now an established part of the annual NIR data workflow processing to identify and confirm areas of observed forest loss.

Additional verification of land clearing is undertaken using data reported in the media and other published reports. 2014 NIR data were compared with published information on high value agricultural clearing approvals in Queensland reported by Taylor (2015), for the period from 2012 to 2015. The analysis undertaken in 2015 indicated that, of the 94 approved sites, 75 per cent were already included in the national inventory while the remaining 25 per cent were being monitored for clearing in the future or were included in a different part of the account such as timber harvesting. In cases where clearing is not yet evident at the time of image acquisition, the national system continues to monitor potential areas and captures any confirmed clearing in subsequent years. Primary reference data such as these are continually updated and are used as part of the standard procedure in attribution and QA/QC.

Reforestation attribution also undergoes a series of QA/QC checks using data collected for the ARD. Figure A5.6.1.10 shows an area reforested under the Emissions Reduction Fund (ERF). Landsat imagery shows how the area had no forest cover in 1989, and a revegetation signal is visible in the 2016 image.

Figure A5.6.1.10 ERF data used to identify reforestation across the time series



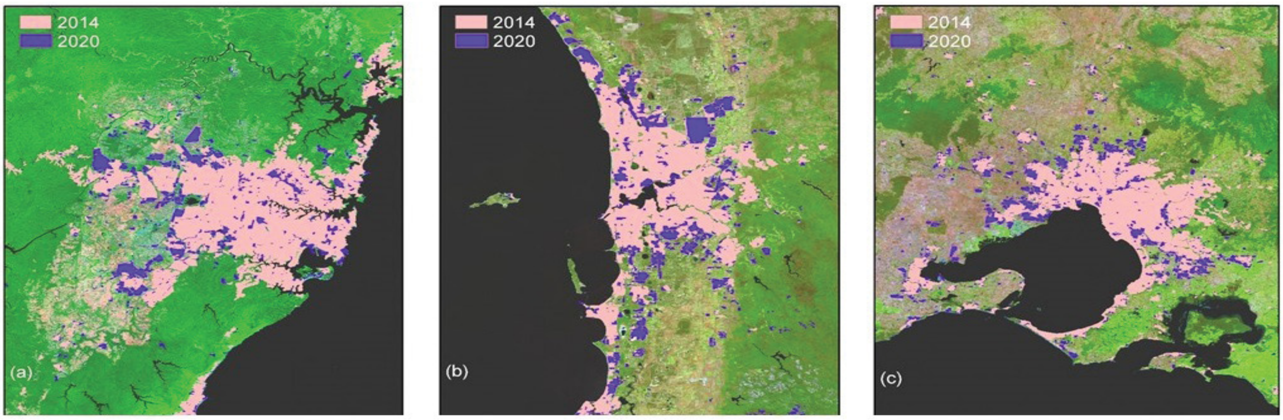
Updates to Settlements dataset

One of the land use categories required by the IPCC 2006 Guidelines (IPCC 2006) is the location of human settlements, and the transitions that occur between settlements and other land use categories. For the National Inventory Report, settlements include areas of residential and industrial infrastructure, including cities, towns, and transport networks (within settlements).

An updated settlements layer was incorporated in the 2019 NIR to take account of the expansion in settlement areas that have occurred since the preceding update in 2014 (see Figure A5.6.1.11). The dataset was derived from the 2017 ABARES catchment scale land use data, unpublished sources and visual assessment of high-resolution imagery.

The updated settlement dataset was added as a base land use layer for FullCAM spatial simulations. In future submissions, this will allow modelling of emissions and reporting of land conversions such as grasslands or croplands converted to settlements, which is one of the ERT recommendations. Further work is planned to develop a time series of base land use data for all IPCC land use categories.

Figure A5.6.1.11 Settlement expansion around (a) Sydney, (b) Perth and (c) Melbourne, between 2014–2020



Refining the CPN algorithm

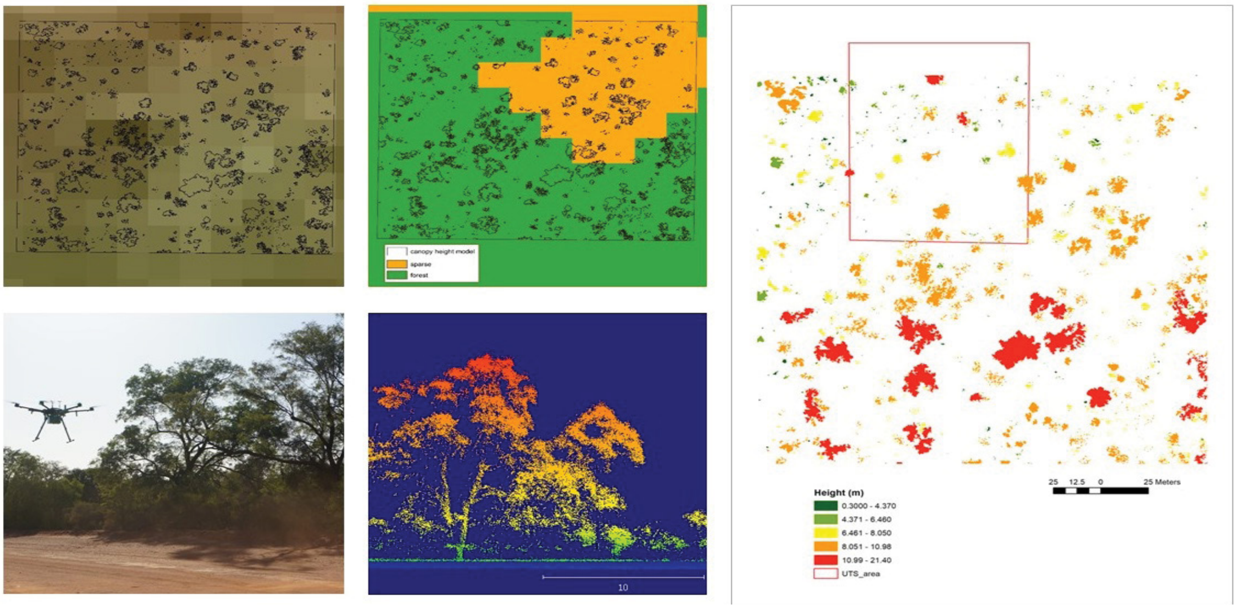
To address the errors of commission and omission related to the sparse classification identified in the CPN woody vegetation products (see continuous improvement and verification programme section in A5.6.1.4), it is necessary to refine the CPN algorithm.

Since the publication of the 2016 National Inventory Report, the Department has undertaken fieldwork to collect woody vegetation data using a LiDAR (light detection and ranging) drone and optical sensors over national parks in the Bourke region of NSW. The vegetation in this area is difficult to classify as the landscape is highly modified through clearing and grazing, vegetation responds to climatic cycles such as drought, and high-resolution imagery is not always available. There are also numerous ERF projects in the area where human-induced revegetation is occurring and being monitored using the woody vegetation data.

Processing of data collected during the fieldwork is ongoing and will result in point-cloud images, canopy height models, vegetation structural data and site statistics. These will act as new regionally specific training data, used to refine the algorithm and during the training of the random forest classifier for the production of the full time series. Figure A5.6.1.12 gives examples of the outputs from the LiDAR analysis, showing the outline of the canopy height model overlaying (L-R) 25m Landsat 2018 imagery, 3–class woody vegetation classes 2018, LiDAR canopy height model classes, fieldwork photo of vegetation structure and a height profile of the LiDAR scan. This also illustrates the issues associated with classifying sparse woody vegetation from 25m Landsat imagery, where trees are clustered and the algorithm looks to nearest neighbours to confirm a classification. LiDAR canopy height model data will also be utilised as training data for other locations across the country, where available.

The planned inclusion of sentinel data will necessitate a fifth continuous improvement and verification program (CIVP). The re-training of the satellite classification algorithm may result in a degree of changes in classifications across all epochs to maintain time series consistency (see section A5.6.1). As such, verification of the algorithm is required across the time series.

Figure A5.6.1.12 Examples of outputs from LiDAR drone analysis



Plantation typing

Validation of plantation type mapping accuracy was carried out against specifically collected field data showing plantation species, stocking, condition, age and extent. This validation data was collected during a national programme of site visits. Plantation mapping achieved an accuracy of 91 per cent in terms of both species and spatial referencing for plantations identified as post-1990 plantations. Incorrect forest typing (e.g., labelling hardwood as softwood and vice versa) contributed 5 per cent of the error, with only 4 per cent being incorrect for both location and type.

The planned transition to Sentinel 1 and 2 data may provide an opportunity to further improve the accuracy and outputs for plantation typing.

Forest conversion prior to 1972

Forest land converted to cropland or grassland remains in the *converted* category for 50 years.

Estimates of *forest land converted to cropland or grassland* since 1972 are derived from observations of forest cover loss using Landsat satellite data.

Estimates of the area of *forest land converted to cropland* or *grassland* for the period 1940–1972 is a gap in the activity data used to prepare the estimates for the *forest conversion* categories. Approaches to the estimation of these missing data have been explored, in line with recommendations in the ARR 2010, ARR 2011 and ARR 2012 reviews of the Australian inventory. Estimates have been produced using extrapolation techniques provided in Volume 1, chapter 6 of the IPCC 2006 Guidelines (IPCC 2006). The results are compared below.

Previous studies

Graetz et al. (1995) estimated that 102.964 million hectares of forest were cleared between 1788 and 1990, or an average of 514,820 ha per year. Similar conclusions have been reached in the *State of the Environment Report for Australia* (State of the Environment 2011 Committee 2011), with the area of forest cover cleared since 1788 estimated to be around 100 million hectares. A study by Barson et al. (2000) found that approximately 92.5 million hectares of forest had been cleared since 1788.

If extrapolated to the period 1940–1972, the Graetz et al. (1995) estimate translates into a cumulative area cleared over the period of 16.4 million hectares.

Forest conversion required to meet additional crop and livestock activity 1940–1972

The demand for additional pasture or cropland was high in the period 1940–72, reflecting relatively high prices paid for agricultural commodities. Cropping lands increased by 50 per cent, or around 6 million hectares in the period 1940–1972. For grazing activity, demand for land increased by the equivalent of 60–100 million hectares (based on agricultural activity data published by the Australian Bureau of Statistics) (ABS 2013).

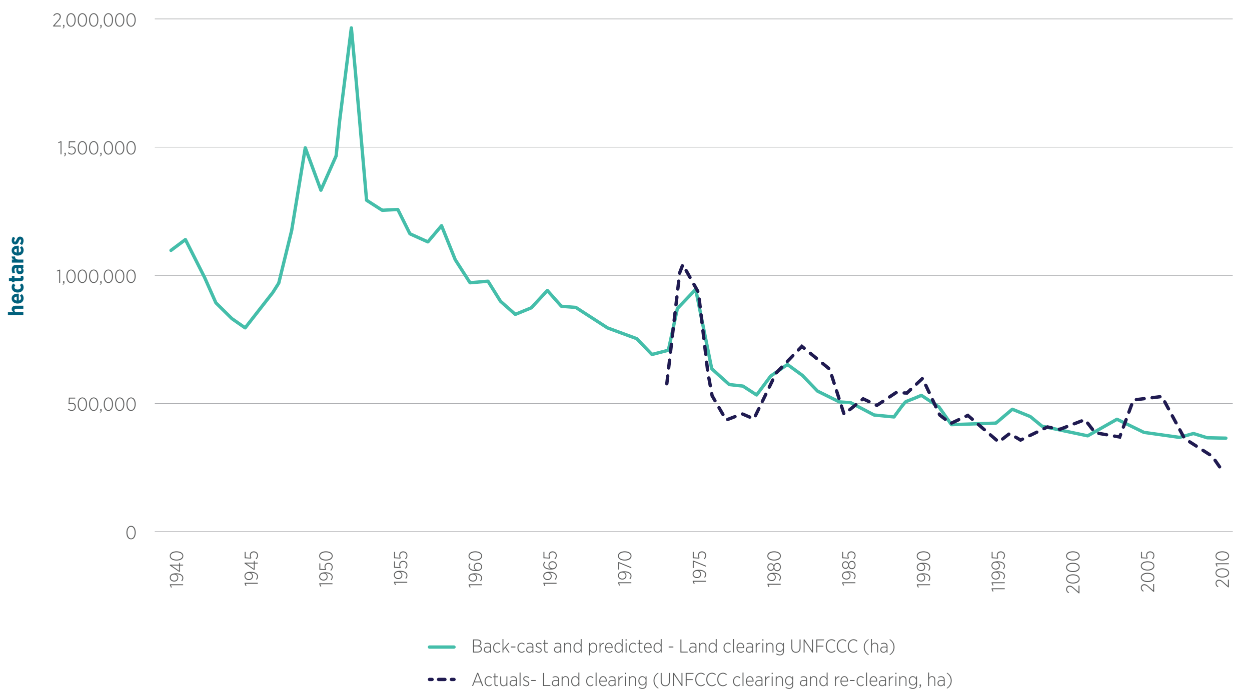
The estimated demand for grazing lands was derived from the increment in cattle and sheep numbers over the period 1940–1972. These data were converted into a demand for cleared land. The conversion was based on assumptions regarding the amount of grazing land needed to support the number of sheep and cattle indicated in the national statistics (1–2 sheep per hectare, 1 cow equal to 10 sheep based on data provided in Hamblin (2001) and Henz ell (2007)).

Not all of the additional demand for pastures would have required a clearing event. With a discount of 50 per cent, the cumulative increase in area of land needed to support the increment in livestock activity was estimated to be 60–100 million hectares in the period since 1940–1972.

Back cast regression of observed clearing on the farmers' terms of trade 1940–1972

Observed land clearing activity has also been established to respond to the farmers' terms of trade index of prices received to prices paid. A linear regression linking area cleared to the farmers' terms of trade was performed for the period where satellite-based land clearing estimates are available (1973 to 2010). The coefficients from this regression were used to back-cast land clearing activity to 1940 (Figure A5.6.1.13).

Figure A5.6.1.13 Estimated area of land clearing and actual land clearing (Source: ABARES various)



Inverted back-cast of 1973–2010 trend

Trends in area under cropland and cattle and sheep numbers indicate a peak of agricultural activity in the early 1970s. The Landsat time series indicates that the peak in land clearing in the period 1972–2013 occurred in 1974. Under this scenario it is assumed that land clearing gradually increased in the period 1940–1970 and peaked in 1974. This estimation of the historical trend was made by inverting the trend observed in the period 1973–2013.

Table A5.6.1.5 Estimated land clearing 1940–1972: comparison of extrapolation methods

	1940–1972 Extrapolation		1973–1990 Landsat imagery
Extrapolation method	**Cumulative land clearing (ha)**	**Annual clearing (ha)**	**Annual clearing (ha)**
Graetz et al. (1995) average annual forest conversion 1788–1972	16,474,240	514, 820	547,222
Forest conversion required to meet additional crop and livestock activity 1940–1972	60,000,000	1,875,000	547,222
Back cast regression of observed clearing on the farmer's terms of trade 1940–1972	34,200,000	1,069,000	547,222
Back cast of 1960–1990 trend in farmers' terms of trade model with clearing peak in 1974	25,200,000	763,636	547,222

The data in Table A5.6.1.5 indicates that the rates of land use change observed from the Landsat record, at 547,222 hectares a year for the period 1973–1990, are similar to the long run average rate of change calculated by Graetz et al. (1995) of 514,820 hectares a year. Independent data on a range of economic forces, including higher prices for agricultural products and reduced costs of forest conversion for this period compared with earlier periods, anecdotal country histories and observed increases in national livestock numbers and cropping areas all indicate that the period 1940–1972 was a period of strong land use change in Australia.

The estimates of *Forest Conversion* presented in Sections 6.7 and 6.9 for 1990 are based on a limited dataset on land use change extending only from 1973–1990. Extending the observed dataset to include estimates for the missing data on land use change for the period 1940–1972 could be implemented using a range of techniques identified in the IPCC 2006 Guidelines (IPCC 2006) based on the data presented in Table A5.6.1.5.

The implementation of an extended dataset on land use change to 1940 would lead to higher emissions estimates for *Forest Conversion* for the entire time series, with larger impacts at the start of the time series, 1990, than for later periods of the time series. It is assessed that the estimate for net emissions for *Forest Conversion* categories would be 13 Mt CO_2-e higher in 1990, if the land clearing trend is back cast with an assumed clearing peak in 1974.

A5.6.2 FullCAM framework

Land sector reporting within Australia's National Inventory System integrates a wide range of spatially referenced data through a process based empirical model (Tier 3) to estimate carbon stock change and greenhouse gas emissions at fine spatial and temporal scales. Analysis and reporting includes all carbon pools (biomass, dead organic matter (DOM) and soil), all principal greenhouse gases (CO_2, CH_4 and N_2O), and covers both forest and non-forest land uses. A Tier 3 method is used to estimate carbon stock changes for agricultural soils, living woody biomass (excluding perennial woody horticulture) and dead organic matter. This approach has several advantages over an IPCC Tier 1 or 2 method:

- Models have the potential to improve coverage and completeness as they can extend beyond existing data to improve geographic coverage/distribution and coverage of source/sink categories by filling in gaps in data.
- Measured climate data are interpolated using a mathematical (multivariate spline) function at the 1 km scale rather than broad climatic region classification. This enables quantification of carbon stock changes at finer spatial scales.
- The method includes detailed characterisation of spatially mapped soil properties that influence soil carbon dynamics as opposed to broad soil taxonomic classification of the IPCC methodology.
- The method provides a more detailed representation of management influences and their interactions. This increases the spatial and temporal resolution of estimates compared to those that are represented by a discrete factor-based approach.
- Soil carbon stock changes are estimated on a more continuous, non-linear and dynamic, monthly basis as a function of the interaction of climate, soil, and land management compared with the linear averaging as applied in Tiers 1 and 2.

Other FullCAM input data is described in Annex 5.6.5.

Overview of the FullCAM Framework

FullCAM is a process based ecosystem model that calculates greenhouse gas emissions and removals in both forest and agricultural lands using a mass balance approach to carbon cycling. The FullCAM framework and its development are described in Richards (2001) and Richards and Evans (2004).

FullCAM has been selected for the Tier 3 method based on several criteria:

- The model has been developed in Australia and extensively tested and verified for Australian conditions. In addition, the model has been widely used for simulating soil and biomass carbon dynamics at project level and nationally.
- FullCAM is capable of simulating cropland, grassland, and forest eco-systems and land-use transitions between these different land uses at the 25m pixel level. As most emissions and removals of greenhouse gases occur on transitions between forest and agricultural land use, integration of agricultural and forestry modelling was essential.
- The model is designed to simulate management practices that influence soil carbon dynamics including quantification of inter-annual variability.
- FullCAM has components that deal with both the biological and management processes which affect carbon pools and the transfers between pools in forest, agricultural and transitional systems. The exchanges of carbon, loss and uptake between the terrestrial biological system and the atmosphere are accounted for in the full/closed cycle (mass balance) model which includes all biomass, litter and soil pools.

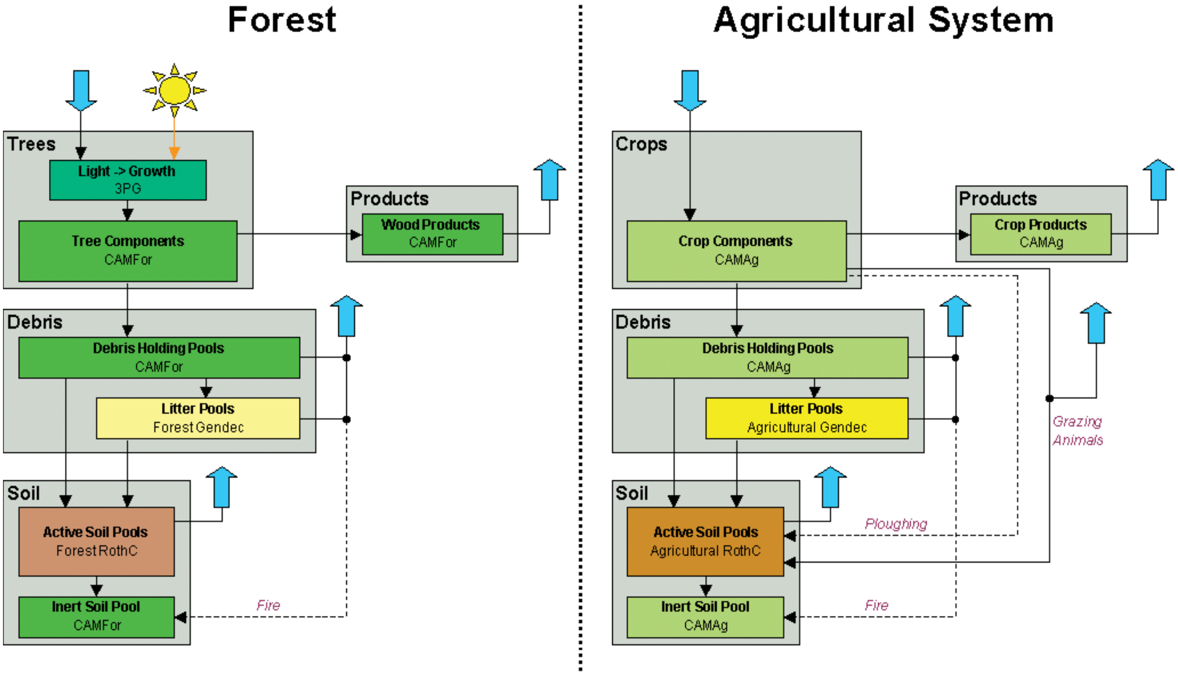
The data required for FullCAM to simulate is available nationally at appropriate scales for the data in a spatially and temporally time series consistent format.

FullCAM Sub-Models

FullCAM has been developed as an integrated compendium model that provides the linkage between various sub-models (Figure A5.6.2.1). The three sub-models integrated to form FullCAM as used in the National Inventory are:

- *CAMFor* (Richards and Evans 2000), the carbon accounting model for forests. *CAMFor* is used to model carbon mass and transfers between the living tree, standing dead and debris pools of forest lands. *CAMFor* has its origins in the 1990 CO_2 Fix model of Mohren and Goldewijk (1990);
- *CAMAg* (Richards and Evans 2000), the carbon accounting model for cropping and grazing systems. The *CAMAg* model reflects the impacts of management on carbon accumulation and allocates masses to various plant, debris and soil pools. Yields need to be prescribed in the model;
- Rothamsted Soil Carbon Model, *Roth-C* (Jenkinson, Hart, et al. 1987) (Jenkinson, Adams and Wild 1991). *Roth-C* models changes in soil carbon based on the inputs of organic matter from dead plant material and soil carbon decomposition rates. It is used in conjunction with both *CAMFor* and *CAMAg.*

Figure A5.6.2.1 The FullCAM pool structure



Sub-model integration

The sub-models described above are integrated into FullCAM which was developed in the programming language C++ with a graphical user interface (Richards 2001) (Richards and Evans 2004). The individual sub-models can be applied independently or in various combinations within the FullCAM framework.

By embedding both the forest and agricultural models within FullCAM, it is possible to represent transitional activities – afforestation, reforestation and deforestation (change at one site) – or a mix of agricultural and forest systems (e.g., agroforestry, discrete activities at separate sites) in a single, mass-balance model framework.

Quality assurance and quality control

Sub-model integration

The integration of the sub-models into a single compendium model was initially undertaken in Excel as a test version. The prototype forest model derived (Richards and Evans 2000) was subsequently tested by CSIRO (K. Paul, P. Polglase, et al. 2002). Several independent studies to test and calibrate the model were completed on various parts, integrations and applications of the models. When there was confidence that the Excel developmental models were giving the same results as the original source code versions, the Excel models were fully documented and returned for verification to the original authors or host organisations. Modifications were only considered subsequent to this initial review. These modifications were made for a variety of reasons including efficiency in code (computational speed and resources) and in recognition of Australia's different biophysical conditions.

Model coherence and validation

Testing for coherence in a Tier 3 (Approach 3) model-based pixel by pixel inventory method requires very different techniques to those applied to checks on trends and emissions factors in Tier 1 and Tier 2 models[5]. Tests of model coherence and validation can only be meaningfully undertaken at the pixel level. This is the approach taken and is consistent with the good practice recommendations of the IPCC 2006 Guidelines (IPCC 2006). As the robustness of the national account simply flows from the correct summing of the outputs of the individual pixels, testing the results at the individual pixel scale will validate the national results. Therefore, programmes to test model cohesion operate in two realms. The first is coherence testing by time series to validate model calibrations and verify the results at the pixel level. The second is quality control to ensure robust summation of the pixels to an aggregate national account.

Representative individual pixels in FullCAM simulations have been validated against field data. These validations have been undertaken by independent agencies. The results of these studies have shown that the model is robust. Examples of the independent initial biomass validation results are shown in further detail in Annex 5.6.4, while debris and soil carbon validation is shown later in this annex.

Individual pixel models are internally checked to ensure that all emissions, removals and transfers of carbon between pools are accounted for. At each monthly time-step FullCAM reconciles removals due to growth, transfers between carbon stocks in pools, and emissions from pools for every pixel modelled. Taking a mass balance, full carbon-cycle approach for each pixel, and running this over an extended period, is a very rigorous way of testing the model's ability to appropriately reflect transfers between carbon pools, and hence the balance of emissions and removals. When multiple pixels are simulated, pixel results are consolidated and then reported at an aggregate level. These aggregate outputs are cross checked by both internal and external processes to ensure that the consolidation process accurately reports all spatial simulation results. The correct summing of model outputs is also critical to model performance and therefore internal and external quality control checks are made on this aspect of the model. The results from the Tier 3 model have also been compared with the results using Tier 2 methods (see Chapter 6.6.2) and were found to be broadly consistent.

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[5] The change in pixel output is also strongly affected by climate variability and disturbance history on that pixel (fire, forest cover changes, harvesting). As there are multiple variable factors, the implied emissions factors from the overall inventory cannot be used to test the model's coherence as the model processes can no longer be observed in anything like their original analytic unit. Analysis of IEFs in the LULUCF sector is further complicated by reporting of accumulating land areas.

Transparency and peer review

For the complex Tier 3 methods, which incorporate models and large datasets, different approaches to transparency and peer review are required. Transparency and review of the land sector accounts is founded on:

- published specifications, protocols and methods.
- published verification results.
- public release of models, tools, and data, and,
- publication in peer reviewed journals or other literature.

Australia has published six series of strategic and technical reports which document the development of FullCAM, the specifications, protocols and methods used, and the results of verification, validation and calibration of FullCAM. All reports are accessible by the public via the FullCAM help guide (https://www.dcceew.gov.au/themes/custom/awe/fullcam/Help-FullCAM2020/index.htm). The methods and data used as part of the land sector accounts have also been extensively published in peer-reviewed papers in scientific journals.

The Australian Centre for Ecological Analysis & Synthesis undertook a modelling workshop in 2011 on improving long-term predictions of carbon and nutrient dynamics in Australia's agro-ecosystems. In the workshop FullCAM soil carbon outputs were compared with those from DayCENT, Century and a Microsoft Excel version of RothC, initially for two sites, Hermitage and Wambiana. Preliminary results suggested little difference between outputs of the four models over the study period. Further, if input data were the same or very similar then all models appeared to simulate soil carbon stocks to within 10 t C/ha (0-30 cm soil profile) of the final result based on a measured value of soil carbon stock (2010 site data).

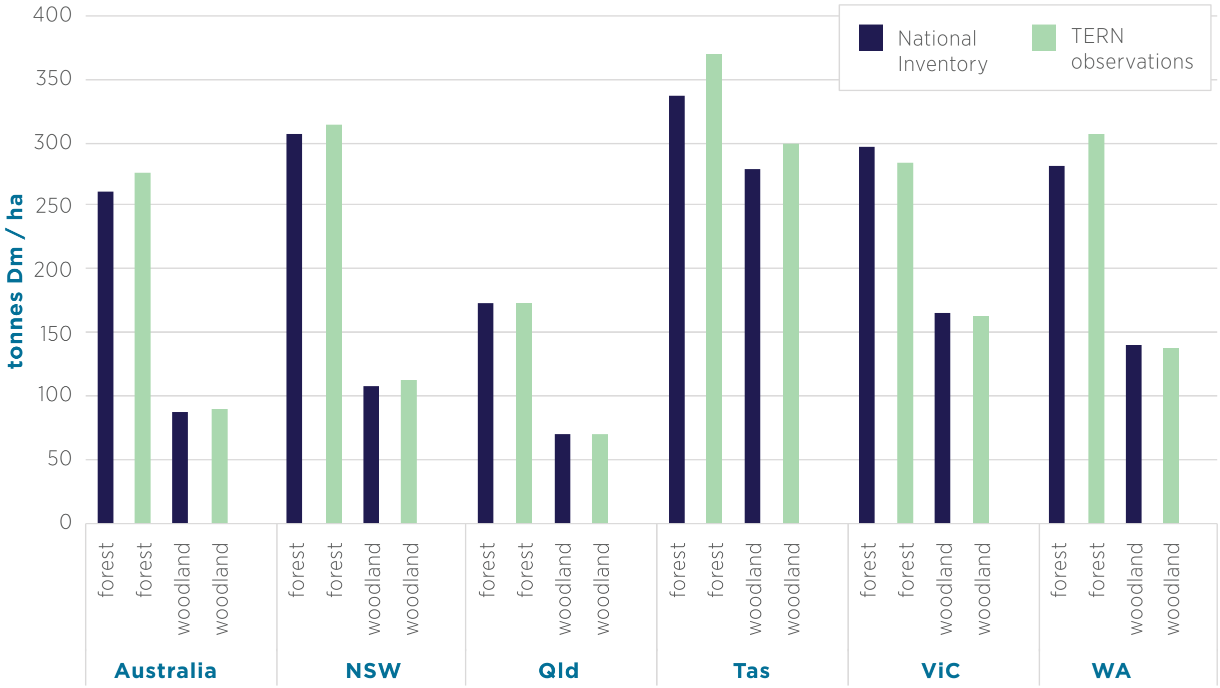
Source-specific QA/QC – land converted to forest land

In recent years, regeneration of native vegetation has become a significant driver in the trend for LULUCF emissions. There has also been substantial recent engagement with commercial plantation and farm forestry stakeholders, with many contributing datasets for FullCAM improvement work, particularly with respect to calibration of FullCAM's Tree Yield Formula (TYF). Hence, over the last few years, key improvements to FullCAM have included an update in the maximum above-ground biomass input layer for mature native forest and refinement of the empirical tree growth curve (TYF). As a result, updates were also required for allocation, turnover and decomposition parameters. These are described in turn below.

Maximum above-ground biomass

The maximum above-ground biomass (M) was updated in the 2017 submission using 5,739 site-based observations of maximum above-ground biomass *M* (Roxburgh and Paul 2019). The work of Roxburgh et al. (2019) compared FullCAM-modelled maximum biomass estimates with the average maximum biomass data from a sample from the TERN biomass library. They found that for forest cover with more than 50 per cent canopy coverage, at the national level, that the modelled estimates were within 10 per cent of the estimates from the sample from the TERN biomass library. For woodland forests, where the canopy cover was between 20 and 50 per cent, the estimate from FullCAM was within 5 per cent of the estimates from the sample from the TERN library (Figure A5.6.2.2).

Figure A5.6.2.2 Comparison of maximum biomass layer and empirical data, Australia and by State, (tonnes of dry mass/ha)



Improved representation of M calibration sites was achieved through significantly increasing their number and spatial extent (Figure A5.6.2.2). In terms of systematic error, the gains in accuracy using the mean residuals as the index was highly statistically significant for mature vegetation at 73.1% (Table A5.6.2.1). In terms of precision (or IQR), the gain in accuracy of site-level AGB prediction was statistically significant for mature vegetation at 45.5% (Table A5.6.2.1; Figure A5.6.2.5b).

Tree Yield Formula parameters

Annual increments in above-ground biomass (AGB) are empirically predicted in FullCAM through the calibration of the Tree Yield Formula (TYF) parameters, with this being informed by AGB measurements obtained from calibration sites of different types of tree stands. The TYF calibration was revised in the 2020 inventory submission for environmental plantings and natural regeneration in farmland or nature conservation areas, and in the 2021 inventory submission for commercial plantation and farm forestry. There are currently 1,246 and 16,737 site-based observations on which the revised TYF parameters were based for environmental and mallee plantings and natural regeneration (Paul and Roxburgh 2020), and for commercial plantations and farm forestry (Paul, Roxburgh and England 2022), respectively.

Environmental and mallee plantings and natural regeneration

Improved representativeness of calibration sites was achieved through significantly increasing their number and spatial extent (Figure A5.6.2.3), which has increased confidence in the model predictions. The efficiency of model prediction (Soares, et al. 1995) of AGB against the 1,246 currently available calibration sites shows that it was 42% for the 2019 version of the model (Figure A5.6.2.4b), compared to 25% for the 2016 version (Figure A5.6.2.4a). There is also an increase in the accuracy of estimates. In terms of systematic error, the gains in accuracy using the mean residuals as the index was of a high statistical significance at 98.8% for regenerating stands (Table A5.6.2.1). In terms of precision (or IQR), the gain in accuracy of site-level AGB prediction in young stands of natural regeneration was highly statistically significant at 32.6% (Table A5.6.2.1; Figure A5.6.2.5a).

Figure A5.6.2.3 Location of the TYF calibration sites for Block stands used for different versions of FullCAM; (a) 2016 and (b) 2019

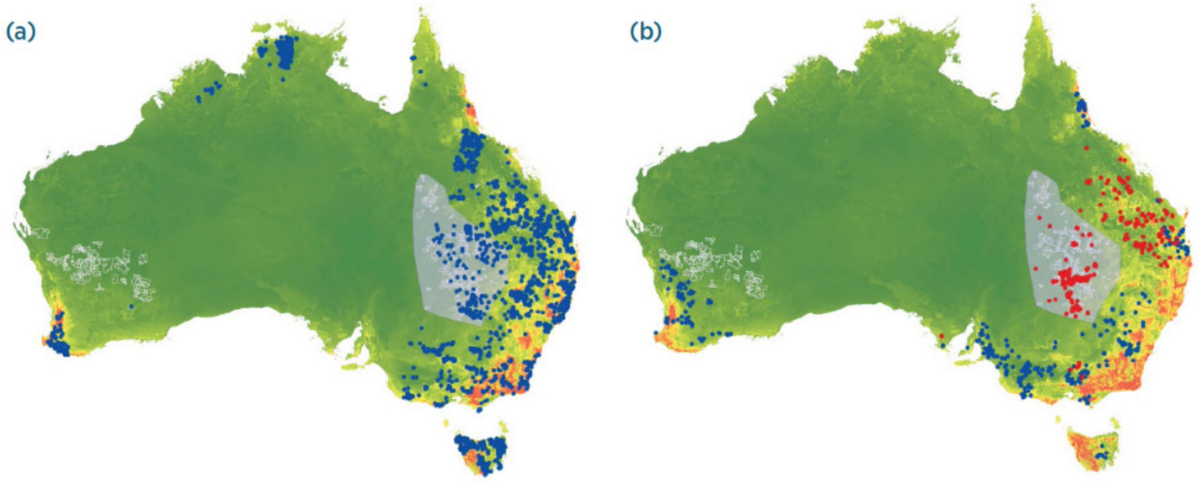
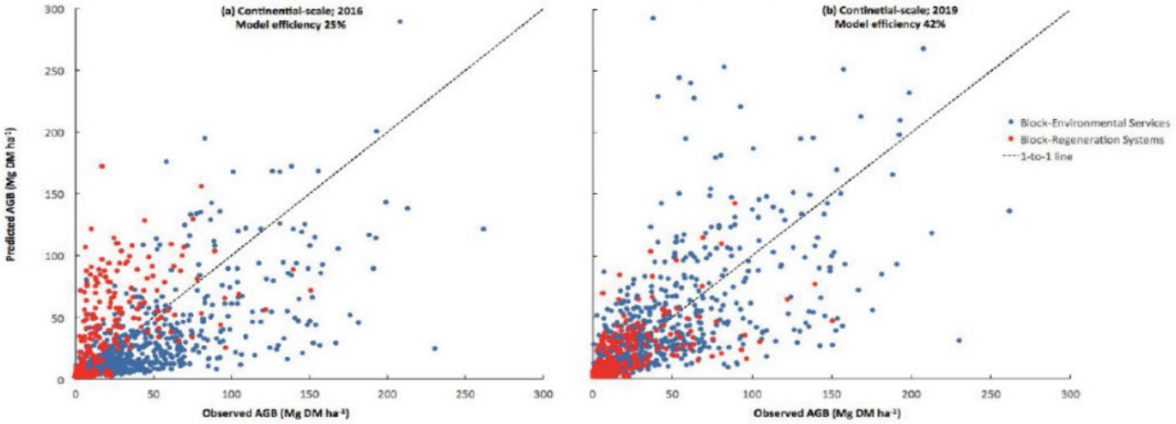


Figure A5.6.2.4 Plot of predicted versus observed AGB for different versions of FullCAM; (a) 2016, and; (b) 2019.



Blue symbols represent regeneration in nature conservation areas ('Block-Environmental Services'). Red symbols represent the regeneration in farmland ('Block-Regeneration Systems').

Figure A5.6.2.5 Continental-scale results of accuracy analysis for the estimation of site-level biomass for the: (a) regeneration in farmland (‘Block-Regeneration System’ category); (b) maximum above-ground biomass, and (c) the regeneration in nature conservation areas

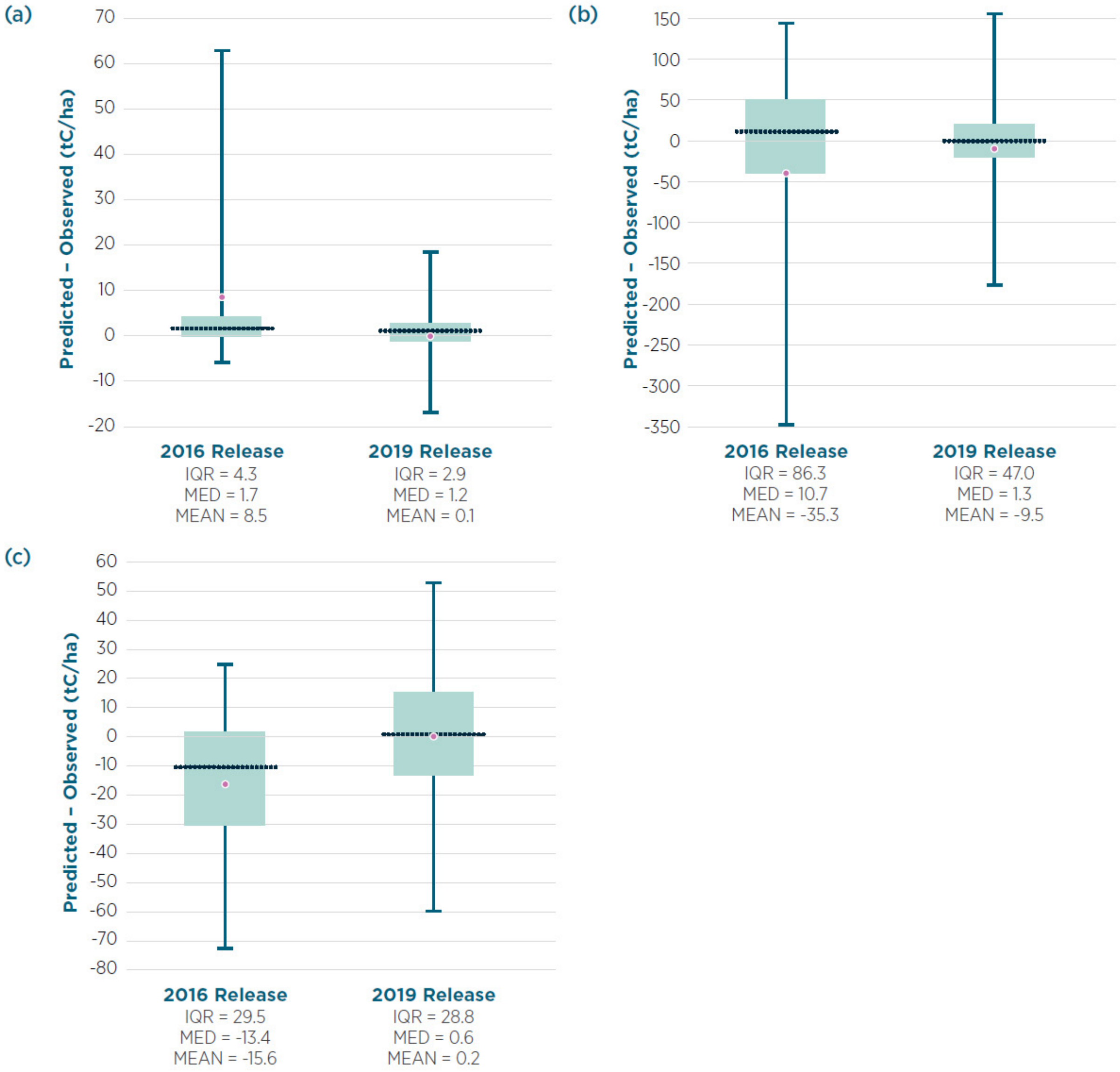


Table A5.6.2.1 Summary of results for the analysis of change in systematic error from the FullCAM (2016) release to the FullCAM 2019 release

			Block – Regeneration	Block – Environmental Services	Maximum Above-ground biomass
Precision	Inter-Quartile range	FullCAM (2016) (tDM/ha)	4.3	29.5	86.3
		FullCAM (2019) (tDM/ha)	2.9	28.8	47.0
		Gain in accuracy (tDM/ha)	1.4	0.7	39.3
		Gain in accuracy (%)	32.6	2.4	45.5
		P	0.020	0.769	<0.000
Systematic error	Median	FullCAM (2016) (tDM/ha)	1.7	-10.4	10.7
		FullCAM (2019) (tDM/ha)	1.2	0.6	1.3
		Gain in accuracy (tDM/ha)	0.5	9.8	9.4
		Gain in accuracy (%)	29.4	94.2	87.9
		P	<0.001	<0.001	<0.001
	Mean	FullCAM (2016) (tDM/ha)	8.5	-15.6	-35.3
		FullCAM (2019) (tDM/ha)	0.1	0.2	-9.5
		Gain in accuracy (tDM/ha)	8.4	15.4	25.8
		Gain in accuracy (%)	98.8	98.7	73.1
		P	<0.000	<0.000	<0.000

Commercial plantations and farm forestry

A database of AGB was developed from 16,737 measurements obtained from 8,737 independent stands of tree plantations across Australia (Figure A5.6.2.6). This database provides the first comprehensive collation of yields of AGB found in stands of tree plantations across Australia. The emphasis on the collated dataset was to maximise temporal- and spatial-representation of calibration stands. Statistical features of the AGB database are given in Table A5.6.2.2 below.

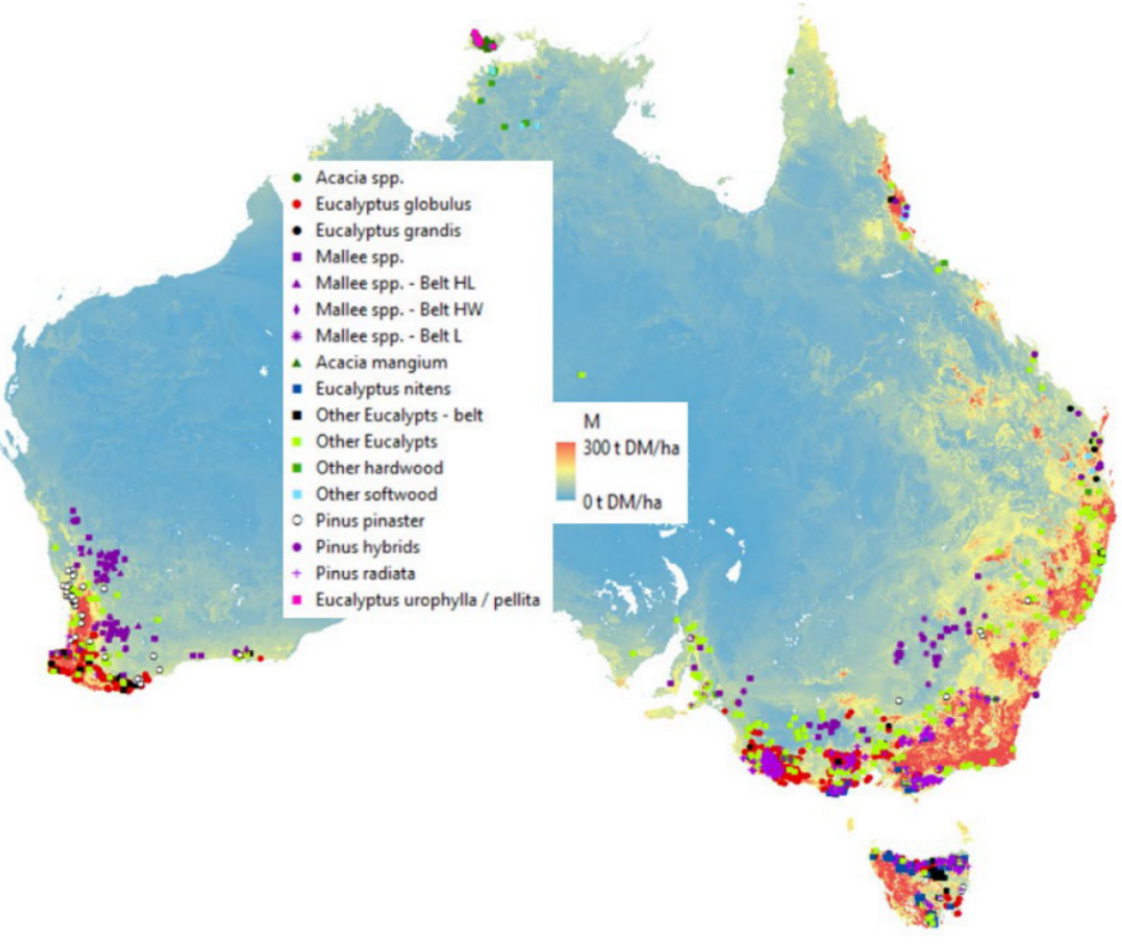
Table A5.6.2.2 Number of observations (N) from independent inventory stands and the repeat measurements from the number of stands (N') and other statistical features* of the dataset used for developing the database

Type	N	N'	AgeMax	Age 95th percentile	M	M range	% Commercial plantations
Globulus	6,614	4,440	20	15	173 ± 87	25-1100	78
Nitens	2,004	1,270	38	17	330±206	57-1100	81
Grandis	327	78	60	48	202 ± 124	47-1100	0
PellitaHyb	276	276	14	14	102 ± 8.8	87-112	100
Radiata	3,706	875	41	28	232 ±165	34-951	92
Pinaster	243	58	54	34	129 ± 60	47-347	0
SouthernPine	98	48	50	29	180 ± 61	88-453	0
Mangium	386	386	15	14	100 ± 25	83-453	99
OtherEuc	1,392	733	80	30	166 ± 141	11-1100	0
OtherHW	253	106	65	36	271 ± 175	31-639	0
OtherSW	94	27	21	10	406 ± 125	38-639	0
OtherAcacia	81	58	10	6	174 ± 97	76-453	0

Type	N	N’	AgeMax	Age 95th percentile	M	M range	% Commercial plantations
MalleeBlock	81	75	50	20	64 ± 34	19-203	0
MalleeBeltL	51	51	20	15	70 ± 29	28-187	0
MalleeBeltHW	492	104	17	13	80 ± 27	21-210	0
MalleeBeltHN	494	73	29	15	75 ± 32	25-152	0
OtherBelt	145	79	31	21	176 ± 70	75-299	0
Total	**16,737**	**8,737**					**65**

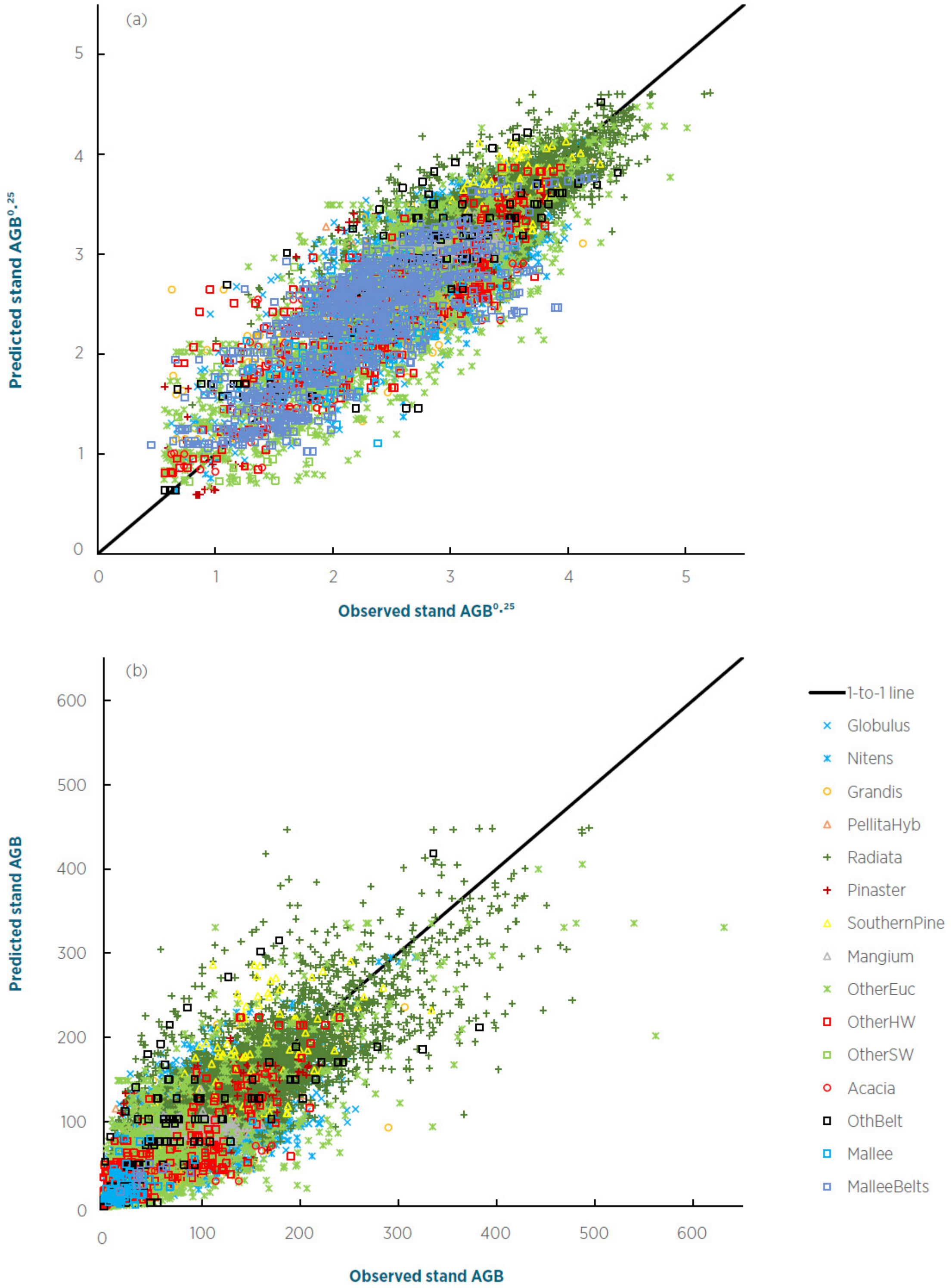
* The other statistical features include: maximum age (AgeMax), 95th percentile of stand ages (years), average (± standard deviation), range of the site productivity potential (M, Mg DM ha^{-1}), and the percentage of the data sourced from commercial plantation growers.

Figure A5.6.2.6 Locations of sites from which data on stand AGB were collated for calibration of FullCAM’s TYF, and their distribution across Australia with respect to the M input layer of site productivity potential



Paul et al. (2022) found that for each category of plantation, there was generally negligible bias in prediction of AGB (< ±0.51 Mg DM ha^{-1}). Paul et al. (2022) also noted that there was no clear systematic bias for any of the plantation categories, with negligible slope in the bias when plotted against either age or M. As found with previous calibrations of the TYF (K. Paul 2015) (Paul and Roxburgh 2020), the precision of predicted AGB is sound (i.e., *MAPE* of about 6 to 21% and *RMSE* of about 17 to 59) across the calibration datasets, although as indicated in the plot of observed vs. predicted AGB, the model remains imprecise for prediction of AGB at any given stand. In terms of overall model performance, the prediction efficiencies were relatively high, and generally ranged between 33 to 80%, and with *LCC’s* ranging between 0.57 to 0.89.

Figure A5.6.2.7 Relationship between observed and predicted AGB on the: (a) fourth-root transformation scale, and (b) natural scale for the various categories of plantation



Refinement of other model parameters for Commercial plantations and farm forestry

Allocation of biomass

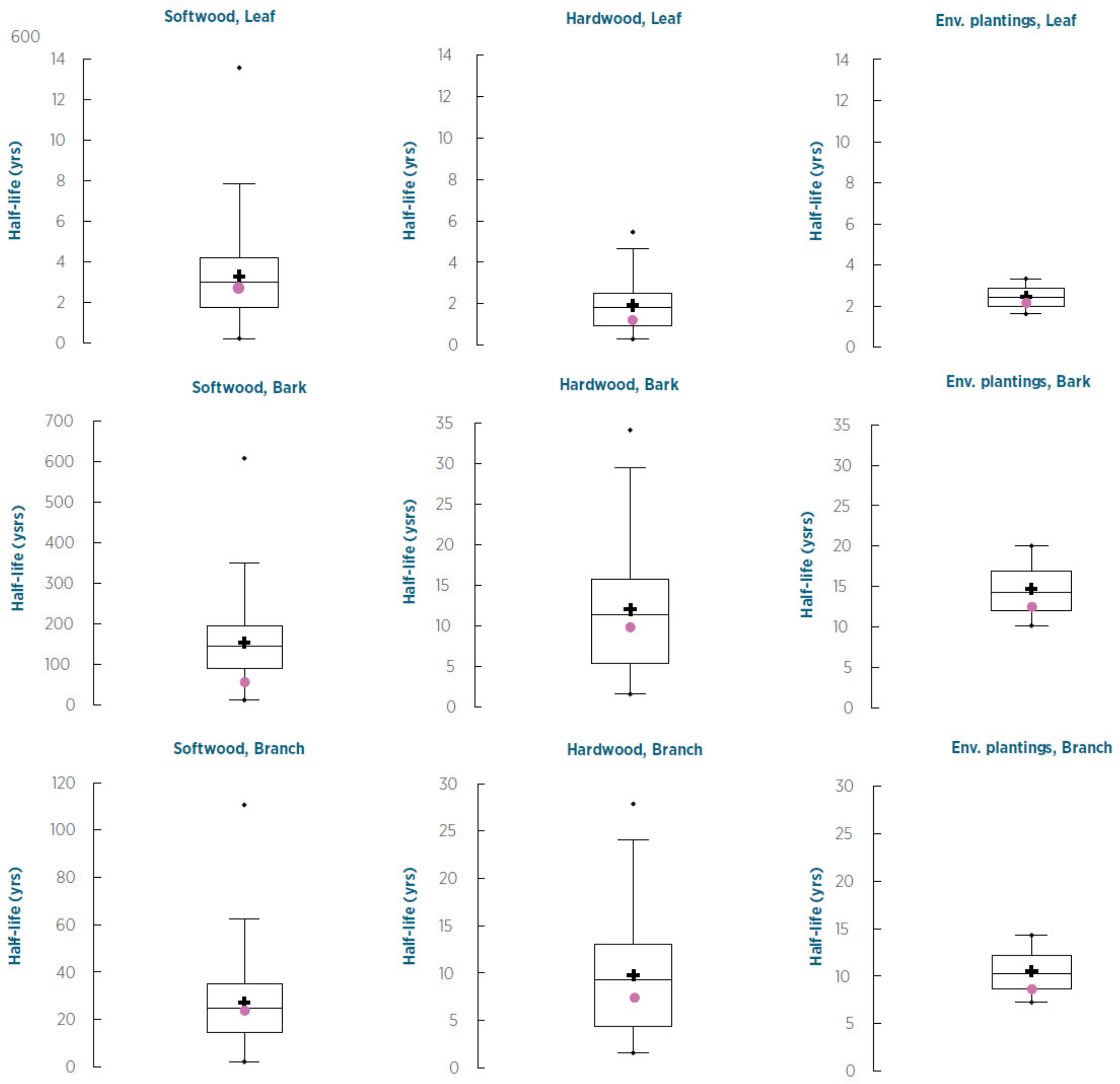
Data on the attribution of total AGB to components of biomass were collated from 2,729 estimates obtained from biomass sampling studies undertaken within various stands of Australian softwoods (N=314), hardwoods (N=436), mallees (N=167) and environmental plantings (N=883) (Paul, Roxburgh and England 2022). Similarly, data on BGB were collated for softwood plantations (N=363), hardwood plantations (N=103), mallees (N=619), and from native vegetation (as a surrogate for environmental plantings, N=615).

Litterfall

Data on litterfall were collated from 274 estimates obtained from litter trap studies undertaken within various stands of Australian softwoods (N=190), hardwoods (N=80), and environmental plantings (N=4). There were no litterfall studies available from mallee plantings, and so here they were assumed to be represented by hardwoods.

FullCAM requires partitioning of litterfall into leaf and other components, which is not always provided in litter studies. Therefore, and also reflecting the large variability in observed rates of litterfall, rather than being applied to directly calibrate turnover parameters, collated data were used to calculate the upper and lower quartiles of leaf, bark and branch litterfall for each planting type, with these quartiles being used to provide a constraint to the calibration of leaf, bark and branch turnover parameters.

Figure A5.6.2.8 Descriptive statistics of litterfall datasets for leaf litter, bark litter and deadwood



* Data obtained from Australian softwoods (N=138), hardwoods (N=80) and environmental plantings (N=4). Black cross symbol represents the mean while the box plot indicates the median, first and third quartile and the minimum and maximum observations, which were considered outliers when above the upper whisker of the box plot. Red circle symbol represents the value calibrated.

Decomposition of litter

Decomposition was described by the rate of exponential decline in the mass of litter within litter bags placed in the field. Datasets from 146 litter bag studies were collated, and included 97 measurements of decomposition of leaf litter, 10 of bark litter and 39 of deadwood.

Figure A5.6.2.9 Decomposition decay curves fitted to leaf litter for the litterbag studies collated*

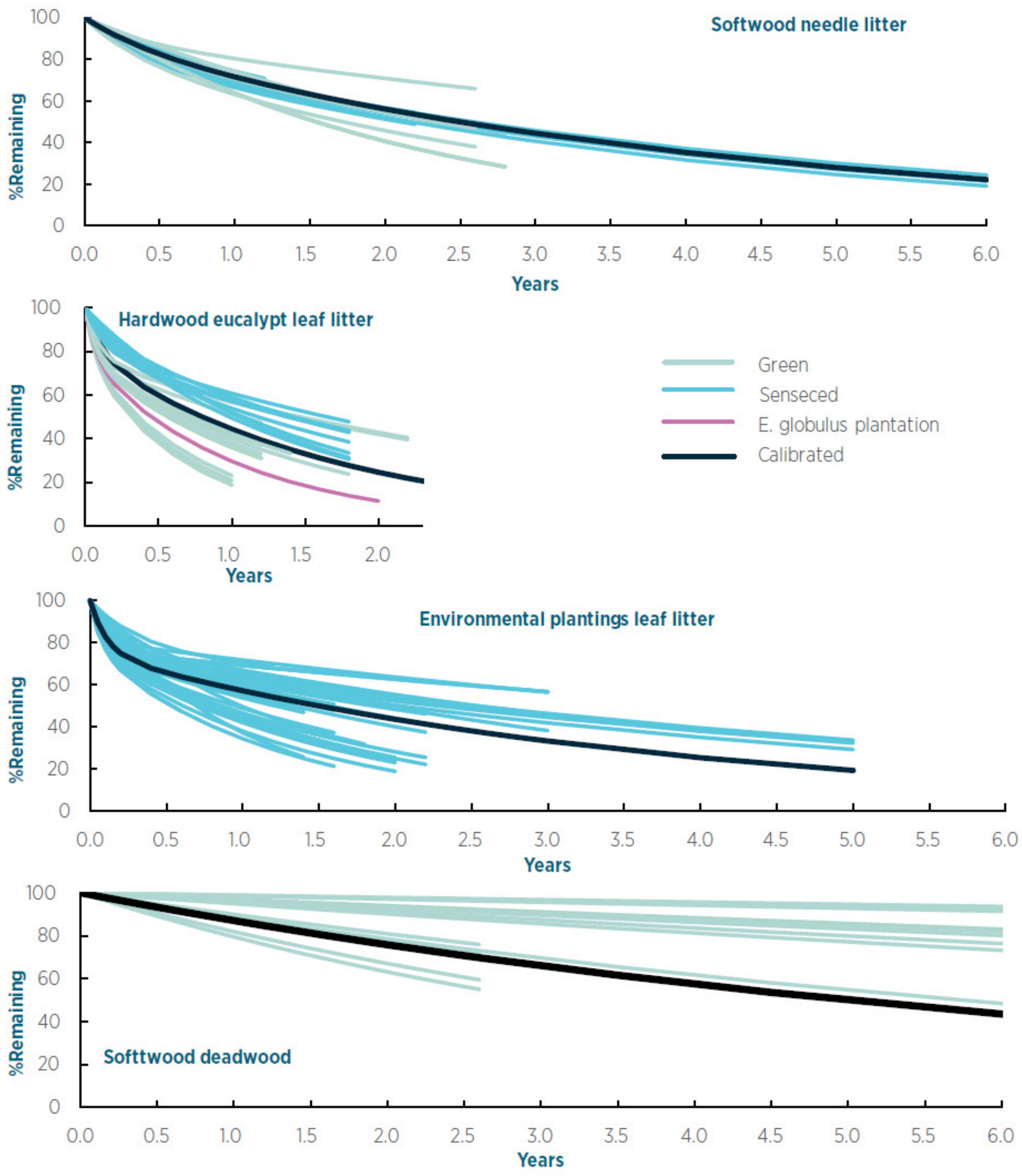
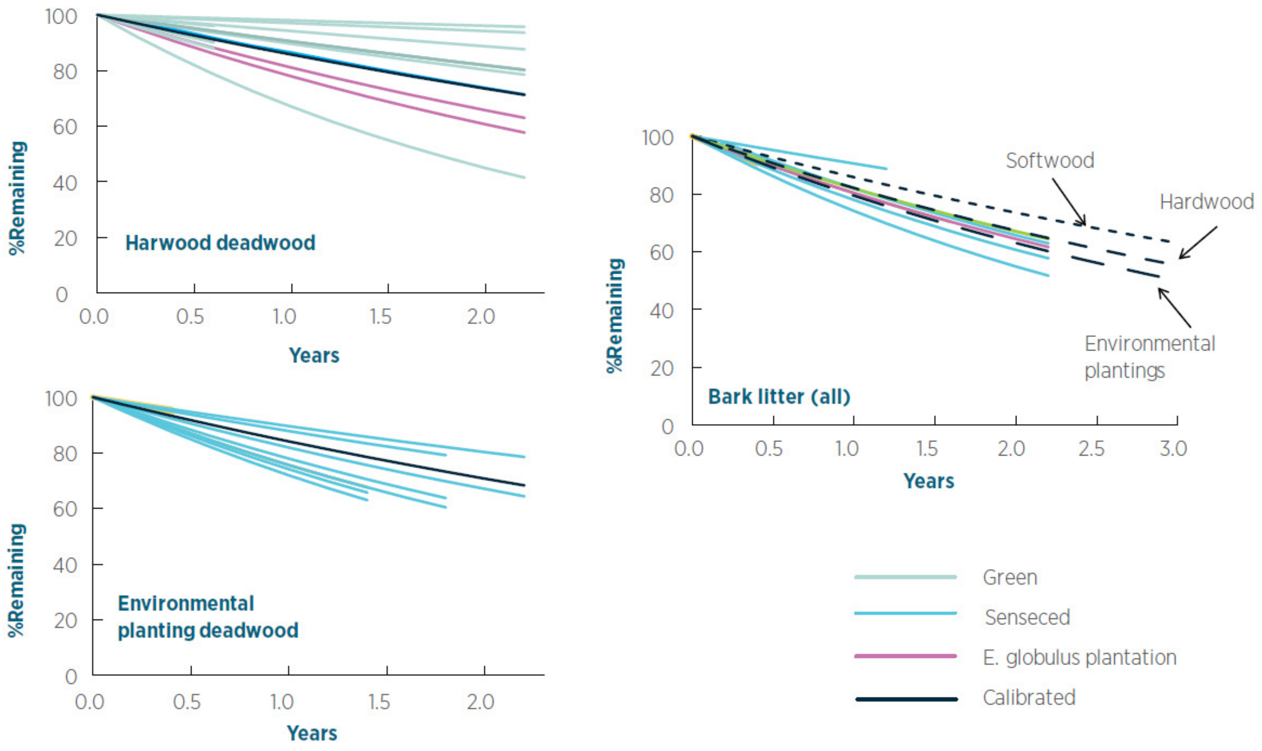


Figure A5.6.2.10 Decomposition decay curves fitted to bark litter and deadwood for the litterbag studies collated

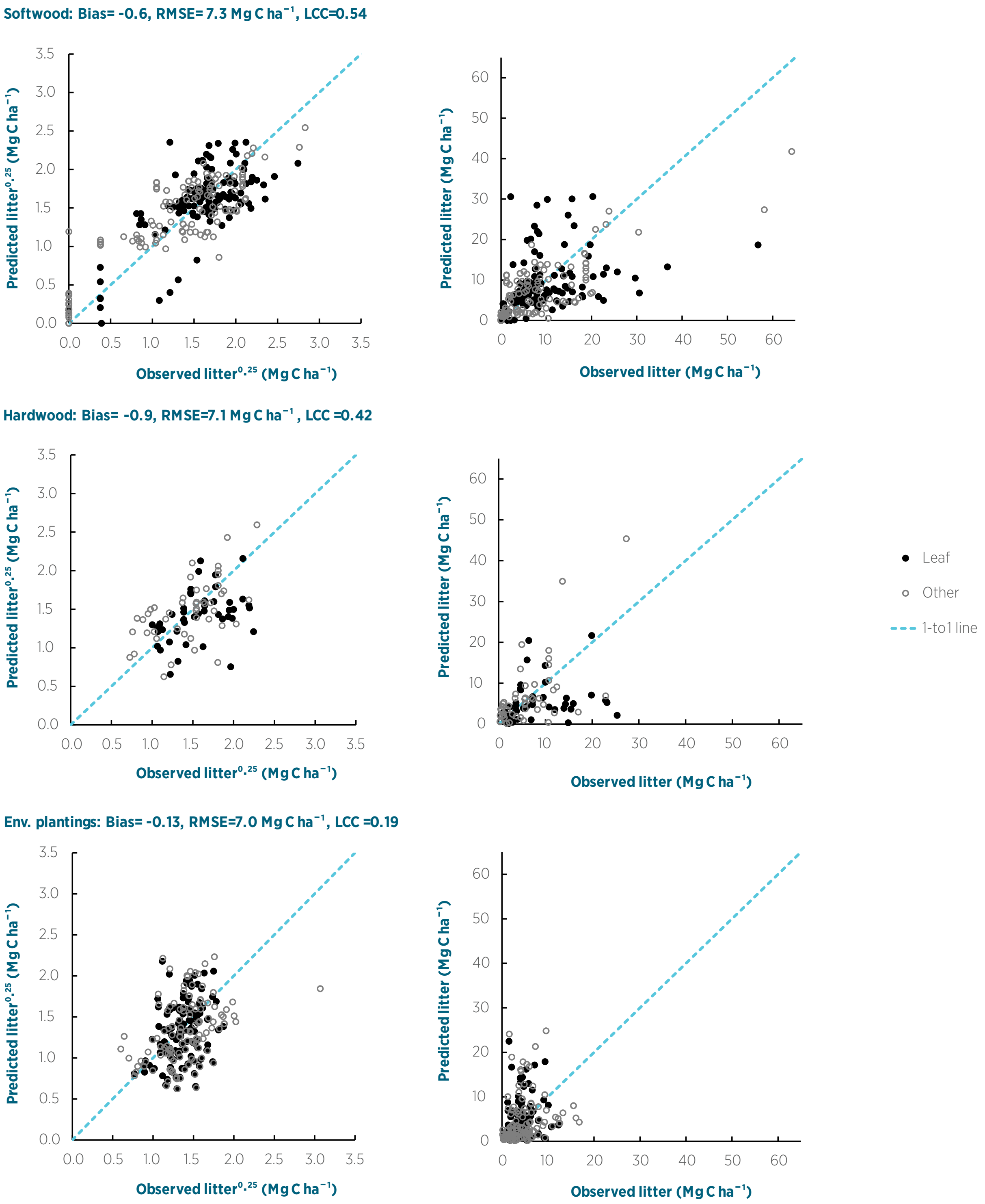


* Litter decomposition datasets collated were generally green litter for softwood and hardwood plantations, and senesced litter for environmental plantings. Thick black line represents the decomposition decay curve that was parameterised in FullCAM.

Constraining parameters for turnover and decomposition using litter mass and residue management studies

The balance between litterfall and decomposition influences the predicted litter mass. To provide further confidence in these parameters influencing predicted litter mass, data was collated from studies in Australian plantings of litter mass, including studies with harvest or thinning residues treatment plots (N=294). Each of these studies were simulated as a unique FullCAM plot file, with this simulation including all reported management events, e.g. planting, thinning, and harvesting of both previous and current rotations. Leaf and other litter pools were then predicted to best match those observed by calibration (via function minimisation methods) of parameters influencing litter, including rates of decomposition of R-deadwood, R-bark litter, D-leaf litter and R-leaf litter pools, and the resistant fraction of leaf litter (Figure A5.6.2.10). Results obtained were used to constrain the range of likely parameter values for litterfall and decomposition as outlined above. This calibration was undertaken separately for softwoods, hardwoods and environmental plantings.

Figure A5.6.2.11 Relationship between predicted and observed litter mass for environmental planting, hardwood and softwood plantation stands



* The relationship between predicted and observed leaf (or needle) litter and other (bark and deadwood) litter mass for: (a) 124 environmental planting stands, (b) 16 hardwood plantation stands, and (c) 25 softwood plantation stands on the natural scale (right) and transformed scale (left) used for model calibration. Model fit statistics provided are for all pools on the natural scale.

Regarding wetland converted to forest land (mangrove), quality control of FullCAM Wetlands – coastal submodel includes spatially explicit comparison and manual checks. The coastal vegetation layer used in FullCAM, derived from NVIS Version 6.0 MVS (Major Vegetation Subgroups) (Table A5.6.10.1) and an intertidal extent model (Figure A5.6.10.1) to define area of mangrove and tidal marsh, was overlaid with DEA mangrove (Landsat, mangrove_cover_v2_0_2, (Lymburner, et al. 2020)) and compared well in most locations. NVIS 6 MVS has extensive in-house quality controls before release into the public domain (metadata, http://www.environment.gov.au/land/native-vegetation/national-vegetation-information-system).

Estimating changes in forest biomass

Forest growth

Forest growth in FullCAM is controlled through two separate biomass increment components of the model:

- the tree yield formula (Richards and Brack 2004) (Brack, Richards and Waterworth 2006) (Waterworth, Richards and Brack, et al. 2007) (Roxburgh, Karunaratne, et al. 2019) (Paul and Roxburgh 2020); and
- direct entry of biomass increment data.

Tree yield formula

The tree yield formula (TYF) is embedded within the FullCAM code and when applied within the National Inventory System provides an empirically constrained process model for the calculation of biomass increment in the living components of forest land. The tree yield formula allows for responses to climatic variability while empirical data and parameters constrain initial aboveground biomass, forest growth, and relative movements between pools. It is the empirical data that constrains the model to reflect extensive field data (both existing and specifically collected).

The tree yield formula is applied to estimate the forest biomass spatial simulations of forests in FullCAM.

The tree yield formula is provided in Equation A5.6.2.1:

$$\text{Aboveground Tree Mass at age a} = M \times e^{(-k/a)} \qquad \text{(A5.6.2.1)}$$

Where a = age of the tree stand

M = biomass predicted by the assumed initial biomass model, and

k =estimated constant that determines the rate of approach towards M.

The value of *k*-sets the rate of growth, where $k = 2 \times BI_a - 1.25$, and BI_a is the age (in years) of maximum aboveground biomass increment.

The long-term average annual increment between *a* and *a* + 1 years I_a for a stand can be estimated from the long-term average productivity (P) (see Annex 5.6.3):

$$I_a = M \times (e^{(-k/a)} - e^{(-k/(a-1))}) \qquad \text{(A5.6.2.2)}$$

However, as productivity in any given year may vary around the average due to non-average weather or other factors, the actual annual increment (I_a is adjusted by the productivity in a given year (P_a) as a ratio with the long-term average productivity (P_{av}):

$$I_a = I_a \times P_a / P_{av} \qquad \text{(A5.6.2.3)}$$

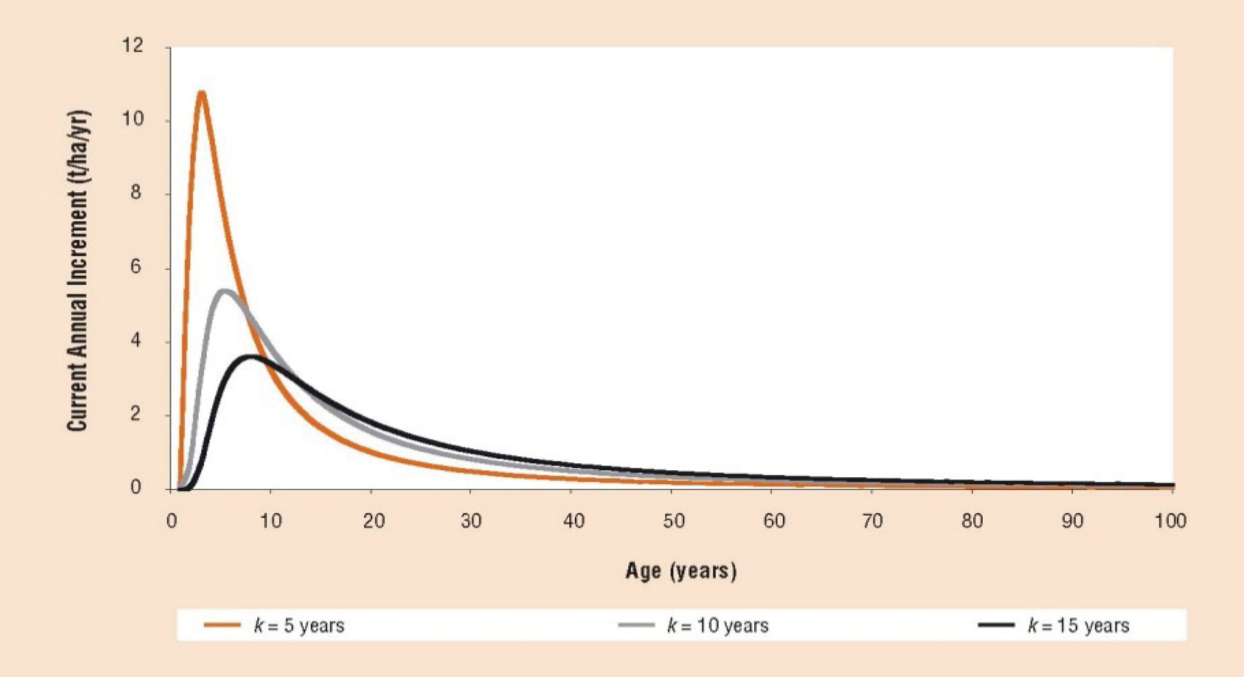
The average increment multiplier (P/P_{av}) in Eqn. A5.6.2.3 needs to be close to 1.0 to enable the attainment of the long-term maximum above-ground biomass of the stand; M. Due to the formulation of FullCAM's TYF, M will not be achieved if the mean of the P_a's for the years across which the simulation is run is less than P_{av}. This was an issue for some regions of Australia when P_{av} was calculated using climatic data from the years 1925–2000. As outlined by Roxburgh and Paul (Roxburgh and Paul 2019), recent improvements to FullCAM have included the more NIR-relevant P_{av} based on the climatic data from the years 1970-2017.

This approach provides biomass stock estimates for a given land unit at any point in time that recognises prior forest disturbance, and the rates of growth for a land unit at any point in time, specific to site condition and age. The patterns of growth will show variability according to the spatial and temporal patterns of the main process drivers, e.g. water balance, captured in the productivity modelling. This ensures that the estimates of biomass in areas of regrowth are then both spatially and temporally relevant.

Maximum aboveground biomass increment

One of the key parameters in the tree yield formula is the age of maximum aboveground biomass increment (BI_a). Figure A5.6.2.12 presents the results of an analysis of the effects of varying age of maximum aboveground biomass increment over the range of three to eight years. While the early age growth increments are very sensitive to BI_a, even by age 18 there is little difference in the annual aboveground biomass growth increment.

Figure A5.6.2.12 Effects of varying age of maximum current annual increment for three values of parameter k (5, 10 and 15 years), corresponding to BI_a = 3.1, 5.6 and 8.1 years, respectively



Available national data and literature sources were analysed to estimate BI_a for commercial plantations (Roxburgh, England and Paul 2019), environmental and mallee plantings of various configurations (Paul and Roxburgh 2020), and natural regeneration or re-growth of woodlands or forests occurring on land that is either set aside for conservation, or managed for grazing (Paul and Roxburgh 2020).

Direct entry of biomass increment data

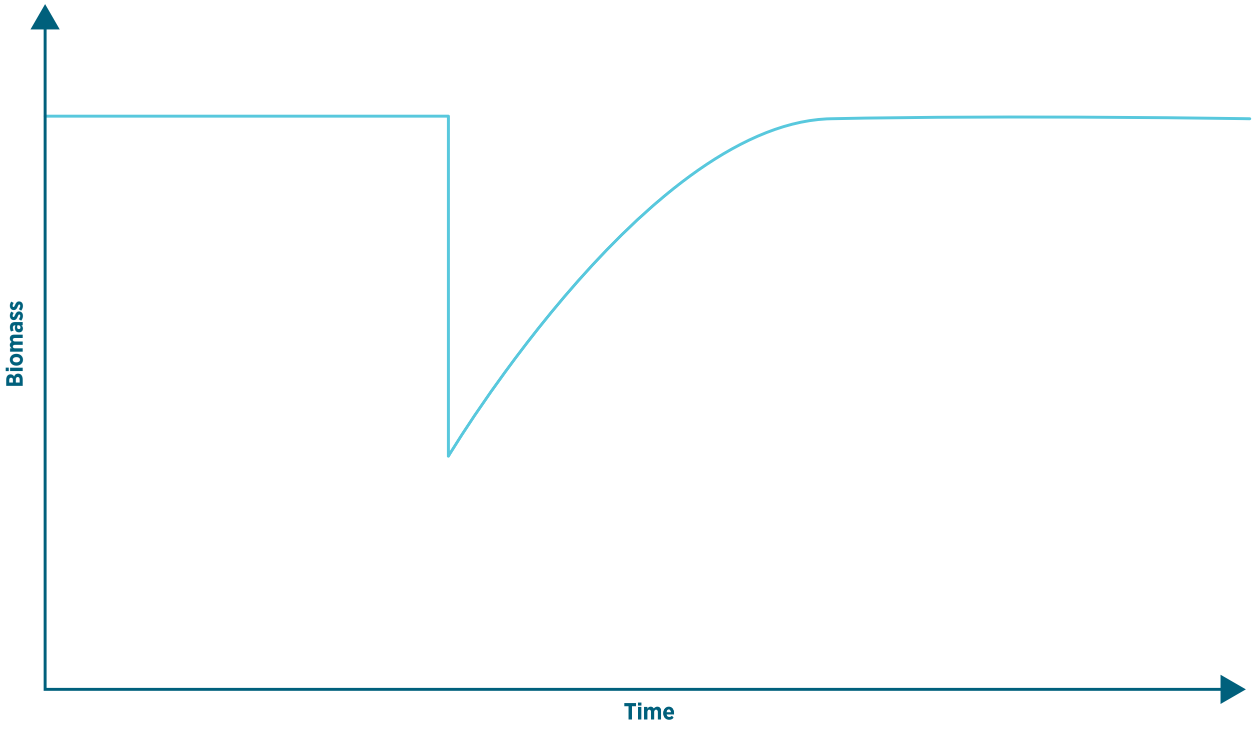
When the direct entry of biomass increment data component of FullCAM is in use, the model uses these data in calculations and so there is no tree yield formula calculation of biomass increment within FullCAM.

The direct entry of biomass increment data component of FullCAM is applied in the source category forest land remaining forest land in the estate-model for Harvested Native Forests in Chapter 6.4.1.2.

Biomass recovery function

A thin response or recovery function has been developed to account for disturbance events that affect live biomass (e.g. fire, thinning) but do not reset stand age. The biomass recovery function is based on the calculated amount of biomass lost from disturbances (fire, thinning). As the forest recovers from the disturbance, the lost biomass is added back as an addition to the TYF annual increment over a number of years. Hence, if the thin occurs in a young stand, the post-thin biomass increment will be the sum of the TYF increment at age t plus the Annual Recovery calculated by the recovery function.

Figure A5.6.2.13 Biomass recovery function



$$R_a = (t_r - t + 1) / (t_r \times (1 + t_r) / 2) \times (AGB_{\text{pre disturbance}} - AGB_{\text{post disturbance}}) \qquad \text{(A5.6.2.4)}$$

Where R_a is the annual amount of biomass recovered

t is the time since disturbance in years

t_r is the total time to recover from the disturbance

$(t_r - t + 1)$ is the remaining years until fully recovered

The amount of biomass lost through fire or thinning is $(AGB_{\text{pre disturbance}} - AGB_{\text{post disturbance}})$

The total time to recover (t_r) depends on the proportion of biomass lost due to fire or thinning, so that the recovery is shorter where less than half the biomass is lost. The calculation of t_r is as follows:

$t_{r\ max}$ is the maximum time to recover, in years
proportion biomass lost = 1 – ($AGB_{pre\ disturbance}$ /$AGB_{post\ disturbance}$)
where proportion biomass lost > 0.5 $t_r = t_{r\ max}$
where proportion biomass lost <= 0.5 $t_r = 2\ t_{r\ max}$ x proportion biomass lost

This thin response and recovery function is applied at the level of individual pools in FullCAM, reflecting the differential impacts of disturbances and recovery periods for leaves, branches, bark and stems.

Partitioning of biomass

FullCAM applies allocation scaling parameters to predict the partitioning of biomass to stem wood, branches, bark, foliage and coarse and fine roots. The units used in the allocation input table are the relative allocations, with allocation to stem, branch, bark, foliage, coarse roots and fine roots components all summing to 1.00.

For aboveground biomass, allocation input tables adjust the relative allocation to wood, branches, bark and foliage, with the total aboveground biomass (AGB) being set by FullCAM's TYF (Equation A5.6.2.1). In contrast, predicted belowground biomass (BGB) is determined by allocation to coarse roots (BGBC) and fine roots (BGBF) as defined in the allocation input table. The allocation of biomass in FullCAM also determines the management- or disturbance-induced impacts on C stocks. Accurate biomass allocation predictions are important when predicting changes in on-site C stocks following events such as fire, pruning, thinning or harvesting. This is because these events affect the different pools of biomass in different ways.

Calibration of partitioning parameters

As outlined in detail by Paul and Roxburgh (2017) and Paul et al. (2022), large datasets on biomass partitioning of tree or shrubs have recently been collated for Australia. These data provided a useful means to revise FullCAM input tables of allocation of biomass. This database included over 3,000 individual trees or shrubs with measurement of partitioning of AGB, and over 1,000 individuals with measurements of the relative allocation of BGBC to AGB, where BGBC is the biomass of coarse roots (>2 mm diameter). For all forest type, BGBF were predicted from AGB using a global empirical model (Mokany, Raison and Prokushkin 2006).

Previously, FullCAM allocation inputs varied with stand age only. But the new expanded datasets on biomass partitioning facilitated the development of new empirical models that demonstrated that, at least for some types of forests, AGB partitioning and R:S varies not just with stand age, but also with the stands total AGB, average rainfall, density, and species or species-mix.

An example of the how the revised predictions of biomass partitioning compare to that observed is given below (Table A5.6.2.3) for native forests systems, where datasets were collated from 46-168 different sources, depending on the biomass component being measured, as described by Paul and Roxburgh (2017). Predictions were directly derived from FullCAM default allocation parameters for native forests in high rainfall regions. Further details, and results for other forest types, are described by Paul and Roxburgh (2017) and Paul et al. (2022).

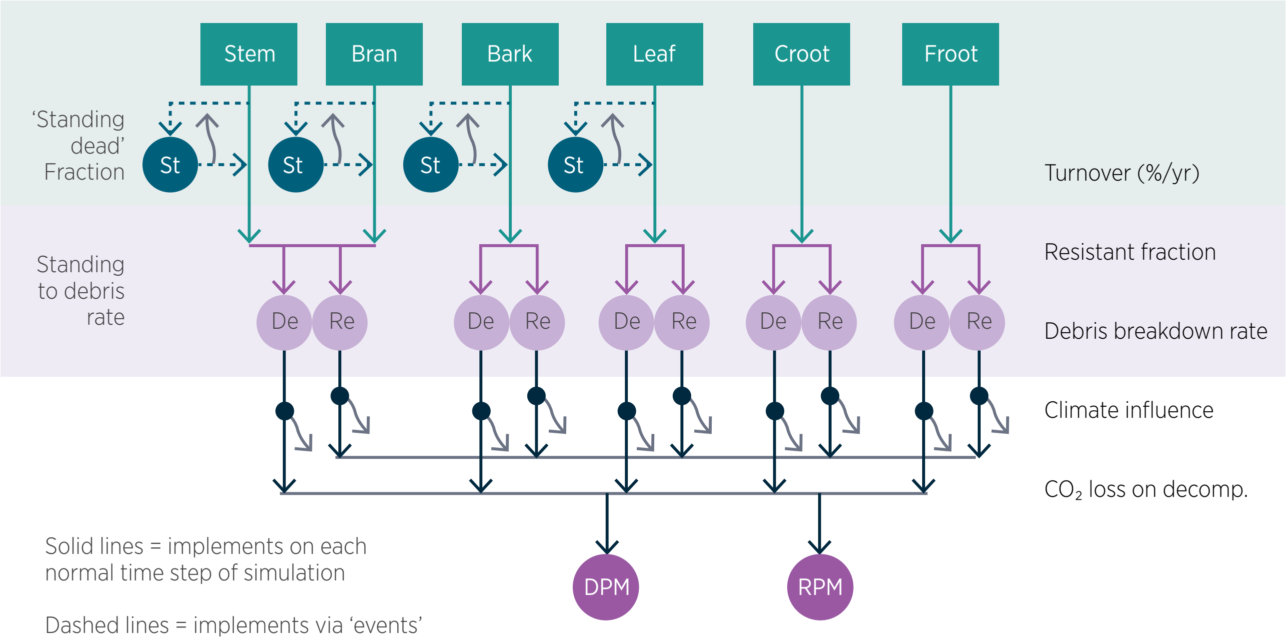
Table A5.6.2.3 Mean (± SD) observed and predicted biomass ratios for native forest

Ratio of biomass components	Observed	Predicted
Wood:AGB	0.65 ± 0.12	0.68
Bark:AGB	0.12 ± 0.06	0.15
Branch: AGB	0.14 ± 0.09	0.13
Foliage: AGB	0.05 ± 0.06	0.05
BGBC: AGB	0.33 ± 0.14	0.33

Estimating changes in forest standing dead

FullCAM allows for the modelling of standing dead pools following disturbance events such as wildfires, prescribed burns, management burns (e.g. slash burns and site preparation burns), clearing or commercial harvesting (Paul and Roxburgh 2019). At each such event, a proportion of each pool of live biomass may be assumed to be disturbed to such an extent that it will slowly die. The rates of such senescence will be relatively slow when compared to the relatively fast rates of breakdown of pools of debris, which were calibrated to litter bag decomposition studies.

Figure A5.6.2.14 FullCAM structure with regard to standing dead (St) pools, and how these may be created from live biomass pools following disturbance events, and their slow transfer of carbon into the decomposable (De) and resistant (Re) pools of debris due to the slow process of standing dead senescence



Based on data presented in Table A5.6.2.4 below, it was also assumed that rates of senescence were 0.83 per cent mo^{-1} for standing dead stem or branch wood, 1.25 per cent mo^{-1} for standing dead bark, and 1.67 per cent mo^{-1} for standing dead foliage. In contrast to live biomass pools above-ground, it is assumed that any coarse or fine roots below-ground affected by disturbances are converted to debris, not standing dead pools. There is a paucity of data on the fate of biomass decomposed from standing dead pools; namely the split between atmospheric emissions (CO_2-C loss) and material passed into the debris pools. Given standing dead pools generally have poor contact with soil and hence, decomposers, the assumption made was that the carbon use efficiency during senescence of standing dead pools was be relatively poor, with 90 per cent of the material being lost as CO_2-C and only 10 per cent being converted to debris carbon. This assumption was consistent with that applied by Paul and Roxburgh (Paul and Roxburgh 2019).

Table A5.6.2.4 Collation of decomposition constants (k) fitted to a single exponential decay model of observed in situ decay of coarse woody debris, from South-West, Western Australia

Species	Component (& diameter, cm)	In situ decomposition time (years)	k	Source
Eucalyptus diversicolor	Twigs (<0.5)	1.5	-0.120	(O'Connell 1997)
E. diversicolor	Stem (2.5)	2	-0.046	(O'Connell 1997)
E. diversicolor	Stem (4.3)	2	-0.030	(O'Connell 1997)
E. diversicolor	Stem (8.4)	2	-0.022	(O'Connell 1997)
E. diversicolor	Twigs (0.8)	2	-0.107	(O'Connell 1997)
E. diversicolor	Twigs (1.1)	2	-0.120	(O'Connell 1997)
E. diversicolor	Twigs (1.4)	2	-0.094	(O'Connell 1997)
Acaia urophylla	Stem (1.9)	2	-0.115	(O'Connell 1997)
Acaia urophylla	Stem (3.7)	2	-0.109	(O'Connell 1997)
Bossiaea laidlawiana	Stem (1.7)	2	-0.114	(O'Connell 1997)
Bossiaea laidlawiana	Stem (4.3)	2	-0.093	(O'Connell 1997)
Trymalium spathulatum	Stem (1.8)	2	-0.123	(O'Connell 1997)
Trymalium spathulatum	Stem (4.0)	2	-0.081	(O'Connell 1997)
E. diversicolor	Stem (10-15)	5	-0.174	(Brown, et al. 1996)
E. marginata	Branch (3-5)	5	-0.067	(Brown, et al. 1996)
Pinus pinaster	Branch (3-5)	5	-0.049	(Brown, et al. 1996)
Allocasurian fraseriana	Branch (3-5)	5	-0.072	(Brown, et al. 1996)
Banksia grandis	Branch (3-5)	5	-0.133	(Brown, et al. 1996)
E. calophylla	Branch (3-5)	5	-0.215	(Brown, et al. 1996)

Estimating changes in forest debris

FullCAM allows for the modelling of debris accumulation and decay based on forest growth and management. Debris accumulates from the turnover of live plant material (e.g. branches, bark, leaves, and roots) to dead organic matter (DOM) (e.g. litter, coarse woody debris and dead roots). The turnover rates determine the amount of material being added to the debris pool. Decomposition rates determine the rates of loss of carbon back to the atmosphere and soil as the debris breaks down. The balance of these two factors determines the amount of debris on site excluding the effects of management.

In the absence of forest disturbances such as harvest or fire, debris mass increases with age to a steady state where the addition of forest material to the debris pools and loss from decomposition is in balance. Debris pools are also increased by the addition of slash material following harvest and decreased by any residue management techniques, in particular residue burning.

Calibration of rates of turnover and decomposition

Recent work on reviewing field studies with litter traps (Paul and Roxburgh 2017) (Paul, Roxburgh and England 2022) has greatly expanded the Australian database of forest turnover rates based on that previously available. Measurements of litterfall via litter trap studies were collated from across a range of forest types:

- Environmental plantings: 4
- Hardwood and softwood plantations: 95 and 175 respectively
- Native forests and woodlands: 83 and 24, respectively.

As described by Paul and Roxburgh (2017) and Paul et al. (2022), these litter trap studies were used to determine average rates of litterfall of foliage, twigs and bark from different forest types. Where required, average per cent foliage, per cent twig and per cent bark observed for the different forest types were used to 'fill-gaps' for studies where the total litterfall was not partitioned into these components.

Recent work on reviewing litter bag studies (Paul and Roxburgh 2017) (Paul, Roxburgh and England 2022) has also greatly expanded the Australian database of forest decomposition rates. Measurements of litter decomposition were available from litter bag studies installed under a range of forests, including:

- Eucalypt-dominant stands; 23, 13 and 59 measurements of decomposition of deadwood, bark litter and foliage litter, respectively.
- Softwood plantations; 13 and 15 measurements of decomposition of needle litter and deadwood respectively.

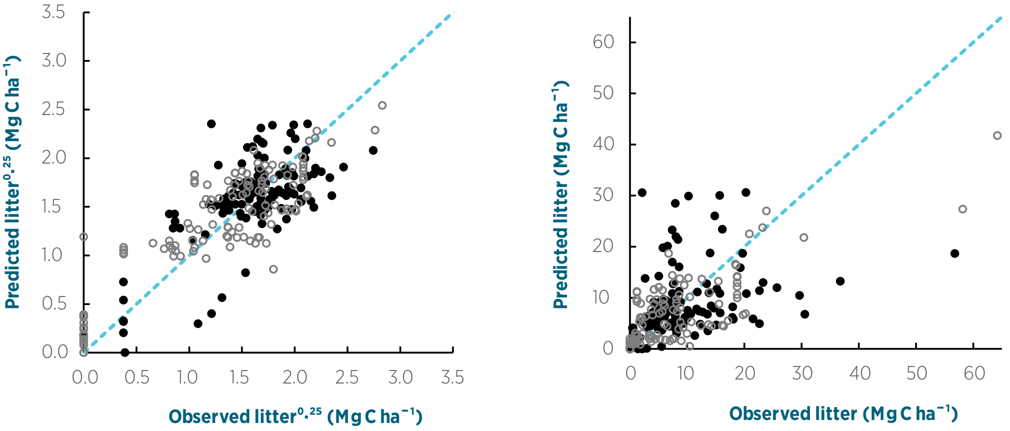
Simple double- or single-pool decay functions are commonly calibrated to datasets obtained from litterbag studies. On review of these, it was found that single-pool models were justified for deadwood and bark litter, while two-pool double models were justified for foliage litter. Hence for all forest types, FullCAM inputs of the fraction of debris that was resistant was set to 100 per cent for deadwood and bark, while for foliage it was set to the average values observed from the fitting of the double-pool decay function to litterbag studies of foliage. On average, the resistant fraction of pine needle litter was higher than that of eucalypt leaves, and so the revised FullCAM parameter for resistant fraction of foliage debris was higher (set at 83 or 89 per cent) for softwood plantations than all other forest types (set at 77 to 80 per cent). These proportions, as well as the rate parameters derived from calibration of the decay functions, were used as inputs into FullCAM as described by Paul and Roxburgh (2017) and Paul et al. (2022).

Rates of decomposition in FullCAM are influenced by temperature and rainfall using the options of either 'Mulch-style' or 'Soil-style' sensitivity. Decomposition was particularly sensitive to climate using a 'Soil-style' approach. Given the lack of data on how climate impacts rates of decomposition, the more conservative approach of using 'Mulch-style' sensitivity was originally applied; with sensitivity values of 1 being used as per previous NIRs (Paul and Roxburgh 2017). However, with recent refinement of decomposition calibration for tree plantings in Australia, the 'Soil-style' sensitivity is now utilised (Paul, Roxburgh and England 2022).

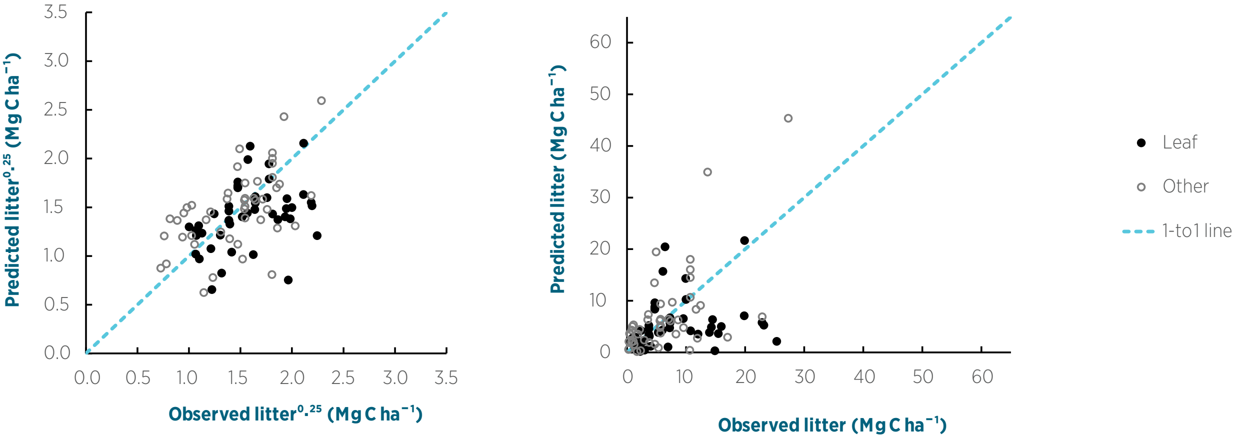
As a result of revising the parameters for rates of turnover and decomposition, predictions of inputs and outputs from the debris pool were changed. Figure A5.6.2.15 below (taken from Paul et al. (2022)) shows that, for the various forest types, using these revised parameters, prediction of litter mass and coarse woody debris was generally within the bounds on one standard deviation in the average observed stocks of these pools. Both the observed and predicted masses of debris will be strongly influenced by the management regime (e.g. harvesting or fire).

Figure A5.6.2.15 Relationship between predicted and observed leaf (or needle) litter and other (bark and deadwood) litter mass for: 25 softwood plantation stands, 16 hardwood plantation stands, and 124 environmental planting stands on the natural scale (right) and transformed scale (left) used for model calibration. Model fit statistics provided are for all pools on the natural scale. Datasets used are listed in Paul et al. (2022)

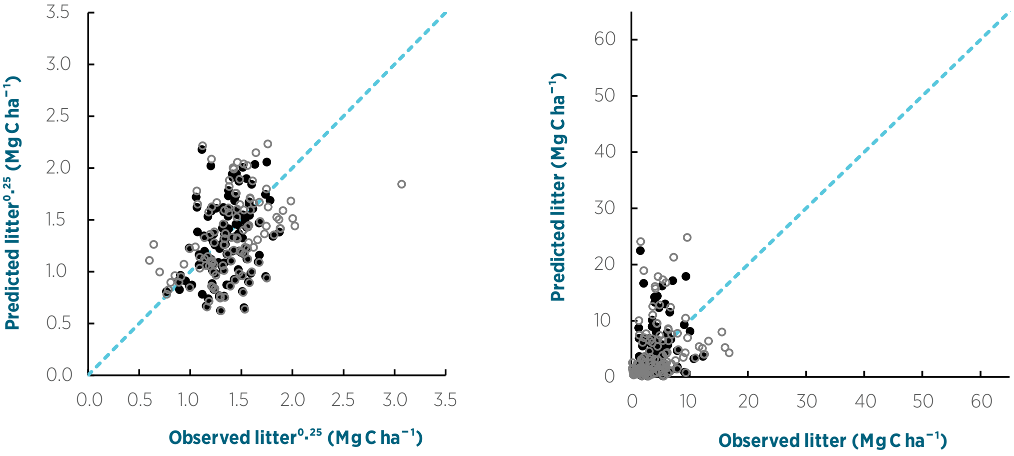
Softwood: Bias= -0.6, RMSE= 7.3 Mg C ha^{-1}, LCC=0.54



Hardwood: Bias= -0.9, RMSE=7.1 Mg C ha^{-1}, LCC =0.42



Env. plantings: Bias= -0.13, RMSE=7.0 Mg C ha^{-1}, LCC =0.19



Estimating changes in forest soils

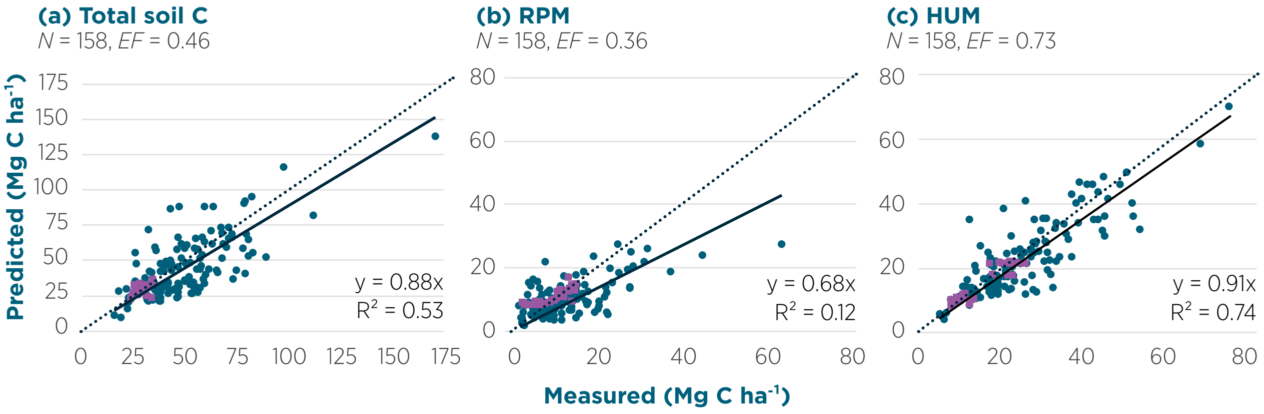
Soil can often be the largest storage of C in forests, and many pools of soil C significantly change in response to land use change, or changes in management. However, the modelling of stocks of soil C is complicated given: stocks are the balance of C inputs from debris decomposition, and outputs from turnover of soil pools, and; many of the important processes influencing soil C are difficult to measure. Hence, there is a paucity of data for inputs such as root turnover and decomposition, the fraction of C lost as CO_2 on decomposition, and turnover rates of the soil pools. Having measurements of the various pools of soil C simulated by FullCAM's RothC sub-model (e.g. RPM, HUM etc., (Baldock, et al. 2013) (Chappell and Baldock 2017)), together with measurements of biomass and litter mass, has been useful to constrain the calibration of some of these parameters (Paul and Polglase 2004) (Paul and Roxburgh 2017) (Paul, England, et al. 2018).

Calibration of key parameters influencing predictions of pools of soil C under forests

Recent datasets of measurement of biomass, litter and pools of soil C were collated from a wide range of forest types across Australia(Paul and Roxburgh 2017). This included 124 paired environmental planting sites (Paul and Roxburgh 2017) and 20 fertiliser and irrigation treatment plots under hardwood and softwood plantations (Paul and Polglase 2004).

As described in detail by Paul and Roxburgh (Paul and Roxburgh 2017), these studies found no justification to adjust any of the RothC parameters calibrated for agricultural soils (Table A5.6.2.9). The approach used was to effectively 'tune' rates of root turnover and decomposition, and the fraction of CO_2-C loss on debris decomposition, to ensure that predicted pools of soil C match that observed, while at the same time constraining predictions of biomass, litterfall and litter mass to that observed. In the absence of any justification to assume otherwise, the values of the parameters for root turnover and decomposition, and the fraction of CO_2-C loss on debris decomposition, were assumed to be the same, regardless of forest type. With such constraints, obtaining high efficiencies of calibration of pools of soil C was challenging. Nonetheless, efficiencies of prediction of total soil C pools was still 43 per cent (and 31 per cent for RPM and 69 per cent for HUM) (Figure A5.6.2.16).

Figure A5.6.2.16 Relationship between observed and predicted carbon stocks (Mg C ha^{-1}) in surface soil (0–30 cm) for: (a) total soil organic carbon; (b) RPM pool of soil C; and (c) HUM pool of soil C



Datasets used in Figure A5.6.2.16 are described by Paul and Polglase (2004) and Paul et al. (2017). Dark green dots represent the paired-site environmental plantings. Pink dots represent the hardwood and softwood repeated-measured forestry trials.

Estimating changes in crop and pasture biomass and debris

Biomass

The model uses crop and pasture yield data and the proportional allocation of dry matter to different plant components to estimate annual dry matter accumulation in agricultural ecosystems.

An earlier analysis (Unkovich, Baldock and Marvanek, Which crops should be included in a carbon accounting system for Australian agriculture? 2009) defined the relevant crops for carbon accounting purposes (Table A5.6.2.5) at the Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (ABS 2010).

Table A5.6.2.5 Field crops accounting for >95 per cent (I), and additional crops for >99 per cent (O) of field crop sowings for Australia as a whole, and in each Australian State in 2006 (Unkovich, Baldock and Marvanek, 2009)

Crop	Aust.	NSW	Vic.	Qld	SA	WA	Tas.
Wheat *(Triticum spp)*	I	I	I	I	I	I	I
Barley *(Hordeum vulgare)*	I	I	I	I	I	I	I
Narrow-leaf lupin *(Lupinus angustifolius)*	I	O	O		O	I	
Canola *(Brassica napus)*	I	I	I		I	I	
Oat *(Avena sativa)*	I	I	I	O	I	O	I
Sorghum (Sorghum vulgare)	I	I		I			
Sugarcane *(Saccarum officinarum)*	I	O		I			
Cotton *(Gossypium hirsutum)*	I	I		I			
Triticale *(Triticum durum xSecale cereale)*	I	I	I		I		I
Chickpea *(Cicer arietinum)*	O	O	O	I			
Field Pea *(Pisum sativum)*	O		I		I	O	
Faba bean *(Vicia faba)*	O	O	O		O		
Rice *(Oryza sativa)*	O	I					
Sunflower *(Heliantus annus)*	O	O		I			
Lentil *(Lens culinaris)*	O		I				
Maize *(Zea mays)*		O		O			
Vetch *(Vicia sativa)*			O		O		
Mung bean *(Phaseolus aureus)*				O			
Peanut *(Arachis hypogaea)*				O			
Soybean *(Glycine max)*				O			
Millet *(Pennisetum spp)*				O			
Oil Poppies *(Papaver somniferum)*							I

The available data has been reviewed to develop appropriate harvest indices for each plant type to enable conversion from mass of saleable product to total plant mass (Unkovich, Baldock and Forbes 2010). The proportional allocations of dry matter to plant components were determined from estimates by expert field agronomists and includes allocations to roots, GBF (grains, buds and fruit), stalks and leaves, coarse roots and fine roots. The crop types and plant partitioning used in the model are shown in Table A5.6.2.6.

The crop and pasture yield data for each cropping system, SA2 region and soil type are estimated in FullCAM (see Appendix 5.6.5).

Table A5.6.2.6 Plant partitioning by crop and pasture type

Species Name	Yield Allocation to Grains, Buds or Fruit (fraction)	Yield Allocation to Stalks (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Annual & perennial (incl. Mulga)	0.00	0.00	0.53	0.00	0.47
Annual grass	0.00	0.00	0.53	0.00	0.47
Annual legume	0.00	0.00	0.53	0.00	0.47
Annual legume irrigated	0.00	0.00	0.53	0.00	0.47
Aristida-Bothriochloa	0.00	0.00	0.53	0.00	0.47
Barley	0.30	0.00	0.47	0.00	0.23
Black speargrass	0.00	0.00	0.53	0.00	0.47
Blady grass	0.00	0.00	0.53	0.00	0.47
Blue lupin	0.00	0.00	0.53	0.00	0.47
Bluebush/Saltbush	0.00	0.00	0.53	0.00	0.47
Bluegrass-browntop	0.00	0.00	0.53	0.00	0.47
Canola	0.21	0.00	0.56	0.00	0.23
Chickpea	0.28	0.00	0.49	0.00	0.23
Cotton – irrigated	0.33	0.10	0.13	0.22	0.22
Cotton – rainfed	0.33	0.10	0.13	0.22	0.22
Faba bean	0.23	0.00	0.54	0.00	0.23
Field pea	0.28	0.00	0.49	0.00	0.23
Grass only – brigalow/ gidyea	0.00	0.00	0.53	0.00	0.47
Grazed cereal	0.00	0.00	0.53	0.00	0.47
Grazed cereal – irrigated	0.00	0.00	0.53	0.00	0.47
Grazed vetch	0.00	0.00	0.53	0.00	0.47
Lentil	0.26	0.00	0.51	0.00	0.23
Lucerne	0.00	0.00	0.53	0.00	0.47
Lucerne irrigated	0.00	0.00	0.53	0.00	0.47
Maize	0.38	0.31	0.08	0.00	0.23
Millet	0.20	0.00	0.57	0.00	0.23
Mitchell grass	0.00	0.00	0.53	0.00	0.47
Monsoonal annual	0.00	0.00	0.53	0.00	0.47
Monsoonal perennial	0.00	0.00	0.53	0.00	0.47
Mung bean	0.23	0.00	0.54	0.00	0.23
Narrow-leaf lupin	0.22	0.00	0.55	0.00	0.23
Native annual	0.00	0.00	0.53	0.00	0.47
Native annual improved	0.00	0.00	0.53	0.00	0.47
Oat	0.16	0.00	0.61	0.00	0.23
Oil poppies	0.385	0.00	0.385	0.00	0.23
Peanut	0.25	0.00	0.52	0.00	0.23
Perennial grass	0.00	0.00	0.53	0.00	0.47

Species Name	Yield Allocation to Grains, Buds or Fruit (fraction)	Yield Allocation to Stalks (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Perennial grass Irrigated	0.00	0.00	0.53	0.00	0.47
Perennial grass/clover	0.00	0.00	0.53	0.00	0.47
Perennial legume	0.00	0.00	0.53	0.00	0.47
Queensland bluegrass	0.00	0.00	0.53	0.00	0.47
Rice	0.31	0.00	0.46	0.00	0.23
Samphire	0.00	0.00	0.53	0.00	0.47
Sorghum	0.352	0.00	0.418	0.00	0.23
Soybean	0.23	0.00	0.54	0.00	0.23
Spinifex	0.00	0.00	0.53	0.00	0.47
Sugarcane	0.00	0.64	0.13	0.00	0.23
Sunflower	0.31	0.31	0.15	0.00	0.23
Triticale	0.26	0.00	0.51	0.00	0.23
Tropical grass	0.00	0.00	0.53	0.00	0.47
Vetch	0.30	0.00	0.47	0.00	0.23
Wheat	0.275	0.00	0.495	0.00	0.23

Carbon contents of crop and grass species

Plant dry matter is converted to carbon using a crop carbon content value that is specific to the species in use, in the model. These average values for crop species are sourced from Roth-C (https://www.rothamsted.ac.uk/rothamsted-carbon-model-rothc). These values are a ratio of 1.44 for DPM/RPM for agricultural crops and improved grassland, and a ratio of 0.67 for unimproved grassland.

Debris

The amount of plant residue generated and available onsite by a crop or grass species is dependent on both the plant growth and management practice. As well as containing the crop/pasture growth and species data, the relational database describes the agricultural management practices, (e.g. stubble management) applied to each crop/pasture (see Annex 5.6.5). These parameters describe how much of the crop mass becomes litter residue, the rate of residue decomposition, and how much of the decomposed residue is incorporated into the soil carbon pools.

Initial crop litter mass and decomposition rates and carbon use efficiency

The initial mass of litter assigned, decomposition rates and carbon use efficiency for each decomposable and resistant plant pool are shown in Table A5.6.2.7.

Table A5.6.2.7 Initial litter mass and decomposition rates and carbon use efficiency for crop systems

Plant Component	Initial Mass t ha^{-1}	Decomposition Rate yr^{-1}	Carbon Use Efficiency
Grains, Buds, Fruit (Resistant)	0.01	0.1	60%
Grains, Buds, Fruit (Decomposable)	0	0.3	60%
Stalks (Resistant)	0.01	0.1	60%
Stalks (Decomposable)	0.01	0.3	60%
Leaves (Resistant)	0.01	0.1	60%
Leaves (Decomposable)	0.01	0.3	60%

Plant Component	Initial Mass t ha^{-1}	Decomposition Rate yr^{-1}	Carbon Use Efficiency
Coarse Roots (Resistant)	0.01	1	60%
Coarse Roots (Decomposable)	0.01	1	60%
Fine Roots (Resistant)	0.01	1	60%
Fine Roots (Decomposable)	0.01	1	60%

Crop turnover rates

Turnover represents the natural shedding of material by the plant. Turnover moves directly to the debris pool. All parts of a plant are subject to turnover, including roots. Root sloughing in response to grazing is included in the model which maintains the relative ratio of aboveground to belowground plant mass when grazed. Table A5.6.2.8 shows the monthly turnover rates applied to crop and pasture systems.

Table A5.6.2.8 Turnover rates applied to crop and pasture systems

	Turnover Rates month^{-1}	
Plant Component	**Pasture species**	**Annual crop species**
Grains, Buds, Fruit	0	0
Stalks	0	0.008
Leaves	0.07	0.07
Coarse Roots	0	0.008
Fine Roots	0.125	0.125

Estimating changes in soil carbon

The Rothamsted soil carbon model *(Roth-C)* is a soil carbon model developed by Jenkinson et al. (1991). *Roth-C* models changes in soil carbon based on the inputs of organic matter from dead plant material and soil carbon decomposition rates. Within *Roth-C* there are five soil carbon pools generally defined by classes of resistance to decomposition. Plant residues are firstly split into decomposable and resistant plant material. Turnover rates for each soil pool are determined by rainfall, temperature, groundcover and evaporation other than decomposition rate constants specific to each soil carbon pool. *Roth-C* is used in conjunction with both *CAMFor* and *CAMAg* to model soil carbon stocks in the national account.

The model was initialised using measureable soil carbon fractions (see Annex 5.6.5) by replacing the key conceptual pools namely DPM, RPM and HUM defined in the *Roth-C* model. *Roth-C* model also utilises clay content and the initial topsoil moisture deficit as inputs to carry out soil carbon simulations.

Model calibration, validation and verification

Calibration of *Roth-C* was undertaken using available long-term field trial data, which had sufficiently detailed and complete long-term data to enable calibration of the model against long-term field measurements. Only a minimum of data supplementation was accepted at these calibration sites. Other sites with incomplete long-term data, but providing a robust temporal pattern of carbon change under known management and climate, were used for model validation and verification (Skjemstad and Spouncer, 2002).

Calibration and validation

Two agricultural and seven forestry long term trial sites were selected for estimating changes in soil carbon.

One agricultural site was located on a monsoonal subtropical environment with heavy clay soil and the other was located in a temperate Mediterranean climate with a light textured soil. At each agricultural site, archival soil samples (0-30 cm depth) collected throughout the life of the trials were fractionated into particulate organic carbon (POC), charcoal (char-C) and humic (HUM) pools (Skjemstad and Spouncer 2003).

The soil carbon model *(Roth-C)* used to calculate changes in soil carbon stocks caused by shifts in agricultural practice was independently calibrated and validated (Skjemstad and Spouncer 2003). The results were found to be sensitive to the partitioning of carbon between the various soil fractions (Janik, et al. 2002) (J. Skjemstad, L. Spouncer, et al. 2004) (Paul and Polglase 2004).

Testing of the seven forestry sites and two agricultural sites confirmed the model calibrations for soil carbon pool allocations for both forestry and agricultural sites. Details of the calibration and testing of the model are provided in Paul et al. (2002) (2003).

Model validation used existing time-series data and new paired-site comparisons to test model predictions of change. Calibration of the model demonstrated that the measureable soil carbon fractions (POC, HUM and Char-C pools/ROC) fitted well with the modelled carbon pools (RPM, HUM and IOM) as defined in *Roth-C*.

A full description of the model calibration and validation results for agriculture can be found in Skjemstad and Spouncer (2003).

In general terms the coefficient of variation for modelled outputs of soil carbon is around 5 per cent (Janik, et al. 2002), whereas the coefficient of variation for measured soil carbon is 15-40 per cent (McKenzie, Jacquier, et al. 2000) (McKenzie, Ryan, et al. 2000) (Janik, et al. 2002). Further details are provided in Murphy et al. (2002), Harms and Dalal (2003) and Griffin et al. (2002).

More recently Chappell and Baldock (2017) were commissioned by the Department of the Environment and Energy to enhance the reliability of soil carbon change estimates provided by the FullCAM framework.

A local optimisation was performed separately for each of the 103 plots of the calibration and verification sites (Skjemstad and Spouncer 2003) allowing optimisation of three initial stocks of SOC pools (RPM, HUM and IOM) and the decomposition rate constant parameters (RPM and HUM). The optimised values of the initial soil carbon pools were then used in a separate global optimisation of the same measurement data but with optimisation of only the decomposition parameters (RPM and HUM).

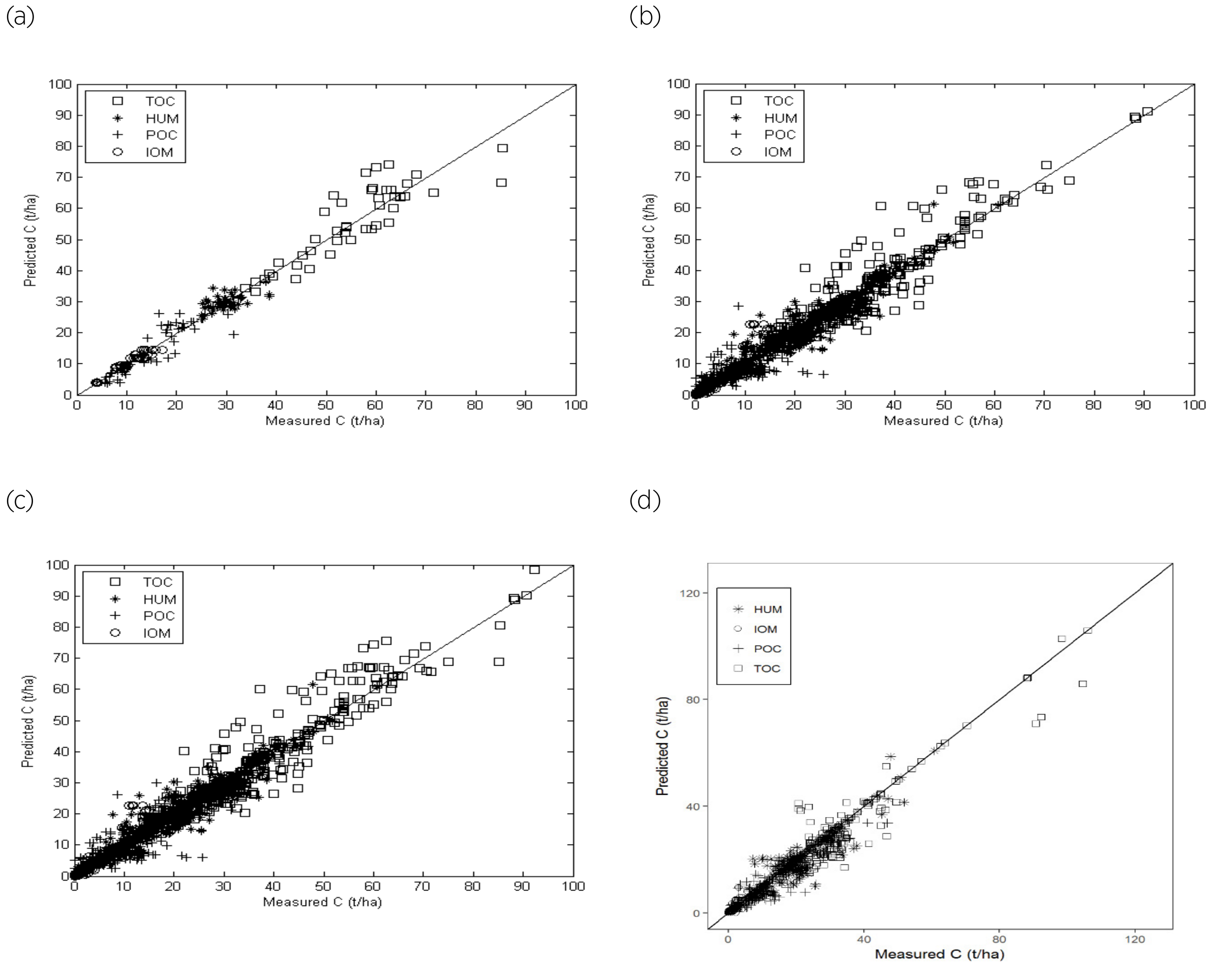
The results are shown in Table A5.6.2.9.

Table A5.6.2.9 Roth-C model including soil redistribution globally fitted decomposition rates and their goodness of fit

	RPM	HUM	RMSE
Global optimistation	y^{-1}	y^{-1}	(C t ha^{-1})
Calibration sites	0.207	0.021	0.234
Verification sites	0.149	0.029	0.095
All sites	0.173	0.028	0.090

Figure A5.6.2.17a (below) shows a plot of measured C for all site data of Brigalow and Tarlee against *Roth-C* predicted C using the optimised values of the decomposition parameters RPM=0.207 y^{-1} and HUM=0.021 y^{-1}. The RMSE of the global model fitting was 0.234 (C t/ha) which describes the error associated with model predictions using the parameter values calibrated against these data.

Figure A5.6.2.17 Global optimisation of the Roth-C model (using decomposition parameters for RPM and HUM) against the measured C of the RPM (POC), HUM (HOC) and IOM (ROC) pools of the (a) calibration site Brigalow and Tarlee, (b) the verification sites only and (c) the calibration verification sites combined and (d) verification of selected sites using FullCAM

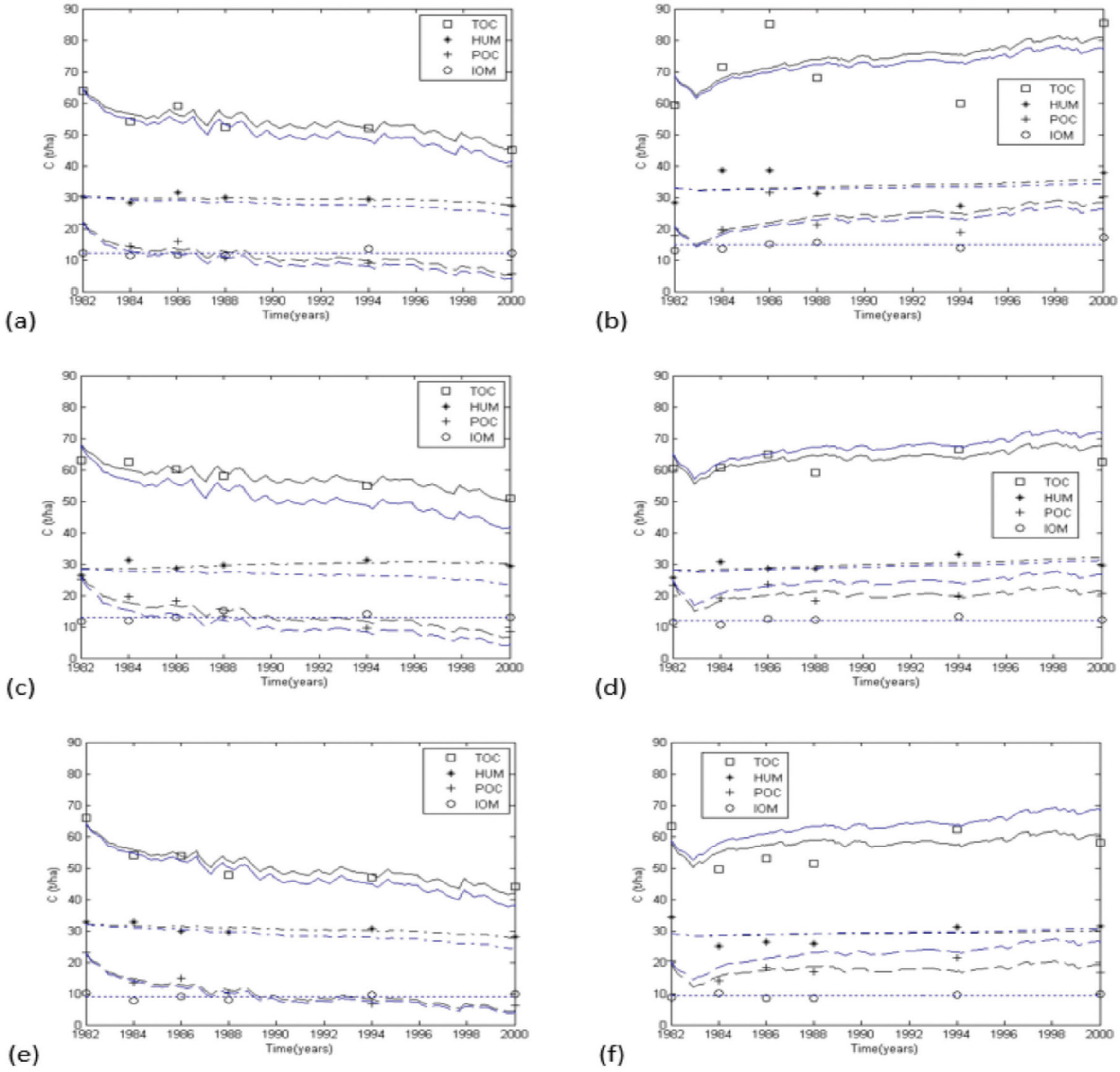


Source: Chappell and Baldock (2017) and the unpublished work carried out by the DoEE (2017).

Figure A5.6.2.17b shows a plot of measured C for all site verification data against Roth-C predicted C using the optimised values of the decomposition parameters RPM=0.149 y-^{1} and HUM=0.029 y^{-1}. The RMSE of the global model fitting was 0.095 (C t/ha). Figure A5.6.2.16c shows a plot of measured C for all sites (calibration and verification) data against Roth-C predicted C using the optimised values of the decomposition parameters RPM=0.173 y^{-1} and HUM=0.028 y^{-1}. The RMSE of the global model fitting was 0.090 (C t/ha). Evidently, the previously recommended values of RPM = 0.15 y^{-1} and HUM = 0.02 y^{-1} are within the variation found across the plots and sites around Australia but these values are smaller than the globally fitted decomposition rates. As such the decomposition parameters have been adjusted to reflect this latest research and provide the most robust calibration of FullCAM. Further verification using FullCAM revealed that correlation between measured and simulated total soil carbon reported 0.94 correlation while RMSE value was reported as 5.74 C t/ha.

Figure A5.6.2.18 shows the behaviour of *Roth-C* model temporal simulations for two sites in Brigalow with RPM and HUM soil decomposition rate constants values obtained from local and global optimization process. Even though the locally optimised rate constant values mimic much closer representativeness with simulated data and measurable fractions, globally optimised parameters also produced very similar pattern.

Figure A5.6.2.18 Brigalow continuous wheat (a, c & e) and Brigalow continuous pasture (b, d & f) with Roth-C local model fits (black line) and global model fits (blue line) using decomposition parameter values RPM=0.173 and HUM=0.028



Source: Chappell and Baldock (2017)

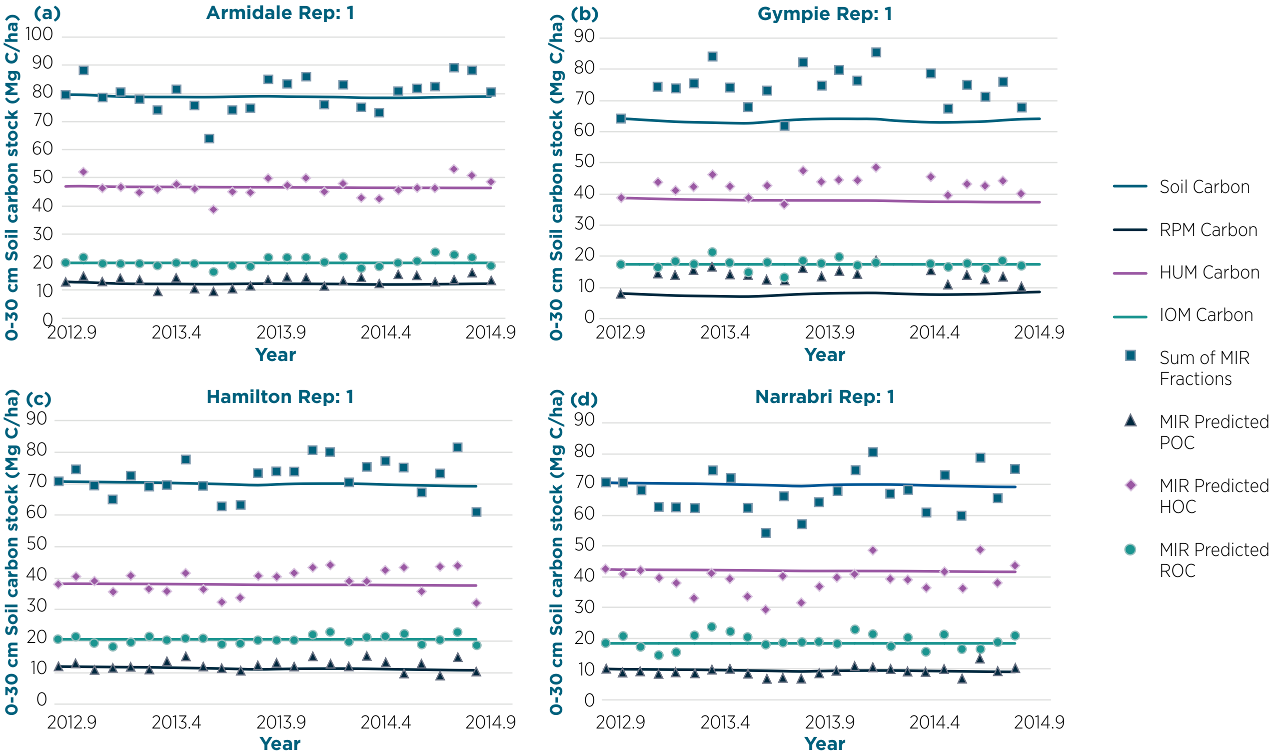
Verification of FullCAM Outputs

Independent soil carbon measurements undertaken through the Filling the Research Gap (FtRG) program, funded by the Australian Government Department of Agriculture and Water Resources, were used to verify the FullCAM simulations.

Figure A5.6.2.19 shows comparison of selected FullCAM plot simulations with field data (MIR predicted) collected by CSIRO Agriculture and Food, under the FtRG program. These sites represent the major cropping regions of the country. For this verification, we used site specific climate data, soil carbon fractions measured using mid-infrared spectroscopy, while temporal carbon inputs were added based on the cropping regimes included in the FullCAM database.

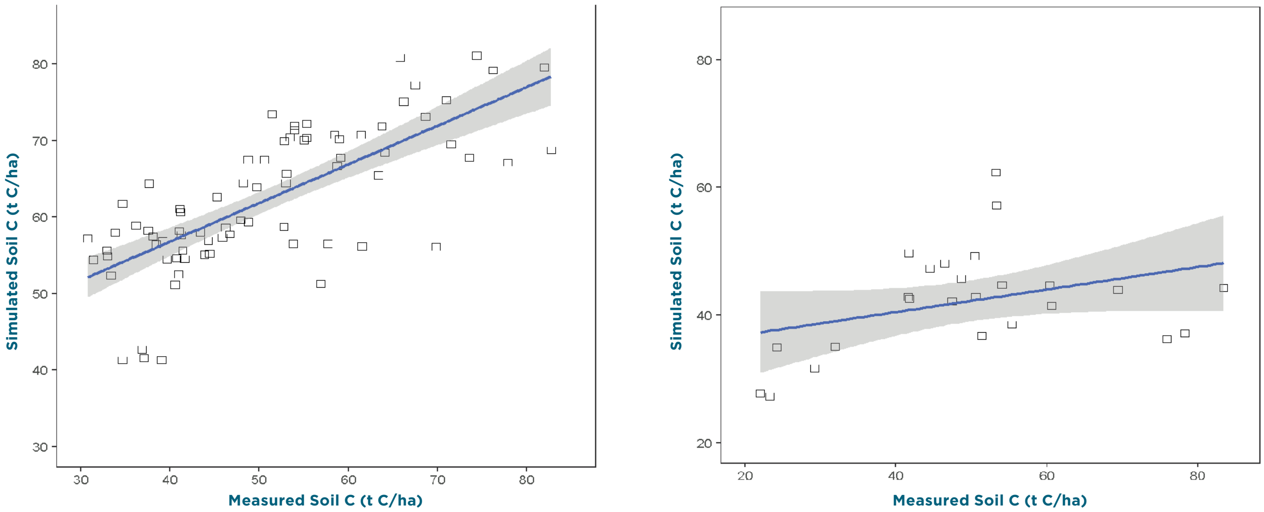
This verification exercise confirmed the reliability of FullCAM estimates as indicated by overall RMSE value of 9.21 tC/ha and correlation value of 0.60 for the temporal values recorded for 20 sites.

Figure A5.6.2.19 FullCAM outputs (solid lines) using global decompositions parameters with field measured (MIR predicted) (dotted points) total soil carbon and its fractions for the selected sites Armidale, (b) Gympie, (c) Hamilton and (d) Narrabri



Additionally, FullCAM outputs were assessed using a second of set of independent field data collected by the Department of Economic Development, Jobs, Transport and Resources (DEDJTR) – Victoria State Government (n=77 sites) and CSIRO Agriculture and Food (n=25 sites). In this case, soil fractions data was not available and total soil carbon measurements were obtained for one time only. The results showed an RMSE error of 14.4 C t/ha and 16.8 C t/ha and correlation between measured and simulated soil carbon values as 0.73 and 0.36 for the DEDJTR and CSIRO Agriculture and Food respectively (Figure A5.6.2.20).

Figure A5.6.2.20 Verification of FullCAM estimates using measured soil carbon data from the DEDJTR (a) and CSIRO Agriculture and Food (b)

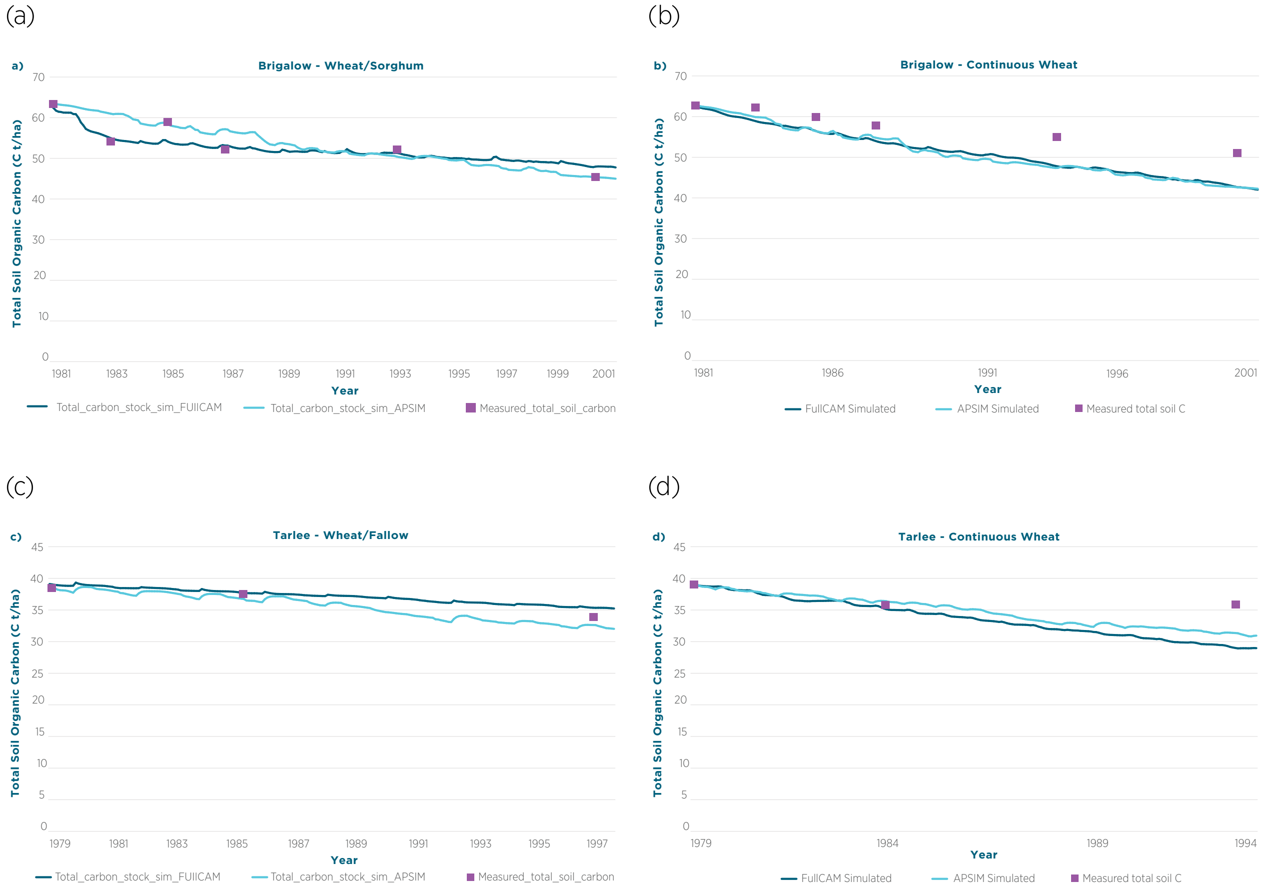


Comparison of the FullCAM estimates with APSIM outputs

FullCAM outputs were also compared with the Agricultural Production Systems sIMulator model (APSIM) version 7.0 as shown in Figure A5.6.2.21. APSIM is internationally recognized as a highly advanced simulator of agricultural systems. It contains a suite of modules which enable the simulation of systems that cover a range of plant, animal, soil, climate and management interactions (Keating, et al. 2003). For this comparison, APSIM results for four sites were provided by CSIRO Agriculture and Food (Luo, et al. 2015). Both FullCAM and APSIM were run using the same set of field measurements.

The correlation analysis for the temporal simulations between FullCAM and APSIM for each month reported 0.92, 0.99, 0.98, 0.99 for four sites in Brigalow – Wheat/Sorghum, Brigalow – Continuous Wheat, Tarlee – Wheat/Fallow and Tarlee – Continuous Wheat respectively indicating high level of confidence in the outputs. FullCAM, which is specifically designed for carbon accounting purposes, was able to replicate the APSIM, which was designed for agricultural system modelling.

Figure A5.6.2.21 Comparison of FullCAM simulations with APSIM simulations for the selected sites (a) Brigalow – Wheat/Sorghum, (b) Brigalow – continuous Wheat, (c) Tarlee – Wheat/Fallow and (d) Tarlee – continuous Wheat



Subsequent to the implementation of the baseline map of organic carbon in Australian soil (Viscarra Rossel, Bui and Baldock 2014), the Australian three-dimensional soil grid (Clay) (R. Viscarra Rossel, C. Chen, et al. 2015), updated species (Table A5.6.2.4) and management practices (Annex 5.6.5) as well as the optimisation of the decomposition rates (Calibration and Validation), the Department of Environment and Energy undertook a modelling exercise in which FullCAM was used to simulate the effects on soil carbon of changes in practices to manage stubble, tillage and the amount of crop biomass as well as estimate the effects of a change in land use from a continuous cropping to a pasture system and a continuous pasture to rotational cropping system.

Given the impact of climate and soil properties on the technical potential of soil carbon enhancement and the uncertainty distribution around the technical potential, seven sites were selected to reflect four main temperature and moisture regimes (Cool-Wet; Cool-Dry; Warm-Wet; Warm-Dry) defined in accordance with the IPCC 2006 Guidelines (IPCC 2006). For each of the sites selected, the Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (ABS 2010) in which the site is located was identified.

For each of the seven selected sites, statistics (minimum, mean and maximum values and standard deviations of the values) for the percentage of soil that is clay by weight and total were determined for the SA2 in which the selected sites were located and regression analysis on the percentage of soil that is clay by weight and total soil carbon for the SA2s was carried out to determine the correlation coefficient between the two key soil properties.

The minimum, mean and maximum values, and standard deviations for the percentage of soil that is clay by weight and total soil carbon were applied as risk variables in the Monte-Carlo analysis using @Risk (Palisade Corporation 2005). Parameterisation was designed to ensure that values that would not occur within the SA2 of the selected site were not used in the Monte-Carlo analysis. This approach ensures regional specificity by removing/reducing skew/bias and normalises the outputs according the input data so that the outcomes are truly reflective of that particular SA2, while allowing for the inherent variability in climate and soil type across the Australian landscape and, more specifically, the SA2.

The correlation between the percentage of soil that is clay by weight and total carbon, (including the 1:1 correlation between the soil fractions and the total soil carbon) was applied in the Monte-Carlo simulation correlation matrix to ensure proportionality of soil fractions and clay were observed.

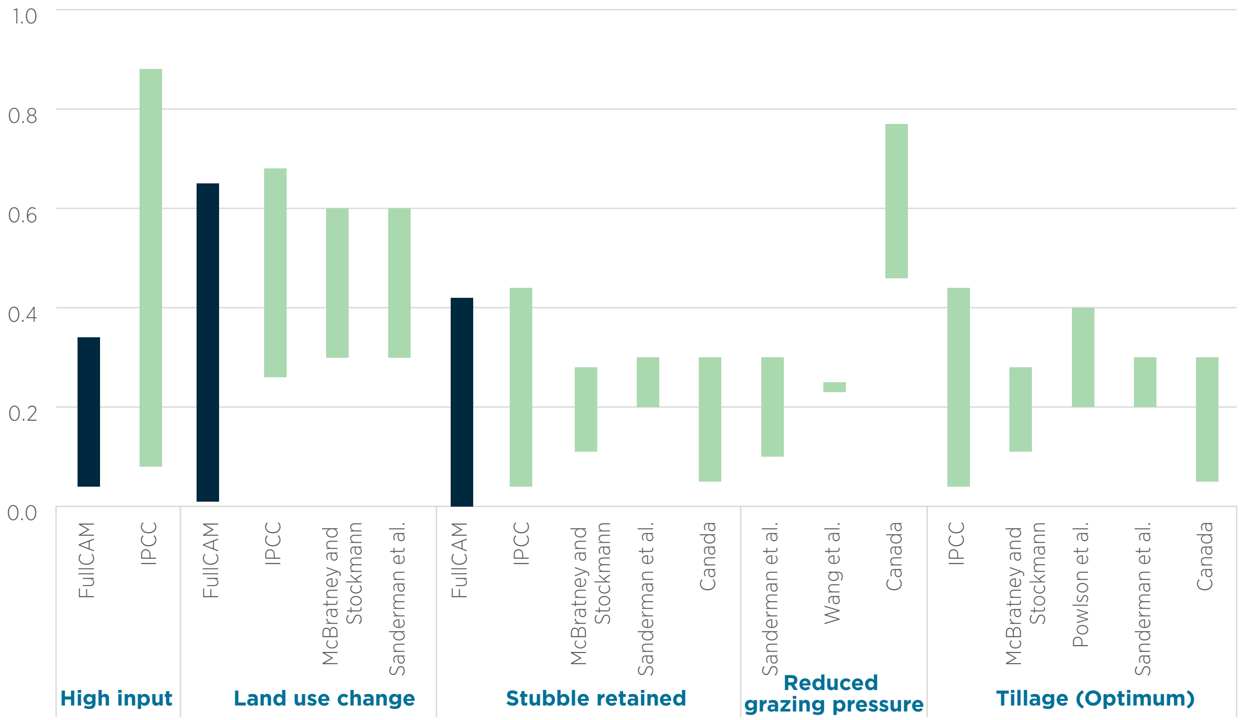
A truncated normal distribution was applied to the Monte-Carlo simulations to ensure the probability distribution of the output value for soil carbon stock is bounded above and below by the minimum and maximum values for the input risk variables.

The Monte-Carlo simulations were run for a full 1000 simulations as opposed to ceasing when convergence was met. This repeated sampling enabled the output value for soil carbon stock to converge on as close to the most probable technical potential value attainable for the SA2.

Factual (baseline) and counter-factual (scenario) simulations of selected activities identified in the IPCC 2006 Guidelines (IPCC 2006) and the 2013 IPCC Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (KP) Supplement (IPCC 2014) were run in FullCAM.

National values for the estimated response of soil carbon to changes in various management practices are presented in Figure A5.6.2.22. The results are within expected ranges and consistent with empirical literature and international practice. The model does not generate a single value, but a range of values where the distribution of values generated by the model is presented for each of the changes in management practices. The distribution of values demonstrates the variability in outcomes modelled by FullCAM, mainly reflecting spatial variations in soil quality, which is entirely expected from empirical experience across Australia. Figure A5.6.2.22 illustrates the variation in outcomes of differences in soil carbon sequestration and/or reduction in the rate of losses in a sensitivity scenario where the yields were increased by 20 per cent over a period of years.

Figure A5.6.2.22 Comparison for soil carbon response to changes in management practices for FullCAM and from domestic empirical literature and international practice



Comparison of the FullCAM estimates with IPCC Tier 2 Soil Carbon Method

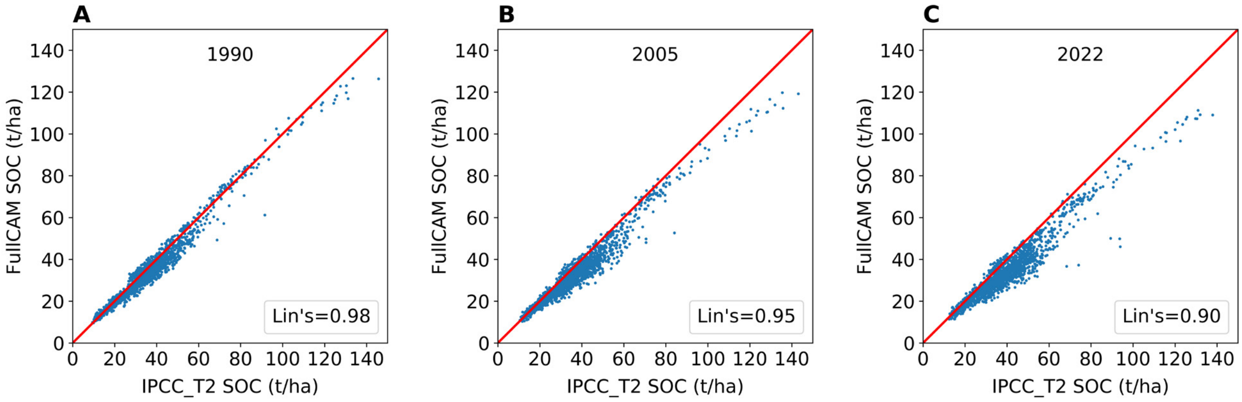
The Tier 2 steady-state soil carbon model provided in the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2019, Volume 4 Chapter 5) was compared with FullCAM outputs for croplands. Detailed analysis of the application of the IPCC Tier 2 steady-state soil carbon model to Australian croplands is provided in Baldock et al. (2021). The model has been rerun and compared with FullCAM outputs incorporating revised yields, grass handling changes, and spatial updates.

The IPCC Tier 2 model (IPCC_T2) is based on the Century model with three conceptual carbon sub-pools, while the Inventory's Tier 3 FullCAM, with a soil module is based on the RothC model, has five conceptual sub-pools. In addition, the FullCAM model has been calibrated and verified with measured data points for Australian conditions, and includes variable land management practices such as stubble and tillage events, while the IPCC_T2 has been calibrated with global datasets that overwhelmingly represents the northern hemisphere.

The same land management, yield data (to generate carbon inputs) and climate datasets were used for both FullCAM and IPCC_T2, and the IPCC_T2 model was initialised with measurable fractions considering FullCAM RPM (Resistant Plant Material) stock as the initial slow pool stock and the HUM (humus) and IOM (inert) stock as the initial passive pool stock. The initial stock of the IPCC_T2 active organic carbon was set to zero.

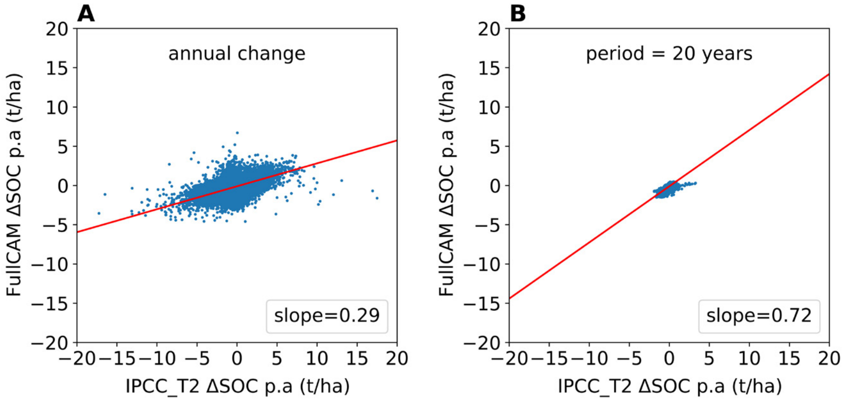
Simulations were carried out from 1970-2022 using 1795 cropland sites collated from the Australian Soil Carbon Research Program (SCaRP), covering the main cropping regions of Australia. Figure A5.6.2.23 shows the relationship between soil carbon stocks in 1990, 2005, and 2022; excellent agreement between the two approaches is indicated by a Lin's concordance correlation coefficient of 0.90-0.98. The Tier 2 model tends to predict slightly higher soil carbon in more recent years than FullCAM.

Figure A5.6.2.23 Comparison of soil carbon stocks for 1795 SCaRP sites generated using the IPCC Tier 2 steady-state model and FullCAM in (A) 1990, (B) 2005, and (C) 2022



Plotting the annual change in soil carbon for the two models as a scatter plot (Figure A5.6.2.24a) shows that the IPCC_T2 is more volatile, with changes greater than ±15 t/ha in some cases, while FullCAM changes up to ±5 t/ha. This difference in annual changes is not reflected in long-term carbon stock changes over longer periods, the two models showed average annual stock changes with lower magnitude (±2.6 t/ha/ year) and in close agreement, particularly over an interval of 20 years (Figure A5.6.2.24b).

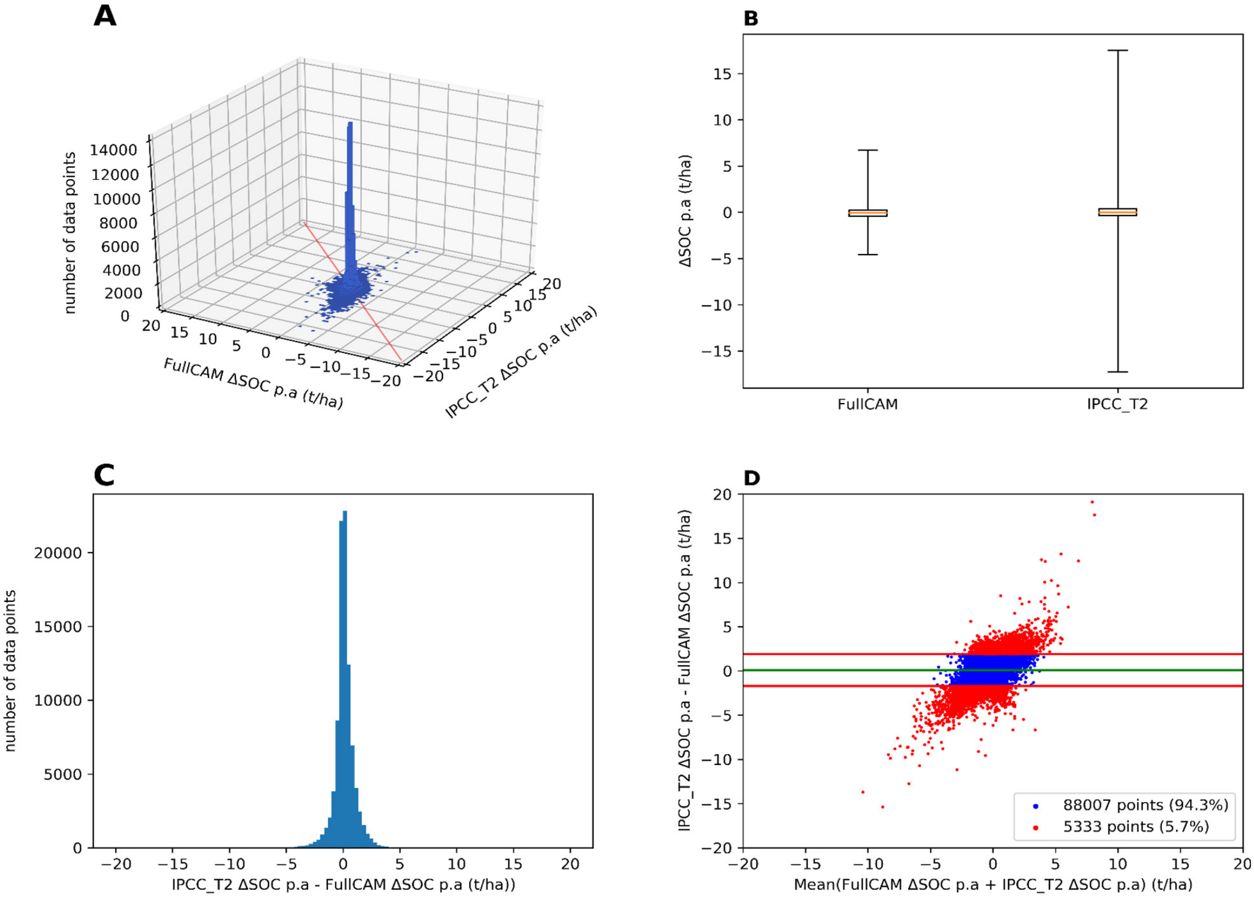
Figure A5.6.2.24 (A) Annual changes in soil carbon stocks 1970-2022 across all sites using the IPCC_T2 and FullCAM models. (B) Averaged over a 20-year interval (p.a: per annum)



The scatter plot in Figure A5.6.2.24a also obscures the intense clustering of data, therefore further analysis of the annual changes in soil carbon stocks was undertaken. A 3D bar plot (Figure A5.6.2.25a) indicates the vast majority of data points fall on the concordance line close to zero. Box and whisker plots (Figure A5.6.2.25b) indicate that the annual stock changes generated from the two models have similar distributions, means and quartiles. This is further corroborated by a difference analysis (Figure A5.6.2.25c), which shows the differences between the models displaying a normal distribution with a mean centred near zero (0.11 t/ha/year) and low variance (s.d. 0.905). Finally, a Bland-Altman analysis (Figure A5.6.2.25d) indicates that >94% of the data points lie within 2 standard deviations of the mean difference, where 95% is considered good agreement between two methods.

The new IPCC_T2 model provided a valuable opportunity to compare estimates of soil carbon change with those produced by the FullCAM model used in the National Inventory. There is statistically good agreement even between annual changes, and this agreement becomes very good over longer periods, including the 20-year period noted by the IPCC Guidelines as the typical time to achieve new equilibrium following a change in management conditions.

Figure A5.6.2.25 Analysis of annual carbon stock changes from the IPCC_T2 and FullCAM. (A) 3D barplot of data from Fig A5.6.2.14a (bins = 0.5 t/ha). (B) Box and whisker plots showing similar means and interquartile ranges for the two models, but greater spread for IPCC_T2. (C) Histogram (nbins =120) of difference in annual stock changes modelled using Tier 2 steady state model and FullCAM (mean 0.11 t/ha/year, s.d. 0.905). (D) Bland-Altman plot (green line: mean difference, red lines: ±2 standard deviations from mean difference, blue points within ±2 s.d. of mean difference, red points > 2 s.d. from mean difference)



Parameters for forest plantations

The parameters and calibrations discussed thus far are relevant for the behaviour of native vegetation, but do not support the cultivation of plantation species with monoculture characteristics. For these types of forests, a different set of parameters are used.

Forest growth

As described in detail by Paul et al (2022) the empirical Tree Yield Formula (TYF) was calibrated to predict the accumulation of live above-ground biomass for a range of tree species and species groups. The TYF parameters were calibrated to commercial plantings and farm forestry yield data collected through a literature search and augmented by plantation industry input.

Similarly, as described in detail by Paul and Roxburgh (2020), the empirical Tree Yield Formula (TYF) was also calibrated for land converted to forest through regeneration from natural seed source. The TYF parameters were calibrated to yield data collected through a literature search.

Although the TYF is applied to predict forest growth from seed or tube stock, the Biomass Recovery Formula (BRF) is applied to empirically predict recovery of above ground biomass post-thin or post-coppice, as discussed earlier in this annex. Paul et al. (2022) provides some verification of the recovery function for some specific examples from thinning studies in commercial plantations.

Partitioning of biomass and growth of below-ground biomass

Allocation of total live biomass to stem, branches, bark, leaves, coarse roots and fine roots (Table A5.6.2.10) were informed by datasets collated from biomass sampling studies across a range of different types of tree plantings as described in detail by Paul et al. (2022) for commercial plantations and farm forestry, and by Paul and Roxburgh (2019) for natural regeneration in regions of relatively high and low rainfall.

Table A5.6.2.10 Example of the different partitioning of biomass to each of the tree components under different types of plantation species

Forest Type	Allocation (proportions)					
	Stem	Branch	Bark	Leaf	Coarse roots	Fine roots
Softwoods	0.473	0.136	0.064	0.086	0.209	0.032
Softwoods (pinaster)	0.378	0.108	0.051	0.069	0.325	0.068
Hardwoods	0.408	0.190	0.072	0.106	0.193	0.031
Mallees	0.238	0.164	0.041	0.114	0.363	0.080
Environmental plantings	0.291	0.198	0.086	0.131	0.246	0.048
Natural regeneration (>500 mm)	0.492	0.106	0.091	0.038	0.240	0.033
Natural regeneration (<500 mm)	0.277	0.217	0.081	0.074	0.266	0.084

Carbon content

The carbon fractions of above and below ground biomass components for Australian vegetation are reported in Table A5.6.2.11 and taken from Gifford (2000).

Table A5.6.2.11 Percent carbon of tree components – land converted to forest land

Tree Component	Hardwood carbon content %	Softwood carbon content %	Other (environmental plantings) carbon content %
Stems	50.0	51.0	50.0
Branches	46.8	51.4	46.8
Bark	48.7	53.3	48.7
Leaves	52.9	51.1	52.9
Coarse roots	49.2	50.4	49.2
Fine roots	46.1	48.4	46.1

Forest management practices

The Tier 3, Approach 3 modelling system is supported by a comprehensive database of the plantation management practices used in Australia since 1970 (Waterworth and Richards 2008). The plantation management database contains information on management practices for each tree species within each region. The range of possible management actions is shown in Table A5.6.2.12. The management regimes are assigned frequencies within each region to enable time series management regimes to be developed for each plantation pixel through time (Table A5.6.2.13) (Waterworth and Richards 2008).

Table A5.6.2.12 Management actions, the FullCAM events used to represent them and the choices available through parameterisation of the FullCAM event

Management action	FullCAM event type	Effect in model	Standard event options
Chopper roll	Chopper roll (forest)	Transfers woody debris to faster decaying ‘chopped wood’ pool	Chopper roll
Management fires	Forest fire (forest)	Transfers carbon from trees to debris and atmosphere, and debris to the atmosphere or soil pools.	Prescribed burn Broadcast burn Windrow and burn
Wildfire	Forest fire (forest)	Transfers carbon from trees to debris and atmosphere, and debris to the atmosphere or soil pools.	Trees killed Trees not killed
Grazing	Graze (agriculture)	Removes aboveground herbaceous species mass and varies root slough	Normal Heavy
Plant trees	Plant trees (forest)	Establishes trees on a site	Different initial masses depending on stocking
Cultivation	Plough (agricultural)	Moves herbaceous species carbon to debris, mulch and soil	Spot cultivation Strip cultivation Broadcast cultivation

Source: Waterworth and Richards (2008)

2013. 1. Although not a management practice, wildfire events allow for the future spatial modelling of their effect on carbon stocks. See the discussion for more details.

Table A5.6.2.13 Plantation management database – Time series management regime

Year	Day	Species	Management action	FullCAM event
0	152	Agricultural species	Cultivation: Strip plow	Plow
0	196	Pinus radiata	Plant trees: seedlings normal stocking	Plant trees
0	196	NA	Forest percentage -> determined by tree yield formula	Forest percentage Change
1	196	Agricultural species	Weed control post planting: Strip herbicide	Herbicide
10	196	Pinus radiata	Fertilisation: Mid-rotation (Medium)	Type 1 Forest Treatment
10	197	Pinus radiata	Prune (Selective 33%)	Forest Thin
20	196	Pinus radiata	Thin 2 (SthnTbl ACT 1978–1996)	Forest Thin
30	196	Pinus radiata	Thin 3 (SthnTbl ACT 1987–1996)	Forest Thin
See note	196	Pinus radiata	Thin clearing Pa (SthnTbl ACT 1987–1996)	Forest Thin

Note: The year of plantation harvesting is determined using satellite imagery.

The species table in FullCAM contains information on tree species characteristics including forest growth model parameters, carbon allocation to tree components over time, biomass carbon percentages, turnover rates for each tree component, decay and product use data. These data allow FullCAM to model forest growth for any point based on the site and climate data using the methods described previously.

Debris

Turnover and decomposition rates

The amount of carbon moved from living biomass to the DOM pools due to forest harvesting is determined in the model by the age, type of harvest and species characteristics. The above ground harvest residues were assumed to be standing dead material, which slowly breaks down (Table 6.4.7a) to produce CO_2 and debris at an assume ratio of 9:1 (Paul and Roxburgh 2019) consistent with the methods applied for harvested native forests.

Parameter values for turnover and decomposition for stands of commercial plantations and farm forestry were informed by litterfall, decomposition and soil carbon datasets as described by Paul et al. (2022), and are summarised below (Table A5.6.2.14 and Table A5.6.2.15).

Table A5.6.2.14 Tree component turnover rates*

Turnover (half-life, yrs)	Branch	Bark	Leaf	Coarse roots	Fine roots
Softwoods	30.02	40.02	2.62	25.03	5.03
Hardwoods (& Mallees)	6.82	10.02	1.32	25.03	5.03
Env. Plantings	8.02	12.02	2.92	25.03	5.03

Table A5.6.2.15 Debris decomposition rates*

	Dead biomass						
Resistant (proportions)	**Deadwood**	**Bark**	**R-Leaf**	**D-Leaf**	**Coarse roots**	**R-Fine roots**	**D- Fine roots**
Softwoods	1.002	1.002	0.892	0.112	1.003	0.853	0.153
Hardwoods (& Mallees)	1.002	1.002	0.802	0.202	1.003	0.853	0.153
Env. Plantings	1.002	1.002	0.752	0.252	1.003	0.853	0.153

Decomposition (half-life, yrs)	**Deadwood**	**Bark**	**R-Leaf**	**D- Leaf**	**BGBC**	**R-BGBF**	**D-BGBF**
Softwoods	5.0002	4.5002	2.9972	0.28012	3.0003	0.00013	0.00013
Hardwoods (& Mallees)	4.5002	3.5002	1.1752	0.0772	3.0003	0.00013	0.00013
Env. Plantings	4.0002	3.0002	2.5602	0.0752	3.0003	0.00013	0.00013

Carbon Use Efficiency (proportions)	**Deadwood**	**Bark**	**R-Leaf**	**D- Leaf**	**BGBC**	**R-BGBF**	**D-BGBF**
	0.803	0.703	0.553	0.403	0.803	0.003	0.003

* Deadwood = dead stem and branch wood; R resistant pool; D decomposable pool.

Soil Carbon

Soil carbon remains estimated using the fully spatially explicit approach described in earlier in this annex and in Annex 5.6.5, with a recent soil carbon map as the base input data for modelling *plantations*.

Parameters governing the input of carbon to the soil following the decomposition of DOM are the fractions of decomposed DOM that is lost to the atmosphere as CO_2-C. The remaining decomposed DOM that is not lost as CO_2-C is predicted to enter the pools of soil C. Values for these parameters were calibrated using forest soil carbon studies as described by Paul et al. (2017).

A5.6.3 The forest productivity index

To derive the spatial and temporal patterns of forest growth the simplified form of the *3–PG* model (Landsberg and Waring 1997) (Coops, Waring and Landsberg 1998) (Coops, Waring and Brown, et al. 2001) was used to provide relative indices of growth potential (productivity indices[6]) at a 1 km grid scale on a monthly basis since 1970. The site-based, multi-temporal productivity indices are used to support a generalised empirical growth model. All modelling is done on the basis of aboveground biomass with subsequent factors to account for belowground (fine and coarse root) material.

A truncated version of the *3–PG* model (Landsberg and Waring 1997), retaining the essential features of biomass net primary production *(NPP)* estimation, without the carbon partitioning procedures is used to provide a site index of plant productivity that is independent of the type of forest present.

The essence of the model is the calculation of the amount of photosynthetically active radiation absorbed by plant canopies *(APAR). APAR* is calculated (Equation A5.6.3.1) as half the amount of short-wave (global) incoming radiation *(SWRadn)* absorbed by plant canopies.

$$\text{APAR} = \text{SWRadn} \times 0.5 \times (1-e^{(-0.5 \times \text{LAI})}) \times \text{days in month} \qquad \text{(A5.6.3.1)}$$

Where LAI is the Leaf Area Index and the coefficient 0.5 is a general value for the extinction coefficient.
LAI is derived by the expression ln(1–FPAR)/(-0.5) where FPAR is calculated by (NDVI * 1.0611) + 0.3431.
APAR is multiplied by a factor that converts it to biomass

This, in effect, amalgamates two steps, the conversion of absorbed CO_2 ion products (gross primary production) and the loss of a proportion of those products by respiration to give NPP. The value of the conversion factor (e, g Biomass MJ^{-1} APAR) used was obtained from literature (Potter, et al. 1993) (Ruimey, Saugier and Dedieu 1994) (Landsberg and Waring 1997).

There is substantial variation in e values, but no clear pattern in relation to plant type, so a value of 1.25 g Biomass MJ^{-1} APAR was used based on expert judgement. As the resultant output from the model is used as an index of 'productivity' (the Forest Productivity Index) and not as an absolute mass increase value, precision in the conversion factor is not critical. This NPP value assumes that there are no other constraints on growth.

To account for the effects of other factors the potential NPP is reduced by modifiers reflecting non-optimal nutrition, soil water status, temperature and atmospheric vapour pressure deficits.

Calculation of growth modifying factors

Modifiers are dimensionless factors with values between zero (complete restriction of growth) and 1 (no limitation). Modifiers used in this way are discussed by Landsberg (1986), McMurtrie et al. (1992) and Landsberg and Waring (1997).

The modifying factors are:

Soil fertility: because of natural variation and the considerable uncertainty surrounding soil fertility values, only three levels of soil fertility were used; high (effective modifier = 1), medium (effective modifier = 0.8) and low (effective modifier = 0.6), giving e values of 1.25, 1 and 0.75, respectively. These were applied for each pixel, depending on soil type, before environmental modifiers were applied. Information on soils and their characteristics was obtained from McKenzie et al. (2000).

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[6] A generic model of Net Primary Productivity derived a classification of productivity, on a scale of 1–30. Temporal and spatial variability is identified by a change in classification. This is not a linear relationship with biomass growth increment.

Vapour Pressure Deficit (VPD): VPD is a measure of atmospheric drought. VPD affects stomatal, and hence canopy conductance as trees regulate their water use. This can lead to reduced growth even where soil water content is high. The VPD modifier equation (A5.6.3.2) used is:

$$\mathbf{VPDmod = e^{(-0.05 \times VPD)}} \qquad \text{(A5.6.3.2)}$$

This modifier essentially acts as a control on the rate of water loss and is conditional upon soil water content (see below).

Soil Water Content: This is derived from water balance calculations, which take into account the maximum soil water holding capacity (Equation A5.6.3.6) in the root zone of plants. Plant water use (Equation A5.6.3.4) is calculated from the equation for equilibrium evaporation (Equation A5.6.3.3, see Landsberg and Gower (1997); 79), modified by feed-back from current soil water content, and a conventional water balance equation (Equation A5.6.3.5):

$$\mathbf{EqEvapn = ((0.67 \times NetRadn \times (1-0.05)) / 2.47) \times days\ in\ month} \qquad \text{(A5.6.3.3)}$$

$$\mathbf{Transpiration = EqEvapn_j \times SWmod_{j-1}} \qquad \text{(A5.6.3.4)}$$

$$\mathbf{WaterBal = (Rain \times (1-interception)) - Transpiration} \qquad \text{(A5.6.3.5)}$$

$$\mathbf{SoilWaterContent_j = SoilWaterContent_{j-1} + WaterBal_j} \qquad \text{(A5.6.3.6)}$$

Initial Soil Water Content was taken as 0.75 x SWcapacity. Soil Water Content carries over from one time step to the next. The soil moisture calculation sequence was run for 3 years, after which Soil Water Content had essentially equilibrated to stable monthly values. Soil Water Content values in year 3 were therefore used in the analysis. The soil water modifier *(SWmod,* Equation A5.6.3.8) was calculated from the moisture ratio *(MoistRatio,* Equation A5.6.3.7), which is Soil Water Content normalised to Scapacity. The equation describes the variable effect of MoistRatio across the range from wet soil (MoistRatio « 1) to dry soil (MoistRatio « 0).

$$\mathbf{MoistRatio = SoilWaterContent/SWcapacity} \qquad \text{(A5.6.3.7)}$$

$$\mathbf{SWmod = 1 / (1 + ((1-MoistRatio)/0.6)^{0.7})} \qquad \text{(A5.6.3.8)}$$

The soil water and VPD modifiers are not multiplicative; the lowest one applies. The argument is that if plant growth (conversion of radiant energy into biomass) is limited more by VPD than soil water (i.e., if VPDmod < SWmod) then soil water is not a limiting factor, even if soil water content is relatively low. The converse applies, that is, if SWmod < VPDmod, soil water is the limiting factor.

Temperature: The growth of any plant species is limited by temperatures outside the optimum range for that species. Since plants are dealt with in a generic way the assumption was made that, in any particular region, the plants are well-adapted to the temperature range. The equation (A5.6.3.9) describing the effect of temperature is:

$$\mathbf{T_{mod} = ((T_{av} - T_{low}) / (T_{opt} - T_{low})) \times ((T_{high} - T_{av}) / (T_{high} - T_{opt}))} \qquad \text{(A5.6.3.9))}$$

T_{av} is the average monthly temperature, T_{min} is the monthly average temperature below which plant growth stops, T_{max} is the monthly average temperature above which plant growth stops and T_{opt} is the optimum temperature for growth $(T_{min} + T_{max})/2$. The temperature modifier (T_{mod}) is 1 when $T_{av} = T_{opt}$.

Equation A5.6.3.9 gives a hyperbolic response curve, with T_{mod} = 0 when T_{av} = T_{min} or T_{max} T_{min} is set to ½ the minimum temperature of the coldest month (if the minimum temperature of the coldest month is greater than or equal to 0°C, T_{min} was set to the minimum temperature of the coldest month plus V the minimum temperature of the coldest month if the minimum temperature of the coldest month is less than 0°C). Tmax is set to 5°C above max the maximum temperature of the hottest month of the year and T_{opt} as equal to the average of T_{min} and T_{max}. Consequently, T_{mod} generally had relatively small effects on the calculation of NPP.

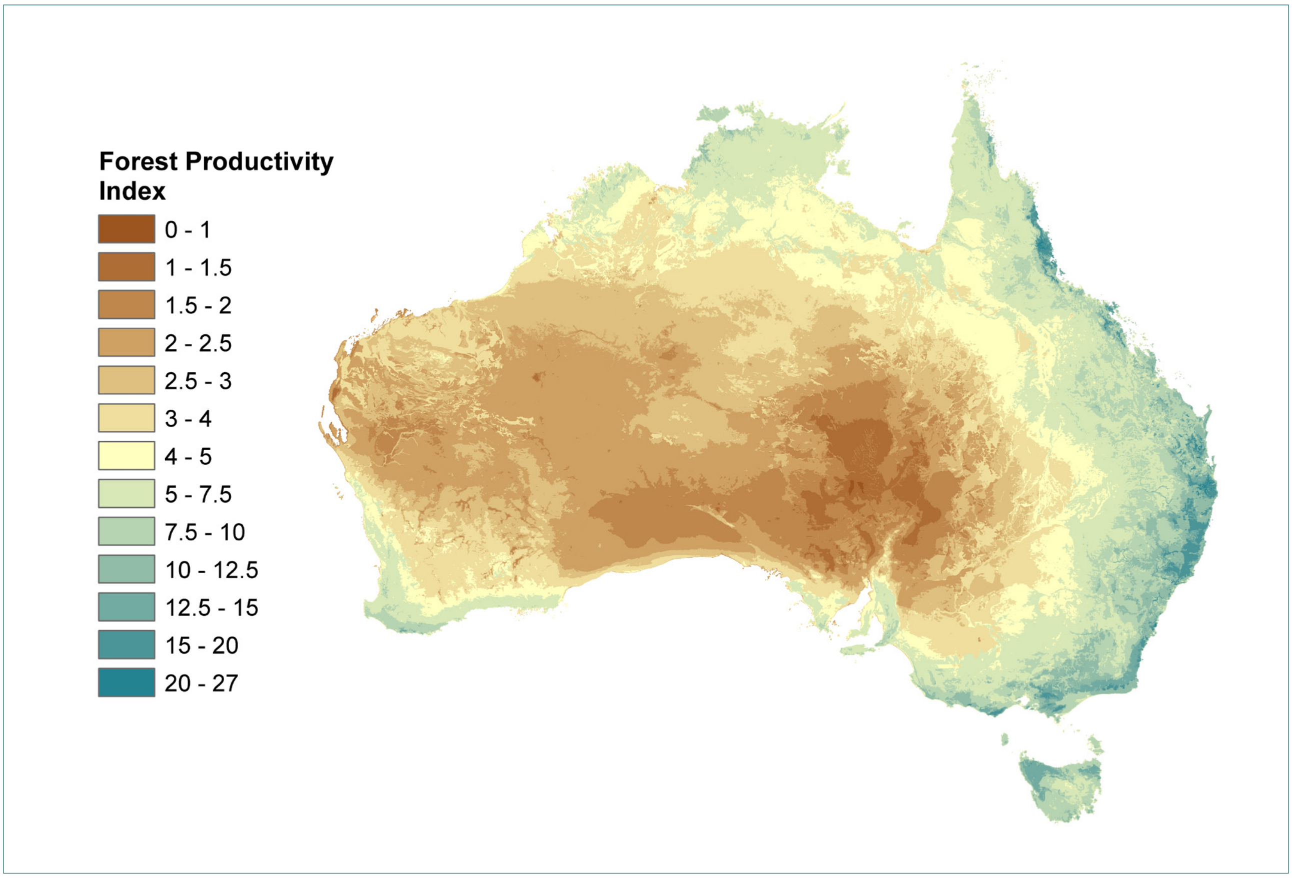
A frost modifier is included, using the simple assumption that frost temporarily inactivates the photosynthetic mechanism in foliage, so there is no growth on a frost day. The modifier is, therefore, simply the ratio of number of frost days/month to the number of days in the month.

Calculation of the forest productivity index

The Forest Productivity Index (FPI) is calculated both temporally and spatially using the monthly (since 1968) 1km grid climate and site information described in Annex 5.6.5. A further 250 m long-term average FPI is also calculated using yearly average data from 1970–2017, using a slope and aspect corrected APAR calculation (Figure A5.6.3.1).

These productivity maps are used to describe the spatial and temporal variation in forest biomass and growth.

Figure A5.6.3.1 250m slope and aspect corrected productivity index



A5.6.4 Initial forest biomass

The initial forest biomass layer is used to estimate the initial biomass of forests on lands that is incremented in the following subcategories:

- Forest land converted to Cropland;
- Forest land converted to Grassland;
- Forest land converted to Wetlands (flooded lands); and
- Forest land (terrestrial) converted to Settlements.

An estimate of biomass (the assumed initial biomass) of mature forests is required to estimate emissions due to first time clearing events. The assumed initial biomass is applied to all first-time clearing events whenever they occur. The assumed initial biomass for a pixel is calculated based on a regression model of the relationship between the Forest Productivity Index and measured biomass (Raison, et al. 2003) (Richards and Brack 2004), with subsequent modifications by Roxburgh et al. (2019) (described below).

Calibration data

Biomass measurements used in the calibration include all forest conditions except those with visible evidence of recent disturbance such as clearing, harvest or fire since 1970. The lands may, however, have an ongoing low-level disturbance such as grazing and low intensity fires.

In the collection of the calibration plot data, caution was exercised to exclude forest 'gaps' contained in some field measurements. Plots taken as part of fixed-grid or transect systems could potentially fall in gaps in sparse forests. As the remote sensing programme at 25 m resolution is capable of separating such forest gaps from clearing events, the forest carbon mapping needs to represent the biomass of forested plots, not of that averaged over the gaps.

In the update by Roxburgh et al. (2019) the original calibration database was augmented with forest biomass observations from the TERN/AusCover National Biomass Library (http://www.auscover.org.au/purl/biomassplot-library). This library is a collation of stem inventory and biomass estimates compiled from federal, state and local government departments, universities, private companies and other agencies. Of the approximately 14,500 site biomass records in the database, 5,739 were deemed consistent with the requirements for estimating initial mature biomass.

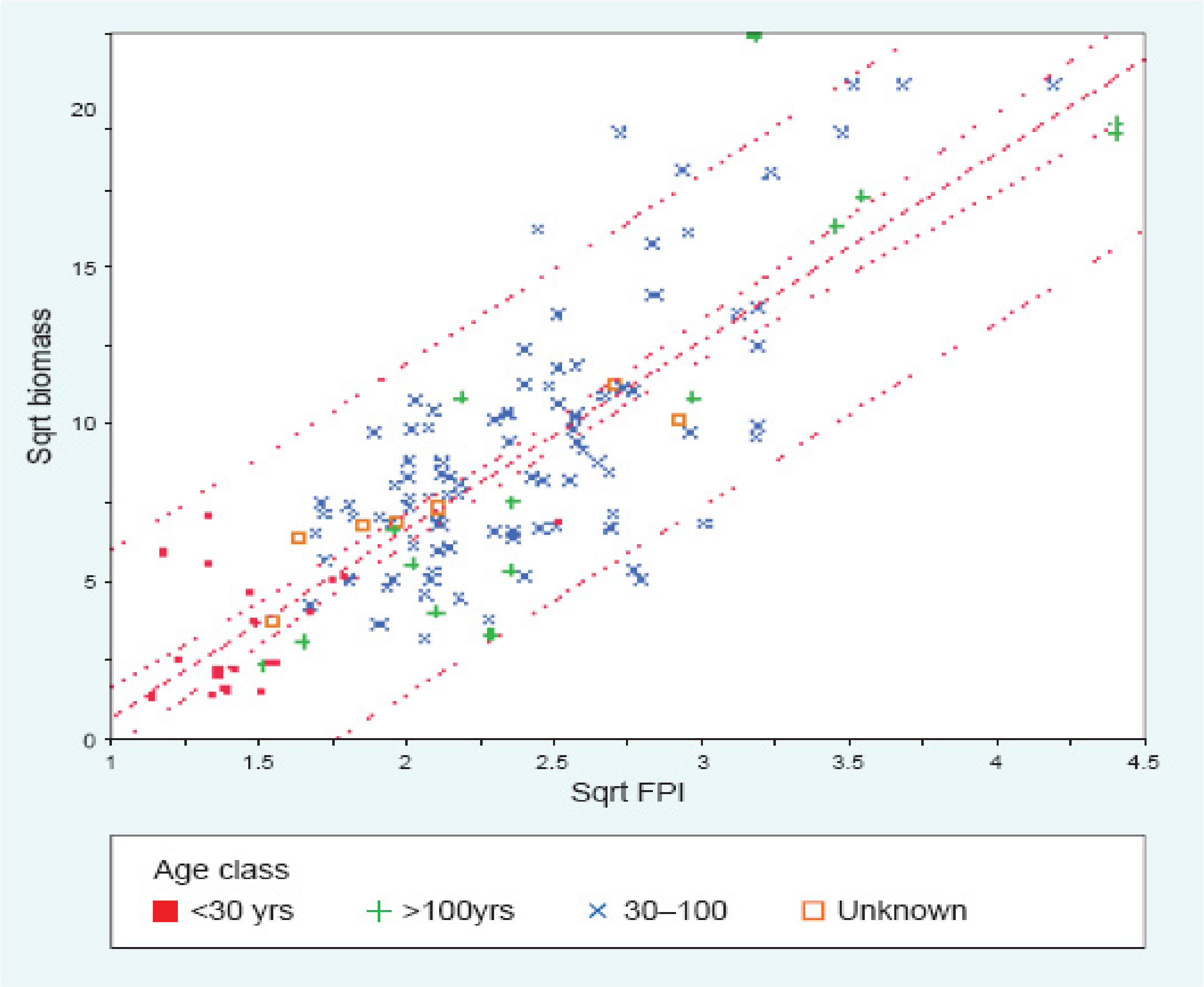
Assumed initial biomass relationship

For the original calibration of FullCAM the initial forest biomass for an individual forest site was fitted to the productivity map. The red line in Figure A5.6.4.1 represents the line of best fit for predicting the initial forest biomass of an individual forest site.

A regression found a significant relationship ($p < 0.01$, $r^2 = 0.68$) between the stand biomass measures *(M)* and the Long-Term Forest Productivity Index (P) (Equation A5.6.4.1). A square root transformation was required to meet assumptions of normality and homogeneity (Figure A5.6.4.1).

$$M = (6.011 \times \sqrt{P} - 5.291)^2 \qquad \text{(A5.6.4.1)}$$

Figure A5.6.4.1 The assumed initial biomass relationship



The goodness of the fit of Equation (A5.6.4.1) to the measured data ($r^2 = 0.68$, $p < 0.01$) confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates although with some suggestion of under-prediction of high-biomass productive forests. The outer 95 per cent confidence limits (outer pair of dotted lines) show the reliability for predicting biomass at any individual site, and the inner 95 per cent confidence intervals (inner pair of dotted lines) show the confidence in the line of best fit being able to represent the variability in the field data at the national scale.

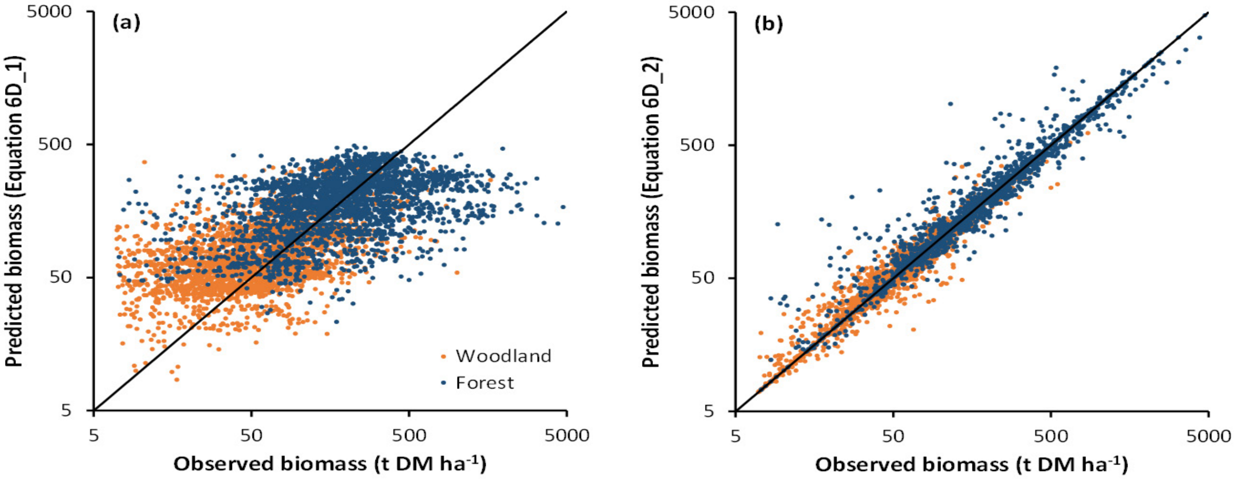
Applying Equation A5.6.4.1 to the data from the TERN/AusCover National Biomass Library suggested the biomass predictions were accurate up to approximately 300–400 t DM ha^{-1}, after which point there was a strong tendency for the equation to under-predict actual biomass, such that all biomass observations greater than 5001 DM ha^{-1} are predicted to be less than 500 t DM ha^{-1} (Figure A5.6.4.2a). To correct for this bias, a spatially-explicit modifier (X) was calculated based on the observed discrepancy between the observed and predicted biomass. Because of issues regarding non-normality and variability in the data, the non-parametric ‘Random Forest’ ensemble machine learning algorithm was used to estimate X, using as predictor variables elevation, soil organic carbon content, and 21 climatic variables (Roxburgh, Karunaratne, et al. 2017). The revised model predictions, for pixel I, were therefore calculated as:

$$Mi = \lambda_i \times (6.011 \times \sqrt{P_i} - 5.291)^2 \qquad \text{(A5.6.4.2)}$$

For regions in which the current model (Equation A5.6.4.1) is consistent with the new data then I is expected to be close to 1.0; for regions where biomass is being under-predicted then X is expected to be >1, and for regions where biomass is being over-predicted then X is expected to be <1.

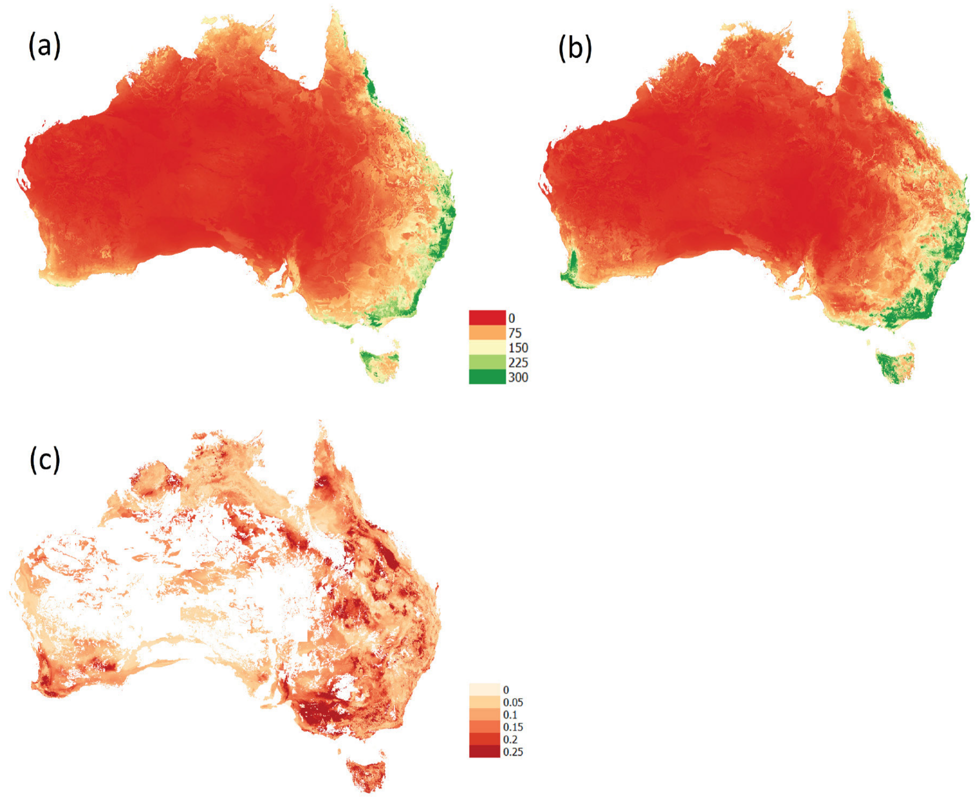
Under Equation A5.6.4.1, and when applied to the full biomass database, the overall root mean square error (RMSE) was 239 t DM ha^{-1}, with a model efficiency (EF) of 0.14 and a mean error (ME) confirming an overall bias of -35 t DM ha^{-1} (Figure A5.6.4.2a). Under Equation A5.6.4.2, which includes the modifier X, the model fit statistics all improved, with reductions in the RMSE and ME to 62 t DM ha^{-1} and -0.2 t DM ha^{-1} respectively, and a model efficiency (EF) of 0.94 (Figure A5.6.4.2b). The revised model is therefore characterized by a much closer fit to the 1:1 line, and negligible bias over the full range of forest biomass (equivalent statistics when observations were withheld as part of model validation testing are given in the next section).

Figure A5.6.4.2 (a) Observed vs. predicted biomass for the predictions using Equation A5.6.4.1. (b) Observed vs. predicted biomass for the predictions using Equation A5.6.4.2. 'Woodland' indicates sites with a canopy cover up to 50 per cent (i.e. including some sites classified as sparse woody vegetation with canopy cover 5–20 per cent). 'Forest' indicates sites with a canopy cover >50 per cent. Lines are the 1:1 relationship, where observations equal predictions



The initial assumed biomass at a chosen resolution for the entire continent can then be calculated by applying Equation (A5.6.4.2) to the FPI mapping (Annex 5.6.3) and is shown in Figure A5.6.4.3a. The revised map of M (Figure A5.6.4.3b) differs from the original (Figure A5.6.4.3a) most obviously in the increased biomass density (i.e. darker green) in the taller forests of Western Australia, Tasmania, Victoria and New South Wales. Other regional-scale differences include declines in predicted initial biomass for the northern territory, and coastal Queensland.

Figure A5.6.4.3 (a) Original FullCAM maximum biomass layer (t DM ha^{-1}). (b) Revised maximum biomass layer (t DM ha^{-1}). (c) Coefficient of variation (standard deviation / mean) of M, calculated over 100 replicate Random Forest model fits. White areas in (c) were excluded from analysis, and in (b) are filled with values from the original maximum biomass layer



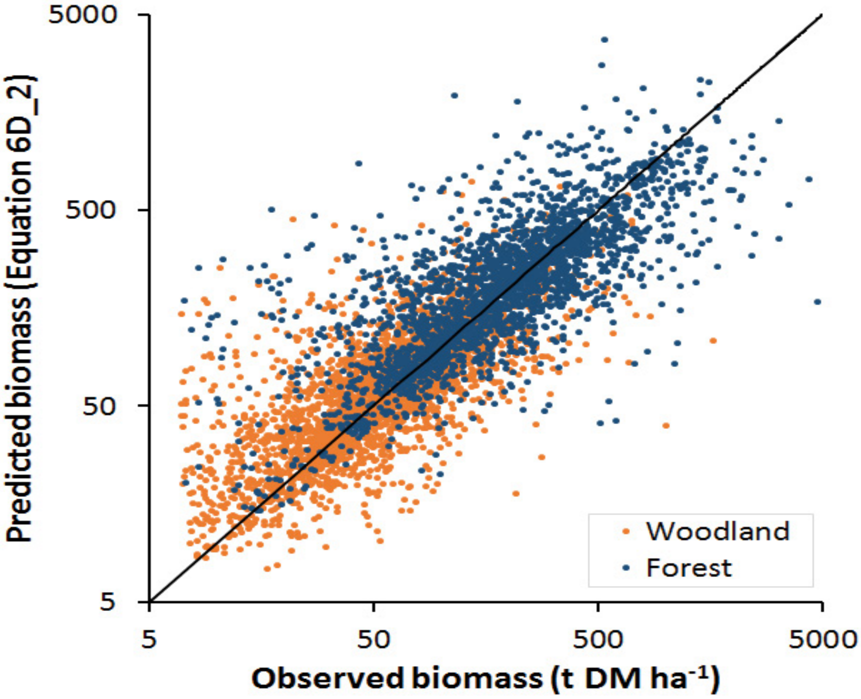
While the goodness of fit and lack of bias in error estimates (Figure A5.6.4.2b) provides confidence in the application of Equation (A5.6.4.2) as a model to predict biomass at maturity, there is an obvious scatter in the data which is somewhat masked by the logarithmic scales on which the figures are displayed. This is attributable to the range of age classes and forest histories used in the model, the differing methods used in the field estimation, an inherent variability between the 'plot' locations used to scale to one hectare mass estimates compared to the average condition reflected in the 250 m resolution productivity estimation, and to natural variability in forest biomass.

Validation and verification of assumed initial biomass

As part of the modelling procedure to predict I the empirical database of 5,739 records was split at random into a 70 per cent model fitting (calibration) subset and a 30 per cent withheld (validation) subset. This was repeated 100 times as part of a Monte-Carlo estimation procedure, generating 100 separate models that were then used to estimate the mean and uncertainty of the predictions. Each observation therefore had the opportunity to be included both for model fitting (results shown in Figure A5.6.4.2b) and also for independent validation, where withheld observations are used to estimate the error associated with the prediction of 'new' observations not included in the model fitting procedure (Figure A5.6.4.4).

As expected, the scatter around the 1:1 line was larger when sites were used for independent validation (compare Figure A5.6.4.2b with Figure A5.6.4.4), with a RMSE of 201 t DM ha^{-1}, a model efficiency (EF) of 0.4, and a mean absolute (ME) error indicating a an overall bias of -8 t DM ha^{-1}, corresponding to an error of approximately 5 per cent at the continental scale.

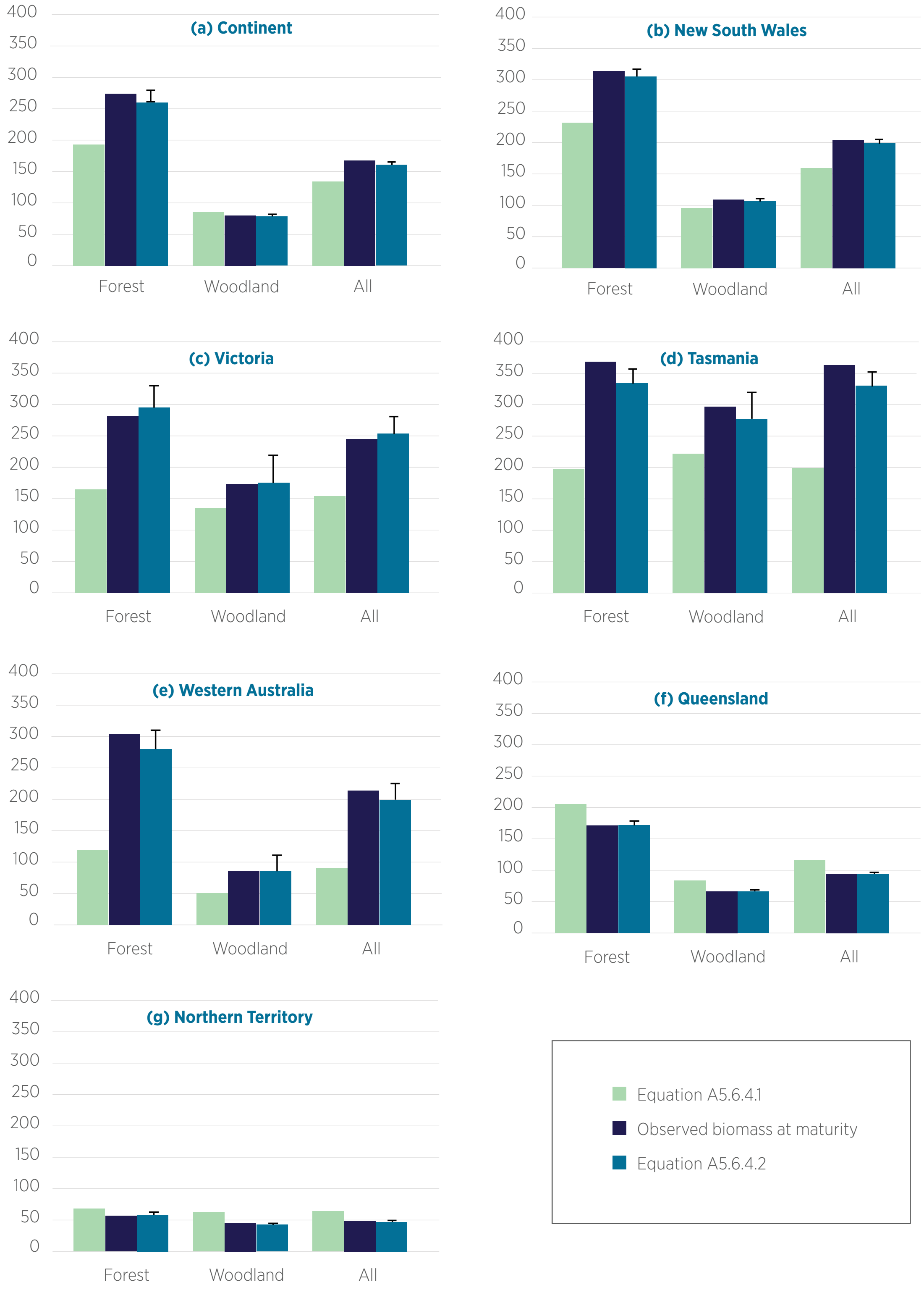
Figure A5.6.4.4 Observed vs. predicted biomass for the predictions using Equation A5.6.4.2 when observations were withheld from model fitting and used for model validation. 'Woodland' indicates sites with a canopy cover up to 50 per cent (i.e. including some sites classified as sparse woody vegetation with canopy cover 5–20 per cent); 'Forest' indicates sites with a canopy cover >50 per cent. Lines are the 1:1 relationship, where observations equal predictions



The validation results can be more readily interpreted when the data is summarised regionally (Figure A5.6.4.5). At the continental scale, and for woodland forests with a canopy cover 20–50 per cent, there was a slight decline in predicted biomass at maturity when comparing Equation A5.6.4.1 (92 t DM ha^{-1}) to Equation A5.6.4.2 (86 t DM ha^{-1}). In contrast, for forests with a canopy cover greater than 50 per cent, the average biomass increased, from 193 to 260 t DM ha^{-1}. At the scale of individual states these forest increases were more pronounced; for example in Western Australia (119 to 280 t DM ha^{-1}), Tasmania (198 to 334 t DM ha^{-1}), Victoria (165 to 295 t DM ha^{-1}), and New South Wales (231 to 305 t DM ha^{-1}). Overall, comparison of the medium grey and dark grey bars in Figure A5.6.4.5 show that predictions from Equation A5.6.4.2, for the validation subset, are all consistent with the observations.

When model predictions are averaged geographically then similar trends are apparent, with minor differences at the continental scale for woodland forests (48 t DM ha^{-1} using Equation A5.6.4.1 and 49 t DM ha^{-1} using Equation A5.6.4.2), and increases in the >50 per cent canopy cover forest class (172 t DM ha^{-1} using Equation A5.6.4.1 and 234 t DM ha^{-1} using Equation A5.6.4.2).

Figure A5.6.4.5 Comparison of mean above-ground biomass across the 5739 observed data points with the mean biomass from the original (Equation A5.6.4.1) and revised (Equation A5.6.4.2) predictions of above-ground biomass. South Australia is excluded due to lack of data. Error bars for Equation A5.6.4.2 are the standard deviations of predictions across 100 replicate Monte-Carlo analyses



A5.6.5 Other FullCAM input data

Soil carbon input data

Initial soil carbon layer

To estimate soil carbon stock changes FullCAM requires spatial soil data including soil type, clay content and a pre-disturbance or initial soil carbon content. The soil data is used to derive water holding capacity which along with soil clay content determines the rate of decomposition of plant residues and the allocation of carbon to the different soil pools (Richards 2001) (Webb 2002).

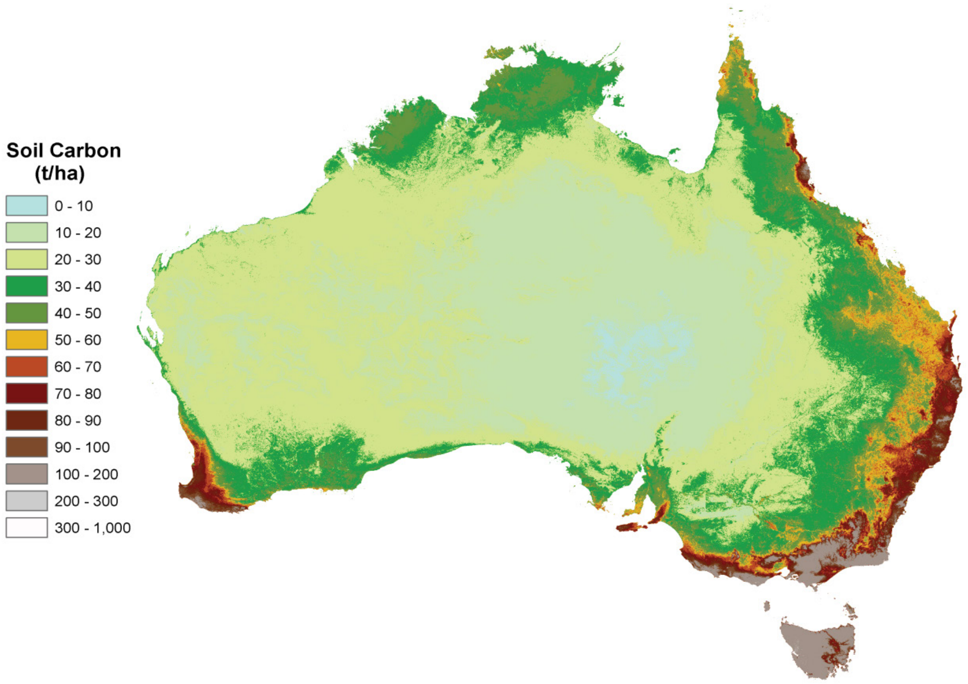
Viscarra-Rossel et al. (2014) has derived spatially explicit estimates, and their uncertainty, of the distribution and stock of organic carbon in the soil of Australia. This was achieved through the assembly and harmonisation of data from Australia's National Soil Carbon Research Program (SCaRP), the National Geochemical Survey of Australia (NGSA) and the Australian Soil Resource Information System (ASRIS) to produce the most comprehensive set of data on the current stock of organic carbon in soil of the continent.

A fine spatial resolution baseline map of organic carbon at the continental scale was produced by combining the bootstrap, a decision tree with piecewise regression on environmental variables, and geostatistical modelling of residuals. Values of stock were predicted at the nodes of a 3-arc-sec (approximately 90 m) grid and mapped with their uncertainties. Baselines of soil organic carbon storage over the whole of Australia, its states and territories, and regions that define bioclimatic zones, vegetation classes and land use were then calculated.

Viscarra-Rossel et al. (2014) determined that the average amount of organic carbon in Australian topsoil is estimated to be 29.7 t ha^{-1} with 95 per cent confidence limits of 22.6 and 37.9 t ha^{-1} The total stock of organic carbon in the 0-30 cm layer of soil for the continent is 24.97 Gt with 95 per cent confidence limits of 19.04 and 31.83 Gt.

Figure A5.6.5.1 shows the baseline map of organic soil carbon in Australian soil to support national carbon accounting and monitoring under climate change. Soil carbon content was corrected to methodological standards where the initial method of measurement was known; otherwise, the data were considered unusable and were not included in the final product.

Figure A5.6.5.1 Baseline map of organic carbon in Australian Soil Viscarra-Rossel et al. (2014)



Soil carbon fractions

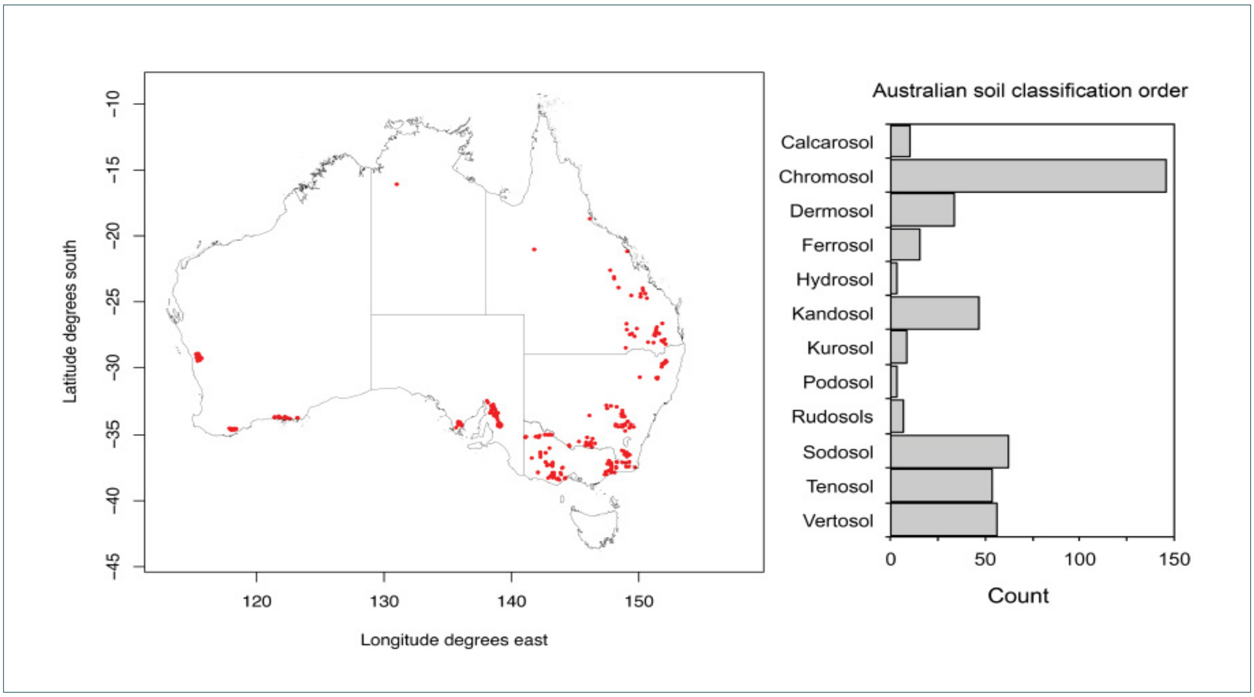
Measureable soil carbon fractions that can replace the conceptual pools of the Roth-C model which are used to simulate soil carbon changes within FullCAM are used to initialise FullCAM. These fractions are defined by their differences in turnover times and biological significance (Baldock, et al. 2013).

Fine spatial resolution continental scale maps of the soil carbon fractions (particulate organic carbon (POC), humic organic carbon (HOC) and resistant organic carbon (ROC)) are generated by CSIRO Land and Water using a methodology that is similar to that used to derive the baseline map of organic carbon in Australian soil (Viscarra Rossel, Bui and Baldock 2014).

There were 400 soil data points with measurements of POC, HOC, and ROC. Largely, these data originated from the Soil Carbon Research Program (SCaRP), and a small number are from two smaller projects that were funded under the Department of Agriculture (DA) Filling the Research Gap (FTRG) Programs. The data represented all Australian Soil Classification Orders but they were sparsely distributed across Australia and represented soil that is mostly under agriculture, but also forests. The spatial distribution of the data is shown in Figure A5.6.5.2.

The visible near-infrared and mid-infrared spectra of the 400 soil samples were recorded and spectroscopic calibrations were derived to predict POC, HOC and ROC of other soil samples for which data on the organic carbon fractions were not available. The calibrated models were used to predict the fractions of around 4,000 soil samples that cover the extent of Australia and represent all land use types, and all climatic and bio-geographical regions.

Figure A5.6.5.2 Spatial distribution of soil organic carbon fractions (POC, HOC, ROC) and the number of observations per Australian Soil Classification order

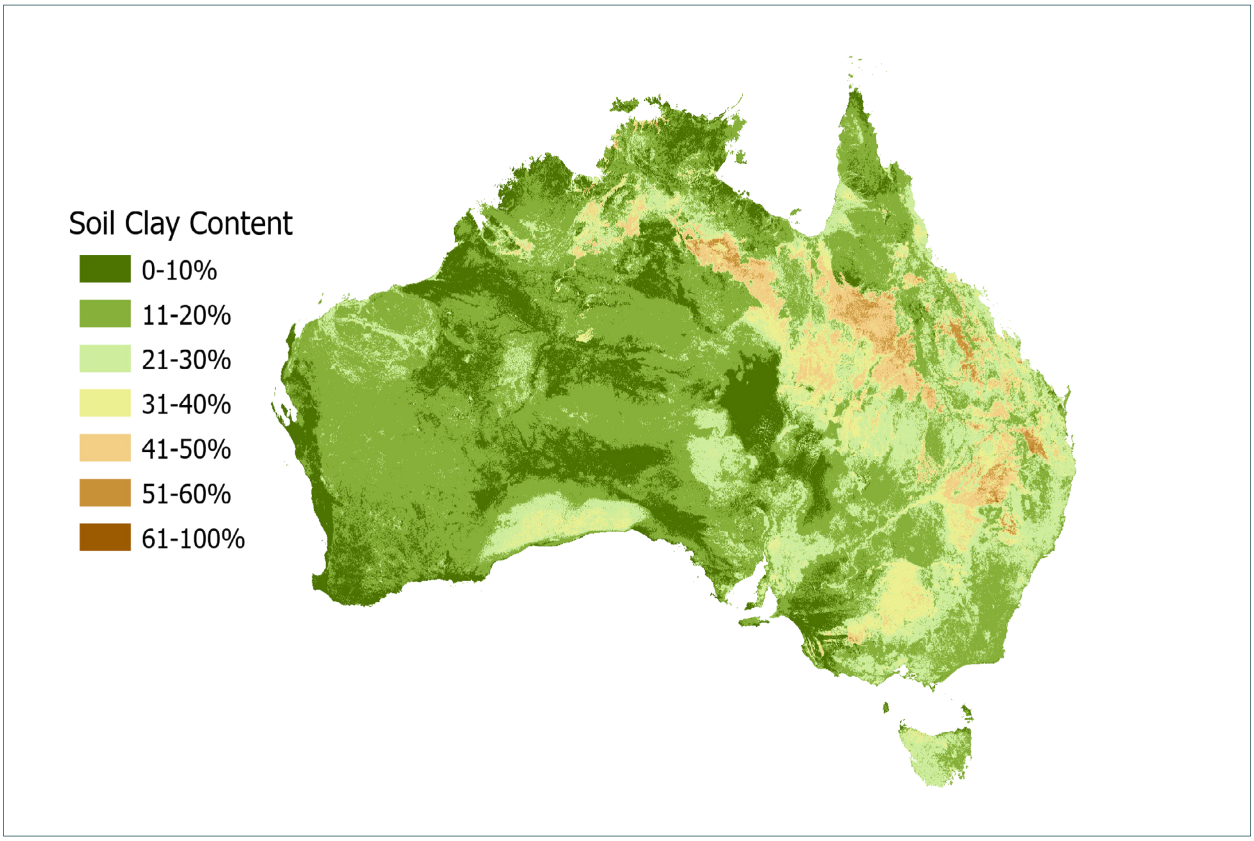


Once the spectroscopic predictions were made, the spatial modelling of the data was performed by combining the bootstrap, a decision tree with piecewise regression on environmental variables and geostatistical modelling of residuals. The spatial models were validated with an independent data set and the fine spatial resolution continental maps of the soil carbon fractions have been incorporated in FullCAM to ensure internal consistency of spatial soil inputs. In calculation of soil carbon fraction stocks for FullCAM, respective fractions were allocated based on the total soil carbon stock map produced by Viscarra-Rossel et al. (2014) multiplied by the respective soil carbon fraction.

Soil clay content

A map of clay content was developed (Figure A5.6.5.3) by Viscarra-Rosel et al. (2015) and subsequently refined and updated by Malone and Searle (2021). The version 2 Soil and Landscape Grid of Australia-wide Soil Attribute Maps were generated using laboratory and field measured soil attribute data from existing databases in the national soil site data collation and spectroscopic estimates made with the CSIRO's National spectroscopic database (Viscarra Rossel and Webster 2012). The spatial modelling was performed using the Soil Texture Algorithm (Malone and Searle 2021). Thirty five environmental covariates were used in the modelling. Uncertainty was derived using a bootstrap approach to derive for each pixel an empirical probability distribution, from which 90 per cent confidence limits are derived. The approach is described in Malone and Searle (2021).

Figure A5.6.5.3 The version 2 Soil Landscape Grid of Australia (Clay) (Malone and Searle 2021).



Climate data

Model sensitivity testing identified that inter-annual climate variability has a significant effect on both soil (Janik, et al. 2002) and forest (Brack and Richards 2002) carbon stock change. The use of long-term average and regionally averaged climate data was shown to be inadequate to support spatially and temporally disaggregated carbon modelling, frequently generating spurious results when tested. To account for the effects of climate both spatially and temporally over the modelled period, weather station data from the Bureau of Meteorology for rainfall, minimum and maximum temperature, evaporation and solar radiation were obtained for the period since 1970 and updated annually. Monthly climate surfaces at 1 km resolution for each variable were then derived using ANUSPLIN (Hutchinson and Xu 2013) (McMahon et al. 2000) surface interpolation techniques.

Climate data are produced on an annual basis to incorporate new data captured by the Bureau of Meteorology, and updated processing methods as new technology becomes available. ANUSPLIN Version 4.6 was used to derive climate surfaces as it encompasses new developments that improve surface accuracy. These methods significantly improve on the spline based methods described by Kesteven et al. (2004). The revised methods incorporate the use of mean background fields based on the full historical climate data network to reduce interpolation error and facilitate reliable detection and removal of source data errors.

Raw data

Within the Bureau of Meteorology database there are approximately 700 weather stations recording temperature, over 4,000 stations recording rainfall, 150 stations recording evaporation and 700 stations recording frost days. Solar radiation surfaces were calculated as a function of monthly minimum and maximum temperature and rainfall using a model calibrated on historical solar radiation data for 40 stations. Precise location and elevation data were available all weather stations, providing a quality reference set of points from which to spatially interpolate climate surfaces. Version 2 of the 9 second (approximately 250 m resolution) national digital elevation model (AUSLIG 2001) was used to provide elevation and proximity to the coast information to support the calculation of the interpolating spline functions by the ANUSPLIN software.

Derived outputs

The weather station climate data are interpolated (modelled) using mathematical (multivariate spline) functions that reflect influences on micro-climate such as elevation and proximity to the coast. Climate grids are derived at a grid spacing of 0.01 degrees longitude/latitude (approximately 1 km) using the ANUSPLIN software (Hutchinson and Xu 2013). The list of outputs and their resolution is shown in Table A5.6.5.1. Figures A5.6.5.4 and A5.6.5.5 illustrate national long-term average annual climate surfaces generated from the data produced using the ANUSPLIN software.

The surface interpolation from weather station data provides climate mapping which is both temporally and spatially relevant to the application of FullCAM.

Table A5.6.5.1 List of climate and productivity maps developed for land sector reporting in the National Inventory System

Climate Variable	Description
Rainfall	1 km resolution continentally, monthly 1968-2022
Temperature	1 km resolution min., max., and average continentally, monthly 1968-2022
Evaporation	1 km resolution continentally, monthly 1968-2022
Frost Days	1 km resolution continentally, monthly 1968-2022
Long-term productivity	250 m resolution
Annual productivity	(sum of monthly) 1 km resolution (1970-2022)

Figure A5.6.5.4 Long-term average annual evaporation

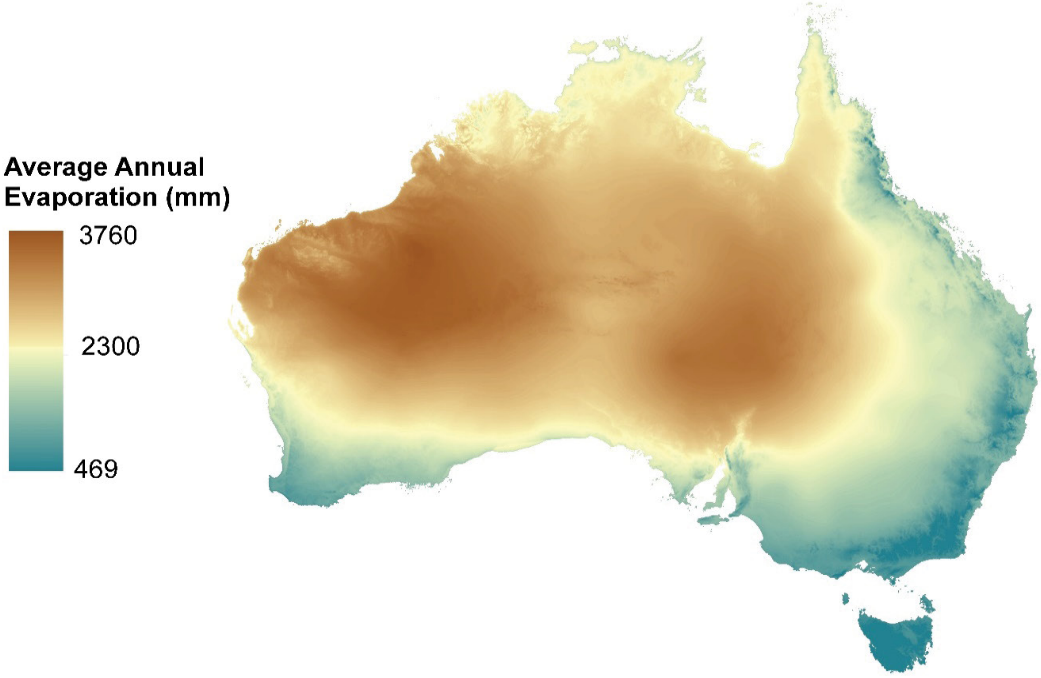
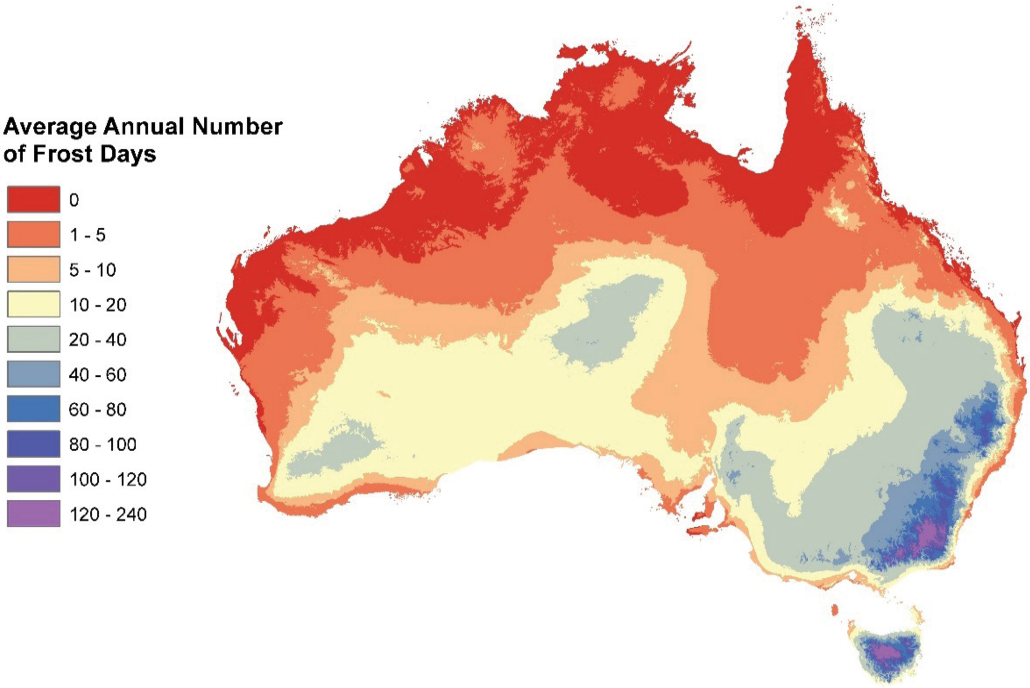


Figure A5.6.5.5 Long-term average number of frost days per year



Land use and land management

Land use and management data

Land management practices in both agriculture and forestry in Australia have varied considerably over time depending on species, region, desired products and site conditions. In 2014, the Department of Environment and Energy commissioned CSIRO to collate all available information regarding agricultural management systems to ensure a consistent, nationally available compilation of this information.

For the forest management data program, a focus group was established comprising researchers and practitioners to give all management issues (e.g., forest and crop type, burning, harvesting and thinning) a jurisdictional (geographic) and temporal coverage. All available information was collated and supplemented with expert knowledge to give completeness where records were not available. The information gathered by these groups for use in the management databases is documented in Swift and Skjemstad (2002) and Raison and Squire (2008).

Cropping systems

For cropping systems the crop species identified by Unkovich et al. (2009) (Annex 5.6.2) were sourced from the Australian Bureau of Statistics agricultural census small area data in electronic format.

The collated datasets were concorded to the then new, Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (ABS 2010). All years between 1983 and 1997 were concorded to 1996 statistical local area boundaries (Australian Bureau of Statistics 2000), the 2001 at 2001 statistical local area boundaries (Australian Bureau of Statistics 2002), the 2006 at 2006 statistical local area boundaries (Australian Bureau of Statistics 2008) and for 2011 on 2011 statistical local area boundaries (Australian Bureau of Statistics 2013). This concordance ensured spatial consistency across the time series.

The datasets were used to extract the area of each of the crops listed in Table A5.6.2.5 for each SA2 to construct a time series dataset from 1983 to 2011 to cover 99 per cent of total crop sowing areas in each Australian State. Since the ABS has more recently (post 2001) changed from annual agricultural censuses to five yearly census, five yearly data blocks, in synchrony with the recent censuses were used to represent management epochs (Table A5.6.5.2).

Table A5.6.5.2 Agricultural census year data used to provide crop representation for five-year periods

Census Year	Applied to
1983	1969-70 to 1983-84
1986	1984-85 to 1988-89
1991	1989-90 to 1993-94
1996	1994-95 to 1998-99
2001	1999-00 to 2003-04
2006	2004-05 to 2008-09
2011	2009-10 to 2013-14
2016	2014-15 to 2020-21

The year 1983 is the earliest time that data are available electronically and this is thus used to populate the time series back to the 1969-70 start point.

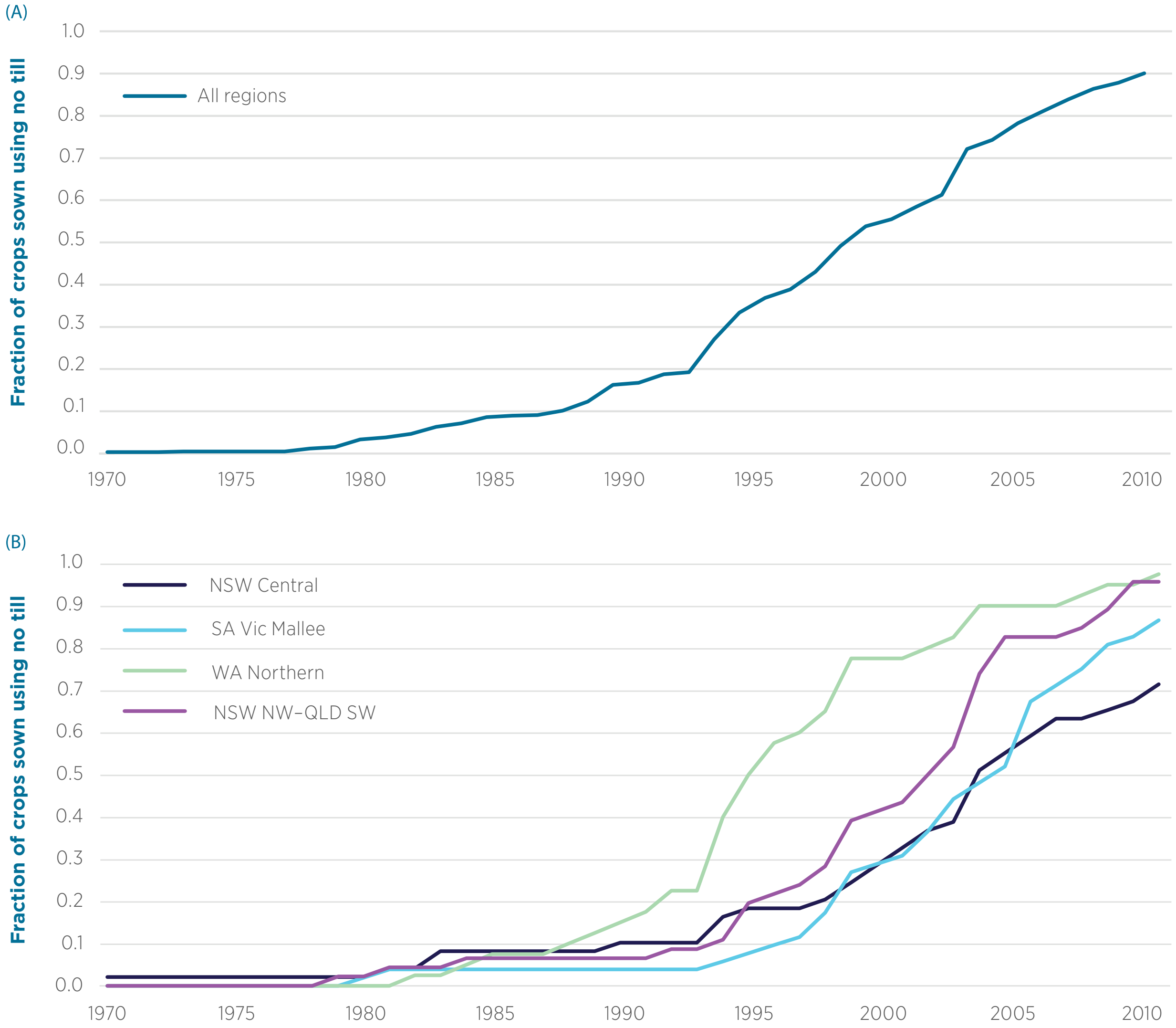
Cropping systems have evolved over time with the use of herbicides to control weeds instead of tillage and sowing machinery adapted to sow into standing stubble of antecedent crops. This means that there has been a significant change over time in the extent of tillage and the incorporation of crop residues into soils which might influence carbon return to soils, carbon cycling and soil carbon stocks.

Two datasets assisted in informing these changes in management over time.

Time series data on the adoption of no till practices on a region by region basis is available through a survey in 2008 of the "Adoption of no-till cropping practices in Australian grain growing regions" (Llewellyn, D'Emden and Gobbett 2009) (Llewellyn, D'Emden and Kuehne 2012), and includes farmer estimates of the historical adoption of no-till seeding systems, back to 1960. This dataset is the only available resource describing the adoption of no till seeding systems across the Australian grain cropping zone on a temporal and spatial basis. This dataset, updated in 2014, provides opportunity to describe changes in the intensity of tillage on croplands over time. A second dataset, available from the Australian Bureau of Statistics, provides detailed information at SA2 scale on the management of crop stubbles in 2010-2011. Using these two data sources a time series dataset of tillage x stubble management at SA2 scale has been developed.

Details of the survey and the broad outcomes are given in Llewellyn and D'Emden (2009) and Llewellyn et al. (2012). The dataset provides information on the fraction crops established using "no till" seeding systems on a regional basis. In this case the regions were clusters of Statistical Local Areas (Trewin 2005). These regional data were used to populate an SA2 level dataset.

Figure A5.6.5.6 Adoption of changed tillage practices in Australia: 1970–2013



Note: Fraction of crops sown with no till (single pass) seeding technology across (A) the Australian grain belt, and (B) for four of thirteen regional areas Calculated from a revised dataset of Llewellyn et al. (2012).

The Llewellyn et al. (2012) dataset was used to produce regional scalars (0–1) describing the adoption of no till crop established from 1970 until 2010[7]. This was then applied against the 2010–11 ABS point census to created SA2 level data back in time. As a result, the data of Figure A5.6.5.6 were normalised such that the value for 2010 was 1.0, and the preceding years scaled proportionately. These time series values were then applied to the 2010–11 ABS SA2 level census data to provide the historical no till fraction. The national and state level trends are shown to be about half that apparent in the Llewellyn et al. (2012) dataset.

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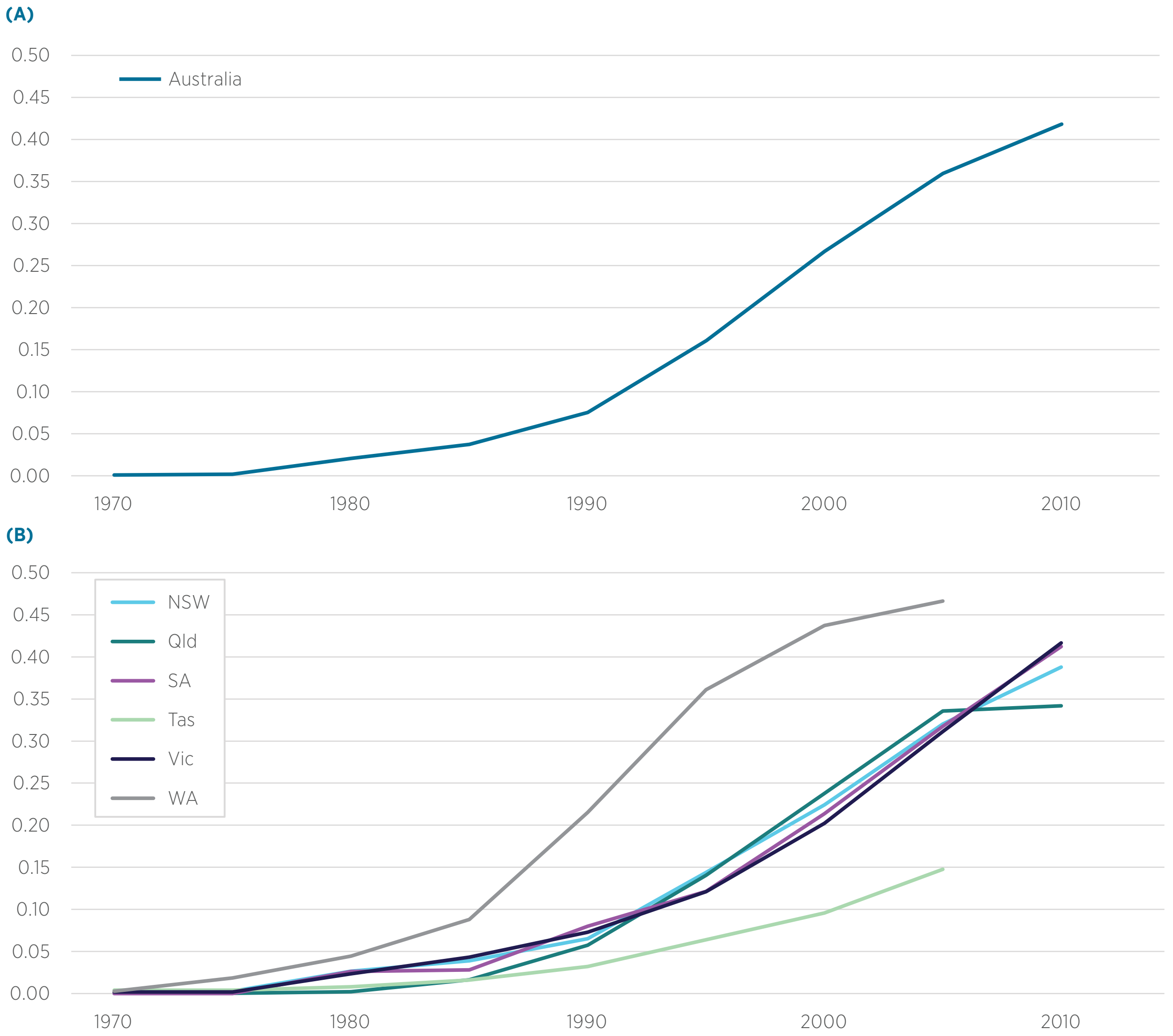
[7] When the data of Figure A5.6.5.6 and A5.6.5.7 were compared with the ABS survey of land management (2011) (ABS 2013) it was found that the fraction of crops sown with “no till” were very much higher in the Llewellyn et al. (2012) dataset than that apparent in the ABS census of 2011 (ABS 2013). This may be because the ABS census was for all cropping land, whereas the Llewellyn survey was very much skewed toward farmers who were primarily grain growers. It is likely that dedicated grain growers have larger cropping areas and invest in efficient no-till systems compared to mixed farmers or farmers with relatively small holdings. The ABS survey data was explicitly for the total area sown within an SA2.

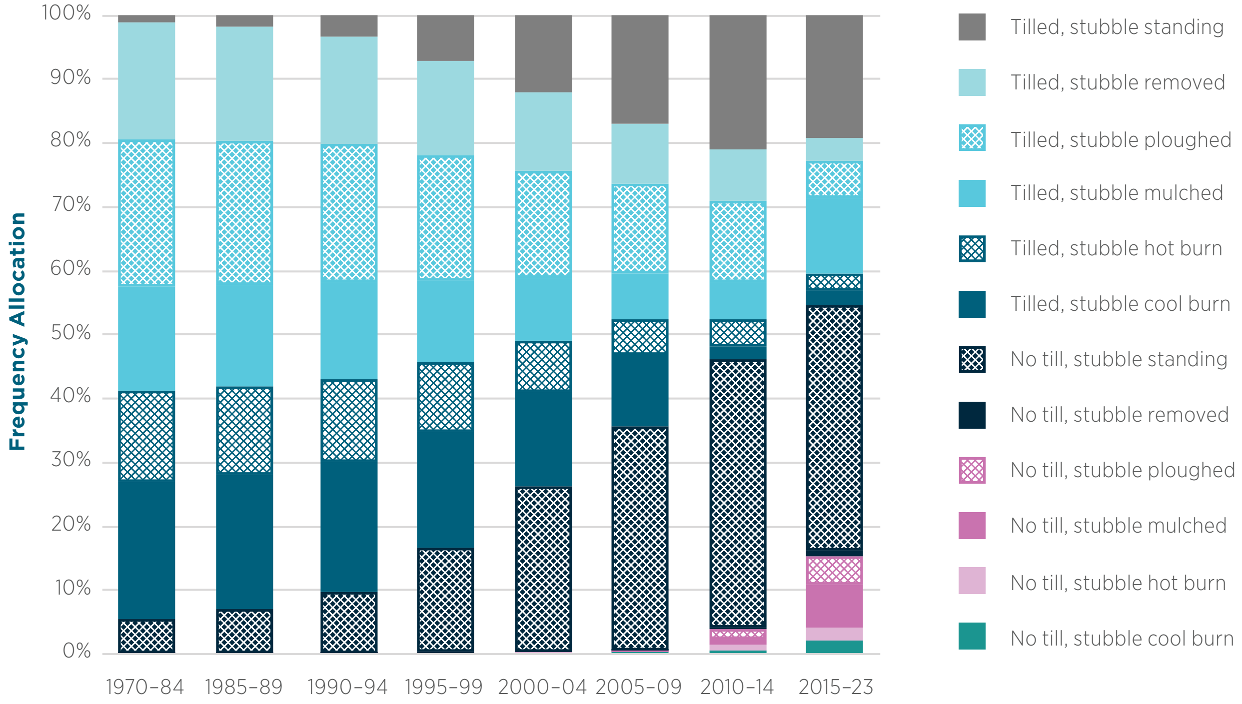
Figure A5.6.5.7 Adoption of changed tillage practices in Australia by state: 1970–2013



Note: Estimated fraction of crops sown with no till (single pass) seeding technology across (A) the Australian grain belt, and (B) for each of the primary Australian cropping States, calculated by scaling the 2011 ABS census data according to the data of Figure A5.6.5.6.

Changing management practices over time is one of the primary drivers for trends in emissions from Australian crop and pasture lands. Figure A5.6.5.8 illustrates the changing management practices for all crop species in Australia since 1970 for each epoch taken from Table A5.6.5.2. The benefit of changing management practices seen within the first 10 years and the diminishing returns afterwards, are a result of the soil carbon stock attempting to reach a new equilibrium. Peaks in net gains or removals attributed to SOC generally are not caused by management change but are experienced during regional drought or flood events in which the net balance between C inputs and C losses is altered.

Figure A5.6.5.8 Changing allocation of management practices for cropland since 1969-70, generated from the management crop management frequency database embedded in FullCAM



One of the key operational challenges for any process-based model that simulates changes in carbon dynamics in spatio-temporal mode is to implement the changes occurring in the crop management practices over space and time related to tillage operations and stubble management within the simulation setup.

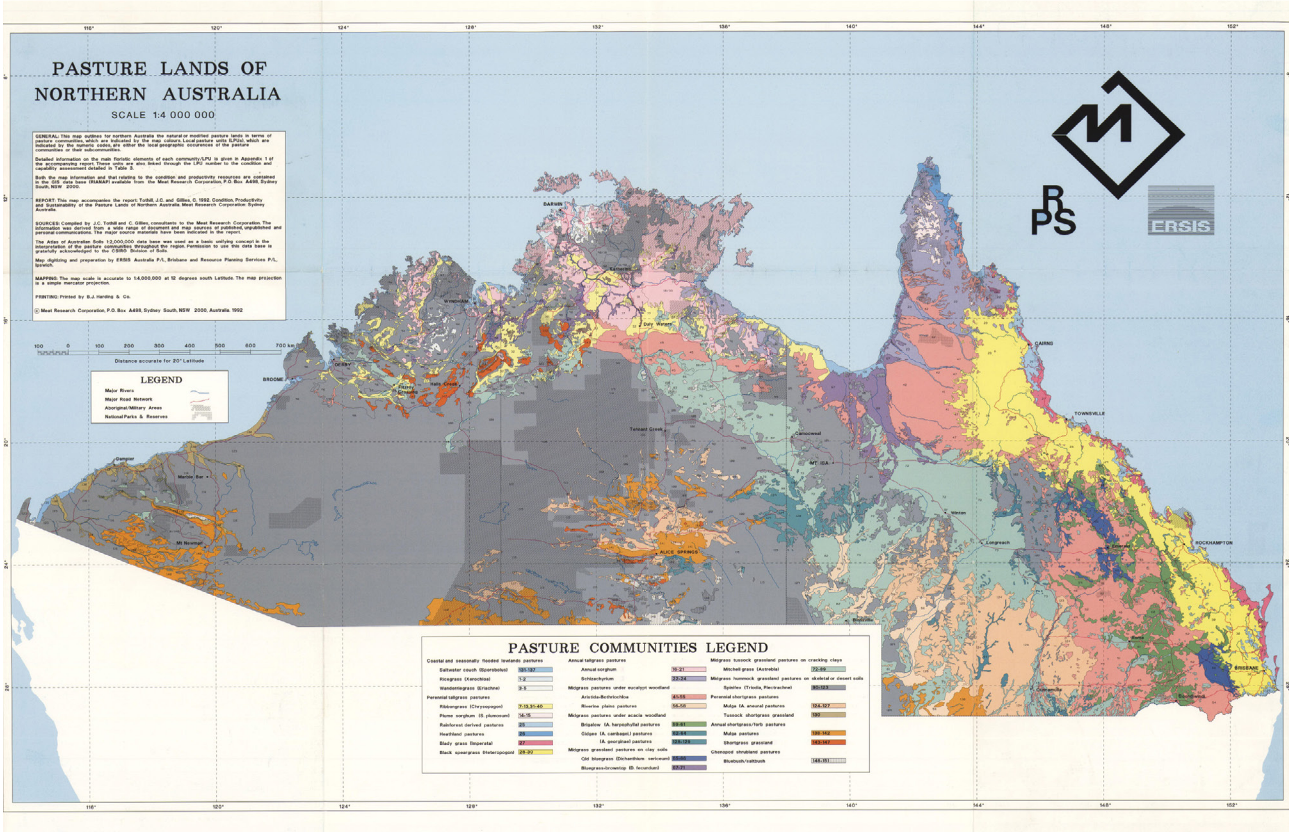
Based on the information collected by Llewellyn and D'Emden (2009) and Llewellyn et al. (2012) and using farmer estimates of the historical use of no-till seeding systems back to 1960 clearly shows that there is an increasing trend in adoption of no-tillage practices in Australian grain growing regions (Figure A5.6.5.8).

New functionality has been added to FullCAM to be able to retain a given management practice or species at the plot level based on reported Agricultural census data. Farming practices which show an increasing adoption rate are based on no-tillage practices and include stubble retention and no-till practices prior to cropping. This FullCAM functionality can also be applied at the species level and is used to simulate regions of pasturelands comprised of native grass species which have remained unchanged over time.

Grazing systems

As with the data preparation for cropping systems, the pasture species identified in Table A5.6.2.6 were concorded to the then new, Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (ABS 2010) (see Figure A5.6.5.10) and the recent ABS censuses were used to represent management epochs (Table A5.6.5.2). The species and management data were, however, collated from a number of sources. Grassland types in southern Australia after 2000 were sourced from Donald (2012) and, prior to 2000, were obtained from the Australian Temperate Pastures Database (Hill and Donald 1998). The digitised map (Figure A5.6.5.9) of the pasture lands of Northern Australia (Tothill and Gillies 1992) provided data for northern Australia for all years and grassland types.

Figure A5.6.5.9 Pasture Lands of Northern Australia



GENERAL: This map outlines for northern Australia the natural or modified pasture lands in terms of pasture communities, which are indicated by the map colours. Local pasture units (LPUs), which are indicated by the numeric codes, are either the local geographic occurences of the pasture communities or their subcommunities.

Detailed information on the main floristic elements of each community/LPU is given in Appendix 1 of the accompanying report. These units are also linked through the LPU number to the condition and capability assessment detailed in Table 3.

Both the map information and that relating to the condition and productivity resources are contained in the GIS data base (RIANAP) available from the Meat Research Corporation, P.O. Box A498, Sydney South, NSW 2000.

REPORT: This map accompanies the report: Tothill, J.C. and Gillies, C. 1992. Condition, Productivity and Sustainability of the Pasture Lands of Northern Australia. Meat Research Corporation: Sydney Australia.

SOURCES: Compiled by J.C. Tothill and C. Gillies, consultants to the Meat Research Corporation. The information was derived from a wide range of document and map sources of published, unpublished and personal communications. The major source materials have been indicated in the report.

The Atlas of Australian Soils 1:2,000,000 data base was used as a basic unifying concept in the interpretation of the pasture communities throughout the region. Permission to use this data base is gratefully acknowledged to the CSIRO Division of Soils.

Map digitizing and preparation by ERSIS Australia P/L, Brisbane and Resource Planning Services P/L, Ipswich.

MAPPING: The map scale is accurate to 1:4,000,000 at 12 degrees south Latitude. The map projection is a simple mercator projection.

PRINTING: Printed by B.J. Harding & Co.

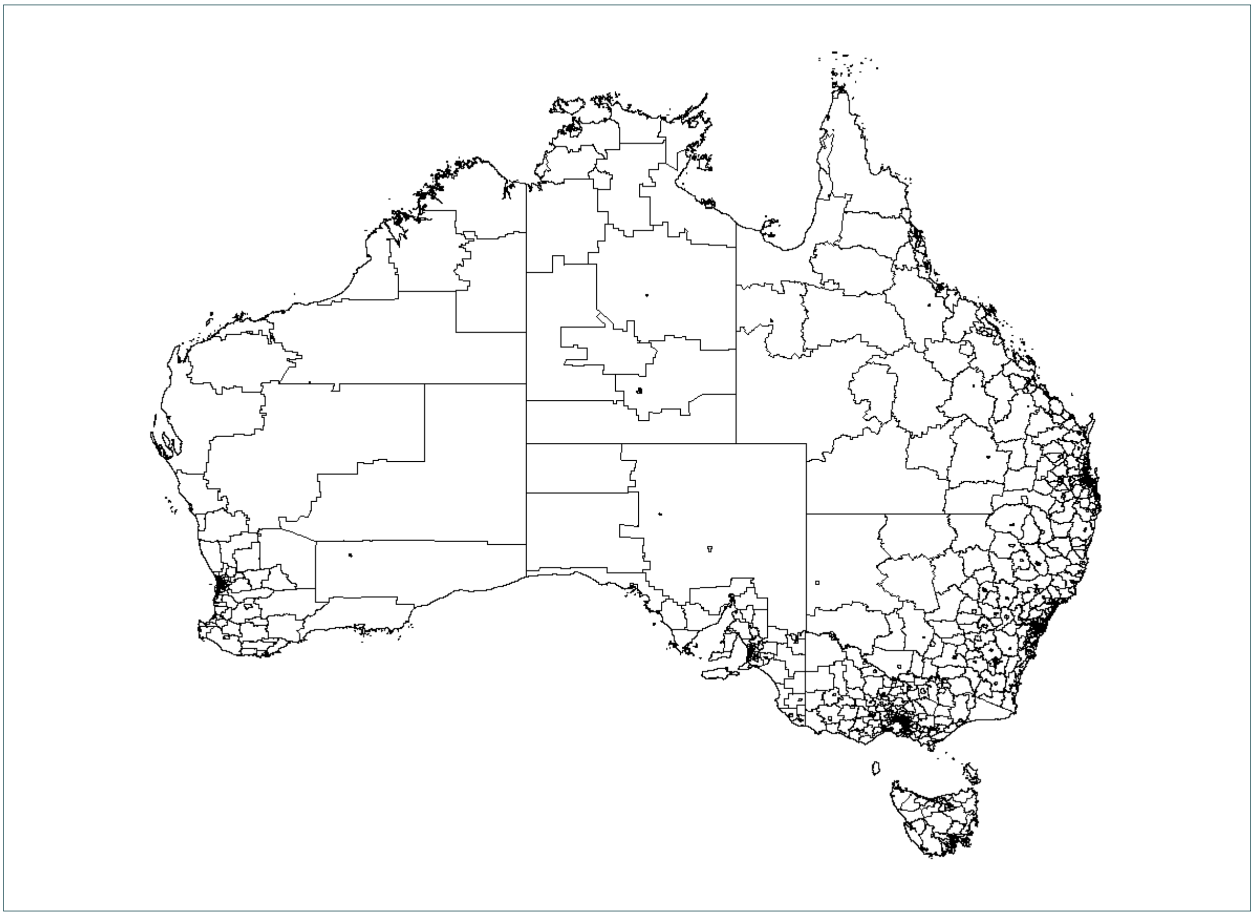
© Meat Research Corporation, P.O. Box A498, Sydney South, NSW 2000, Australia. 1992

The information collected describes 527 grazing and cropping systems, with associated management practice data also held within FullCAM relational database. Table A5.6.5.3 provides an example of the data collected. Allocation to a land use and management system is designated according to the relative frequency of land use and management for each soil type in each SA2 region in each year. For each of these systems the key management practices, such as the use of fire, when grazing is applied, ploughing and herbicide treatment, were implemented in the model.

Table A5.6.5.3 Example land use table

SA2	Start Year	End Year	Agriculture Species	Management practice
31173	2009-10	2013-14	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 122, 10y, 1 burn
71050	1989-90	1993-94	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 122, 2y, 0 burns
71055	1989-90	1993-94	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 244, 2y, 0 burns
31177	2009-10	2013-14	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 244, 5y, 1 burn
31503	1984-85	1988-89	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 30, 1y, 0 burns
51207	1989-90	1993-94	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, 0 burns
71068	1999-00	2003-04	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, 0 burns
71065	2004-05	2008-09	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, 0 burns
71068	1999-00	2003-04	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, 8 burns
51207	1989-90	1993-94	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, 0 burns
71068	1999-00	2003-04	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, 0 burns
71065	2004-05	2008-09	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, 0 burns
71068	1999-00	2003-04	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, 8 burns
31406	1999-00	2003-04	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, 8 burns
71055	1999-00	2003-04	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, 8 burns
11238	1999-00	2003-04	Barley	Barley, No till, stubble cool burn
11238	2009-10	2013-14	Barley	Barley, No till, stubble hot burn
11238	1989-90	1993-94	Barley	Barley, No till, stubble mulched
11238	1994-95	1998-99	Barley	Barley, No till, stubble ploughed
11238	2004-05	2008-09	Barley	Barley, No till, stubble removed
11238	1999-00	2003-04	Barley	Barley, No till, stubble standing
11238	2004-05	2008-09	Barley	Barley, Tilled, stubble cool burn
11238	1994-95	1998-99	Barley	Barley, Tilled, stubble hot burn
11238	2004-05	2008-09	Barley	Barley, Tilled, stubble mulched
11238	1989-90	1993-94	Barley	Barley, Tilled, stubble ploughed
11238	1989-90	1993-94	Barley	Barley, Tilled, stubble removed
11238	2009–10	2013-14	Barley	Barley, Tilled, stubble standing

Figure A5.6.5.10 Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (ABS 2010)



Native forest harvesting spatial data

The FullCAM spatial method for *harvested native forests* uses spatial datasets provided by state forest management agencies to specify the area, date and type of timber harvesting events. Within a FullCAM *harvested native forests* simulation, this data triggers timber harvesting, associated management and subsequent forest regrowth at the appropriate times and locations. For the current inventory, spatial data on native forest harvesting was provided for Victoria, New South Wales, Tasmania and Queensland. In each case a spatial dataset was provided in which polygons define the discrete areas, or logging coupes, where harvest has occurred.

For Victoria, the Harvested Logging Coupes dataset (Victorian Government 2023), accessed from data.gov.au, maps Victorian commercial logging events for each season, including silvicultural operation type and start/end dates of logging events. After filtering for valid dates there were approximately 30,000 mapped harvest events for the period 1931-32 to 2020-21, each assigned to one of 15 harvest types, as listed in Table 6.4.4.

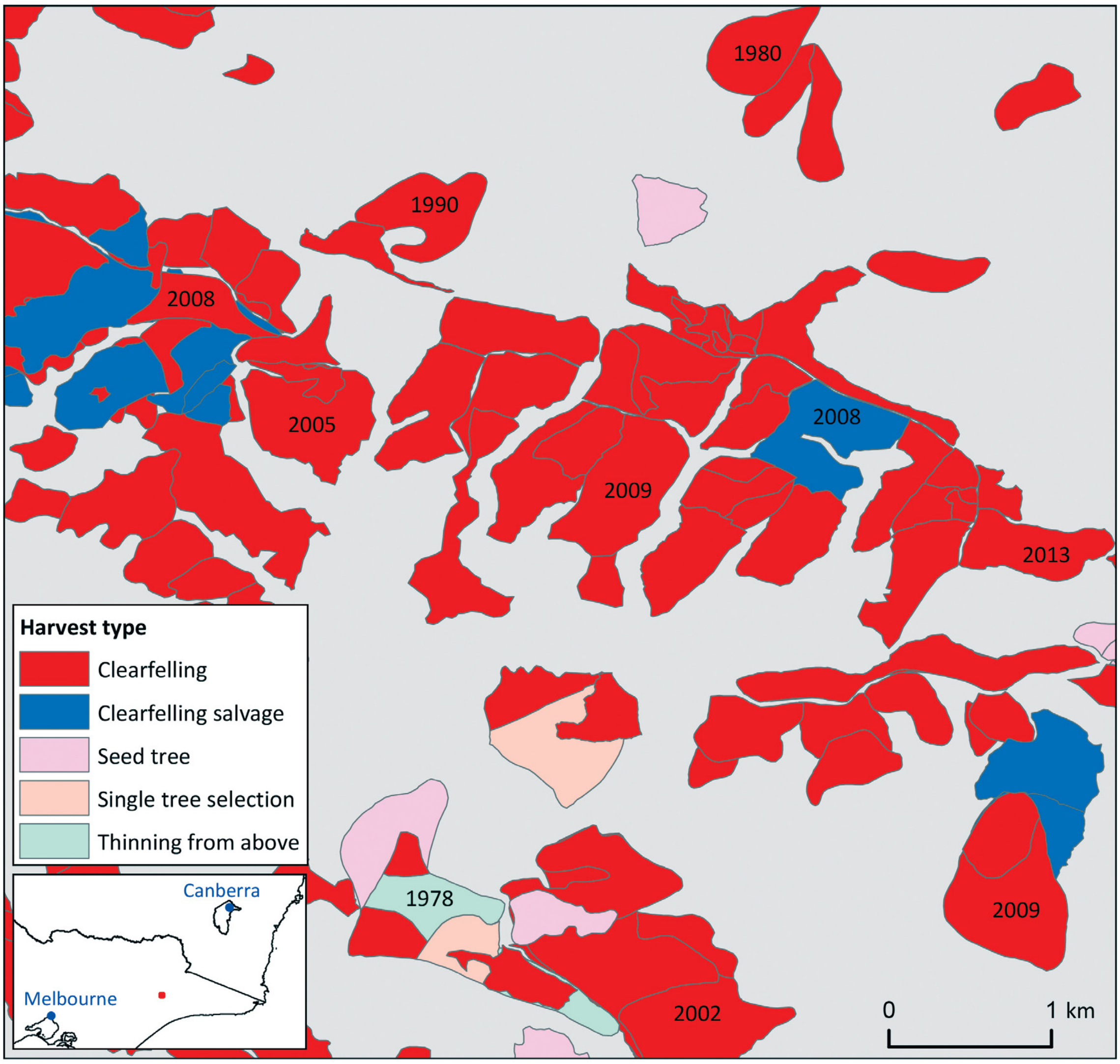
For New South Wales harvest polygons were provided by Forestry Corporation of NSW (2023), with 25,000 events covering the period from 1950-51 to 2020-21. Harvest and operation type were grouped, with advice from the Forestry Corporation, to derive 14 harvest types for NSW as listed in Table 6.4.4.

For Tasmania harvest polygons were provided by Sustainable Timber Tasmania (2023), with 23,800 events covering the period from 1900-01 to 2020-21, 85% of these since 1970. Harvest and operation type were grouped, with advice from the Sustainable Timber Tasmania, to derive 14 harvest types for Tasmania as listed in Table 6.4.4.

For Queensland, harvest polygons were provided by the Queensland Department of Agriculture and Fisheries (2023), with approximately 5,000 events covering the period from 1919-20 to 2021-22. Harvest and operation type were grouped, with advice from the Queensland Department of Agriculture and Fisheries, to derive 20 harvest types for Queensland as listen in Table 6.4.4.

The harvest data polygons were converted to a 25m x 25m grid, which matches the resolution used for other land use and land-cover change data in FullCAM. For each 25m pixel the year, month and type of each harvest event were encoded.

Figure A5.6.5.11 Example of forest harvest data from Gippsland, Victoria



Multiple use forest extent

The *harvested native forest model* covers areas of public land which are available for commercial timber harvesting, typically described as *multiple use forest.* Areas defined as multiple use forest in FullCAM include areas currently managed for uses including timber production, such as state forests. As well as areas currently available for harvesting, multiple use forests in FullCAM also include areas which were previously available for timber harvesting after 1990. Typically such areas were transferred from state forests to national parks or other protected tenures.

The spatial data which defines multiple use forest in FullCAM was prepared by the *Australian Bureau of Agricultural and Resource Economics and Sciences* (Mutendeudzi, et al. 2014) based on an analysis which selected from forest areas using the following criteria:

- land tenure (public land which has been available for harvest at some time since 1990);
- commerciality (sufficient forest productivity and presence of merchantable species);
- distance from wood processing facilities (< 200km);
- slope (< 50%); and
- not rainforest in mainland areas.

For Tasmania and Queensland, the multiple use forest extent was adjusted beyond the Mutendeuzi et al. (2014) extent where necessary, to ensure the inclusion of all forest areas currently managed as multiple use forest by Sustainable Timber Tasmania and the Queensland Department of Agriculture and Fisheries respectively.

Crop and pasture yield

Crop/pasture growth model

FullCAM uses crop and pasture yield data in the estimation of biomass accumulation in agricultural systems. Yield data is estimated using a crop/pasture growth model developed by CSIRO Land and Water to generate estimates based on rainfall availability during the growth period (Unkovich, Baldock and Marvanek 2009). The model uses a water balance routine to estimate daily evapotranspiration, using fixed crop x region specific splits for bare soil evaporation or crop water use (transpiration) to estimate crop and pasture productivity. A minor modification to the water balance model was made in 2024, which corrected an error that limited plant available water to the capacity of the top 30cm of soil. This limited plant growth when high rainfall occurred. Plant available water now extends up to a nominated capacity to 1m as was the original intention of the model. Two plant production modules are used, one to accommodate annual crops and pastures (Figure A5.6.5.12), and the second for perennial pasture systems (Figure A5.6.5.13). The two modules cover summer and winter grain and forage crops, sugarcane, sown and native pastures, and grass growth in rangeland ecosystems. For crops, a single annual yield value is generated for each year, while for pastures, a monthly value is generated. In both cases the yield values are inclusive of the turnover component.

Figure A5.6.5.12 Conceptual model of annual crop growth module

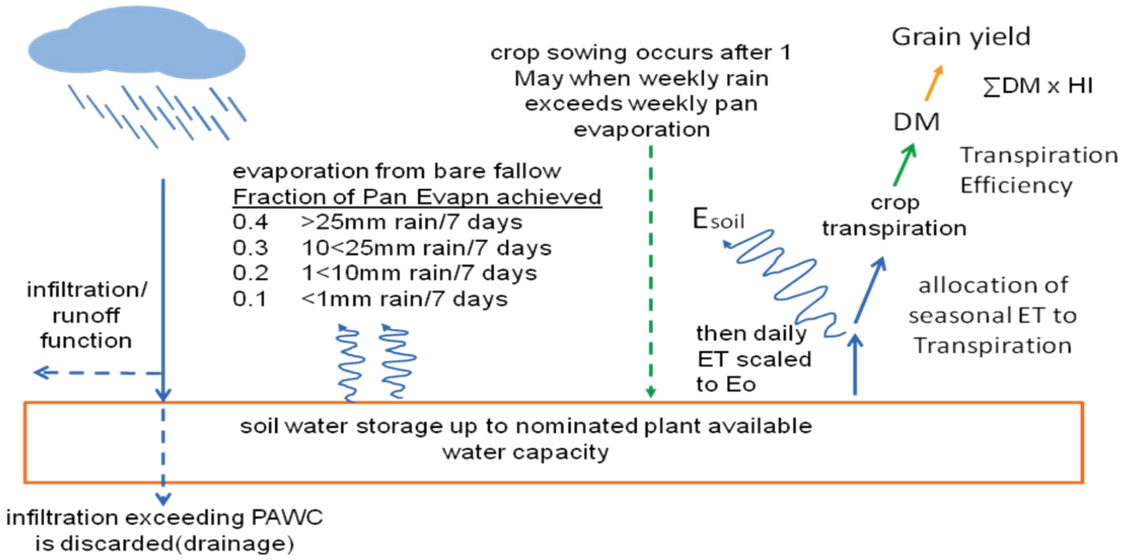
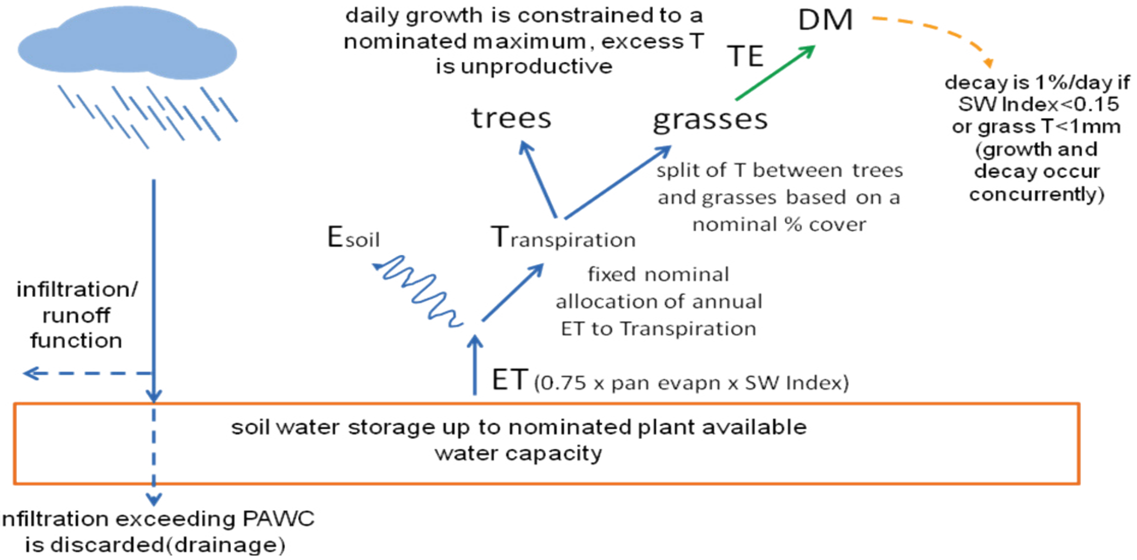


Figure A5.6.5.13 Conceptual model of perennial grass/pasture module



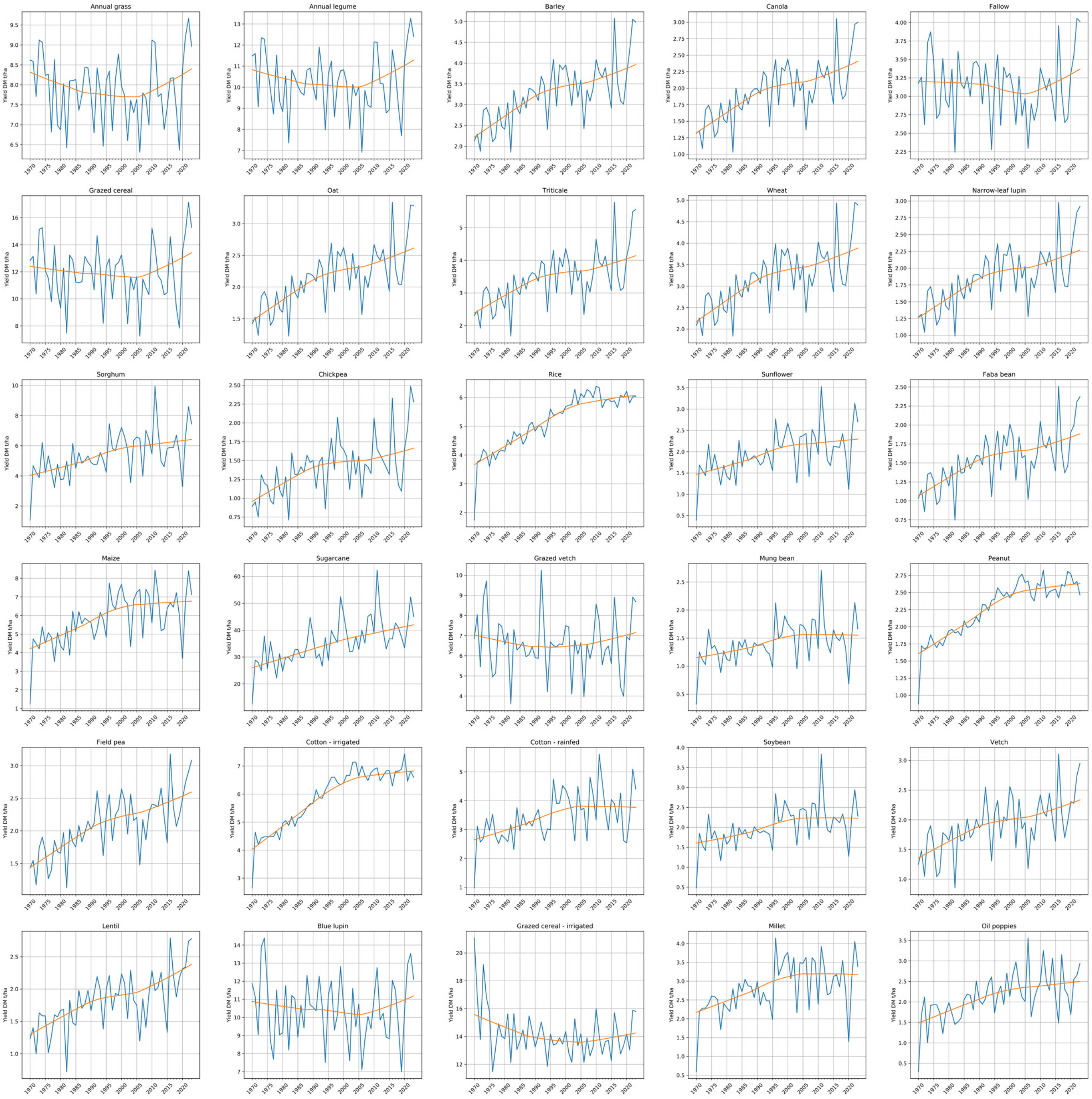
Productivity improvement trends

As the model of crop growth is based on recent agricultural management practices it is necessary to scale the modelled dry matter production through time according to long term trends in farm crop productivity. Taking 2000 as the base year, modelled yields have been scaled from this time at the indicative rate (1.36 per cent pa) for the 1970-2000 time period. While this rate of change also includes yield increases due to improvements in crop harvest index (Unkovich, Baldock and Forbes 2010) these have not removed from the dry matter productivity increases because HI is currently held constant in FullCAM.

Yields validation in FullCAM

Figure A5.6.5.14 depicts the variation of Australia wide average annual yield for major crops. The yields show high fluctuations due to factors such as climate with the blue line denoting the general trend of the yields for considered crops from 1970–2022. Annual yield data plays a major role in the flow of carbon masses within FullCAM, with residues incorporated into soil over the growing period and after the harvest event. Most crops show an increasing trend from 1970 while annual pastures show U-shaped patterns over the 1970–2022 period.

Figure A5.6.5.14 Australian average crop yields for crop, tonnes dry matter/ha/year, 1970–2022



Verification of the model

CSIRO has tested the model construct output against a database of crop yield data (Unkovich, Baldock and R. 2014) and, in general (regional) testing, the modules accounted for about 50 per cent of the variance in annual crop grain yield or of shoot dry matter of perennial pastures on any given day. In site specific tests the annual grain crop model was able to explain up to 80 per cent of the variance in crop yield.

Annual crop species growth model

The annual growth model is designed to model annual crop growth. Crop growth being for a plant that is planted, grown and then harvested in an annual rotation. This model accounts for varying growth periods given crops do not grow for the entire year. The growth modelled is a process within FullCAM of assigning the proportions of species yields generated by the CSIRO model to specific time increments.

The annual growth formula is a sigmoidal curve fitted with different parameters specific to individual crops by CSIRO Agriculture and Food and aligns with the work carried out by Unkovich (2013). The formula gives the step (or daily) fraction, which is a factor applied to yield to produce the daily portion of growth (Figure A5.6.5.15).

$$\textit{Daily fraction} = \frac{1}{1 + e \left(\frac{\textit{An\_season\_day}\ \text{sigmoidal GrowthA}^{*}\textit{An\_max\_days}}{\text{sigmoidal GrowthB}^{*}\textit{An\_sow\_day}^{*}\textit{An\_max\_days}} \right)}$$

Pasture species growth model

Running model simulations with annual and perennial pasture species under the above crop growth model is unrealistic as it has no ability to simulate an ongoing growth cycle and because pasture species tend to respond more closely to recent climatic conditions rather than according to a sigmoidal function. This has an impact on the fidelity of grassland simulations, producing results that do not represent pasture growth and produce less soil carbon capture than generally expected from pasture species.

The CSIRO model provides monthly growth increments for annual and perennial grass species in Australia while FullCAM handles the turnover component at each time step. Together these estimate the standing dry matter for annual and perennial species within the grassland account.

A5.6.6 Plantation forest growth model

Forest growth model

Plantations commonly produce more biomass than native forest systems in Australia, at least in the short to medium term (15–40 years). For example, Baker and Attiwill (1985) showed that *Pinus radiata* achieved 70–100 per cent more biomass compared to an 80–year-old native forest, grown under similar conditions, in only 20 years. These growth differences are driven by factors such as nutrient addition, reduction in insect herbivory associated with the use of non-endemic species or through control of pests, site-specific species matching and management[8], and possibly greater physiological efficiency in utilising site resources by the introduced species.

Calculation of r and G

The two key TYF (Eq. A5.6.2.2) parameters calibrated for plantation species are G (which determines the rate of growth) and r (which influences the maximum biomass obtained), where.

$$\Delta AGB = M \times r \times [e^{(-k / A_2)} - e^{(-k / A_1)}] \times (FPI / FPI_{ave}) \qquad \text{A5.6.6.1}$$

r = Site-productivity-dependent multiplier (Waterworth, Richards and Brack, et al. 2007), which for tree plantations, is also influenced by *M*,

and where:

$r = \text{Exp}(ar) \times M^{br}$, if $r \times M$ is between $\text{Min}_{r\times M}$ and $\text{Max}_{r\times M}$, else

$r = \text{Min}_{r\times M} / M$, if $r\times M < \text{Min}_{r\times M}$, or

$r = \text{Max}_{r\times M} / M$, if $r\times M < \text{Max}_{r\times M}$.

A_1, A_2 = age (years) in year 1 and 2, respectively.

$k = 2 \times G - 1.25$, where G = tree age of maximum growth rate (years).

FPI / FPI_{ave} = Ratio of the Forest Productivity Index (FPI) in a given year to the long-term average.

As part of recent work by Paul et al. (2022) to calibrate *G* and *r* (or more specifically, the *ar* and *br* parameters applied to calculate *r* based on M), AGB data were collated separately for eight species (and/or hybrids of species) commonly grown in Australian plantations, with a minimum requirement of 98 observations per 'species'; Eucalyptus globulus ('Globulus'), E. nitens ('Nitens'), E. grandis ('Grandis'), E. pellita and its hybrids with E. urophylla and E. brassiana ('PellitaHyb'), Pinus radiata ('Radiata'), P. pinaster ('Pinaster'), P. caribaea/P. elliottii and their hybrids ('SouthernPine'), and Acacia mangium ('Mangium'). Other species for which there was less AGB data were grouped into either: other eucalypts ('OtherEucs'), other non-eucalypt hardwoods ('OtherHW'), other softwoods ('OtherSW'), or other acacia species ('OtherAcacia').

To model the growth of each stand in this AGB database (N = 8,749), a unique FullCAM simulation was constructed, with the simulation including any coppice or thinning regime, and accounting for the site quality (via the *M* input), planting date and the climatic conditions over the period between planting and the time of growth measurement(s) (i.e., via the FPI and FPI_{ave} inputs). The initial AGB at planting was taken as half of average AGB observed in one year old stands for the category of planting being simulated. The G, *ar* and *br* parameters were calibrated for each category via function minimisation based on the methods described in Paul et al. (2022).

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[8] The relatively high growth rates observed by plantations are inherently accounted for in the empirical calibrations of FullCAM's growth curve – the Tree Yield Formula, i.e. the impacts of fertiliser application and weed control are subsumed within the TYF parameters obtained during the calibration to observed yield data.

TYF parameters (G and ar, br) for various categories of plantings, including the Min_{rxM} and Max_{rxM} values of application, and the six fit statistics obtained against the corresponding calibration datasets given in Table A5.6.6.1. Fit statistics include Bias (Mg DM ha^{-1}), mean absolute error (MAE, Mg DM ha^{-1}), Mean Absolute Percentage Error (MAPE, %), Root Mean Squared Error (RMSE), Model Efficiency (EF) and Lin's concordance correlation coefficient (LCC). Only the MAPE was applied to the transformed scale, with all other fit statistics applied to un-transformed data.

Table A5.6.6.1 Values of TYF parameters (G and ar, br) for various categories of plantings, including the Min_{rxM} and Max_{rxM} values of application, and the six fit statistics

Type	*G*	*ar*	*br*	*Bias*	*MAE*	*MAPE*	*RMSE*	*EF*	*LCC*
Globulus	5.554	4.358	-0.767	0.000	21.8	8.1	30.1	0.347	0.736
Nitens	6.913	3.317	-0.576	0.000	23.7	9.7	31.6	0.408	0.709
Grandis	4.229	2.695	-0.514	0.000	26.9	15.7	35.6	0.665	0.837
PellitaHyb	4.051	2.861	-0.446	0.510	19.4	6.9	26.7	0.607	0.732
Radiata	6.311	3.828	-0.617	0.000	36.4	7.2	49.4	0.553	0.739
Pinaster	11.318	2.769	-0.386	0.000	24.2	13.4	35.0	0.621	0.799
SouthernPine	6.505	3.204	-0.447	3.600	47.7	9.4	59.4	0.202	0.666
Mangium	3.936	3.630	-0.681	0.000	19.4	5.7	24.1	-0.004	0.131
OtherEuc	8.002	2.355	-0.368	-0.010	28.5	21.2	46.0	0.611	0.778
OtherHW	6.745	3.230	-0.584	0.100	22.9	21.4	32.0	0.694	0.831
OtherSW	10.917	3.204	-0.447	0.000	9.7	18.8	16.5	0.803	0.890
OtherAcacia	6.547	2.251	-0.384	0.000	14.0	18.5	27.0	0.438	0.543
MalleeBlock	6.317’	0.000	0.0001	1.108	14.3	17.7	19.4	0.173	0.534
MalleeBeltL	4.533’	0.1821	0.0001	5.500	15.1	15.8	19.4	0.001	0.358
MalleeBeltHW	3.4921	0.1821	0.0001	5.816	15.5	15.5	25.2	0.333	0.569
MalleeBeltHN	2.288	0.475	0.0001	7.884	22.0	18.4	32.0	0.555	0.739

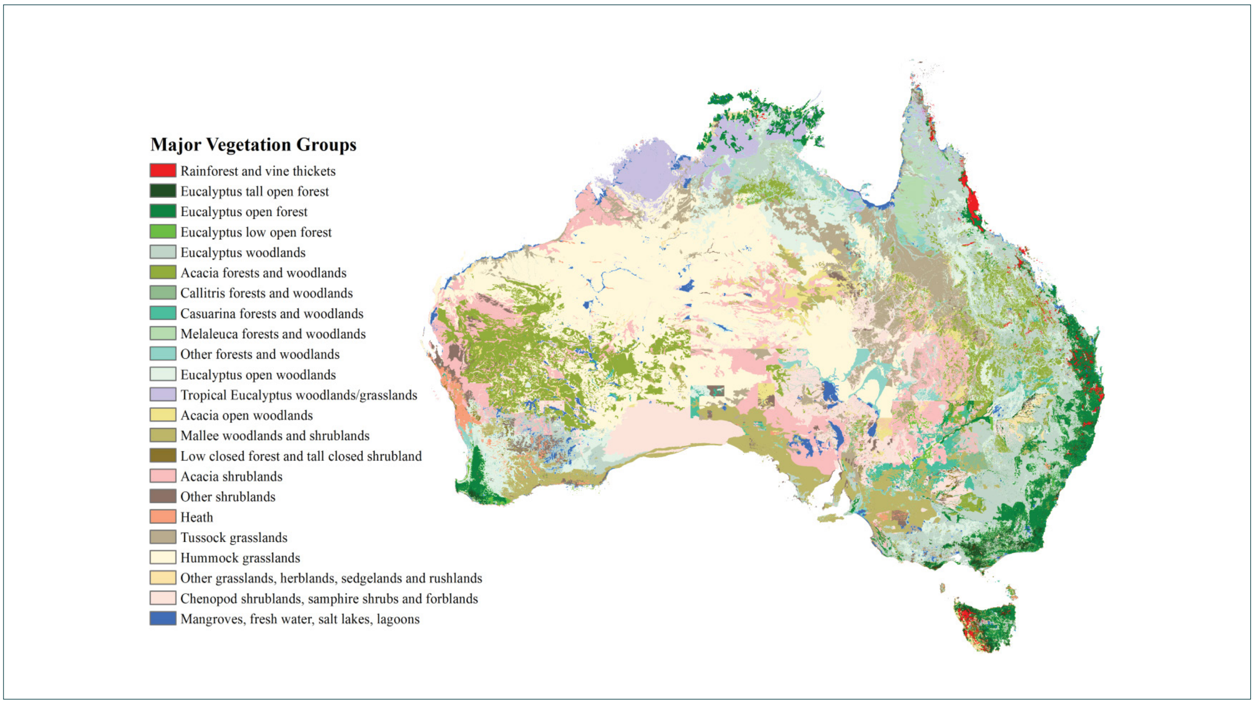
1 TYF parameters were calibrated previously by Paul and Roxburgh (2020) and verified here. Note, given br was zero, the value of r reported in Table 4 of Paul and Roxburgh (2020) is calculated as Exp(ar).

A5.6.7 Major vegetation groupings classified by the national vegetation information system

The Major Vegetation Groups (MVG) (Figure A5.6.7.1) are used to specify the biomass allocations of *forest land converted to cropland* or *grassland.* In addition, the MVG are used to spatially disaggregate the land included in the *forest land converted to cropland* or *grassland* classifications in the CRF tables.

The National Vegetation Information System (NVIS, see NLWRA (2001)) provides a composite of the best available vegetation mapping in Australia. For the *forest land converted to cropland* and *forest land converted to grassland* category, various forest characteristics (e.g., forest floor coarse woody debris and litter) are associated with the forest types extracted from the NVIS. The NVIS collates and provides, in a consistent taxonomy and classification, the best available vegetation maps from all available sources. For the purposes of carbon accounting the Level III MVG categories were applied. These vegetation types are described in below.

Figure A5.6.7.1 Major vegetation groups (MVG)



In addition to the 'current' vegetation mapping which represents a composite of recently collected data, the NVIS also modelled forest distributions to infer a pre-European settlement (i.e., pre 1770) vegetation map. Some of the land clearing identified by Australia's land cover change programme pre-dated the current vegetation mapping (which was generally based on data from 1990 onwards). This meant that areas identified as cleared land in the NVIS could have been forested between 1972 and the date used in the NVIS mapping. In these instances, the vegetation type allocation was drawn from the 1770 modelled (inferred) vegetation map.

Group 1. Rainforest and vine thickets

Rainforest communities in Australia are mostly confined to the wet and cooler areas or climatic refuges in eastern Australia, apart from the semi-evergreen vine thickets of the Brigalow Belt and the monsoonal vine thickets that are found in the tropics in Western Australia and the Northern Territory. Community types include cool temperate rainforest, sub-tropical rainforest, tropical rainforest, vine thickets, and semi-deciduous and deciduous vine thickets. Rainforests were cleared extensively in the late 19th or early 20th centuries for high value timbers, dairying, tobacco/sugar cane or other agricultural production. The best known examples of this are the "Big Scrubs" of Illawarra and northern New South Wales and the Atherton Tableland in north Queensland.

Group 2. Eucalyptus tall open forest

These communities are restricted to all but the wetter areas of eastern Australia from the margins of the wet tropical rainforests of north Queensland to Tasmania, and the southwest of Western Australia, often in rugged mountainous areas. At their maximum development in Tasmania and parts of Victoria, they contain the world's tallest flowering plants, with some trees rising to heights in excess of 100 m. These communities are typified by a well-developed often broad-leaved shrubby understorey or sometimes tree ferns and are mostly found adjacent to, or in association with, rainforest communities. Extensive areas of these communities were cleared for agriculture and grazing early in the 20th century, particularly where they occurred in association with rainforests. Major areas remain today in crown reserves as State Forests or National Parks.

Group 3. Eucalyptus open forest

This group is widespread along the sub-coastal plains, foothills and ranges of the Great Dividing Range in eastern Australia and the sub-coastal ranges of the southwest of Western Australia. Generally, this group has a shrubby understorey which is low to moderate in height, but in drier sites they may have a grassy understorey with scattered shrubs and/or cycads. There has been widespread clearing of these communities for grazing and agriculture in the major agricultural zones of eastern Australia and the southwest of Western Australia. The rate of clearing in these communities by the early 20th century saw the development of crown reserves for the protection of forests, either as national parks or as production forests, and the establishment of forestry departments within several jurisdictions.

Group 4. Eucalyptus low open forest

This group contains a series of montane communities of the Great Dividing Range such as Snow Gum, Red Stringybark and Scribbly Gum, and the drier Jarrah communities in the southwest of Western Australia. Extensive areas of these communities have been cleared principally for grazing.

Group 5. Eucalyptus woodland

This group is widespread throughout the mountain ranges and plains west of the divide in Eastern Australia and east of the sub-coastal ranges of southwest Western Australia. This group includes a series of communities, which have come to typify inland Australia. For example, the box (poplar box, white box, yellow box etc.) and ironbark woodlands of eastern Australia are included in this group. The Eucalyptus woodlands have been extensively cleared and modified, particularly in the agricultural zones of eastern Australia and in southwest Western Australia. In many regions only small, isolated fragments remain today, in many instances found only along creeks and road verges.

Group 6. Acacia forest and woodland

Brigalow *(Acacia harpohylla)* and Mulga *(A. aneura)* dominate this group with mulga covering large parts of the arid interior of the continent. A series of other acacias such as Lancewood (A. *shirelyii*) and Myall (A. *pendula)* are also included. Mulga is one of the most widespread species on the continent, occurring on a series of forest, woodland and shrubland communities. The Mulga and Brigalow communities of eastern Australia have been extensively cleared for grazing and agriculture and in many regions only scattered remnants are found today. Mulga communities in the arid interior have not been subject to clearing to the same degree but many areas have been subject to modification by grazing pressures from cattle/sheep and feral animals, and increased macropod populations supported by the increased availability of water from bores.

Group 7. Callitris forest and woodland

Cypress Pine forests are found mostly in a series of discrete regions, notably in the Brigalow Belt, but also in the arid areas in South Australia and in association with mallee communities near the South Australia Victoria border. Extensive areas have been cleared for grazing in the Brigalow Belt and in the Mallee bio regions in particular, but major areas are included in State Forests and other crown reserves in Queensland and New South Wales.

Group 8. Casuarina forest and woodland

Containing both Casuarina and Allocasuarina genera, these occur in a series of quite distinct communities, notably foredune *(C. equisetifolia)* communities, swamp *(C. glauca)* communities, riverine *(C. cunninghamiana)* and desert (C. *cristata)* communities. These communities have been extensively cleared in many coastal areas for agriculture, or for industrial uses or urban developments. Areas in the arid zone are subject to modification by grazing of domestic stock and from feral herbivores.

Group 9. Melaleuca forest and woodland

These cover substantial areas in the tropical north but are also found in temperate climates most often in or adjoining coastal or montane wetlands. These communities have been extensively cleared in many coastal areas for agriculture or housing near major cities. Extensive areas remain in the tropical north, in particular southern Cape York Peninsula.

Group 10. Other forest and woodland

This is a diverse group of communities, some of which such as Banksia woodland are comparatively restricted in their extent but may be locally abundant. It also includes a series of mixed communities of the arid zone, which are not dominated by any particular species. These communities have been extensively cleared in many coastal areas for agriculture or urban uses. Extensive areas remain in the arid zone but are subject to modification by grazing of domestic stock and from feral herbivores.

Group 11. Eucalyptus open woodland

These cover extensive areas of the arid zone or drier tropical north mostly with a shrubby or grassy ground layer. Little of this group has been cleared. Many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 12. Tropical eucalyptus woodland/grassland

This group contains the so-called tall bunch-grass savannas of north Western Australia and related Eucalyptus woodland and Eucalyptus open woodland communities in the Northern Territory and in far north Queensland, including Cape York Peninsula. They are typified by the presence of a suite of tall annual grasses, notably *Sorghum spp,* but do not include communities in more arid sites where *Triodia spp* becomes more dominant. The fundamental difference between how Western Australia and the Northern Territory and Queensland describe these vegetation communities, necessitated their separation into a separate MVG.

Group 13. Acacia open woodland

These also cover extensive areas of the arid zone or drier tropical north mostly with a shrubby or grassy ground layer such as Blue Grass *(Dicanthiumsericeum).* Eucalyptus species such as the Yapunyah *(E. thozetiana)* may also be present. Little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 14. Mallee woodland and shrubland

Multi-stemmed eucalyptus trees in association with a broad range of other shrubs or grasses cover extensive areas of the southern arid zone from Victoria to the southwest of Western Australia. The mallee communities in Victoria and parts of South Australia have been extensively cleared, with only isolated remnants remaining in some areas, but these communities are still widespread in the arid zone of South Australia and Western Australia. These are subject to modification by grazing of domestic stock and from feral herbivores.

Group 15. Low closed forest and closed shrubland

These dense communities are found mostly in coastal environments, for example Kunzea and Leptospermum scrubs, or sub-coastal plains e.g., Banksia scrubs, and can cover significant areas. They also occur in rugged mountainous areas, such as sub-alpine areas in Tasmania. They have been extensively cleared in many coastal areas for agriculture or urban development.

Group 16. Acacia shrubland

Mulga, Gidgee and mixed species communities of the central Australian deserts dominate this group, but it also includes a series of other desert acacia communities. Little of this group has been cleared outside of the major agricultural zones, but they have been subject to modification by grazing from domestic stock and from feral herbivores.

Group 17. Other shrubland

This is a diverse group containing a series of communities dominated mainly by genera from the Mrytaceae family. Kunzea, Leptospermum and Melaleuca shrublands are important component of this group, but it also includes a suite of mixed arid zone communities and other communities dominated by typical inland genera such as Eremophila and Senna. This group has been extensively cleared in the agricultural regions and in coastal areas adjoining major cities. In the arid zone, little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 18. Heath

This group includes the stunted (< 1 m tall) vegetation of the coastal sand masses, typified by the family Epacridaceae and also other dense low shrublands in sub-coastal or inland environments, mostly on drainage impeded soils or natural hollows or depressions. The communities have been cleared for sand mining, agriculture and urban development.

Group 19. Tussock grassland

This group contains a broad range of native grasslands from the Blue Grass and Mitchell Grass communities in the far north to the temperate grasslands of Southern New South Wales, Victoria and Tasmania. The group contains many widespread genera including *Aristida, Astrebla, Austrodanthonia, Austrostipa, Crysopogon, Dichanthium, Enneapogon, Eragrostis, Eriachne, Heteropogon, Poa, Themeda, Sorghum* and *Zygochloa* and many mixed species communities. Extensive areas of this group have been cleared and replaced by exotic pasture species and most other areas have been subject to modification by grazing, weed invasion and land management practices associated with grazing domestic stock, such as frequent fire and the application of fertilisers.

Group 20. Hummock grassland

The spinifex *(Triodia spp.* and *Plechrachnespp)* communities of the arid lands are quintessential to the Australian outback. These cover extensive areas of the continent either as the dominant growth form with the occasional emergent shrub or small tree (either acacia or eucalypt). They are also a conspicuous element of other communities such as open woodlands. Little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 21. Other grassland, herbland, sedgeland and rushland

This diverse group contains a series of communities, some of which are restricted within the landscape, some of which occur as mosaics and others that are otherwise too small or diffuse across the landscape to be easily discerned at a continental scale.

Group 22. Chenopod shrub, samphire shrub and forbland

The chenopods such as Saltbush (*Atriplexspp.*) and Bluebush *(Maireana spp),* cover extensive areas of the arid interior on saline soils. They are also associated with the ephemeral salt lakes of these arid areas, often in association with samphires such as *Halosarciaspp.* Similarly, some forbland communities contain a mix of species including samphires and chenopods. Other forblands containing Asteraceae species are found in Queensland.

Group 23. Mangrove, tidal mudflat, samphire, claypan, salt lakes, bare areas, sand, rock, lagoons and freshwater lakes

Mangroves vary from extensive tall closed forest communities on Cape York Peninsula to low closed forests or shrublands in southern regions. Samphires (salt-tolerant, non-woody plants) are found in the coastal mudflats and marine plains, adjoining mangrove areas in many instances, but they also cover extensive marine plains inland from the southern Gulf of Carpentaria and other parts of the tropical north. In the harsh environments of the arid interior extensive areas devoid of vegetation can be found as bare ground, either sand dune, claypan or salt lakes. Similarly, the coastal sand masses can often contain extensive areas of bare sands, mostly as active dunes. In mountainous areas, large areas of bare rock or scree may be a feature of the landscape. This is particularly the case where large rocky outcrops dominate the landscape, such as Uluru and the Olgas in central Australia, Bald Rock in northern New South Wales and many examples of large monadnocks in the southwest of Western Australia. There can be widespread clearing or infilling of mangroves and tidal mudflats in coastal areas near urban major centres for industrial uses or urban developments.

A5.6.8 Tier 2 forest conversion model

Forest land converted to cropland and *grassland* emissions estimates are based on the Tier 3 Approach 3 model and national time-series of Landsat satellite data. Verification of the use of the Tier 3 model to estimate emissions from this sub-category was performed through comparison with a Tier 2, Approach 2 method. The Tier 2 model was developed as an excel spreadsheet model. This model formed the basis for reporting emissions prior to the implementation of the Tier 3, Approach 3 methods and has been subsequently enhanced. The Tier 2 model is used to estimate changes in biomass from the conversion of 'mature' forest, the regrowth of forest on previously cleared land, the growth of crops and grasses on cleared land, and the subsequent re-clearing of a proportion of this regrowth.

The model also calculates changes in the dead organic matter (DOM) and soil pools and emissions (CO_2 and non-CO_2) associated with burning.

The annual area converted or re-cleared (activity data) were the same as those used as input to the Tier 3 model for *forest land converted to cropland* and *grassland*.

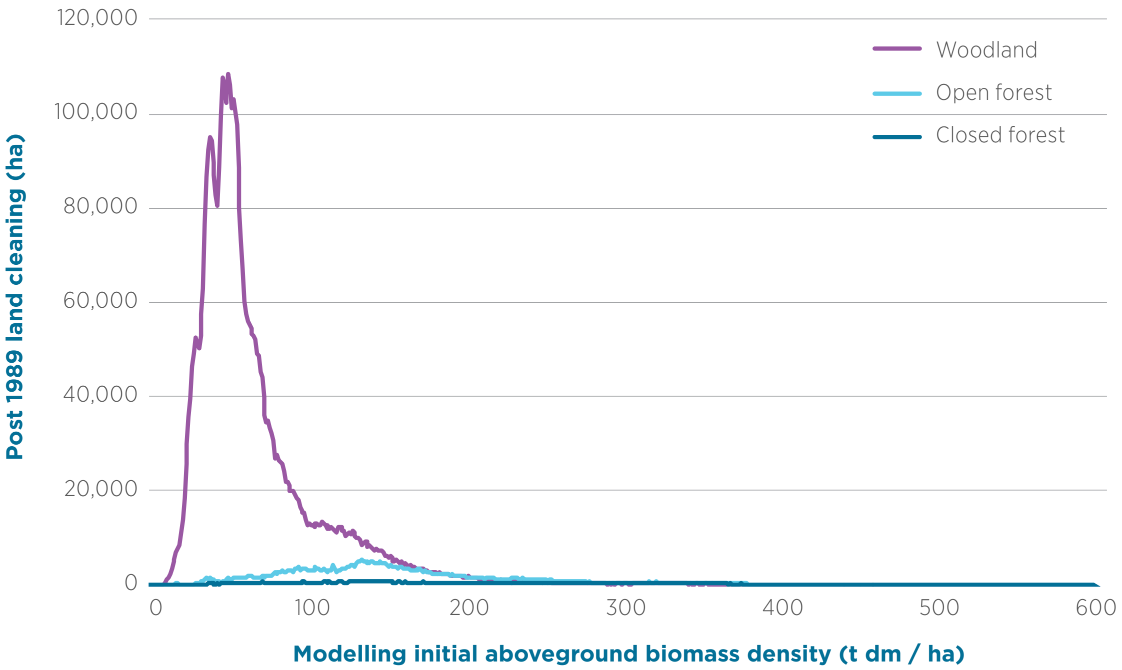
In the Tier 2 model land clearing is stratified into three broad forest classes:

- closed (tropical forest);
- open (predominantly eucalypt forest); and
- woodland forest

This stratification was undertaken by overlaying the areas cleared from the remote sensing analysis on the major vegetation groups of the National Vegetation Information System (NVIS; see Appendix A5.6.7).

Figure A5.6.8.1 shows that the majority of land clearing since 1989 has occurred in woodland forests. This information was used in the Tier 2 model to allocate the area cleared in each year to clearing of woodland, open forest and closed forest (Table A5.6.8.1).

Figure A5.6.8.1 Initial assumed biomass of land cleared post-1989 which has entered Australia's deforestation accounts



Carbon pools

Biomass – aboveground and below ground trees

To determine the biomass of each forest class that is used in the Tier 2 model, analysis was undertaken of the initial assumed above ground biomass of the lands that are within Australia's deforestation account. To undertake this analysis the simulated cells layer for lands within the deforestation account were intersected with the initial assumed above ground biomass surface. Table A5.6.8.1 shows the results of this analysis. The estimates are expressed as averages within three forest types – closed forest, open forest and woodland. The area converted from forest land to cropland and grassland areas were allocated to the three forest types by matching their locations to the locations of Australia's major vegetation groups.

Table A5.6.8.1 Tier 2 forest coefficients used to estimate emissions and removals from first time forest clearing

	Closed Forest	Open Forest	Woodland Forest
Proportion of annual clearing (%)	2	10	88
Initial biomass of forests(a)(b) (t dm ha^{-1})	198.7	152.8	67.6
Root : shoot ratio	0.25	0.25	0.40
Debris onsite mass(b) (t dm ha^{-1})	100	75	50
Initial soil carbon (t C ha^{-1})	70	73	60
Proportion of area subject to forest regrowth (%)	25	25	25

(a) Aboveground biomass.
(b) Used for all States and Territories.

Areas of previously cleared land that re-grew to forest are assumed to achieve their original biomass in 25 years. The biomass of forest subject to reclearing is 32 per cent of the mature biomass.

Biomass – above ground and below ground herbaceous species

Sequestration associated with the growth of crop and grass species is included in the model on land which is not subject to forest regrowth. Table A5.6.8.2 provides the biomass increment parameters applied to estimate this variable. These parameters are multiplied by the total area of clearing recorded each year to estimate the biomass accumulated by crop and grass species on cleared land.

Table A5.6.8.2 Biomass accumulated by crop and grass species on cleared land

	Crops	Grasses
Proportion of cleared land (%)	15	60
Above ground mass, including debris (tdm ha^{-1})	4.0	4.2
Root : shoot ratio	0.5	0.5

Dead organic matter

The forest debris onsite prior to forest clearing is presented in Table A5.6.8.1. Debris associated with crops and grasses is included with living biomass (Table A5.6.8.2). Forest debris, including initial debris and debris remaining after forest conversion, was assumed to decay over a period of 10 years (IPCC 2003).

Soil carbon

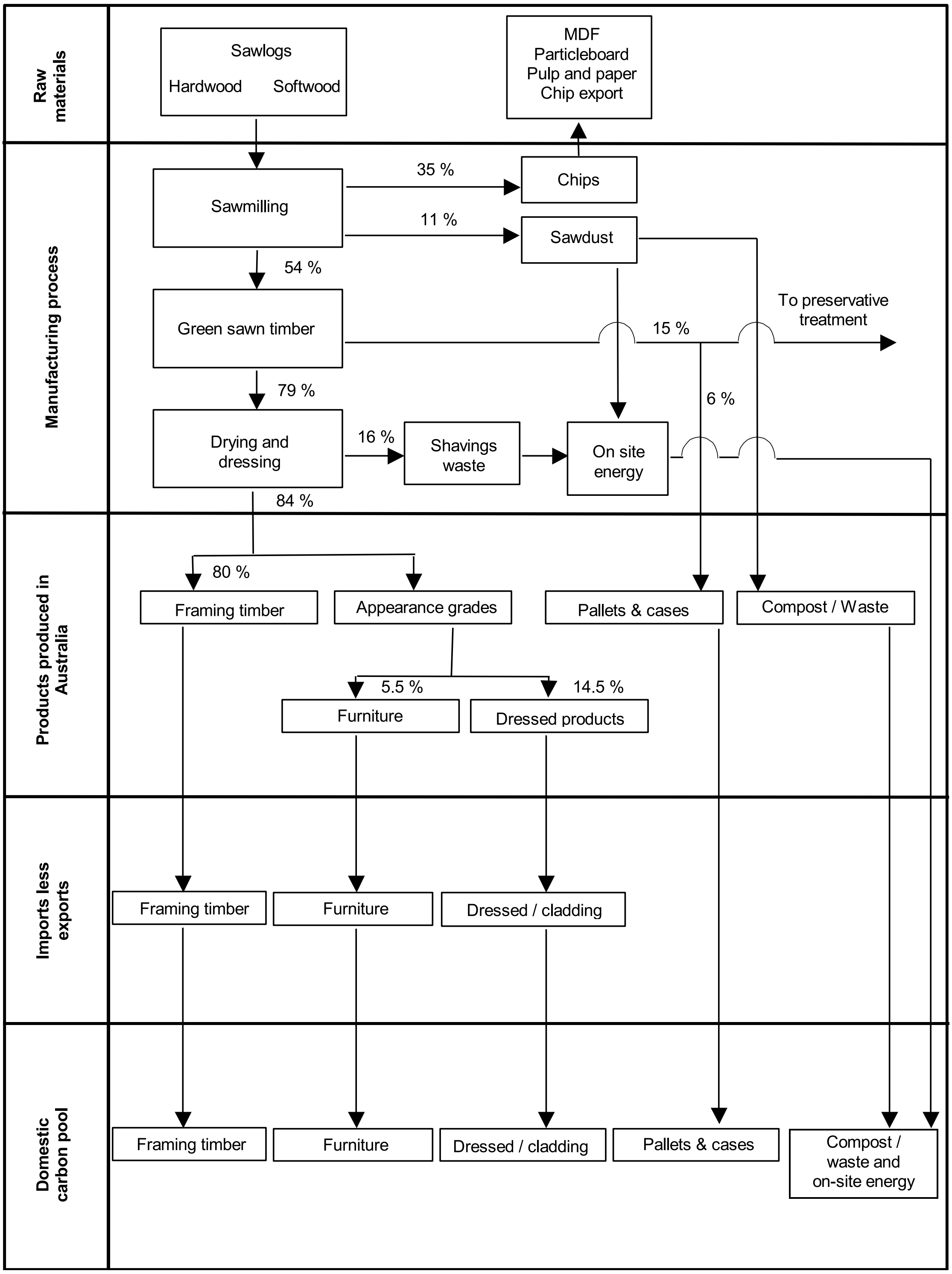
Emissions of soil carbon following conversion are estimated by applying the Roth C model for all first time cleared land (See Appendix A5.6.2). The Roth C model was parameterised with climate data (rainfall, temperature, open pan evaporation) from a representative site in central Queensland.

Non CO_2 emissions

Non-CO_2 (CH_4 and N_2O) emissions were estimated by multiplying the CO_2 emissions from onsite burning and onsite burning of debris with a 'non-CO_2 to CO_2' coefficient. The non-CO_2 to CO_2 coefficient incorporates the ratio of mass of non-CO_2 gas to the mass of carbon it contains, the ratio of non-CO_2 gas emitted to carbon emitted, the ratio of the amount of CO_2 with equivalent greenhouse gas effect to an amount of non-CO_2 gas and the fraction of CO_2 that is carbon by weight.

A5.6.9 Wood flows by sector

Figure A5.6.9.1 National Inventory Model – Sawmilling wood flows*



* percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

Figure A5.6.9.2 National Inventory Model for Wood Products – Wood flows in preservative treated products

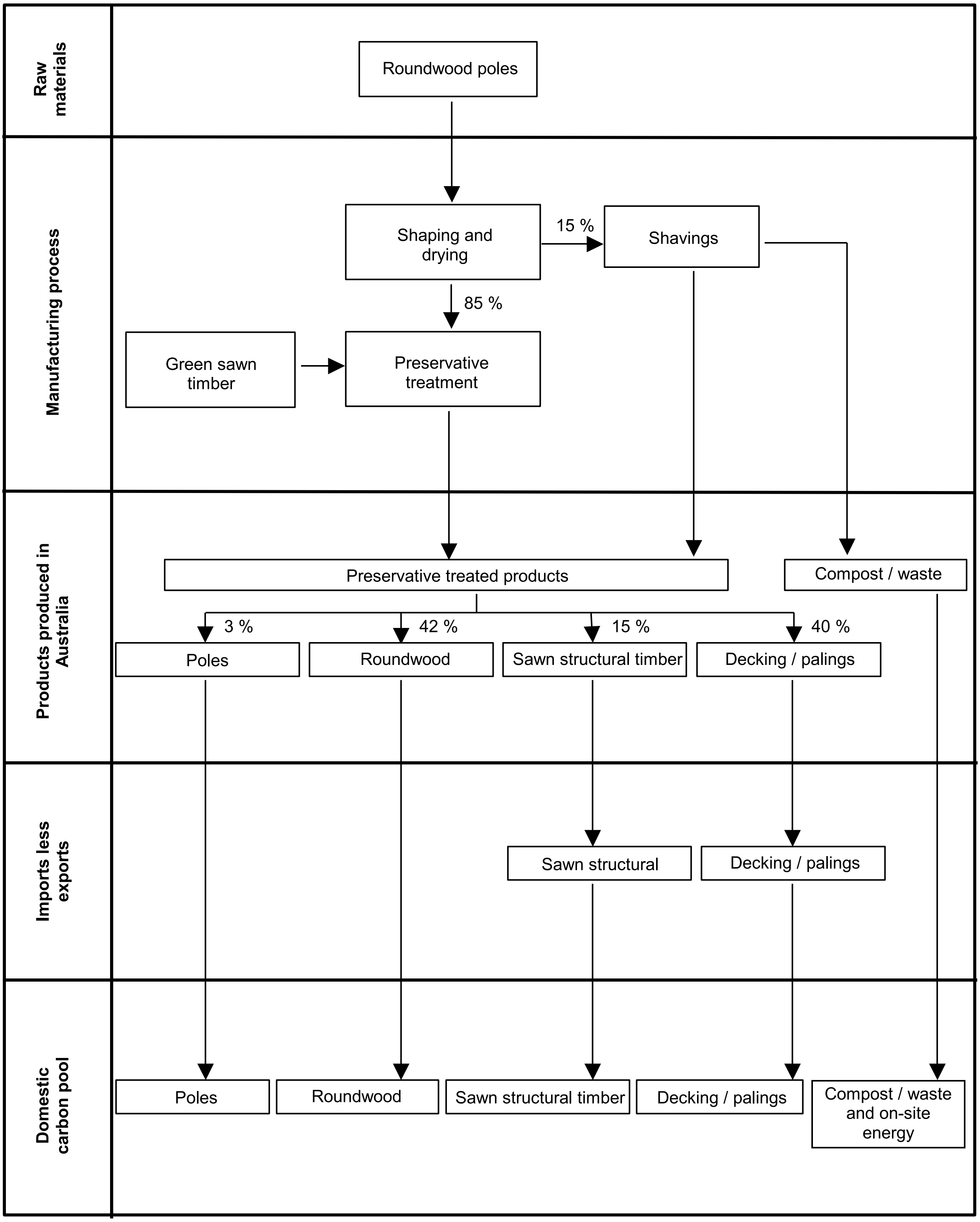


Figure A5.6.9.3 National Carbon Accounting Model for Wood Products – Wood Flows in plywood production

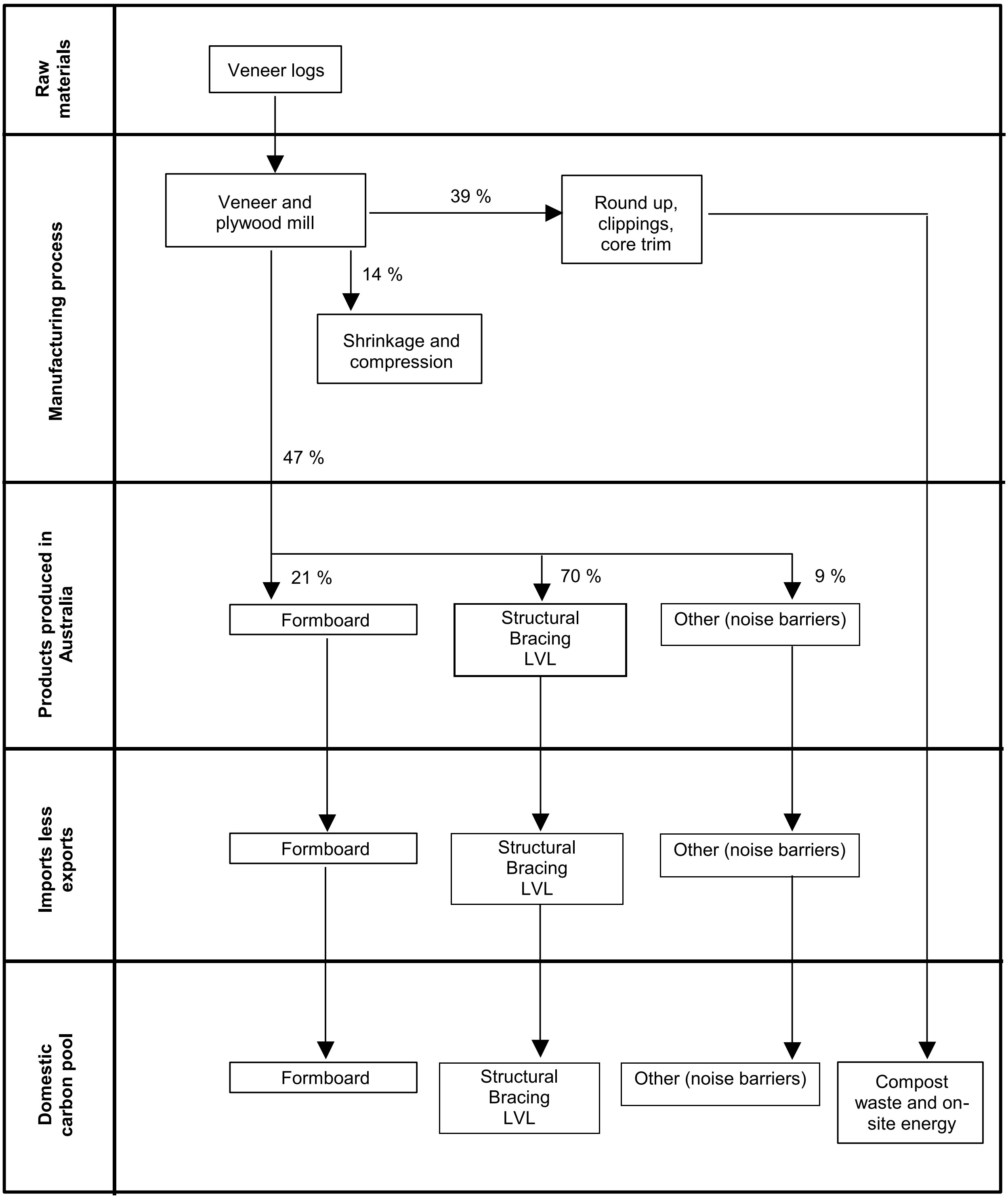


Figure A5.6.9.4 National Inventory Model for Wood Products – Wood flows in plywood production

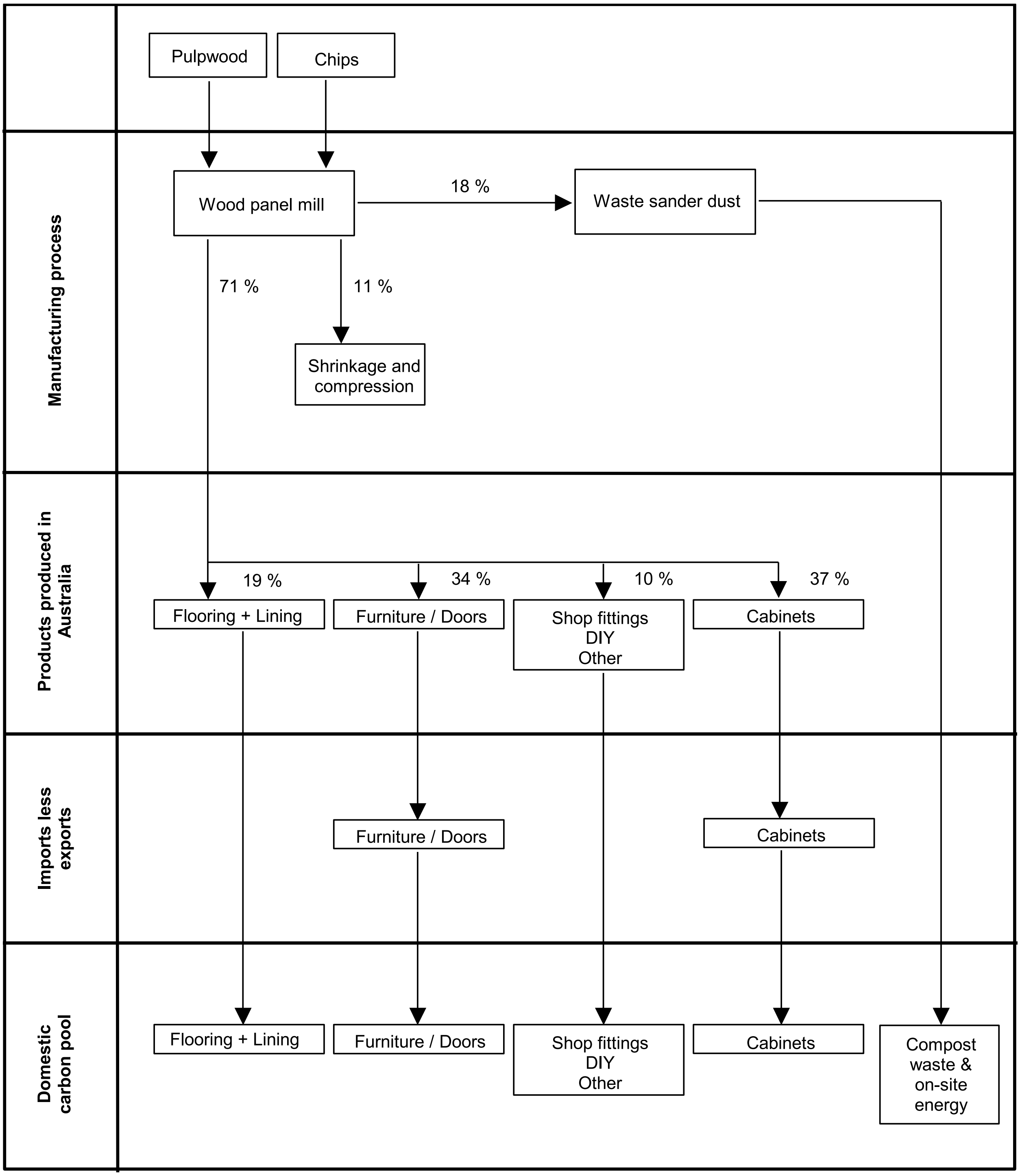
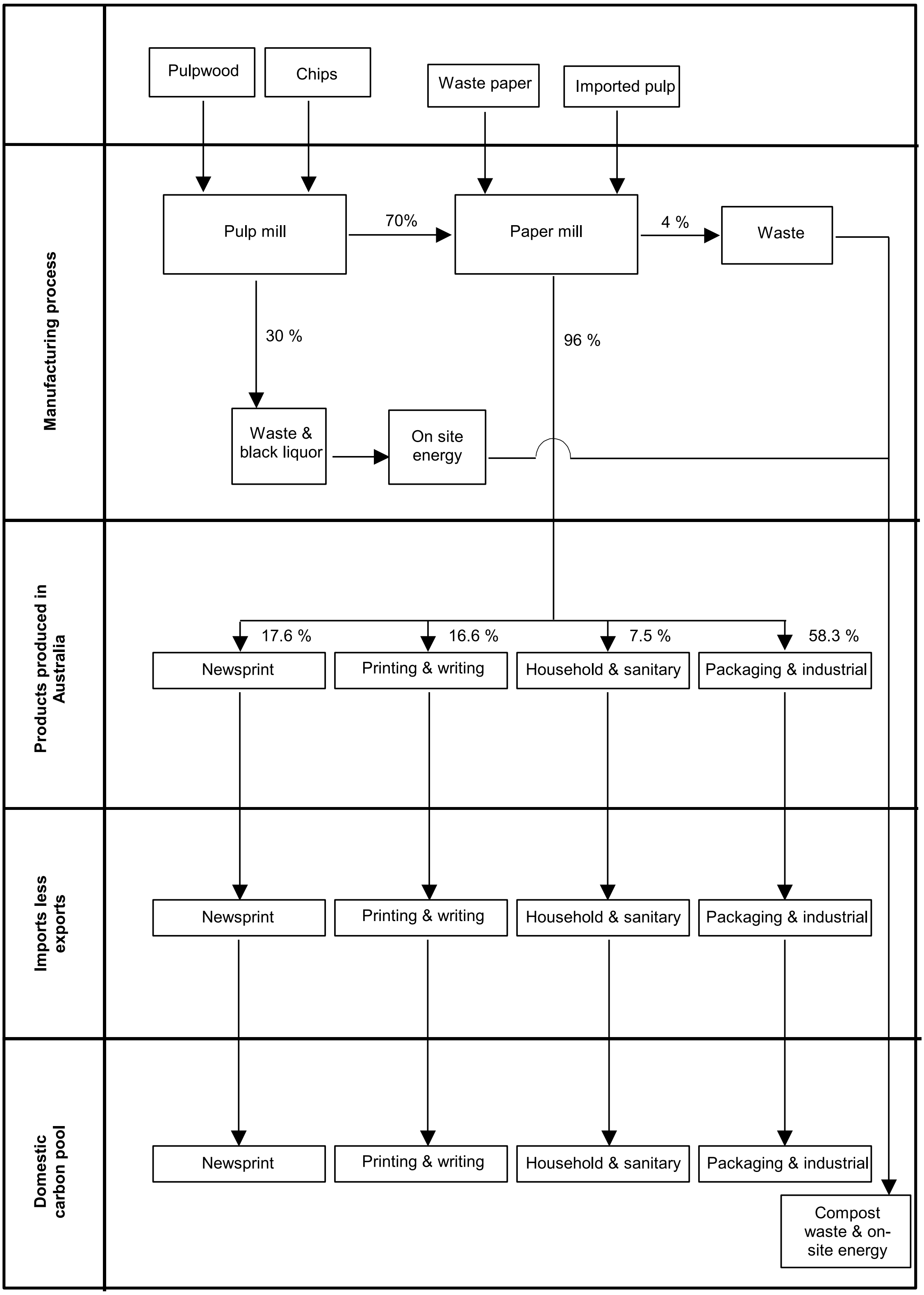
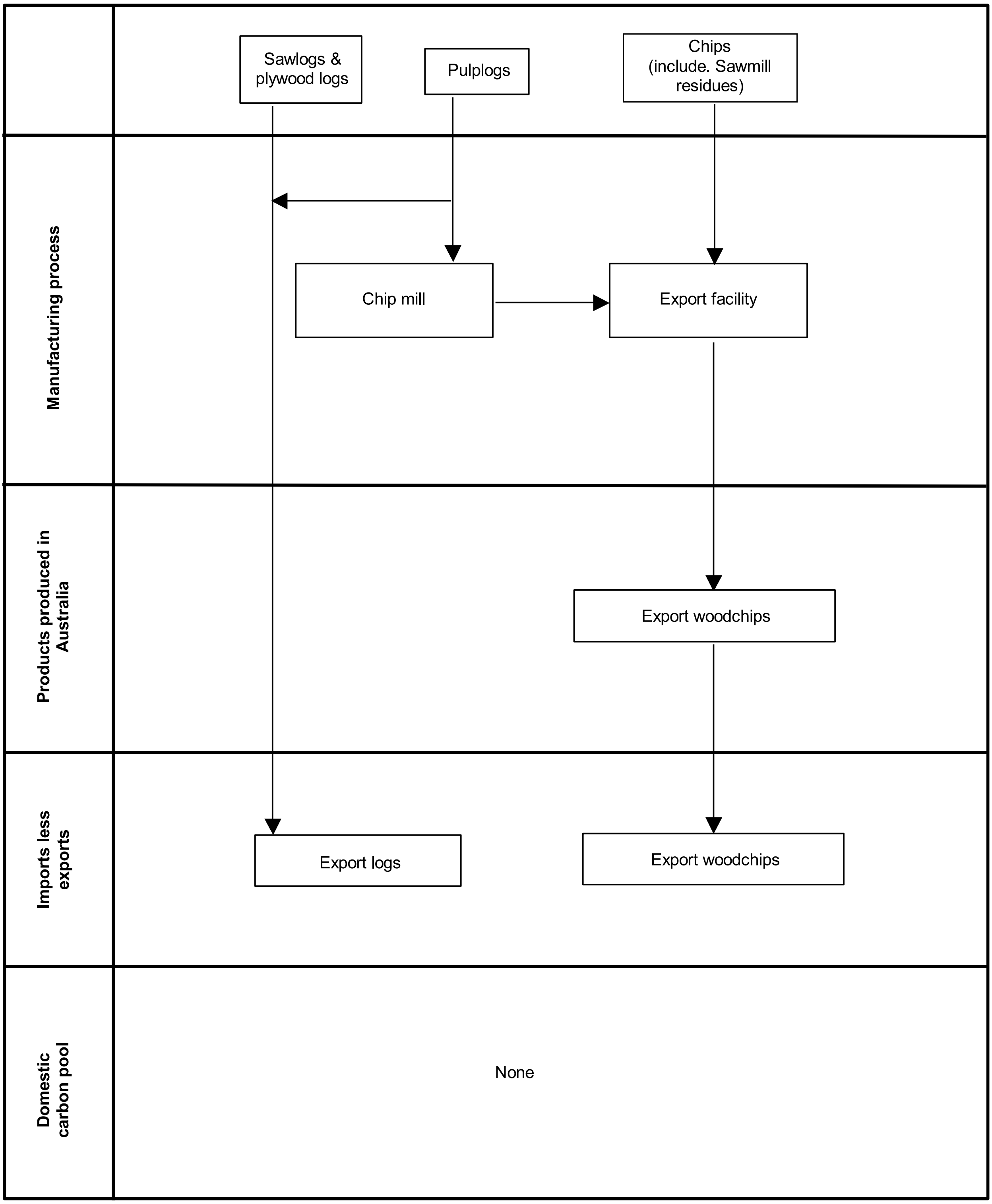


Figure A5.6.9.5 National Inventory Model for Wood Products – Wood flows in MDF and particleboard manufacture



* percentages shown for particleboard manufacture – see model for details on MDF

Figure A5.6.9.6 National Inventory Model for Wood Products – Wood flows in pulp and paper manufacture



A5.6.10 Wetland methods

Coastal Wetlands

Emissions and removals associated with conversions of conventional forest to wetlands (flooded lands), of mangrove forest to settlements, and of mangrove forest to grassland or cropland are simulated with FullCAM Tier 3 method (described here with reference to Annexes A5.6.1 and A5.6.2). Tidal marsh typically forms neighbouring communities with mangroves. Design considerations are presented here followed by the approach taken for calibrating the model.

It is important to note that coastal wetlands experience a variety of environmental conditions spatially and temporally, typically resulting in stratified vegetation distributions in the tidal zone (Metcalfe 1999) (Staben, et al. 2020). Therefore, observational data from the same point location were used to represent site data to calibrate the model.

At the spatial scale, a coastal vegetation layer, derived from NVIS Version 6.0 MVS (Major Vegetation Subgroups) (Table A5.6.10.1) and an intertidal extent model (Figure A5.6.10.1), was used to define the area of mangrove and tidal marsh. The coast of Australia was divided into regions based on Australian water resource assessment river regions (Figure A5.6.10.2) – these regions reflect major bioregions of Australia and major drainage basins that influence mangrove and tidal marsh community structure, productivity and carbon balances.

The area of mangrove is taken as MVS=40 and tidal marsh as MVS=39 and 41 (Table A5.6.10.1). Thus, tidal marsh is a generic classification; mixed chenopod, samphire, forbs, saline/brackish sedge/grass (Table A5.6.10.1). A combined area (MVS=39, 40, 41) is used in the FullCAM framework (Annex A5.6.2) to represent vegetation of potential interest within coastal wetlands, which interacts with the CPN time series woody and not woody vegetation as per Annex A5.6.1 and thus, defines transitions between these woody mangrove and non-woody tidal marsh vegetation types. The method takes a mixed woody, non-woody approach and mangrove is simulated as a (woody) forest and tidal marsh is simulated as a non-woody perennial grass; thus, tidal marsh productivity is a function of standing biomass and growth and die-off time series. Also at the spatial scale, variations in key parameters were used to achieve differences in productivity and decomposition rates for mangrove and tidal marsh in the 11 regions of Australia (Figure A5.6.10.2).

Figure A5.6.10.1 Coastal wetland vegetation groups and area extent are derived from National Vegetation Information System (NVIS) Version 6.0 Major Vegetation Subgroups – Extant Vegetation (NVIS 6) and clipped to the intertidal extent 95% confidence interval (pink outline) derived from Digital Earth Australia Intertidal Extents Model 25m 2.0.0 (Sagar, et al. 2017); Coastal wetlands fall in 22 of the 37 tiles covering the extent of Australia (light blue outline)

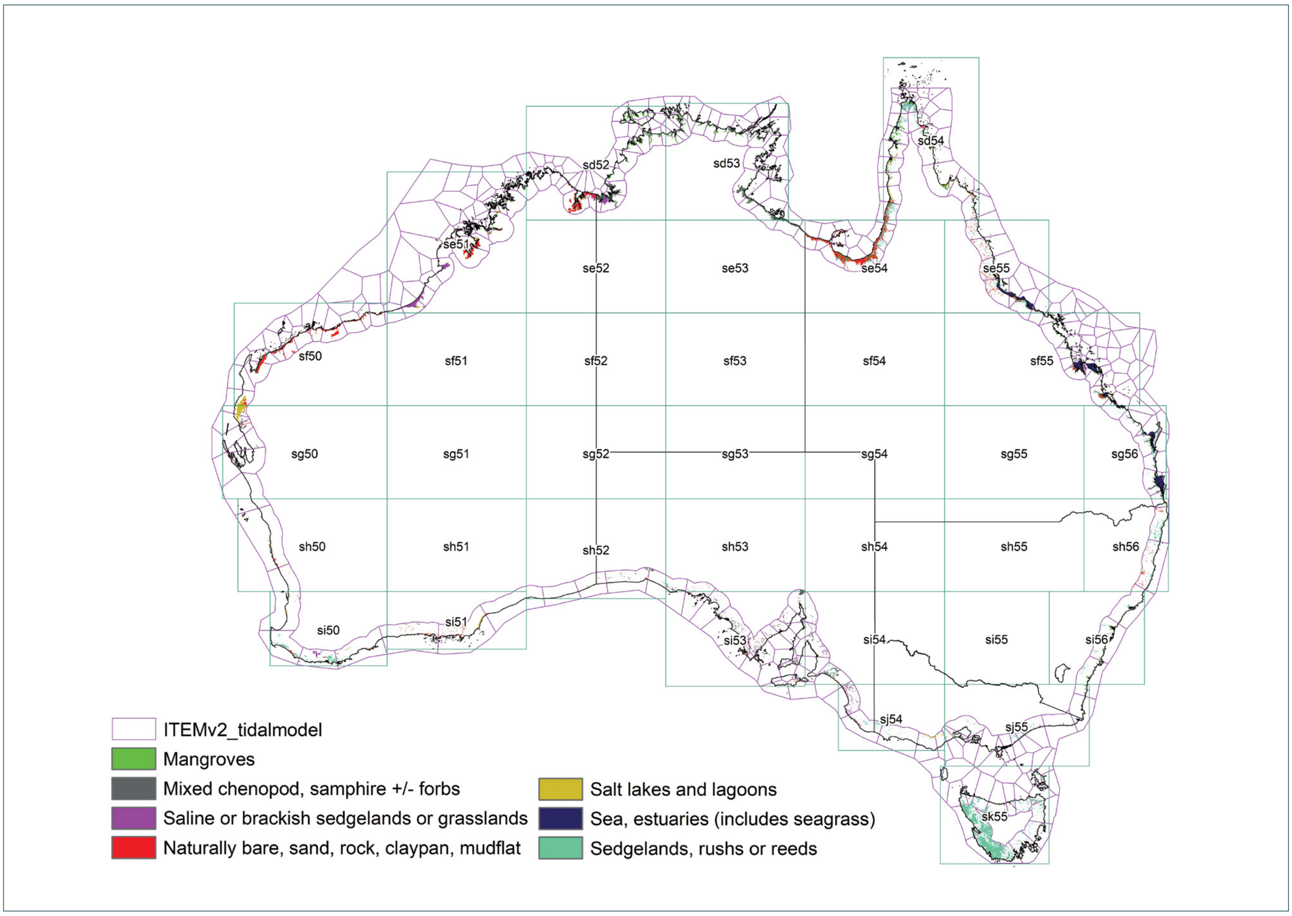


Figure A5.6.10.2 **Coastal wetlands (mangroves and tidal marsh) are divided into 11 regions based on the Australian water resource assessment (AWRA) drainage divisions that have coastal margins – (Bureau of Meteorology, AWRA Drainage Divisions and River Regions, accessed 25 August 2021); a further two regions, 12 and 13, cover inland areas and complete full coverage of Australia but are not used in FullCAM Wetlands coastal simulations**

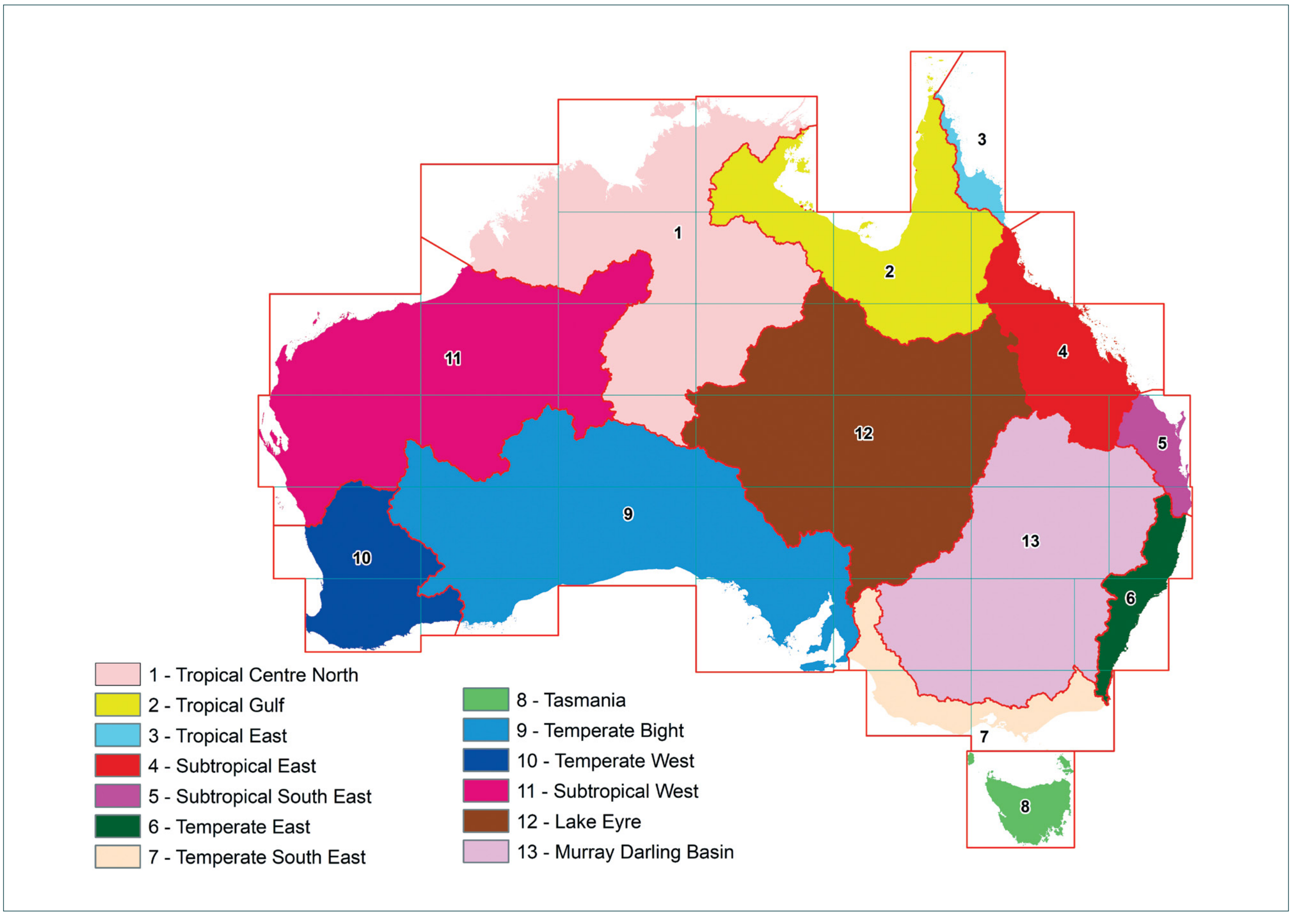


Table A5.6.10.1 **Major vegetation subgroups (MVS) included in the spatial coastal vegetation layer**

MVS Number	MVS Name
39	mixed chenopod, samphire, forbs
40	mangroves
41	saline/brackish sedge/grass
42	naturally bare
43	salt lakes/lagoons
46	sea/estuary
63	sedges, rushes, reeds

Calibration

Wetlands – coastal sub-model was calibrated using an iterative approach to fit FullCAM in plot mode to a small set of observational data that were taken to represent different mangrove plant-soil systems located around the coastline of Australia. These data were selected from a national collation of carbon accumulation field data for Australian coastal wetlands – mangrove and tidal marsh (Serrano, et al. 2019) (Lovelock, et al. 2022).

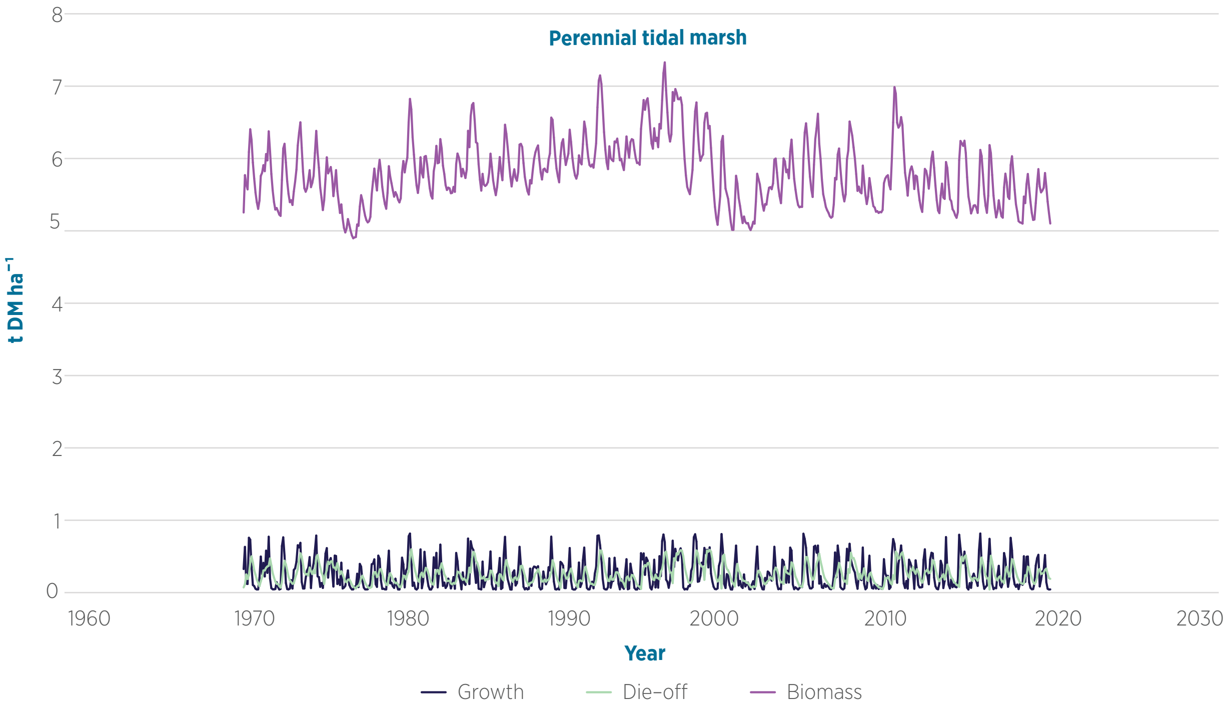
The national set of carbon accumulation field data for mangrove and tidal marsh in Australian coastal wetlands (Serrano, et al. 2019) (Lovelock, et al. 2022) was analysed for patterns and relationships in and between aboveground biomass, belowground biomass, soil carbon and rate of soil carbon accumulation. This analysis was ultimately used to group observations into 'sites' (Table A5.6.10.2) to use for plot-level calibrations.

At the plot scale, allocation, turnover and breakdown parameters were set to achieve good flow of organic matter to debris (litter and deadwood) and to the soil pool where substantial organic matter can accumulate (Duarte, et al. 2013) (Lamont, et al. 2020). A rate modifier was applied to slow decomposition rates (Table A5.6.10.3a). The rate modifier was used to emulate slower decomposition rates under low oxygen conditions for mangrove and tidal marsh regularly inundated with seawater and exposed to high saline conditions compared to terrestrial vegetation occurring outside the tidal zone (Rogers, et al. 2019).

Calibration was driven, primarily, by altering productivity via estimates of M, maximum aboveground biomass. This was achieved by using FullCAM in plot mode to simulate long-term steady state equilibria to the various productivity (aboveground biomass) and soil carbon levels observed for mangrove 'sites' located in different regions of Australia (Table A5.6.10.2).

Tidal marsh was simulated like a perennial grassland (Figure A5.6.10.3). Three tidal marsh types were developed using three initial leaf biomass values and fixed growth and die-off time series (Table A5.6.10.3a,b). Tidal marsh is implemented in each of the 11 regions (Figure A5.6.10.2) using one of the three tidal marsh types. Calibration involved setting initial standing biomass (t DM ha^{-1}) to one of three values for the 11 regions; tropical and subtropical (1.5), temperate (8) and Tasmania (5) (Table A5.6.10.a); this was based on general trends in field data (Table A5.6.10.4).

Figure A5.6.10.3 Tidal marsh biomass, example for an initial standing biomass of 5 t DM ha^{-1}, showing monthly variation as a function of growth and die-off time series



Key parameters are given in Table A5.6.10.3a,b along with their values for the 11 regions dividing the coastline of Australia (Figure A5.6.10.2); inland regions denoted 12 & 13 are excluded from Wetlands – coastal.

Table A5.6.10.2 Observational data representing ‘sites’; from Serrano et al. (2019)

(g C nr^2)							(t DM ha^1)			
Latitude	Longitude	Site no.	Site name	AGB (g C m^2)	Soil C (g C m^2)	C burial (g C m^2)	AGB (t DM ha^{-1})	Soil (t DM ha^{-1})	Burial (t DM ha^{-1})	AGB/SOM
-10.43315	142.49090	1		27600			552			
-12.37701	131.03787	2	2M	17300	48900	199	346	978	3.98	0.35
-12.50961	130.83430	3	3M	23400	23179		468	464		1.01
-14.66921	145.46350	4		15900			318			
-16.36023	145.42749	5	5M	11713	22672		234	453		0.52
-18.41415	146.20753	6	6M	16067	26370	150	321	527	3.00	0.61
-19.27020	147.04114	7	7M	4892	12491		98	250		0.39
-20.34723	118.59856	8	8M	21520	18601		430	372		1.16
-20.68974	116.66446	9	9M	14625	17894		293	358		0.82
-22.16132	114.31113	10	10M	6632	13614		133	272		0.49
-24.19060	151.87654	11	11M							
-27.30369	153.17675	12	12M	10108	37145	85	202	743	1.69	0.27
-32.13471	152.26877	13	13S		289	140		5.8	2.80	
-32.86420	151.72142	14	14M	5698	331		114	6.6		17.22
-33.95485	151.10370	15	15M	10470	225		209	4.5		46.53
-35.07750	150.72850	16	16S		252			5.0		
-35.70474	150.18683	17								
-37.85630	145.92817	18	18S		338			6.8		
-38.43260	145.53508	19	19S		223	122		4.5	2.44	

Table A5.6.10 3a Key parameters specific to the 11 Regions in Figure A5.6.10.2

Vegetation Group ID	1	2	3	4	5	6	7	8	9	10	11
Vegetation Group Name	**Tropical Centre North**	**Tropical Gulf**	**Tropical East**	**Subtropical East**	**Subtropical South East**	**Temperate East**	**Temperate South East**	**Tasmania**	**Temperate Bight**	**Temperate West**	**Subtropical West**
MANGROVES											
Productivity											
Maximum aboveground biomass	490	440	480	430	420	225	210	0	160	205	430
Decomposition											
Decomposition multiplier	0.5	0.5125	0.5	0.475	0.4875	0.475	0.45	0.45	0.5125	0.5125	0.5125
TIDAL MARSH											
Biomass	Leaves	Leaves	Leaves	Leaves	Leaves	Leaves	Leaves	Leaves	Leaves	Leaves	Leaves
Initial standing dry matter	1.5	1.5	1.5	1.5	1.5	8	8	5	8	8	1.5

Table A5.6.10.3b Key parameters shaping allocation, turnover, breakdown and decomposition processes for mangrove and tidal marsh

	Stems	Branches	Bark	Leaves	Coarse roots	Fine roots j
MANGROVES						
Allocation						
Biomass Allocation	0.3732	0.1422	0.0155	0.0604	0.3732	0.0355
Carbon percentages	50	47	49	52	50	48
Stem Density	0.7					
Turnover						
Turnover – half life (years)		27.38	27.38	1.73	55	0.4307
Turnover – percentage loss per year		2.5	2.5	33	1.25	80
Debris traits:						
Debris resistant percentage	100	100	100	77	100	62
Breakdown						
Percentage breakdown – half life (years)	Decomposable	2	1	0.053	4	0.0001
	Resistant	2	1	0.866	4	0.0001
Percentage loss to atmosphere	Decomposable	90	90	90	90	90
	Resistant	80	80	80	80	80
Decomposition						
Soil organic matter pools	DPM	RPM	BIO-F	BIO-S	HUM	
Decomposition rate multipliers	10	0.17	0.66	0.66	0.03	
TIDAL MARSH						
Perennial time series	Growth	Die-off				
Maximum	0.8168	0.5983				
Minimum	0.0418	0.0436				
Standard Deviation	0.2136	0.1244				
Number of monthly values (n)	612	612				
Standard Error	0.00863	0.00503				

Table A5.6.10.4 Description tidal marsh field data from Serrano et al. (2019)

	Mean	Max.	Min.	SE	n
AGB (Mg C ha^{-1})	7.59	23.66	0.88	0.9379	39
Soil C (Mg C ha^{-1})	170.02	962.68	13.93	7.5383	285
Burial (Mg C ha^{-1} year^{-1})	0.39	2.21	0.03	0.0173	285

Capital dredging – Seagrass

Australia includes seagrass under the wetlands land use category in LULUCF. This accounts for emissions arising from the excavation of seagrass habitat due to capital dredging for port construction or expansion, or other commercial, industrial and development activities. Capital dredging is any excavation of the seabed previously undisturbed by such activity.

A survey was commissioned to provide information on capital dredging activities in Australian ports (Kettle 2017). Fifty-five separate capital dredging activities were recorded nationally from 1990 to 2016, with a total area excavated of 118 km^2. Intersections between the capital dredging spatial polygons and those for seagrass meadow extents (mostly state and territory survey data) provided data on areas of excavated seagrass meadow as a time series. Nationally, 416 ha of seagrass habitat were removed resulting in a total of 129 kilotonnes of CO_2 emissions for the period 1990 to 2016.

Australian capital dredging activity after 2016 is identified by annual review of the following information sources:

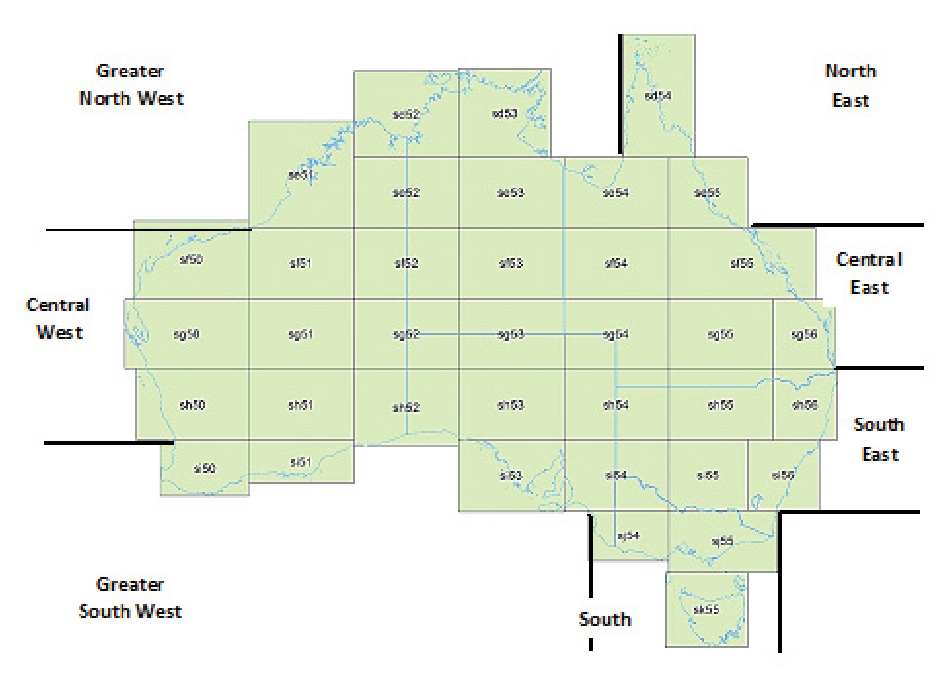
- Australian Notices to Mariners (Australian Hydrographic Office, https://www.hydro.gov.au/n2m/notices.htm), and
- State Development Approvals websites for Australian States and Territories

These surveys are supplemented by reviews of commercial websites focused on dredging, for example;

- https://www.dredgingtoday.com/
- https://www.tamsgroup.com.au/

The seagrass excavation model has a Tier 1 model structure to which country-specific parameter values are applied, elevating it to a Tier 2 model (IPCC 2014). Parameter values were estimated from pooled data collected from the scientific literature (Table A5.6.10.6). Where possible these are based on species-specific values within a regional context. Species presence and abundance within each coastal region was estimated from available survey data (Table A5.6.10.5). Reference lists for these data are provided in Tables A5.6.10.7 and A5.6.10.8). The coastal regions applied to the seagrass model are presented in Figure A5.6.10.4.

Figure A5.6.10.4 Australian coastal regions applied to seagrass parameter development



The model is populated with area estimates for excavated seagrass meadow obtained by spatial modelling in ArcGIS. Kettle (2017) provided dredge-related shape files (Table A5.6.10.9) that are placed as overlays 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 (A5.6.10.10).

It is reported in the literature that seagrass habitat takes time to recover after removal or burial, depending on the species involved (Preen, Lee Long and Coles 1995) (Campbell and McKenzie 2004) (Smith, et al. 2016) (Vanderklift, et al. 2017). Some seagrass habitats, including those dominated by temperate, high biomass species, may not re-establish when disturbance is regular, periodic, or catastrophic (Meehan and West 2002) (Erftemeijer and Robin Lewis 2006) (Wu, et al. 2015). As navigational channels also undergo scheduled periodic maintenance dredging it is assumed that seagrass habitat is removed permanently when establishing a channel. Also, in keeping with Tier 1 assumptions, all excavated plant and soil based organic carbon is mineralised in the year of removal. Finally, an estimation of the soil organic carbon removed by dredging is based on an excavated depth of one meter only.

Table A5.6.10.5 Relative abundance of major seagrass species within each Coastal Region within each Coastal Region

Species	North East Coast	Central East Coast	South East Coast	South Coast	Greater South West Coast	Central West Coast	Greater North West Coast
Amphibolis antarctica	0	0	0	0.1	0.35	0.84	0
Cymodocea spp.	0.1	0.1	0	0	0	0.07	0.3
Enhalus acroides	0	0	0	0	0	0.01	0.05
Halodule uninervis	0.35	0.35	0	0	0.05	0.01	0.1
Halophila spp.	0.45	0.4	0.13	0.1	0.05	0.01	0.45
Posidonia spp.	0	0	0.46	0.1	0.5	0.05	0
Thalassia hemprichii	0.05	0.05	0	0	0	0.01	0.1
Zostera muelleri	0.05	0.1	0.41	0.7	0.05	0	0

Table A5.6.10.6 Seagrass model parameter values obtained from the scientific literature

Parameter	Species	North East Coast	Central East Coast	South East Coast	South Coast	Greater South West Coast	Central West Coast	Greater North West Coast
Carbon fraction	*Amphibolis antarctica*	0	0	0	0.3	0.3	0.3	0
	Cymodocea spp.	0.3	0.3	0	0	0	0.3	0.3
	Enhalus acroides	0	0	0	0	0	0.3	0.3
	Halodule uninervis	0.3	0.3	0	0	0.3	0.3	0.3
	Halophila spp.	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Posidonia spp.	0	0	0.3	0.3	0.3	0.3	0
	Thalassia hemprichii	0.3	0.3	0	0	0	0.3	0.3
	Zostera muelleri	0.3	0.3	0.3	0.3	0.3	0	0
BGB (t ha^{-1})	*Amphibolis antarctica*	0	0	0	2.77	2.77	2.77	0
	Cymodocea spp.	0.6	0.6	0	0	0	0.6	0.6
	Enhalus acroides	1.52	1.52	0	0	0	1.52	1.52
	Halodule uninervis	0.07	0.07	0	0	0.07	0.07	0.07
	Halophila spp.	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Posidonia spp.	0	0	3.4	3.4	3.4	3.4	0
	Thalassia hemprichii	3	3	0	0	0	3	3
	Zostera muelleri	1.8	1.8	1.8	1.8	1.8	0	0
SOC (t ha^{-1})	*Amphibolis antarctica*	0	0	0	28	28	38	0
	Cymodocea spp.	63	63	0	0	0	63	63
	Enhalus acroides	51	51	0	0	0	51	51
	Halodule uninervis	52	52	0	0	52	52	52
	Halophila spp.	86	86	86	86	86	86	86
	Posidonia spp.	0	0	60	200	200	60	0
	Thalassia hemprichii	24	24	0	0	0	24	24
	Zostera muelleri	81	31	151	182	182	0	0

Table A5.6.10.7 Sources of biogeographical and relative abundance data for seagrass species within Australian state waters

State/Territory	Source documents
National	(Short, et al. 2007)
Queensland	(Lee Long, Mellors and Coles 1993) (Lee Long, McKenzie and Coles 1997) (Lee Long, McKenzie and Roelofs, et al. 1998) (Lee Long, Roelofs, et al. 2002) (Campbell, et al. 2002) (Abal and Dennison 1996) (Carruthers, Dennison and Longstaff, et al. 2002) (Poiner, Staples and Kenyon 1987) (Coles, Long, et al. 1994) (Coles, McKenzie, et al. 1996)
New South Wales	(Astles, Creese and West 2010) (Fyfe 2004) (King 1988) (Larkum and West 1990) (Meehan and West 2002) (Sanderson 1997) (West 2010) (Williams and Meehan 2004)
Victoria	(Roob and Ball 1997) (Roob, Werner and Morris 1998) (Blake, Roob and Patterson 2000) (Blake and Ball 2001) (O'Hara, Norman and Staples 2002) (Ball and Blake 2007) (Ball and Blake 2007) (Walker, Seagrasses 2011) (Monk, et al. 2011) (Pope, Monk and Ierodiaconou 2013) (D. Ball 2013)
Tasmania	(Barrett, et al. 2001)
South Australia	(Edyvane 1999) (Bourman, Murray-Wallace and Harvey 2016)
Western Australia	(, Dennison and Kendrick, et al. 2007) (Walker, Kendrick and McComb 1988) (Hillman, McComb and Walker 1995) (McMahon, et al. 1997)
Northern Territory	(L. McKenzie 2008) (Roelofs, Coles and Smith 2005) (Poiner, Staples and Kenyon 1987) (Kenyon, Conacher and Poiner 1997)

Table A5.6.10.8 Sources of seagrass model parameter values Carbon fraction BGB

Carbon fraction	BGB	SOC
(C. M. Duarte 1990) (Moore and Wetzel 2000)	(L. McKenzie 1994) (Duarte, Merino, et al. 1998) (Paling and McComb 2000)	(Lavery, et al. 2013) (Brown, et al. 2016) (Carnell, et al. 2016)

Table A5.6.10.9 List of locations subject to capital dredging projects recorded for the period 1990 to 2016

Shapefiles (Kettle 2017) of each project provide a polygon representing the dredge footprint and area excavated.

State	Location name	Commencement Year	Polygon Area (km²)
NSW	Port Macquarie Marina	2001	0.0392
NSW	Newcastle Port	2005	3.08
NSW	Port Macquarie Marina	2008	0.136
NSW	Port Macquarie Marina	2008	0.0392
NT	Bing Bong	1994	0.238
NT	Port Darwin	2000	2.44
NT	Port of Groote Eylandt	2010	0.07
NT	Port Darwin	2011	0.27
Qld	The Jetty Precinct	1993	0.14
Qld	Port Hinchinbrook Marina	1995	0.206
Qld	Laguna Quays Marina	1995	0.114
Qld	Port of Karumba	1996	0.75
Qld	Nelly Bay Marina	2002	0.148
Qld	Abell Point Marina	2003	0.252
Qld	Hay Point Harbour	2006	0.4
Qld	Port of Hay Point	2007	6.25
Qld	Ephraim Island Marina	2007	0.4764
Qld	Gladstone Marina	2009	0.514

State	Location name	Commencement Year	Polygon Area (km²)
Qld	Keppel Bay Marina	2010	0.227
Qld	Port of Gladstone	2011	11.9
Qld	Port of Gladstone	2011	4.38
Qld	Port of Brisbane	2011	3.46
Qld	Port Denison	2011	0.26
Qld	Port of Weipa	2012	2.94
Qld	Brisbane Airport Middle Banks	2014	6.07
Qld	Port of Cooktown	2014	0.11
SA	Port Vincent Marina (CYSA)	1996	0.09
SA	Copper Cove Marina	2005	0.25
SA	Port of Whyalla	2013	0.466
SA	Whyalla Marina	2013	0.076
SA	Whyalla Wharf	2013	0.06
Vic	Port Melbourne	2007	25.3
Vic	Port Melbourne	2007	8.27
Vic	Portland Marina	2012	0.902
Vic	Queenscliff Harbour	2012	0.158
Vic	Yaringa Marina	2014	0.05
WA	Port of Bunbury	1994	0.92
WA	Port Dampier	1995	7.76
WA	Exmouth Harbour	1997	0.282
WA	Albany Waterfront Marina	2000	0.093
WA	Port of Geraldton	2003	1.45
WA	Port of Geraldton	2003	1.05
WA	Hillarys Boat Harbour	2004	0.265
WA	Fremantle Harbour	2005	1.53
WA	Jurien Bay Boat Harbour	2005	0.152
WA	Emu Point Boat Harbour	2006	0.049
WA	Rous Head Harbour	2007	0.183
WA	Cockburn Marine Complex	2009	7.44
WA	Barrow Island	2009	1.4
WA	Barrow Island	2009	0.271
WA	Casuarina Boat Harbour	2009	0.04
WA	Port Walcott	2010	14.4
WA	Port Dampier	2010	0.408
WA	Wheatstone LNG Port	2011	0.167
WA	Casuarina Boat Harbour	2015	0.04

Table A5.6.10.10 Seagrass habitat extent shapefiles

State or national seagrass extent	Source Credit	Date accessed	Accessed at
Australia, base layer	World Imagery: DigitalGlobe (2016) Vivid – Australia	28/08/2017	http://goto.arcgisonline.com/maps/WorldImagery
Australia, national seagrass set	CSIRO (2015): Seagrass Dataset – CAMRIS. v1. CSIRO. Data Collection Lucieer V, Walsh P, Flukes E, Butler C, Proctor R, Johnson C (2017). Seamap Australia – a national seafloor habitat classification scheme. Institute for Marine and Antarctic Studies (IMAS), University of Tasmania (UTAS).	28/08/2017 12/04/2021	https://metadata.imas.utas.edu.au/geonetwork/srv/eng/catalog.search#/metadata/4739e4b0-4dba-4ec5-b658-02c09f27ab9a
NSW	NSW Department of Primary Industries, New South Wales Government (2013). Estuarine Macrophytes of NSW	05/09/2017	https://metadata.imas.utas.edu.au/geonetwork/srv/eng/catalog.search#/metadata/281FAA64-F6F3-400C-A48F-D342E4ABCA83
NT	Mount, R.E. and PJ. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project – National Intertidal-Subtidal Benthic Habitat (NISB) Map (Original dataset not available, see “Australia, National seagrass set” above)	31/08/2017	https://ozcoasts.org.au/wp-content/uploads/2018/04/NationalECMHabitatMapSeriesUserGuide_v7.pdf
NT	Smit, N (2011). Darwin Harbour marine habitats. Department of Environment and Natural Resources, Northern Territory Government	31/08/2017	http://metadata.imas.utas.edu.au/geonetwork/srv/eng/metadata.show?uuid=2e754ed7–caab-4640–a133–5ead9e077edb
QLD	James Cook University (2014). Torres Strait Seagrass Mapping Consolidation	05/09/2017	https://metadata.imas.utas.edu.au/geonetwork/srv/eng/catalog.search#/metadata/e7ea913e-2528-4ece-847c-a25722e11c1f
QLD	Department of National Parks, Sport and Racing, Queensland Government (2008). Moreton Bay broadscale habitats 2008	05/09/2017	http://metadata.imas.utas.edu.au/geonetwork/srv/eng/metadata.show?uuid=806decf7–1260–44b8–b5a0–cc96a746cedc
QLD	TropWATER, JCU: NESP TWQ 3.1 – Collation of spatial seagrass data (meadow extent polygons, species presence/ absence points) from 1984–2014 for the Great Barrier Reef World Heritage Area (GBRWHA)	05/09/2017	http://eatlas.org.au/data/uuid/77998615–bbab-4270–bcb1–96c46f56f85a
QLD	Mount, R.E. and PJ. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project – National Intertidal-Subtidal Benthic Habitat (NISB) Map (Original dataset not available, see “Australia, National seagrass set” above)	05/09/2017	
SA	Mount, R.E. and PJ. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project – National Intertidal-Subtidal Benthic Habitat (NISB) Map	30/09/2017	https://ozcoasts.org.au/wp-content/uploads/2018/04/NationalECMHabitatMapSeriesUserGuide_v7.pdf
Vic	The State of Victoria, Department of Economic Development, Jobs, Transport and Resources, 2017, Port Phillip Bay seagrass mapping at nine aerial assessment regions in April 2011	26/09/2017	Port Phillip Bay seagrass mapping at nine aerial assessment regions in April 2011 - Dataset - Victorian Government Data Directory

State or national seagrass extent	Source Credit	Date accessed	Accessed at
Vic	The State of Victoria, Department of Economic Development, Jobs, Transport and Resources, 2017, Port Phillip Bay 1:25,000 Seagrass 2000	26/09/2017	Port Phillip Bay 1:25,000 Seagrass 2000 - Dataset - Victorian Government Data Directory
Vic	Mount, R.E. and PJ. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project – National Intertidal – Subtidal Benthic Habitat (NISB) Map	26/09/2017	https://ozcoasts.org.au/wp-content/uploads/2018/04/NationalECMHabitatMapSeriesUserGuide_v7.pdf
WA	Mount, R.E. and PJ. Bricher, 2008. Estuarine, Coastal and Marine (ECM) National Habitat Map Series Project – National Intertidal-Subtidal Benthic Habitat (NISB) Map	05/09/2017	https://ozcoasts.org.au/wp-content/uploads/2018/04/NationalECMHabitatMapSeriesUserGuide_v7.pdf

Flooded land (Reservoirs)

The activity data for emissions from reservoirs in *flooded* land is based on the development of water gauge depth to surface area look-up tables for each reservoir included in the account and is summarised here.

Source of Method Guidance and EF values

Chapter 7 Wetlands in *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (2019 Refinement, https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html) (IPCC 2019):

- Applied Tier 1 methodology for the initial account (used IPCC default emission factor values as there is insufficient published scientific information on GHG emission rates from most Australian climate zones).
- The Tier 1 method sets the trophic state adjustment factor (Table 7.11) to one, so that the trophic state of a reservoir is not considered when estimating its methane emissions.
- The Tier 1 method sets the ratio of total downstream CH_4 emission to total CH_4 emission from the reservoir surface at 0.09.

EF values from the Chapter 7 Wetlands 2019 Refinement to the 2006 IPCC Guidelines:

- CH_4 reservoir *(Flooded land remaining flooded land,* i.e. for dams greater than 20 years old): Table 7.9 (average values)
- CH_4 reservoir *(Land converted to flooded land,* i.e. for dams up to 20 years old): Table 7.14 (average values)
- CH_4 downstream flux proportion (dams of all ages): Table 7.10 (set at 0.09 for all Tier 1 estimates).
- CO_2 reservoir *(Land converted to flooded land,* i.e. for dams up to 20 years old): Table 7.13

Dam information

Information on the dams, including function (Hydro, non-hydro), owner, location (State), age and reservoir area (when filled) was obtained from the Register of Large Dams in Australia (2020) produced by the Australian National Committee of Large Dams (ANCOLD, https://ancold.org.au/).

Activity data

Activity data used in NIR 2020–18 and NIR 2021–19 accounts was based on a data set formed by merging the BOM geofabric data (http://www.bom.gov.au/water/geofabric/download.shtml, accessed 04/10/2019) with the DEA Waterbodies data https://data.dea.ga.gov.au/?prefix=projects/WaterBodies/, accessed 04/10/2019) for waterbodies catalogued as Reservoirs only. The merger, representing about 600 waterbodies, produced two data files:

- A csv file that contains a timeseries of estimated surface area of each reservoir; and
- A shapefile that contains corresponding FID's, climate zone classification, state codes and, in some cases, names.

The average annual surface area was estimated, using data from the csv file, for all reservoirs included in the data set, for each year of the time series 1990 to 2018. Weather impacted satellite image quality for many reservoirs so that their data was inconsistent over time and reduced the accuracy of estimated surface area changes.

The development of a reservoir surface area model based on gauge data, which is described below, significantly reduced the uncertainty associated with the activity data. However, data gaps in gauge data that extend for months or years do occur for some reservoirs. In such cases the mean average surface area is still estimated using the merged BOM/DEA dataset where that data is available.

Climate zone attribution

Climate zone classification, included in the shapefile described above, is based on BOM's modified Koppen climate classification system and standard 30–year climatology data (http://www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp).

Emission factors

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), and which are reproduced in Table A5.6.10.11.

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.

Table A5.6.10.11 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/ 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	0
Tropical – dry	Old	284	0
Tropical – moist	Old	151	0
Temperate – warm	Old	151	0
Temperate – cool	Old	54	0

Using dam gauge data to model a reservoir's monthly average surface area.

An alternate method was developed that reduces the requirement for satellite-based data of reservoir surface area. A spatial model, linking reported gauge depth at the dam to the reservoir's observed surface area (using satellite image analysis) at matching dates, was developed for individual reservoirs. The result, a lookup table of surface area to gauge depth for individual reservoirs, enables the surface area of individual reservoirs to be estimated consistently and with greater accuracy across the time series. This simplifies the methodology in estimating a reservoir's monthly average surface area used to then calculate its annual average surface area by financial year.

The ANCOLD *Register of Large Dams Australia* (https://www.ancold.org.au/, accessed 17/08/2020) (2020) provides the date of establishment for most dams on its list. This information was used to classify reservoirs under *Flooded land remaining flooded land* (> 20 years old), or under *Land converted to flooded land* (<= 20 years old). Methane emissions are reported under both land use sub-categories, whereas CO$_2$ emissions are reported for *Land converted to flooded land* only, i.e., reservoirs up to 20 years old. The updated model continues to use the IPCC default emission factor values for CH$_4$ and CO$_2$ listed in Table A.5.6.10.11.

The 201 reservoirs listed in Table A5.6.10.12 form the basis for the reservoir account from NIR 2022–20 onwards. These reservoirs represent a subset of the 600 waterbodies initially modelled in NIR 2020–18 and NIR 2021–19. Based on the ANCOLD list of large Australian dams these 199 reservoirs represent > 95% of the total maximum surface area of Australia's large reservoirs when listed from largest to smallest. Reservoirs associated with hydro-dams (as identified on ANCOLD's list of large Australian dams) are included in the account. They are not assessed separately from other reservoirs within LULUCF.

Table A5.6.10.12 Reservoirs included in this account listed by state or territory

State/Territory	Reservoir
Australian Capital Territory	Bendora Reservoir at Dam
Australian Capital Territory	Corin Reservoir at Dam
Australian Capital Territory	Cotter Reservoir at Dam
Australian Capital Territory	Googong Reservoir at Dam
New South Wales	Avon
New South Wales	BELUBULA RIVER AT CARCOAR DAM-STORAGE GAUGE
New South Wales	BROGO RIVER AT BROGO DAM (STORAGE)
New South Wales	BURRINJUCK DAM
New South Wales	Cataract
New South Wales	Cordeaux
New South Wales	CUDGEGONG RIVER AT WINDAMERE DAM-STORAGE GAUGE
New South Wales	DARLING RIVER AT LAKE MENINDEE – STORAGE GAUGE
New South Wales	Eucumbene River at Lake Eucumbene
New South Wales	FISH RIVER AT OBERON DAM – STORAGE GAUGE
New South Wales	Fitzroy Falls
New South Wales	Geehi River at Geehi Reservoir
New South Wales	GLENNIES CREEK AT GLENNIES CREEK DAM-STORAGE
New South Wales	Grahamstown Dam
New South Wales	GWYDIR RIVER AT COPETON DAM-STORAGE GAUGE
New South Wales	HUNTER RIVER AT GLENBAWN DAM-STORAGE GAUGE
New South Wales	IRONPOT CREEK AT TOONUMBAR DAM-STORAGE GAUGE
New South Wales	Khancoban Back Creek at Murray 2 Pondage
New South Wales	MACQUARIE RIVER AT BURRENDONG DAM – STORAGE GAUGE
New South Wales	Mangrove Creek Dam
New South Wales	MANILLA RIVER AT SPLIT ROCK DAM STORAGE GAUGE
New South Wales	MURRAY RIVER AT HUME DAM – STORAGE GAUGE NO.2
New South Wales	Murrumbidgee River at Tantangara Reservoir
New South Wales	NAMOI RIVER AT KEEPIT DAM – STORAGE GAUGE
New South Wales	PEEL RIVER AT CHAFFEY DAM – STORAGE GAUGE
New South Wales	Plashett
New South Wales	Prospect
New South Wales	SEVERN RIVER AT PINDARI DAM-STORAGE GAUGE
New South Wales	Snowy River at Guthega Pondage
New South Wales	Snowy River at Island Bend Pondage
New South Wales	Snowy River at Lake Jindabyne
New South Wales	Stephens Creek
New South Wales	Swampy Plain River at Khancoban Pondage
New South Wales	Talbingo Dam – RO Intake
New South Wales	Tallowa Dam
New South Wales	Tooma River at Tooma Reservoir
New South Wales	TUMUT RIVER AT BLOWERING DAM – STORAGE GAUGE
New South Wales	Tumut River at Jounama Pondage

State/Territory	Reservoir
New South Wales	Tumut River at Tumut 2 Dam
New South Wales	Tumut River at Tumut Pond Dam
New South Wales	Warragamba
New South Wales	WINGECARRIBEE DAM
New South Wales	WORONORA RIVER AT WORONORA DAM
New South Wales	WYANGALA DAM AT STORAGE GAUGE
Northern Territory	Darwin River Dam – Intake Tower
Northern Territory	MANTON DAM
Northern Territory	MARY ANN DAM
Queensland	Atkinson Dam HW
Queensland	Balonne R at Jack Taylor Weir HW
Queensland	Barker Ck at Bjelke-Petersen Dam HW
Queensland	Baroon Pocket Dam HW
Queensland	Barron R at Tinaroo Falls Dam HW
Queensland	Bill Gunn Dam HW
Queensland	Borumba Dam HW
Queensland	Boyne R at Boondooma Dam HW
Queensland	Broken R at Eungella Dam HW
Queensland	Burdekin R at Burdekin Falls Dam HW
Queensland	Burnett R at Claude Wharton Weir HW
Queensland	Burnett R at Ned Churchward Weir HW
Queensland	Burnett R at Paradise Dam HW (ALERT)
Queensland	Callide Ck at Callide Dam HW (Intake)
Queensland	Condamine R at Chinchilla Weir HW
Queensland	Cressbrook Dam
Queensland	Dawson R at Glebe Weir HW
Queensland	Dawson R at Gyranda Weir HW
Queensland	EJBEARDMORE
Queensland	Ewen Maddock Dam HW
Queensland	FITZROY RIVER BARRAGE
Queensland	Hinze Dam HW
Queensland	Kolan R at Fred Haigh Dam HW
Queensland	KOOMBOOLOOMBA
Queensland	LAKE MITCHELL DAM
Queensland	Lake Paluma
Queensland	Leichhardt R at Julius Dam HW (boat ramp)
Queensland	LEICHHARDT RIVER
Queensland	Lenthals
Queensland	Leslie Harrison Dam HW
Queensland	MacIntyre Bk at Coolmunda Dam HW
Queensland	Mackenzie R at Bedford Weir HW
Queensland	Maroon Dam HW
Queensland	Moogerah Dam HW
Queensland	Nogo R at Wuruma Dam HW

State/Territory	Reservoir
Queensland	Nogoa R at Fairbairn Dam HW
Queensland	NORTH PINE
Queensland	Nth Sandy Ck at Kinchant Dam HW
Queensland	Pike Creek at Glenlyon Dam Headwater
Queensland	Proserpine R at Peter Faust Dam HW
Queensland	Raw Water from Awoonga Dam
Queensland	Ross River Dam
Queensland	Sandy Ck at Leslie Dam Wall HW
Queensland	Somerset Dam HW
Queensland	Teemburra Ck at Teemburra Dam HW
Queensland	Three Moon Ck at Cania Dam HW
Queensland	Wivenhoe Dam HW
Queensland	Wyaralong Dam HW
South Australia	BAROSSA RESERVOIR
South Australia	HAPPY VALLEY RESERVOIR
South Australia	HOPE VALLEY RESERVOIR
South Australia	Kangaroo Creek Reservoir
South Australia	Little Para Reservoir
South Australia	Millbrook Reservoir
South Australia	Mt Bold Reservoir
South Australia	Myponga Reservoir
South Australia	South Para Reservoir
South Australia	Warren Reservoir
Tasmania	ARTHURS LAKE – AT PUMP STATION
Tasmania	AUGUSTA LAKE – AT INTAKE
Tasmania	BARRINGTON LAKE – AT DAM
Tasmania	Bradys Lake
Tasmania	BRONTE LAGOON – AT DAM
Tasmania	BURBURY LAKE – AT CROTTY DAM
Tasmania	CATAGUNYA LAKE – AT DAM
Tasmania	CETHANALAKE – AT DAM
Tasmania	CLUNY LAGOON – AT DAM
Tasmania	DEE LAGOON – AT TUNNEL INLET
Tasmania	ECHO LAKE – AT DAM
Tasmania	GORDON LAKE – AT INTAKE
Tasmania	GREAT LAKE – AT POATINA INLET
Tasmania	HENTY LAKE – AT DAM
Tasmania	KING WILLIAM LAKE – AT DAM
Tasmania	LAKE BINNEY
Tasmania	LAUGHING JACK LAGOON – AT DAM
Tasmania	MACKENZIE LAKE – AT DAM
Tasmania	MACKINTOSH LAKE – AT DAM
Tasmania	MEADOWBANK LAKE – AT DAM
Tasmania	MURCHISON LAKE – AT DAM

State/Territory	Reservoir
Tasmania	NEWTON LAKE – AT DAM
Tasmania	PALOONA LAKE – AT DAM
Tasmania	PARANGANA LAKE – AT DAM
Tasmania	PEDDER LAKE – AT SERPENTINE
Tasmania	PIEMAN LAKE – AT DAM
Tasmania	PINE TIER LAGOON – AT DAM
Tasmania	PLIMSOLL LAKE – AT INTAKE
Tasmania	REPULSE LAKE – AT DAM
Tasmania	ROSEBERY LAKE – AT DAM
Tasmania	ROWALLAN LAKE – AT DAM
Tasmania	St.CLAIR LAKE – AT PUMP HOUSE POINT
Tasmania	TREVALLYN LAKE – AT DAM
Tasmania	TUNGATINAH LAGOONS – AT DAM
Tasmania	WAYATINAH LAGOON – AT INTAKE
Tasmania	WHITE SPUR POND – AT DAM
Victoria	Barkers Creek Storage
Victoria	Bostock Reservoir
Victoria	Cairn Curran Reservoir
Victoria	CARDINIA RESERVIOR HEAD GAUGE
Victoria	Dartmouth
Victoria	DEVILBEND RESERVOIR
Victoria	EILDON
Victoria	FELLMONGERS CREEK AT GONG RES. H.G.
Victoria	GOULBURN WEIR
Victoria	Korweinguboora Reservoir
Victoria	Laanecoorie Reservoir
Victoria	Lake Bellfield
Victoria	Lake Buffalo
Victoria	Lake Eppalock
Victoria	Lake Mokoan
Victoria	Lake Nillahcootie
Victoria	Lake William Hovell
Victoria	MACALISTER RIVER @ LAKE GLENMAGGIE (HEAD GAUGE)
Victoria	Malmsbury Reservoir
Victoria	MOORABOOL R WEST BRANCH AT MOORABOOL RESERVOIR HG
Victoria	Pine Lake
Victoria	Rocklands Reservoir
Victoria	SUGARLOAF RESERVOIR DAM SITE
Victoria	TANJIL RIVER @ BLUE ROCK LAKE (HEAD GAUGE)
Victoria	TARAGO RIVER AT TARAGO RESERVOIR HEAD GAUGE NEERIM STH
Victoria	Taylors Lake
Victoria	THOMSON RESERVOIR
Victoria	Tullaroop Reservoir
Victoria	Upper Coliban Reservoir

State/Territory	Reservoir
Victoria	WARANGA BASIN
Victoria	Wartook Reservoir
Victoria	WATTS RIVER AT MAROONDAH RESERVOIR HEAD GAUGE
Victoria	White Swan Reservoir HG @ Glen Park
Victoria	Wurdee Boluc Reservoir
Victoria	YAN YEAN RESERVOIR HEAD GAUGE
Victoria	YARRA RIVER AT UPPER YARRA RESERVOIR HEAD GAUGE
Victoria	Yarrawonga Weir
Western Australia	Argyle Vill Top Dam Wsl
Western Australia	Canning Wsl-Ranger
Western Australia	Drakes Bk Wsl
Western Australia	Glen Mervyn Wsl – Logger
Western Australia	Harding WSL – GIS logger at Damsite
Western Australia	Harris Wsl – Lake Ballingall
Western Australia	Harvey Dam Water Level-Manual
Western Australia	Kununurra Dv. Wsl
Western Australia	Mundaring Wsl-Ranger
Western Australia	New Victoria Water Level-Ranger
Western Australia	Nth Dandalup Water Level-Ranger
Western Australia	OPHTHALMIA
Western Australia	Serpentine Main Dam WSL – Ranger
Western Australia	Sth Dandalup Wsl-Ranger
Western Australia	Stirling Wsl
Western Australia	Wellington Wsl Logger
Western Australia	Wungong Water Level-Ranger

The polygons (shapefile) used to estimate the surface area for reservoirs of interest come from the National Hydropolys dataset which is available from the Digital Earth Australia website (https://cmi.ga.gov.au/data-products/dea/613/dea-water-observations-landsat). The Australian Bureau of Meteorology (BOM) compiles gauge data, which is supplied by the States and Territories, in time series for reservoirs reported here (http://www.bom.gov.au/waterdata/).

A procedure for compiling the depth to surface area lookup table was developed within the DEA environment (Dugdale and Alger 2021). The relevant python script is available on that platform as a Jupyter notebook: *Estimating surface area from reservoir depth.* The script needs to be run in the DEA Sandbox environment as it accesses the DEA-based Water Observations from Space data cube.

Flooded land (Other Constructed Waterbodies)

Introduction

We report here the methodology used to estimate the total methane emissions (diffusive and ebullitive) from Australian farm dams, also known as agricultural ponds, a subset of the *Other Constructed Waterbodies* sub-category. The methods described here are from a series of recent peer-reviewed scientific papers. Please refer to the original research articles (see references) for complete descriptions of the methods summarised here, including details on databases, source code access, and statistical techniques.

National farm dam population and distribution

Malerba et al. (2021) estimated national farm dam numbers by using trained convolutional neural networks (CNN) to detect farm dams using high-resolution satellite images and quantify omission (false negative) and commission (false positive) errors in the data. The full farm dam dataset is available online in a free interactive portal at AusDams.org.

The farm dam database developed by Malerba et al. (2021) included 1,694,675 farm dams in all States and Territories of Australia. The original sources included (1) the Water Observations from Space (WOfS) map by Geoscience Australia (N = 934,381), (2) the Department of Environment, Land, Water & Planning of the Victorian Government (N = 429,398), (3) the Department for Environment and Water in South Australia (N = 105,361), (4) the Department of Primary Industries and Regional Development in Western Australia (N = 162,785), (5) the Department of Natural Resources and Environment in Tasmania (N = 61,897) and (6) the Environment & Planning Directorate in the Australian Capital Territory (N = 853).

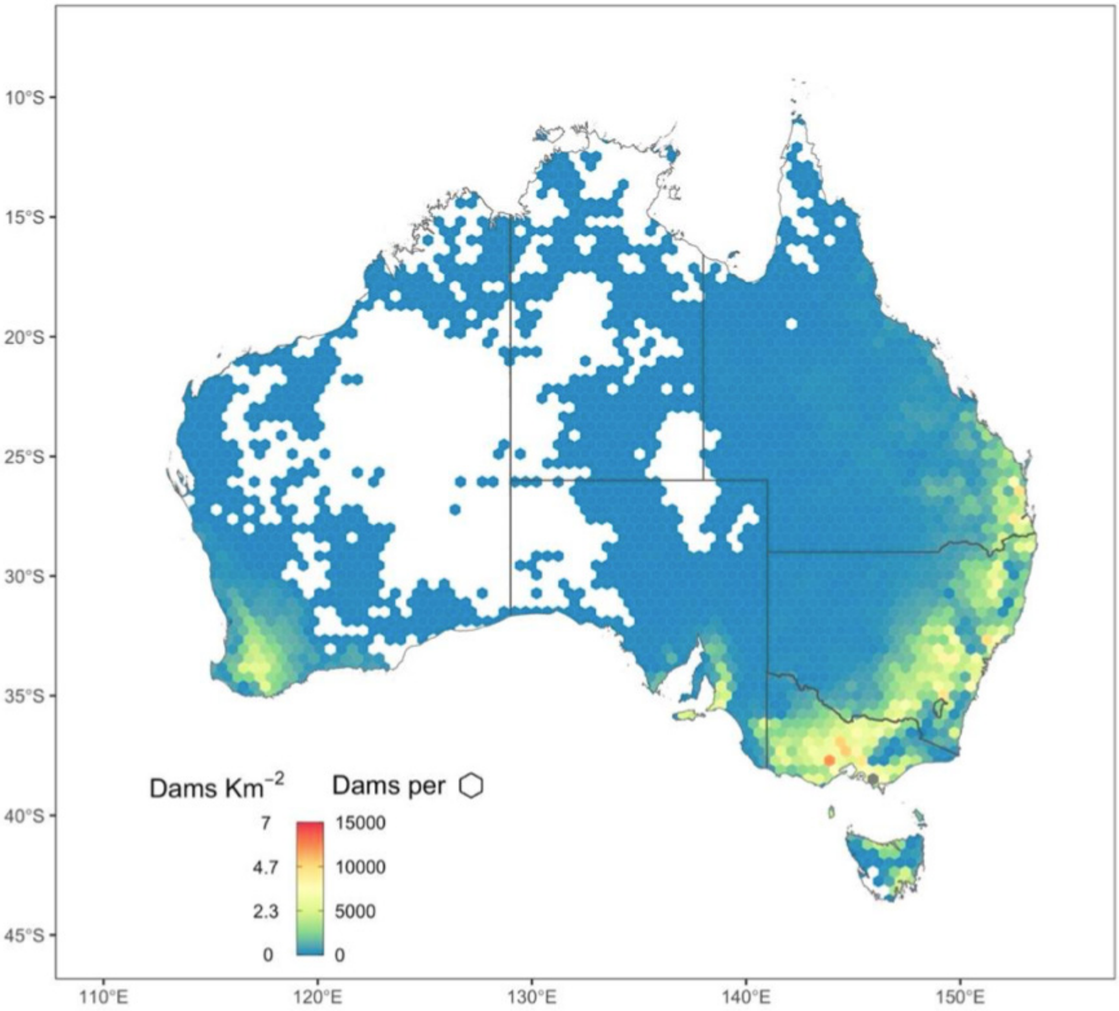
To exclude waterbodies other than farm dams, Malerba et al. (2021) removed any waterbodies larger than 10^5 m^2 (10 hectares) in surface area that appeared natural in origin (i.e., had complex shapes), using a threshold on circularity (i.e., 4 x Area / [n x perimeter^2] < 0.5). Some farm dams were reported as points rather than polygons. These were included in the dataset, with their surface areas assumed at the minimum detection area noted in the metadata of the original source (typically 625 m^2), and the perimeter assumed to be perfectly circular. The authors ensured there were no repeating or overlapping shapes in the data.

Malerba et al. (2021) developed and trained a deep learning CNN to detect farm dams using the Python-based open-source library "fastai" version 1 (available at https://github.com/fastai/fastai). The model was calibrated using high-resolution RGB satellite images of 7362 Australian locations (typically between 2018 to 2019) from three different repositories. Most (75%) images were sampled from the dam dataset, while the remaining 25% represented randomly selected locations from within Australia. Pixel resolution was normally 0.45m, in cases where this was not available lower resolutions that range from 1–5m were used. An 80–20% split was applied for training and validation datasets respectively. See Malerba et al. (2021) for technical details on the training and calibration of the CNN model.

The results from the CNN model were used to account for omission (false negative) and commission (false positive) errors in the data and generate an overall estimate for the expected number of farm dams in each State and Territory.

A bootstrapping procedure was used to quantify the overall uncertainty in the model. One thousand simulated data sets were created by sampling observations with replacement. Statistics for omission and commission errors were calculated for each simulated data. The final results of the models were reported as a median farm dam density (i.e., number of farm dams per km^2) and median total surface area (i.e., m^2 of farm dam water surface per km2), each with 95% confidence intervals from the bootstrap distribution. The distribution of farm dams in Australia is represented in Figure A5.6.10.5.

Figure A5.6.10.5 Distribution of documented dams in each Australian State and Territory based on Malerba et al. (2021). The colour represents density (dams km^{-2}) and total counts (dams per hexagon), with empty hexagons indicating no reports of dams in the area. (Used with authors' permission)



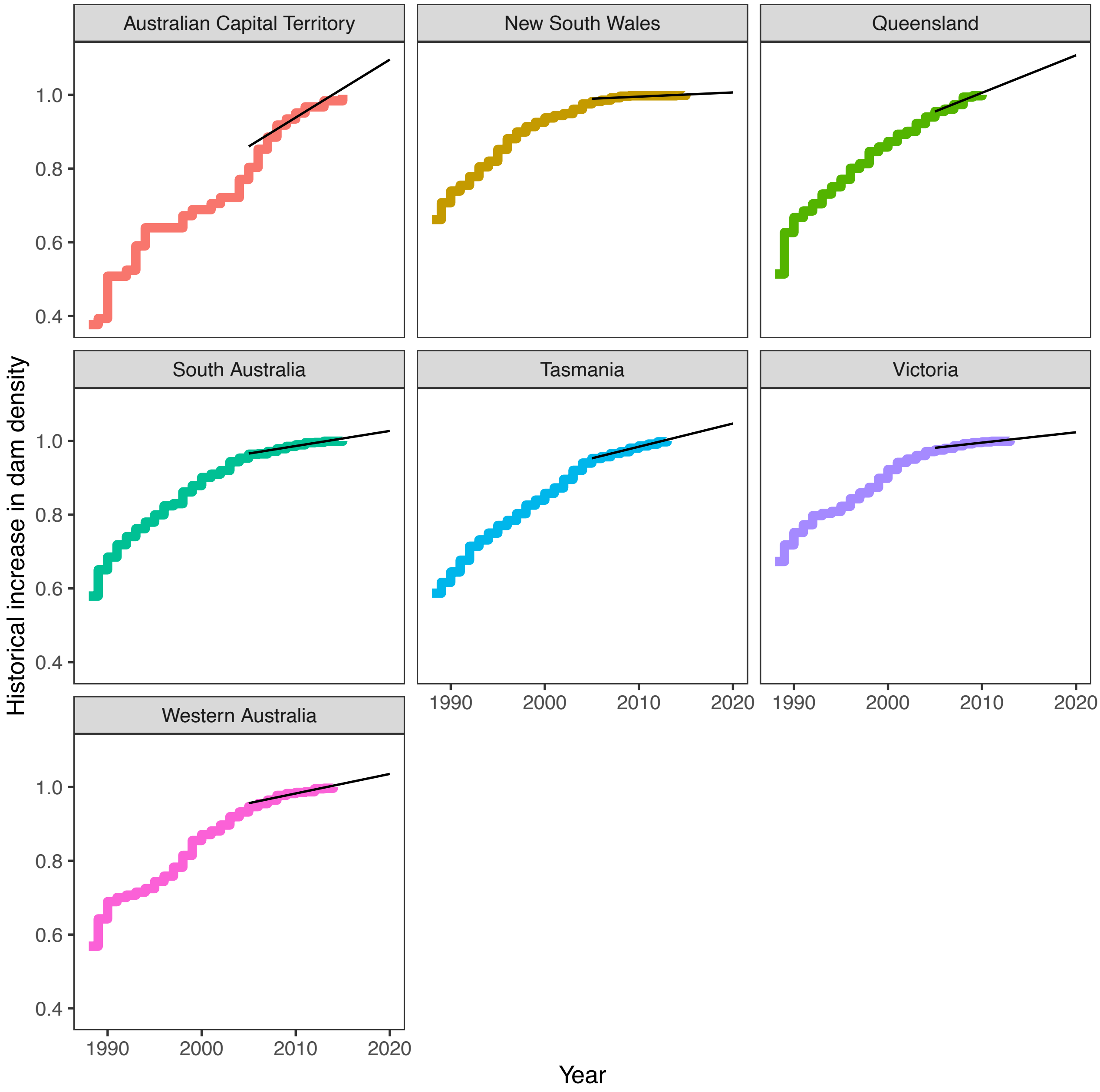
Historical trends in farm dam populations

Malerba et al. (2021) quantified historical changes in density and surface area of farm dam populations in Australia from 1988 to present using the Water Observations from Space (WOfS). The WOfS uses Landsat 5 and Landsat 7 satellite images to detect surface water at a 30 m grid size across Australia at an approximate bi-weekly frequency. The Digital Earth Australia (DEA) Waterbodies elaborates data from WOfS to provide 28 years of bi-weekly time series of relative wet surface area for 300,000 waterbodies across Australia.

The authors extracted WOfS/DEA waterbodies that overlapped with farm dams from AusDams.org. About 1000 farm dams were selected from each State and Territory, excluding the Northern Territory for which there were too few documented dams. Each time series quantified the number of pixels inside each selected farm dam area that were identified as water on a bi-weekly temporal scale from 1988 to 2015. The year of establishment of a farm dam was taken as the year when the WOfS time series consistently reported water in at least 25% of the farm dam surface area. This dataset was used to calculate relative and absolute rates of farm dam accumulation over time in each State and Territory (Figure A5.6.10.6).

Because the historical trends in Malerba et al. (2021) were only until 2015, farm dam densities in 2021 were predicted using the average annual rates calculated between 2010 and 2015 for each State and Territory and projecting to 2021 (Figure A5.6.10.6). The only exception was for the Northern Territory, where we lacked historical trends. Here we applied the national average expansion rate for farm dams developed for the initial reservoir model used in previous inventory reports.

Figure A5.6.10.6 Observed (thick coloured lines) and predicted (thin black lines) rates of historical farm dam increase for each State and Territory in Australia. Based on Malerba et al. (2021). Data for the Northern Territory were not available, so we used a prior national average expansion rate developed for previous inventory reports. (Used with authors' permission).



Dam maximum water surface

Malerba et al. (2022) developed statistical methods to analyse high-resolution satellite images and quantify the water surface area of a farm dam and the theoretical maximum water surface area. Specifically, they selected 148,344 satellite images and used two deep-learning convolutional neural networks (CNN) to measure the surface area of water inside the dams ("Water segmentation CNN") and the theoretical maximum water surface area including the bare clay area above the waterline and within the farm dam walls ("Maximum fill segmentation CNN"). The sample size used here represents nearly 10% of the Australian farm dam population and ensured national coverage and robust statistics while allowing reasonable computation times. The samples were comprised of high-definition RGB satellite image (0.5 m resolution) acquired between Jan 2011 and Dec 2020 from https://server.arcgisonline.com for each dam. Both segmentation CNNs were trained using the Python open-source library fastai, and both were initialised from pre-trained ResNet-18 UNets. The maximum fill extent and surface water extent for 569 randomly selected images of farm dams from the database were used to fine tune the segmentation CNNs. See Malerba et al. (2022) for technical details on the training and calibration of the CNN models.

A Filtration classification CNN was developed to remove unreliable results from false positives in dam database or due to poor quality of the satellite images. The Filtration classification CNN was initialised similarly to the classification CNN in Malerba et al. (2021), utilising the same Python library and an 80:20 training: validation split.

The final dataset in Malerba et al. (2022) included 106,903 Australian farm dams in New South Wales (N = 36,027), Victoria (N = 27,692), Queensland (N = 17,884), Western Australia (N = 15,789), South Australia (N = 5272), Tasmania (N = 4,178), and the Australian Capital Territory (N= 61). Due to lack of spatial data, we used the mean farm dam values across Australia to estimate farm dam properties in the Northern Territory. See Malerba et al. (2022) for more details on the models.

Monthly time series of dam water surface

The water surface area of Australian farm dams can change substantially between dry and wet seasons. For accurate predictions of total water surface in farm dams for each month and year, Malerba et al. (2023, in review) developed a statistical method to predict surface water based on local conditions of temperature and precipitation at each farm dam. Calibrating a model on temperature and precipitation avoided having to rely on time series of high-resolution satellite images, which are costly to source because most are exclusive to commercial satellite image providers.

The model developed by Malerba, Wright, and Macreadie (2022) is used to measure the surface area of a pond and its theoretical maximum water surface area, which includes the bare clay area above the waterline. The model was a deep-learning CNN developed with the Python open-source library "fastai". The model was used to analyse 148,344 randomly selected agricultural ponds in Australia (nearly 10% of the total) using RGB satellite images (usually 0.5 m resolution) with acquisition dates between Jan 2011 and Dec 2020 from ARCGIS online (https://server.arcgisonline.com). The dataset included agricultural ponds in the States and Territories of New South Wales, Victoria, Queensland, Western Australia, South Australia, Tasmania, and the Australian Capital Territory.

The Northern Territory lacked data on pond size, so we used the monthly averages for total pond size and water surface area across Australia and multiplied that by the dams in the Northern Territory (15183), as estimated by Malerba et al. (2021).

The climate data to calibrate the CNN model were from ANUClimate (version 2.0), covering Australia at a 0.01° grid size (M. Hutchinson, T. Xu, et al. 2021). The resolution of climate data from ANUClimate was sufficient to characterise each farm dam with unique time series of local rain and temperature. This dataset is curated by the Australian National University and offers historical records since 1965 of several climate variables from climate stations of the Australian Bureau of Meteorology analysed with the ANUSPLIN package (Hutchinson and Xu 2013). We obtained monthly data on total rainfall (mm) and average temperature (°C) for the thirteen months predating each RGB satellite image, for a sample size of (13 months x 120,939 farm dams x 2 climate variables =) 3,144,414 climatic observations.

Overall, the calibrated model allowed us to estimate monthly time series of nation-wide water surface (units of kha) in farm dams from 1990 to 2022 for Australian farm dams. The model reached a mean absolute percentage error of 46.4% at predicting the water surface area of a farm dam using data on temperature, precipitation and dam theoretical maximum water surface area.

Dam water capacity

Satellite images can inform on the water surface area (m^2) of a farm dam but cannot inform on water depth or total water capacity. To convert satellite-derived water surface area (m^2) into water capacity (ML), Malerba et al. (2021) derived a calibration curve based on a meta-analysis from published data on 558 farm dams in Victoria, Queensland, and South Australia (see Equation A5.6.10.1 and Fig. A5.6.10.7). Water capacity was calculated using GIS techniques and Light Detection And Ranging (LIDAR) data. Surface area was calculated using satellite images.

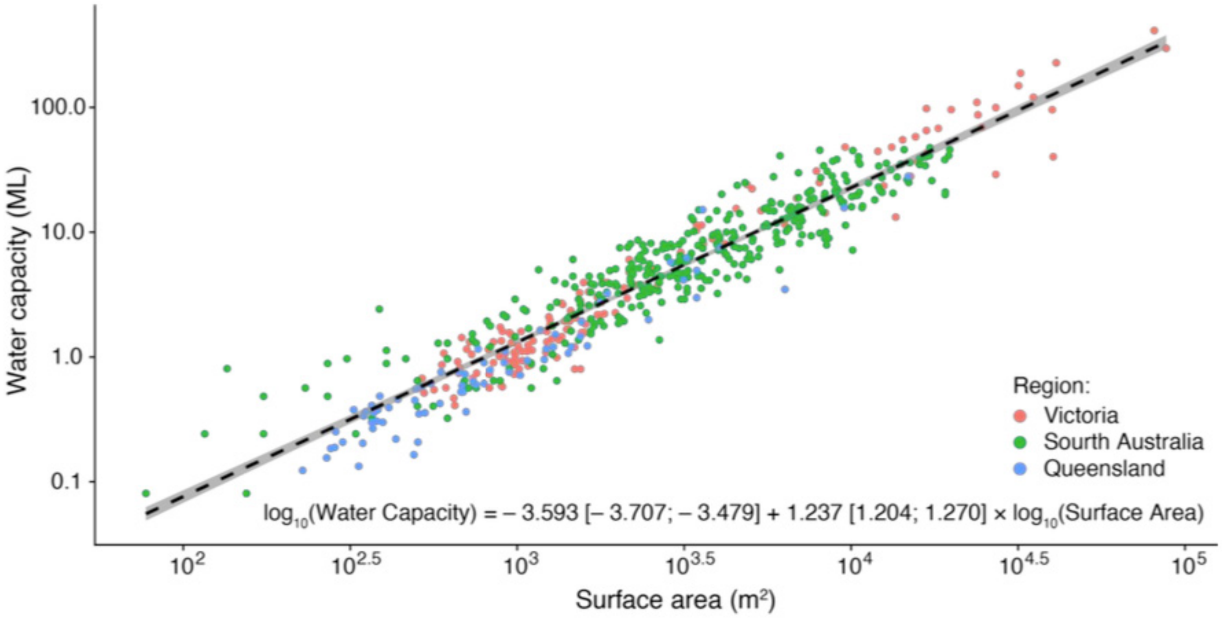
Estimating water capacity from surface area:

$$\log_{10}(\text{Water Capacity}) = -3.593\ [-3.707; -3.479] + 1.237\ [1.204; 1.270] \times \log_{10}(\text{Surface Area}) \qquad \text{A5.6.10.1}R^2$$

$R^2 = 0.91$; $F_{1556} = 5359.6$, $p < 0.001$

Numbers in square brackets are the constant values representing the lower and upper 95% CI for this model

Figure A5.6.10.7 Calibration curve and model coefficients [±95% confidence intervals] to estimate the water capacity of a farm dam from its surface area ($R^2 = 0.91$, $F_{1556} = 5360$, $p < 0.001$). Source: Malerba et al. (2021). (Used with authors' permission).



Methane emission rates from farm dams

Malerba et al. (2022) developed a model to estimate the total emission rate of methane (diffusive + ebullitive) for farm dams while adjusting for local temperature. In summary, (1) they compiled data from the scientific literature and additional fieldwork on methane fluxes from 286 farm dams in subtropical, temperate, semi-arid, and tropical climates, (2) they used a meta-analysis to standardise all emissions to 15 °C, and (3) another meta-analysis to account for the average temperature-dependent contribution of methane ebullition to the total methane flux of farm dams.

To compare estimates across sites and climates, Malerba et al. (2022) used the Boltzmann-Arrhenius relationship to standardise the methane emission rates from the scientific literature at 15°C (Equation A5.6.10.2).

$$\ln[M_i\,(T_{15})] = \ln[M_i\,(T)] - E_M \times ((1/(k_B \times T_{15})) - (1/(k_B \times T_i))) \qquad \text{A5.6.10.2}$$

Where: $\ln[M_i\,(T)]$: loge-transformed rate of daily methane emissions (mg CH_4/day/m²), recorded at site i (i = 1, 2, …, 286), at the local air temperature

T_i : local air temperature in degrees Kelvin for site i

T_{15}: the temperature used to standardise rates, expressed in degrees Kelvin (where 15°C is 288.15 K),

$\ln[M_i\,(T_{15})]$: is the equivalent rate standardised to 15°C, for site i

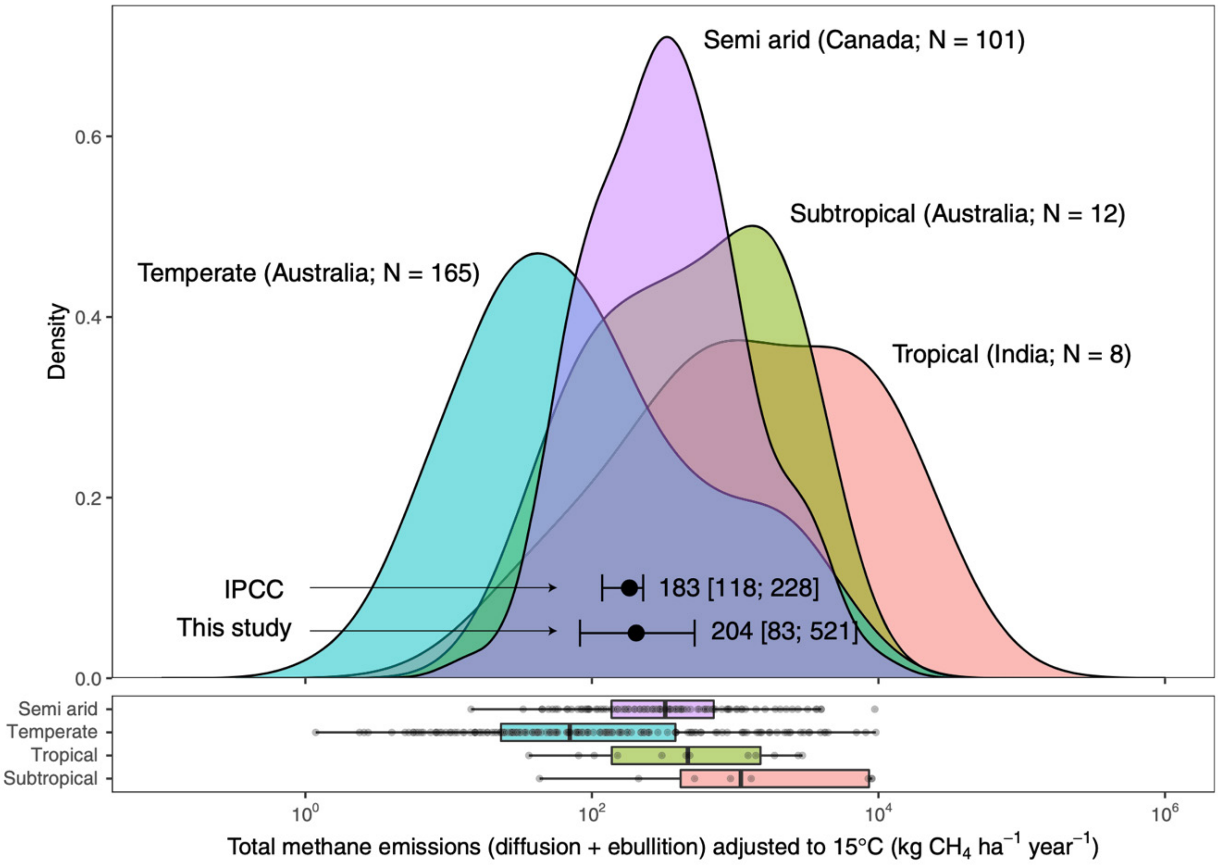
E_M: is the temperature sensitivity for methane emissions (eV mg CH_4/day/m²), and estimated from the data set published by Rosentreter *et al.* (2021); E_m [+/- 95% CI] = 0.43 [0.21, 0.64]

k_B: Boltzmann constant (8.617×10^{-5} eV/K)

To parameterise Equation A5.6.10.2, Malerba et al. (2022) used the 10–year median daily temperature recorded by MODIS Terra Land Surface Temperature. For the temperature sensitivity of methane emissions (EM), the authors used a dataset published by Rosentreter et al. (2021). Equation 2 was then used to calculate total methane emissions (diffusion + ebullition), standardised at 15°C (Figure A5.6.10.8).

Total methane emissions from Australian dams were calculated by multiplying water surface area of a farm dam by the temperature-corrected emission factors. Specifically, the “weather-to-water” model (described above) provided monthly time series from 1990 to 2022 of water surface areas for each farm dam in Australia (n = 1.7 million). The temperature-correction using the Boltzmann-Arrhenius relationship (Equation A5.6.10.2) predicted the average temperature-corrected total methane emission rate per m^2 of a farm dam. Local temperature for each dam was obtained from the ANUSPLIN monthly climate surfaces (Hutchinson and Xu 2013) (McMahon et al. 2000). ANUSPLIN provides local climate data, including daily mean temperature, at 1 km resolution nationally, and over the time series 1989/90 to 2020/21. Aggregating the results for individual dams over each financial year and according to jurisdiction provides the annual methane emissions reported by state and territory and nationally.

Figure A5.6.10.8 Meta-analysis on total methane emissions (diffusion + ebullition) from farm dams standardised to 15C using the Boltzmann-Arrhenius (Eqn A5.6.10.2). Black points indicate either the IPCC emission factor recommended for constructed waterbodies across all climates (Table 7.12 in Lovelock et al. (2019)), or the geometric mean calculated from all data compiled in the meta-analysis – with error bars representing the 95% confidence intervals. Box-and-whiskers show the distribution of the compiled data divided by climate. Data from Malerba et al. (2022). (Used with authors’ permission)



Baseline vs stock dam emissions

Manure contamination in the water is an important driver of methane emissions from Australian farm dams. However, the "manure component" of the total methane emissions is reported elsewhere in the National Inventory Report (see "manure management" in Agriculture). So, we partitioned total methane emissions between the "manure component" and the "baseline component". The "baseline component" is reported in this section, whereas the "manure component" is reported under "manure management" in Agriculture.

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. Moreover, Grinham et al. (2018) showed that ponds used for stock watering on grazing land (assumed high organic input) on average generate 1.5 times more methane than ponds used for irrigation or "urban use" on cropland or settlement land (assumed lower organic inputs). This result corresponds to a mean ratio of 0.4 for crop dams and farm tanks relative to stock dams.

We used these statistics to partition the total estimated methane emissions from Australian farm dams between "baseline component" (40%) and the "manure component" (60%). Only the baseline component is reported in this section.

A5.6.11 Biomass burning

There are six different types of biomass burning events (Table A5.6.11.1). With the exception of prescribed burns, biomass burning events are monitored via monthly Advanced Very High Resolution Radiometer imagery (AVHRR, 1988–present, with 1970–1987 gap-filling as per Meyer (2016)). The FullCAM-predicted impacts of fire were predicted at the pixel resolution of 25 x 25 m, with the fire events only being applied to a proportion of cells randomly selected within the fire scar in accordance with the assumed fire patchiness, *P*. *P* has been shown to vary between the six different burning events (Table A5.6.11.1).

For historical fire events not detected using AVHRR imagery, assumptions were made in order to simulate spatial and temporal variations in fires. These assumptions were based on available estimates of typical fire return intervals, time of year fires occur, area of the fire scar, and the proportion of early dry season (EDS) to late dry season (LDS) burns in the savanna fire zone where available from previous studies and expert opinion (Table A5.6.11.2) (Meyer et al. 2009) (Murphy, et al. 2013). To introduce variation in the simulated fire events, uniform probability distribution functions were applied to vary these assumptions between what was deemed to be their upper and lower bounds.

FullCAM simulates fire in two fire zones:

- The temperate fire zone, comprised of New South Wales, Victoria, the Australian Capital Territory, South Australia, Tasmania and the southern regions of Queensland and Western Australia; and
- The savanna fire zone; comprised of the Northern Territory and the northern regions of Queensland and Western Australia.

Wildfire in the temperate fire zone and all fire in the savanna and rangelands zones is captured by the AVHRR activity data. Prescribed fire in the temperate fire zone is identified through the supply of digitised, spatially explicit mapping of prescribed burning treatment areas from state or territory fire authorities. This is due to the limitations of satellite data in detecting controlled fires in closed canopy forests. Fire in Australia's rangelands (primarily located in the central areas of Western Australia and the Northern Territory) is modelled at the Tier 2 level, using activity data on burnt area derived from the AVHRR imagery.

Table A5.6.11.1 Assumed patchiness (P, varying between 0 and 1) in various fire zones of Australia

Fire zone	Fire type	Patchiness (P)
Temperate zone forests & woodlands	Prescribed	0.650
	Wildfire	0.800
Savanna Woodland; > 1000 mm MAR	EDS	0.709
	LDS	0.889
Savanna Woodland; < 1000 mm MAR	EDS	0.790
	LDS	0.970

Data sources: Meyer et al. (2015) and Roxburgh et al. (2015).

Table A5.6.11.2 'Rules' applied when simulating prescribed fires or wildfires prior to 1987–88; including, typical return intervals, Julian days at which fires occur, area of the fire scar, and relative proportion of EDS and LDS fires in the savanna woodlands

All wildfires were assumed to have scar areas of 3000x3000 m while all other fires were assumed to have scar areas of 1500x1500 m. Based on empirical evidence and expert option as outline by Murphy et al. (2013) and Meyer et al. (2015).

		Wildfires		Prescribed burns or non-temperatefires[1]		
Region	**Vegetation subclass**	**Fire return interval (yrs)**	***Julian day at which fire occurs***	**Fire return interval (yrs)**	***Julian day at which fire occurs***	**Proportion of EDS (or LDS) fires**
Temperate	Tall eucalypt forest (B)	31–185	15±30	5–15	105±30	-
	Eucalypt forest (C)	8–147	334±60	5–15	105±30[2]	-
	Rainforest (D)	154–318	105±30	5–15	105±30[2]	-
	Heath (E)	31–154	344±60	5–15	105±30[2]	-
	Eucalypt woodland (H)	31–182	15±30	5–15	105±30[2]	-
	Mallee (N)	31–182	344±60	5–15	105±30[2]	-
Arid & Semi-arid	Tussock grassland (K)	31–182	344±60	5–15	105±30[2]	-
	Acacia shrubland (mulga) (P)	27–156	344±60	5–15	105±30[2]	-
	Tussock grassland (T)	27–156	344±60	5–15	105±30[2]	-
	Acacia woodland (Brigalow) (J)	31–182	344±60	5–15	105±30[2]	-
Tropical Semi-arid	Acacia woodland (O)	31–154	288±30	5–15	105±30[2]	-
	Eucalypt woodland (Q)	8–147	344±60	5–15	105±30[2]	-
	Chenopod shrubland (R)	27–156	344±60	5–15	105±30[2]	-
	Hummock grassland (S)	7–125	288±30	5–15	105±30[2]	-
Tropical	Rainforest (tropical) (A)	154–308	288±30	5–15	105±30[2]	-
	Eucalypt forest & woodland[3] (I)	8–147	288±30	5–15	105±30[2]	-

		Wildfires		Prescribed burns or non-temperatefires[1]		
Region	**Vegetation subclass**	**Fire return interval (yrs)**	***Julian day at which fire occurs***	**Fire return interval (yrs)**	***Julian day at which fire occurs***	**Proportion of EDS (or LDS) fires**
Monsoonal Savanna Woodland	Melaleuca Woodland (Other)	-	-	5–8	166+60 (258+30)	0.41 (0.59)
		-	-	5–8	166+60 (258+30)	0.20 (0.80)
		-	-	3–7	166+60 (258+30)	0.30 (0.70)
	Open Forest Mixed (hOFM)	-	-	3–6	166+60 (258+30)	0.31 (0.69)
		-	-	15–18	166+60 (258+30)	0.06 (0.94)
		-	-	1–5	166+60 (258+30)	0.41 (0.59)
	Shrubland Hummock (hSHH)	-	-	2–6	166+60 (258+30)	0.58 (0.42)
		-	-	6–9	166+60 (258+30)	0.08 (0.92)
		-	-	3–6	166+60 (258+30)	0.36 (0.64)
	Woodland Hummock (hWHu)	-	-	2–6	166+60 (258+30)	0.43 (0.57)
		-	-	6–9	166+60 (258+30)	0.14 (0.86)
		-	-	2–6	166+60 (258+30)	0.36 (0.64)
		-	-	1–5	166+60 (258+30)	0.51 (0.49)
	Woodland Mixed (hWMi)	-	-	3–6	166+60 (258+30)	0.15 (0.85)
		-	-	1–5	166+60 (258+30)	0.41 (0.59)
	Open woodland, mixed (lOWM)	-	-	4–8	135+60 (288+30)	0.34 (0.66)
		-	-	4–7	135+60 (288+30)	0.22 (0.78)
		-	-	3–6	135+60 (288+30)	0.34 (0.66)
	Shrubland Hammock (lSHH) WA	-	-	4–8	135+60 (288+30)	0.40 (0.60)
		-	-	4–7	135+60 (288+30)	0.21 (0.79)
		-	-	3–6	135+60 (288+30)	0.38 (0.62)
	Woodland Hammock (lWHu) WA	-	-	4–7	135+60 (288+30)	0.32 (0.68)
		-	-	5–8	135+60 (288+30)	0.11 (0.89)
		-	-	2–6	135+60 (288+30)	0.40 (0.60)
	Woodland, Mixed grass (lWMi)	-	-	3–7	135+60 (288+30)	0.28 (0.72)
		-	-	9–12	135+60 (288+30)	0.18 (0.82)
		-	-	11–14	135+60 (288+30)	0.37 (0.63)
	Woodland, Tussock grass (lWTu)	-	-	2–6	135+60 (288+30)	0.41 (0.59)
		-	-	11–14	135+60 (288+30)	0.18 (0.82)
		-	-	2–6	135+60 (288+30)	0.37 (0.63)
	Pindan	-	-	3–7	166+60 (258+30)	0.30 (0.70)

1 Fire return intervals reported by Meyer et al. (2015) were divided by Pas described in the text.

2 Exception is 243±30 in WA, and 151±30 in Qld.

3 When simulating wildfires prior to European settlement, it was assumed that areas of cleared land deemed by Murphy et al. (2013) to be ‘temperate pasture’ or ‘tropical and subtropical pasture’ were ‘temperate eucalypt woodland’ and ‘tropical eucalypt forest and woodland’.

For all biomass burning events simulated by FullCAM, it is assumed that the live biomass recovers post burning. As outlined in detail by Paul and Roxburgh (2019), for wildfire simulations (which were not assumed to be stand-replacing fires, and hence only had relatively small impacts on live biomass pools), recovery of live woody biomass was assumed to take 12 years, with the exception of foliage, which took only 3 years. For all other biomass burning simulations, it was assumed that recovery of live woody biomass took a maximum of 2 years, with the exception of foliage, which took only 0.5 years. For the savanna fire zone, in addition to some fire-related mortality of live biomass, there was also assumed to be regular non-fire related mortality as outlined by Paul and Roxburgh (2022) (Table A5.6.11.3).

Table A5.6.11.3 Calibrated parameters determining the percentage of AGB that is fire-affected (i.e. extent of top-kill) in the different categories of savanna vegetation, including woodland and open forest vegetation types in low rainfall zones (LRZ) or high rainfall zones (HRZ), and the shrubland vegetation types in low rainfall zones (lSHH or Pindan) or high rainfall zones (hSHH)

Vegetation	Non-fire related	Fire death	% of AGB assumed to be fire-affected	
	death (% yr-1)	impact-level	EDS	LDS
HRZ	2.025*	Mild	2.50	10.0
LRZ	1.120+	Low	0.00	5.00
hSHH	2.025*	High	7.50	20.0
lSHH	1.680*	Moderate	5.00	15.0
Pindan	1.680*	Moderate	5.00	15.0

* 75% or +50% of the total annual mortality calculated by Cook et al. (2020)

Grass under woody vegetation can be a key component of fine fuel pools. Hence, when simulating biomass burn events, FullCAM is configured to simulate woody vegetation as well as a perennial grass understorey, with the assumed growth rates and die-off rates provided in Table A5.6.11.3. The proposal area occupied by grass is given by the parameter, *Agrass.*

As outlined in detail by Paul and Roxburgh (2019) (2022), the model was calibrated to ensure that the overall emissions and fuel dynamics were consistent with previous estimates under typical conditions. This gave litterfall rates and *Agrass* estimates as shown in Table A5.6.11.4 and estimates of C loss from live biomass and debris are provided in Tables A5.6.11.5 and A5.6.11.6, respectively. Generally, by the time of a return fire event, all of the standing dead material was assumed to have decomposed. However, for any remaining stem, branch or bark standing dead material, the total C lost on burning was assumed to be 31 per cent for intense fires and 14 per cent for less intense fires. For any remaining foliage standing dead material, the total C lost on burning was assumed to be 85 per cent for intense fires and 70 per cent for less intense fires. Of the C lost on burning standing dead pools, there was an assumed 0.90:0.10 split of CO_2-C-to-debris loss of C.

Table A5.6.11.4 Values applied in FullCAM for rates of litterfall of foliage, bark and branches (L, per cent month^{-1}), and the proportional area occupied by grasses (A_{grass})

				L (% month^{-1})			
Region		**Vegetation subclass**	**State**	***Foliage***	***Bark***	***Branch***	**A_{grass}**
Temperate	~	~	NSW	2.708	0.409	0.738	0.05
			TAS	2.708	0.409	0.738	0.40
			WA	2.708	0.409	0.738	0.00
			SA	2.708	0.409	0.738	0.35
			Vic	2.708	0.409	0.738	0.20
			Qld	2.708	0.409	0.738	0.50
			ACT	2.708	0.409	0.738	0.10
Tropical	> 1000 mm MAR	Open Forest Mixed (hOFM)	-	NA*	NA*	NA*	0.40
		Shrubland Hummock (hSSH)	-	NA*	NA*	NA*	0.75
		Other	-	NA*	NA*	NA*	0.70
	< 1000 mm MAR	Open woodland with mixed grass (lOWM)	-	NA*	NA*	NA*	0.90
		Shrubland with hummock grass (lSHH)	-	NA*	NA*	NA*	0.90
		Pindan	-	NA*	NA*	NA*	0.70
		Other	-	NA*	NA*	NA*	0.80

Note: rates of litterfall for temperate fire regions were based on litterfall studies as reviewed by Paul and Roxburgh (2017).
Note: NA* indicates data not provided as L was based on empirical seasonal (as opposed to annual average) litterfall data (Table A5.6.11.6).

Table A5.6.11.5 Calibrated litterfall rates for branch, bark, and foliage litter in the savanna fire zone

	Litterfall rate (half-life, years)			
Month	**Branch**	**Bark**	**Foliage (HRZ)**	**Foliage (LRZ)**
Jan	6.9	8	1.99	1.40
Feb	12.5	13.2	1.75	1.58
Mar	26	27	1.51	1.58
Apr	33	34	1.15	1.58
May	33	34	1.03	3.60
Jun	15	16.2	1.03	2.33
Jul	9.5	10.5	0.88	1.95
Aug	9.5	10.5	0.88	1.73
Sep	8.0	9.0	0.97	1.35
Oct	4.3	5.0	1.27	1.05
Nov	4.6	5.0	1.51	1.05
Dec	6.5	7.3	1.69	1.05
Annual	**9**	**10**	**1.2**	**1.5**

Table A5.6.11.6 Values of calibrated FullCAM parameters for the percentage of live biomass-C that was assumed to be converted to either CO_2-C or the standing dead pool ($t\ ha^{-1}$) as a result of fire in the temperate fire region (Paul and Roxburgh 2019). Two pairs of values are provided. The first pair represents percentage C loss to CO_2-C & standing dead ($t\ ha^{-1}$) in low intensity fire types (prescribed). The second pair, given in parenthesis, represents percentage C loss to CO_2-C & standing dead in high intensity fires type (wildfire)

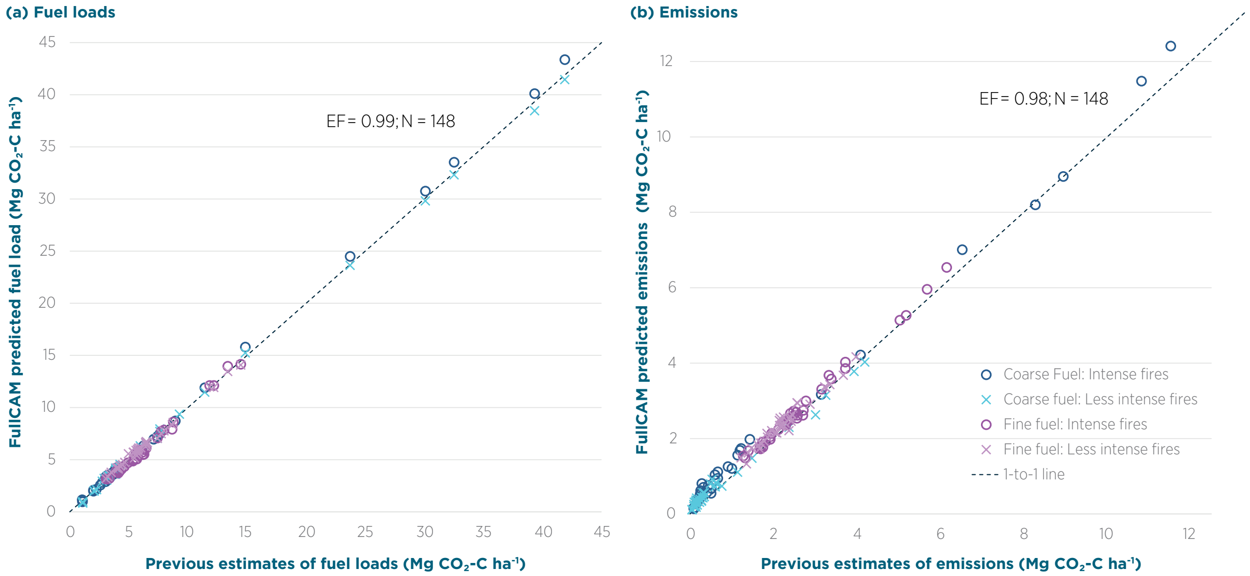
Region		Vegetation subclass	State	Deadwood	Bark litter	Foliage litter	
Temperate forests and woodlands	~	~	ACT	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			NSW	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			Qld	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			SA	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			TAS	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			Vic	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)
			WA	4.5&0.5 (9&1)	4.5&0.5 (9&1)	4.5&0.5 (9&1)	2.5&0.5 (5&5)

Table A5.6.11.7 Values of calibrated FullCAM parameters for the percentage of debris-C that was assumed to be converted to CO_2-C as a result of fire. Two values are provided. The first represents low intensity fire types (prescribed). The other, given in parenthesis, represents high intensity fires type (wildfire). For all fire types, it was assumed that no debris-C was converted to inert soil C as a result of fire.

Region		Vegetation subclass	State	Deadwood	Bark litter	Foliage litter
Temperate forests – and woodlands	~	~	ACT	18 (55)	25 (65)	55 (90)
			NSW	18 (55)	25 (65)	53 (85)
			Qld	18 (50)	28 (65)	40 (90)
			SA	18 (50)	25 (65)	30 (90)
			TAS	18 (50)	25 (65)	30 (90)
			Vic	18 (50)	25 (65)	50 (85)
			WA	18 (55)	25 (65)	55 (85)

The calibrated parameters given in Tables A5.6.11.4–6 ensured that FullCAM-predicted pre-fire fuel loads, and emissions on burning, were consistent with NIR estimates under typical conditions (Paul and Roxburgh 2019).

Figure A5.6.11.1 Comparison between FullCAM-predicted: (a) fuel loads, and (b) emissions of CO_2-C and that expected based on previous NIR-based estimates for coarse and fine fuels for the 37 fire zones and under both intense fires (wildfires in the temperate fire zone) and less intense fires (prescribed burns in the temperate fire zone)



For fires in the savanna regions, the burn efficiency (BEF) parameters for woody vegetation are given in Table A5.6.11.8 and were calibrated to empirical datasets as described by Paul and Roxburgh (2022). Regardless of the type of fire event, 95% of the grass biomass was assumed to be affected by the fire, but given the calibrated BEF for grass foliage was 93%, the remaining 2% of affected grass foliage was predicted to transfer from live grass to dead grass (i.e. grass litter). Also regardless of the fire event, the calibrated BEF for foliage litter was 99%.

Table A5.6.11.8 Calibrated parameters determining the burn efficiency factor (BEF) for components of AGB and heavy fuel, and for the key components contributing to coarse and fine fuel (Paul and Roxburgh 2022)

		Components			
BEF parameters	**Fire type**	**Stem**	**Branch**	**Bark**	**Foliage**
Live biomass+	HRZ-EDS	0.20	0.30	0.60	0.70
	HRZ-LDS	0.30	0.40	0.70	0.80
	LRZ-EDS	0.10	0.20	0.60	0.70
	LRZ-LDS	0.11	0.30	0.70	0.80
Standing dead (Heavy fuel)	HRZ-EDS	0.20	0.30	0.70	0.80
	HRZ-LDS	0.30	0.40	0.80	0.90
	LRZ-EDS	0.10	0.20	0.70	0.80
	LRZ-LDS	0.10	0.30	0.80	0.90
Debris pools (Coarse and fine fuel)	HRZ-EDS	-	0.20*	0.75*	0.80
	HRZ-LDS	-	0.40*	0.85*	0.90
	LRZ-EDS	-	0.10*	0.75*	0.80
	LRZ-LDS	-	0.20*	0.85*	0.90

		Components			
BEF parameters	**Fire type**	**Stem**	**Branch**	**Bark**	**Foliage**
Grass (live biomass component of grass fuel)	All	-	-	-	0.93
Grass debris (dead biomass component of grass fuel)	All	-	-	-	0.99

+ For example, if the fire event had 10% impact on live biomass, with 3% being converted to CO$_2$-C (and the remaining 7% being converted to standing dead), the calculated BEF of that pool of live biomass was 30% (=3/10)

* 60% of these components are assumed to be coarse fuel, with 40% contributing to fine fuel. All of the foliage debris contributes to the fine fuel.

Table A5.6.11.9 Molecular Mass conversion factors

Conversion	Value
N to N$_2$O	44/28
C to CH$_4$	16/12
C to CO$_2$	44/12
N to NO$_X$	46/14
C to CO	28/12
C to NMVOC	14/12

Table A5.6.11.10 Nitrogen to Carbon ratio in fuel burnt (C)

			N:C				
Vegetation class		**Rainfall Zone**	**Aggregated**	**Fine and Grass**	**Coarse**	**Heavy**	**Live**
Tropical Zone [(a)]	Woodland hummock	High	NA	0.010	0.008	0.008	0.009
	Shrubland hummock	High	NA	0.010	0.008	0.008	0.009
	Woodland mixed	High	NA	0.010	0.008	0.008	0.009
	Open forest mixed	High	NA	0.010	0.008	0.008	0.009
	Melaleuca woodland	High	NA	0.010	0.008	0.008	0.009
	Shrubland (heath) with hummock grass	Low	NA	0.011	0.004	0.015	0.004
	Woodland with mixed grass	Low	NA	0.011	0.004	0.015	0.004
	Open woodland with mixed grass	Low	NA	0.011	0.004	0.015	0.004
	Woodland with tussock grass	Low	NA	0.011	0.004	0.015	0.004
	Woodland with hummock grass	Low	NA	0.011	0.004	0.015	0.004
	Pindan	Low	NA	0.011	0.004	0.015	0.004
Subtropical and semi-arid zone	[(b)]	NA	0.0087	NA	NA	NA	NA
Temperate Forest	[(c)]	NA	0.011	NA	NA	NA	NA
Temperate Grasslands	[(d)]	NA	0.012	NA	NA	NA	NA

Table A5.6.11.11 CH$_4$ Emission Factors (Gg CH$_4$–C/Gg C)

Vegetation class		Rainfall Zone	CH$_4$ EF (Gg CH$_4$–C/Gg C)				
			Aggregated	Fine and Grass	Coarse	Heavy	Live
Tropical Zone (a)	Woodland hummock	High	NA	0.0031	0.0031	0.01	0.0031
	Shrubland hummock	High	NA	0.0015	0.0015	0.01	0.0015
	Woodland mixed	High	NA	0.0031	0.0031	0.01	0.0031
	Open forest mixed	High	NA	0.0031	0.0031	0.01	0.0031
	Melaleuca woodland	High	NA	0.0031	0.0031	0.01	0.0031
	Shrubland (heath) with hummock grass	Low	NA	0.0013	0.0013	0.0111	0.0013
	Woodland with mixed grass	Low	NA	0.0015	0.0015	0.0146	0.0015
	Open woodland with mixed grass	Low	NA	0.0015	0.0015	0.0146	0.0015
	Woodland with tussock grass	Low	NA	0.0015	0.0015	0.0146	0.0015
	Woodland with hummock grass	Low	NA	0.0015	0.0015	0.0146	0.0015
	Pindan	Low	NA	0.0013	0.0013	0.0111	0.0013
Subtropical and semi-arid zone	(b)	NA	0.0012	NA	NA	NA	NA
Temperate Forest	(c)	NA	NA	0.0025	0.0126	NA	NA
Temperate Grasslands	(d)	NA	0.0035	NA	NA	NA	NA

(a) Russell-Smith et al. (2015)
(b) Meyer and Cook (2011)
(c) Roxburgh et al. (2015)
(d) Hurst et al. (1994) (1994)

Table A5.6.11.12 N_2O Emission Factors (Gg N_2O-N/Gg N)

Vegetation class		Rainfall Zone	N_2O EF (Gg N_2O-N/Gg N)				
			Aggregated	Fine and Grass	Coarse	Heavy	Live
Tropical Zone [a]	Woodland hummock	High	NA	0.0075	0.0075	0.0036	0.0075
	Shrubland hummock	High	NA	0.0066	0.0066	0.0036	0.0066
	Woodland mixed	High	NA	0.0075	0.0075	0.0036	0.0075
	Open forest mixed	High	NA	0.0075	0.0075	0.0036	0.0075
	Melaleuca woodland	High	NA	0.0075	0.0075	0.0036	0.0075
	Shrubland (heath) with hummock grass	Low	NA	0.0059	0.0059	0.0146	0.0059
	Woodland with mixed grass	Low	NA	0.0075	0.0075	0.0146	0.0075
	Open woodland with mixed grass	Low	NA	0.0075	0.0075	0.0146	0.0075
	Woodland with tussock grass	Low	NA	0.0075	0.0075	0.0146	0.0075
	Woodland with hummock grass	Low	NA	0.0075	0.0075	0.0146	0.0075
	Pindan	Low	NA	0.006	0.006	0.0146	0.0059
Subtropical and semi-arid zone	[b]	NA	0.0066	NA	NA	NA	NA
Temperate Forest	[c]	NA	NA	0.0111	0.0067	NA	NA
Temperate Grasslands	[d]	NA	0.0076	NA	NA	NA	NA

(a) Russell-Smith et al. (2009); Lynch et al. (2015)
(b) Meyer and Cook (2011)
(c) Roxburgh et al. (2015)
(d) Hurst et al. (1994) (1994)

Table A5.6.11.13 Emission Factors (CO, NMVOC and NOx)

Gas	Unit	Tropical and semi-arid Emission Factor	Temperate Emission Factor
CO	Gg CO-C/Gg C	0.078	0.091
NMVOC	Gg NMVOC-C/Gg C	0.0091	0.022
NOX	Gg NOX-N/Gg N	0.21	0.15

Hurst et al. (1994) (1994)

Table A5.6.11.14 Prescribed burning spatial data sources

State	Source	License
Australian Capital Territory	Environment, Planning and Sustainable Development Directorate	Creative Commons 4.0
New South Wales	NSW Department of Climate Change, Energy, the Environment and Water	Creative Commons 4.0
Queensland	Department of Environment and Science	Creative Commons 3.0
South Australia	Department for Environment and Water	Creative Commons 4.0
Tasmania	Department of Natural Resources and Environment Tasmania	Creative Commons 3.0
Victoria	Department of Environment, Land, Water and Planning	Creative Commons 4.0
Western Australia	Department of Biodiversity, Conservation and Attractions	Creative Commons 4.0

Tier 2 Prescribed burning model parameters

Table A5.6.11.15 Fine Fuels – fuel accumulation model parameters

State	Vegetation class	Vegetation subclass	Rainfall zone	Fire variant	FLO	L	D	Gc
TAS	Temperate Zone	Temperate Forests	NA	Controlled burning	5.3436	2.3389	0.267	1.00
WA	Temperate Zone	Temperate Forests	NA	Controlled burning	7.2163	2.2004	0.186	1.00
Qld	Temperate Zone	Temperate Forests	NA	Controlled burning	8.8267	11.1130	0.768	1.00
NT	Temperate Zone	Temperate Forests	NA	Controlled burning	2.5010	1.2177	0.297	1.00

Table A5.6.11.16 Coarse Fuels – fuel accumulation model parameters

State	Vegetation class	Vegetation subclass	Rainfall zone	Fire variant	FLO	L	D
TAS	Temperate Zone	Temperate Forests	NA	Controlled burning	11.9623	3.96762	0.267
WA	Temperate Zone	Temperate Forests	NA	Controlled burning	31.6687	7.31724	0.186
Qld	Temperate Zone	Temperate Forests	NA	Controlled burning	24.2305	23.1168	0.768
NT	Temperate Zone	Temperate Forests	NA	Controlled burning	3.3005	1.2177	0.297

Table A5.6.11.17 Burning Efficiency (BEF)

Vegetation class	Fuel Size	Fire variant	Rainfall zone	Percent
Temperate Zone	Fine	Controlled burning	NA	60.0%
Temperate Zone	Coarse	Controlled burning	NA	30.0%

Table A5.6.11.18 Carbon Content in fuel burnt (C)

Vegetation class	Vegetation subclass	Rainfall zone	Fuel Size	Percent
Temperate Zone	Temperate Forests	NA	NA	50.0%

A5.6.12 Activity Data – Annual areas of forest conversions and sparse woody transitions

The following tables provide National and State/Territory time series (1989–90 to 2021–22) of annual areas of:

- primary forest conversion to other land uses and secondary conversion (re-clearing) of forest that has emerged on previously cleared land (Table A5.6.12.1 a);
- for each year, the area of identified regrowth on previously cleared land and the resultant net clearing of forest when combined with the previous table, (kha) (Table A5.6.12.1b);
- gain and loss of sparse woody vegetation across grasslands, wetlands and settlements (Table A5.6.12.5)

Tables A5.6.12.2–4, show primary and secondary conversion and cleared forest regrowing – by ABARES land use region; Bureau of Meteorology river region; and Natural Resource Management region for each of the years from 2017–2022.

These tables show actual changes in the year of observation, whereas the land representation matrix (Chapter 6.2.3) allocates regrowth events to the year after which they are observed. This ensures that, where there is doubt in the satellite image interpretation causing the forest state to swap between a forested and non-forested state in annual intervals, any 'false' regrowth event will occur in the same year as a subsequently 'false' re-clearing event. This is consistent with the timing in which for which such parcels of land are identified as sustained regrowth and allocated to *land converted to forest land* and ensures a more reliable time series of territorial forest areas.

Showing the changes in the year of observation allows for greater transparency, and for the tables in this appendix to be a more reliable comparison with other independently-produced datasets on forest change observations. Tables A5.6.12.6–15 provide disaggregated information on areas of forest clearing and regrowth in the observed year of transition, and the associated carbon emissions and removals, nationally and by state/territory across the time period from 1990 to 2022. The area of sustained regrowth, prepared on the inventory-basis, is also shown for comparison. Tables A5.6.12.16 to A5.6.12.23 provide a State/Territory level disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity (Table 6.3.4) from 1989-90 to 2021-22.

Tables A5.6.12.16 to A5.6.12.23 provide a State/Territory level disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity (Table 6.3.4) from 1989–90 to 2021–22.

Table A5.6.12.1a Annual areas of forest cleared over the period 1990 to 2022 (kha)

Year	National		NSW		NT		QLD		SA		TAS		VIC		WA		ACT	
	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing
1989–90	597.3	322.7	68.7	64.8	3.5	2.8	421.3	208.8	14.2	7.4	12.3	4.0	17.4	14.4	59.7	20.1	0.2	0.3
1990–91	481.6	353.2	53.4	76.2	3.1	3.0	339.3	216.4	10.3	7.7	14.5	7.7	13.8	17.9	47.1	23.9	0.2	0.5
1991–92	379.4	393.1	41.0	83.8	4.3	4.8	281.6	248.6	7.3	9.1	6.7	7.1	10.9	19.9	27.4	19.3	0.1	0.5
1992–93	269.4	313.6	26.7	56.5	1.6	2.9	201.9	210.6	4.6	6.3	5.6	5.1	7.2	16.1	21.7	15.9	0.1	0.2
1993–94	274.4	337.2	27.6	58.7	1.5	3.2	207.7	228.8	3.8	6.0	4.8	4.3	6.2	19.2	22.6	16.8	0.1	0.2
1994–95	219.6	259.5	20.3	48.9	1.3	3.0	165.1	168.4	3.2	5.0	4.9	4.1	5.5	14.9	19.3	15.0	0.1	0.2
1995–96	224.7	294.1	18.4	57.4	2.1	3.9	174.0	193.0	2.8	5.5	3.9	3.6	5.7	14.1	17.8	16.3	0.1	0.3
1996–97	223.2	286.1	18.7	56.1	2.1	4.2	171.5	185.9	2.9	5.5	4.3	4.2	5.9	14.0	17.8	15.9	0.1	0.3
1997–98	226.1	302.8	17.6	55.7	1.4	3.1	180.0	207.4	2.7	5.9	3.8	3.7	5.6	13.0	14.9	13.8	0.1	0.3
1998–99	263.4	379.8	20.3	73.6	1.3	3.0	216.3	263.0	2.9	7.8	3.4	4.1	5.9	14.6	13.2	13.4	0.1	0.3
1999–00	271.2	347.2	18.0	59.9	1.1	3.1	228.5	247.1	2.6	7.3	3.2	3.2	4.7	11.6	13.0	14.7	0.1	0.3
2000–01	315.1	400.8	18.6	63.1	1.4	4.2	269.7	289.6	3.4	9.2	3.4	3.1	4.4	9.7	14.3	21.5	0.0	0.4
2001–02	283.0	357.0	16.7	54.4	1.2	4.0	232.8	251.5	3.2	8.9	3.2	3.2	11.5	13.4	14.3	21.0	0.1	0.5
2002–03	227.2	371.7	15.9	61.5	1.2	3.5	159.9	236.2	3.0	9.8	3.9	6.6	26.5	27.7	16.6	25.6	0.2	0.9
2003–04	236.6	400.1	18.0	68.2	1.1	3.5	175.9	254.4	3.4	12.2	4.3	6.4	17.0	27.1	16.7	27.4	0.2	0.9
2004–05	294.8	568.4	21.3	93.4	2.3	7.1	235.9	368.5	3.9	17.8	5.3	8.0	7.7	35.3	18.4	37.3	0.1	0.9
2005–06	248.4	537.5	18.3	105.8	1.8	8.7	189.8	307.0	4.3	18.8	4.6	7.9	10.2	43.7	19.5	44.8	0.1	0.9
2006–07	209.1	499.6	17.4	102.0	2.0	6.7	155.4	295.4	4.0	15.2	4.5	7.8	7.2	30.8	18.6	40.9	0.1	0.8
2007–08	146.0	391.8	12.2	68.1	1.6	4.9	105.3	238.7	2.3	9.8	4.7	10.7	6.2	24.9	13.6	34.3	0.0	0.3
2008–09	111.7	355.0	10.6	74.6	1.1	4.8	72.9	193.0	2.3	10.2	4.3	8.5	8.3	29.2	12.2	33.8	0.0	0.8
2009–10	90.0	341.1	10.0	81.5	0.9	5.1	52.8	169.3	2.2	11.9	4.7	9.4	6.1	28.0	13.3	35.4	0.0	0.5
2010–11	75.3	319.7	10.1	81.8	0.7	3.3	44.2	167.4	1.8	12.1	3.7	7.6	2.9	17.5	12.0	29.7	0.0	0.4
2011–12	60.8	333.3	10.0	79.0	0.6	4.3	37.9	193.3	1.7	12.7	1.5	4.9	1.4	13.9	7.6	25.0	0.0	0.2
2012–13	63.0	434.0	9.5	79.9	0.8	5.6	40.1	277.8	2.1	16.5	1.6	5.1	1.6	22.7	7.2	26.2	0.0	0.2
2013–14	63.2	394.5	9.4	63.3	0.9	5.6	39.0	249.3	2.3	17.6	1.9	5.3	2.1	26.4	7.6	26.9	0.0	0.1

Year	National		NSW		NT		QLD		SA		TAS		VIC		WA		ACT	
	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing	Primary Conversion	Re-clearing
2014–15	64.5	377.0	9.2	52.4	1.1	5.6	40.3	251.8	1.5	13.3	1.6	5.8	2.0	20.7	8.8	27.4	0.0	0.1
2015–16	68.8	418.8	10.8	54.8	1.5	9.0	43.3	295.6	0.7	9.2	1.4	5.6	1.4	16.4	9.7	28.1	0.0	0.1
2016–17	62.4	406.9	13.6	64.9	0.7	4.3	40.8	289.5	0.7	8.0	1.1	5.2	1.0	14.1	4.4	20.7	0.0	0.1
2017–18	53.5	390.7	14.3	72.7	0.5	3.4	32.3	268.3	0.7	7.9	1.1	4.9	0.8	14.0	3.9	19.3	0.0	0.1
2018–19	39.8	306.7	12.7	61.1	0.6	3.3	21.7	202.8	0.4	6.8	0.9	3.6	0.7	13.3	2.9	15.6	0.0	0.1
2019–20	35.1	281.4	11.2	51.7	0.5	4.7	18.7	182.8	0.6	8.6	0.7	4.0	0.8	14.3	2.5	15.2	0.0	0.2
2020–21	31.7	288.6	8.5	44.3	0.5	3.4	17.0	197.5	0.7	6.9	0.9	5.5	1.0	14.9	3.0	15.9	0.0	0.2
2021–22	21.6	164.5	7.8	32.8	0.4	2.4	9.0	98.6	0.4	4.6	0.8	4.6	0.7	9.4	2.5	12.0	0.0	0.1

Table A5.6.12.1b Annual areas of identified regrowth and resultant net clearing of forest over the period 1990 to 2021 (kha)

Year	National		NSW		NT		QLD		SA		TAS		VIC		WA		ACT	
	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing
1989–90	235.9	684.1	46.7	86.8	4.8	1.5	145.7	484.4	5.4	16.2	3.9	12.4	9.1	22.8	20.1	59.7	0.2	0.3
1990–91	254.5	580.3	55.8	73.8	3.6	2.5	149.7	406.1	6.6	11.3	5.7	16.5	10.5	21.1	22.4	48.6	0.2	0.4
1991–92	272.5	500.0	66.1	58.8	5.8	3.3	149.7	380.4	7.0	9.4	4.7	9.1	13.8	17.0	25.2	21.5	0.2	0.5
1992–93	234.3	348.7	52.4	30.9	3.1	1.5	136.6	275.9	9.2	1.7	3.9	6.8	12.8	10.5	16.1	21.5	0.2	0.0
1993–94	256.8	354.8	54.7	31.6	3.5	1.2	151.2	285.4	13.1	-3.3	4.3	4.9	13.7	11.7	16.0	23.4	0.2	0.0
1994–95	193.3	285.9	40.7	28.4	3.7	0.7	111.0	222.6	10.2	-2.1	4.1	4.9	9.3	11.2	14.1	20.2	0.2	0.0
1995–96	190.7	328.1	38.9	37.0	4.3	1.7	113.9	253.1	7.8	0.5	2.9	4.5	7.9	11.9	14.9	19.2	0.1	0.2
1996–97	185.8	323.5	38.4	36.3	4.7	1.6	108.8	248.6	8.0	0.3	3.3	5.3	7.9	12.1	14.6	19.1	0.1	0.2
1997–98	195.6	333.4	39.1	34.1	5.1	-0.6	113.0	274.3	6.7	1.9	3.1	4.5	9.5	9.1	18.8	9.9	0.1	0.2
1998–99	251.8	391.3	52.8	41.1	6.2	-1.9	134.8	344.5	6.5	4.2	6.3	1.1	15.4	5.1	29.5	-2.8	0.4	0.0
1999–00	200.6	417.9	44.6	33.3	4.6	-0.3	101.2	374.4	6.3	3.6	5.2	1.2	13.0	3.3	25.4	2.3	0.3	0.1
2000–01	211.8	504.1	50.0	31.7	4.2	1.4	103.4	455.8	9.8	2.8	5.4	1.2	13.5	0.5	25.4	10.4	0.2	0.2

Year	National		NSW		NT		QLD		SA		TAS		VIC		WA		ACT	
	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing	Identified regrowth	Net forest clearing
2001–02	207.3	432.7	50.0	21.1	3.9	1.4	106.3	378.0	8.6	3.5	4.8	1.6	11.7	13.2	21.8	13.5	0.2	0.4
2002–03	249.9	349.0	70.4	7.1	5.6	-1.0	124.9	271.2	8.5	4.2	5.8	4.7	12.8	41.4	21.7	20.5	0.2	0.9
2003–04	263.7	373.1	74.9	11.3	5.8	-1.2	129.8	300.4	9.7	5.9	6.4	4.4	14.7	29.4	22.3	21.8	0.2	0.9
2004–05	337.9	525.4	89.4	25.3	6.2	3.2	175.7	428.6	12.7	9.0	9.5	3.8	18.8	24.2	25.3	30.4	0.2	0.9
2005–06	328.1	457.8	81.3	42.7	5.8	4.7	173.2	323.5	11.9	11.2	10.7	1.8	18.8	35.1	26.2	38.1	0.2	0.8
2006–07	345.6	363.1	79.6	39.7	5.7	2.9	186.2	264.7	11.6	7.6	6.9	5.4	24.5	13.5	30.7	28.8	0.4	0.6
2007–08	454.0	83.8	93.1	-12.8	6.1	0.4	271.6	72.4	14.9	-2.8	7.0	8.4	29.3	1.8	31.4	16.6	0.7	-0.4
2008–09	521.3	-54.7	103.0	-17.8	5.2	0.6	327.5	-61.6	20.5	-8.0	7.2	5.7	26.2	11.3	31.4	14.6	0.2	0.6
2009–10	471.9	-40.7	95.4	-3.8	5.2	0.8	279.9	-57.8	22.8	-8.7	8.2	5.8	29.5	4.6	30.6	18.1	0.3	0.3
2010–11	451.9	-56.8	77.0	14.9	5.9	-1.8	257.6	-46.0	24.5	-10.6	9.8	1.4	42.9	-22.5	34.0	7.7	0.2	0.2
2011–12	527.8	-133.8	71.6	17.4	4.6	0.3	336.5	-105.3	25.5	-11.1	10.0	-3.6	39.0	-23.7	40.4	-7.7	0.3	-0.1
2012–13	517.9	-21.0	82.3	7.1	3.6	2.7	315.6	2.4	22.4	-3.9	10.1	-3.3	31.6	-7.3	51.8	-18.4	0.5	-0.3
2013–14	564.3	-106.6	80.7	-8.0	4.5	2.0	363.0	-74.7	17.6	2.2	9.6	-2.3	32.1	-3.6	56.3	-21.9	0.6	-0.5
2014–15	514.9	-73.4	81.1	-19.5	4.9	1.7	335.6	-43.5	17.6	-2.9	7.7	-0.3	30.4	-7.7	36.8	-0.6	0.7	-0.6
2015–16	479.1	8.5	72.7	-7.0	4.5	6.0	319.4	19.5	19.2	-9.3	5.7	1.3	25.6	-7.8	31.5	6.2	0.5	-0.4
2016–17	312.8	156.4	43.2	35.3	3.7	1.2	206.2	124.2	13.5	-4.8	4.9	1.5	15.9	-0.9	25.2	-0.1	0.2	0.0
2017–18	248.3	196.0	29.2	57.7	4.8	-0.9	165.5	135.1	10.5	-1.9	3.8	2.1	12.3	2.5	21.9	1.3	0.1	0.0
2018–19	231.2	115.3	26.8	47.0	3.4	0.6	160.1	64.5	8.8	-1.7	3.9	0.6	10.7	3.3	17.4	1.0	0.1	0.0
2019–20	263.0	53.5	40.5	22.3	3.0	2.3	168.8	32.7	8.8	0.4	4.6	0.2	13.6	1.6	23.6	-5.9	0.1	0.0
2020–21	400.7	-80.4	77.1	-24.2	3.6	0.3	257.7	-43.2	11.3	-3.7	3.9	2.5	15.6	0.4	31.4	-12.5	0.2	0.0
2021–22	436.7	-250.6	86.3	-45.7	2.5	0.4	287.9	-180.3	13.8	-8.8	4.3	1.1	16.5	-6.4	25.2	-10.7	0.2	-0.1

Table A5.6.12.2 Activity in ABARES Land Use regions, 5 years to June 2022 (kha)

	2017–18			2018–19			2019–20			2020–21			2021–22		
	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth
1 Conservation and natural environments															
1.1 Nature conservation	0.5	3.8	3.8	0.5	3.0	3.4	0.5	3.3	4.5	0.3	2.9	7.1	0.2	2.2	7.6
1.2 Managed resource protection	0.8	1.7	2.4	1.9	1.9	2.5	1.6	1.7	2.3	1.2	1.3	2.5	1.5	1.0	2.9
1.3 Other minimal use	7.8	19.9	19.7	6.1	15.8	16.2	6.0	15.7	21.3	5.9	15.0	30.8	4.1	10.0	29.2
2 Production from relatively natural environments															
2.1 Grazing native vegetation	39.3	300.2	177.3	26.7	226.9	168.9	22.7	203.6	184.7	20.2	212.3	293.7	12.7	112.4	330.8
2.2 Production native forests	1.0	4.1	6.6	0.7	3.9	6.3	0.5	3.9	9.0	0.5	3.5	12.3	0.4	2.4	12.2
3 Production from dryland agriculture and plantations															
3.1 Plantation forests	0.4	6.0	4.0	0.5	6.1	3.0	0.5	6.5	3.4	0.5	5.6	4.0	0.3	4.3	3.4
3.2 Grazing modified pastures	0.8	16.6	13.1	0.7	15.3	10.5	0.7	15.5	12.0	0.8	14.6	15.0	0.5	9.5	15.4
3.3 Cropping	0.5	10.6	10.9	0.3	8.2	8.0	0.3	7.6	9.0	0.3	8.5	12.3	0.2	5.7	12.6
3.4 Perennial horticulture	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1
3.5 Seasonal horticulture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.6 Land in transition	0.1	0.5	0.5	0.0	0.3	0.4	0.0	0.5	0.4	0.0	0.3	0.5	0.0	0.4	0.5
4 Production from irrigated agriculture and plantations															
4.0 Production from irrigated agriculture and plantations	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.1 Irrigated plantation forests	0.0	0.1	0.3	0.0	0.2	0.3	0.0	0.1	0.2	0.0	0.2	0.2	0.0	0.1	0.1
4.2 Grazing irrigated modified pastures	0.0	0.5	0.7	0.0	0.5	0.4	0.0	0.5	0.4	0.0	0.5	0.3	0.0	0.5	0.4
4.3 Irrigated cropping	0.0	3.8	2.5	0.0	3.8	1.7	0.0	2.1	1.4	0.0	1.6	1.4	0.0	1.1	1.4
4.4 Irrigated perennial horticulture	0.0	0.2	0.2	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.1	0.0	0.1	0.1
4.5 Irrigated seasonal horticulture	0.0	0.3	0.3	0.0	0.3	0.3	0.0	0.3	0.2	0.0	0.3	0.2	0.0	0.2	0.2
4.6 Irrigated land in transition	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.1

	2017–18			2018–19			2019–20			2020–21			2021–22		
	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth
5 Intensive uses															
5.0 Intensive uses	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.1 Intensive horticulture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
5.2 Intensive animal production	0.0	0.2	0.3	0.0	0.3	0.2	0.0	0.3	0.2	0.0	0.3	0.2	0.0	0.2	0.2
5.3 Manufacturing and industrial	0.0	0.3	0.2	0.0	0.2	0.2	0.0	0.2	0.2	0.0	0.2	0.2	0.0	0.1	0.1
5.4 Residential and farm infrastructure	0.8	8.3	5.5	0.7	7.6	4.9	0.6	6.6	5.4	0.6	6.7	6.3	0.4	4.0	5.9
5.5 Services	0.1	1.4	1.2	0.1	1.2	1.0	0.1	1.2	1.0	0.1	1.2	1.2	0.1	0.8	1.0
5.6 Utilities	0.0	0.2	0.2	0.0	0.1	0.2	0.0	0.2	0.2	0.0	0.2	0.2	0.0	0.1	0.1
5.7 Transport and communication	0.2	2.4	2.3	0.1	2.0	1.9	0.1	2.2	1.9	0.1	2.3	2.1	0.1	1.4	2.3
5.8 Mining	0.1	1.4	5.3	0.2	1.4	4.5	0.1	1.8	3.5	0.1	2.2	2.8	0.1	1.3	2.9
5.9 Waste treatment and disposal	0.0	0.2	0.1	0.0	0.2	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1
6 Water															
6.0 Not elsewhere defined	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.1 Lake	0.0	0.3	0.3	0.0	0.2	0.2	0.0	0.2	0.3	0.0	0.2	0.3	0.0	0.2	0.4
6.2 Reservoir/dam	0.0	1.8	1.8	0.0	1.6	1.3	0.0	1.5	1.2	0.0	1.7	1.4	0.0	1.4	1.1
6.3 River	0.1	0.7	0.6	0.1	0.6	0.5	0.1	0.6	0.5	0.1	0.7	0.6	0.0	0.5	0.5
6.4 Channel/aqueduct	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0
6.5 Marsh/wetland	0.2	1.7	1.3	0.1	1.4	1.1	0.1	1.3	1.1	0.2	1.4	1.5	0.1	0.8	1.4
6.6 Estuary/coastal waters	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Undefined	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
All lands	**52.7**	**387.5**	**261.9**	**38.8**	**303.9**	**238.4**	**34.2**	**278.0**	**264.8**	**31.0**	**284.5**	**397.6**	**21.0**	**161.0**	**433.0**

Table A5.6.12.3 Activity in BoM River regions, 5 years to June 2022 (kha)

	2017–18			2018–19			2019–20			2020–21			2021–22		
	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth
Gulf Of Carpentaria	1.9	5.3	3.6	2.0	3.9	4.8	1.7	3.5	6.2	1.4	4.5	5.2	1.7	3.0	5.9
Indian Ocean	0.2	1.3	1.5	0.1	0.9	1.2	0.1	0.9	1.9	0.1	1.0	2.5	0.1	0.8	1.7
Lake Eyre	1.7	27.7	9.1	0.8	15.8	14.9	1.1	19.8	16.4	1.1	19.6	19.9	0.7	11.5	21.1
Murray-Darling	30.3	169.5	65.5	21.5	122.4	62.7	18.0	100.6	94.7	14.6	92.4	168.9	9.9	59.8	214.9
North East Coast	10.5	125.1	128.1	7.2	109.7	109.0	6.4	100.8	93.5	6.3	116.1	138.1	3.0	51.2	131.9
North Western Plateau	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Australian Gulf	0.1	1.4	3.4	0.2	2.7	2.5	0.2	3.8	2.3	0.1	1.6	3.7	0.1	1.3	4.0
South East Coast	3.2	31.4	18.6	2.9	27.4	18.6	3.3	26.9	20.0	3.3	26.6	22.8	2.0	15.8	21.9
South West Coast	2.7	14.7	17.9	1.9	11.9	13.3	1.8	11.4	19.0	2.0	12.4	26.2	1.5	9.2	20.8
South Western Plateau	1.0	3.5	5.6	0.8	2.9	4.7	0.6	3.1	4.1	0.9	2.5	4.1	0.9	1.9	4.7
Tasmania	1.1	4.8	3.9	0.9	3.6	4.0	0.7	3.9	4.6	0.9	5.5	3.9	0.8	4.5	4.2
Timor Sea	0.2	2.6	4.3	0.3	2.4	2.4	0.2	3.2	1.9	0.3	2.1	2.0	0.2	1.8	1.6
Undefined	0.0	0.2	0.3	0.0	0.2	0.2	0.0	0.2	0.3	0.0	0.2	0.3	0.0	0.1	0.3
All lands	**52.7**	**387.5**	**261.9**	**38.8**	**303.9**	**238.4**	**34.2**	**278.0**	**264.8**	**31.0**	**284.5**	**397.6**	**21.0**	**161.0**	**433.0**

Table A5.6.12.4 Activity in NRM regions, 5 years to June 2022 (kha)

	2017–18			2018–19			2019–20			2020–21			2021–22		
	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth
ACT	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.2	0.1	0.0	0.2	0.2	0.0	0.1	0.2
Adelaide and Mount Lofty Ranges	0.0	0.2	0.3	0.0	0.1	0.3	0.0	0.1	0.3	0.0	0.1	0.4	0.0	0.1	0.4
Alinytjara Wilurara	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Maranoa Balonneand Border Rivers	2.6	33.2	18.3	1.7	24.1	16.2	1.5	21.7	17.6	1.6	23.7	31.4	1.0	14.6	42.9
Burdekin	4.2	36.8	21.2	1.8	19.7	26.2	1.8	17.7	26.1	1.7	20.6	53.5	0.5	6.8	42.4
Burnett Mary	2.0	16.4	5.8	1.4	9.4	3.8	0.8	5.3	8.5	0.9	6.0	9.5	0.2	3.0	11.8
Cape York	1.3	2.4	1.6	1.9	1.9	2.4	1.5	1.9	3.0	1.2	1.2	2.7	1.6	0.9	2.7
Central Tablelands	0.3	4.5	2.4	0.2	3.2	2.3	0.3	3.9	2.6	0.3	4.6	3.3	0.2	2.8	3.2
Central West	3.2	11.8	6.2	2.6	10.5	3.9	1.7	7.3	6.2	1.2	6.2	14.8	1.1	5.2	15.7
Condamine	0.2	3.3	2.4	0.1	2.4	1.6	0.2	1.6	2.2	0.1	1.7	3.4	0.1	1.0	3.6
Co-operative Management Area	0.2	0.4	0.1	0.0	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1
Corangamite	0.1	1.3	1.4	0.1	0.9	1.0	0.1	1.2	0.9	0.1	1.7	0.8	0.1	1.0	0.6
Desert Channels	1.4	22.6	8.4	0.7	13.6	11.4	1.0	18.2	10.4	0.9	17.7	15.0	0.6	10.5	16.6
East Gippsland	0.1	1.7	0.5	0.1	1.2	0.8	0.1	1.5	1.1	0.1	0.8	1.8	0.0	0.5	1.4
Eyre Peninsula	0.1	1.5	4.8	0.0	1.2	3.5	0.0	1.3	2.9	0.0	1.3	3.3	0.0	1.2	4.0
Fitzroy	2.5	60.8	93.2	2.4	67.6	71.0	2.5	68.8	52.4	2.7	82.6	66.1	1.5	37.2	70.0
Glenelg Hopkins	0.1	1.7	1.6	0.0	2.1	0.6	0.1	1.9	0.7	0.1	1.9	0.8	0.1	1.0	1.0
Goulburn Broken	0.1	0.8	1.2	0.1	0.9	0.8	0.0	0.7	0.8	0.1	0.9	0.6	0.0	0.7	0.7
Greater Sydney	0.2	1.7	0.7	0.1	1.4	1.0	0.1	1.3	0.8	0.2	1.4	0.7	0.1	1.1	0.6
El u nter	0.5	4.6	2.6	0.4	4.0	3.1	0.3	3.1	3.8	0.3	3.2	3.8	0.3	2.1	3.1
Kangaroo Island	0.0	0.3	0.4	0.1	1.6	0.4	0.1	2.6	0.4	0.1	0.5	1.2	0.0	0.3	1.2
Mackay Whitsunday	0.3	4.2	3.3	0.4	6.2	4.3	0.3	3.7	2.1	0.4	3.3	3.4	0.3	1.9	2.7
Mallee	0.0	0.8	2.7	0.0	0.8	3.1	0.0	0.9	4.8	0.0	1.1	6.1	0.0	1.0	7.0
Murray	0.1	1.8	2.2	0.3	3.0	1.5	0.5	3.7	1.7	0.1	1.9	2.9	0.1	2.1	3.1

	2017–18			2018–19			2019–20			2020–21			2021–22		
	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth
North NRM Region	0.5	1.9	1.8	0.3	1.4	1.9	0.3	1.6	1.9	0.5	2.9	1.1	0.4	2.5	1.1
North Central	0.1	1.8	1.7	0.0	1.5	1.3	0.1	2.0	1.4	0.1	2.5	1.6	0.1	1.4	1.7
North Coast	0.7	3.3	4.8	0.5	3.6	4.4	0.5	3.2	4.0	0.5	3.2	3.3	0.3	2.4	2.2
North East	0.1	1.0	1.4	0.1	1.5	1.2	0.1	1.9	1.5	0.1	1.0	1.7	0.0	0.7	1.6
North West NRM Region	0.3	1.6	1.0	0.3	1.2	1.1	0.2	1.2	1.2	0.2	1.3	1.4	0.2	1.1	1.3
North West NSW	1.1	6.3	2.4	0.8	4.4	1.4	0.4	3.2	2.8	0.5	3.8	8.2	0.5	3.4	9.8
Northern and Yorke	0.0	0.4	0.9	0.0	0.3	0.6	0.0	0.4	0.6	0.0	0.4	0.9	0.0	0.3	1.0
Northern Gulf	0.5	2.1	1.2	0.2	1.7	1.8	0.3	1.3	2.4	0.2	2.2	2.1	0.1	0.8	2.2
Northern Tablelands	0.9	4.9	2.5	1.2	5.9	2.2	1.3	6.1	2.6	0.7	3.9	4.2	0.4	2.2	4.2
Northern Territory	0.3	2.4	4.3	0.4	2.3	2.5	0.3	3.2	2.1	0.4	2.4	2.1	0.3	1.7	1.7
Port Phillip and Western Port	0.1	1.9	0.8	0.1	1.7	0.9	0.1	1.7	0.9	0.2	2.1	0.6	0.1	1.2	0.6
Riverina	0.2	2.1	1.3	0.3	2.3	1.1	0.3	2.3	1.6	0.1	1.4	2.7	0.1	1.1	2.7
South NRM Region	0.3	1.3	1.1	0.2	1.1	1.1	0.2	1.2	1.5	0.2	1.3	1.6	0.2	0.9	1.9
South Australian Arid Lands	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1
South Australian Murray Darling Basin	0.3	3.1	2.1	0.1	1.5	2.4	0.1	1.3	2.8	0.1	1.4	3.3	0.1	1.1	4.3
South East	0.1	1.4	1.2	0.1	1.3	1.2	0.3	2.1	1.0	0.4	2.3	0.8	0.1	0.8	1.1
South East NSW	0.7	10.4	4.0	0.8	8.2	3.9	0.9	7.9	5.1	0.8	7.1	10.1	0.4	3.5	11.6
South East Queensland	1.0	4.9	1.8	0.8	4.4	1.3	0.6	3.4	1.7	0.4	2.1	2.9	0.3	1.4	2.7
South West Queensland	15.5	78.3	15.2	9.3	48.3	23.9	7.5	36.4	41.7	6.3	32.5	64.1	2.4	17.2	85.9
Southern Gulf	0.1	1.0	1.2	0.0	0.7	1.2	0.0	0.7	1.0	0.0	0.8	0.8	0.0	1.0	1.5
Torres Strait	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West Gippsland	0.1	1.7	0.8	0.1	1.6	0.9	0.1	1.2	1.1	0.2	1.4	1.0	0.1	0.9	0.9
Western	6.4	21.3	3.1	5.3	14.6	3.5	4.8	9.7	10.2	3.8	7.6	23.6	4.2	6.8	30.3
Wet Tropics	0.3	1.2	2.2	0.3	1.8	1.5	0.2	1.2	2.0	0.2	1.1	1.9	0.1	0.7	1.6
Wimmera	0.0	1.0	1.1	0.0	0.9	0.6	0.1	1.0	0.6	0.1	1.3	0.6	0.0	0.8	0.8

	2017–18			2018–19			2019–20			2020–21			2021–22		
	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth	Primary Conversion	Re-clearing	Identified regrowth
Northern Agricultural Region	0.6	3.6	5.9	0.4	2.6	4.3	0.3	3.5	6.1	0.4	4.5	8.6	0.4	3.4	6.5
Peel-Harvey Region	0.2	1.0	0.9	0.2	0.8	0.5	0.2	0.6	0.7	0.1	0.6	0.9	0.1	0.4	0.6
Swan Region	0.3	1.2	1.3	0.2	0.9	1.3	0.2	1.1	2.2	0.3	1.3	2.6	0.2	1.0	1.3
Rangelands Region	0.9	2.4	2.0	0.6	1.8	2.2	0.5	2.0	2.0	0.8	1.5	2.2	0.9	1.2	2.0
South Coast Region	0.9	5.4	5.4	0.7	4.6	4.5	0.6	3.7	5.6	0.5	3.2	7.3	0.2	2.2	6.9
South West Region	0.3	2.4	3.1	0.3	2.6	1.5	0.2	2.0	2.2	0.2	2.2	2.5	0.1	2.2	1.2
Avon River Basin	0.6	2.8	3.6	0.5	2.0	2.9	0.5	2.1	4.7	0.5	2.2	6.9	0.4	1.2	6.0
All lands	**52.7**	**387.5**	**261.9**	**38.8**	**303.9**	**238.4**	**34.2**	**278.0**	**264.8**	**31.0**	**284.5**	**397.6**	**21.0**	**161.0**	**433.0**

Table A5.6.12.5 Annual areas of sparse woody vegetation gains and losses over the period 1990 to 2022 (kha)

	National		NSW		NT		QLD		SA		TAS		VIC		WA		ACT	
Year	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses
1989–90	1,065	2,024.5	103.3	169.3	205.4	314.5	521	897.4	32.1	66.6	2.7	6.4	5.4	20	194.8	550.1	0.1	0.2
1990–91	1,118.6	1,837.2	108.9	151.4	222.3	310.6	485.7	740.3	41.4	68.3	2.7	6.8	5.9	13.5	251.6	546	0.1	0.2
1991–92	1,084.2	1,827.4	91.9	125.7	237.4	410.7	440.8	774.3	47.7	50.3	1	5.1	5	13	260.2	448.2	0.1	0.1
1992–93	933.8	921.2	65.6	83.5	193.9	188.5	369.9	403.9	51.1	27	1.1	3.5	5.7	7.7	246.4	207.2	0.2	0.1
1993–94	994.6	934.2	68.7	86.5	204.1	192.7	399	409.9	57.1	25.5	1.3	1.7	6.5	5.3	257.5	212.5	0.2	0.1
1994–95	854.5	675.4	51.4	72.7	179.3	130.6	325	242.6	44.3	27.2	1.3	1.8	4.1	5.5	249	195	0.2	0.1
1995–96	913.4	692.3	46.3	81.9	214.6	128.7	343.6	241.9	36	31.4	0.9	1.6	2.7	5.9	269.1	200.9	0.1	0.1
1996–97	927.9	704.3	47	82.8	224.2	133.7	33	240.3	37.3	32.4	1	1.8	2.8	6.2	278.4	207.1	0.1	0.1
1997–98	917.1	737.9	67.3	68.4	186.7	158.5	344.2	271.8	36.5	33.6	0.9	1.6	4	5.3	277.3	198.7	0.1	0.1
1998–99	1,345.3	1,039.7	100.3	65.3	276.1	252.1	559	415	51.1	54.7	1.3	1.8	6.2	5.1	350.9	245.6	0.3	0.1
1999–00	1,037.7	983.5	89.1	58.9	246	235.3	386.7	385	47.5	45.2	1.3	1.2	6.6	4.3	260.2	253.5	0.3	0.1
2000–01	983.1	1,084	93.5	65.8	248.7	251.4	330.4	432.8	51.6	42.3	1.6	1	9.1	4	247.9	286.6	0.3	0.1
2001–02	916.1	1,059	84.8	70.5	237.6	246.9	323.4	418.8	45.7	39.2	1.4	1.1	8.9	4.1	214.1	278.3	0.2	0.1
2002–03	1,004.3	1,147.9	91.1	90.5	206.5	306.9	417	369.3	43.1	38.8	1.5	2.3	10.4	5.3	234.4	334.5	0.2	0.2

Year	National		NSW		NT		QLD		SA		TAS		VIC		WA		ACT	
	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses
2003–04	1,087.8	1,238.2	118.6	103.6	214.0	322.1	415.2	413.6	38.9	57.8	1.4	2.4	10.2	8.7	289.4	329.8	0.2	0.3
2004–05	1,431.5	1,796.9	156.3	131.8	293.1	491.1	468.5	671.0	41.5	81.8	1.6	2.8	11.0	14.9	459.1	403.1	0.4	0.3
2005–06	1,827.9	1,656.4	146.0	156.9	374.6	392.7	630.6	637.9	55.0	74.9	2.1	2.2	10.4	16.8	609.0	374.6	0.3	0.4
2006–07	2,082.8	1,733.4	180.1	176.7	475.5	386.0	655.3	708.2	71.0	70.4	2.6	1.8	11.7	12.4	686.6	377.3	0.1	0.5
2007–08	2,258.8	1,379.4	206.7	122.1	462.8	307.8	825.4	486.9	79.3	66.3	2.9	2.5	12.4	12.0	669.1	381.4	0.1	0.3
2008–09	2,282.2	1,255.1	231.8	158.3	532.7	231.4	744.0	442.0	94.2	48.6	5.5	2.0	16.6	13.2	657.3	359.1	0.1	0.5
2009–10	2,755.3	1,360.1	218.5	221.1	733.6	251.2	915.7	444.6	103.3	51.4	6.4	3.6	20.4	11.6	757.0	376.3	0.4	0.4
2010–11	2,807.0	1,493.2	224.6	179.5	625.2	320.0	967.2	486.7	115.9	64.5	4.2	5.4	31.8	9.2	837.4	427.7	0.6	0.3
2011–12	2,544.6	1,880.7	258.7	160.8	499.0	512.3	814.0	629.4	114.0	85.0	5.6	3.7	43.6	8.8	808.7	480.5	1.0	0.2
2012–13	2,330.8	2,787.8	328.4	176.4	346.1	727.9	665.7	1,202.3	111.1	115.5	6.7	3.8	35.8	16.3	835.6	545.4	1.4	0.2
2013–14	2,382.1	2,465.1	303.4	173.7	410.7	602.4	626.8	958.3	111.6	141.2	6.1	5.0	38.6	19.3	883.7	565.1	1.3	0.2
2014–15	2,026.7	2,606.8	250.1	194.6	387.1	888.3	531.0	811.2	120.6	127.9	6.0	4.5	34.7	23.5	696.4	556.4	1.0	0.3
2015–16	2,505.0	2,539.6	264.4	213.3	401.1	808.1	914.4	676.6	142.7	103.3	7.5	3.1	29.7	25.3	744.3	709.6	1.0	0.3
2016–17	2,323.1	2,185.9	249.0	180.4	511.2	487.0	662.9	681.7	143.5	92.4	10.1	1.7	38.2	21.4	706.9	721.1	1.3	0.1
2017–18	2,155.8	1,958.2	204.5	177.7	494.9	509.7	604.3	579.0	129.2	80.4	9.3	1.9	41.4	21.2	670.7	588.2	1.5	0.2
2018–19	1,925.3	1,652.9	118.5	167.2	485.6	488.4	609.2	443.3	89.8	73.4	4.9	3.7	24.9	20.5	591.4	456.1	0.9	0.4
2019–20	1,873.9	1,660.6	109.5	195.5	463.4	489.6	704.8	386.6	81.1	75.4	2.4	7.7	17.2	23.2	495.1	481.8	0.4	0.8
2020–21	2,292.9	1,883.7	180.0	226.3	485.5	643.7	888.9	371.7	110.0	82.5	2.0	9.3	16.1	24.6	610.1	524.3	0.2	1.2
2021–22	1,778.9	1,563.6	178.1	154.0	209.0	578.2	757.2	360.8	113.0	70.9	1.8	6.1	12.7	15.0	507.0	377.9	0.2	0.7

Table A5.6.12.6 UNFCCC Forest conversions – National annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1989–90	597.3	118.2	322.7	9.7	45.1	235.9	926.0	-4.0	684.1
1990–91	481.6	104.7	353.2	9.8	39.1	254.5	1067.8	-4.5	580.3
1991–92	379.4	71.8	393.1	9.2	38.2	272.5	1204.7	-5.2	500.0
1992–93	269.4	57.8	313.6	8.4	37.0	234.3	1374.4	-6.4	348.7
1993–94	274.4	48.7	337.2	8.5	26.6	256.8	1495.7	-5.8	354.8
1994–95	219.6	44.2	259.5	8.3	22.5	193.3	1655.6	-7.2	285.9
1995–96	224.7	36.6	294.1	7.1	22.8	190.7	1726.4	-8.7	328.1
1996–97	223.2	39.4	286.1	8.8	23.4	185.8	1798.9	-9.2	323.5
1997–98	226.1	37.0	302.8	9.3	19.4	195.6	1852.6	-10.3	333.4
1998–99	263.4	42.1	379.8	11.2	26.3	251.8	1873.7	-10.2	391.3
1999–00	271.2	43.4	347.2	12.9	18.3	200.6	1965.3	-11.0	417.9
2000–01	315.1	45.1	400.8	13.4	32.3	211.8	1971.0	-10.9	504.1
2001–02	283.0	47.5	357.0	15.4	27.3	207.3	2011.7	-10.3	432.7
2002–03	227.2	39.1	371.7	13.8	31.0	249.9	2035.5	-10.1	349.0
2003–04	236.6	37.7	400.1	15.2	23.0	263.7	2079.7	-10.9	373.1
2004–05	294.8	47.3	568.4	19.9	23.7	337.9	2029.9	-11.2	525.4
2005–06	248.4	46.6	537.5	21.1	39.1	328.1	2047.9	-10.1	457.8
2006–07	209.1	43.0	499.6	20.9	20.1	345.6	2052.6	-10.3	363.1
2007–08	146.0	31.3	391.8	14.9	27.3	454.0	2126.8	-11.7	83.8
2008–09	111.7	25.1	355.0	12.8	14.6	521.3	2330.2	-10.8	-54.7
2009–10	90.0	22.1	341.1	13.4	25.8	471.9	2601.4	-12.2	-40.7
2010–11	75.3	19.3	319.7	11.5	12.1	451.9	2832.8	-13.2	-56.8
2011–12	60.8	13.2	333.3	9.7	9.1	527.8	3039.0	-14.4	-133.8
2012–13	63.0	12.3	434.0	11.2	30.9	517.9	3251.9	-14.5	-21.0
2013–14	63.2	14.3	394.5	12.6	27.0	564.3	3473.8	-14.4	-106.6
2014–15	64.5	11.8	377.0	10.6	20.0	514.9	3751.8	-15.5	-73.4

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
2015–16	68.8	13.8	418.8	12.0	2.2	479.1	3943.1	-18.5	8.5
2016–17	62.4	12.0	406.9	12.0	26.1	312.8	4101.4	-18.6	156.4
2017–18	53.5	11.3	390.7	12.4	16.3	248.3	4103.2	-18.9	196.0
2018–19	39.8	8.9	306.7	11.0	7.4	231.2	4107.3	-16.8	115.3
2019–20	35.1	7.8	281.4	10.2	20.2	263.0	4113.9	-17.8	53.5
2020–21	31.7	7.4	288.6	10.4	2.8	400.7	4143.8	-22.6	-80.4
2021–22	21.6	5.9	164.5	8.6	-8.6	436.7	4410.5	-23.8	-250.6

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under Land converted to Forest for regrowth on previously cleared lands.

Table A5.6.12.7 UNFCCC Forest conversions – QLD annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth (a)	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1989–90	421.3	63.0	208.8	5.2	23.6	145.7	536.5	-1.6	484.4
1990–91	339.3	57.0	216.4	5.0	26.0	149.7	629.1	-1.7	406.1
1991–92	281.6	39.3	248.6	4.9	19.0	149.7	711.5	-1.9	380.4
1992–93	201.9	32.7	210.6	4.6	22.1	136.6	797.0	-2.5	275.9
1993–94	207.7	28.6	228.8	4.8	14.3	151.2	862.7	-2.2	285.4
1994–95	165.1	25.6	168.4	4.5	14.0	111.0	953.6	-2.9	222.6
1995–96	174.0	22.9	193.0	3.9	11.6	113.9	986.6	-3.4	253.1
1996–97	171.5	24.6	185.9	4.8	13.5	108.8	1026.5	-4.0	248.6
1997–98	180.0	23.2	207.4	5.1	12.3	113.0	1046.7	-4.5	274.3
1998–99	216.3	30.5	263.0	6.9	17.2	134.8	1041.5	-4.1	344.5

	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
Year	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1999–00	228.5	31.4	247.1	7.8	8.0	101.2	1066.7	-4.5	374.4
2000–01	269.7	33.0	289.6	8.5	23.1	103.4	1034.7	-4.1	455.8
2001–02	232.8	34.4	251.5	9.6	17.4	106.3	1025.8	-3.7	378.0
2002–03	159.9	24.0	236.2	7.7	22.5	124.9	1026.4	-3.3	271.2
2003–04	175.9	21.3	254.4	8.0	14.7	129.8	1030.8	-3.7	300.4
2004–05	235.9	29.5	368.5	10.6	14.0	175.7	969.7	-3.4	428.6
2005–06	189.8	27.8	307.0	10.4	22.0	173.2	972.0	-3.2	323.5
2006–07	155.4	24.1	295.4	9.3	15.5	186.2	959.3	-3.4	264.7
2007–08	105.3	18.0	238.7	7.3	15.1	271.6	981.1	-3.7	72.4
2008–09	72.9	12.2	193.0	5.5	10.5	327.5	1119.5	-3.2	-61.6
2009–10	52.8	9.2	169.3	4.8	14.1	279.9	1322.5	-3.6	-57.8
2010–11	44.2	7.4	167.4	4.0	9.2	257.6	1473.1	-3.7	-46.0
2011–12	37.9	6.1	193.3	4.0	2.5	336.5	1587.8	-4.8	-105.3
2012–13	40.1	5.8	277.8	4.7	22.2	315.6	1723.4	-4.7	2.4
2013–14	39.0	6.4	249.3	5.3	17.3	363.0	1851.4	-4.8	-74.7
2014–15	40.3	5.6	251.8	4.9	11.0	335.6	2022.9	-4.9	-43.5
2015–16	43.3	6.3	295.6	6.0	7.8	319.4	2129.0	-6.0	19.5
2016–17	40.8	6.3	289.5	6.4	12.8	206.2	2218.2	-5.8	124.2
2017–18	32.3	5.5	268.3	6.0	10.4	165.5	2206.9	-5.9	135.1
2018–19	21.7	4.2	202.8	5.4	4.8	160.1	2208.0	-5.2	64.5
2019–20	18.7	2.6	182.8	3.6	13.3	168.8	2220.6	-5.5	32.7
2020–21	17.0	3.2	197.5	4.8	5.1	257.7	2228.0	-7.8	-43.2
2021–22	9.0	1.8	98.6	3.1	-8.7	287.9	2404.2	-8.2	-180.3

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table A5.6.12.8 UNFCCC Forest conversions – NSW annual areas and related GHG emissions

Year	Annual Area of primary forest converted kha	Direct emissions from primary forest clearing Mt CO_2-e	Annual area of secondary forest converted kha	Direct emissions from secondary forest clearing Mt CO_2-e	Emissions from decay on previously cleared lands Mt CO_2-e	Annual area of identified regrowth kha	Total area of sustained regrowth (a) kha	Net emissions from the regrowing forest (negative values denote removals) Mt CO_2-e	Net clearing of forests (conversions less identified regrowth) kha
1989–90	68.7	26.7	64.8	2.9	7.9	46.7	175.6	-0.7	86.8
1990–91	53.4	20.0	76.2	2.7	3.9	55.8	199.6	-0.8	73.8
1991–92	41.0	15.8	83.8	2.7	8.7	66.1	226.3	-0.9	58.8
1992–93	26.7	11.5	56.5	2.2	3.6	52.4	271.6	-1.5	30.9
1993–94	27.6	10.2	58.7	2.4	4.4	54.7	302.4	-1.3	31.6
1994–95	20.3	9.0	48.9	2.4	2.3	40.7	338.2	-1.6	28.4
1995–96	18.4	5.8	57.4	1.8	2.9	38.9	354.4	-2.1	37.0
1996–97	18.7	6.2	56.1	2.3	1.9	38.4	369.7	-2.1	36.3
1997–98	17.6	5.9	55.7	2.5	1.9	39.1	382.9	-2.4	34.1
1998–99	20.3	5.8	73.6	2.9	2.6	52.8	385.9	-2.5	41.1
1999–00	18.0	6.2	59.9	3.4	3.1	44.6	408.1	-2.6	33.3
2000–01	18.6	5.7	63.1	3.0	2.6	50.0	417.5	-2.7	31.7
2001–02	16.7	6.1	54.4	3.5	3.2	50.0	436.5	-2.4	21.1
2002–03	15.9	4.6	61.5	2.8	2.8	70.4	449.4	-2.7	7.1
2003–04	18.0	4.7	68.2	3.2	2.5	74.9	477.9	-3.0	11.3
2004–05	21.3	7.5	93.4	4.7	1.3	89.4	493.0	-3.0	25.3
2005–06	18.3	7.1	105.8	4.9	5.1	81.3	512.1	-2.7	42.7
2006–07	17.4	7.3	102.0	5.8	-1.4	79.6	522.0	-2.6	39.7
2007–08	12.2	4.7	68.1	3.6	5.0	93.1	553.2	-3.2	-12.8
2008–09	10.6	3.9	74.6	3.1	0.4	103.0	591.3	-3.3	-17.8
2009–10	10.0	3.4	81.5	3.3	2.4	95.4	634.2	-4.0	-3.8
2010–11	10.1	3.6	81.8	3.8	-0.2	77.0	670.4	-4.2	14.9
2011–12	10.0	3.3	79.0	3.5	2.9	71.6	689.5	-4.0	17.4
2012–13	9.5	3.4	79.9	4.1	1.3	82.3	702.9	-4.2	7.1
2013–14	9.4	3.5	63.3	4.0	5.3	80.7	738.1	-4.2	-8.0
2014–15	9.2	2.8	52.4	2.9	0.6	81.1	780.4	-4.4	-19.5

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
2015–16	10.8	2.7	54.8	2.6	-4.5	72.7	821.8	-5.8	-7.0
2016–17	13.6	3.2	64.9	3.0	5.5	43.2	846.3	-5.3	35.3
2017–18	14.3	3.9	72.7	4.0	4.3	29.2	836.8	-5.7	57.7
2018–19	12.7	3.2	61.1	3.6	0.0	26.8	821.3	-4.9	47.0
2019–20	11.2	3.8	51.7	4.2	0.7	40.5	808.8	-4.9	22.3
2020–21	8.5	2.7	44.3	3.2	-2.9	77.1	815.5	-6.4	-24.2
2021–22	7.8	2.4	32.8	3.0	-2.5	86.3	867.4	-6.8	-45.7

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table A5.6.12.9 UNFCCC Forest conversions – VIC annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1989–90	17.4	7.7	14.4	0.7	2.5	9.1	42.3	-0.2	22.8
1990–91	13.8	5.8	17.9	0.7	0.9	10.5	47.8	-0.3	21.1
1991–92	10.9	4.0	19.9	0.6	2.0	13.8	53.5	-0.3	17.0
1992–93	7.2	3.6	16.1	0.6	2.3	12.8	63.1	-0.3	10.5
1993–94	6.2	2.2	19.2	0.5	1.4	13.7	70.1	-0.3	11.7
1994–95	5.5	2.1	14.9	0.6	0.3	9.3	79.1	-0.5	11.2
1995–96	5.7	1.6	14.1	0.5	1.7	7.9	83.5	-0.5	11.9
1996–97	5.9	1.8	14.0	0.6	1.6	7.9	86.7	-0.6	12.1
1997–98	5.6	1.7	13.0	0.6	0.4	9.5	90.1	-0.6	9.1
1998–99	5.9	0.9	14.6	0.4	1.2	15.4	94.4	-0.7	5.1

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1999–00	4.7	0.8	11.6	0.5	0.8	13.0	105.4	-0.7	3.3
2000–01	4.4	1.5	9.7	0.6	0.9	13.5	114.3	-0.7	0.5
2001–02	11.5	1.7	13.4	0.7	1.2	11.7	121.8	-0.8	13.2
2002–03	26.5	4.5	27.7	1.3	1.6	12.8	120.1	-0.8	41.4
2003–04	17.0	5.2	27.1	1.6	1.0	14.7	119.4	-0.8	29.4
2004–05	7.7	2.8	35.3	1.8	2.4	18.8	115.2	-0.9	24.2
2005–06	10.2	4.5	43.7	2.7	2.4	18.8	109.3	-0.7	35.1
2006–07	7.2	3.9	30.8	2.4	0.7	24.5	109.9	-0.7	13.5
2007–08	6.2	2.3	24.9	1.4	2.6	29.3	118.4	-0.7	1.8
2008–09	8.3	3.5	29.2	1.6	1.3	26.2	127.9	-0.7	11.3
2009–10	6.1	3.9	28.0	2.4	1.4	29.5	134.8	-0.6	4.6
2010–11	2.9	1.4	17.5	1.0	1.0	42.9	152.8	-0.6	-22.5
2011–12	1.4	0.6	13.9	0.6	0.8	39.0	187.1	-0.8	-23.7
2012–13	1.6	0.6	22.7	0.7	0.4	31.6	212.1	-1.1	-7.3
2013–14	2.1	0.8	26.4	1.0	1.5	32.1	226.5	-0.9	-3.6
2014–15	2.0	0.8	20.7	0.9	2.0	30.4	244.0	-1.2	-7.7
2015–16	1.4	0.7	16.4	0.9	-0.5	25.6	262.7	-1.7	-7.8
2016–17	1.0	0.5	14.1	0.7	1.5	15.9	277.7	-1.8	-0.9
2017–18	0.8	0.4	14.0	0.7	-0.3	12.3	282.9	-1.9	2.5
2018–19	0.7	0.3	13.3	0.7	-0.1	10.7	285.0	-1.7	3.3
2019–20	0.8	0.3	14.3	0.9	0.5	13.6	284.7	-1.9	1.6
2020–21	1.0	0.4	14.9	0.9	-0.6	15.6	286.8	-2.5	0.4
2021–22	0.7	0.4	9.4	0.9	0.5	16.5	295.0	-2.5	-6.4

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table A5.6.12.10 UNFCCC Forest conversions – WA annual areas and related GHG emissions

	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
Year	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1989–90	59.7	13.5	20.1	0.6	6.7	20.1	89.0	-0.5	59.7
1990–91	47.1	12.7	23.9	0.8	5.0	22.4	99.9	-0.5	48.6
1991–92	27.4	6.5	19.3	0.5	4.6	25.2	114.0	-0.6	21.5
1992–93	21.7	4.4	15.9	0.4	6.2	16.1	131.5	-0.6	21.5
1993–94	22.6	4.9	16.8	0.5	4.2	16.0	139.4	-0.6	23.4
1994–95	19.3	4.6	15.0	0.5	3.8	14.1	148.0	-0.7	20.2
1995–96	17.8	3.6	16.3	0.5	3.7	14.9	153.8	-0.9	19.2
1996–97	17.8	4.0	15.9	0.6	3.5	14.6	160.5	-0.9	19.1
1997–98	14.9	3.6	13.8	0.6	2.9	18.8	168.0	-1.1	9.9
1998–99	13.2	2.7	13.4	0.6	2.9	29.5	179.4	-1.1	-2.8
1999–00	13.0	2.8	14.7	0.6	4.6	25.4	200.4	-1.3	2.3
2000–01	14.3	2.9	21.5	0.8	3.4	25.4	212.5	-1.2	10.4
2001–02	14.3	3.0	21.0	0.9	3.0	21.8	224.9	-1.2	13.5
2002–03	16.6	3.6	25.6	1.2	2.5	21.7	230.8	-1.2	20.5
2003–04	16.7	3.9	27.4	1.5	3.0	22.3	235.3	-1.2	21.8
2004–05	18.4	4.3	37.3	1.6	2.6	25.3	233.4	-1.3	30.4
2005–06	19.5	4.3	44.8	2.0	6.6	26.2	229.5	-1.4	38.1
2006–07	18.6	5.0	40.9	2.3	2.9	30.7	227.8	-1.4	28.8
2007–08	13.6	3.9	34.3	1.7	2.4	31.4	233.4	-1.4	16.6
2008–09	12.2	3.4	33.8	1.6	1.6	31.4	239.3	-1.3	14.6
2009–10	13.3	3.4	35.4	1.8	5.8	30.6	243.7	-1.1	18.1
2010–11	12.0	4.4	29.7	1.8	1.2	34.0	251.1	-1.4	7.7
2011–12	7.6	2.1	25.0	1.1	1.5	40.4	264.9	-1.6	-7.7
2012–13	7.2	1.6	26.2	0.9	4.8	51.8	283.8	-1.5	-18.4
2013–14	7.6	2.3	26.9	1.2	1.5	56.3	313.1	-1.6	-21.9
2014–15	8.8	1.5	27.4	1.0	3.7	36.8	346.6	-1.7	-0.6

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
2015–16	9.7	3.0	28.1	1.5	0.2	31.5	360.0	-1.9	6.2
2016–17	4.4	1.3	20.7	0.8	3.2	25.2	373.6	-2.2	-0.1
2017–18	3.9	1.0	19.3	0.9	0.0	21.9	382.1	-2.1	1.3
2018–19	2.9	0.7	15.6	0.7	1.0	17.4	390.6	-1.9	1.0
2019–20	2.5	0.6	15.2	0.6	2.5	23.6	394.9	-2.0	-5.9
2020–21	3.0	0.6	15.9	0.7	0.1	31.4	405.0	-2.4	-12.5
2021–22	2.5	0.6	12.0	0.7	1.3	25.2	426.1	-2.6	-10.7

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table A5.6.12.11 UNFCCC Forest conversions – TAS annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1989–90	12.3	3.6	4.0	0.1	1.3	3.9	6.5	0.0	12.4
1990–91	14.5	6.8	7.7	0.4	1.6	5.7	9.0	0.0	16.5
1991–92	6.7	4.4	7.1	0.3	1.5	4.7	12.5	0.0	9.1
1992–93	5.6	3.9	5.1	0.3	0.6	3.9	15.7	0.0	6.8
1993–94	4.8	2.0	4.3	0.2	0.8	4.3	18.3	0.0	4.9
1994–95	4.9	2.1	4.1	0.2	0.8	4.1	21.3	0.0	4.9
1995–96	3.9	1.8	3.6	0.2	0.9	2.9	23.7	0.0	4.5
1996–97	4.3	1.9	4.2	0.2	0.9	3.3	24.4	0.0	5.3
1997–98	3.8	1.8	3.7	0.2	0.6	3.1	25.8	-0.1	4.5
1998–99	3.4	1.5	4.1	0.2	0.9	6.3	27.2	0.0	1.1

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1999–00	3.2	1.5	3.2	0.2	0.8	5.2	32.2	-0.1	1.2
2000–01	3.4	1.4	3.1	0.2	0.6	5.4	35.9	0.0	1.2
2001–02	3.2	1.5	3.2	0.2	0.7	4.8	39.8	-0.1	1.6
2002–03	3.9	1.6	6.6	0.3	0.6	5.8	40.7	-0.1	4.7
2003–04	4.3	1.9	6.4	0.4	0.2	6.4	42.6	-0.2	4.4
2004–05	5.3	2.1	8.0	0.5	1.8	9.5	43.8	-0.2	3.8
2005–06	4.6	2.0	7.9	0.5	1.0	10.7	48.0	-0.1	1.8
2006–07	4.5	1.7	7.8	0.4	0.8	6.9	53.1	-0.2	5.4
2007–08	4.7	1.9	10.7	0.5	0.7	7.0	51.9	-0.2	8.4
2008–09	4.3	1.7	8.5	0.5	0.3	7.2	52.4	-0.2	5.7
2009–10	4.7	1.6	9.4	0.5	1.1	8.2	52.4	-0.2	5.8
2010–11	3.7	2.2	7.6	0.6	0.6	9.8	54.7	-0.2	1.4
2011–12	1.5	0.7	4.9	0.3	0.7	10.0	60.7	-0.3	-3.6
2012–13	1.6	0.5	5.1	0.2	1.0	10.1	66.7	-0.4	-3.3
2013–14	1.9	0.7	5.3	0.4	0.2	9.6	72.5	-0.4	-2.3
2014–15	1.6	0.6	5.8	0.4	0.5	7.7	77.2	-0.5	-0.3
2015–16	1.4	0.6	5.6	0.6	-0.8	5.7	80.0	-0.5	1.3
2016–17	1.1	0.5	5.2	0.6	1.8	4.9	81.3	-0.5	1.5
2017–18	1.1	0.4	4.9	0.4	-0.1	3.8	81.9	-0.6	2.1
2018–19	0.9	0.4	3.6	0.3	0.2	3.9	82.6	-0.5	0.6
2019–20	0.7	0.3	4.0	0.3	0.2	4.6	83.1	-0.5	0.2
2020–21	0.9	0.3	5.5	0.4	0.3	3.9	82.8	-0.6	2.5
2021–22	0.8	0.4	4.6	0.6	0.2	4.3	82.8	-0.6	1.1

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table A5.6.12.12 UNFCCC Forest conversions – SA annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1989–90	14.2	2.9	7.4	0.2	2.3	5.4	38.7	-0.2	16.2
1990–91	10.3	1.8	7.7	0.2	0.8	6.6	41.5	-0.2	11.3
1991–92	7.3	1.1	9.1	0.1	1.1	7.0	44.7	-0.3	9.4
1992–93	4.6	1.1	6.3	0.2	1.0	9.2	49.1	-0.3	1.7
1993–94	3.8	0.6	6.0	0.1	0.5	13.1	55.5	-0.2	-3.3
1994–95	3.2	0.6	5.0	0.1	0.4	10.2	66.5	-0.2	-2.1
1995–96	2.8	0.4	5.5	0.1	0.9	7.8	74.3	-0.3	0.5
1996–97	2.9	0.5	5.5	0.1	1.0	8.0	79.6	-0.3	0.3
1997–98	2.7	0.4	5.9	0.1	0.3	6.7	85.0	-0.4	1.9
1998–99	2.9	0.4	7.8	0.2	0.6	6.5	87.9	-0.4	4.2
1999–00	2.6	0.4	7.3	0.2	0.0	6.3	90.7	-0.4	3.6
2000–01	3.4	0.5	9.2	0.2	0.8	9.8	92.3	-0.5	2.8
2001–02	3.2	0.6	8.9	0.3	0.8	8.6	97.6	-0.4	3.5
2002–03	3.0	0.5	9.8	0.3	0.2	8.5	101.6	-0.4	4.2
2003–04	3.4	0.5	12.2	0.4	0.7	9.7	104.1	-0.4	5.9
2004–05	3.9	0.7	17.8	0.5	0.8	12.7	104.4	-0.4	9.0
2005–06	4.3	0.6	18.8	0.5	1.2	11.9	106.1	-0.4	11.2
2006–07	4.0	0.7	15.2	0.5	0.6	11.6	108.4	-0.5	7.6
2007–08	2.3	0.4	9.8	0.3	0.8	14.9	113.8	-0.5	-2.8
2008–09	2.3	0.3	10.2	0.3	-0.1	20.5	121.9	-0.5	-8.0
2009–10	2.2	0.3	11.9	0.3	0.4	22.8	134.5	-0.6	-8.7
2010–11	1.8	0.3	12.1	0.3	-0.2	24.5	148.9	-0.8	-10.6
2011–12	1.7	0.3	12.7	0.3	-0.1	25.5	164.5	-0.7	-11.1
2012–13	2.1	0.3	16.5	0.4	0.6	22.4	178.2	-0.6	-3.9
2013–14	2.3	0.4	17.6	0.5	0.6	17.6	188.0	-0.6	2.2
2014–15	1.5	0.3	13.3	0.3	1.4	17.6	195.9	-0.7	-2.9

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
2015–16	0.7	0.1	9.2	0.2	-1.0	19.2	206.6	-0.9	-9.3
2016–17	0.7	0.1	8.0	0.2	0.2	13.5	219.5	-1.0	-4.8
2017–18	0.7	0.1	7.9	0.2	0.8	10.5	226.8	-0.8	-1.9
2018–19	0.4	0.1	6.8	0.1	0.4	8.8	231.8	-0.7	-1.7
2019–20	0.6	0.1	8.6	0.4	1.9	8.8	233.9	-0.9	0.4
2020–21	0.7	0.1	6.9	0.2	0.0	11.3	237.0	-1.1	-3.7
2021–22	0.4	0.1	4.6	0.2	-0.4	13.8	244.5	-1.3	-8.8

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table A5.6.12.13 UNFCCC Forest conversions – NT annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1989–90	3.5	0.8	2.8	0.1	0.9	4.8	36.9	-0.9	1.5
1990–91	3.1	0.5	3.0	0.1	0.8	3.6	40.4	-1.0	2.5
1991–92	4.3	0.7	4.8	0.1	1.1	5.8	41.5	-1.2	3.3
1992–93	1.6	0.4	2.9	0.0	1.2	3.1	45.5	-1.3	1.5
1993–94	1.5	0.2	3.2	0.0	1.1	3.5	46.4	-1.3	1.2
1994–95	1.3	0.2	3.0	0.0	1.0	3.7	47.8	-1.4	0.7
1995–96	2.1	0.3	3.9	0.0	1.0	4.3	48.8	-1.5	1.7
1996–97	2.1	0.4	4.2	0.1	0.9	4.7	50.2	-1.3	1.6
1997–98	1.4	0.3	3.1	0.1	1.0	5.1	52.8	-1.3	-0.6
1998–99	1.3	0.2	3.0	0.1	0.9	6.2	55.9	-1.4	-1.9

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1999–00	1.1	0.2	3.1	0.1	0.9	4.6	60.1	-1.4	-0.3
2000–01	1.4	0.2	4.2	0.1	0.9	4.2	61.9	-1.7	1.4
2001–02	1.2	0.2	4.0	0.1	1.0	3.9	63.4	-1.7	1.4
2002–03	1.2	0.2	3.5	0.1	0.8	5.6	64.9	-1.6	-1.0
2003–04	1.1	0.2	3.5	0.1	0.8	5.8	68.2	-1.6	-1.2
2004–05	2.3	0.4	7.1	0.1	0.8	6.2	69.2	-1.9	3.2
2005–06	1.8	0.3	8.7	0.2	0.8	5.8	69.9	-1.6	4.7
2006–07	2.0	0.3	6.7	0.2	1.1	5.7	71.3	-1.6	2.9
2007–08	1.6	0.2	4.9	0.1	0.7	6.1	74.1	-2.0	0.4
2008–09	1.1	0.1	4.8	0.1	0.8	5.2	77.0	-1.7	0.6
2009–10	0.9	0.1	5.1	0.1	0.6	5.2	78.6	-2.0	0.8
2010–11	0.7	0.1	3.3	0.1	0.5	5.9	81.2	-2.3	-1.8
2011–12	0.6	0.1	4.3	0.1	0.8	4.6	83.8	-2.2	0.3
2012–13	0.8	0.1	5.6	0.1	0.6	3.6	84.0	-2.1	2.7
2013–14	0.9	0.2	5.6	0.2	0.6	4.5	83.0	-1.9	2.0
2014–15	1.1	0.2	5.6	0.2	0.8	4.9	83.0	-2.0	1.7
2015–16	1.5	0.3	9.0	0.3	0.9	4.5	80.4	-1.8	6.0
2016–17	0.7	0.2	4.3	0.2	1.0	3.7	81.8	-2.0	1.2
2017–18	0.5	0.1	3.4	0.1	1.2	4.8	82.8	-1.9	-0.9
2018–19	0.6	0.1	3.3	0.1	1.2	3.4	85.1	-1.8	0.6
2019–20	0.5	0.1	4.7	0.2	1.0	3.0	85.0	-2.0	2.3
2020–21	0.5	0.1	3.4	0.1	0.9	3.6	85.8	-1.8	0.3
2021–22	0.4	0.1	2.4	0.1	1.1	2.5	87.3	-1.8	0.4

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table A5.6.12.14 UNFCCC Forest conversions – ACT annual areas and related GHG emissions

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1989–90	0.2	0.1	0.3	0.0	0.0	0.2	0.4	0.0	0.3
1990–91	0.2	0.1	0.5	0.0	0.0	0.2	0.5	0.0	0.4
1991–92	0.1	0.0	0.5	0.0	0.0	0.2	0.6	0.0	0.5
1992–93	0.1	0.0	0.2	0.0	0.0	0.2	0.8	0.0	0.0
1993–94	0.1	0.0	0.2	0.0	0.0	0.2	0.9	0.0	0.0
1994–95	0.1	0.0	0.2	0.0	0.0	0.2	1.1	0.0	0.0
1995–96	0.1	0.0	0.3	0.0	0.0	0.1	1.2	0.0	0.2
1996–97	0.1	0.0	0.3	0.0	0.0	0.1	1.2	0.0	0.2
1997–98	0.1	0.0	0.3	0.0	0.0	0.1	1.3	0.0	0.2
1998–99	0.1	0.0	0.3	0.0	0.0	0.4	1.4	0.0	0.0
1999–00	0.1	0.0	0.3	0.0	0.0	0.3	1.7	0.0	0.1
2000–01	0.0	0.0	0.4	0.0	0.0	0.2	1.8	0.0	0.2
2001–02	0.1	0.0	0.5	0.0	0.0	0.2	1.9	0.0	0.4
2002–03	0.2	0.1	0.9	0.0	0.0	0.2	1.6	0.0	0.9
2003–04	0.2	0.1	0.9	0.1	0.0	0.2	1.3	0.0	0.9
2004–05	0.1	0.1	0.9	0.1	0.0	0.2	1.2	0.0	0.9
2005–06	0.1	0.0	0.9	0.0	0.0	0.2	1.0	0.0	0.8
2006–07	0.1	0.0	0.8	0.0	0.0	0.4	0.7	0.0	0.6
2007–08	0.0	0.0	0.3	0.0	0.0	0.7	0.8	0.0	-0.4
2008–09	0.0	0.0	0.8	0.0	0.0	0.2	0.9	0.0	0.6
2009–10	0.0	0.0	0.5	0.0	0.0	0.3	0.7	0.0	0.3
2010–11	0.0	0.0	0.4	0.0	0.0	0.2	0.7	0.0	0.2
2011–12	0.0	0.0	0.2	0.0	0.0	0.3	0.8	0.0	-0.1
2012–13	0.0	0.0	0.2	0.0	0.0	0.5	0.9	0.0	-0.3
2013–14	0.0	0.0	0.1	0.0	0.0	0.6	1.3	0.0	-0.5
2014–15	0.0	0.0	0.1	0.0	0.0	0.7	1.8	0.0	-0.6

	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(a)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
Year	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
2015–16	0.0	0.0	0.1	0.0	0.0	0.5	2.5	0.0	-0.4
2016–17	0.0	0.0	0.1	0.0	0.0	0.2	2.9	0.0	0.0
2017–18	0.0	0.0	0.1	0.0	0.0	0.1	3.0	0.0	0.0
2018–19	0.0	0.0	0.1	0.0	0.0	0.1	3.0	0.0	0.0
2019–20	0.0	0.0	0.2	0.0	0.0	0.1	3.0	0.0	0.0
2020–21	0.0	0.0	0.2	0.0	0.0	0.2	3.0	0.0	0.0
2021–22	0.0	0.0	0.1	0.0	0.0	0.2	3.1	0.0	-0.1

(a) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands.

Table A5.6.12.15 UNFCCC Forest conversions – Great Barrier Reef Catchment[(a)] annual areas and related GHG emissions

	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(b)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
Year	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1989–90	232.4	31.5	111.6	2.7	12.1	78.5	245.1	0.1	265.5
1990–91	194.6	34.2	118.4	2.9	14.3	66.9	292.4	0.1	246.1
1991–92	160.7	22.6	139.4	2.8	10.0	58.7	319.5	-0.2	241.5
1992–93	105.4	18.9	118.2	2.7	12.5	59.0	339.9	-0.4	164.6
1993–94	105.5	15.1	129.9	2.7	7.4	68.9	355.5	-0.2	166.4
1994–95	75.4	13.2	83.9	2.5	7.0	49.6	392.5	-0.5	109.6
1995–96	75.3	9.7	85.9	1.8	6.4	54.6	405.6	-0.6	106.7
1996–97	73.3	10.2	81.7	2.0	5.7	51.0	425.9	-0.8	103.9
1997–98	67.6	9.8	90.7	2.2	6.0	54.1	435.1	-1.0	104.2
1998–99	71.1	10.3	106.6	2.8	8.7	63.9	437.2	-0.8	113.8

Year	Annual Area of primary forest converted	Direct emissions from primary forest clearing	Annual area of secondary forest converted	Direct emissions from secondary forest clearing	Emissions from decay on previously cleared lands	Annual area of identified regrowth	Total area of sustained regrowth [(b)]	Net emissions from the regrowing forest (negative values denote removals)	Net clearing of forests (conversions less identified regrowth)
	kha	Mt CO_2-e	kha	Mt CO_2-e	Mt CO_2-e	kha	kha	Mt CO_2-e	kha
1999–00	103.4	11.1	106.9	3.1	1.5	46.5	451.2	-1.1	163.7
2000–01	137.7	16.5	130.4	3.8	11.7	46.1	434.7	-1.1	222.0
2001–02	124.9	17.4	115.7	4.4	7.6	46.3	426.6	-1.0	194.3
2002–03	66.0	12.1	93.4	3.6	13.0	48.3	428.2	-0.9	111.1
2003–04	74.1	9.2	110.2	3.5	8.3	43.7	420.5	-1.0	140.6
2004–05	116.8	14.2	188.5	5.7	6.1	68.1	363.3	-0.9	237.2
2005–06	77.8	13.7	124.3	5.2	8.9	93.2	356.6	-0.8	108.9
2006–07	60.1	10.8	115.8	4.0	4.5	98.3	373.6	-0.8	77.6
2007–08	41.9	8.1	109.1	3.3	10.7	156.4	394.3	-0.7	-5.4
2008–09	27.1	5.2	77.7	2.5	5.0	182.3	495.6	-0.6	-77.5
2009–10	18.0	3.5	72.9	2.0	7.2	126.6	623.2	-0.6	-35.7
2010–11	14.6	3.0	76.4	1.9	4.8	105.8	690.7	-0.3	-14.7
2011–12	11.3	2.3	87.8	1.8	0.4	151.3	731.0	-1.4	-52.2
2012–13	13.9	2.2	134.4	2.2	11.1	135.0	782.7	-1.4	13.3
2013–14	14.9	2.6	118.8	2.5	8.2	201.3	824.8	-1.7	-67.6
2014–15	18.0	2.6	132.9	2.4	5.7	177.4	920.0	-1.6	-26.6
2015–16	18.8	3.1	150.5	3.0	3.6	173.0	976.9	-2.2	-3.7
2016–17	13.1	2.6	127.4	2.9	3.7	125.2	1049.3	-2.0	15.3
2017–18	9.5	1.8	120.2	2.4	4.6	118.3	1077.5	-2.1	11.4
2018–19	6.5	1.5	105.3	2.5	0.9	103.0	1109.2	-2.1	8.8
2019–20	5.8	1.0	97.4	1.8	5.1	89.7	1130.7	-2.2	13.5
2020–21	6.0	1.0	114.0	2.3	3.0	134.7	1124.7	-3.2	-14.8
2021–22	2.7	0.7	49.8	1.6	-4.6	129.1	1217.2	-3.2	-76.6

(a) The Great Barrier Reef Catchment is defined as the Australian Drainage Division of the North East Coast excluding where it overlaps with the Natural Resource Management region of South East Queensland Catchments.

(b) The area of sustained regrowth only includes those area which had identified regrowth in an earlier year and continue to show forest cover. This means that where identified regrowth is subjected to re-clearing in the following year then it will not be counted in the area of sustained forest. This area correlates with the emissions reported under *Land converted to Forest* for regrowth on previously cleared lands

Table A5.6.12.16 Queensland disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989–90	26	-24	93	182	26	-25	96	186
1990–91	19	26	74	-21	19	-3	88	99
1991–92	21	-55	129	330	21	33	70	-52
1992–93	4	121	29	-417	4	-137	151	654
1993–94	5	98	27	-333	5	-90	140	471
1994–95	90	-877	496	3,712	90	-47	124	295
1995–96	3	261	19	-938	3	-26	118	215
1996–97	12	163	48	-548	12	-28	122	225
1997–98	0	224	0	-821	0	166	31	-577
1998–99	6	90	47	-282	6	124	41	-414
1999–00	13	91	40	-294	13	113	35	-380
2000–01	13	53	67	-127	13	70	51	-205
2001–02	3	109	19	-379	3	47	57	-117
2002–03	15	6	80	57	15	-76	115	392
2003–04	8	-22	77	157	8	-46	103	270
2004–05	68	-523	333	2,252	68	-186	174	857
2005–06	2	202	7	-735	2	-137	163	666
2006–07	86	-595	372	2,553	86	-189	198	890
2007–08	7	251	25	-896	7	-408	324	1,819

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
2008–09	69	-279	253	1,278	69	-337	324	1,560
2009–10	225	-1,618	963	6,895	225	-571	471	2,565
2010–11	2	556	9	-2,029	2	-742	597	3,317
2011–12	325	-1,765	1,103	7,575	325	-747	663	3,401
2012–13	196	-602	660	2,865	196	-378	536	1,921
2013–14	138	-304	584	1,697	138	-334	534	1,760
2014–15	94	225	325	-502	94	-112	440	850
2015–16	181	-519	663	2,566	0	-53	425	619
2016–17	153	-373	634	2,003	153	80	353	59
2017–18	135	-113	583	999	135	168	288	-329
2018–19	70	514	226	-1,658	70	-228	456	1,292
2019–20	222	-1,503	1,155	6,665	0	20	345	273
2020–21	93	-598	838	3,030	93	40	308	159
2021–22	21	1,085	78	-3,902	21	-40	328	475

Table A5.6.12.17 New South Wales disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989–90	11	973	59	-3,509	11	423	281	-1,270
1990–91	22	591	155	-2,013	22	691	119	-2,416
1991–92	2	813	14	-2,965	2	-485	611	2,388
1992–93	1	655	6	-2,395	1	-420	622	2,162
1993–94	381	-5,456	2,819	22,823	381	-267	591	1,570
1994–95	9	1,296	115	-4,638	9	-228	589	1,426
1995–96	0	1,356	0	-4,973	0	-191	589	1,289
1996–97	1	1,007	5	-3,686	1	955	63	-3,438
1997–98	1	841	4	-3,079	1	823	41	-2,976
1998–99	24	274	194	-811	24	618	61	-2,206
1999–00	1	636	4	-2,329	1	-1,339	932	5,842
2000–01	15	334	100	-1,125	15	-1,106	931	4,987
2001–02	537	-8,781	4,356	36,553	537	-844	899	3,992
2002–03	949	-21,227	10,807	88,640	0	-709	899	3,500
2003–04	6	5,780	34	-21,159	6	-582	892	3,026
2004–05	1	4,788	3	-17,553	1	737	323	-2,380
2005–06	7	3,784	66	-13,807	7	548	357	-1,650
2006–07	149	163	1,512	915	149	409	380	-1,119
2007–08	19	3,025	171	-10,922	19	18	542	476

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
2008–09	18	2,613	146	-9,436	18	52	529	338
2009–10	91	731	814	-1,867	91	655	237	-2,165
2010–11	2	2,318	3	-8,497	2	92	446	107
2011–12	8	1,733	50	-6,304	8	113	417	1
2012–13	149	-1,054	1,217	5,082	149	107	403	9
2013–14	381	-5,268	3,266	22,583	0	-198	527	1,253
2014–15	86	840	745	-2,334	86	-496	677	2,497
2015–16	72	905	622	-2,696	72	-264	621	1,590
2016–17	102	338	801	-438	102	-393	710	2,151
2017–18	104	380	940	-454	104	-122	562	1,010
2018–19	63	1,114	445	-3,640	63	57	441	231
2019–20	5,140	-116,080	55,912	481,539	0	250	296	-620
2020–21	2	22,453	20	-82,307	2	6	317	295
2021–22	30	18,620	75	-68,200	30	-81	285	583

Table A5.6.12.18 Victoria disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989–90	0	576	0	-2,113	0	287	120	-933
1990–91	17	206	124	-631	17	354	63	-1,236
1991–92	0	425	0	-1,557	0	342	36	-1,217
1992–93	0	347	0	-1,271	0	250	48	-869
1993–94	4	155	55	-514	4	249	24	-887
1994–95	3	117	60	-370	3	198	24	-702
1995–96	4	199	7	-724	4	156	24	-548
1996–97	0	172	0	-630	0	130	21	-456
1997–98	0	137	0	-503	0	123	10	-441
1998–99	25	25	38	-53	25	99	9	-353
1999–00	1	82	7	-294	1	57	19	-189
2000–01	2	78	2	-284	2	44	19	-142
2001–02	26	-38	47	188	26	44	14	-148
2002–03	1,024	-24,999	11,599	103,263	0	37	14	-122
2003–04	8	4,614	16	-16,901	8	-121	84	529
2004–05	2	3,856	4	-14,136	2	-79	74	363
2005–06	88	2,374	352	-8,352	88	-133	110	597
2006–07	1,031	-21,860	11,730	91,883	0	-1,638	827	6,833
2007–08	33	6,386	177	-23,237	33	-1,561	934	6,657

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
2008–09	262	-1,978	3,601	10,855	262	-1,154	880	5,112
2009–10	32	4,894	542	-17,402	32	-952	887	4,379
2010–11	8	5,112	80	-18,663	8	-1,491	1,224	6,691
2011–12	7	4,314	32	-15,786	7	336	504	-730
2012–13	165	-356	1,863	3,167	165	446	434	-1,200
2013–14	298	-2,732	2,930	12,946	0	321	465	-714
2014–15	37	3,656	195	-13,211	37	211	500	-275
2015–16	27	2,923	235	-10,483	27	835	202	-2,859
2016–17	18	2,349	210	-8,404	18	696	202	-2,348
2017–18	34	1,597	372	-5,484	34	617	163	-2,100
2018–19	164	-2,320	1,960	10,467	0	557	122	-1,921
2019–20	1,415	-45,609	22,505	189,737	0	502	84	-1,756
2020–21	14	10,386	30	-38,051	14	363	81	-1,251
2021–22	6	8,714	17	-31,935	6	219	102	-700

Table A5.6.12.19 Western Australia disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989–90	164	-1,468	998	6,381	164	-1,220	916	5,389
1990–91	432	-2,022	1,300	8,714	432	-1,084	949	4,923
1991–92	175	-1,502	1,313	6,819	175	-1,046	990	4,826
1992–93	79	508	405	-1,457	79	-973	1,025	4,594
1993–94	398	-747	935	3,674	398	-801	1,051	3,987
1994–95	170	-1,104	1,172	5,218	170	-235	824	1,687
1995–96	145	-1,159	1,432	5,681	145	-546	1,010	3,013
1996–97	30	1,325	177	-4,680	30	-309	944	2,076
1997–98	269	-1,046	1,335	5,170	269	65	777	537
1998–99	55	440	605	-1,007	55	24	754	665
1999–00	69	768	335	-2,480	69	-192	839	1,542
2000–01	454	-1,364	1,321	6,323	454	292	572	-498
2001–02	129	244	599	-296	129	165	583	-21
2002–03	490	-3,054	2,199	13,396	0	-294	789	1,867
2003–04	66	618	659	-1,607	66	-27	663	762
2004–05	218	-854	1,365	4,497	218	-222	748	1,563
2005–06	69	489	692	-1,101	69	-451	883	2,536
2006–07	157	-297	1,023	2,113	157	-417	895	2,425
2007–08	144	605	678	-1,539	144	-714	1,065	3,685

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
2008–09	127	272	719	-277	127	-575	1,053	3,161
2009–10	503	-2,764	2,214	12,350	503	-459	1,059	2,744
2010–11	88	859	628	-2,521	88	-327	1,007	2,206
2011–12	123	-17	1,058	1,120	123	-220	993	1,800
2012–13	89	983	416	-3,188	89	-174	965	1,603
2013–14	110	583	648	-1,490	110	71	839	580
2014–15	308	-2,741	2,073	12,124	308	-310	1,009	2,147
2015–16	462	-3,912	2,875	17,218	0	-644	1,190	3,553
2016–17	192	-1,026	1,908	5,670	192	-318	1,060	2,226
2017–18	208	27	1,320	1,220	208	541	646	-1,338
2018–19	379	-671	1,789	4,250	0	34	832	707
2019–20	911	-2,536	2,555	11,853	0	422	624	-923
2020–21	113	1,278	930	-3,755	113	97	734	379
2021–22	94	1,584	870	-4,938	94	-413	918	2,434

Table A5.6.12.20 Tasmania disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989–90	0	103	0	-378	0	55	19	-183
1990–91	0	85	0	-312	0	72	6	-258
1991–92	0	71	0	-259	0	68	2	-248
1992–93	0	57	0	-209	0	34	12	-113
1993–94	1	25	9	-83	1	28	12	-90
1994–95	11	-67	50	296	11	22	12	-69
1995–96	0	54	0	-197	0	17	12	-52
1996–97	0	42	0	-152	0	2	17	9
1997–98	0	34	0	-124	0	23	7	-75
1998–99	2	-51	37	222	2	12	10	-34
1999–00	0	35	0	-127	0	-10	19	56
2000–01	2	1	13	11	2	-69	46	300
2001–02	3	-69	45	297	3	-43	40	199
2002–03	15	-261	138	1,096	15	-34	40	167
2003–04	1	78	7	-281	1	-22	38	118
2004–05	0	79	0	-288	0	2	29	21
2005–06	0	63	0	-232	0	-156	102	674
2006–07	130	-1,920	909	7,950	0	-146	112	646
2007–08	36	-692	503	3,042	36	-150	126	675

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
2008–09	5	428	54	-1,514	5	-138	133	637
2009–10	12	301	71	-1,031	12	-122	138	586
2010–11	2	330	34	-1,175	2	-176	175	822
2011–12	5	302	26	-1,083	5	-210	205	973
2012–13	96	-1,177	690	5,006	96	-178	209	862
2013–14	12	85	202	-111	12	-131	202	682
2014–15	10	316	92	-1,066	10	-195	243	957
2015–16	120	-2,869	1,542	12,060	0	112	117	-293
2016–17	39	479	231	-1,525	39	180	77	-582
2017–18	9	757	62	-2,713	9	186	59	-622
2018–19	192	-3,892	2,105	16,375	0	136	67	-430
2019–20	33	956	227	-3,279	0	198	28	-700
2020–21	5	1,206	45	-4,379	5	-102	147	519
2021–22	4	1,024	31	-3,722	4	-202	183	925

Table A5.6.12.21 South Australia disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989–90	0	70	3	-253	0	-20	38	113
1990–91	0	74	0	-271	0	64	2	-231
1991–92	0	53	0	-195	0	57	1	-209
1992–93	0	45	0	-165	0	49	0	-180
1993–94	1	45	1	-162	1	39	0	-141
1994–95	0	29	0	-107	0	33	0	-120
1995–96	0	21	0	-76	0	26	0	-95
1996–97	0	24	0	-88	0	-16	16	75
1997–98	0	11	0	-40	0	-46	29	198
1998–99	59	-166	79	686	59	-66	41	282
1999–00	27	-120	67	507	27	-55	41	243
2000–01	9	-77	61	343	9	-59	48	264
2001–02	0	77	0	-283	0	-14	32	82
2002–03	7	-9	34	66	7	-7	32	57
2003–04	0	61	0	-222	0	-26	41	135
2004–05	15	-87	64	382	15	-18	41	107
2005–06	57	-170	107	730	57	-173	117	750
2006–07	137	-423	255	1,807	0	-134	118	609
2007–08	74	-684	413	2,922	74	-82	105	404

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
2008–09	2	337	3	-1,233	2	-21	84	162
2009–10	0	233	0	-853	0	-22	86	168
2010–11	1	180	5	-656	1	145	8	-523
2011–12	4	149	6	-540	4	114	8	-409
2012–13	5	92	26	-309	5	85	13	-300
2013–14	182	-668	366	2,814	0	71	13	-247
2014–15	8	221	29	-783	8	45	20	-144
2015–16	2	199	6	-724	2	43	16	-142
2016–17	15	88	38	-284	15	36	17	-114
2017–18	4	139	8	-502	4	34	11	-112
2018–19	2	143	4	-519	2	14	16	-36
2019–20	166	-1,664	814	6,916	0	26	9	-88
2020–21	11	345	28	-1,237	11	-22	27	106
2021–22	1	352	2	-1,290	1	-42	32	187

Table A5.6.12.22 Northern Territory disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989–90	0	0	0	0	0	0	0	0
1990–91	0	0	0	0	0	0	0	0
1991–92	0	0	0	0	0	0	0	0
1992–93	0	0	0	0	0	0	0	0
1993–94	0	0	0	0	0	0	0	0
1994–95	0	0	0	0	0	0	0	0
1995–96	0	0	0	0	0	0	0	0
1996–97	0	0	0	0	0	0	0	0
1997–98	0	0	0	0	0	0	0	0
1998–99	0	0	0	0	0	0	0	0
1999–00	0	0	0	0	0	0	0	0
2000–01	0	0	0	0	0	0	0	0
2001–02	0	0	0	0	0	0	0	0
2002–03	0	0	0	0	0	0	0	0
2003–04	0	0	0	0	0	0	0	0
2004–05	0	0	0	0	0	0	0	0
2005–06	0	0	0	0	0	0	0	0
2006–07	0	0	0	0	0	0	0	0
2007–08	0	0	0	0	0	0	0	0

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
2008–09	0	0	0	0	0	0	0	0
2009–10	0	0	0	0	0	0	0	0
2010–11	0	0	0	0	0	0	0	0
2011–12	0	0	0	0	0	0	0	0
2012–13	0	0	0	0	0	0	0	0
2013–14	0	0	0	0	0	0	0	0
2014–15	0	0	0	0	0	0	0	0
2015–16	0	0	0	0	0	0	0	0
2016–17	0	0	0	0	0	0	0	0
2017–18	0	0	0	0	0	0	0	0
2018–19	0	0	0	0	0	0	0	0
2019–20	0	0	0	0	0	0	0	0
2020–21	0	0	0	0	0	0	0	0
2021–22	0	0	0	0	0	0	0	0

Table A5.6.12.23 Australian Capital Territory disaggregation of total managed land proxy flux into natural disturbances component and identification of trend in emissions associated with human activity

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
1989–90	0	36	0	-132	0	17	6	-58
1990–91	0	27	0	-100	0	21	3	-75
1991–92	0	23	0	-85	0	24	0	-88
1992–93	0	20	0	-72	0	19	0	-71
1993–94	0	14	0	-50	0	16	0	-58
1994–95	0	13	0	-47	0	13	0	-48
1995–96	0	10	0	-38	0	10	0	-38
1996–97	0	9	0	-32	0	9	0	-31
1997–98	0	7	0	-25	0	7	0	-25
1998–99	0	4	0	-15	0	5	0	-19
1999–00	0	4	0	-14	0	4	0	-14
2000–01	0	3	0	-10	0	2	0	-9
2001–02	0	2	0	-6	0	2	0	-6
2002–03	120	-4,197	1,923	17,313	0	1	0	-3
2003–04	0	750	0	-2,750	0	0	0	-2
2004–05	0	647	0	-2,373	0	0	0	0
2005–06	0	484	0	-1,774	0	0	0	0
2006–07	0	408	0	-1,495	0	0	0	0
2007–08	0	348	0	-1,274	0	0	0	0

Years	Total MLP flux from wildfires				Refined wildfire flux after application of ND			
	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 wildfires reported in NIR (kha)	Carbon stock change (kt C)	Non-CO_2 fluxes (kt CO_2-e)	CO_2-e (kt)
2008–09	0	303	0	-1,111	0	0	0	0
2009–10	0	240	0	-879	0	0	0	0
2010–11	0	203	0	-745	0	0	0	0
2011–12	0	162	0	-593	0	0	0	0
2012–13	0	112	0	-410	0	-16	7	65
2013–14	0	67	0	-244	0	-13	7	55
2014–15	2	-34	36	163	2	-11	7	47
2015–16	0	56	0	-206	0	-9	7	40
2016–17	0	38	0	-140	0	-7	7	35
2017–18	0	41	0	-151	0	10	0	-35
2018–19	0	30	0	-108	0	8	0	-28
2019–20	82	-2,825	1,310	11,669	0	6	0	-23
2020–21	0	541	0	-1,984	0	5	0	-19
2021–22	0	457	0	-1,675	0	5	0	-17

A5.7 Sector-specific Black Carbon Emission Estimation Methods

Black carbon definition

The meaning of "Black Carbon" (BC) varies depending on the perspective. The definition depends on whether a BC analysis is focused on climate-forcing or health-based outcomes. From a climate-forcing perspective, the term Black Carbon may be used for the broader metric of "light absorbing carbon" (LAC), comprising both light-absorbing elemental carbon (EC) and light-absorbing organic carbon (OC) (or brown carbon). From a health perspective, BC has typically been defined only as the mass of EC (i.e., the graphitic component of PM). So, BC may refer to the mass of EC only, or to the broader, optically-defined LAC.

For the purpose of calculating Australia's Black Carbon emissions, data is obtained from the National Pollutant Inventory (NPI) which tracks emissions of 93 different hazardous substances, including PM2.5, PM10 and SO2.

Black Carbon emissions can be calculated using either a Tier 3 or Tier 2 method.

Tier 3 Method

For the Tier 3 method, NPI PM2.5 emissions data is used to calculate black carbon emissions.

This method involves multiplying the PM2.5 emissions with a speciation factor, or the fraction of BC contained in the PM2.5, that converts PM2.5 to BC emissions. Because the NPI PM2.5 emissions are considered measured, this is Tier 3.

$PM_2.5$ emissions × Speciation Factor = BC emissions

The speciation factors are specified by sector and by fuel type. The fractions are sourced from US EPA Speciate 4.5 database. The PM2.5 emissions are from the NPI database.

The NPI emissions are categorised by the mass of fuel used by fuel type. A calculation is performed to allocate the total emissions by facility into each fuel type.

Black carbon emissions are determined by inventory sector, by jurisdiction and aggregated to the National level. The NPI dataset includes data for Energy, Industrial Processes and Waste.

Tier 2 method

For the Tier 2 method, inventory analysis data is used to calculate BC emissions. In this method, the amount of fuel combusted is used and multiplied by a PM2.5 emission factor (by fuel type) and a speciation factor.

Quantity of fuel combusted × $PM_2.5$ emission factor × BC Fractions = BC emissions by sector

For sectors that are not covered by the NPI, the Tier 2 method is used.

Energy, Industrial Processes and Waste

For these sectors, Tier 3 method was used with PM2.5 emissions from the NPI dataset and speciation factors.

Transport

For the Transport sector, the methods are sub-sector specific using the Tier 2 approach.

On-road Sources

Tier 2 for On-road sources Total Black Carbon emissions from on-road vehicles (EBC)

i	Type of fuel
j	vehicle class
$Q_{i,j}$	quantity of fuel type i for vehicle class j
$EF_{i,j}$,EC	fuel based EC (elemental carbon) emission factor for fuel type i and vehicle class j
En_i	energy content of fuel type i

$$EBC = \Sigma_{i,j} (Q_{i,j} \times EF_{i,j},EC \times 1/En_i)$$

Non-road Sources

Total Black Carbon emissions from non-road vehicles (EBC)

c	equipment use category
i	fuel type
t	technology level (year it was made)
$Q_{c,i,t}$	fuel consumption for a given equipment use category c, fuel type i, and technology level t
$EF_{c,i,t}$,PM2.5	PM2.5 emission factor for a given equipment use category c, fuel type i, and technology level t
$SF_{i,t}$,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for fuel type i, and technology level t (if available)

$$EBC = \Sigma_{c,i,t} (Q_{c,i,t} \times EF_{c,i,t},PM\ 2.5 \times SF_{i,t},BC/PM2.5)$$

Railway

Total Black Carbon emissions from locomotives (EBC)

i	rail operation type
Q_i	amount of locomotive fuel combusted, by rail operation type i
EF_i,PM2.5	PM2.5 emission factor for rail operation type i
SFBC/PM2.5	speciation factor to convert PM2.5 to black carbon for locomotives

$$EBC = \Sigma_i (Q_i \times EF_i,PM\ 2.5) \times SFBC/PM\ 2.5)$$

Marine

Tier 1 Method for Marine Sources

Total Black Carbon emissions from marine sources (EBC)

i	fuel type
Q_i	fuel consumption for fuel type i
EF_i,PM2.5	PM2.5 emission factor for fuel type i
SF_i,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for fuel type i

$$EBC = \Sigma_i (Q_i \times EF_i,PM\ 2.5 \times SFi,BC/PM_2.5)$$

Aviation

Method for Aviation: Tier 2 – Tier 1 = cruising emissions

Tier 2: Total Black Carbon emissions from aviation sources (EBC)

$LTO_{i,j}$	activity annual airport LTOs (landing and take-off cycles) for aircraft type i using fuel type j
I	aircraft type (i.e. commercial air carriers, air taxis, general aviation, military)
j	aircraft fuel type (i.e. aviation gasoline, or jet fuel)
$EF_{i,j}$,PM2.5	PM2.5 emission factor for aircraft type i and fuel type j
$SF_{i,j}$,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for fuel type j

$$\mathbf{EBC = \Sigma_{i,j} (LTO_{i,j} \times EF_{i,j},PM\ 2.5 \times SF_{i,j},BC/PM2.5)}$$

Tier 1: Total Black Carbon emissions from aviation sources (EBC)

I	type of fuel (i.e. aviation gasoline or jet fuel). Note that piston engines associated with smaller aircraft and helicopters use aviation gasoline while jet fuel is used by larger helicopters and aircraft equipped with turboprops, turbofans and jets
Q_i	quantity of aviation fuel used by fuel type, i
EF_i,PM2.5	PM2.5 emission factor for aircraft type i and fuel type i
SF_i,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for fuel type i

$$\mathbf{EBC = \Sigma_{i,j} (Q_i \times EF_i,PM\ 2.5 \times SF_i,BC/PM2.5)}$$

Residential Combustion

For this sector, the Tier 2 method was used for wood heaters.

Other Sources

Biomass Burning

Open Burning

A Tier 3 FullCAM method was used for Biomass Burning.

Variable	Description
0.45	Fraction of carbon in fuel
A_k	area burned of biome'k'
B_k	fuel load (mass of fuel per area for biome'k')
a_k	Fraction of above-ground biomass for biome'k'
b_k	Combustion efficiency (fraction of fuel burned for biome'k')
EF_k,PM2.5	PM2.5 emission factor for biome'k' (i.e. emissions per mass of C in the fuel [kg/kg-C in fuel])
SF_k,BC/PM2.5	speciation factor to convert PM2.5 to black carbon for biome'k'

$$\mathbf{EBC = (0.45 \times A_k \times B_k \times a_k \times b_k) \times EF_k,PM\ 2.5 \times SF_k,BC/PM_2.5)}$$

Agricultural Burning

For this sector, the Tier 2 method is used.

A5.7.1 Black Carbon Emissions by Sector

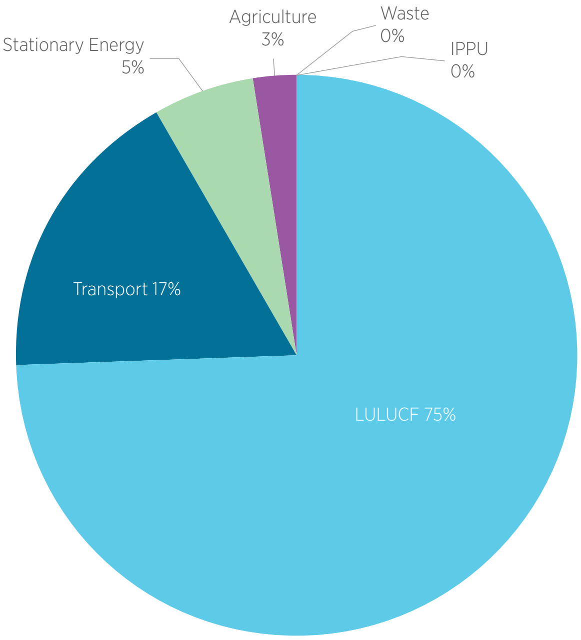
The black carbon emissions by sector from 2008–09 to 2021–22 are displayed below. There is a downward trend of black carbon emissions in this period.

Table A5.7.1.1 Black carbon emissions (kt) including Land Use, Land-Use Change and Forestry (LULUCF)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1 Energy	**45.3**	**49.1**	**52.0**	**56.4**	**58.5**	**60.2**	**61.0**	**63.1**	**62.7**	**66.2**	**66.0**	**62.0**	**56.1**	**60.1**
Fuel Combustion	45.3	49.1	52.0	56.4	58.5	60.2	61.0	63.1	62.7	66.2	66.0	62.0	56.1	60.1
Energy Industries	5.2	5.3	5.1	6.9	6.9	7.4	6.8	7.1	5.0	5.5	5.7	5.7	5.4	5.5
Manufacture of Solid Fuels and Other Energy Industries	4.4	4.6	4.4	6.3	6.2	6.7	6.2	6.5	4.5	5.1	5.2	5.3	4.9	5.1
Petroleum Refining	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Public Electricity and Heat Production	0.7	0.4	0.5	0.5	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.3
Manufacturing Industries and Construction	6.3	6.0	6.1	7.2	7.5	7.6	7.4	7.4	7.7	7.4	7.5	7.5	7.6	8.1
Other (not elsewhere classified)	0.2	0.3	0.4	0.3	0.3	0.4	0.3	0.4	0.3	0.4	0.3	0.4	0.3	0.2
Other Sectors	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3
Transport	33.3	37.4	40.2	41.7	43.6	44.5	46.1	47.8	49.3	52.4	52.2	48.0	42.5	46.0
2 Industrial Processes	**0.4**	**0.3**	**0.4**	**0.3**	**0.2**	**0.3**	**0.3**	**0.4**	**0.4**	**0.4**	**0.3**	**0.4**	**0.4**	**0.4**
3 Agriculture	**4.1**	**3.6**	**5.2**	**5.2**	**4.9**	**4.6**	**4.4**	**4.0**	**6.5**	**4.5**	**2.9**	**3.1**	**6.4**	**6.7**
4 Land Use, Land Use Change and Forestry UNFCCC	**367.4**	**352.6**	**329.3**	**290.5**	**285.9**	**304.4**	**281.1**	**282.5**	**275.5**	**254.1**	**236.2**	**218.7**	**214.0**	**198.7**
5 Waste	**0.0**	**0.1**	**0.0**	**0.0**	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Memo Items (including International Bunkers – Marine and Aviation)	18.2	23.4	22.7	24.0	24.7	26.8	26.7	28.5	30.7	32.4	34.2	26.4	9.1	12.9
Total (excluding Memo Items)	**417.2**	**405.7**	**386.9**	**352.5**	**349.6**	**369.5**	**346.8**	**350.1**	**345.3**	**325.2**	**305.4**	**284.3**	**276.9**	**266.0**

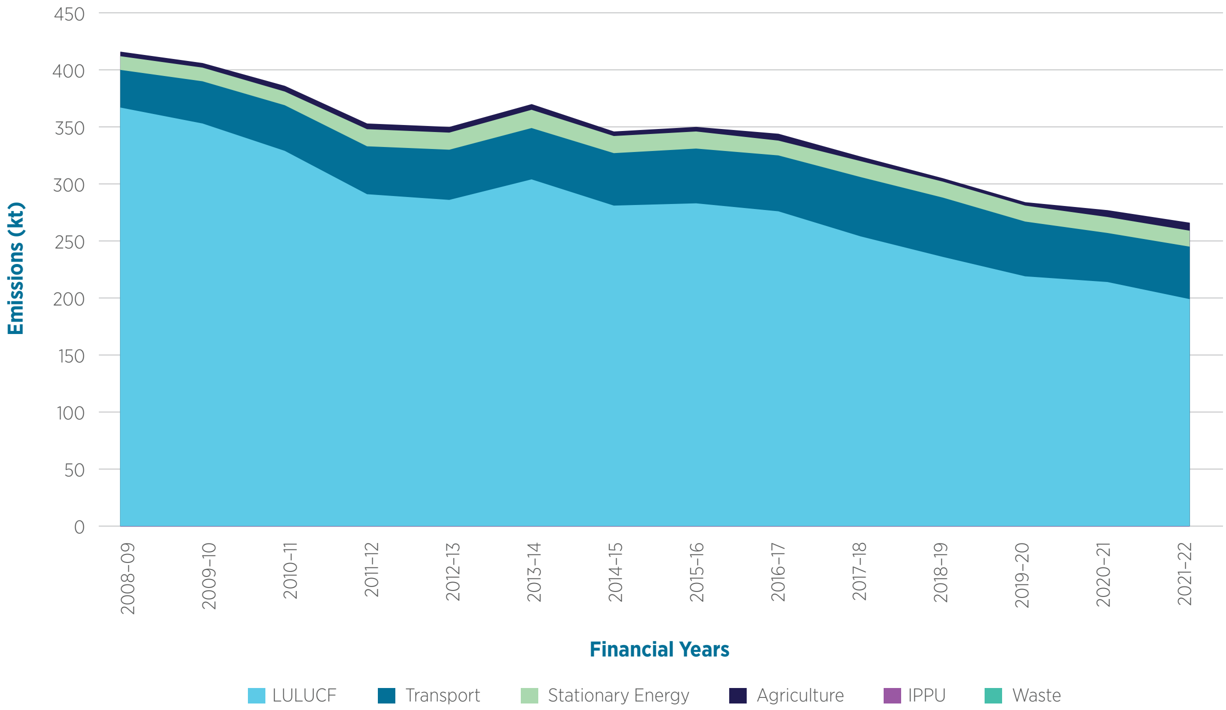
The distribution of black carbon by sector for year 2022 is displayed below. LULUCF sector (including biomass burning) is the highest emitter of black carbon followed by Transport sector (including diesel consumption in heavy vehicle and Kerosene consumption in aviation).

Figure A5.7.1.1 Black Carbon distribution by sector for year 2021–22



The figure below displays the trend of black carbon distribution by sector. Over this period, LULUCF and Transport sectors were the largest emitters.

Figure A5.7.1.2 Black carbon distribution by sector, trend



Measured data from the NPI for aerosol particulate matter with an aerodynamic diameter less than 10μm (PM10) and the precursor SO_2, since 2008–09, is presented below.

Table A5.7.1.2 National pollutant Inventory measured PM10 data from combustion processes, 2008–09 to 2021–22

	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
1 Energy	**518.6**	**521.6**	**623.3**	**724.8**	**812.0**	**892.6**	**930.7**	**943.9**	**898.9**	**826.0**	**883.3**	**953.1**	**1,061.0**	**1,128.4**
Fuel Combustion	518.6	521.6	623.3	724.8	812.0	892.6	930.7	943.9	898.9	826.0	883.3	953.1	1,061.0	1,128.4
Energy Industries	245.9	244.0	320.1	354.4	408.7	450.8	432.8	429.6	394.6	356.5	364.7	376.8	348.3	416.0
Manufacture of Solid Fuels and Other Energy Industries	212.2	219.8	293.0	328.9	386.4	427.7	406.9	405.1	371.3	334.4	342.6	357.8	329.8	397.7
Petroleum Refining	1.2	1.1	0.8	0.8	1.1	1.0	0.8	0.6	0.6	0.5	0.6	0.6	0.5	0.3
Public Electricity and Heat Production	32.5	23.2	26.3	24.7	21.2	22.1	25.1	23.8	22.8	21.7	21.5	18.4	18.1	18.0
Manufacturing Industries and Construction	264.4	264.5	293.7	360.1	394.7	432.4	487.9	501.4	492.2	457.6	505.6	558.6	698.0	697.9
Other Sectors	8.3	13.1	9.5	10.3	8.5	9.4	10.0	13.0	12.1	11.9	13.0	17.7	14.7	14.6
2 Industrial Processes	**11.3**	**11.7**	**12.0**	**11.2**	**12.0**	**13.7**	**12.8**	**13.4**	**13.3**	**13.5**	**15.3**	**14.6**	**16.5**	**16.4**
5 Waste	**0.4**	**0.5**	**0.2**	**0.2**	**0.2**	**0.4**	**1.5**	**1.4**	**1.5**	**2.1**	**2.7**	**3.1**	**3.0**	**4.8**
Total	**530.3**	**533.8**	**635.6**	**736.2**	**824.2**	**906.8**	**945.0**	**958.7**	**913.8**	**841.5**	**901.2**	**970.8**	**1,080.6**	**1,149.6**

Table A5.7.1.3 National pollutant Inventory measured SO2 data from combustion processes, 2008–09 to 2021–22

	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
1 Energy	**777.2**	**759.3**	**733.0**	**726.7**	**700.7**	**679.5**	**661.6**	**645.1**	**640.4**	**642.4**	**630.6**	**603.6**	**591.7**	**573.1**
Fuel Combustion	777.2	759.3	733.0	726.7	700.7	679.5	661.6	645.1	640.4	642.4	630.6	603.6	591.7	573.1
Energy Industries	651.6	632.9	608.6	604.2	577.0	560.4	560.5	546.9	543.6	543.1	531.2	506.8	491.9	470.8
Manufacture of Solid Fuels and Other Energy Industries	11.4	13.8	11.8	14.7	14.3	13.1	11.3	11.5	13.0	11.4	11.7	12.4	11.8	9.7
Petroleum Refining	8.7	9.1	9.8	7.4	7.7	7.2	6.4	5.6	5.4	5.7	5.6	4.8	3.8	3.8
Public Electricity and Heat Production	631.4	610.1	587.0	582.1	554.9	540.1	542.8	529.7	525.3	525.9	513.9	489.6	476.3	457.3
Manufacturing Industries and Construction	90.7	90.8	89.2	88.2	92.8	87.4	68.5	65.1	61.7	62.2	61.7	61.0	61.8	62.8
Other (not elsewhere classified)	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.4	0.3	0.3	0.3	0.4	0.3	0.2
Other Sectors	7.4	7.5	7.4	7.8	7.9	8.0	8.3	8.5	9.0	9.1	7.8	7.0	8.7	9.3
Transport	27.3	27.8	27.4	26.1	22.7	23.4	24.0	24.3	25.8	27.7	29.6	28.6	29.1	29.9
2 Industrial Processes	**1,820.2**	**1,618.8**	**1,774.0**	**1,791.4**	**1,713.5**	**1,819.4**	**1,723.3**	**1,820.7**	**1,647.7**	**1,441.6**	**1,568.4**	**1,519.5**	**1,632.4**	**1,382.9**
Total	**2,597.4**	**2,378.1**	**2,507.0**	**2,518.1**	**2,414.2**	**2,499.0**	**2,384.9**	**2,465.8**	**2,288.1**	**2,084.1**	**2,199.0**	**2,123.1**	**2,224.1**	**1,956.0**

A5.8 Emissions tables by sector and by gas

Summaries of Australia's emissions by sector and by greenhouse gas are presented in the following tables for the 2021–22 year.

Table A5.8.1 Energy sector emissions by greenhouse gas in gigagrams of carbon dioxide equivalent (Gg CO_2-e), 2021–22

Greenhouse Gas Source and Sink Categories	CO₂-e emissions (Gg)			
	CO_2	CH_4	N_2O	Total
1. Energy	**361,194**	**33,065**	**2,452**	**396,712**
A. Fuel Combustion	**344,054**	**2,163**	**2,419**	**348,636**
1 Energy Industries	189,680	790	766	191,236
a Public Electricity and Heat Production	155,881	348	538	156,767
b Petroleum Refining	2,397	1	2	2,400
c Manufacture of Solid Fuels	31,402	441	226	32,069
2 Manufacturing Industries and Construction	42,634	69	423	43,127
3 Transport	88,425	309	1,029	89,763
a Domestic aviation	5,770	1	11	5,782
b Road Transportation	75,990	173	594	76,758
c Railways	3,609	6	410	4,025
d Navigation (domestic)	2,118	125	13	2,256
e Other Transportation	938	5	0	943
4 Other Sectors	22,593	994	195	23,782
5 Other Mobile (military)	722	1	5	728
B. Fugitive Emissions From Fuels	**17,140**	**30,902**	**34**	**48,076**
1 Solid Fuels	1,961	23,659	0	25,620
2 Oil and Natural Gas	15,179	7,243	33	22,455
C. CO_2 Transport, Injection and Geological Storage	**0.3**	**NA**	**NA**	**0.3**
1 Injection and Storage	0.3	NA	NA	0.3
2 Transport	NA	NA	NA	NA

Table A5.8.2 Industrial Processes and Product Use sector emissions by greenhouse gas in gigagrams of carbon dioxide equivalent (Gg CO_2-e), 2021–22

Greenhouse Gas Source and Sink Categories	CO_2-e emissions (Gg)				
	CO_2	CH_4	N_2O	HCF/ PFC/SF_6	Total
2. Industrial Processes and Product Use	**19,933**	**84**	**1,499**	**11,451**	**32,967**
A. Mineral Industry	5,582	-	-	-	5,582
B. Chemical Industry	3,254	12	1,484	-	4,750
C. Metal Industry	10,695	72	15	247	11,028
D. Non-energy products from fuels and solvent use	178	-	-	-	178
E. Electronics industry	NA	NA	NA	NA	NA
F. Product uses as substitutes for Ozone Depleting Substances	-	-	-	11,047	11,047
G. Other product manufacture and use	-	-	-	158	158
H. Other	223	-	-	-	223

Table A5.8.3 Agriculture sector emissions by greenhouse gas in gigagrams of carbon dioxide equivalent (Gg CO_2-e), 2021–22

Greenhouse Gas Source and Sink Categories	CO_2-e emissions (Gg)			
	CO_2	CH_4	N_2O	Total
3. Agriculture	**3,202**	**61,846**	**12,402**	**77,451**
A. Enteric fermentation	NA	54,682	NA	54,682
B. Manure management	NA	6,514	671	7,184
C. Rice cultivation	NA	291	NA	291
D. Agricultural soils	NA	NA	11,585	11,585
E. Prescribed burning of savannas	NA	IE	IE	IE
F. Field burning of agricultural residues	NA	360	147	507
G. Liming	1,318	NA	NA	1,318
H. Urea	1,884	NA	NA	1,884

Table A5.8.4 Land Use Change and Forestry sector emissions by greenhouse gas in gigagrams of carbon dioxide equivalent (Gg CO_2-e), 2021–22

Greenhouse Gas Source and Sink Categories	CO_2-e emissions (Gg)			
	CO_2	CH_4	N_2O	Total
4. Land use, land use change and forestry	**-105,680**	**13,959**	**3,347**	**-88,374**
A. Forest Land	-72,108	6,005	1,521	-64,582
1 Forest Land remaining Forest Land	-21,835	5,769	1,187	-14,878
2 Land converted to Forest Land	-50,272	235	334	-49,704
B. Cropland	-11,713	16	14	-11,682
1 Cropland remaining Cropland	-11,730	-	-	-11,730
2 Land converted to Cropland	17	16	14	47
C. Grassland	-17,420	5,705	1,649	-10,067
1 Grassland remaining Grassland	-23,137	4,969	1,427	-16,741
2 Land converted to Grassland	5,717	735	221	6,674
D. Wetland	-75	-	0	-75
1 Land converted to Wetland	-583	2,219	153	1,790
2 Wetland remaining Wetland	5	14	-	19
E. Settlements	1,754	14	10	1,778
1 Settlements remaining Settlements	NA	NA	NA	NA
2 Land converted to Settlements	1,830	14	10	1,854
F. Other Land	NO, NA	NO, NA	NO, NA	NO, NA
G. Harvested Wood Products	-5,611	-	-	-5,611

Table A5.8.5 Waste sector emissions by greenhouse gas in gigagrams of carbon dioxide equivalent (Gg CO_2-e), 2021–22

Greenhouse Gas Source and Sink Categories	CO_2-e emissions (Gg)			
	CO_2	CH_4	N_2O	Total
5. Waste	**32**	**13,477**	**355**	**13,865**
A. Solid Waste disposal	NA	10,552	NA	10,552
B. Biological treatment of solid waste	NA	129	156	285
C. Incineration and open burning of waste	32	NA	NA	32
D. Wastewater treatment and discharge	NA	2,797	199	2,996

ANNEX VI:
Common Reporting Tables

The Common Reporting Tables for Australia are available on the UNFCCC Website. The associated information is also published online as Australia's National Greenhouse Accounts. The data can be explored at https://greenhouseaccounts.climatechange.gov.au/

The use of Common Reporting Tables, as prescribed under the Paris Agreement, results in some differences with previous submissions (prior to NIR 2021, submitted in 2023). For example, emissions are estimated using global warming potential values from the IPCC 5th Assessment Report rather than the 4th Assessment Report, the addition of some new reporting categories (for example, for flaring from underground coal mines), and a revised approach to reporting recovered emissions.

Online tools for submitting the Common Reporting Tables to the UNFCCC remain under development by the UNFCCC Secretariat at the time of publishing of this report. As a result, the tables have been manually populated. They will provide a useful basis for testing the new online tools as part of a trial conducted by the UNFCCC secretariat. It is expected that the tables will be resubmitted using the new online tools as part of that trial. Australia welcomes this opportunity to support the development and implementation of the Paris Agreement Enhanced Transparency Framework.

ANNEX VII:

General notes, glossary and abbreviations

A7.1 General notes

Units

The units mainly used in this inventory are joules (J), grams (g), tonnes (t), metres (m) and litres (L), together with their multiples. Standard metric prefixes used in this inventory are:

kilo (k) = 103 (thousand)

mega (M) = 106 (million)

giga (G) = 10^9

tera (T) = 10^{12}

peta (P) = 10^{15}

Emissions are generally expressed in gigagrams (Gg) in the inventory tables, as called for under international guidelines, and in megatonnes (Mt) in the text of the inventory report. Please note that 1 gigagram (Gg) = 1,000 tonnes = 1 kilotonne (kt) and 1 megatonne (Mt) = 1,000,000 tonnes = 1,000 Gg.

Gases

CF_4	perfluoromethane (a PFC)
C_2F_6	perfluoroethane (a PFC)
CH_3CF_3	trifluoroethane (HFC-143a)
CHF_3	trifluoromethane (HFC-23)
CHF_2CF_3	pentafluoroethane (HFC-125)
CH_2FCF_3	tetrafluoroethane (HFC-134a)
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
HFCs	Hydrofluorocarbons
NF_3	nitrogen trifluoride
N_2O	nitrous oxide
NMVOC	non-methane volatile organic compounds
NO_x	oxides of nitrogen
PFCs	perfluorocarbons
SF_6	sulphur hexafluoride
SO_2	sulphur dioxide

Global warming potentials

A comparison of the IPCC's Second Assessment Report (SAR), Fourth Assessment Report (AR4), and Fifth Assessment Report (AR5) is published under Global Warming Potential Values (Greenhouse Gas Protocol, last accessed 2023). In line with reporting requirements for the Paris Agreement and UNFCCC inventory, 100-year GWPs from AR5 are used in this inventory. Key AR5 GWPs are summarised below:

$CO_2 = 1$
$CH_4 = 28$
$N_2O = 265$
$CF_4 = 6{,}630$
$C_2F_6 = 11{,}100$
$CHF_3 = 12{,}400$
$CHF_2CF_3 = 3{,}170$
$CH_2FCF_3 = 1{,}300$
$CH_3CF_3 = 4{,}800$
$SF_6 = 23{,}500$

Conversion factors

Atomic weights can be used to determine the relative mass of an element (e.g. the mass of carbon or nitrogen) within a molecule. These conversion factors can be used to calculate the mass of an element within any given quantity of gas (and vice versa). For the key direct greenhouse gases, the conversion factors are presented in the following table.

From element basis to molecular mass	From molecular mass to element basis
$\frac{CO_2}{C} = \frac{44}{12} = 3.67$ Where 44 is the molecular weight of CO_2, and 12 is the molecular weight of C. This means, for example, that 1 kg of combusted carbon (C) produces 3.67kg of CO_2, [1 kg C x (44/12) = 3.67 kg CO_2]	$\frac{C}{CO_2} = \frac{12}{44} = 0.27$ Where 12 is the molecular weight of C and 44 is the molecular weight of CO_2. This means, for example, that 1kg of CO_2 contains 0.27kg of carbon (C), [1 kg CO_2 x (12/44) = 0.27 kg C]
$\frac{CH_4}{C} = \frac{16}{12} = 1.33$ Where 16 is the molecular weight of CH_4, and 12 is the molecular weight of C. This means, for example, that 1 kg of carbon (C) can produce 1.33kg of CH_4, [1 kg C x (16/12) = 1.33 kg CH_4]	$\frac{C}{CH_4} = \frac{12}{16} = 0.75$ Where 12 is the molecular weight of C and 16 is the molecular weight of CH_4. This means, for example, that 1kg of CH_4 contains 0.75kg of carbon (C), [1 kg CH_4 x (12/16) = 0.75 kg C]
$\frac{N_2O}{N} = \frac{44}{28} = 1.57$ Where 44 is the molecular weight of N_2O, and 28 is the molecular weight of 2 x N. This means, for example, that 1 kg of nitrogen (N) can produce 1.57kg of N_2O, [1 kg x (44/28) = 1.57 kg]	$\frac{N}{N_2O} = \frac{28}{44} = 0.64$ Where 28 is the molecular weight of 2 x N, and 44 is the molecular weight of N_2O. This means, for example, that 1 kg of N_2O contains 0.64 kg N, [1 kg N_2O x (28/44) = 0.64 kg]

A7.1.1 Indicators

In the tables, the following standard indicators are used:

NO	(not occurring) when the activity or process does not occur in Australia
NA	(not applicable) when the activity occurs in Australia but the nature of the process does not result in emissions or removals
NE	(not estimated) where it is known that the activity occurs in Australia but there are no data or methodology available to derive an estimate of emissions
IE	(included elsewhere) where emissions or removals are estimated but included elsewhere in the inventory
C	(confidential) where reporting at a disaggregated level could lead to the disclosure of confidential information

A7.2 Glossary

Term	Description
Activity	A process that generates greenhouse gas emissions or uptake. In some sectors it refers to the level of production or manufacture for a given process or category.
Automotive Diesel Oil (ADO)	A middle distillate petroleum product used as a fuel in high-speed diesel engines. It is mostly consumed in the road and rail transport sectors and agriculture, mining and construction sectors.
Anaerobic	A process relying on bacteria that can live without oxygen.
Anthropogenic	Resulting from human activities. In the inventory, anthropogenic emissions are distinguished from natural emissions.
Bagasse	The fibrous residue of the sugar cane milling process which is used as a fuel in sugar mills.
Briquettes	A composition fuel manufactured from brown coal, which is crushed, dried and moulded under high pressure without the addition of binders.
Bushfire	A term used in Australia to describe wildfire in native vegetation.
Calibration	Model calibration is the estimation and adjustment of model parameters and constants to improve the agreement between model outputs and a data set. Calibration requires high quality data that represent the range of conditions under which the model is required to perform so as to avoid possible bias in emission estimates.
Clinker	An intermediate product from which cement is made.
Coke	The solid product obtained from the carbonisation of suitable types of coal at high temperature. It is low in moisture and volatile matter and is mainly used in the iron and steel industry as an energy source and chemical agent. Semi-coke or coke obtained by carbonisation at low temperatures is included in this category.
Dolomite	A naturally occurring mineral ($CaCO_3$.mg CO_3) which can be used to produce lime, iron and steel.
Emission Factor	The quantity of greenhouse gases emitted per unit of some specified activity.
Emission Intensity	The total emissions divided by the total energy content of the fuels or the total energy used in a sector. The overall emissions intensity of coal used in Australia, for example, is determined by the quantity and emission factors for each of the many types and grades of coal used.
Enteric Fermentation	The process in animals by which gases, including methane, are produced as a by-product of microbial fermentation associated with digestion of feed.
Feedlot	A confined yard area with watering and feeding facilities where livestock (mainly beef cattle) are completely handfed for the purpose of production. It does not include the feeding or penning of cattle for weaning, dipping or similar husbandry purposes or for drought or other emergency feeding, or at a slaughtering place or in recognised saleyards.
Feedstocks	Products derived from crude oil and destined for further processing in the refining industry, other than blending. Products include those imported for refinery intake and those returned from the petrochemical industry to the refining industry, such as naphtha.

Term	Description
Flaring	The process of combusting unwanted or excess gases and/or oil at a crude oil or gas production site, a gas processing plant or an oil refinery.
Forest	Parties are required to select single minimum values for land area, tree crown cover and tree height. Australia uses a criteria of 20% tree crown cover, 2 metre minimum tree height, and a minimum of 0.2 hectares in land area for inclusion. These minimum criteria are within the ranges outlined in the Marrakech Accords.
Fuel Oil	Covers all residual (heavy) fuel oils including those obtained by blending.
Fugitive Emissions	Generally deliberate but not fully controlled emissions that typically result from leaks, including those from pump seals, pipe flanges and valve stems. Fugitive emissions also include methane emitted from coal mine seams. During petroleum storage tank filling, venting loss of vapour is a fugitive emission.
Global Warming Potential (GWP)	Represents the relative warming effect of a unit mass of a gas compared with the same mass of CO_2 over a specific period. Multiplying the actual amount of gas emitted by the GWP gives the CO_2 – equivalent emissions.
Greenhouse Gases	Gases that contribute to global warming, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). In addition, the photochemically important gases – NMVOCs, oxides of nitrogen (NO_x) and carbon monoxide (CO) – are also considered. NMVOC, NO_x and CO are not direct greenhouse gases. However, they contribute indirectly to the greenhouse effect by influencing the rate at which ozone and other greenhouse gases are produced and destroyed in the atmosphere.
Hydrofluorocarbons (HFCs)	Used as substitutes for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).
Intergovernmental Panel on Climate Change (IPCC)	The international body responsible for assessing the state of knowledge about climate change. The IPCC increases international awareness of climate change science and provides guidance to the international community on issues related to climate change response.
Key Category	The IPCC Good Practice report (IPCC 2000) introduces the concept of key categories for prioritising the inventory development process. A key category has a significant influence on a country's total inventory of direct greenhouse gases in terms of absolute level of emissions, the trend in emissions, or both. The tier 1 key category analysis identifies categories that contribute to 95% of the total emissions or 95% of the trend of the inventory in absolute terms. Tier 2 analysis identified categories that contribute to 90% of total uncertainty in the inventory.
Kyoto Protocol	The Kyoto Protocol to the convention on climate change was developed through the UNFCCC negotiating process. The protocol was negotiated in Kyoto, Japan, in 1997. It sets binding greenhouse gas emissions targets for UNFCCC developed country Parties that ratify the agreement. The first commitment period of the KP ran from 2008–2012. In 2012, Parties to the KP agreed to the Doha Amendment, establishing a second commitment period (CP2) that ran from 2013–2020. The CP2 true-up period is yet to be completed.
Liquefied Petroleum Gas (LPG)	A light hydrocarbon fraction of the paraffin series. It occurs naturally, associated with crude oil and natural gas in many oil and gas deposits, and is also produced in the course of petroleum refinery processes. LPG consists of propane (C3H8) and butane (C4H10), or a mixture of the two. In Australia, LPG as marketed contains more propane than butane.
Lubricants	Hydrocarbons that are rich in paraffin and not used as fuels. They are obtained by vacuum distillation of oil residues.
Military Transport	Includes all activity by military land vehicles, aircraft and ships.
Natural Disturbances	In accordance with the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019), natural disturbances include some wildfire events which are non-anthropogenic and are beyond the control of, and not materially influenced by, Australian authorities and occur despite costly and ongoing efforts across regional and national government agencies and emergency services organisations to prevent, manage and control them.
Natural Gas	Consists primarily of methane (around 90%, with traces of other gaseous hydrocarbons, as well as nitrogen and carbon dioxide) occurring naturally in underground deposits. As a transport fuel it is generally used in compressed or liquefied form.
Navigation	All civilian (non-military) water-borne transport of passengers and freight. Domestic water-borne transport consists of coastal shipping (freight and cruises), interstate and urban ferry services, commercial fishing, and small pleasure craft movements. International shipping using marine bunker fuel purchased in Australia is reported but not included in the national inventory emissions total.

Term	Description
NMVOC	Non-methane volatile organic compounds such as alkanes, alkenes and alkynes, aromatic compounds and carbonyls that are gases at standard temperature and pressure (i.e. Boiling points below 200°C) and normally 10 or less carbon atoms per molecule; excludes chlorofluorocarbons (CFCs).
PFC	Perfluorocarbons, chemical compounds containing carbon and fluorine atoms only (e.g. CF_4 and C_2F_6).
Prescribed Burning	The intentional burning of forests to reduce the amount of combustible material present and thereby reduce the risk of wildfires. In Australia this is known as 'fuel reduction burning' or 'hazard reduction burning'.
Process Emission	The gas released as a result of chemical or physical transformation of materials from one form to another.
Reference approach	A 'top-down' tier 1 IPCC methodology for estimating CO_2 emissions from fuel combustion activities (1.a).
Sink	Any process, mechanism, or activity that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.
Solid Waste	Waste from various activities; includes municipal solid waste (waste from domestic premises and council activities largely associated with servicing residential areas, such as street sweepings, street tree lopping, parks and gardens and litter bins), commercial and industrial waste, and building and demolition waste.
Solvent	An organic liquid used for cleaning or to dissolve materials.
Source	Any process or activity that releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere.
Tier	The IPCC methods for estimating emissions and removals are divided into 'tiers' encompassing different levels of activity and technology detail. Tier 1 methods are generally very simple (activity multiplied by default emissions factor) and require less data and expertise than the most complicated tier 3 methods. Tier 2 and 3 methods generally require more detailed country-specific information on things such as technology type or livestock characteristics. The concept of tiers is also used to describe different levels of key source analysis, uncertainty analysis, and quality assurance and quality control activities.
Town Gas	Includes all manufactured gases that are typically reticulated to consumers, including synthetic natural gas, reformed natural gas, tempered LPG, and tempered natural gas.
Uncertainty	Uncertainty is a parameter associated with the result of measurement that characterises the dispersion of values that could be reasonably attributed to the measured quantity (e.g. The sample variance or coefficient of variation). In general inventory terms, uncertainty refers to the lack of certainty (in inventory components) resulting from any causal factor such as unidentified sources and sinks, lack of transparency etc.
United Nations Framework Convention on Climate Change (UNFCCC)	An international environmental treaty which entered into force in 1994. Parties to the convention have agreed to work towards achieving the ultimate aim of stabilising 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.
Validation	Model validation is a demonstration that a model, within its domain of applicability, possesses a satisfactory range of accuracy consistent with the intended application of the model. Validation compares simulated system output with real system observations using data not used in model development. It is used to test the model performance and that the calibration of the model has not produced biased emission estimates.
Verification	In terms of the inventory verification refers to the collection of activities and procedures that can be followed during the planning and development, or after completion of an inventory that can help establish its reliability for the intended application of that inventory. Typically methods external to the inventory are used to verify the truth of the inventory, including comparisons with estimates made by other bodes. Verification as it pertains to modelling is a demonstration that the modelling formalism is correct. It is a check that calculations, inputs, and computer code is correct.
Venting	The process of releasing gas into the atmosphere without combustion. This may be done either at the production site or at the refinery or stripping plants. It is done to dispose of non-commercial gas or to relieve system pressure.

A7.3 Abbreviations

AAA	Aerosol Association of Australia
AAC	Australian Aluminium Council
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABR	Australian Business Register
ABS	Australia Bureau of Statistics
ACARP	Australian Coal Association Research Program
ACT	Australian Capital Territory
AD	Activity Data
ADC	Aluminium Development Council
ADO	Automotive Diesel Oil
ADR	Australian Design Rule
AEC	Australian Energy Council
AEMO	Australian Energy Market Operator
AES	Australian Energy Statistics
AEZ	Agro Ecological Zones
AFRC	Agriculture and Food Research Council
AGA	Australian Gas Association
AGEIS	Australia Greenhouse Emissions Information System
AGO	Australian Greenhouse Office
AIHW	Australian Institute of Health and Welfare
ALFA	Australian Lot Feeders Association
ANAO	Australian National Audit Office
ANGA	Australian National Greenhouse Accounts
ANZSIC	Australia New Zealand Standard Industrial Classification
API	American Petroleum Institute
APPEA	Australian Petroleum Production and Exploration Association
APS	Australian Petroleum Statistics
ARC	Agricultural Research Council
ARRBTR	Australian Road Research Board Transport Research
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.
ASRIS	Australian Soil Resource Information System
AUASB	Auditing and Assurance Standards Board
AUSLIG	Australian Surveying and Land Information Group
AVHRR	Advanced Very High Resolution Radiometer
AWTA	Australian Wool Testing Authority
BEF	Burning Efficiency
BITRE	Bureau of Infrastructure, Transport and Regional Economics
BoM	Bureau of Meteorology
BREE	Bureau of Resources and Energy Economics
BRS	Bureau of Rural Science
CAAANZ	Conservation Agriculture Alliance of Australia and New Zealand
CCS	Carbon Capture and Storage

CER	Clean Energy Regulator
COBIT	Control Objectives for Information and related Technology
COD	Chemical Oxygen Demand
CP1	Kyoto Protocol/ First Commitment Period
CP2	Kyoto Protocol/ Second Commitment Period
CPN	Conditional Probability Network
CRF	Common Reporting Format
CRT	Common Reporting Table
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUEDC	Composite Urban Emissions Drive Cycle
DAFF	Department of Agriculture, Fisheries and Forestry
DAWE	Department of Agriculture, Water and the Environment
DCC	Department of Climate Change
DCCEE	Department of Climate Change and Energy Efficiency
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DEDJTR	Department of Economic Development, Jobs, Transport and Resources
DoEE	Department of the Environment and Energy
DES	Data Exchange Standards
DEWHA	Department of Environment, Water, Heritage and the Arts
DEWR	Department of the Environment and Water Resources
DIS	Department of Industry and Science
DISER	Department of Industry, Science, Energy and Resources
DISR	Department of Industry, Science and Resources
DIT	Department of Infrastructure and Transport
DM	Dry Matter
DMD	Dry Matter Digestibility
DMIRS	Department of Mines and Petroleum Industry, Regulation and Safety
DNRM	Department of Natural Resources and Mines
DOC	Degradable Organic Carbon
DOC_f	fraction of Degradable Organic Carbon dissimilated
DOM	Database Operations Manager
DRET	Department of Resources, Energy and Tourism
DSEWPC	Department of Sustainability, Environment, Water, Population and Communities
DSITI	Queensland Department of Science, Information Technology and Innovation
E&P Forum	Exploration and Production Forum
EEA	European Environment Agency
EDC	Emission Decay Curve
EDS	Early Dry Season
EF	Emission Factor
EIS	Environmental Impact Statements
EITEI	Emissions Intensive Trade Exposed Industries EPA Environmental Protection Agency
ENA	Electricity Networks Association
EPA NSW	NSW Environment Protection Authority
ERIC	Environmental Research and Information Consortium Pty Ltd
ERT	Expert Review Team

ESAA	Energy Supply Association of Australia
FAO	Food and Agriculture Organisation
FOD	First Order Decay
FORS	Federal Office of Road Safety
FPA	Forest Practices Authority
FullCAM	Full Carbon Accounting Model
GA	Geoscience Australia
GCV	Gross Calorific Equivalents
GE	Gross Energy
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GWA	George Wilkenfeld and Associates
GWP	Global Warming Potential
HDPE	High Density Polyethylene
HFC	Hydrofluorocarbon
IBRA	Interim Biogeographic Regionalisation for Australia
IDF	Industrial Diesel Fuel
IEA	International Energy Agency
IEF	Implied Emission Factor
IPCC	Intergovernmental Panel on Climate Change
IUFRO	International Union of Forest Research Organizations
JCPAA	Joint Committee of Public Accounts and Audit
KP	Kyoto Protocol
LDS	Late Dry Season
LKD	Lime Kiln Dust
LNG	Liquefied Natural Gas
LPG	Liquid Petroleum Gas
LTO	Landing/Takeoff
LULUCF	Land use, land use change and forestry
MCF	Methane Correction Factor
MDI	Metered Dose Inhaler
MLA	Meat and Livestock Australia
MMS	Manure Management Systems
MSW	Municipal Solid Waste
MVG	Major Vegetation Groups
MWTP	Municipal Wastewater Treatment Plants
NAILSMA	North Australian Indigenous Land & Sea Management Alliance
NATA	National Association of Testing Authorities
NCAS	National Carbon Accounting System
NG	Natural Gas
NGER	National Greenhouse and Energy Reporting
NGGI	National Greenhouse Gas Inventory
NGGIC	National Greenhouse Gas Inventory Committee
NIR	National Inventory Report
NLWRA	National Land and Water Resources Audit

NORP	Nitrous Oxide Research Program
NSW	New South Wales
NT	Northern Territory
NURG	National Greenhouse Gas Inventory User Reference Group
NVIS 6	National Vegetation Information System V6.0
OECD	Organisation for Economic and Co-operation Development
PVC	Polyvinyl Chloride
QA/QC	Quality assurance/Quality control
QLD	Queensland
RBA	Reserve Bank of Australia
RET	Department of Resources, Energy and Tourism
RIRDC	Rural Industries Research and Development Corporation
ROU	Recycled Organics Unit
RMSE	Root Mean Square Error
RRA	Refrigerant Reclaim Australia
SA	South Australia
SCA	Standing Committee on Agriculture
SCaRP	Soil Carbon Research Program
SECV	State Electricity Commission of Victoria
SUV	Sports Utility Vehicle
SWDS	Solid Waste Disposal Site
TAS	Tasmania
TOC	Total Organic Carbon
UAG	Unaccounted for Gas
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
VIC	Victoria
Vic Forests	Victoria Forests
VKT	Vehicle Kilometres Travelled
VOC	Volatile Organic Compounds
WA	Western Australia
WBCSD	World Business Council for Sustainable Development
WMAA	Waste Management Association of Australia
WRI	World Resource Institute
WSAA	Water Services Association of Australia
YSLB	Years Since Last Burnt

ANNEX VIII: References

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