Life Cycle Inventory of Cement & Concrete produced in Australia

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Final V.1.3

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Document Control

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Contents

Figures

Tables

1 Introduction

This report outlines the inventory development process for the cement concrete produced in Australia.

The first section of the report outlines the inventory development process for cement produced in Australia. The inventories are based on the three major integrated cement manufacturers however they are not based entirely on industry specific data as there are gaps in the published literature of the operation and impacts of the Australian cement industry. Table 1 shows 6 cement production inventories produced in this inventory consisting of cement from local integrated plants and from grinding of imported clinker and an average of the two. For these three options are presented in ordinary cement and general purpose cement.

Table 1: Cement products in this inventory

Case No.	Production type	Cement type
1	Australian cement production from integrated cement facilities	Ordinary Portland Cement
2	Australian cement production from imported clinker	
3	Average Australian cement supply	
4	Australian cement production from integrated cement facilities	General Purpose Cement
5	Australian cement production from imported clinker	
6	Average Australian cement supply	

The inventory developed is based on the available data from seven integrated clinker and cement facilities belonging to the three major companies as mentioned in the below table:

Table 2: Major integrated Clinker Cement facilities

Holding Company	Facility	State
Adelaide Brighton Cement Ltd	Angaston Special Products	SA
	Birkenhead Plant	SA
	Munster (Russell Rd) Operations	WA
Boral Cement Ltd	Berrima Cement Works	NSW
	Maldon Cement Works	NSW
Cement Australia	Fisherman’s Landing	QLD
	Railton Works	TAS

Source: (CIF) website

The table below shows the annual cement producing capacity of each facility.

Table 3: Annual Cement production capacity

Holding Company	Facility	State	Annual Cement Capacity (Mt)
Adelaide Brighton Cement Ltd	Angaston Special Products	SA	0.25
	Birkenhead Plant	SA	1.95
	Munster (Russell Rd) Operations	WA	0.63
Boral Cement Ltd	Berrima Cement Works	NSW	1.60
	Maldon Cement Works	NSW	0.88
Cement Australia	Fisherman's Landing	QLD	2.20
	Railton Works	TAS	2.00
Total			**9.51**

Source: (Cemnet.com) website

2 Cement Inventory Development

2.1 System Boundary

Figure below describes system boundary that defines the limits of this inventory.

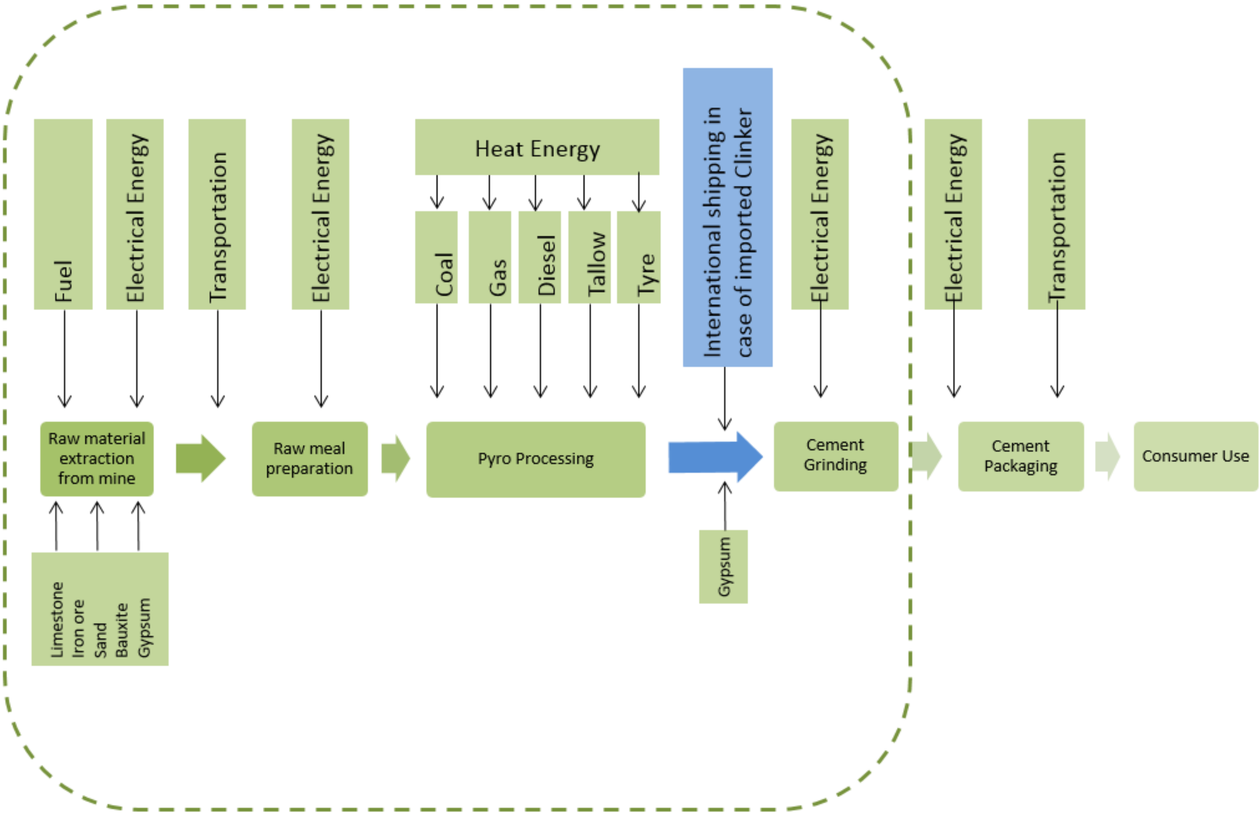


Figure 1: System Boundary for production of cement

2.2 Types of Cement and mixes

Ordinary Portland and General purpose types of cement have been considered in the scope of preparation of the inventory, following table indicates the mix ratios adopted for the two types of cement.

Table 4: Types of Cements

Cement type	Clinker	Gypsum	Limestone
Ordinary Portland cement	95 %	5 %	-
General purpose cement	90 %	5 %	5 %

Source: Adopted from Appendix B (Cement Industry Federation 2005)

2.3 Clinker

2.3.1 Raw Meal

Clinker is the main component of Cement produced by limestone and constitutes up to 95% quantity of the cement. Clinker is produced from a mixture of limestone, shale, clay, Aluminium oxide, iron oxide which is primarily obtained from mines. It is transported, mixed accurately and finally grinded to a fine powder called the raw meal. Typically 1.57 tonnes of raw meal is required to produce 1 tonne of clinker (Nilsson, Persson et al. 2007).

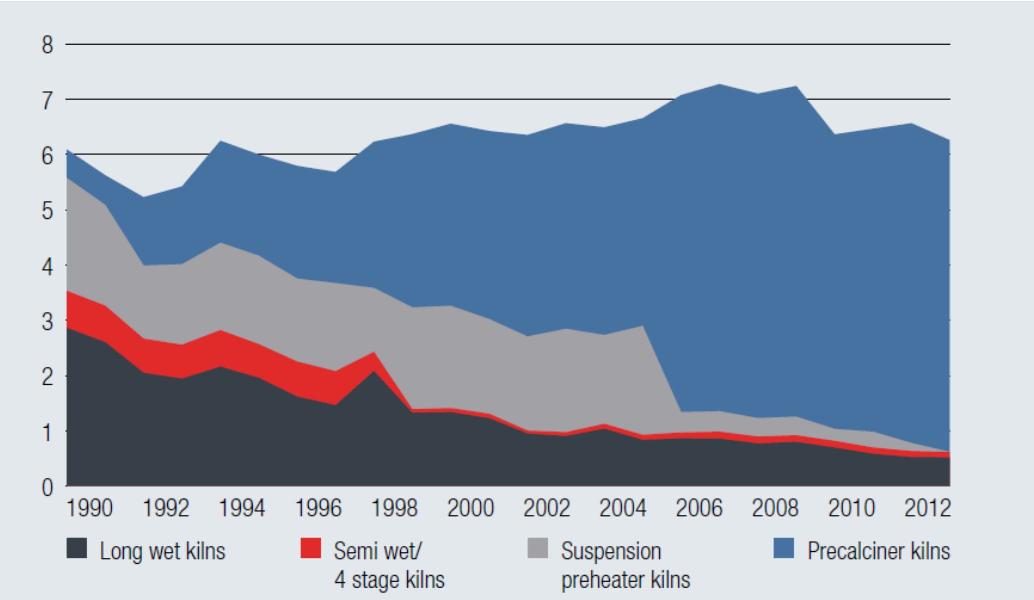
The "raw meal" mix and its proportions adopted for this study has been tabulated below.

Table 5: Raw meal mix taken for clinker production

Material as fed in the raw meal	Percentage of material fed	Chemical component in material	Percentage of chemical in material	Comment
Limestone	89%	Calcium Carbonate	80 %	Assumed that limestone contains 80% of pure calcium carbonate
		Silicon oxide	20%	Rest 20% is assumed to be sand which is added as a percentage of sand
Sand	3%	Silicon oxide	100 %	20% impurities in limestone is assumed to be silica and 3% more is added to make the final silica component equal to 21%.
Iron Ore	2%	Iron oxide	100 %	
Bauxite	3%	Aluminium oxide	100 %	
Calcareous Marl	3%	Calcareous Marl	100 %	Listed as other materials but modelled as calcareous marl based on ecoinvent process

2.3.2 Kiln technologies

Pre-calciner kiln technology is used in production of more than 90% share of clinker and is continuing to grow therefore it has been assumed in this inventory.



Source: (Cement Industry Federation 2013)

Figure 2: Clinker production by kiln type (million tonnes)

2.3.3 Cement vs Clinker produced

The total amount of cement production reported by Australian cement industry was 8.6 million tonnes in the year 2012-13 while clinker production was 6.3 million tonnes (Cement Industry Federation 2013).

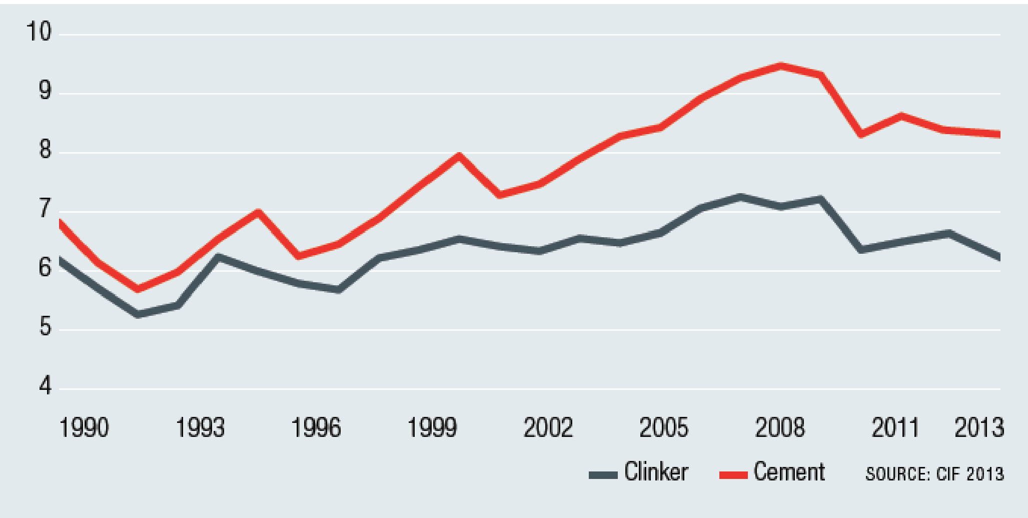


Figure 3: Clinker and cement production over time (million tonnes)

2.3.4 Clinker imports

The deficit between the clinker and cement production is accounted by importing clinker from other countries, as well as gypsum, fly ash and slags incorporated into cement. In 2012–13 clinker imports into Australia were 1.86 Mt sourced mainly from Japan (65%), China (30%) and Indonesia (3%) table below shows the share of imported clinker adopted for the development of the inventory.

Table 6: Share of imported clinker from other countries

Country	Share
Japan	65 %
China[1]	35 %

Source: (Cement Industry Federation 2013)
1 China' share was 30% as per (Cement Industry Federation 2013), rest 5% imported from other countries such as Indonesia, Thailand is also added in China' share for the purpose of producing inventory.

2.4 Fuel

2.4.1 Primary Fuel

The raw meal is heated in kiln at high temperature of up to 1450 °C which enables the raw materials to form clinker. Coal and Gas are the primary fuels used in the Australian Cement Industry, the table below shows the primary Fuel used in each Facility.

Table 7: Types of Primary Fuel used in Australian Cement Plants

Cement Plant	Primary Fuel	Comments
Angaston Special Products	Gas	
Birkenhead Plant	Gas	
Munster (Russell Rd) Operations	Gas/Coal	Assumed to be 50% Gas and 50% Coal
Berrima Cement Works	Coal	
Maldon Cement Works	Coal	
Fisherman's Landing	Coal	
Railton Works	Data not available	Assumed to be 50% Gas and 50% Coal

Source: Table:1 (Warnken and Giurco 2003)

Primary fuel mix for the study has been adopted as weighted mean from the above table and production capacity of Industry from Table 3. The share of primary fuel comes out to be 63% from Coal and 37% from Gas as Fuel.

Table 8: Share of Primary Fuel used in Australian Cement Plants

Cement Plant	Per cent share[1]
Coal	63 %
Gas	37 %

1 Weighted mean adopted from Table 3 and Table 7

2.4.2 Alternative Fuel

Industry is trying hard to cut down the CO_2 emissions, since burning of fuels for generation of heat is one of the biggest contributors, therefore replacing part of conventional fuel share with alternative fuels is being considered. In 2012-13 the share of alternative fuel in Australian Cement industry was 7.8 percent (Cement Industry Federation 2013). The table below shows the alternative fuels and their share used in the inventory.

Table 9: Share of Alternative Fuels

Fuel type	Percentage share[2]	Comments
Tallow[1]	33.35 %	50 % share divided between tallow and waste oil
Waste Oil[1]	33.35 %	50 % share divided between tallow and waste oil
Tyres	16.65 %	
Coke	16.65 %	Coke is listed in CIF report under the category of alternative fuel, those which are not a part of traditional fuels

Source: Adapted from (Cement Industry Federation 2005)
1 Listed as liquid fuels, taken to be a mix of tallow and waste oil.
2 Estimated from mix of alternative fuels listed in Table 6 in (Cement Industry Federation 2005)

2.4.3 Fuel Mix

A Fuel mix has been derived for the study based on the available data and generalising it for the entire integrated cement production in Australia. The table below represents the fuel mix adopted for the model.

Table 10: Australian fuel mix for production of cement

Type of Fuel	Share	Fuel adopted	Percentage
Primary Fuel	91 %	Coal	57.00 %
		Gas	34.00 %
Alternative Fuel	8 %	Tallow	2.665 %
		Waste oils	2.665 %
		Tyre	1.33 %
		Coke	1.33 %
Lighting kiln	1 %	Diesel	1.00 %

Source: Adapted from (Cement Industry Federation 2005) and data in Table 7 and Table 9

Table 11: Fuel mix for imported Clinker

Type of Fuel	Fuel adopted	Japan	China
Coal	Coal	94.0 %	94.0 %
Oil	Fuel Oil	3.0 %	5.5 %
Gas	Natural Gas	0.0 %	0.5 %
Others	Tyres	1.5 %	0.0 %
	Waste Oil	1.5 %	0.0 %

Source: (Michael Taylor 2006)

2.5 Electricity

Electricity is used in every step of cement making process, right from mining of the raw materials to the final grinding of clinker to produce cement and forms one of the major component, responsible for 13% of GHG emissions of cement industry (Cement Industry Federation 2013).

The below table shows the electricity requirement for production of domestic and imported cement.

Table 12: Electricity requirements

Country	Electricity in kWh/tonne of cement	Comments
Australia	99	Forecasted by Cement Industry Federation for 2012 (Cement Industry Federation 2005)
Japan	100	From (Michael Taylor 2006)
China	118	From (Michael Taylor 2006)

2.6 Transportation

2.6.1 Local Transportation

Transportation forms an integral part of the process, the distance of limestone quarry from the plant largely varies. Table 13 shows the distance and mode for each plant.

Table 13: Distance and mode of transport for each plant

Plant	Quarry Location	Distance of Quarry from Plant (km)	Mode of transport
Angaston Special Products	Rapid Bay	177	Road
Birkenhead Plant	Rapid Bay	113	Road
Munster (Russell Rd) Operations	Munster Mine	1	Road
Berrima Cement Works	Marulan	70	Rail
Maldon Cement Works	Marulan	130	Rail
Fisherman's Landing	East End Mine	31	Rail
Railton Works	Railton Mine	1	Road

Source: (Information available on various webpage and distances as measured from google maps)

2.6.2 International shipping

The table below shows the shipping distance taken for importing clinker to Australia.

Table 14: Average shipping distance for imported clinker to Australia

Clinker Import Location	Shipping distance to Melbourne* (km)
From Japan	9110
From China	9620

* Clinker is imported all over Australia however for the purpose of calculation of shipping distance, port of Melbourne is adopted

2.7 Unit process for manufacturing of clinker

This inventory is developed accounting for local as well as imported clinker production, the unit processes for clinker produced in the three countries have been tabulated below.

Table showing share of clinker source for production of cement in Australia

Table 15: Clinker source for production of cement in Australia

Clinker Source	Amount of Clinker (Mt)	Per cent share
Domestic	6.23	77 %
Imported	1.86	23 %

Source: (Cement Industry Federation 2013)

2.7.1 Unit process for clinker produced in Australia

Table 16: Unit Process for Clinker produced in Australia

Flow	Unit	Value	Comment
Product			
Clinker	kg	1	Functional Unit
Materials and Energy			
Water, natural origin	l	0.67	670 litres per tonne of cement as per CIP industry report 2013. Assuming 100% water is used till clinker production
Ammonia, liquid	kg	0.0007	0.7 kg ammonia per tonne of clinker as per Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide (Schorcht, Kourti et al. 2013)
Lubricating oil, at plant	kg	0.0000471	As ecoinvent process
Limestone, at mine	kg	1.39	Assuming Limestone contains 80% Calcium Carbonate and 20% Silicon impurities
Iron ore, 65% Fe, at beneficiation	kg	0.0314	Assuming 2% of raw meal is Iron Oxide as per Table 2.
Cement plant	p	6.27E-12	As ecoinvent process
Sand, at mine	kg	0.051	Considering that 20% impurities in limestone is silica and rest of the 21% added as sand
Bauxite, at mine	kg	0.0471	Assuming 3% of raw meal is Aluminium Oxide as per Table 2
Calcareous marl, at plant	kg	0.0471	As ecoinvent process, assuming rest of the 3% part of the raw meal is calcareous marl
Industrial machine, heavy, unspecified, at plant	kg	0.0000376	As ecoinvent process
Electricity, low voltage, Australian	kWh	0.0614	99 kwh/t of cement as per CIF forecast for 2012 62% of this electrical energy is used for production of clinker and rest for cement grinding (Madlool, Saidur et al. 2011)
Black coal, QLD, at mine	kg	0.117	57% of fuel requirement come from Coal, derived from Australian Cement Industry Federation reports
Natural gas, high pressure, Australia	kg	0.028645	34% of fuel requirement come from Gas, derived from Australian Cement Industry Federation reports
Diesel burned in generating set	MJ	0.000942	As ecoinvent process

Flow	Unit	Value	Comment
Tallow, at plant	kg	0.00491	2.67% of fuel requirement come from Tallow, derived from Australian Cement Industry Federation reports
waste oil, delivered to plant/AU U	kg	0.00261	2.67% of fuel requirement come from waste oil, derived from Australian Cement Industry Federation reports
waste tyre, delivered to plant/AU U	MJ	0.00216	As ecoinvent process
Petroleum coke, at refinery	kg	0.00204	1.33% of fuel requirement come from Coke, derived from Australian Cement Industry Federation reports
Light fuel oil, at regional storage	kg	0.0000376	As ecoinvent process
Transport, truck, 40t load/AU U	tkm	0.0766	For transportation of limestone, taken as weighted mean of road distance of cement plants from quarry, comes out as 55 km
Transport, truck, 40t load/AU U	tkm	0.00281	For transportation of sand by road, assumed same as limestone, i.e. 55 km
transport, freight, rail	tkm	0.0878	For transportation of limestone, taken as weighted mean of rail distance of cement plants from quarry, comes out as 63 km
transport, freight, rail	tkm	0.00321	For transportation of sand by rail, assumed same as limestone, i.e. 55 km

2.7.2 Unit process for clinker produced in Japan

Table 17: Unit Process for Clinker produced in Japan

Flow	Unit	Value	Comment
Product			
Clinker	kg	1	Functional Unit
Materials and Energy			
Water, natural origin, Japan	L	0.67	670 litres per tonne of cement as per CIP industry report 2013. Assuming 100% water is used till clinker production
Ammonia, liquid	kg	0.0007	0.7 kg ammonia per tonne of clinker as per Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide (Schorcht, Kourti et al. 2013)
Lubricating oil, at plant	kg	0.0000471	As ecoinvent process
Limestone, at mine	kg	1.39	Assuming Limestone contains 80% Calcium Carbonate and 20% Silicon impurities

Flow	Unit	Value	Comment
Iron ore, 65% Fe, at beneficiation	kg	0.0314	Assuming 2% of raw meal is Iron Oxide as per Table 2.
Cement plant	p	6.27E-12	As ecoinvent process
Sand, at mine	kg	0.051	Considering that 20% impurities in limestone is silica and rest of the 21% added as sand
Bauxite, at mine	kg	0.0471	Assuming 3% of raw meal is Aluminium Oxide as per Table 2
Calcareous marl, at plant	kg	0.0471	As ecoinvent process, assuming rest of the 3% part of the raw meal is calcareous marl
Industrial machine, heavy, unspecified, at plant	kg	0.0000376	As ecoinvent process
Electricity, low voltage, Japan	kWh	0.062	100 kwh/t of cement (Michael Taylor 2006).
Black coal, QLD, at mine	kg	0.192	94% of fuel requirement come from Coal, (Michael Taylor 2006)
waste oil, delivered to plant/AU U	kg	0.00146	1.5% of fossil fuel requirement assumed to be from wasteoil, (Energy Efficiency and CO2 Emissions from the Global Cement Industry by Michael Taylor, Cecilia Tam and Dolf Gielen)
waste tyre, delivered to plant/AU U	MJ	0.00243	1.5% of fossil fuel requirement assumed to be from tyre, (Energy Efficiency and CO2 Emissions from the Global Cement Industry by Michael Taylor, Cecilia Tam and Dolf Gielen)
Light fuel oil, at regional storage	kg	0.0000376	As ecoinvent process
Transport, truck, 40t load/AU U	tkm	0.0766	For transportation of limestone, taken as weighted mean of road distance of cement plants from quarry, comes out as 55 km
Transport, truck, 40t load/AU U	tkm	0.00281	For transportation of sand by road, assumed same as limestone, i.e. 55 km
Transport, freight, rail	tkm	0.0878	For transportation of limestone, taken as weighted mean of rail distance of cement plants from quarry, comes out as 63 km
Transport, freight, rail	tkm	0.00321	For transportation of sand by rail, assumed same as limestone, i.e. 55 km

2.7.3 Unit process for clinker produced in China

Table 18: Unit Process for Clinker produced in China

Flow	Unit	Value	Comment
Product			
Clinker	kg	1	Functional Unit
Materials and Energy			
Water, natural origin, China	L	0.67	67 litres per tonne of cement as per CIP industry report 2013. Assuming 100% water is used till clinker production
Ammonia, liquid	Kg	0.0007	0.7 kg ammonia per tonne of clinker as per Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide (Schorcht, Kourti et al. 2013)
Lubricating oil, at plant	kg	0.0000471	As ecoinvent process
Limestone, at mine	kg	1.39	Assuming Limestone contains 80% Calcium Carbonate and 20% Silicon impurities
Iron ore, 65% Fe, at beneficiation	kg	0.0314	Assuming 2% of raw meal is Iron Oxide as per Table 2.
Cement plant	p	6.27E-12	As ecoinvent process
Sand, at mine	kg	0.051	Considering that 20% impurities in limestone is silica and rest of the 21% added as sand
Bauxite, at mine	kg	0.0471	Assuming 3% of raw meal is Aluminium Oxide as per Table 2
Calcareous marl, at plant	kg	0.0471	As ecoinvent process, assuming rest of the 3% part of the raw meal is calcareous marl
Industrial machine, heavy, unspecified, at plant	kg	0.0000376	As ecoinvent process
Electricity, low voltage, China	kWh	0.0732	118 kwh/t of cement (Michael Taylor 2006)
Black coal, QLD, at mine	kg	0.192	94% of fuel requirement come from Coal, (Michael Taylor 2006)
Natural gas, high pressure	MJ	0.0429	0.5% of fuel requirement come from Gas, (Michael Taylor 2006)
Light fuel oil, at regional storage	kg	0.0000376	As ecoinvent process
Transport, articulated truck, >20t, fully laden, rural	tkm	0.0766	For transportation of limestone, taken as weighted mean of road distance of cement plants from quarry, comes out as 55 km
Transport, articulated truck, >20t, fully laden, rural	tkm	0.00281	For transportation of sand by road, assumed same as limestone, i.e. 55 km

Flow	Unit	Value	Comment
Transport, freight, rail	tkm	0.0878	For transportation of limestone, taken as weighted mean of rail distance of cement plants from quarry, comes out as 63 km
Transport, freight, rail	tkm	0.00321	For transportation of sand by rail, assumed same as limestone, i.e. 55 km

2.8 Unit process for manufacturing of Cement

This inventory is developed for six types of cement as mentioned in Table 1, the unit processes for each type of cement is mentioned separately below. The inventory only covers bulk cement production; i.e. packaging is excluded.

2.8.1 Ordinary Portland cement produced from integrated cement facilities in Australia

Table 19: Intermediary flows for unit process for cement production in Australia

Flow	Unit	Value	Comment
Product			
Ordinary Portland cement, Cement	kg	1	Functional Unit
Materials and Energy			
Cement Plant	p	5.36E-11	As ecoinvent process
Clinker, at plant	kg	0.95	Ordinary Portland cement contains 95% clinker; source: (Cement Industry Federation 2005)
Gypsum, at mine	kg	0.05	Ordinary Portland cement contains 5% gypsum; source: CIF (Cement Industry Federation 2005)
Electricity, low voltage, Australian	kWh	0.0376	38% of electrical energy is consumed in production of cement from clinker; Source: (Madlool, Saidur et al. 2011). Packing of cement is not included as cement is assumed to be conveyed in bulk to batching plants for which conveyance is added in the Concrete Section
Steel, low alloyed, at plant	kg	0.00004	As ecoinvent process

2.8.2 Ordinary Portland cement produced from imported Clinker in Australia

In 2012-13 1.86 tonnes of Clinker was imported from Japan China and Indonesia. The inventory below has been developed considering Japan and China as the suppliers of Clinker to Australia. The table below shows the share of each country in the inventory.

Table 20: Share of imported clinker

Country	Total imported Clinker (Mt)	Per cent share of each country	Quantity of Clinker imported from each country (Mt)
Japan	1.86	65 %	1.209
China		35 %	0.651

Table 21: Intermediary flows for unit process for cement production from imported Clinker, in Australia

Flow	Unit	Value	Comment
Product			
Ordinary Portland cement, imported clinker, Australia	kg	1	Functional Unit
Materials and Energy			
Cement Plant	p	5.36E-11	As ecoinvent process
Clinker, at plant, Japan	kg	0.617	Ordinary Portland cement contains 95% clinker; source: (Cement Industry Federation 2005)
Clinker, at plant, China	kg	0.332	Ordinary Portland cement contains 95% clinker; source: (Cement Industry Federation 2005)
Gypsum, at mine	kg	0.05	Ordinary Portland cement contains 5% gypsum; source: CIF (Cement Industry Federation 2005)
Electricity, low voltage, Australian	kWh	0.0376	38% of electrical energy is consumed in production of cement from clinker; Source: (Madlool, Saidur et al. 2011).
Steel, low alloyed, at plant	kg	0.00004	As ecoinvent process
Transport, transoceanic freight ship	tkm	8.82	Shipping of clinker from Japan and China to Australia

2.8.3 Average ordinary Portland cement produced in Australia

In 2012-13, the total amount of clinker used for production of cement in Australia was reported to be 8.09 tonnes, out of which 6.23 tonnes was produced in Australia. The following inventory has been developed for average cement produced in Australia, including cement produced from local and imported clinker. The table below shows the proportions of clinker and share adopted for each country.

Table 22: Share of clinker for production of cement in Australia

Name of country producing clinker	Total Clinker used for production of cement (Mt)	Per cent share of local and imported clinker	Per cent share of imported clinker	Per cent share of clinker by country	Quantity of Clinker by country (Mt)
Australia	6.23	77 %	-	77 %	6.23
Japan	1.86	23 %	65 %	15 %	1.209
China			35 %	08 %	0.651

Source: Adopted from (Cement Industry Federation 2013)

Table 23: Intermediary flows for unit process for average cement production in Australia

Flow	Unit	Value	Comment
Product			
Ordinary Portland cement, Australian average	kg	1	Functional Unit
Materials and Energy			
Cement Plant	p	5.36E-11	As ecoinvent process
Clinker, at plant, Australia	kg	0.731	77% Australian clinker
Clinker, at plant, Japan	kg	0.142	15% imported clinker from Japan
Clinker, at plant, China	kg	0.076	8% imported clinker from China
Gypsum, at mine	kg	0.05	Ordinary Portland cement contains 5% gypsum; source: CIF (Cement Industry Federation 2005)
Electricity, low voltage, Australian	kWh	0.0383	38% of electrical energy is consumed in production of cement from clinker; Source: (Madlool, Saidur et al. 2011).
Steel, low alloyed, at plant	kg	0.00004	As ecoinvent process
Transport, transoceanic freight ship	tkm	2.03	Shipping of clinker from Japan and China to Australia

2.8.4 General purpose cement produced from integrated cement facilities in Australia

Cement made from Portland cement clinker and gypsum with the optional addition of up to 5 per cent slag, fly ash and/or limestone—made in accordance with AS 3972, the Australian Standard for cement General purpose cement (Cement Industry Federation 2005).

The mix for General purpose cement adopted here is as mentioned in the Table 4.

Table 24: Intermediary flows for unit process for integrated general purpose cement production in Australia

Flow	Unit	Value	Comment
Product			
General purpose cement, Australia	kg	1	Functional Unit
Materials and Energy			
Cement Plant	p	5.36E-11	As ecoinvent process
Clinker, at plant, Australia	kg	0.9	General purpose cement contains 90% clinker; source: (Cement Industry Federation 2005)
Gypsum, at mine	kg	0.05	General purpose cement contains 5% gypsum; source: CIF (Cement Industry Federation 2005)
Limestone, at mine	kg	0.05	Assumed that rest of the part in general purpose cement contains is limestone; source: CIF (Cement Industry Federation 2005).
Electricity, low voltage, Australian	kWh	0.0376	38% of electrical energy is consumed in production of cement from clinker; Source: (Madlool, Saidur et al. 2011).
Steel, low alloyed, at plant	kg	0.00004	As ecoinvent process

2.8.5 General purpose cement produced from imported clinker, in Australia

Share of imported clinker as per Table 20.

Table 25: Intermediary flows for unit process in general purpose cement production from imported clinker

Flow	Unit	Value	Comment
Product			
General purpose cement, imported clinker, Australia	kg	1	Functional Unit
Materials and Energy			
Cement Plant	p	5.36E-11	As ecoinvent process
Clinker, at plant, Japan	kg	0.585	Japan's share of clinker is 65%.
Clinker, at plant, China	kg	0.315	China's share of clinker is 35%.
Gypsum, at mine	kg	0.05	General purpose cement contains 5% gypsum; source: CIF (Cement Industry Federation 2005)
Limestone, at mine	kg	0.05	Assumed that rest of the part in general purpose cement is limestone; source: CIF (Cement Industry Federation 2005)

Flow	Unit	Value	Comment
Electricity, low voltage, Australian	kWh	0.0376	38% of electrical energy is consumed in production of cement from clinker; Source: (Madlool, Saidur et al. 2011).
Steel, low alloyed, at plant	kg	0.00004	As ecoinvent process
Transport, transoceanic freight ship	tkm	8.2	Shipping of clinker from Japan and China to Australia

2.8.6 Average general purpose cement produced in Australia

Share of imported clinker as per Table 20.

Table 26: Intermediary flows for unit process in average general purpose cement production in Australia

Flow	Unit	Value	Comment
Product			
General purpose cement, Australian average	kg	1	Functional Unit
Materials and Energy			
Cement Plant	p	5.36E-11	As ecoinvent process
Clinker, at plant, Australia	kg	0.693	Australia's share of clinker is 77%
Clinker, at plant, Japan	kg	0.135	Japan's share of clinker is 15%.
Clinker, at plant, China	kg	0.072	China's share of clinker is 8%.
Gypsum, at mine	kg	0.05	General purpose cement contains 5% gypsum; source: CIF (Cement Industry Federation 2005)
Limestone, at mine	kg	0.05	Assumed that rest of the part in general purpose cement contains is limestone; source: CIF (Cement Industry Federation 2005)
Electricity, low voltage, Australian	kWh	0.0383	38% of electrical energy is consumed in production of cement from clinker; Source: (Madlool, Saidur et al. 2011).
Steel, low alloyed, at plant	kg	0.00004	As ecoinvent process
Transport, transoceanic freight ship	tkm	1.92	Shipping of clinker from Japan and China to Australia

2.9 Emissions from clinker production

2.9.1 Parameters

Below table shows the adopted energy content, emission factors values and their source, most of these have been directly adopted from National Greenhouse Accounts Factors, 2014 published by Department of Environment.

Table 27: Energy contents and emission factors adopted for of various fuels

Parameter	Value	Unit	Comment
Energy Content Coal	21	GJ/t	From National Greenhouse Accounts Factors July 2014
Energy Content Gas	51.039	MJ/kg	MJ/kg derived from rom National Greenhouse Accounts Factors July 2014, considering density of gas as 0.77 kg/m3
Energy Content tallow	23.4	GJ/t	Energy content of Tallow fuel used in cement production. (2,5,1,1,1,na)
Energy Content Tyres	26.5	GJ/t	Energy content of Tyres fuel used in cement production. (2,5,1,1,1,na)
Energy Content diesel	45.626	MJ/kg	From National Greenhouse Accounts Factors July 2014
Energy Content Coke	28	MJ/kg	From http://www.natural-gas.com.au/about/references.html
Energy Content Fuel-Oil	44.07	MJ/kg	From National Greenhouse Accounts Factors July 2014
Energy Content Waste-Oil	44.07	MJ/kg	Assumed to be same as Fuel oil
CO2 emission factor clinker production	0.544	t/t	From National Greenhouse Accounts Factors July 2014
CO2 emission factor Coal	88.2	Kg/GJ	From National Greenhouse Accounts Factors July 2014
CO2 emission factor Gas	51.2	Kg/GJ	From National Greenhouse Accounts Factors July 2014
CO2 emission factor Tallow	2.75	Kg/GJ	kg/kg, Estimated from 75% Carbon content assuming 100% oxidation- note this is biogenic carbon
CO2 emission factor Diesel	69.2	Kg/GJ	From National Greenhouse Accounts Factors July 2014

Parameter	Value	Unit	Comment
CO_2 emission factor Tyres	79.9	Kg/GJ	From National Greenhouse Accounts Factors July 2014
CO_2 emission factor Coke	104.9	Kg/GJ	From National Greenhouse Accounts Factors July 2014
CO_2 emission factor Fuel-oil	72.9	Kg/GJ	From National Greenhouse Accounts Factors July 2014
CO_2 emission factor waste-oil	72.9	Kg/GJ	Assumed to be same as Fuel oil
CH_4 emission factor Coal	1.4E-03	kg/GJ	From National Greenhouse Accounts Factors July 2014
CH_4 emission factor Gas	4.8E-03	kg/GJ	From National Greenhouse Accounts Factors July 2014
CH_4 emission factor tallow	2.9E-03	kg/GJ	From National Greenhouse Accounts Factors July 2014
CH_4 emission factor diesel	4.8E-03	kg/GJ	From National Greenhouse Accounts Factors July 2014
CH_4 emission factor tyres	9.5E-04	kg/GJ	From National Greenhouse Accounts Factors July 2014
CH_4 emission factor coke	1.4E-03	kg/GJ	From National Greenhouse Accounts Factors July 2014
CH_4 emission factor Fuel-oil	1.4E-03	kg/GJ	From National Greenhouse Accounts Factors July 2014
CH_4 emission factor Waste -oil	1.4E-03	kg/GJ	Assumed to be same as Fuel oil
N_2O emission factor Coal	6.5E-04	kg/GJ	From National Greenhouse Accounts Factors July 2014
N_2O emission factor Gas	9.7E-05	kg/GJ	From National Greenhouse Accounts Factors July 2014
N_2O emission factor tallow	6.5E-04	kg/GJ	From National Greenhouse Accounts Factors July 2014
N_2O emission factor diesel	6.5E-04	kg/GJ	From National Greenhouse Accounts Factors July 2014
N_2O emission factor tyres	6.5E-04	kg/GJ	From National Greenhouse Accounts Factors July 2014

Parameter	Value	Unit	Comment
N2O emission factor coke	6.5E-04	kg/GJ	From National Greenhouse Accounts Factors July 2014
N2O emission factor Fuel-oil	6.5E-04	kg/GJ	From National Greenhouse Accounts Factors July 2014
N2O emission factor Waste-oil	6.5E-04	kg/GJ	Assumed to be same as Fuel oil

2.9.2 Emissions

Emissions reported under the National Pollutant Inventory were analysed for the different cement plants in Australia. By estimating the production level from each kiln based on its capacity and a utilisation factor of 85%, the estimated emissions per tonne of cement were derived. Further, emissions values have been further modified assuming 95% part of cement is clinker. Table 28 shows these emissions from each plant in kg per tonne of clinker with the mean and standard deviation calculated.

Table 28: Emissions (kg/kg of clinker) for clinker production in Australia

Emission	[Angaston-SA]	[Birkenhead-SA]	[New Berrima-NSW]	[Maldon-NSW]	[Railton-TAS]	[Gladstone-QLD]	[Munster-WA]	Mean	Standard Deviation	From ecoinvent process
Plant capacity (85% of actual) in Mt	**0.21**	**1.66**	**1.36**	**0.75**	**1.70**	**1.87**	**0.54**	**1.15**	**0.651**	
Acetaldehyde	-	-	-	-	2.2E-06	-	-	2.2E-06	-	NA
Ammonia	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.3E-05
Antimony	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.0E-09
Arsenic	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.2E-08
Benzene	-	-	-	-	2.3E-07	-	-	2.3E-07	-	NA
Beryllium & compounds	-	-	-	1.0E-08	-	-	-	1.0E-08	-	3.0E-09
Cadmium & compounds	9.9E-10	-	-	1.0E-09	-	-	-	1.0E-09	2.6E-11	7.0E-09
Carbon monoxide	5.3E-04	3.9E-04	1.3E-04	-	1.2E-03	8.3E-04	-	6.2E-04	4.2E-04	4.7E-04
Chlorine & compounds	-	2.4E-06	-	-	-	-	1.3E-05	7.8E-06	7.7E-06	NA
Chromium	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.5E-09

Emission	[Angaston-SA]	[Birkenhead-SA]	[New Berrima-NSW]	[Maldon-NSW]	[Railton-TAS]	[Gladstone-QLD]	[Munster-WA]	Mean	Standard Deviation	From ecoinvent process
Chromium (VI) compounds	-	8.0E-09	-	-	-	-	4.5E-08	2.6E-08	2.6E-08	5.5E-10
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.0E-09
Copper & compounds	-	-	-	-	-	8.4E-07	-	8.4E-07	-	1.4E-08
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.6E-13
Hydrogen chloride	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.3E-06
Lead & compounds	-	-	-	5.2E-08	-	-	-	5.2E-08	-	8.5E-08
Mercury & compounds	-	-	9.1E-09	1.0E-08	-	1.3E-08	7.0E-08	2.6E-08	3.0E-08	3.3E-08
Methane, fossil	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.009
Nickel	NA	NA	NA	NA	NA	NA	NA	NA	NA	5.0E-09
NMVOC, non-methane volatile organic compounds, unspecified origin	NA	NA	NA	NA	NA	NA	NA	NA	NA	5.6E-05
Oxides of Nitrogen	5.0E-03	2.2E-03	1.7E-03	4.8E-04	1.2E-03	1.5E-03	5.7E-03	2.5E-03	2.0E-03	1.1E-03
Particulate Matter 2.5 um	-	1.8E-05	-	-	-	-	-	1.8E-05	-	2.4E-05

Emission	[Angaston-SA]	[Birkenhead-SA]	[New Berrima-NSW]	[Maldon-NSW]	[Railton-TAS]	[Gladstone-QLD]	[Munster-WA]	Mean	Standard Deviation	From ecoinvent process
Particulates, > 10 um	NA	NA	NA	NA	NA	NA	NA	NA	NA	5.7E-06
Particulates, > 2.5 um, and < 10um	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.9E-06
Polychlorinated dioxins and furans (TEQ)	7.4E-13	-	7.7E-14	-	-	-	1.3E-12	6.9E-13	5.9E-13	NA
Selenium	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.0E-09
Sulfur dioxide	3.62E-04	-	-	-	3.06E-04	-	-	3.3E-04	3.9E-05	3.6E-04
Thallium	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.3E-08
Tin	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.0E-09
Total Volatile Organic Compounds	-	-	5.6E-05	-	-	2.3E-05	-	4.0E-05	2.3E-05	NA
Vanadium	NA	NA	NA	NA	NA	NA	NA	NA	NA	5.0E-09
Zinc	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.0E-08

Source: (NPI 2012-13)
NA: Not Available in National Pollutant Inventory data

The table below shows the emissions values, wherever available National Pollutant Inventory data has been used, assuming that the rest of emissions are below threshold and not submitted to National Pollutant Inventory, therefore, in such cases, emissions values from ecoinvent process have been adopted for all types of clinker.

Table 29: Emissions from clinker production (in kg/kg)

Flow	Unit	Australia	China	Japan	Comment
Carbon dioxide from fuel, fossil	kg	0.313	0.919	0.91	Based on emission factors from NGAF 2014
Carbon dioxide from calcination, fossil	kg	0.544			Based on emission factors from NGAF 2014
Carbon dioxide, biogenic	kg	3.2E-4	0.0	0.0	Based on emission factors from NGAF 2014
Methane, fossil	kg	2.3E-4	3.4E-4	1.3E-4	Based on emission factors from NGAF 2014
Methane, biogenic	kg	6.9E-6	0.0	0.0	Based on emission factors from NGAF 2014
Nitrogen dioxide	kg	6.1E-4	8.7E-4	8.4E-4	Based on emission factors from NGAF 2014
Acetaldehyde	kg	2.2E-06	2.2E-06	2.2E-06	From NPI data
Ammonia	kg	2.3E-05	2.3E-05	2.3E-05	From ecoinvent process
Antimony	kg	2.0E-09	2.0E-09	2.0E-09	From ecoinvent process
Arsenic	kg	1.2E-08	1.2E-08	1.2E-08	From ecoinvent process
Benzene	kg	2.3E-07	2.3E-07	2.3E-07	From NPI data
Beryllium & compounds	kg	1.0E-08	1.0E-08	1.0E-08	From NPI data
Cadmium & compounds	kg	1.0E-09	1.0E-09	1.0E-09	From NPI data
Carbon monoxide	kg	6.2E-04	6.2E-04	6.2E-04	From NPI data
Chlorine & compounds	kg	7.8E-06	7.8E-06	7.8E-06	From NPI data
Chromium	kg	1.5E-09	1.5E-09	1.5E-09	From ecoinvent process
Chromium (VI) compounds	kg	2.6E-08	2.6E-08	2.6E-08	From NPI data
Cobalt	kg	4.0E-09	4.0E-09	4.0E-09	From ecoinvent process
Copper & compounds	kg	8.4E-07	8.4E-07	8.4E-07	From NPI data
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	9.6E-13	9.6E-13	9.6E-13	From ecoinvent process
Hydrogen chloride	kg	6.3E-06	6.3E-06	6.3E-06	From ecoinvent process
Lead & compounds	kg	5.2E-08	5.2E-08	5.2E-08	From NPI data

Flow	Unit	Australia	China	Japan	Comment
Mercury & compounds	kg	2.6E-08	2.6E-08	2.6E-08	From NPI data
Nickel	kg	5.0E-09	5.0E-09	5.0E-09	From ecoinvent process
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	5.6E-05	5.6E-05	5.6E-05	From ecoinvent process
Oxides of Nitrogen	kg	2.5E-03	2.5E-03	2.5E-03	From NPI data
Particulate Matter 2.5 um	kg	1.8E-05	1.8E-05	1.8E-05	From NPI data
Particulates, > 10 um	kg	5.7E-06	5.7E-06	5.7E-06	From ecoinvent process
Particulates, > 2.5 um, and < 10um	kg	7.9E-06	7.9E-06	7.9E-06	From ecoinvent process
Polychlorinated dioxins and furans (TEQ)	kg	6.9E-13	6.9E-13	6.9E-13	From NPI data
Selenium	kg	2.0E-09	2.0E-09	2.0E-09	From ecoinvent process
Sulfur dioxide	kg	3.3E-04	3.3E-04	3.3E-04	From NPI data
Thallium	kg	1.3E-08	1.3E-08	1.3E-08	From ecoinvent process
Tin	kg	9.0E-09	9.0E-09	9.0E-09	From ecoinvent process
Total Volatile Organic Compounds	kg	4.0E-05	4.0E-05	4.0E-05	From NPI data
Vanadium	kg	5.0E-09	5.0E-09	5.0E-09	From ecoinvent process
Zinc	kg	6.0E-08	6.0E-08	6.0E-08	From ecoinvent process

Source: (NPI 2012-13) and ecoinvent process

2.10 Waste to treatment

The flows for solid waste to treatment has been adopted from ecoinvent database for each type of clinker, however the municipal solid waste is assumed to be landfilled rather than incinerated as assumed in ecoinvent.

Table 30: Waste to treatment, per kg cement

Flow	Unit	Value	Comment
Disposal, inert waste, 5% water, to inert material landfill	kg	0.00008	Flow taken from ecoinvent cement process
waste treatment, inert waste, at landfill	kg	0.000045	Flow taken from ecoinvent 2.2 cement process

2.11 Summary of results

Cradle-to-gate impacts in terms of kg CO_2 –eq/kg cement have been calculated and are presented in the table below.

Table 31: Summary of impacts for each type of cement, per kg of bulk cement

Production type	Ordinary Portland cement	General purpose cement
Australian cement production from integrated cement facilities	0.969 kg CO_2-eq	0.920 kg CO_2-eq
Australian cement production from imported clinker	1.110 kg CO_2-eq	1.052 kg CO_2-eq
Average Australian cement supply	1.002 kg CO_2-eq	0.951 kg CO_2-eq

2.12 Other impact categories

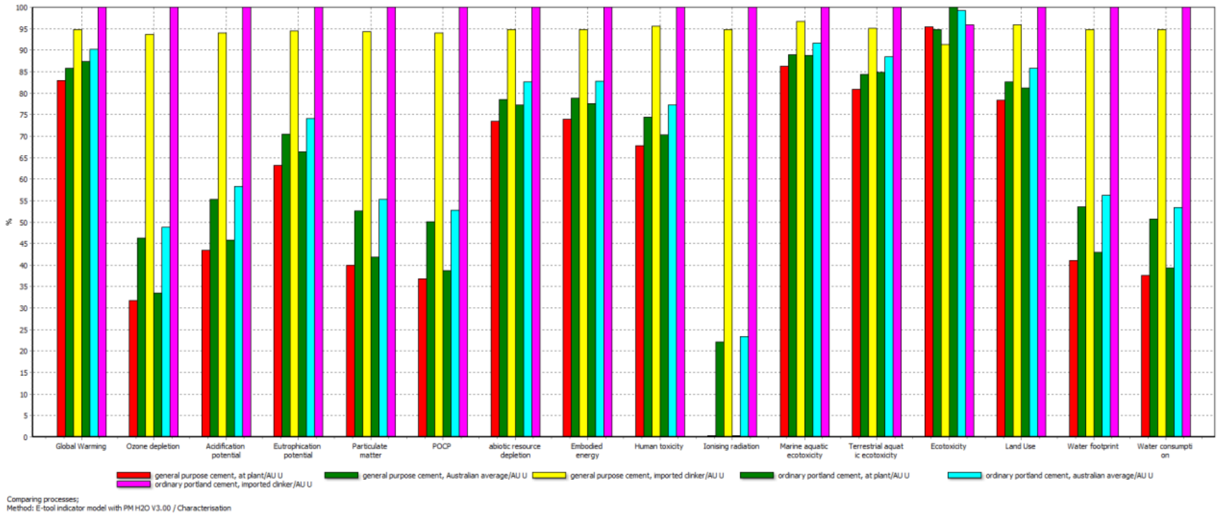


Figure 4: Comparison of all impacts for different types of cement

2.13 Contribution analysis.

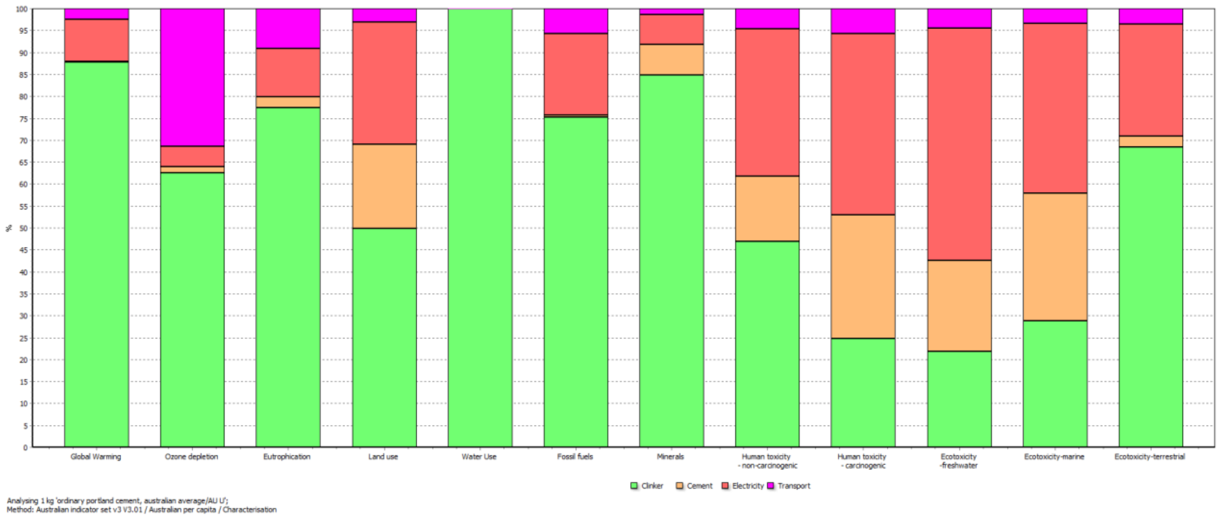


Figure 5: Contribution analysis for ordinary Portland cement Australian average

3 Concrete Inventory Development

3.1 Concrete types

This report outlines the inventory development process for the following three types of concrete produced in Australia

Table 32: Concrete products produced in this inventory

Concrete type	Grades of Concrete included in the study
Ordinary Portland Cement Concrete	M20, M25, M32, M40, M50
Concrete 30% GGBFS	M20, M25, M32, M40, M50
Concrete 30% Flyash	M20, M25, M32, M40, M50

3.2 System Boundary

Figure below describes system boundary that defines the limits of this inventory.

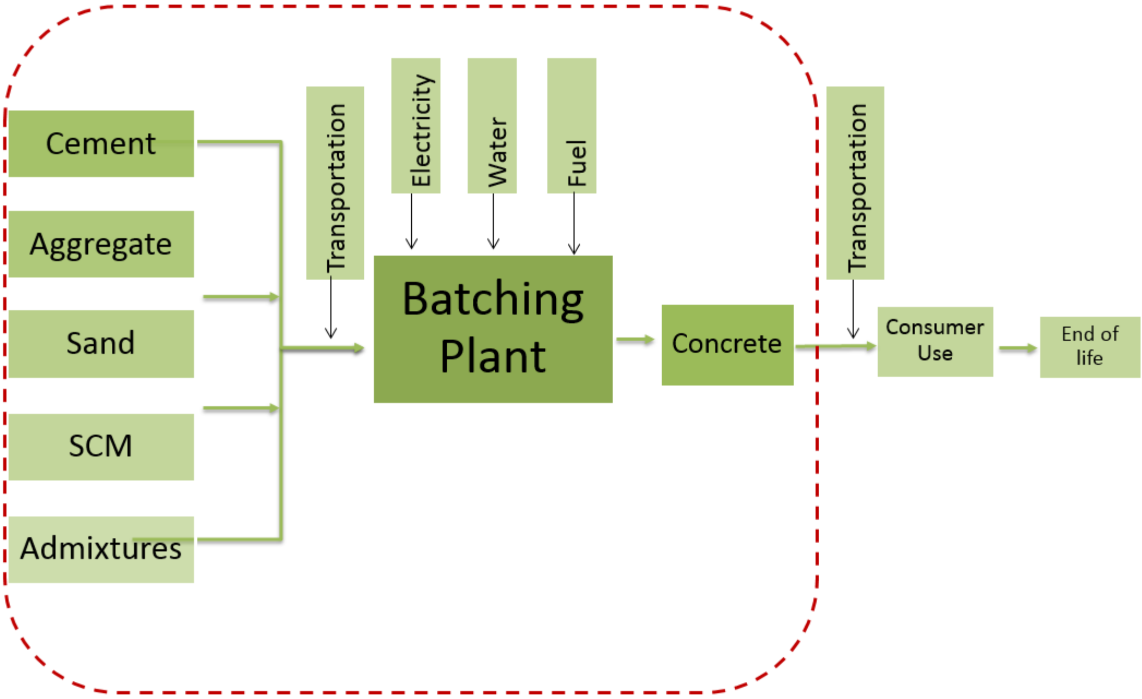


Figure 6: System Boundary for production of concrete

3.3 Types of Concrete and mix proportions

Tables below describes the type of concrete and there mix proportions for building the inventory.

Table 33: Proportions for fixing the concrete mix

Ingredients	Comments
Cement	Values adopted as per Green Building Council Australia recommendations[1]
Coarse Aggregates (Gravel)	65 % of total aggregates
Fine Aggregates (Sand)	35% of total aggregates
Slag concrete	30% of cementitious material has been considered as Blast furnace slag with a replacement factor of 1.3
Fly ash concrete	30% of cementitious material has been considered as Fly ash with a replacement factor of 1.3
Admixtures	Varying with grade of concrete
Water	Varying with grade of concrete

1 Table: 1 (Green Building Council Australia 2012)

Table 34: Concrete design mix adopted for 1 m^3 of ordinary Portland cement concrete

Ingredients	Unit	20 MPa	25 MPa	32 MPa	40 MPa	50 MPa
Cement	kg	280	310	360	440	550
Coarse Aggregates (Gravel)	kg	1303	1280	1232	1167	1087
Fine Aggregates (Sand)	kg	675	663	638	604	563
Admixtures	kg	0	1.55	1.98	2.64	6.6
Water	kg	140	142.6	154.8	167.2	176
Total	**kg**	**2398**	**2397**	**2387**	**2381**	**2382**

Source : Cement quantity from (Green Building Council Australia 2012)

Table 35: Concrete design mix adopted for 1 m^3 of Slag cement concrete

Ingredients	Unit	20 MPa	25 MPa	32 MPa	40 MPa	50 MPa
Cement	kg	196	217	252	308	385
Coarse Aggregates (Gravel)	kg	1274	1249	1198	1129	1044
Fine Aggregates (Sand)	kg	659	647	620	584	541
Slag	kg	109	121	140	172	215

Ingredients	Unit	20 MPa	25 MPa	32 MPa	40 MPa	50 MPa
Admixtures	kg	0	1.55	1.98	2.64	6.6
Water	kg	146	149	161	173	180
Total	**kg**	**2385**	**2384**	**2373**	**2368**	**2370**

Table 36: Concrete design mix adopted for 1 m^3 of Fly ash cement concrete

Ingredients	Unit	20 MPa	25 MPa	32 MPa	40 MPa	50 MPa
Cement	kg	196	217	252	308	385
Coarse Aggregates (Gravel)	kg	1271	1247	1195	1125	1040
Fine Aggregates (Sand)	kg	658	646	619	583	538
Fly ash	kg	109	121	140	172	215
Admixtures	kg	0	1.55	1.98	2.64	6.6
Water	kg	146	149	161	173	180
Total	**kg**	**2381**	**2381**	**2369**	**2363**	**2364**

3.4 Inputs to concrete production

For the default concrete inventories, the average ordinary Portland cement manufactured in Australia has been used, which includes cement made from domestic as well as imported clinker.

Coarse aggregates have been assumed to be from the nearby quarries with a standard transport by 40t truck over a distance of 50km. No other inventory data on aggregates has been developed with the aggregate production processes being based on the ecoinvent shadow database process for gravel, crushed at mine.

Fine aggregates in form of sand are assumed to be from nearest mine and transported by 40t truck over a distance of 50km. The process is based on ecoinvent shadow database for sand, at mine.

Superplasticisers for increasing the workability and reducing water content have been used as **admixtures**. No process inventory has been developed, process being based on ecoinvent shadow database for Melamine formaldehyde resin, at plant. Domestic sources nearest to the batching plant has been considered.

Blast furnace **Slag** from domestic and international sources have been considered and their weighted mean is adopted. 80 per cent of slag is imported from Japan, (Pink 2013) and rest has been assumed to be from domestic supplies. Admixtures, Fly ash and slag have been considered as cementitious material and assumed to be transported by 40t truck for a distance of 200 km on road.

3.4.1 Recycled aggregate

Process for recycled aggregates has been developed based on energy usage data published in Sustainable Aggregates – CO_2 emission factor study (RMCG 2010) and supplemented with minor flows from ecoinvent process for crushed gravel.

Table 37: Unit Process for recycling brick rubble and concrete

Flow	Unit	Value	Comment
Products			
Recycling brick rubble and concrete, at plant/AU U	kg	1	Functional Unit
Materials/fuels			
Lubricating oil, at plant/RER U/AusSD U	kg	0.0000025	Taken from ecoinvent process for crushed gravel production
Building, hall, steel construction/CH/I U/AusSD U	m2	0.00000285	Taken from ecoinvent process for crushed gravel production
Conveyor belt, at plant/RER/I U/AusSD U	m	9.51E-08	Taken from ecoinvent process for crushed gravel production
Diesel, burned in building machine/GLO U/AusSD U	MJ	0.038	Taken from Sustainable Aggregates South Australia
Industrial machine, heavy, unspecified, at plant/RER/I U/AusSD U	kg	0.0000951	Taken from ecoinvent process for crushed gravel production
electricity, low voltage, Australian/AU U	MJ	0.004	Taken from Sustainable Aggregates South Australia
Steel, low-alloyed, at plant/RER U/AusSD U	kg	0.000051	Taken from ecoinvent process for crushed gravel production
Tap water, at user/RER U/AusSD/Link U	kg	0.0122	Taken from ecoinvent process for crushed gravel production

Economic allocation has been used in line with the AusLCI guidelines and EN 15804 for manufacturing of recycled aggregates from concrete. Below table shows the data used for the economic allocation and the results.

Table 38: Economic Allocation for recycled aggregates

Product	Mass produced in kg	Market Price in A$/kg	Allocation by economic value	Comment
Aggregates	0.968	0.048	85.3 %	
Steel	0.032	0.250	14.7 %	Based on 1% steel by volume average across all inputs

Source : Steel price from (EdgeEnvironmentPtyLtd 2012)
Recycled aggregate price from (BCSands 2015)

The GHG emissions for recycling aggregates amount to 5.5 kg CO_2-eq per t of recycled aggregates produced, which compares to 12.7 kg CO_2-eq per tonne for crushed gravel.

3.4.2 Ground granulated blast furnace slag

Slag is a by-product of steel making process, for which economic allocation has been used in line with the AusLCI guidelines and EN 15804. The table following shows the data used for the economic allocation and that the result is a small attribution to slag of less than half of one percent.

Table 39: Unit Process for ground granulated blast furnace slag

Flow	Unit	Value	Comment
Product			
Ground granulated blast furnace slag, at cement plant	t	1	Functional Unit
Materials and Energy			
Water	m^3	0.5	
Blast furnace Slag, at steel plant	1	t	Slag allocation
electricity, low voltage, Australian	50	kWh	from prior report
Heat, natural gas, at industrial furnace low-NOx >100kW	769	MJ	Updated, pers. com Robert Mrzljak, 2013.
Gypsum, mineral, at mine	0.0415	t	8544 t per year, pers. com Robert Mrzljak, 2013.
Ethylene glycol, at plant	0.833	kg	154 KL per year, pers. com Robert Mrzljak, 2013. Modelled as ethylene glycol.
Transport, transoceanic freight ship	6.42E3	tkm	From sea distance calculator for transport from Yokohama, Japan to Sydney.
Transport of imported and domestic on road, truck, 40t load	70	tkm	From domestic Steel plant to Cement plant and port to cement plant

Table 40: Economic Allocation for Slag

Product	Mass produced in kg	Market Price in A$/t	Allocation by mass value	Allocation by economic value	Comment
Pig iron content	1.0	503.00	80 %	99.682 %	Considering all other components other than Slag is Pig iron
Slag content	0.25	6.41	20 %	0.318 %	

Source : Mass proportions from (Gielen and Moriguchi 2001)
Blast furnace slag price from (Mittal 2015)
Pig iron price from (Steelonthenet.com 2015)

The GHG emissions for Blast Furnace Slag amounts to 0.0188 kg CO2-eq per kg of Blast furnace slag produced at steel plant.

3.5 Unit process for manufacturing of concrete

The concrete inventory has been developed for five different grades of three types of concrete mentioned in the Table 1. Unit process for each type of concrete for different grades have been tabulated separately for reach type of concrete.

3.5.1 Unit process for ordinary Portland cement concrete

Table 41: Unit Process for ordinary Portland cement concrete

Flow	Unit	20 MPa	25 MPa	32 MPa	40 MPa	50 MPa	Comment
Product							
Concrete, at batching plant	m^3	1	1	1	1	1	Functional Unit
Materials and Energy							
Concrete mixing plant	p	4.57E-07	4.57E-07	4.57E-07	4.57E-07	4.57E-07	As ecoinvent process
Ordinary Portland cement, Australian average	Kg	282	312	362	443	554	As per GBCA
Gravel, unspecified, at mine	Kg	1310	1286	1237	1172	1090	65% of total aggregates
Sand, at mine	kg	678	666	641	607	565	35% of total aggregates
tap water, at user	kg	141	144	156	169	177	Water cement ratio as per Australian Standards
Melamine formaldehyde resin, at plant[1]	kg	0	1.56	1.99	2.66	6.7	Superplasticiser for increasing workability reduction of water content
Diesel, burned in building machine	MJ	22.7	22.7	22.7	22.7	22.7	As ecoinvent process
electricity, low voltage, Australian	kWh	4.36	4.36	4.36	4.36	4.36	As ecoinvent process
Heavy fuel oil, burned in industrial furnace	MJ	3.09	3.09	3.09	3.09	3.09	As ecoinvent process
Light fuel oil, burned in industrial furnace	MJ	13.3	13.3	13.3	13.3	13.3	As ecoinvent process
Lubricating oil, at plant	kg	0.0119	0.0119	0.0119	0.0119	0.0119	As ecoinvent process
Natural gas, burned in industrial furnace	MJ	1.16	1.16	1.16	1.16	1.16	As ecoinvent process
Steel, low-alloyed, at plant	kg	0.0238	0.0238	0.0238	0.0238	0.0238	As ecoinvent process
Synthetic rubber, at plant	kg	0.00713	0.00713	0.00713	0.00713	0.00713	As ecoinvent process
Transport, truck, 40t load/AU U	tkm	42.29	46.8	54.4	66.5	83.1	Transport of cement from manufacturing plant to batching plant

Flow	Unit	20 MPa	25 MPa	32 MPa	40 MPa	50 MPa	Comment
Transport, truck, 40t load/AU U	tkm	34.14	33.5	32.3	30.6	28.4	Transport of sand from quarry to batching plant
Transport, truck, 40t load/AU U	tkm	65.94	64.8	62.3	59.0	54.9	Transport of aggregates from quarry to batching plant

1 Admixture type from : (www.aboutcivil.org)

3.5.2 Unit process for Cement Concrete 30% Slag

Table 42: Unit Process for cement concrete 30% Slag

Flow	Unit	20 MPa	25 MPa	32 MPa	40 MPa	50 MPa	Comment
Product							
Concrete, at batching plant	m^3	1	1	1	1	1	Functional Unit
Materials and Energy							
Concrete mixing plant	p	4.57E-07	4.57E-07	4.57E-07	4.57E-07	4.57E-07	As ecoinvent process
Ordinary Portland cement, Australian average	kg	197.4	218.5	253.8	310.2	387.7	As per GBCA
Gravel, unspecified, at mine	kg	1283	1258	1206	1137	1051	65% of total aggregates
Sand, at mine	kg	664	651.4	624.6	588.5	544.3	35% of total aggregates
tap water, at user	kg	147.5	149.7	162	173.9	181.1	Water cement ratio as per Australian Standards
Ground granulated blast furnace slag, at cement plant	kg	110	121.7	141.4	172.8	216	30% of cementitious material
Melamine formaldehyde resin, at plant	kg	0	1.56	1.994	2.658	6.646	Superplasticiser to reduce water content and increase workability
Diesel, burned in building machine	MJ	22.7	22.7	22.7	22.7	22.7	As ecoinvent process
electricity, low voltage, Australian	kWh	4.36	4.36	4.36	4.36	4.36	As ecoinvent process
Heavy fuel oil, burned in industrial furnace 1MW	MJ	3.09	3.09	3.09	3.09	3.09	As ecoinvent process
Light fuel oil, burned in industrial furnace 1MW, non-modulating	MJ	13.3	13.3	13.3	13.3	13.3	As ecoinvent process
Lubricating oil, at plant	kg	0.0119	0.0119	0.0119	0.0119	0.0119	As ecoinvent process
Natural gas, burned in industrial furnace	MJ	1.16	1.16	1.16	1.16	1.16	As ecoinvent process
Steel, low-alloyed, at plant	kg	0.0238	0.0238	0.0238	0.0238	0.0238	As ecoinvent process
Synthetic rubber, at plant	kg	0.00713	0.00713	0.00713	0.00713	0.00713	As ecoinvent process
Transport, truck, 40t load/AU U	tkm	42.3	46.8	54.4	66.5	83.08	Cement transportation from manufacturing plant to batching plant
Transport, truck, 40t load/AU U	tkm	33.43	32.8	31.5	29.6	27.41	Transport of sand from quarry to batching plant
Transport, truck, 40t load/AU U	tkm	64.58	63.35	60.7	57.2	52.93	Transport of agg. from quarry to batching plant

Unit process for Cement Concrete 30% Fly ash

Table 43: Unit Process for Cement Concrete 30% Fly ash

Flow	Unit	20 MPa	25 MPa	32 MPa	40 MPa	50 MPa	Comment
Product							
Concrete, at batching plant	m^3	1	1	1	1	1	Functional Unit
Materials and Energy							
Concrete mixing plant	p	4.57E-07	4.57E-07	4.57E-07	4.57E-07	4.57E-07	As ecoinvent process
Ordinary Portland cement, Australian average	kg	197.4	218.5	253.8	310.2	387.7	As per GBCA
Gravel, unspecified, at mine	kg	1280	1256	1203	1133	1047	65% of total aggregates
Sand, at mine	kg	663	650	623	586.6	542	35% of total aggregates
tap water, at user	kg	147.5	149.7	162	173.9	181.1	Water cement ratio as per Australian Standards
Fly ash delivered to site	kg	110	121.7	141	172.8	216	30% of cementitious material
Melamine formaldehyde resin, at plant	kg	0	1.56	1.99	2.658	6.646	Superplasticiser for increasing workability reduction of water content
Diesel, burned in building machine	MJ	22.7	22.7	22.7	22.7	22.7	As ecoinvent process
electricity, low voltage, Australian	kWh	4.36	4.36	4.36	4.36	4.36	As ecoinvent process
Heavy fuel oil, burned in industrial furnace	MJ	3.09	3.09	3.09	3.09	3.09	As ecoinvent process
Light fuel oil, burned in industrial furnace	MJ	13.3	13.3	13.3	13.3	13.3	As ecoinvent process
Lubricating oil, at plant	kg	0.0119	0.0119	0.0119	0.0119	0.0119	As ecoinvent process
Natural gas, burned in industrial furnace low-NOx >100kW	MJ	1.16	1.16	1.16	1.16	1.16	As ecoinvent process
Steel, low-alloyed, at plant	kg	0.0238	0.0238	0.0238	0.0238	0.0238	As ecoinvent process
Synthetic rubber, at plant	kg	0.00713	0.00713	0.00713	0.00713	0.00713	As ecoinvent process
Transport, truck, 40t load/AU U	tkm	42.3	46.8	54.4	66.46	83.08	Transport of cement from manufacturing plant to batching plant
Transport, truck, 40t load/AU U	tkm	33.4	32.7	31.4	29.54	27.29	Transport of sand from quarry to batching plant
Transport, truck, 40t load/AU U	tkm	64.5	63.2	60.6	57.05	52.71	Transport of aggregates from quarry to batching plant

3.6 Waste to treatment

Waste to treatment has been adopted from ecoinvent database for all types of concrete as mentioned in the following table, however the municipal solid waste is assumed to be landfilled rather than incinerated as assumed in ecoinvent.

Table 44: Waste to treatment per m^3 of concrete

Flow	Unit	Value	Comment
Disposal, concrete, 5% water, to inert material landfill/CH U/AusSD U	Kg	16.9	As ecoinvent process
Waste treatment, inert waste, at landfill, NCOS/AU U	Kg	0.0951	As ecoinvent process
Treatment, concrete production effluent, to wastewater treatment, class 3/CH U/AusSD U	m^3	0.0143	As ecoinvent process

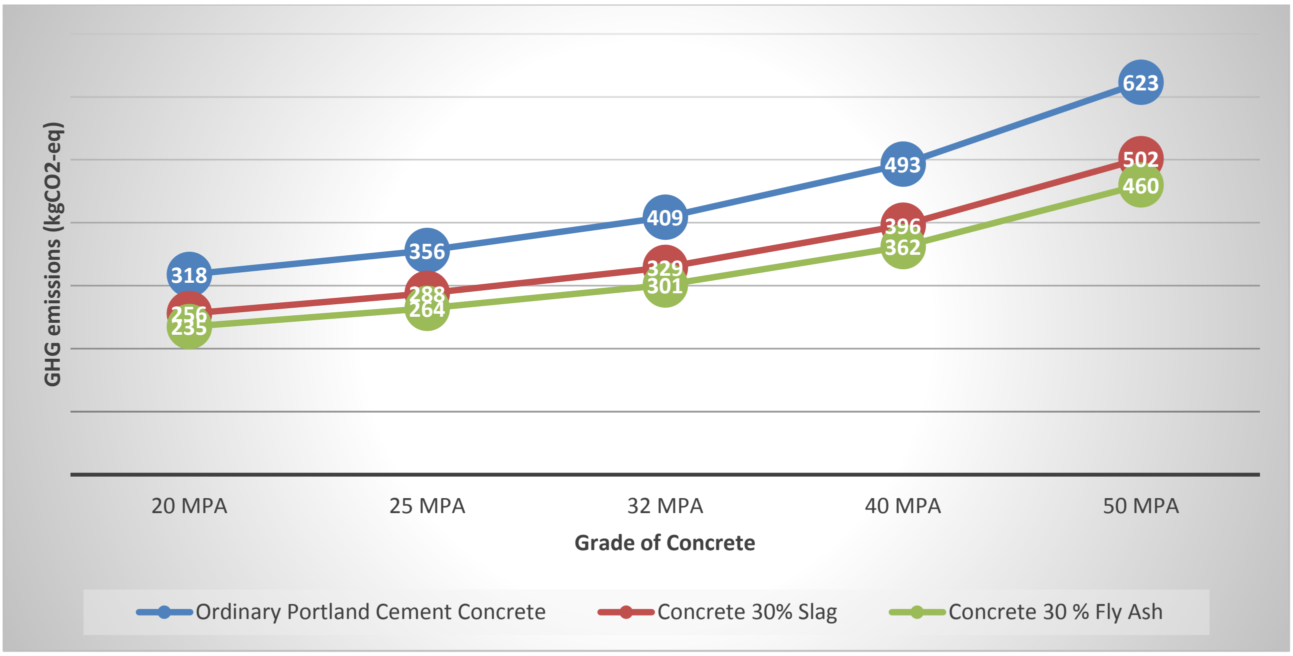
3.7 Summary of results

Impacts in terms of $kgCO_2$ –eq have been calculated for each type of concrete and are presented below.

Table 45: Summary of impacts for each type of concrete, per m^3

Type of concrete	Unit	20 MPa	25 MPa	32 MPa	40 MPa	50 MPa
Ordinary Portland Cement Concrete	$kgCO_2$-eq	318	356	409	493	623
Concrete 30% GGBFS	$kgCO_2$-eq	256	288	329	396	502
Concrete 30% Fly ash	$kgCO_2$-eq	235	264	301	362	460

Figure 7: Comparison of GHG emissions of different types of concrete, per m^3



3.8 Other impact categories

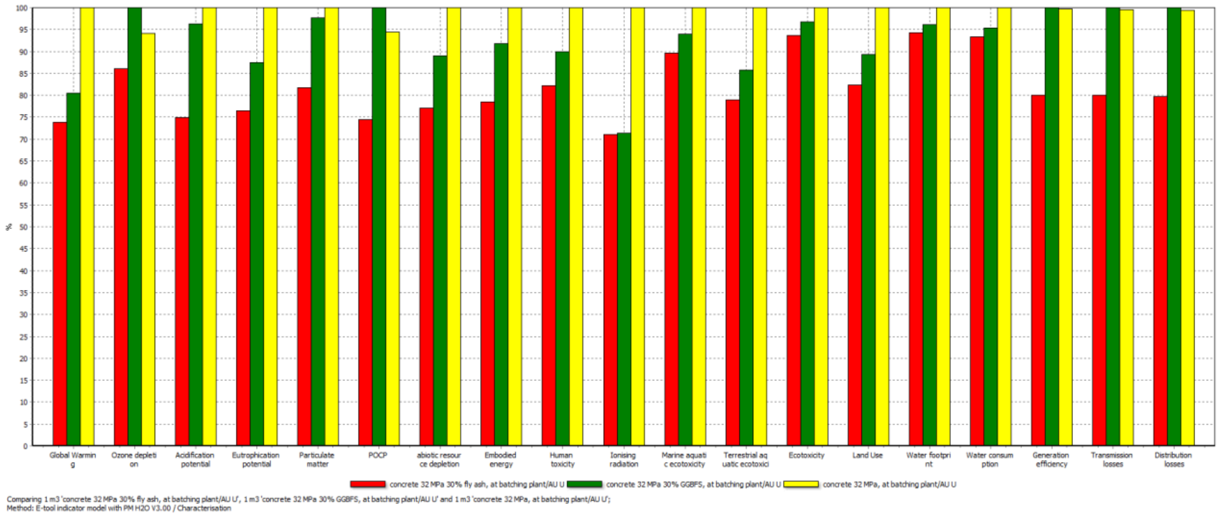


Figure 8: Comparison of all impacts for 32 MPa strength concrete in different types of concrete

3.9 Contribution analysis.

3.9.1 Ordinary Portland cement concrete

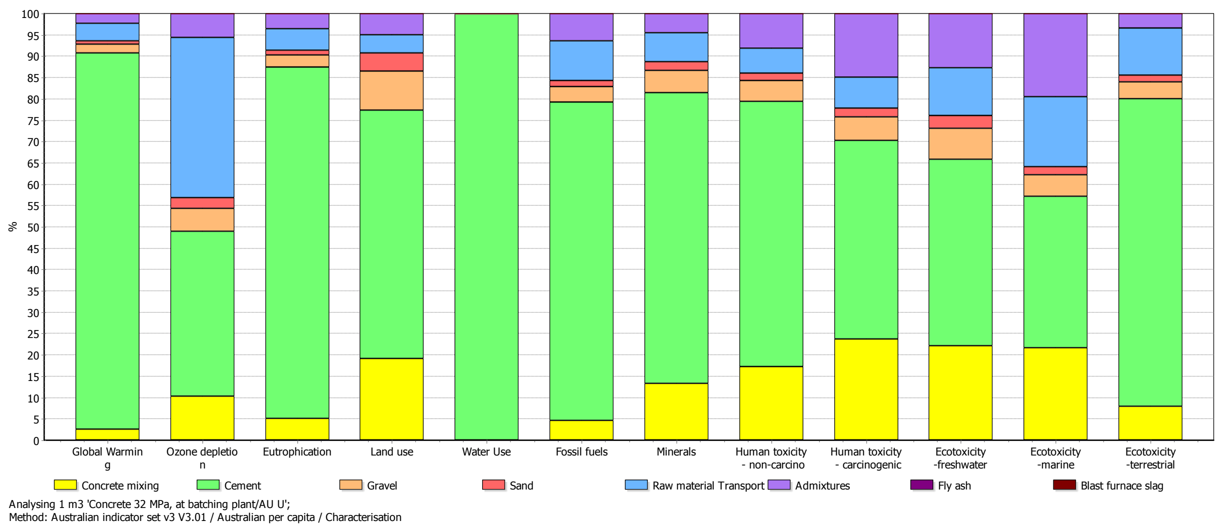


Figure 9: Contribution analysis for 32 MPa strength ordinary Portland cement concrete

3.9.2 Concrete 30% GGBFS

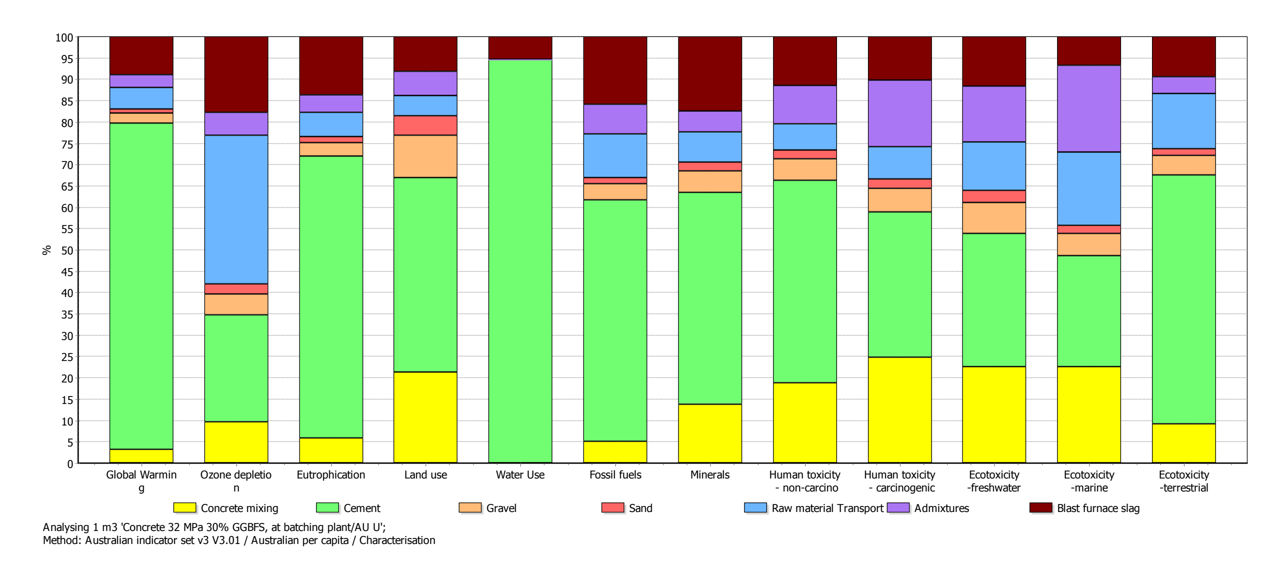


Figure 10: Contribution analysis for 32MPa concrete 30% GGBFS

3.9.3 Concrete 30% Fly ash

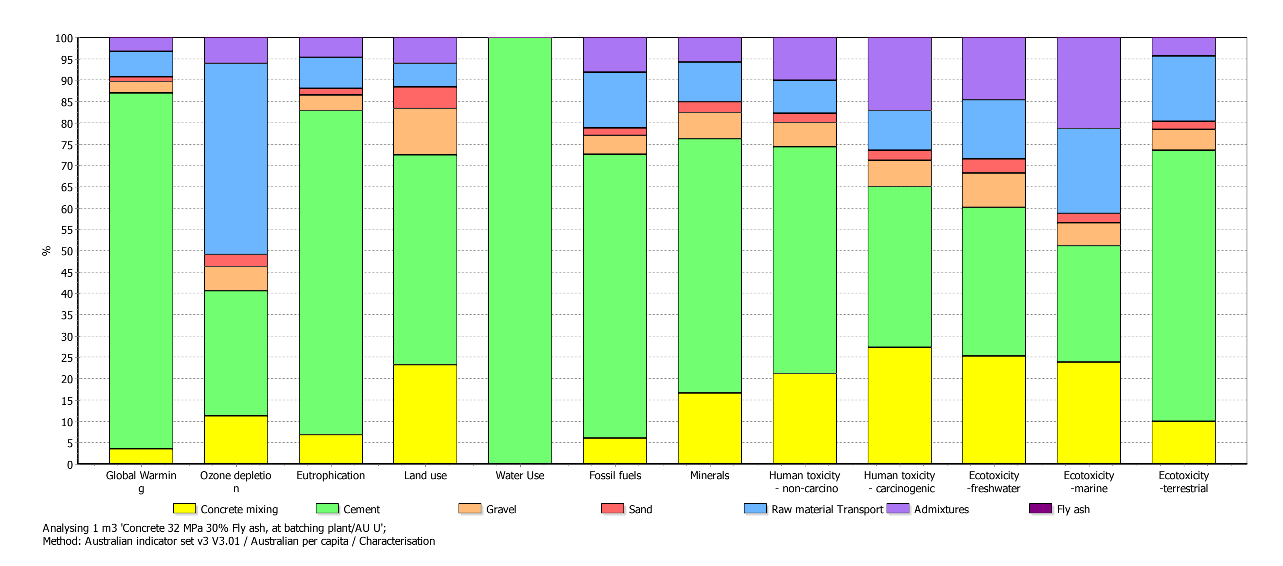


Figure 11: Contribution analysis for 32 MPa Concrete 30% Fly ash

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