COOPERATIVE RESEARCH CENTRE FOR COAL IN SUSTAINABLE DEVELOPMENT
Established and supported under the Australian Government's Cooperative Research Centres Program

LCA OF THE AUSTRALIAN ELECTRICITY GRIDS

TECHNOLOGY ASSESSMENT REPORT 62

Authors:

Phil Brown [1]
Aaron Cottrell [1]
Peter Scaife [2]

[1] CSIRO Energy Technology
[2] The University of Newcastle

March 2007

QCAT Technology Transfer Centre, Technology Court
Pullenvale Qld 4069 AUSTRALIA
Telephone (07) 3871 4400 Facsimile (07) 3871 4444
Email: Administration@ccsd.biz

This page is intentionally left blank

DISTRIBUTION LIST

CCSD

Chairman; Chief Executive Officer; Research Manager, Manager Technology; Files

Industry Participants

Australian Coal Research Limited .... Mr Mark Bennetts
BHP Billiton Mitsubishi Alliance .... Mr Ross Willims
.... Mr Ben Klaassen
.... Dr Andre Urfer
CNA Resources .... Mr Ashley Conroy
CS Energy .... Dr Chris Spero
Delta Electricity .... Mr Greg Everett
Queensland Natural Resources & Mines .... Mr Bob Potter
Rio Tinto (TRPL) .... Mr Kevin Creagh
Stanwell Corporation .... Mr Howard Morrison
Tarong Energy .... Mr Dave Evans
The Griffin Coal Mining Co Pty Ltd .... Mr Jim Coleman
Verve Energy .... Mr Ken Tushingham
Wesfarmers Premier Coal Ltd .... Mr Peter Ashton
Xstrata Coal Pty Ltd .... Mr Colin Whyte
.... Mr Barry Isherwood

Research Participants

CSIRO .... Dr David Brockway
Curtin University of Technology .... Prof Linda Kristjanson
Macquarie University .... Prof Jim Piper
The University of Newcastle .... Prof Barney Glover
The University of New South Wales .... Prof David Young
The University of Queensland .... Prof Don McKee

This page is intentionally left blank

Cooperative Research Centre for
Coal in Sustainable Development
QCAT Technology Transfer Centre
Technology Court
Pullenvale, Qld 4069
Telephone: (07) 3871 4400
Fax: (07) 3871 4444

Feedback Form

To help us improve our service to you may I ask you for five minutes of your time to complete this questionnaire. Please fax or mail it back to me, or, if you would prefer, give me a call.

ATTENTION **MANAGER TECHNOLOGY TRANSFER**

FAX NO **07 3871 4444** **DATE** ....

FROM **NAME:** ....
COMPANY:..

REPORT TITLE: **LCA OF THE AUSTRALIAN ELECTRICITY GRIDS**
AUTHORS: **PHIL BROWN, AARON COTTRELL, PETER SCAIFE**

Would you please rate our performance in the following areas by ticking the appropriate box:

The Research	Agree	Neutral	Disagree	Don't Know
This work has achieved its research objectives				
This work has delivered to agreed milestones				
This work is relevant to my organisation				
Communication of progress has been timely & useful				

The Report

The report is well presented				
The context of the report is clear				
The content of the report is substantial				
The report is clearly written and understandable				
This product is good value				

Any further comments which would assist us in better serving your future requirements?:
……………………………………………………………………………………………………

……………………………………………………………………………………………………

Are there any people you would like to add to our distribution list?:

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Thank you for your response

Disclaimer

Use of the information contained in this report is at the user’s risk. While every effort has been made to ensure the accuracy of that information, neither Australian Black Coal Utilisation Research Limited (ABCUR) nor the participants in the CRC for Coal in Sustainable Development make any warranty, express or implied, regarding it. Neither ABCUR nor the participants are liable for any direct or indirect damages, losses, costs or expenses resulting from any use or misuse of that information.

Copyright

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report gives the results of a life cycle analysis (LCA) for the supply of 1 MWh of electricity from the Australian electricity grids for FY2004. At this time, the grids had a generation capacity of ~50,890MW. In this period, 205,153 GWh was sent out from Australian power stations at a capacity factor of 46.0%. This report is part of a series of LCA studies of the Australian State grids, which are being undertaken for comparison with the benchmark data sets generated for the same systems in 2001. However, the analysis of all of the electricity grids combined has not been done prior. This report will therefore provide a benchmark for any similar future study.

The study aims to provide a more detailed, transparent and disaggregated evaluation of the Australian electricity grids than is reported in other studies (which have focused on greenhouse gas emissions alone). The study includes a range of indicators: resource energy and fresh water consumption as inputs, and greenhouse gas emissions (GGEs), NO_x, SO_x, particulates and solid waste emissions, as well as a range of substances sourced from the National Pollutant Inventory (NPI) database, as outputs. Being LCA-based, it also includes emissions from the supply of other materials and services for mining, transportation, generation and distribution.

The results are summarised in the following table, which includes the inputs and outputs for this study. Figures are on an annual basis for the aggregated state grids. Comparisons with overall Australian values (from all major combustion, agricultural, waste and fugitive activities) are also included, to provide context.

Parameter	Transmission grid 2004 (per MWh)	Distribution grid 2004 (per MWh)	Total from all grids 2004 (per annum)	Total Australia - all sources (per annum)	% of Total
Resource energy	11.05 GJ	11.75	2,188 PJ	5,436 PJ[1]	40.3
Fresh water	1.66 m^3	1.76	329 GL	24,909 GL[2]	1.3
GGE	1,011 kg CO_2-e	1,076	200 Mt	550 Mt[3]	36.4
NO_x	2.51 kg	2.67	497 kt	1,400 kt[4]	35.5
SO_x	3.14 kg	3.34	622 kt	1,400kt[4]	44.4
Particulates	0.55 kg	0.59	107 kt	1,100 kt[4]	9.7

The table below shows the average inputs and outputs related to 1 MWh of power generation, on both a transmission and distribution grid basis.

Parameter	Transmission grid	Distribution grid	Comment
Inputs			
Resource energy (GJ)	11.05	11.75	57.9% black coal, 31.2% brown coal, 8.5% natural gas, 1.8% oil
Fresh water (m^3)	1.66	1.76	Primarily for evaporative cooling
Outputs			
GGE (kg CO_2-e)	1,011	1,076	96.2% from power stations, 2.2% from coal mining, 1.6 from other processes
NO_x (kg)	2.51	2.67	96.4% from fossil fuel power generation, 2.7% from coal mining
SO_x (kg)	3.14	3.34	99.8% from fossil fuel power generation
Particulates (kg)	0.55	0.59	69.0% from power generation, 30.9% from open cut coal mining
Solid waste (kg)	62.2	66.0	99.9% from power generation

The key findings are;

- Resource consumption for the production of 1 MWh of electricity from Australian transmission grids totals on average 11.05 GJ. This equates to an overall energy efficiency of 32.6%. This figure does not simply represent the amount of energy consumed at the power station, but all energy consumed in the entire process from the removal of the resource from the natural environment, to the transmission of the electricity. All sources of electricity are included in this number with the assumption made that hydro and wind sources have negligible resource consumption.
- The resource energy was dominated by coal as expected. From an energy point of view, black coal was the largest source with a 57.9% share of the nation's total, with brown coal at 31.2% on a GJ basis. On a kilogram basis however, brown coal was the biggest contributor, with each MWh of electricity consuming on average 400kg. Black coal consumption amounted to 279kg/MWh on average. This is due to the low energy/ high water content of brown coals.
- The consumption of water is most likely to be the figure with the largest error. For the majority of the large power stations, fresh water consumption was reported. However, some of the larger generators, and many of the small ones, did not publish their water consumption data. In addition, some did not report which method of cooling (dry cooling, sea water, fresh water) is used at the plant. This led to several assumptions where specific water use from one station was applied to others having similar characteristics. The average consumption per MWh came to 1.66 m^3.

- The Australian electricity industry was responsible for 36.4% of the nation's greenhouse gas emission in 2004. Of this total, 88.1% came from Victoria, New South Wales, and Queensland combined. The greenhouse gas intensity of most states was between 900 and 1,000 kg per MWh to the transmission grid. Victoria however, had a greenhouse gas intensity of 1,437 kg/MWh, with a resource energy consumption of 14.32 GJ/MWh. This is due to its heavy reliance on brown coal.
- Australia's electricity industry was responsible for 35.5% of the nation's total NOx emissions in 2004. Of this total, 96.2% came from the combustion of fuel at power stations and 2.7% came as a result of coal mining.
- SOx emissions from power stations alone contributed around 620 kt to the national total of 1,400 kt in 2004. The state with the highest specific contribution was NSW with a SOx intensity of 4.33 kg/MWh.
- Particulate emissions for the Australian electricity industry totalled 107kt in 2004. This represented 9.7% of the national total. Unlike the other externalities, there was a significant contribution from coal mining, which contributed 31% of the total. There was some difficulty in tracking down the specific particulate matter emissions from all coal mines. As such, the known specific emissions of some mines were applied to those for which no data could be found.

1. INTRODUCTION

The purpose of this Life Cycle Analysis is to determine the environmental impacts of power generation in Australia, based on a range of key performance indicators. The basis of the study is the generation of 1 MWh of electricity supplied from transmission and distribution grids. Interstate transfers have been included.

The study aims to provide collated information on the entire integrated power generation grid, including coal mines, transportation and provision of other consumables.

Data is sourced from a range of publicly available sources (some of which are conflicting) and the most representative data has been used – based on prior studies.

1.1. National grids

The installed capacity for grid and (larger) non-grid connected generators is summarised in Table 1 below (includes co-generation and renewables). New South Wales has the largest generating capacity of all states in Australia, with a total capacity of 13,011 MW (June 2004).

Table 1 Power generation capacity of Australian States (June 2004)[1]

State	Principal plant (MW)	Non-grid generators (MW)	Cogeneration (MW)[a]	Total (MW)	% of total
NSW & ACT	12,229	517	265	13,011	25.6
Qld	10,477	617	197	11,291	22.2
VIC	8,527	467	376	9,370	18.4
WA	3,570	1,881	911	6,362	12.5
SA	3,421	151	279	3,851	7.6
Tas	2,571	18	16	2,605	5.1
NT	449	170	105	724	1.4
SMHEA	3,676	-	-	3,676	7.2
Total	44,920	3,821	2,147	50,890	100

[a] Summation error due to rounding

1.2. Australian grid[1,2,3]

In 2004, a total of 204,787 GWh of electricity was exported to their respective transmission grids from Australia's power stations, with around 192,781 GWh consumed Australia-wide.

The breakdown of each states contribution to overall sent-out electricity is shown in Figure 1.

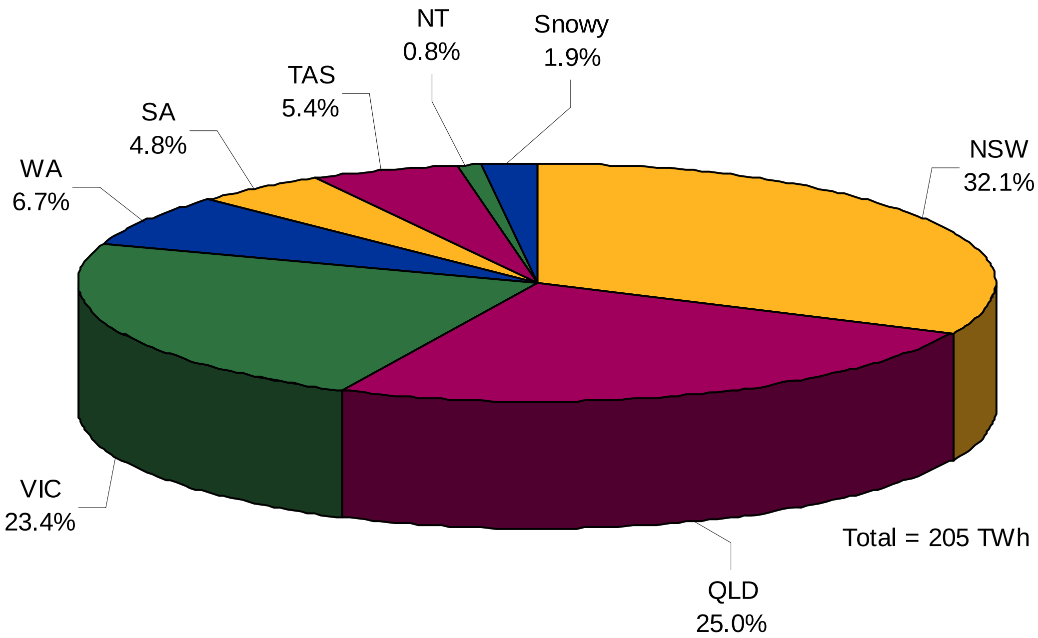

Figure 1 Sent-out electricity on a state basis

The power stations considered for each state, as well as their weighted contribution to both the state and national total, are shown in Tables 2 to 8. It should be noted that some grids were not able to be completed for the 2003/4 financial year, due to limited data. In circumstances where the most recent data is not compatible with the assessed period, generation has been factored according to each station's share for this most recent period. For this reason, the GWh sent out figures may not be correct for the 2003/4 period, but are indicative of the most available data extrapolated to the 2003/4 financial year. The statement under each table regarding the percentage of total generation for each type of plant may not sum to 100%. This is due to small amounts of electricity being sourced from other types of generation.

1.2.1 New South Wales[1,4]

New South Wales power stations sent-out 65,700 GWh in 2004, which represented 32.1% of Australia's total. A breakdown of major power stations, and their contributions to both the state and Australian electricity grids, is shown in Table 2.

Table 2 New South Wales electricity grid data (excludes purchases from interstate, the Snowy Mountains Hydroelectric Authority, and pumped storage)

Station	Operator	Type	Capacity (MW)	Comm. year	Fuel	GWh sent out (2004)	GWh sent out (%NSW)
Eraring	Eraring Energy	Pf boiler	2640	1982	Coal	14,873	22.6
Bayswater	Macquarie Generation	Pf boiler	2640	1984	Coal	17,111	26.0
Liddell	Macquarie Generation	Pf boiler	2000	1971	Coal	8,687	13.2
Vales Point B	Delta Electricity	Pf boiler	1320	1978	Coal	7,173	10.9
Mt Piper	Delta Electricity	Pf boiler	1320	1992	Coal	8,489	12.9
Wallerawang	Delta Electricity	Pf boiler	1000	1976	Coal	5,858	8.9
Munmorah	Delta Electricity	Pf boiler	600	1969	Coal	263	0.4
Redbank	National Power	CFBC boiler	150	2001	Coal	1,119	1.7
Smithfield	Sithe Energy	CCGT	177.5	1997	NG	987	1.5
Appin/Tower	Energy Development	Reciprocating engines	96	1997	CSM[1]	658	1.0
Hume	Eraring Energy	Hydro	58	1957	Oil	<25	0.0
Warragamba	Eraring Energy	Hydro	50	1959	Hydro	66	0.1
Burrendong	Power Facilities	Hydro	20	1996	Hydro	66	0.1
Copeton	Power Facilities	Hydro	20	1996	Hydro	66	0.1
Yarrawonga	Power Facilities	Hydro	9	1997	Hydro	<25	0.0
Burrinjuck	Eraring Energy	Hydro	28	1938/ 2002	Hydro	<25	0.0
Keepit	Eraring Energy	Hydro	6	1938	Hydro	<25	0.0
Glenbawn	Power Facilities	Hydro	5.8	1995	Hydro	<25	0.0
Brown Mountain	Eraring Energy	Hydro	4	1938	Hydro	<25	0.0
Nymboida	Country Energy	Hydro	9.8	1928	Hydro	<25	0.0
Oakey	Country Energy	Hydro	5		Hydro	<25	0.0
Blayney	Eraring Energy	Wind	10	2000	Wind	<25	0.0
Crookwell	Eraring Energy	Wind	5	1999	Wind	<25	0.0
Total			12,514			65,810	99.8

1. Coal seam methane
2. Data estimated based on capacity and assumed capacity factor

In terms of energy sources, 97.5% of the electricity generated in New South Wales came from black coal-fired plants, 1.5% came from natural gas plants, and 1.0% came from coal seam methane.

1.2.2 Queensland[1,5]

Queensland power stations sent-out 51,200 GWh in 2004, which represented 24.9% of Australia's total. A breakdown of major power stations, and their contributions to both the state and Australian electricity grids, is shown in Table 3.

Table 3 Queensland electricity grid data (excludes purchases from interstate)

Station	Operating company	Type	Capacity (MW)	Commissioned	Fuel	GWh sent out (2004)	GWh sent out (% Qld)
Tarong	Tarong Energy	Pf boiler	1400	1984-86	Coal	11,160	21.8
Tarong North	Tarong Energy	Pf boiler	450	2003	Coal	3,584	7.0
Gladstone	Comalco/NRG	Pf boiler	1680	1976-82	Coal	7,730	15.1
Stanwell	Stanwell Corporation	Pf boiler	1400	1993-96	Coal	8,652	16.9
Millmerran	Intergen	Pf boiler	840	2003	Coal	4,659	9.1
Callide B	CS Energy	Pf boiler	700	1988/89	Coal	5,068	9.9
Swanbank B	CS Energy	Pf boiler	500	1970-73	Coal	2,253	4.4
Collinsville	Transfield Services	Pf boiler	190	1998	Coal	563	1.1
Callide Power Plant	CS Energy/ Intergen	Pf boiler	800	2001	Coal	5,836	11.4
Kareeya	Stanwell Corporation	Hydro	72	1957/59	Hydro	410	0.8
Barron Gorge	Stanwell Corporation	Hydro	60	1963	Hydro	154	0.3
Barcaldine	Enertrade	CCGT	53	1993	NG	102	0.2
Roma	Origin Energy	OCGT	76	1999	NG	<20	<0.1
Mt Stuart	Origin Energy	OCGT	288	1999	Oil	<20	<0.1
Mackay	Stanwell Corporation	OCGT	34	1976	Oil	<20	<0.1
Oakey	Oakey Power Holdings	OCGT	320	2000	Gas or diesel	51	0.1
Swanbank C	CS Energy	OCGT	26	1973	NG	<20	
Swanbank D	CS Energy	OCGT	37	1999	NG	<20	<0.1
Swanbank E[1]	CS Energy	CCGT	385	2002	NG	614	1.2
Yabulu	Transfield Holdings	OCGT	165	1999	NG	<20	<0.1
Wivenhoe	Tarong Energy	Pumped hydro[2]	500	1984	Hydro	205	0.4
Total			10,094			51,194	99.7

1. Coal seam methane
2. Pumped storage hydro scheme is a net consumer of power

In terms of energy sources for Queensland, 96.9% of the electricity generated came from black coal-fired plants, 1.6% came from natural gas plants, and 1.5% came from hydro.

1.2.3 Victoria[1,6]

Victorian power stations sent-out 48,000 GWh in 2004, which represented 23.4% of Australia's total. A breakdown of major power stations, and their contributions to both the state and Australian electricity grids, is shown in Table 4.

Table 4 Victorian electricity grid data (does not include purchases from interstate or the Snowy Mountains Hydroelectric Authority)

Station	Operating Company	Type	Capacity (MW)	Commissioned	Fuel type	GWh sent out (2004)	GWh sent out (% Vic)
Loy Yang A	Loy Yang Power	Pf boiler	2000	1984/87	Coal	14,775	30.8
Hazelwood	Hazelwood Power	Pf boiler	1600	1964/71	Coal	11,273	23.5
Yallourn W	TRU Energy	Pf boiler	1480	1973-82	Coal	10,698	22.3
Loy Yang B	Mission Energy[1]	Pf boiler	1000	1993/96	Coal	8,011	16.7
Anglesea	Alcoa	Pf boiler	150	1969	Coal	1,247	2.6
Morwell	Energy Brix	Pf cogen	170	1958-62	Coal	1,007	2.1
Newport D	AES Transpower	Gas boiler	500	1980	NG	288	0. 6
Valley Power	Edison Mission/Origin	Gas turbine	300	2002	NG	< 48	< 0.1
Somerton	AGL	Gas turbine	150	2002	NG	< 48	< 0.1
Jeeralang A & B	AES Transpower	Gas turbine	466	1979/80	NG	96	0.2
Bairnsdale	Duke Energy[3]	Gas turbine	92	2001	NG	48	0.1
West Kiewa	Southern Hydro	Hydro	61.6	1955/56	Hydro	144	0.3
McKay Creek	Southern Hydro	Hydro	96[2]	1960	Hydro	96	0.2
Eildon	Southern Hydro	Hydro	149	1956/57	Hydro	48	0.1
Dartmouth	Southern Hydro	Hydro	180	1977	Hydro	192	0.4
Clover	Southern Hydro	Hydro	29	1955/56	Hydro		
Rubicon	Southern Hydro	Hydro	13.5	1955/56	Hydro		
Lower Rubicon	Southern Hydro	Hydro	2.7	1955/56	Hydro		
Cairn Curran	Southern Hydro	Hydro	2	1955/56	Hydro		
Royston	Southern Hydro	Hydro	0.8	1955/56	Hydro		
Rubicon Falls	Southern Hydro	Hydro	0.3	1955/56	Hydro		
Corio (Shell Refining)	National Mutual	Cogen	44.4	1968/92	Waste gas		
Petroleum/ ESSO-LIP	BHPBilliton	Gas boiler	32	-	Waste gas		
Maryvale	Amcor Paper	Cogen	54.5	1976/89	NG		
Eildon	Pacific Hydro	Hydro	4.5	-	Hydro		
Codrington	Pacific Hydro	Wind	18	2001	Wind		
Total			8,596			47,971	99.9

1 International Power now operates Loy Yang B, but, for the period considered in this LCA, Mission Energy was the operator

2 The McKay power station has since completed an upgrade (2004) from the 96MW shown above, to 150MW

3 Alinta acquired Bairnsdale power station in April 2004

In terms of energy sources, 98.0% of the electricity generated in Victoria came from brown coal-fired plants, 1.0% came from natural gas plants, and 1.0% came from hydro generation.

1.2.4 Western Australia[1,7,8,25]

Western Australian power stations sent-out 13,800 GWh in 2004 which represented 6.7% of Australia's total. A breakdown of major power stations, and their contributions to both the state and Australian electricity grids, is shown in Table 5. The data used to characterise electricity generation in Western Australia considers only the South West Interconnected System (SWIS). Consumables and emissions data were only readily available for stations owned by Western Power which represents over 80% of the SWIS. It is expected that the totals for consumables and emissions are higher in total than considered in this study, but the specific consumption of materials and emissions should be representative of the entire WA electricity system.

Table 5 Western Australian electricity grid data (SWIS)

Station	Operating Company	Type	Capacity (MW)	Commissioned	Fuel type	GWh sent out (2003)	GWh sent out (% WA)
Kalgoorlie	Western Power	Gas Turbine	62.0	1984/90	Oil	<5	<0.1
Kwinana	Western Power	Pf boiler/Gas turbine	901	1970/72/76	Coal/Oil /NG	1,627	11.8
Muja	Western Power	Pf boiler	1,040	1965/86	Coal	5,310	38.5
Mungarra	Western Power	Gas Turbine	112	1990/91	NG	262	1.9
Worsley	Western Power	Cogen/NG	120	2000	NG	441	3.2
Tiwest	Western Power	Gas Turbine	36	1990	NG	110	0.8
Pinjar	Western Power	Gas Turbine	586	1990/92	NG/Oil	372	2.7
Collie	Western Power	Pf boiler	330	1999	Coal	2,055	14.9
Geraldton	Western Power	Gas Turbine	21	1973	NG/Oil	<5	<0.1
Cockburn	Western Power	CCGT	240	2003	NG	1,186	8.6
Other WA systems	Various	Various	900			2,427	17.6
Total			5,357			13,791	100.0

In terms of energy sources, 76.0% of the electricity generated in Western Australia came from black coal-fired plants and 24% came from natural gas plants.

1.2.5 South Australia[1,9,10,11]

South Australian power stations sent-out 9,900 GWh in 2004, representing 4.8% of Australia's total. A breakdown of major power stations, and their contributions to both the state and Australian electricity grids, is shown in Table 6.

Table 6 South Australian electricity grid data

Station	Operating Company	Type	Capacity (MW)	Commissioned	Fuel type	GWh sent out (2003)	GWh sent out (% SA)
Dry Creek	Synergen Energy	Gas Turbine	156	1973	NG	<10	<0
Hallet	AGL	Gas Turbine	183	2002	NG/Diesel	20	0.2
Ladbroke Grove	Origin Energy	Gas Turbine	80	2000	NG	475	4.8
Mintaro	Synergen Energy	Gas Turbine	90	1984	NG	<10	<0
Northern	NRG Flinders	Pf boiler	520	1985	Coal	4,067	41.1
Osborne	ATCO Power	Cogenn Gas	185	1998	NG	1,197	12.1
Pelican Point	International Power	CCGT	478	2000	NG	1,296	13.1
Port Lincoln	Synergen Energy	Gas turbine	50	1998/00	Diesel	<10	<0
Quarantine	Origin Energy	Gas Turbine	96	2002	NG	40	0.4
Snuggery	Synergen Energy	Gas Turbine	63	1978/97	NG	<10	<0
Thomas Playford B	NRG Flinders	Pf boiler	240	1960	Coal	158	1.6
Torrens Island	CLP Power Asia	Gas boiler	1,280	1967/77	NG	2,632	26.6
Total			3,421			9,896	99.9

In terms of energy sources, 57.3% of the electricity generated in South Australia came from natural gas plants and 42.7% came from brown coal-fired plants.

1.2.6 Tasmania[1,12]

Tasmanian power stations sent-out 11,000 GWh in 2004, which represented 5.4% of Australia's total. A breakdown of major power stations, and their contributions to both the state and Australian electricity grids, is shown in Table 7.

Table 7 Tasmanian electricity grid data

Station	Operating Company	Type	Capacity (MW)	Commissioned	Fuel type	GWh sent out[a] (2003)	GWh sent out (% TAS)
Bell Bay	Hydro Tasmania	Gas Boiler	240	1971	NG	954	8.7
King Island	Hydro Tasmania	Diesel Engine	20	n/a	Oil	15	0.1
Flinders Island	Hydro Tasmania	Diesel Engine	6	n/a	Oil		
Great lake Catch.	Hydro Tasmania	Hydro	382	various	Hydro	n/a	
Derwent Catch.	Hydro Tasmania	Hydro	468	various	Hydro	n/a	
Mersey Forth Catch.	Hydro Tasmania	Hydro	308	various	Hydro	n/a	
Gordon Catch.	Hydro Tasmania	Hydro	432	various	Hydro	n/a	
Pieman Catch.	Hydro Tasmania	Hydro	475	various	Hydro	n/a	
King Catch.	Hydro Tasmania	Hydro	143	various	Hydro	n/a	
Yolande Catch.	Hydro Tasmania	Hydro	8.4	various	Hydro	n/a	
King Island	Hydro Tasmania	Wind	750	1998	Wind	n/a	
Total			2,482			11,014	

[a] The absence of generation data for wind and hydro makes no difference as these technologies are assumed to have no resource energy or externalities.

In terms of energy sources, 47.3% of the electricity generated in Tasmania came from natural gas plants, 38.9% came from hydroelectricity plants, and 13.1% came from wind generation.

1.2.7 Northern Territory[13,14,15]

Northern Territory power stations sent-out 1,700 GWh in 2004, representing 0.8% of Australia's total. A breakdown of major power stations, and their contributions to both the state and Australian electricity grids, is shown in Table 8.

Table 8 Northern Territory electricity grid data

Station	Operating Company	Type	Capacity (MW)	Commissioned	Fuel type	GWh sent out (2003)	GWh sent out (% NT)
Berrimah	Power and Water	Gas turbine	30	1979	NG	219	13.1
Channel Island	Power and Water	CCGT/GT/ Gas boiler	300	1986/00	NG	1,055	63.0
Katherine	Power and Water	Gas turbine	21	1987	NG	3	0.2
Ron Goodin	Power and Water	Gas turbine	50.6	1974-88	Diesel	199	11.9
Tennant Creek	Power and Water	Gas reciproc/ Gas tubine	16.4	1975-99	NG	30	1.8
Pine Creek	Energy Developments	CCGT/GT/ Gas boiler	35	1996/98	NG	13	0.8
Brewer	Energy Equity	Diesel engine	8.5	1997	Diesel	35	2.1
Other	Various	Various	170	various	Diesel/NG	117	7.0
Total			631.5			1,674	99.9

In terms of energy sources, 82.0% of the electricity generated in the Northern Territory came from natural gas plants and 18% came from oil and diesel plants.

1.2.8 Snowy Mountains Hydroelectric Authority[1,16]

The contribution of the Snowy Mountains Hydro Scheme is treated as a separate grid in this study. The scheme effectively contributed 3,800 GWh in 2004 representing 1.9% of Australia's total. 100% of its output was derived from hydroelectric plants.

1.3. *State summary*

State	Capacity (MW)	GWh sent out (2003)	GWh sent out (% AUS)
New South Wales	12,514	65,810	32.1
Queensland	10,094	51,194	24.9
Victoria	8,596	47,971	23.4
Western Australia	5,357	13,792	6.7
South Australia	3,421	9,896	4.8
Tasmania	2,482	11,014	5.4
Northern Territory	632	1,674	0.8
Snowy Hydro	3,676	3,802	1.9
TOTAL	46,772	205,153	100

1.3.1 Transmission and distribution

The transmission and distribution of electricity in Australia is controlled by a number of companies. These companies as well as the states in which they operate are shown in Table 9.

Table 9 Electricity transmission and distribution companies

State	Company	Role	Notes
NSW	Energy Australia	Transmission/ Distribution	Energy Australia acts to support Transgrid's transmission network.
	Transgrid	Transmission	
	Integral Energy	Distribution	
	Country Energy	Distribution	Also supplies electricity to QLD
VIC	SPI PowerNet	Transmission	A subsidiary of Singapore Power International. Controlled by NEMMCO
	Alinta	Distribution	Formerly United Energy. Infrastructure business currently undergoing merger with AGL (April 2006)
	AGL		Assets formerly owned by Solaris Power. Infrastructure business currently undergoing merger with Alinta (April 2006)
	CitiPower		
	TRU energy		Formerly Eastern Energy
	Powercor	Distribution	Victoria's largest distributor
QLD	Powerlink	Transmission	Government owned
		Direct link	
	Transenergie	QNI Interconnector	
	ENERGEX	Distribution	Government owned
	Ergon Energy	Distribution	Government owned
	Country Energy	Distribution	NSW distributor whose supply area extends across the NSW/QLD border.
WA	Western Power	Transmission/ Distribution	South West Interconnected system (SWIS) and North West interconnected system (NWIS)
SA	ElectraNet	Transmission	
		500MW Interconnector	
	ETSA	Distribution	Sole electricity distributor regulated by the Electricity Pricing Order
TAS	Transend Networks	Transmission	
	Aurora Energy	Distribution	
	National Grid	Basslink	600MW Tas – Vic, 300MW Vic – Tas interconnector. World's longest sub-sea electricity cable.
NT	Power and Water Corporation	Transmission/ Distribution	Monopoly held by Power and Water Corporation regulated by Northern Territory Utilities Commission.

There are also several interconnectors in Australia which allow for the transfer of electricity across state borders. These are listed below in Table 10.

Table 10 Interstate interconnectors and their capacity

Interconnector	Border	Capacity	Commissioned
Basslink	TAS/VIC	600MW	2006
Queensland New South Wales Interconnector (QNI)	QLD/NSW	750 MW	2001
Murraylink	NSW/VIC/SA	220MW	2002
Heywood	VIC/SA	460MW	n/a
Directlink	NSW/QLD	180MW	2000
Snowy	SNOWY/VIC	1600-1900MW	n/a
Snowy	SNOWY/NSW	2800-3500MW	n/a

Figure 2 shows a map of the Australian transmission system. It includes the main transmission lines as well as their rating in kilovolts. Power stations are shown as the green squares though they are not labelled.

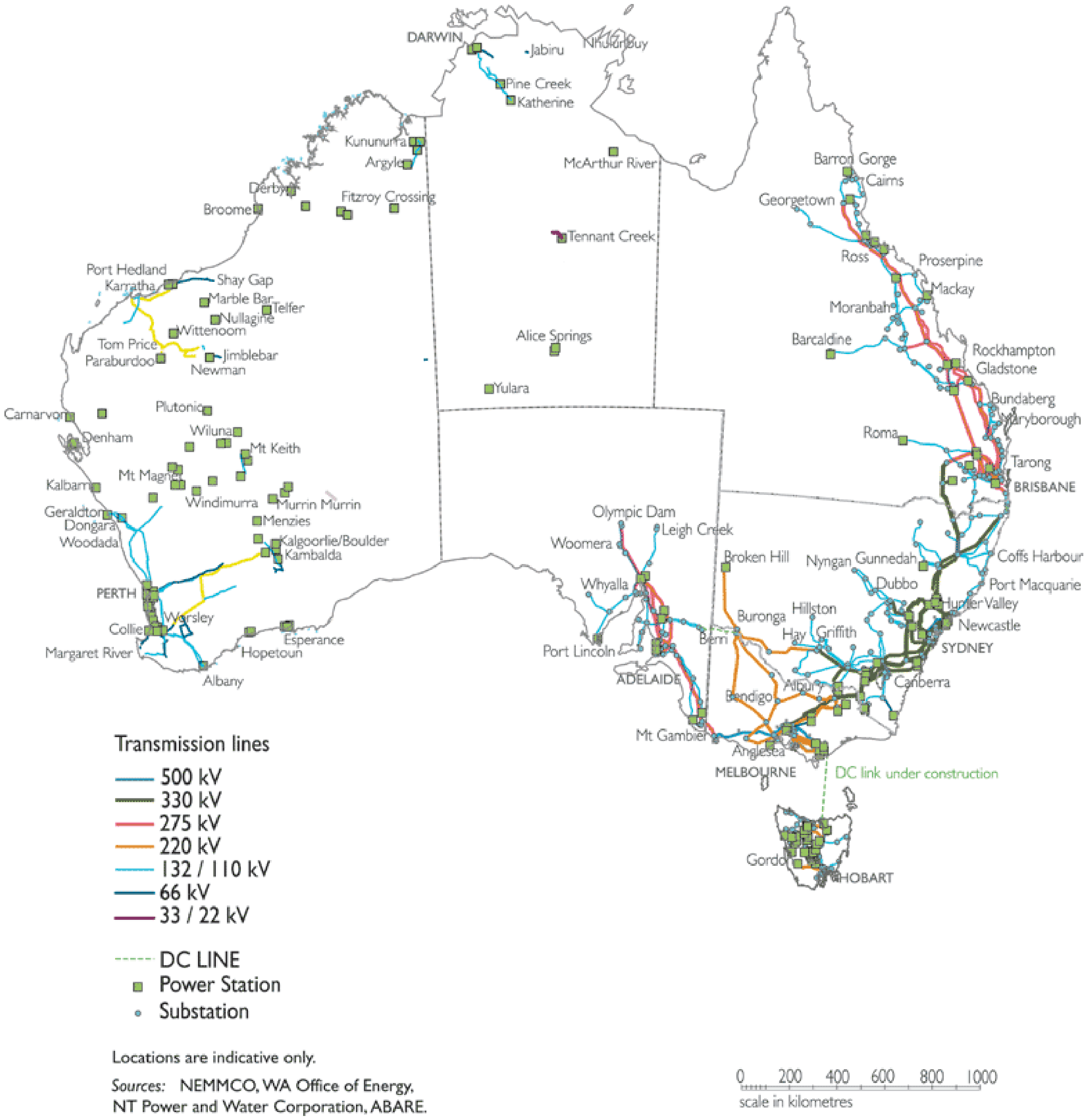

Figure 2- Australian transmission network[17]

1.4. Primary Australian generators

This section of the report describes the characteristics of the top 10 contributors to the Australian grid. These major facilities sent-out ~113 TWh in 2004, representing 55% of total generation. These facilities are described below. Note that all efficiencies on a higher heating value (HHV) basis.

1.4.1 Bayswater power station (1984-85)

Owned by Macquarie Generation, Bayswater is a subcritical pf fired power station located near Muswellbrook in the Hunter Valley. It is the equal largest power station in Australia (Eraring has the same capacity), consisting of 4×660 MW generators, for an overall capacity of 2,640 MW. Coal is supplied by conveyor from nearby open-cut mines. Condenser cooling is via four large natural draft cooling towers, with makeup water sourced from the Hunter

River. Bayswater achieves an annual average sent out thermal efficiency of ~35.6%. Bayswater contributed approximately 17,000 GWh to the NSW grid in 2004 making it the highest contributor Australia-wide, at ~8.3% of the nation's total.

1.4.2 Eraring power station (1982-84)

Eraring is a subcritical pf fired power station located on the western shores of Lake Macquarie, approximately 40 km from Newcastle, and is the equal largest power station in Australia with a capacity of 2,640 MW (4×660 MW generators). It is owned and operated by Eraring Energy. Coal for the power station is transported via conveyor from local mines, and via road or rail from other mines. Condenser cooling water is drawn from Lake Macquarie at Bonnells Bay, and returned to the adjacent Myuna Bay. Eraring achieves an average sent out thermal efficiency of ~36.4%. In 2004, Eraring power station sent out ~14,900 GWh, equivalent to around 7.3% of Australia's total output.

1.4.3 Loy Yang A power station (1984-87)

Loy Yang A is a subcritical pf fired power station located 165 km east of Melbourne, near Traralgon in the Latrobe Valley in Victoria. Loy Yang Power owns and operates the 2,000 MW Loy Yang A power station and the adjacent Loy Yang mine. The company supplies approximately one third of the power requirements for Victoria. The station has 4x500 MW capacity units, with the first two commissioned in 1984 and the final two in 1987. The station is fuelled on brown coal from the Loy Yang mine. It is the largest power station in Victoria and the largest brown coal power station in Australia. Condenser cooling is via four large natural draft cooling towers. Loy Yang A achieves an annual average sent out thermal efficiency of ~26.3%. Loy Yang A sent out ~14,800 GWh in 2004, approximately equal to 7.2% of Australia's total.

1.4.4 Hazelwood power station (1964/71)

Hazelwood is a subcritical pf fired power station located 140 km southeast of Melbourne near Morwell in Victoria. Hazelwood Power is owned by International Power plc. The power station consists of 8x200 MW generators, and has an overall capacity of 1600 MW. Hazelwood was commissioned in 1964/71 along with the adjoining Hazelwood mine, which supplies the power station and Energy Brix (Morwell) with brown coal. The station utilises cooling water from the artificial lake called Hazelwood pondage, which maintains a temperature of at least 23°C. Hazelwood achieves an annual average sent out thermal efficiency of ~24.8% (HHV). Hazelwood sent out ~11,300 GWh in 2004, equating to around 5.5% of Australia's total.

1.4.5 Tarong power station (1984/86, 1983)

Tarong power station, (owned and operated by Tarong Energy), is a subcritical pf fired power station located at Nanango, 180 km northwest of Brisbane, and is one of Queensland's largest power stations. With a total generating capacity of 1,400 MW (4x350 MW generating units), Tarong generates base load power for the Queensland grid. The first of Tarong's four generating units became operational in May 1984, and the station was completed in 1986. Coal is supplied via conveyor from Meandu coal mine. Cooling water for the natural draft evaporative cooling towers is via pipeline from Boondooma dam. Tarong achieves an annual sent out thermal efficiency of 35%-36% (HHV). Tarong sent out ~11,200 GWh in 2004, equivalent to around 5.4% of Australia's total.

1.4.6 Yallourn W power station (1973-75, 1981-82)

Yallourn W is owned and operated by TRU Energy following a recent name change from Yallourn Power. Yallourn W is a subcritical pf fired power station located 140km east of Melbourne, at Yallourn, and consists of 2x360 MW (commissioned 1973-75) and 2x380 MW (commissioned 1981-82) generators, an overall capacity of 1480 MW. Coal is sourced from the adjacent Yallourn coal mine. Evaporative cooling towers are used for condenser cooling. Yallourn W achieves an annual average sent out thermal efficiency of ~26.2% (HHV). In 2004, Yallourn W sent out ~10,700 GWh, equal to around 5.2% of Australia's total.

1.4.7 Liddell power station (1971-73)

Liddell is a subcritical pf fired power station located near Muswellbrook in the Hunter Valley, close to the Bayswater power station. It is owned and operated by Macquarie Generation and was the first power station in NSW to be located inland, away from the abundant supply of salt water cooling. Lake Liddell was constructed around the power station to provide cooling water, which is topped up from the Hunter River. Liddell power station consists of 4×500 MW (2,000 MW) generators, with coal supplied by conveyor from nearby open-cut mines. Liddell achieves an annual average sent out thermal efficiency of ~32.7% (HHV). Liddell sent out around 8,700 GWh in 2004, equivalent to 4.2% of Australia's total.

1.4.8 Stanwell power station (1993/96)

Stanwell is a subcritical pf fired power station located 22 km west of Rockhampton that is owned and operated by Stanwell Corporation. Stanwell has a capacity of 1,400 MW (4×350 MW generating units) and operates as a base load station. Coal for the power station is sourced mostly from Curragh and Blackwater coal mines. First producing electricity in 1993, the fully automated, coal-fired power station became fully operational in 1996. Condenser cooling is via large natural draft evaporative cooling towers. Stanwell achieves an annual sent out thermal efficiency of over 35% (HHV). In 2004, Stanwell sent out ~8,700 GWh, approximately the same as Liddell power station, equivalent to ~4.2% of Australia's total.

1.4.9 Mt Piper power station (1992-93)

Mt Piper is a subcritical pf fired power station located in the Central West region of New South Wales, approximately 25 km west of Lithgow. Owned and operated by Delta Electricity, Mt Piper has a capacity of 1,320 MW (2×660 MW generating units). Coal from surrounding coal mines is burned in the power station boilers. Cooling water for use in the evaporative cooling towers is sourced from Lyle Dam on Cox's River via a 20 km pipeline. Mt Piper achieves an annual average sent out thermal efficiency of ~37.2% (HHV). Mt Piper sent out ~8,500 GWh in 2004, approximately equal to 4.1% of Australia's total.

1.4.10 Loy Yang B power station (1993/96)

Loy Yang B is a subcritical pf fired power station located 165 kilometres east of Melbourne, adjacent to the Loy Yang A power station. It is owned and operated by Mission Energy, which is owned by Edison International. Loy Yang B power station is the youngest of the coal fired power stations on the Victorian grid. Loy Yang B consists of 2x500 MW generators with an overall generating capacity of 1000 MW. Evaporative cooling towers are used for condenser cooling. Loy Yang B achieves an annual average sent out thermal efficiency of ~25.0% (HHV). Loy Yang B sent out ~8,000 GWh in 2004, equivalent to around 3.9% of Australia’s total.

1.5. Future generating capacity[1]

Australia wide, there are many new power stations on the drawing board. These include stations that are in the proposal stage, through to those under construction. The planned and proposed stations, as well as those which are currently being built, are shown in Table 11.

Table 11 Planned and proposed power stations in Australia

State	Plant	Developer	Type	Size (MW)	Fuel Type	Proposed Comm. Yr.
NSW	Broadwater	Delta Electricity	Cogen	30	Biomass	2007
	Condong	Delta Electricity	Cogen	30	Biomass	2007
	Gunning	Delta Electricity	Wind	62	Wind	2006/7
	Munmorah	Delta Electricity	GT	600	NG	2008/9
	Mt Piper upgrade	Delta Electricity	Steam	180	Black Coal	2007/8
	Mt Piper extension	Delta Electricity	Steam	1,500	Black Coal	2011-13
	Nowra	Delta Electricity	CCGT	400	NG	2009/10
	TBC	Delta Electricity	CCGT	400	NG	2011/12
	Tallawarra	Texas Utilities	CCGT	400	NG	
	Tomago 1 & 2	Macquarie Generation	GT	360	NG	2007
	Tomago 3	Macquarie Generation	Steam	270	Black Coal	n/a
	Wagga Wagga	Wambo Power Ventures	GT	450	NG	n/a
QLD	Braemar	Babcock & Brown/ ERM power	GT	450	NG	
	Peak Downs	BHPBilliton	Steam	230	Black Coal	2006/7
	Chinchilla	Qld Gas Co.	CCGT	57	NG	n/a
	Kogan North	CS Energy	Steam	750	Black Coal	2008
	MIM/Entergy	MIM/Entergy	Steam	700	Black Coal	2007/8
	Surat Dawson	Surat Dawson Development Corp.	Steam	470	Black Coal	n/a
	Townsville	Stanwell	CCGT	766	NG	n/a
	Pioneer II	CSR Sugar	Steam	63	Bagasse	n/a
	Spring Gully	Origin Energy	CCGT	1,000	NG	2008/9
VIC	Hazelwood upgrade	Hazelwood power	Steam	90	Brown Coal	2003-08
	Kiewa expansion	Southern Hydro	Hydro	130	Water	n/a
	Laverton Nth	Snowy Hydro	GT	312	NG	2006
	Loy Yang A upgrade	Loy Yang power	Steam	236	Brown Coal	2008
	Maryvale	Paperlinx/Alinta	Cogen	200	NG	
	Mortlake	Origin Energy	CCGT	1,000	NG	2008
	Portland	Pacific Hydro	Wind	195	Wind	2006
	Yaloak	Pacific Hydro	Wind	115.5	Wind	2006

State	Plant	Developer	Type	Size (MW)	Fuel Type	Proposed Comm. Yr.
	Yambuk	Pacific Hydro	Wind	30	Wind	2006
WA	Alinta	AlintaGas	Cogen	100	NG	n/a
	Bluewaters 1	Griffin Group	Steam	200	Black coal	2008
	DESTEC Energy	DESTEC Energy	GT	660	NG	n/a
	Emu Downs	Stanwell/Griffin Energy	Wind	8	Wind	2006
	Freemantle	Pacific Hydro	Wind	7.2	Wind	2006
	Perth Energy Plant	Perth Energy Ltd	CCGT	120	NG	2006
	Siemens AG	Siemens AG	CCGT	400	NG	n/a
	Transalta	Transalta	CCGT	470	NG	n/a
	Telfer gold mine	Newcrest Mining	GT	135	NG	n/a
	Western Power Corp	Western power	Steam	350/400	Black coal	2006
	Western Power Peaking	Western power	GT	120	NG	2006
SA	ATCO	Auspine	Cogen	60	NG	n/a
	Innamincka	Geodynamics	Steam	13	Hot Dry Rocks	n/a
	Clements Gap	Pacific Hydro	Wind	57.8	Wind	2006
	Hallett	AGL	Wind	135	Wind	n/a
	Pelican Point expansion	International Power	GT	250/300	NG	n/a
	Port Pirie	International Power	GT	230	NG	n/a
	Quarantine expansion	Origin Energy	CCGT	70/200	NG	2006/7
	Tungketta Hill	Ausker Energie/ ANZ Infrastructure Services	Wind Turbines	55	Wind	n/a
	Vincent North	Pacific Hydro	Wind Turbines	59.4	Wind	2006
TAS	Heemskirk	Hydro Tasmania	Wind	160	Wind	n/a
	Musselroe	Hydro Tasmania	Wind	150	Wind	2008/9
ACT	TBC	AGL	GT	90/300	NG	n/a

2. LCA METHODOLOGY

The study was based on a cradle-to-gate analysis for the generation, transmission and distribution of electricity in Australia. It excludes power station construction and small non-grid generation (mostly small and remote facilities), or grid-connected facilities which do not result in net export of power (*eg* Bluescope Steel*, Port Kembla). Losses due to pumped storage are included in transmission losses.

The functional unit is 1 MWh of electricity supplied by Australian electricity grids (transmission and distribution), in the 12 months ending June 2004.

* Formerly BHP Steel

2.1. System boundary

The system boundary contains resource extraction, transportation, provision of other fuels and consumables, and emissions, associated with the generation of 1 MWh of electricity in Australia.

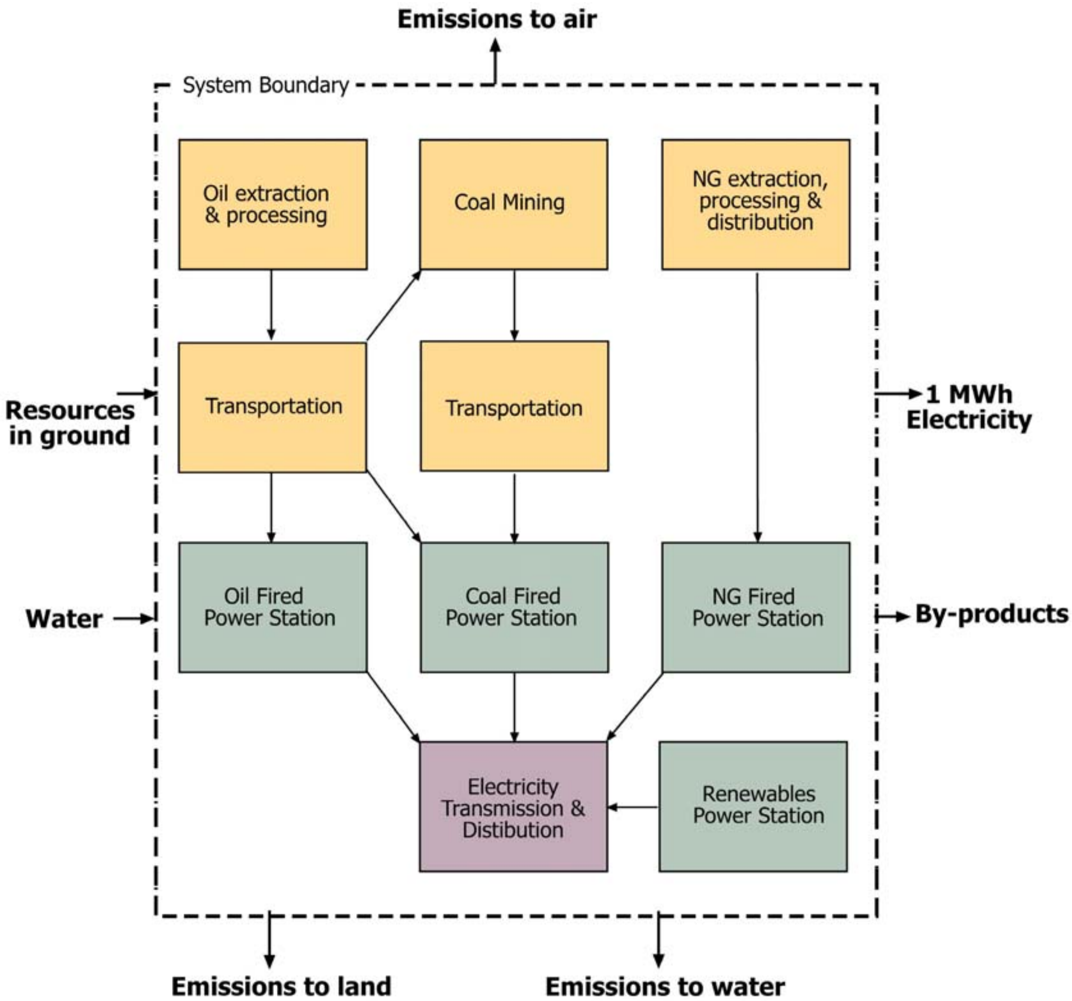

Figure 3 LCA system boundary

2.1.1 Power plant data

Data for Australia's primary plants are summarised in the following tables, using information sourced from the Energy Supply Association of Australia, (formerly the Electricity Supply Association of Australia)[1,2,3] and other publicly available reports including the National Greenhouse Gas Inventory Workbook for Fuel Combustion (Stationary Sources)[18], company annual and environment reports, the National Pollutant Inventory[19], and others[20,21,22].

All efficiency values are on a HHV basis and CO_2 intensity is either sourced from company environment reports, or is calculated from fuel consumption assuming 99% of carbon in the fuel is converted to CO_2. The shaded boxes indicate where NPI data has been employed.

Table 12 Efficiency and emissions data for the primary generators contributing to the New South Wales transmission grid

Station	Efficiency (%)	CO_2 (kg/MWh)	NO_x (kg/MWh)	SO_x (kg/MWh)	PM_{10} (kg/MWh)	Fresh water (m^3/MWh)
Appin/Tower	32.1[a]	569[b]	2.73	0.003	<0.1	Not reported
Bayswater	35.6	879	2.3	5.44	0.02	2.29
Eraring	36.4	870	2.27	3.24	0.07	0.1[g]
Hunter Valley	28.0	940	17.1	Not reported	Not reported	0
Liddell	32.7	949	2.21	4.96	0.07	3.05
Mt Piper	37.2	843	2.9	4.29	0.02	1.55
Munmorah	32.0	984	2.21	2.92	0.09	0.3[g]
Smithfield	42.4	431	0.21	<0.1	0.014	Not reported
Redbank	32.0	978	0.56	2.04	0.12	2.08
Vales Point B	35.6	896	2.40	3.3	0.23	0.13
Wallerawang	33.2	893	2.02	4.2	0.17	1.81

a) Estimate

b) Actual emissions from generation – overall this facility results in negative net emissions due to the avoidance of fugitive CH_4. This net saving is shown in its LCA results.

Table 13 Efficiency and emissions data for the primary generators contributing to the Victorian transmission grid

Station	Efficiency (%)	CO_2 (kg/MWh)	NO_x (kg/MWh)	SO_x (kg/MWh)	PM_{10} (kg/MWh)	Fresh water (m^3/MWh)
Anglesea	29.2	1,230	3.08	32.3	0.29	3.48
Bairnsdale	35.0	522	0.23	0.01	0.03	*not reported*
Hazelwood	24.8	1,550	2.42	1.00	0.22	2.27
Jeeralang A & B	24.8/26.9	697	2.19	0.03	0.04	*not reported*
Loy Yang A	26.3	1,220	1.97	3.31	0.10	2.47
Loy Yang B	25.0	1,280	1.59	2.17	0.06	2.47
Energy Brix (Morwell)	16.9	2,280	2.96	2.01	0.55	3.95
Newport D	34.9	524	0.40	<0.01	0.03	*not reported*
Somerton	29.0	630	0.88	<0.01	0.03	*not reported*
Valley	29.0	630	1.01	0.01	0.04	*not reported*
Yallourn	26.2	1,410	1.20	1.61	0.33	3.11

Table 14 Efficiency and emissions data for the primary generators contributing to the Queensland transmission grid

Station	Efficiency (%)	CO_2 (kg/MWh)	NO_x (kg/MWh)	SO_x (kg/MWh)	PM_{10} (kg/MWh)	Fresh water (m^3/MWh)
Tarong	35.0	906	4.48	2.48	0.90	2.62
Tarong North	37.4	851	1.7	1.88	0.05	2.15
Barcaldine	45.0	398	0.35	Not reported	0.03	Not reported
Millmerran	40.0	748	1.52	3.37	0.24	0.225
Gladstone	35.0	934	5.12	3.43	0.12	0.02
Stanwell	35.3	909	3.24	3.59	0.13	2.15
Mount Stuart	32.7	802	1.02	0.05	0.08	Not reported
Callide B	35.1	967	3.95	1.65	0.27	2.35
Swanbank B	32.1	934	2.89	4.69	0.08	3.0
Swanbank E	50.0	358	0.07	<0.1	0.02	Not reported
Collinsville	26.3	1220	4.15	8.41	0.2	1.64
Callide Power Plant	39.1	869	1.14	1.6	0.08	1.50

Table 15 Efficiency and emissions data for the primary generators contributing to the Western Australian transmission grid

Station	Efficiency (%)	CO_2 (kg/MWh)	NO_x (kg/MWh)	SO_x (kg/MWh)	PM_{10} (kg/MWh)	Fresh water (m^3/MWh)
Collie	33.5	961	1.40	5.34	0.2	2.15
Muja	29.3	1120	3.86	5.97	7.8	2.37
Kalgoorlie	16.0	1660	0.80	0.85	<0.1	<0.1
Pinjar	22.1	842	1.96	0.02	<0.1	<0.1
Kwinana	28.2	800	3.43	2.75	0.09	0.79
Mungarra	22.2	839	2.00	<0.01	0.05	<0.1
Worsley	23.3	799	2.93	<0.01	<0.01	<0.1
Cockburn	50	373	0.32	<0.01	<0.01	<0.1
Tiwest	21.3	875	1.02	<0.01	<0.01	<0.1

Table 16 Efficiency and emissions data for the primary generators contributing to the South Australian transmission grid

Station	Efficiency (%)	CO_2 (kg/MWh)	NO_x (kg/MWh)	SO_x (kg/MWh)	PM_{10} (kg/MWh)	Fresh water (m^3/MWh)
Northern	31.5	1,140	3.19	2.14	0.2	n/a
Torrens Island	29.7	615	0.65	0.01	0.03	n/a
Playford	23.0	1,570	2.56	5.03	0.35	n/a
Dry Creek	30.0	609	2.9	0.01	0.06	n/a
Mintaro	30.0	609	2.09	<0.01	0.05	n/a
Snuggery	26.0	703	6.82	0.5	0.05	n/a
Hallett	35.0	522	18.1	0.07	0.06	n/a
Port Lincoln	26.0	955	6.77	0.5	0.05	n/a
Ladbroke Grove	34.0	537	1.19	<0.01	0.03	n/a
Pelican Point	47.0	389	0.34	<0.01	<0.01	n/a
Quarantine	32.0	571	0.49	<0.01	0.04	n/a
Osborne	43.4	435	0.3	<0.01	0.03	n/a

Table 17 Efficiency and emissions data for the primary generators contributing to the Tasmanian transmission grid

Station	Efficiency (%)	CO_2 (kg/MWh)	NO_x (kg/MWh)	SO_x (kg/MWh)	PM_{10} (kg/MWh)	Fresh water (m^3/MWh)
Bell Bay	36.3	504	1.17	<0.01	0.03	<0.1
Flinders/King Island	32.9	797	15.7	0.68	0.7	<0.1

Table 18 Efficiency and emissions data for the primary generators contributing to the Northern Territory transmission grid

Station	Efficiency (%)	CO_2 (kg/MWh)	NO_x (kg/MWh)	SO_x (kg/MWh)	PM_{10} (kg/MWh)	Fresh water (m^3/MWh)
Channel Island	29.5	543	2.12	<0.01	0.03	0.84
Berrimah	25.0	745	2.74	<0.01	<0.01	<0.1
Katherine	22.0	847	3.0	0.02	0.05	<0.1
Pine Creek	22.0	847	5.27	0.04	0.42	<0.1
Tennant Creek	26.0	928	8.1	0.57	0.17	<0.1
Ron Goodin	26.0	716	7.29	0.04	0.04	<0.1
Brewer	22.0	847	19.1	<0.01	0.05	<0.1

For this study, the Snowy Hydro Scheme, (as well as all other hydro plants) has been assumed to operate at an efficiency of 100% as it has negligible resource energy consumption. It is also assumed that the externalities for hydro generation are equal to zero. It is however recognised, that some externalities will be prevalent as a result of dam construction as well as from the decomposition of biomass resulting from the dam's presence. It is assumed that these externalities, while having a reasonable impact on the specific emission for hydro stations, will have negligible affect on the overall Australian results.

Construction

The construction of power stations and infrastructure was not included in this case study, as previous LCAs have shown that power station construction contributes only a small amount to the overall resource consumption and emissions.

Emissions

For fossil fuelled power generation technologies, it is assumed that 99% of the carbon in coal, and 99.5% of carbon in natural gas and oil, is converted to CO_2 in the combustion process (as is used in the Australian NGGIC Workbook for Fuel Combustion[18]).

Other power station emissions, and emissions for power generation externalities (*eg* coal mining, chemical production *etc*) are included and are sourced from the Australian National Greenhouse Gas Inventory Workbooks[18,23,24], US EPA and the Australian National Pollutant Inventory[19].

Cooling

The cooling systems at each of the major coal fired power stations depend on the location of the plant. Coastal power stations such as Eraring, Gladstone and Vales Point utilise saltwater cooling with large volumes of sea or lake water, whereas the inland stations usually use recirculated cooling water systems incorporating evaporative cooling towers, with makeup from rivers, dams or lakes. Hazelwood power station, like many other inland coal fired stations, uses a dedicated pondage (Hazelwood Pondage) to provide cooling water, with heat dissipation directly from the lake via a combination of evaporation and convective effects. Air/dry cooling is the other option available to inland power stations. Millmerran power station in Queensland utilises dry cooling, despite the fact that this reduces station efficiency by around 2% when compared to water cooled stations.

Waste management

The majority of solid waste produced in the supply of grid power is coal ash from coal-fired stations (includes both fly ash and bottom ash). Most fly ash is collected in bag houses or electrostatic precipitators, mixed with bottom ash, and pumped or conveyed to tailings dams.

At selected power stations, some of the ash is classified and transported to cement, or cement batching plants, where it is used as a cement extender. Fly ash can be added for several purposes (including, for example, concrete pumpability). The effective replacement rate for Portland cement can be 1:1 (cement: fly ash replacement), and replacement can be up to 1:1.5 for other applications. The potential for the use of coal ash in Australia is restricted to ash collected from black coal-fired stations as ash from brown coal stations lacks the properties required for this application.

It should be noted that those power stations which are located close to markets for recycling coal ash have a much greater opportunity to gain benefit from exploring this opportunity, as the majority of cost is in the transportation to the cement plant. Eraring power station, located just south of Newcastle in NSW, is a prime example, recycling around 50% of fly ash generated.

2.1.2 Transmission and distribution

Losses of electricity in transmission were sourced from the Electricity Supply Association of Australia 1997 report, and distribution losses were sourced from the Electricity Supply Association of Australia 2004 report[1]. Where values were not available from these reports, they came from the MEPS for electricity distribution transformers report from the Australian Greenhouse Office[25].These values represent a weighted average loss from the entire grid (with SMHEA and interstate effects omitted). These losses range from 0.9% to 5.3% for high voltage transmission, and from 5.1% to 6.0% for distribution.

Table 19 Comparison of transmission and distribution losses for different grids (2003 data)

Grid	Transmission losses (%)	Distribution losses (%)
New South Wales	2.7	5.6
Queensland	5.3	5.8
Victoria	2.5	6.0
Western Australia[1]	-	7.8
South Australia	0.7	6.0
Tasmania	0.9	5.5
Northern Territory	2.7	5.1
Australia	3.2	5.9

1 WA distribution losses include transmission losses

The Australian totals in the final row of the table represent the weighted average loss based on electricity available for both transmission and distribution across all of the states except for Western Australia. It should be noted that Western Australian data was not used in the calculation of overall transmission and distribution losses because it was not possible to accurately distinguish between its transmission and distribution loss percentages.

2.1.3 Coal

Coal is the primary fuel used for power generation in Australia. Approximately 134.5 Mt of coal was used in 2004, all from domestic supply. Table 20 gives the major coal sources used in each state, as well as total state consumption. This list is not comprehensive, as small amounts of coal may have been sourced from other mines.

Table 20 Coals used in major Australian power stations

State	Main Coals used	Amount Black (Mt)	Amount Brown (Mt)	Amount Total (Mt)
NSW	Angus Place, Bayswater, Chain Valley, Cooranbong, Cullen Valley, Drayton, Enhance Place, Invincible, Ivanhoe, Munmorah, Narama, Newstan, Ravensworth, Springvale, Stratford, Ulan, Warkworth, Westside, Wyee	27.52	~0	27.52
Queensland	Commodore, Callide (Southern), Collinsville, Callide (Boundary Hill), Curragh, Ebeneezer, Jeebropilly, Wilkie Creek, Blackwater, Meandu, Jeebropilly	23.21	~0	23.21
Victoria	Anglesea, Energy Brix, Hazelwood, Loy Yang, Yallourn	~0	75.88	75.88
Western Australia	Collie, Muja, Premier	4.53	~0	4.53
South Australia	Leigh Ck	~0	3.38	3.38
Tasmania	-	~0	~0	~0
Northern Territory	-	~0	~0	~0
Australia		55.27	79.27	134.52

This table only shows major coal providers. Small amounts of coal may be sourced from other mines.

From Table 20, it can be seen that well in excess of half of the coal consumed in Australia is brown coal. Table 21 shows the weighted average coal compositions for coal fired power stations in Victoria compared to those in Queensland or New South Wales.

Table 21 – Weighted average coal properties by state

Properties	Victoria	New South Wales	Queensland
C (%)	23.3	54.2	51.6
H (%)	-	3.4	3.1
N (%)	-	1.2	0.9
S (%)	0.1	0.4	0.3
O (%)	-	6.0	7.9
Ash (%)	0.8	22.5	19.2
TM (%)	61.0	8.8	13.6
SE (MJ/t)	8.7	22.6	21.0

It can be seen that the coal properties do not vary extensively between Queensland and New South Wales, but Victorian coals possess very different properties. Victorian coals are much higher in total moisture and are much lower in specific energy content.

2.1.4 Natural gas

Natural gas supply to Australian power stations is via pipeline from several basins located around the nation. The main NG sources for each state are shown in Table 22.

Table 22 Natural gas sources and power station consumption on a state basis[26]

State	Natural Gas Pipeline	Consumption (PJ)
New South Wales	Moomba	18.6
Queensland	Roma/Denison	33.6
Victoria	Longford	21.0
Western Australia	Dampier/Dongarra	110
South Australia	Moomba	58.4
Tasmania	Longford	4.25
Northern Territory	Amadeus	22.3
Total		268

Energy consumption and associated emissions for extraction, processing and transmission, and distribution of natural gas, are included[27,28].

Fugitive emissions from all stages of processing are based on data given by the Australian Gas Association in its Greenhouse Challenge Collaborative Agreement with the Australian Federal Government[28], and from the National Greenhouse Gas Inventory Workbook for Fugitive Emissions[24].

The CO_2 content of the raw natural gas (which is stripped to give < 2% CO_2, ie. pipeline quality) is not reported for individual wells. For the present analysis, average pipeline raw gas data is used - as reported by the Australian Greenhouse Gas Inventory. There are also issues regarding leakages in transportation which are yet to be quantified. These issues are the subject of a present study for the CCSD, and will require collaboration with the Australian gas industry.

As gas accounts for < 9% of current Australian generation, the overall effects on delivered electricity will be minor. The main objective of a more accurate assessment would be to obtain a one-on-one comparison of generation technologies using different energy sources (eg. coal-fired versus gas-fired generation). For gas, wellhead stripping is likely to become more significant.

The pipeline composition of each natural gas (as used in the analysis) is given in Table 23. Natural gas pipeline specifications are sourced from the National Greenhouse Gas Inventory (NGGIC).

Table 23 Average composition of NG in Australian pipelines (% vol)[29]

Component	Longford (VIC)	Moomba (NSW/SA)	Roma (QLD)	Denison (QLD)	Dampier (WA)	Dongarra (WA)	Amadeus (NT)
Methane (CH_4)	90.1	89.9	88.8	90.8	83.9	91.1	75.7
Ethane (C_2H_6)	5.8	7.2	6.5	3.2	7.2	2.9	10.7
Propane (C_3H_8)	1.1	0.1	1.5	1.0	3.1	0.9	3.3
Butane (C_4H_{10})	0.2	0.0	0.5	0.2	1.0	0.3	1.1
CO_2	1.9	1.6	1.8	1.5	2.3	3.0	0.0
SE (MJ/Nm^3)	39.3	38.9	40.1	38.3	40.8	38.0	40.7

2.1.5 Other materials

A number of other materials are used in power generation, primarily in mining (ANFO and diesel), and for water treatment in cooling and boiler feedwater circuits. The materials used in this case study, and an example of the location of manufacture for NSW, are listed in Table 24. Data were sourced from a range of company reports. For the primary power stations, where specific chemical consumption data are not available, estimates based on other stations were used.

Table 24 Consumables used, manufacturing process and example locations

Consumable	Use	Example of location of manufacture (NSW case)
ANFO	Overburden blasting at open cut coal mines	Ammonium nitrate (produced from natural gas) at Incitec on Kooragang Island (Newcastle). Fuel oil produced at NSW oil refinery at Botany. ANFO is mixed at a batching plant near the mine site.
Chlorine	For bacteria control in cooling towers	Produced via the chloralkali process at Botany, with sodium hydroxide produced as a by-product.
Lime	Cooling water softener	Depending on the location of the power station, lime may be sourced from a range of kilns at Marulan or Tamworth.
Sodium hydroxide	Used for anion resin regeneration	Sodium hydroxide is produced in the chloralkali process at Botany.
Ammonia	Used in the steam condensate line to counter carbonic acid formation and to raise pH	Produced at the Incitec plant on Kooragang Island (Newcastle).
Sulfuric acid	Used in cation resin regeneration	Based on generic sulfuric acid plant.

2.1.6 Transportation

Transportation of coal and materials to power stations and other upstream operations (such as mines and chemical plants) is via road, rail or conveyor. Fuel consumption and emissions data for road and diesel rail transportation systems were sourced from the National Greenhouse Gas Inventory Workbook for Transport[23].

2.2. LCA considerations

There are a number of factors that may affect the LCA results. These are listed below.

- The contribution of CO_2 emissions from wellhead stripping of natural gas has not been adequately quantified in this study due to the lack of data. While this will have only a minor impact on the overall grid due to the small contribution of gas, it will have a greater impact on GGE from individual gas based electricity generators.
- Power station efficiency data is based on annual average data for the station, and is not necessarily representative of the best possible efficiency at continuous operation. Individual station efficiency will be significantly affected by its position in the grid hierarchy.
- The accuracy of NPI data. Values may vary significantly between reporting periods. Also, aggregation of values on an enterprise basis affects accuracy in use.
- Allocation of solid wastes, in particular coal washery rejects and ashes. For example, many NSW generators use higher ash coals produced as a co product during the production of export coals, which increases ash generation.
- Infrastructure (power stations, transmission lines, *etc*) have not been included due to the small effect shown in previous studies – however, this factor is important when comparing technologies for individual plants, especially for renewable technologies.

2.3. Data quality

Estimated data accuracies for key items in the life cycle analysis are given in Table 25, together with the overall impacts on the GGE values.

Table 25 Data accuracies of key items

	Accuracy	Impact on energy	Impact on GGE
Electricity generation	± 5%	± 5%	± 5%
Coal mining	± 5%	< 0.1%	± 0.5%
Chemical production	± 10%	negligible	negligible
Transportation	± 10%	negligible	negligible

2.4. Allocation

All impacts are allocated to the functional unit of 1 MWh of electricity supplied from Australian electricity grids.

2.5. *Impact assessment*

Impact assessment is based on direct comparison of the following inventory values:

- Resource energy
- Fresh water
- GGE (CO_2-e)
- NO_x
- SO_x
- Particulates
- Solid waste
- All available NPI data for power generation, coal mining, *etc*.

2.5.1 National Pollutant Inventory[19]

The National Pollutant Inventory (NPI) is an Internet database (http://www.npi.gov.au/) designed to provide the community, industry and government with information on the types and amounts of certain substances being emitted to the environment.

Australian industrial facilities using more than a specified amount of the substances listed on the NPI reporting list are required to estimate and report emissions of these substances annually.

Since 2002, the number of reportable substances has been extended from 36 to 90.

Table 26 lists these 90 substances as well as the associated reporting thresholds, which are governed by the following conditions;

- The threshold for category 1 acids refers to the amount of the acid compound used (for example, in the case of hydrochloric acid, the threshold refers to the amount of hydrogen chloride used). This amount can be calculated from volume and concentration;
- The thresholds for total nitrogen and total phosphorus refer only to the amounts of those nitrogen and phosphorus compounds that give rise to nitrate/nitrite and phosphate ions respectively;
- The threshold for ammonia (total) refers to the total amount of both ammonia (NH_3) and the ammonium ion (NH_4^+) in solution;
- The threshold for chlorine includes the amount of hypochlorite and like substances used;
- The threshold for category 1 substances that are listed as a metal and its compounds, refers to the total amount of the metal and its compounds used (for example, lead & compounds refers to lead and all compounds which incorporate lead);
- The threshold for phenol refers, at the discretion of the reporting facility, to either the total amount of phenolic compounds used, or the total amount of phenol used.

Table 26 Listed Substances on the NPI from July 2001 [19]

Substance	Category	Substance	Category
Acetaldehyde	1	Acetic acid (ethanoic acid)	1
Acetone	1	Acetonitrile	1
Acrylamide	1	Acrylic acid	1
Acrylonitrile (2-propenenitrile)	1	Ammonia (total)	1
Aniline (benzenamine)	1	Antimony & compounds	1
Arsenic & compounds	1,2b	Benzene	1
Benzene hexachloro- (HCB)	1	Beryllium & compounds	1,2b
Biphenyl (1,1-biphenyl)	1	Boron & compounds	1
1,3-Butadiene (vinyl ethylene)	1	Cadmium & compounds	1,2b
Carbon disulfide	1	Carbon monoxide	1,2a
Chlorine	1	Chlorine dioxide	1
Chloroethane (ethyl chloride)	1	Chloroform (trichloromethane)	1
Chlorophenols (di, tri, tetra)	1	Chromium (III) compounds	1,2b
Chromium (VI) compounds	1,2b	Cobalt & compounds	1
Copper & compounds	1,2b	Cumene (1-methylethylbenzene)	1
Cyanide (inorganic) compounds	1	Cyclohexane	1
1,2-Dibromoethane	1	Dibutyl phthalate	1
1,2-Dichloroethane	1	Dichloromethane	1
Ethanol	1	2-Ethoxyethanol	1
2-Ethoxyethanol acetate	1	Ethyl acetate	1
Ethyl butyl ketone	1	Ethylbenzene	1
Ethylene glycol (1,2-ethanediol)	1	Ethylene oxide	1
Di-(2-Ethylhexyl) phthalate (DEHP)	1	Fluoride compounds	1,2a
Formaldehyde (methyl aldehyde)	1	Glutaraldehyde	1
n-Hexane	1	Hydrochloric acid	1,2a
Hydrogen sulfide	1	Lead & compounds	1,2b
Magnesium oxide fume	1,2b	Manganese & compounds	1
Mercury & compounds	1,2b	Methanol	1

Substance	Category	Substance	Category
2-Methoxyethanol	1	2-Methoxyethanol acetate	1
Methyl ethyl ketone	1	Methyl isobutyl ketone	1
Methyl methacrylate	1	4,4'-Methylene-bis(2-chloroaniline) (MOCA)	1
Methylenebis (phenylisocyanate)	1	Nickel & compounds	1,2b
Nickel carbonyl	1,2b	Nickel subsulfide	1,2b
Nitric acid	1	Organo-tin compounds	1
Oxides of nitrogen	2a	Particulate Matter 10.0 um (PM10)	2a
Phenol	1	Phosphoric acid	1
Polychlorinated dioxins and furans	2b	Polycyclic aromatic hydrocarbons	2a
Selenium & compounds	1	Styrene (ethenylbenzene)	1
Sulfur dioxide	1,2a	Sulfuric acid	1
1,1,1,2-Tetrachloroethane	1	Tetrachloroethylene	1
Toluene (methylbenzene)	1	Toluene-2,4-diisocyanate	1
Total nitrogen	3 (15 t/yr)	Total phosphorus	3 (3 t/yr)
Total volatile organic compounds	1a,2a	1,1,2-Trichloroethane	1
Trichloroethylene	1	Vinyl chloride monomer	1
Xylenes (individual or mixed isomers)	1	Zinc and compounds	1

The category thresholds are shown in Table 27.

Table 27 Category threshold definitions

Category	Description
1	Consumption of 10 t per year
1a	Consumption of 25 t per year, or a design capacity of 25 kt for bulk storage facilities
2a	Consumption of 400 t per year of fuel or 1 t of fuel per hour at any time within the period
2b	Consume 2,000 t per year of fuel, or 60,000 MWh, or at any time within the period consumed electricity at a rate of 20 MW.
3	Special case (emission based)

3. RESULTS

3.1. Energy and raw material flows

Resource consumption per MWh of power supplied to Australian transmission grids is shown in Table 28. It should be noted that these resources represent consumables used directly or indirectly for the generation of electricity on the grid. All results are inclusive of the contributions of all hydro plants including Snowy Hydro. Infrastructure (power stations, transmission lines etc) have not been included, and thus resources for materials of construction are not included.

Table 28 Resource consumption per MWh of electricity from the Australian transmission grid

Resource	Amount	Unit	Comment
Biomass	0.3	kg	Mainly from NSW
Black Coal	0.279	t	Coal fired boiler fuel
Brown Coal	0.400	t	Brown coal fired boiler fuel (VIC & SA)
Coal seam methane	0.03	GJ	Used mainly in NSW
Crude oil	0.22	GJ	For coal-fired boiler start-up, gas turbine peaking stations and transport fuel
Electricity	0.077	MWh	Renewable power input to the grid
Limestone	0.1	Kg	Lime production for pH adjustment of power station cooling water
NG	0.94	GJ	Gas fired peaking stations and ammonia/ammonium nitrate production
Fresh water	1.7	m^3	Primarily for power station evaporative cooling and boiler feedwater

The largest consumables per MWh of power supplied to Australian grids are brown coal (400 kg), black coal (279 kg), natural gas (0.94 GJ) and fresh water (1,700 kg). Chemical feedstocks, petroleum based fuels and biomass are consumed at comparatively low rates.

Although not an actual resource, it should also be noted that hydro and other renewables contribute 77 kWh per MWh of electricity supplied by the electricity grid. This includes Tasmania Hydro and Snowy Mountains Hydro, as well as small renewable contributions from other states.

3.2. Impact assessment values

The totals for electricity sent-out from power stations, and electricity available to the transmission and distribution grids, are shown in Table 29. This reflects the losses due to transmission and distribution which are approximately 3% and 6%, respectively.

Table 29 - Total electricity flow through Australian grids from major generators

Total sent out electricity (GWh)	Electricity available from transmission grid (GWh)	Electricity available from distribution grid (GWh)
205,160	198,115	186,401

A summary of the results for the production of 1 MWh of electricity is shown in Table 30.

Table 30 Impact assessment values for 1 MWh of grid electricity

Parameter	Transmission grid	Distribution grid	Comment
Inputs			
Resource energy (GJ)	11.05	11.75	57.9% black coal, 31.2% brown coal, 8.5% natural gas, 1.8% oil
Fresh water (m^3)	1.66	1.76	Primarily for evaporative cooling
Outputs			
GGE (kg CO_2-e)	1,011	1,076	96.2% from power stations, 2.2% from coal mining, 1.6 from other processes
NO_x (kg)	2.51	2.67	96.4% from fossil fuel power generation, 2.7% from coal mining
SO_x (kg)	3.14	3.34	99.8% from fossil fuel power generation
Particulates (kg)	0.55	0.59	69.0% from power generation, 30.9% from open cut coal mining
Solid waste (kg)	62.2	66.0	99.9% from power generation

The difference between 1 MWh of electricity from the transmission and distribution grids is the distribution loss of 5.9% (average) in the distribution system.

In summary:

- The resource energy consumption for the Australian transmission grid is dominated by coal (57.9% black, 31.2% brown), with only small contributions from natural gas, oil and coal seam methane. Note that breakdown is on an energy basis and that there were more tonnes of brown coal consumed than black coal due to the lower energy content of brown coal.

- Fresh water is consumed primarily by the inland coal fired power stations for condenser cooling. On average, every MWh of electricity generated results in the consumption of around, 1.66 m^3 of fresh water. This equates to a total consumption of around 329 GL per annum.
- Greenhouse gas emissions are dominated by emissions from coal fired power stations (96.2%), followed by coal mining (2.2%).
- The majority of NO_x, SO_x and solid waste emissions are from coal fired power stations. For particulate emissions, open cut coal mining contributes a substantial proportion of the overall particulates emitted.

When the LCA results are projected out to an Australian basis, an assessment can be made on the contribution of power generation (including associated coal mining, transportation, chemical production, etc) to the National total. Table 31 shows the projected emissions from the Australian grids, compared to the total for Australia.

Table 31 Projected emissions from Australian power generation compared to National totals[19,30,31]

Parameter	Transmission grid 2004 (per MWh)	Distribution grid 2004 (per MWh)	Total from all grids 2004 (per annum)	Total Australia - all sources (per annum)	% of Total
Resource energy	11.05 GJ	11.75	2,188 PJ	5,436 PJ[1]	40.3
Fresh water	1.66 m^3	1.76	329 GL	24,909 GL[2]	1.3
GGE	1,011 kg CO_2-e	1,076	200 Mt	550 Mt[3]	36.4
NO_x	2.51 kg	2.67	497 kt	1,400 kt[4]	35.5
SO_x	3.14 kg	3.34	622 kt	1,400kt[4]	44.4
Particulates	0.55 kg	0.59	107 kt	1,100 kt[4]	9.7

1. 2003/4 ABARE data
2. 2001 data most recent available
3. 2003 data is most recent
4. Weighted average 2003 and 2004 NPI data

The comparison shows that a significant proportion of all impacts in Australia are associated with the generation of electricity. The notable exceptions are the emission of particulates, and water consumption which is dominated by agricultural use.

3.2.1 Point source emissions

The point source greenhouse gas, NO_x, SO_x and particulate emissions are shown in Figure 4 to Figure 7, per MWh of electricity from Australian transmission grids. The data is presented with the top bar graph representing the contribution from each state to the total emission resulting from the transmission of 1 MWh from the grids, and the bottom graph showing the rate of emission per MWh generated in that state alone. The pie graph indicates the percentage of total emission that each state is responsible for.

For greenhouse gas emissions (Figure 4), the primary contributors are Victoria, NSW and Queensland. It is expected that Victoria has the highest greenhouse gas intensity due to its heavy reliance on brown coal.

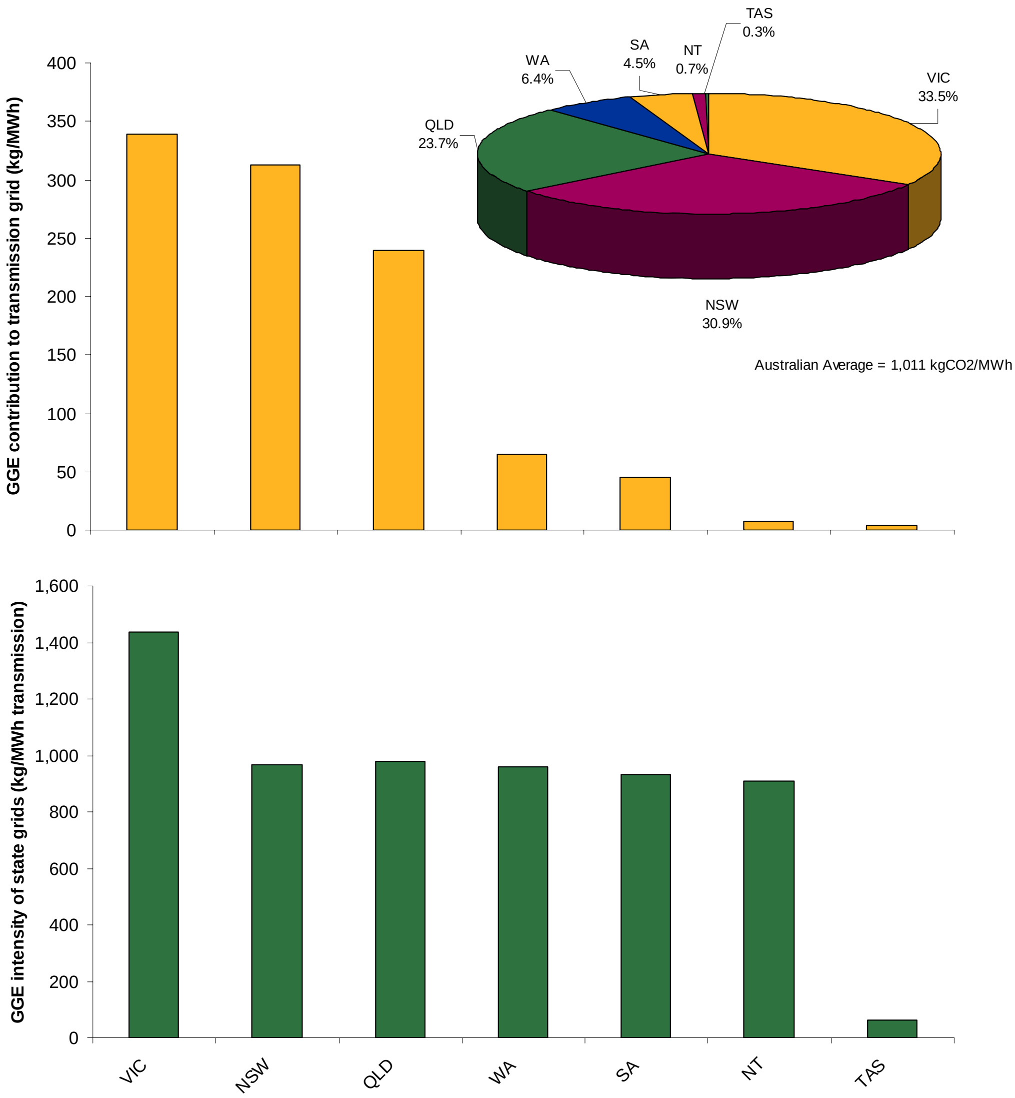

Figure 4 Breakdown of GGE per MWh of electricity from Australian transmission grids

NO_x emissions (Figure 5) are again primarily from the eastern states (Queensland, New South Wales, and Victoria). The fact that Northern Territory has the highest specific NOx emissions per MWh of output is due to the reliance on lower efficiency diesel and gas turbines in comparison to other states. This has little effect on results however with the Northern Territory contributing only 0.8% to the Australian total.

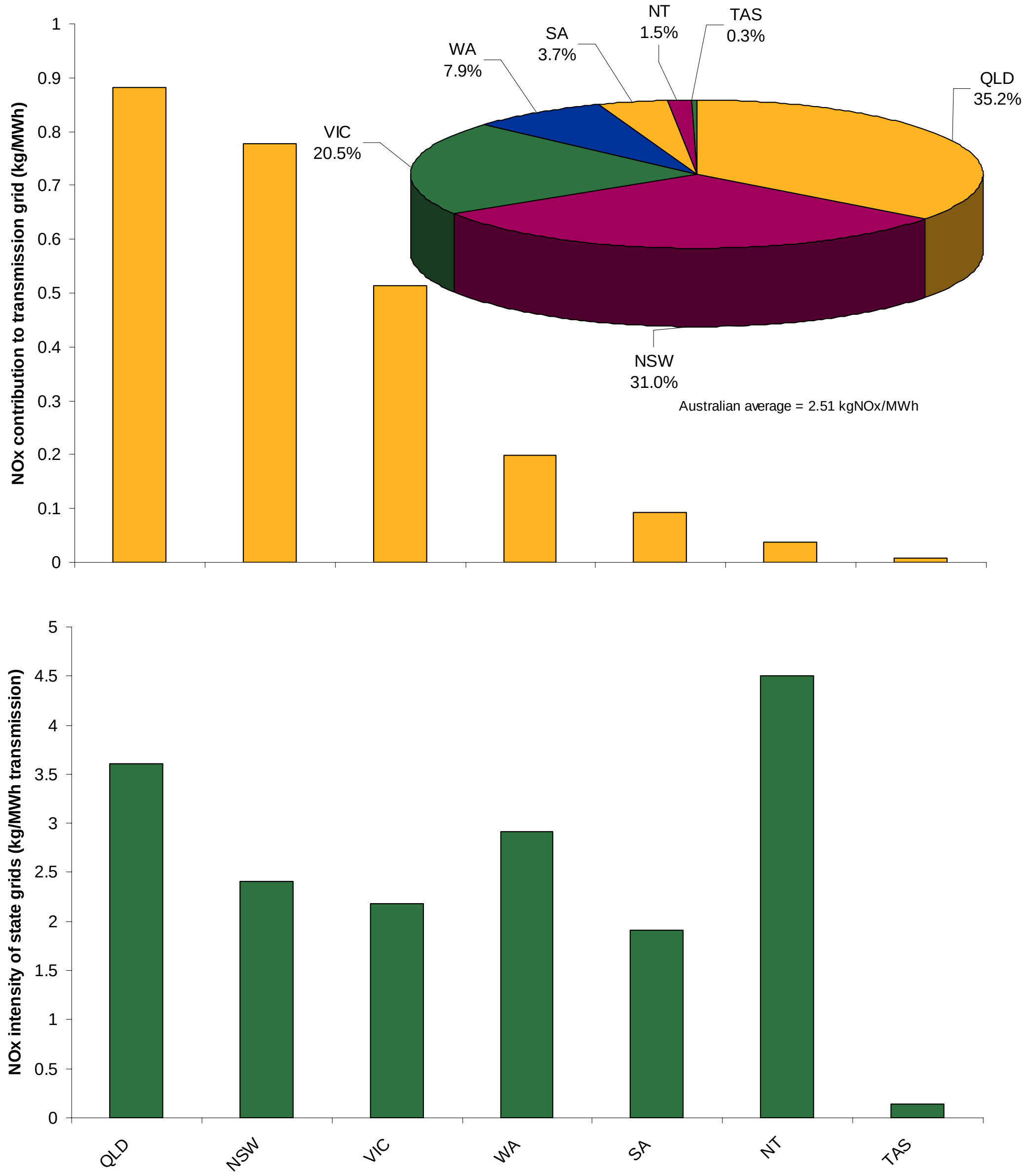

Figure 5 Breakdown of NO_x per MWh of electricity from Australian transmission grids

SO_x emissions (Figure 6) are again primarily from the eastern states. SO_x emissions from sources other than power stations were found to be insignificant.

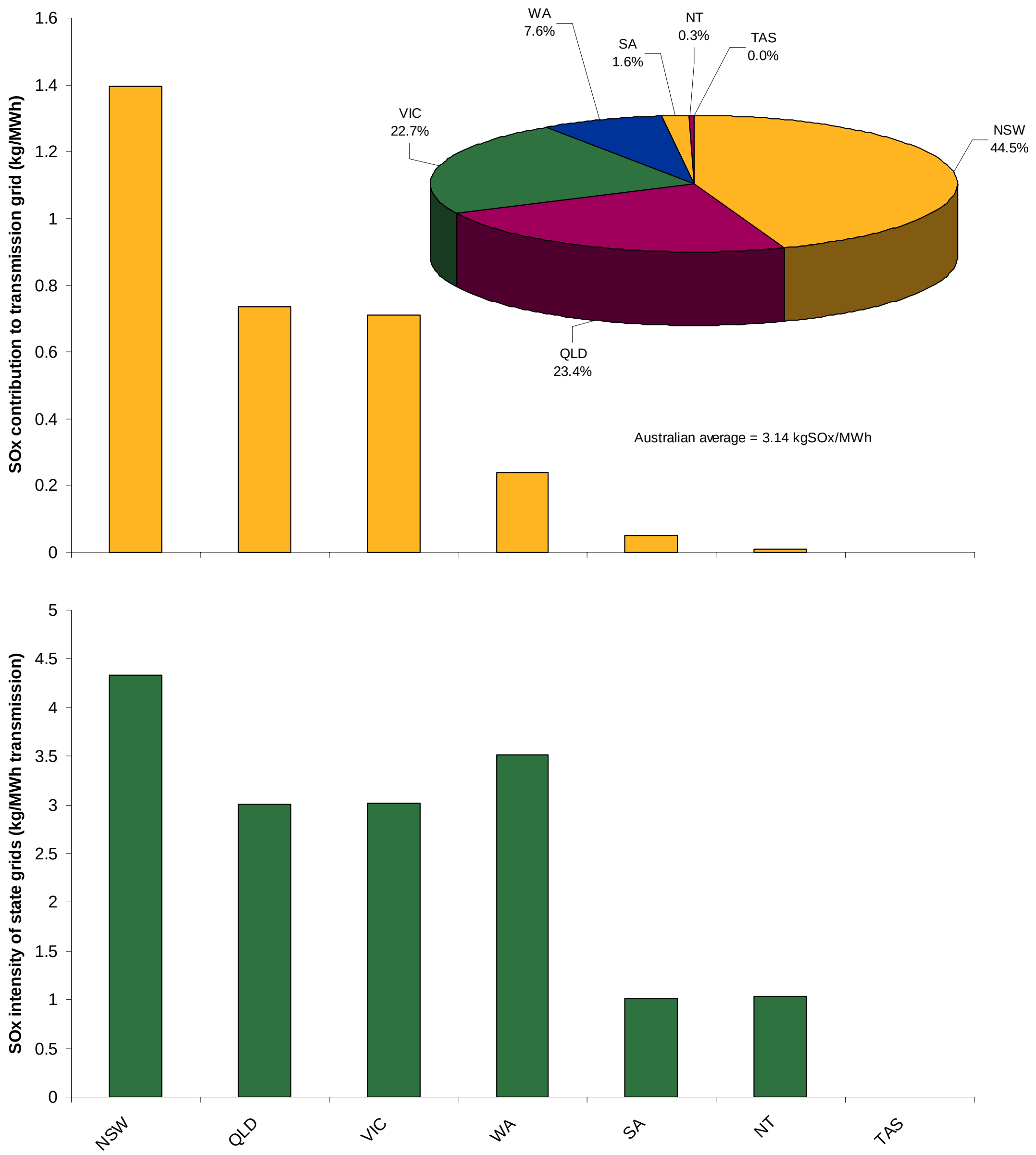

Figure 6 Breakdown of SO_x per MWh of electricity from Australian transmission grids

For particulates, (Figure 7), Western Australia is the largest contributor. This is due to Muja power station having a much higher specific PM_{10} emission rate compared to the other baseload coal fired power stations in Australia. The fact that Muja contributes nearly 40% of Western Australia's power supply raises the overall PM_{10} contribution of Western Australia to the top, regardless of only contributing 6.7% of the nation's electricity. The nation's largest electricity generator, NSW, has the second highest specific rate of PM_{10} emissions.

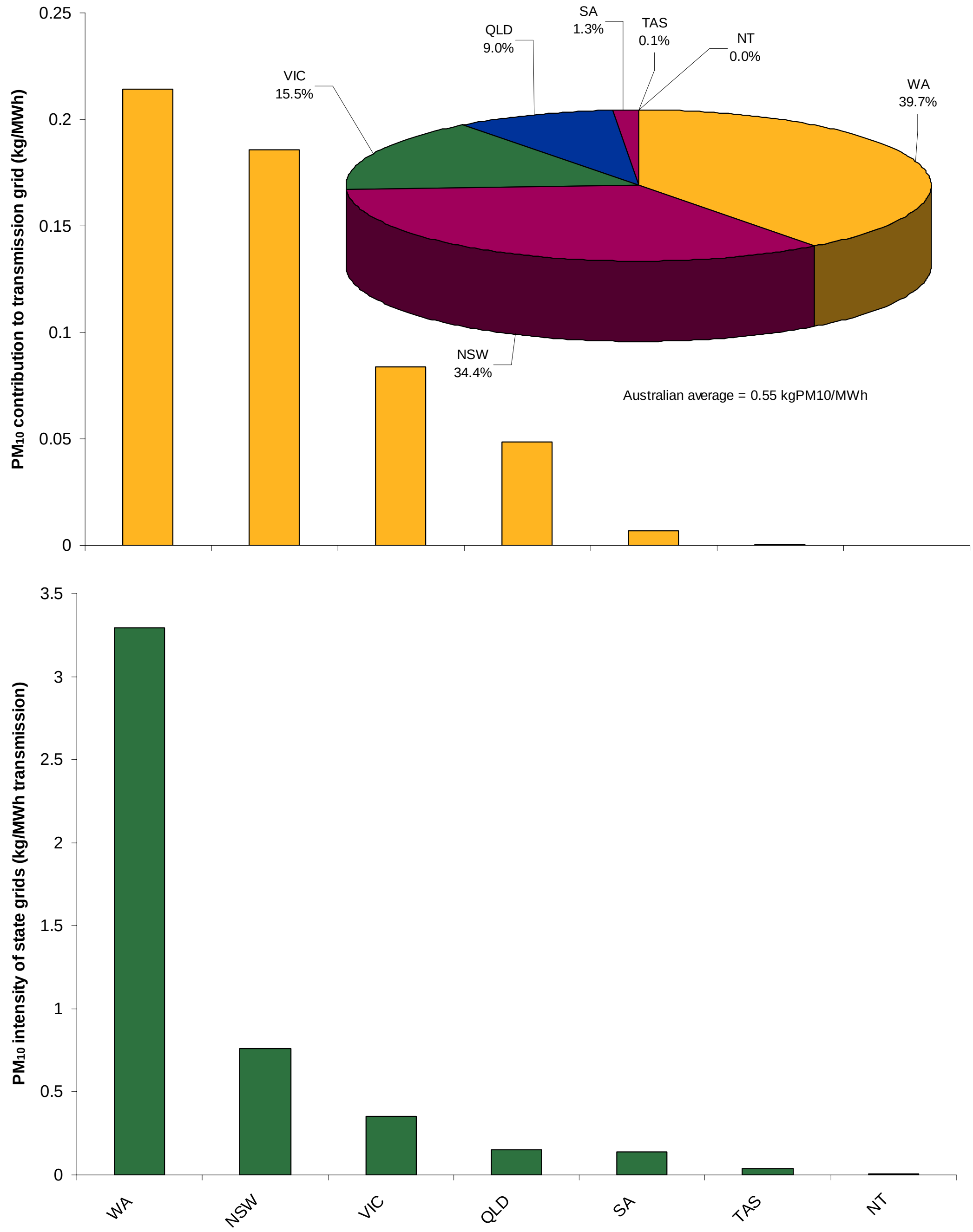

Figure 7 Breakdown of particulate emissions per MWh of electricity from Australian transmission grids

Figure 8 shows a breakdown of the ash generated per MWh of electricity from the state transmission grids. The orange bar at the top of the first graph represents the total ash contribution to the Australian total, and the green portion of the bar represents what portion of this is recycled, (mainly as a substitute in Portland cement). The bottom graph represents the specific ash generation of each state's grid, which follows the same format for the first graph with the total at the top and the utilised portion below. The brown portions of the graph represent ash disposed of as a result of brown coal utilisation and the black portions from black coal utilisation.

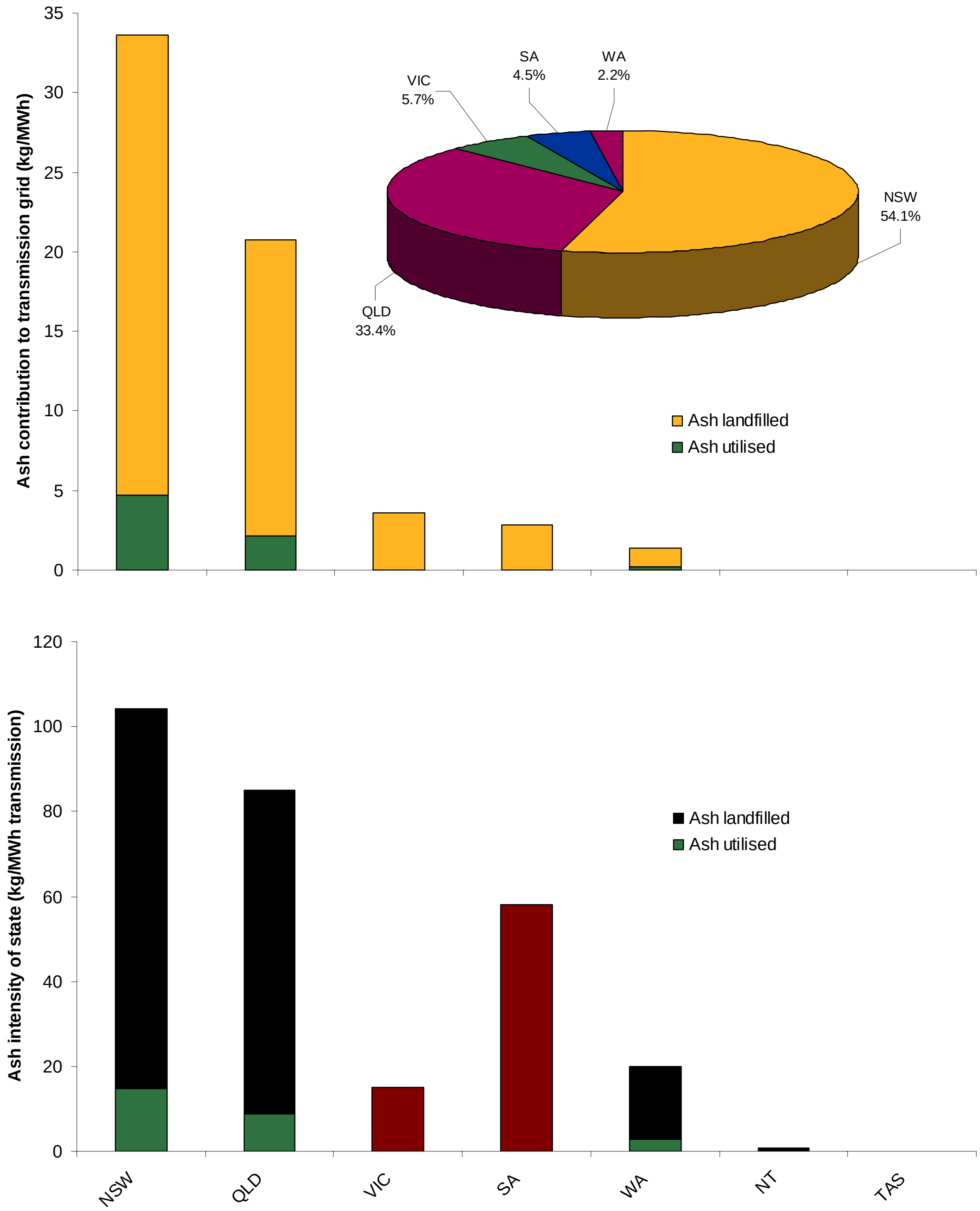

Figure 8 Breakdown of ash generation and utilisation per MWh of electricity from the Australian grids

Overall this equates to a utilisation rate of approximately 7.08 kg/MWh or an annual use of around 1.4 Mt of ash from over 12.3 Mt of ash produced. According to the Ash Development Association of Australia, in 2003, the quantity of fly ash sold in cementitious product Australia wide was approximately 1.42 Mt (10.9% of ash generated), and sales are increasing[32]. This analysis indicates that 11.4% of fly ash was utilised Australia wide in 2004.

3.3. Facility specific contributions

This section of the report is designed to show which power generation facilities or mines are responsible for the largest proportion of the national emission totals. The results show the top 10 emitters Australia-wide and their share of the national total.

Figure 9 shows that total greenhouse gas emissions are dominated by the three major Victorian stations, Loy Yang A, Hazelwood and Yallourn. Together, these three stations are responsible for over 25% of total Australian emissions while being responsible for less than 18% of Australia's total generation (see page 22). Other stations with contributions over 5% include Bayswater and Eraring power stations in NSW, Loy Yang B in Victoria, and Tarong in Queensland. Overall, the top 10 emitting facilities are responsible for 62.9% of the Australian electricity industry's total.

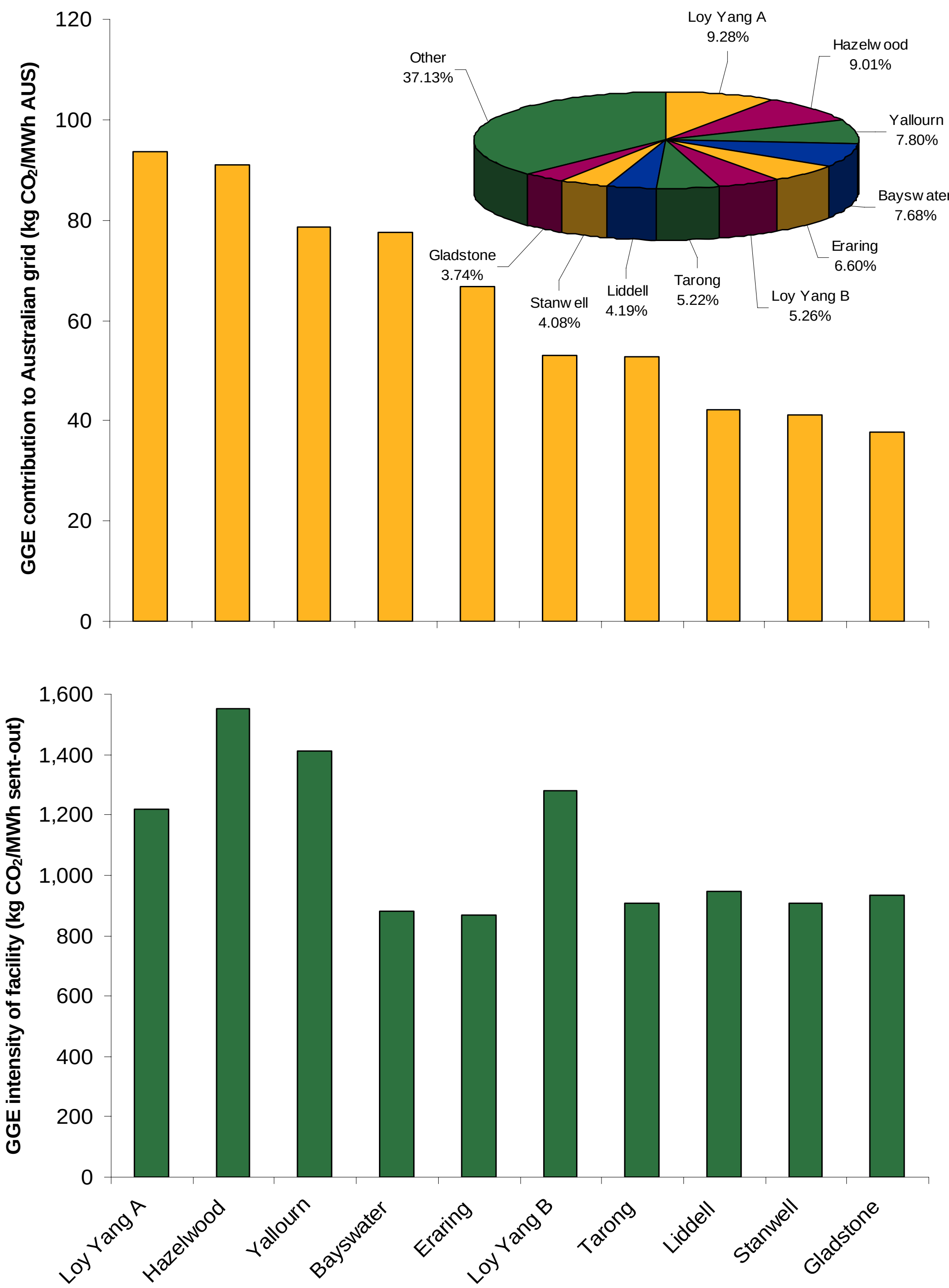

Figure 9 - Facility specific data for greenhouse gas emissions

Figure 10 indicates that the two highest contributors to NOx emissions are Tarong and Gladstone power stations. According to the NPI, these two power stations have the highest specific NOx emissions per MWh of output when compared to the other 8 highest emitting factilities. Bayswater and Eraring power stations are the next two highest, although they both contribute a lesser percentage of NOx emissions that their share of electricity to the grid, indicating that they have lower than average specific NOx emissions. Overall, the top 10 emitters are responsible for over 65% of total emissions for Australian electricity generation.

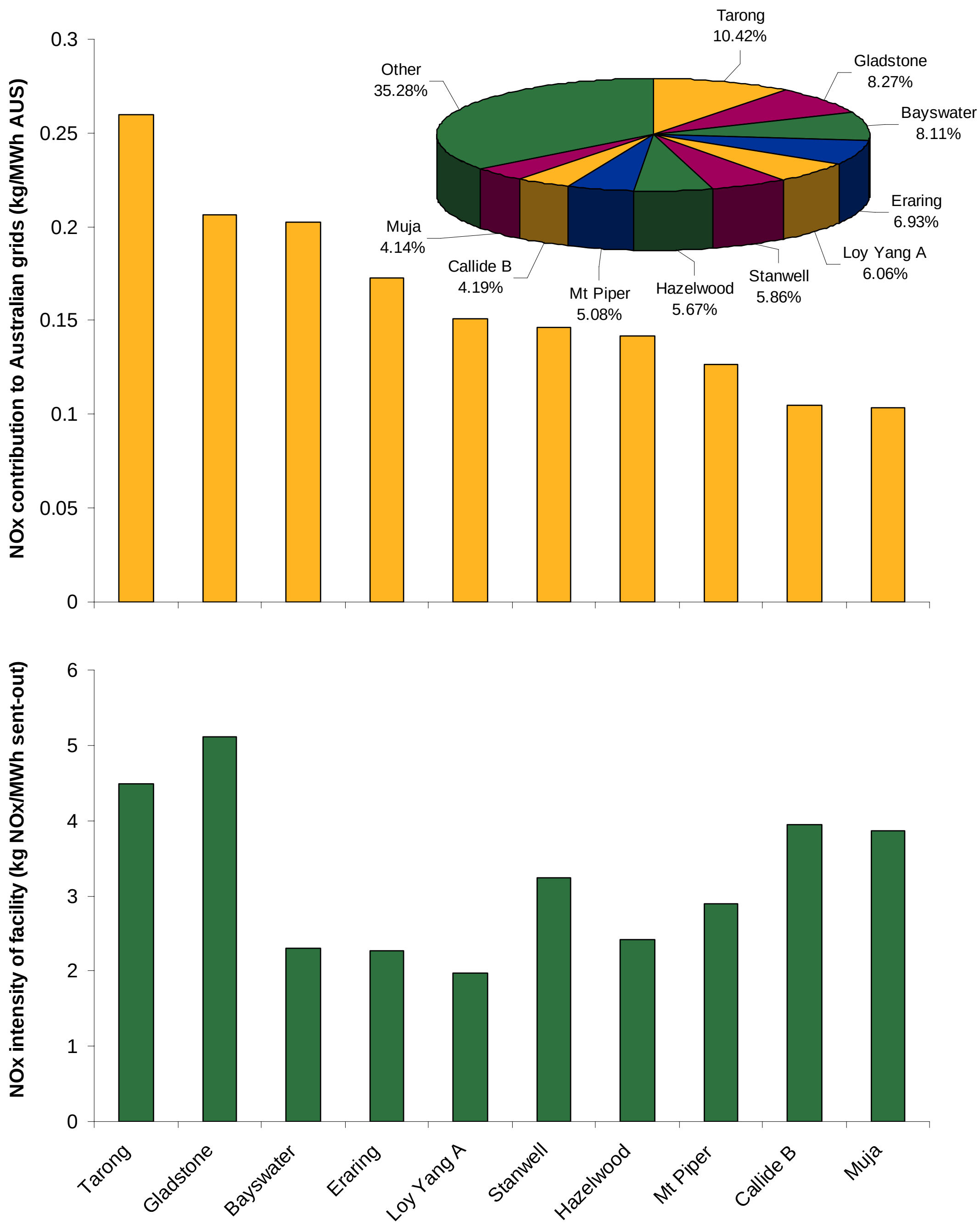

Figure 10 - Facility specific data for NOx emissions

Figure 11 shows that Bayswater is responsible for 15% of national SOx emissions for the Electricity supply industry. This is substantial, as Bayswater is the generator which holds the largest share of generation at 8.3%. However, with a 15% share of SOx emissions, this indicates that Bayswater emits SOx at a rate nearly double that of the Australian average. This is also the case for Liddell power station. Although Loy Yang A is the second largest emitter of SOx, its contribution is roughly in line with it's contribution of electricity to the grid, meaning it emits SOx at a rate approximately equal to the Australian average. It is worthy to note that Anglesea has a SOx emission rate around 10 times the industry average. This is due to the fact that the station uses brown coal with a very high sulphur content (around 10 times that of other brown coal stations in Victoria). Overall, the major 10 emitters of SOx are responsible for around 69% of the electricity industry's total.

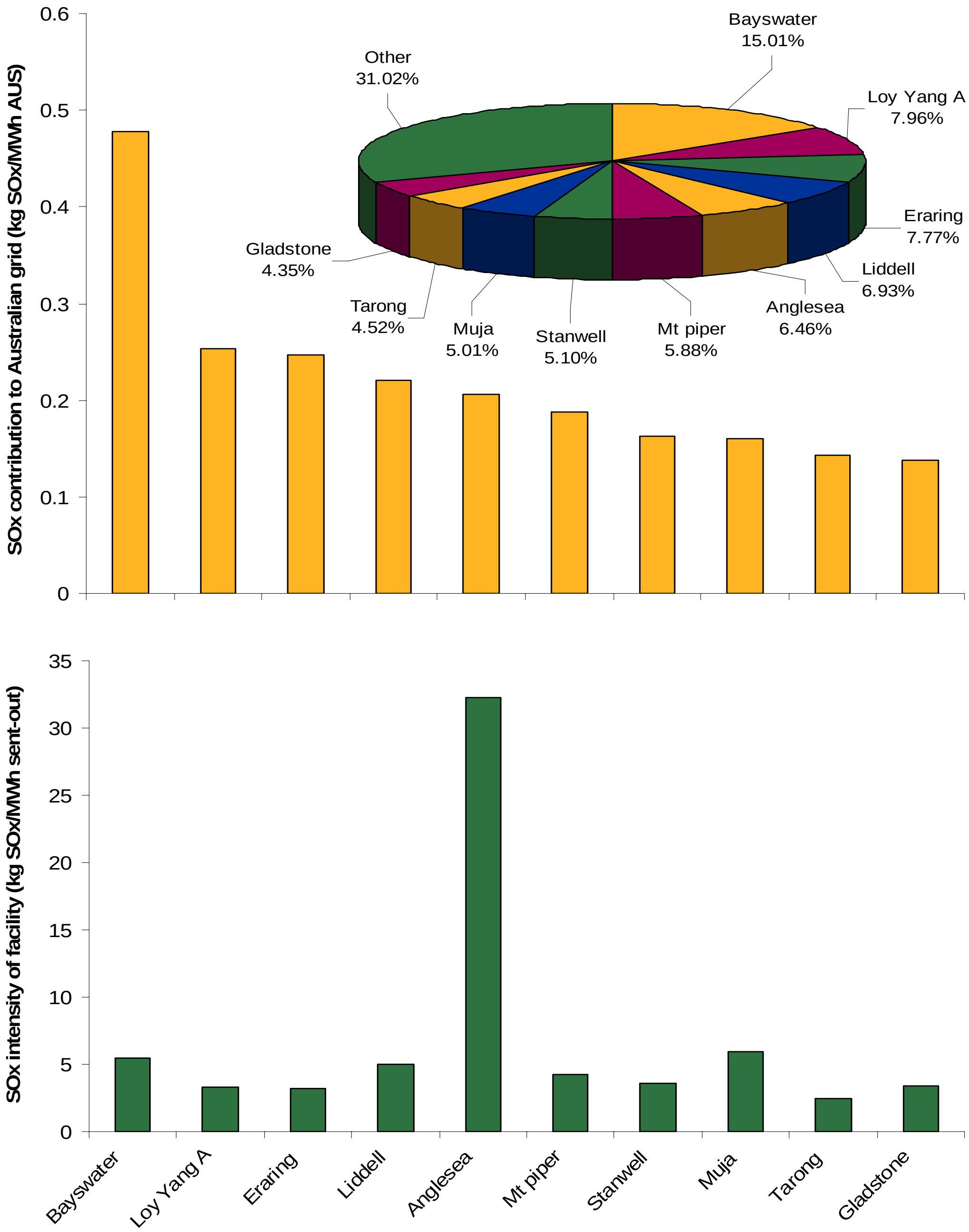

Figure 11 - Facility specific data for SOx emissions

PM_{10} emissions are dominated by Muja power station in Western Australia. Muja is responsible for over 38% of the Australian electricity industry's total, at a rate greater than 8 times the national average. Other than Muja, Tarong is the only other power station which exhibits higher than average emissions for a substantial quantity. Tarong generated around 5.4% of Australian electricity generation with a 9.6% share of PM_{10} emissions. It should be noted that the specific value for the emission of PM_{10} from coal mines per unit of electricity sent out is not defined. However, the effective PM_{10} emission rate per unit of coal from open cut mines is around 0.3 kg per tonne of coal mined, and for underground mines PM_{10} emissions are negligible.

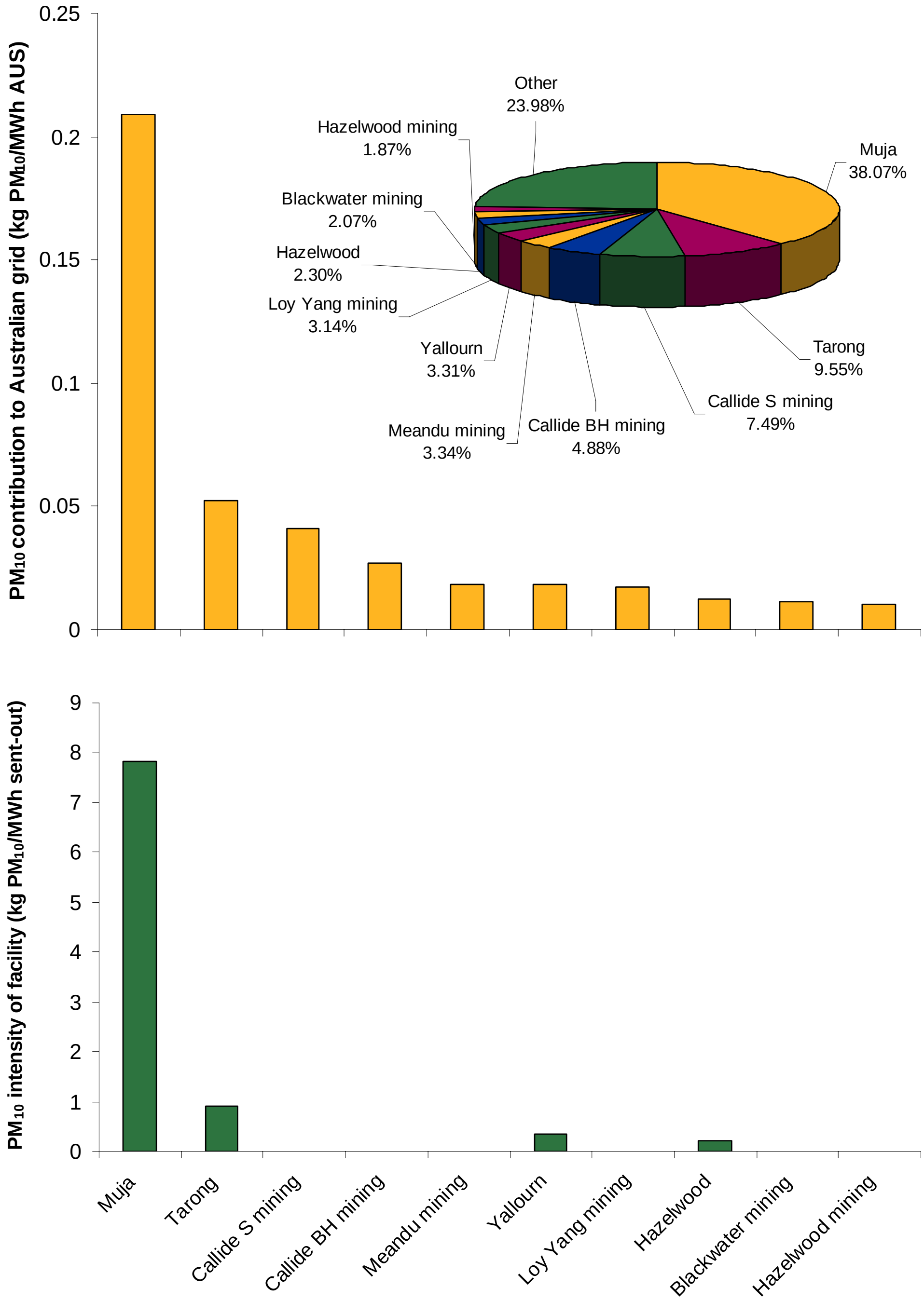

Figure 12- Facility specific data for PM_{10} emissions

3.3.1 National Pollutant Inventory

The National Pollutant Inventory (NPI) data per MWh of electricity, from the Australian transmission grids for 2004, are given in Table 32, Table 33 and Table 34, reporting emissions to air, water and land, respectively. The results are given on a per MWh basis and on a tonnes per annum basis.

Table 32 NPI emissions to air per MWh of electricity from the Australian transmission grids

Emission Type	Emission (t/MWh)	Emission (t/a)
1,1,2-trichloroethane	1.02×10^{-11}	0.002
1,2-dibromoethane	2.77×10^{-13}	~0
1,3-butadiene (vinyl ethylene)	2.21×10^{-10}	0.040
acetaldehyde	9.22×10^{-10}	0.180
acetone	6.94×10^{-12}	~0
ammonia (total)	8.25×10^{-07}	163
antimony & compounds	4.15×10^{-11}	0.010
arsenic & compounds	6.34×10^{-08}	13.0
benzene	2.07×10^{-08}	4.10
beryllium & compounds	2.78×10^{-08}	5.51
boron & compounds	4.10×10^{-06}	813
cadmium & compounds	4.28×10^{-09}	0.848
carbon disulfide	1.99×10^{-10}	0.040
carbon monoxide	4.11×10^{-03}	815,000
chlorine	1.32×10^{-09}	0.261
chloroform (trichloromethane)	9.23×10^{-11}	0.018
chromium (III) compounds	3.08×10^{-08}	6.10
chromium (VI) compounds	1.80×10^{-08}	3.56
cobalt & compounds	1.28×10^{-08}	2.54
copper & compounds	9.26×10^{-08}	18.3
cumene (1-methylethylbenzene)	1.68×10^{-09}	0.333
cyanide (inorganic) compounds	3.29×10^{-08}	6.52
cyclohexane	1.01×10^{-09}	0.200
di-(2-ethylhexyl) phthalate (DEHP)	1.14×10^{-10}	0.023
dibutyl phthalate	8.62×10^{-11}	0.017
ethylbenzene	2.22×10^{-10}	0.044
Fluoride compounds	1.72×10^{-05}	3,400
fluorides	1.44×10^{-07}	28.5
Formaldehyde (methyl aldehyde)	7.57×10^{-07}	150
hydrochloric acid	2.48×10^{-04}	49,000
lead & compounds	4.63×10^{-08}	9.17
magnesium oxide fume	5.31×10^{-10}	0.105
manganese & compounds	1.94×10^{-07}	38.4

Emission Type	Emission (t/MWh)	Emission (t/a)
mercury & compounds	5.62×10^{-09}	1.11
methanol	8.00×10^{-12}	0.002
methyl ethyl ketone	3.42×10^{-08}	6.79
methyl isobutyl ketone	2.46×10^{-10}	0.049
methyl methacrylate	3.07×10^{-11}	0.006
n-hexane	1.06×10^{-07}	21.0
nickel & compounds	3.76×10^{-08}	7.45
oxides of nitrogen	2.40×10^{-03}	475,000
particulate matter 10.0 um	3.85×10^{-04}	76,400
phenol	2.98×10^{-11}	0.006
phosphorous (total)	6.86×10^{-11}	0.014
polycyclic aromatic hydrocarbons	2.35×10^{-08}	4.65
selenium & compounds	4.23×10^{-08}	8.38
styrene (ethenylbenzene)	2.66×10^{-11}	0.005
sulfur dioxide	3.13×10^{-03}	619,000
sulfuric acid	2.43×10^{-05}	4,820
tetrachloroethylene	6.74×10^{-11}	0.013
toluene (methylbenzene)	7.55×10^{-08}	15.0
total nitrogen	1.01×10^{-08}	2.01
total volatile organic compounds	1.51×10^{-05}	3,000
trichloroethylene	1.94×10^{-14}	~0
xylenes (individual or mixed isomers)	5.08×10^{-08}	10.1
zinc & compounds	6.75×10^{-08}	13.4

Table 33 NPI emissions to water per MWh of electricity from the Australian transmission grids

Emission Type	Emission (t/MWh)	Emission (t/a)
ammonia	3.90×10^{-08}	7.73
ammonia (total)	4.23×10^{-07}	83.8
arsenic & compounds	2.18×10^{-09}	0.432
beryllium & compounds	5.19×10^{-11}	0.010
boron & compounds	3.15×10^{-08}	6.24
cadmium & compounds	1.48×10^{-10}	0.029
chlorine	2.48×10^{-07}	49.1
chromium (III) compounds	1.84×10^{-09}	0.365
chromium (VI) compounds	6.96×10^{-10}	0.138
cobalt & compounds	1.90×10^{-10}	0.038
copper & compounds	6.13×10^{-09}	1.22
fluoride compounds	6.50×10^{-08}	12.9
fluorides	6.98×10^{-09}	1.38
lead & compounds	1.87×10^{-09}	0.370
manganese & compounds	4.26×10^{-08}	8.44
mercury & compounds	6.79×10^{-11}	0.013
nickel & compounds	1.47×10^{-09}	0.291
phosphorus	1.38×10^{-10}	0.027
polycyclic aromatic hydrocarbons	1.41×10^{-12}	~0
selenium & compounds	2.38×10^{-11}	0.005
sulfuric acid	1.32×10^{-07}	26.1
total nitrogen	2.27×10^{-07}	45.0
total phosphorus	2.08×10^{-08}	4.12
zinc & compounds	8.76×10^{-09}	1.74

Table 34 NPI emissions to land per MWh of electricity from the Australian transmission grids

Emission Type	Emission (t/MWh)	Emission (t/a)
antimony & compounds	1.35 x10^{-09}	0.268
arsenic & compounds	1.04 x10^{-09}	0.206
benzene	3.08 x10^{-11}	0.006
beryllium & compounds	7.90 x10^{-10}	0.156
cadmium & compounds	5.61 x10^{-10}	0.111
chromium (III) compounds	3.65 x10^{-09}	0.723
chromium (VI) compounds	1.71 x10^{-08}	3.39
cobalt & compounds	1.12 x10^{-08}	2.21
copper & compounds	1.96 x10^{-08}	3.89
fluorides	7.94 x10^{-11}	0.016
lead & compounds	1.63 x10^{-08}	3.22
manganese & compounds	4.66 x10^{-08}	9.24
mercury & compounds	9.62 x10^{-11}	0.019
nickel & compounds	6.75 x10^{-09}	1.34
polycyclic aromatic hydrocarbons	1.00 x10^{-11}	0.002
xylenes (individual or mixed isomers)	3.69 x10^{-10}	0.073
zinc and compounds	3.02 x10^{-08}	5.99

The results show that per MWh of electricity supplied by the Australian transmission grids, small amounts of most emission types are emitted; of the order of micrograms (*eg* acetone) up to kilograms (*eg* NO_x, SO_x). However, when these emissions are converted to a per annum basis, the quantities range from 0.1 kg to 619,000 tonnes.

It must be noted that the totals from NPI data may be lower than for the output from the life cycle analysis due to some facilities not reporting their emissions either due to exclusion of the industry or emitting at levels below thresholds as set by the NPI. There are also instances where company environment or annual reports indicate very different emission levels when compared to the NPI data. In such circumstances, the data from the company report has been used and the NPI data ignored.

Of the reported emissions in Australia, power generation represents a significant proportion for some types. For example, the total reported NO_x emissions in Australia on the NPI for the year ending June 2004 were approximately 1,400 kt. The present study has shown that emissions of NO_x associated with power generation from the Australian transmission grids for the year ending June 2004 were 497 kt, or over 35% of the total reported emissions.

3.4. System displacement credits

A potential displacement credit has been calculated for the present utilisation of coal ash as a cement extender (assumes that 11.4% is used as cement extender). There is also analysis for 100% coal ash recycling as well as a calculation of credits using black coal only (see Table 35). At present, brown coal ash lacks the appropriate properties for use in the supplementation of Portland cement. It is for this reason that at the present stage, the maximum potential recycling of coal ash in Australia is 89.7%, equal to black coal ash's share of the total.

Table 35 Displacement credits for coal ash utilisation as a cement extender for 1 MWh of electricity from the Australian transmission grids.

Parameter	0% displacement	11.4% displacement (current - all ash to cement)	89.7% displacement (current potential)	100% displacement (max potential)
Resource energy (GJ)	11.05	11.00	10.72	10.68
GGE (kg CO_2-e)	1,011	1,004	953	946
NO_x (kg)	2.51	2.50	2.40	2.39
SO_x (kg)	3.14	3.14	3.11	3.11

The factors used to calculate these credits come from a previously completed study on cement production using 1 tonne as the functional unit. These factors are shown in Table 36. It is important to note that the assumed replacement rate is 1:1 therefore reducing cement production emissions and resource consumption by approximately 50%.

Table 36 Impact assessment values for cement production

Parameter	Factor
Resource energy (GJ)	5.9
GGE (kg CO_2-e)	1050
NO_x (kg)	1.89
SO_x (kg)	0.46

4. KEY FINDINGS

The key findings are;

- Resource consumption for the production of 1 MWh of electricity from the transmission grid totals on average 11.05 GJ. This equates to an overall energy efficiency of 32.6%. This figure does not simply represent the amount of energy consumed at the power station, but all energy consumed in the entire process from the removal of the resource from the natural environment, to the transmission of the electricity. All sources of electricity are included in this number with the assumption made that hydro and wind sources have negligible resource consumption.
- The resource energy was dominated by coal as expected. From an energy point of view, black coal was the largest source with a 57.9% share of the nation's total. Brown coal has a 31.2% share on a GJ basis. On a kilogram basis however, brown coal was the biggest contributor, with each MWh of electricity consuming on average 400kg. Black coal consumption amounted to 279kg/MWh on average. This is due to the low energy/ high moisture content of brown coals.
- The consumption of water is most likely to be the figure with the largest inherent error. For the majority of the large power stations, fresh water consumption was reported. However, some of the larger generators, and many of the small ones, did not publish their water consumption data. In addition, some did not report which method of cooling (dry cooling, sea water, fresh water) is used at the plant. This led to several assumptions where specific water use from one station was applied to others having similar characteristics.
- The Australian electricity industry was responsible for 36.4% of the nation's greenhouse gas emissions in 2004. Of this total, 88.1% came from Victoria, New South Wales, and Queensland combined. The greenhouse gas intensity of most states was between 900 and 1,000 kg per MWh to the transmission grid. Victoria however, had a greenhouse gas intensity of 1,437 kg/MWh, with a resource energy consumption of 14.32 GJ/MWh. This is due to its heavy reliance on the use of brown coal.
- Australia's electricity industry was responsible for 35.5% of the nation's total NOx emissions in 2004. Of this, 96.2% came from the combustion of fossil fuel at power stations and 2.7% came as a result of coal mining.
- SOx emission from power stations alone contributed around 620 kt to the national total of 1,400 kt in 2004. The state with the highest specific contribution was NSW with a SOx intensity of 4.33 kg/MWh.
- Particulate emissions for the Australian electricity industry totalled 107kt in 2004. This represented 9.7% of the national total. Unlike the other externalities, there was a significant contribution from coal mining, which contributed 31% of the total. There was some difficulty in tracking down the specific particulate matter emissions from all coal mines. As such, the known specific emissions of some mines were applied to those for which no data could be found.

5. REFERENCES

1 Electricity Supply Association of Australia, Electricity Australia 2005

2 Electricity Supply Association of Australia, ESAA Statistics for the NEM 2002-2003

3 Electricity Supply Association of Australia, ESAA Statistics for the NEM 2003-2004

4 LCA for the NSW electricity grid for YED 2003, CCSD 2005

5 LCA of the Queensland electricity grid for YEJ 2004, CCSD 2005

6 LCA of the Victorian electricity grid for YED 2003, CCSD 2006

7 Western Power Annual Report 2004 – Operations review

8 Transalta production data 2004, (http://www.transalta.com/website2001/tawebsite.nsf/AllDoc/1EEAD6C9F7C6417687256D12007218F2?OpenDocument)

9 'SRMC and LRMC of generators in the NEM', ACIL Tasman, April 2003

10 Report on NEM generator costs – Part 2, (www.**nem**mco.com.au/transmission_distribution/419-0013.pdf)

11 Australian Energy News - Issue 11, March 1999 - Osborne Cogeneration Plant

12 Hydro Tasmania – Annual report 2005, (http://www.hydro.com.au/Documents/Corporate/Annual%20Reports/2005/hydro_ar.html)

13 Power and Water - Annual report 2004, (http://www.powerwater.com.au/news/annreps/annrep_2004.html)

14 Northern Territory Utilities Commission Power Systems Review 2004, (http://www.nt.gov.au/ntt/utilicom/s_docs/2004_psr_final2.pdf)

15 Northern Territory Utilities Commission - Northern Territory Electricity Market - YE June 2004, (http://www.nt.gov.au/ntt/utilicom/s_docs/market_info_2003-04.pdf)

16 Snowy Hydro Website (www.snowyhydro.com.au)

17 Securing Australia's Energy Future – A National Energy Policy Framework, (http://www.dpmc.gov.au/publications/energy_future/chapter3/6_framework.htm)

18 Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Fuel Combustion Activities (Stationary Sources), National Greenhouse Gas Inventory Committee, Workbook 1.1, Canberra, 1998

19 National Pollutant Inventory. Environment Australia (http://www.npi.gov.au/)

20 Bayswater Power Station – Technical Information and Vital Statistics on Pacific Power's Leading Environmentally Managed Electricity Producer, Pacific Power Public Affairs

21 Bayswater Power Station Environmental Impact Statement, June 1979 [Extract], Pacific Power, 1979

22 McLennan Magasanik Associates Pty Ltd, "Projections of Price of Renewable Energy Certificates to Meet the 2% Renewable Energy Target", November 1999

23 Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Transport (Mobile Sources), National Greenhouse Gas Inventory Committee, Workbook 3.1, Canberra, 1998

24 Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Fugitive Fuel Emissions (Fuel Production, Transmission, Storage and Distribution), National Greenhouse Gas Inventory Committee, Workbook 2.1, Canberra, 1998

25 "Minimum Energy Performance Standards and Alternative Strategies for Electricity Distribution Transformers", Australian Greenhouse Office, January 2002 (http://www.energyrating.gov.au/library/pubs/200218-transformers.pdf, last accessed: 20 April 2006)

26 Australian Energy Statistics-Australian energy consumption by industry & fuel type by state-energy units 1973-74 to 2003-04, (http://abareonlineshop.com/product.asp?prodid=13180)

27 Gas Statistics Australia 2001, Australian Gas Association, September 2001

28 Greenhouse Challenge Program, Greenhouse Challenge Facilitative Agreement, Australian Gas Association, November 1997 (from http://www.gas.asn.au/facilit.htm, last accessed: 21 June 2001)

29 Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks, Fuel Combustion Activities (Stationary Sources), National Greenhouse Gas Inventory Committee, Canberra, 2003

30 AusStats 4610.0 Water use – Australian economy consumes 50 Sydney harbours, http://www.abs.gov.au/Ausstats/abs@.nsf/0/cc9d340e1feef80bca256e9900810f09?OpenDocument

31 NGGI for New South Wales 2003, (http://www.greenhouse.gov.au/inventory/stateinv/pubs/nswinventory.pdf)

32 Ash Development Association of Australia website (http://www.adaa.org.au/)