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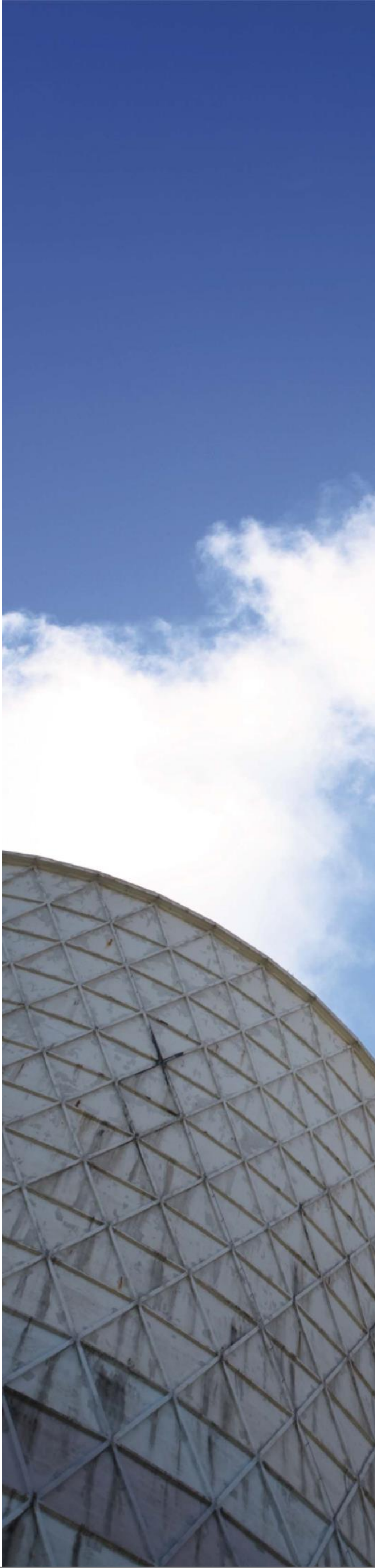
MARSDEN JACOB ASSOCIATES

FINAL REPORT – VOLUME 2: APPENDICES

ECONOMIC ANALYSIS TO INFORM THE NATIONAL PLAN FOR CLEAN AIR (PARTICLES)



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Appendix A CALCULATION OF BASE YEAR EMISSIONS AND CONCENTRATIONS

A.1 NEW SOUTH WALES AND VICTORIA

The treatment of NSW and Victoria for the base year involved the following steps:

- Spatial estimation of primary anthropogenic PM_{10} and $PM_{2.5}$ emissions. Gridded emission inventories were obtained from state authorities (**Section A.1.1** for NSW; **Section A.1.2** for Victoria).
- Spatial estimation of primary anthropogenic PM_{10} and $PM_{2.5}$ concentrations using a regional air pollution model (**Section A.1.3**).
- Adjustment of the predicted concentrations according to measurements, taking into account the modelling approach and measurement techniques used (**Section A.1.4** and **Appendix B**).
- Mapping of natural and secondary PM_{10} and $PM_{2.5}$ components, and calculation of total concentrations (**Section A.1.5**).
- An investigation of the relationships between emissions and concentrations (**Section A.1.6**).
- Weighting of gridded concentrations by population (**Section A.1.7**).

The methods used are described in more detail the following Sections.

A.1.1 Primary anthropogenic emissions of PM_{10} and $PM_{2.5}$ in New South Wales

A.1.1.1 Description of emissions inventory

The NSW GMR inventory included both urban and rural areas, and covered approximately 75% of the population of NSW. The extent of the GMR is shown in **Figure A1**. The inventory region measured 210 km (east-west) by 273 km (north-south). The base year of the latest inventory was 2008, and projections were available for 2011 (as well as 2016, 2021, 2026, 2031 and 2036). In NSW the year 2011 was chosen for the emission mapping, as this represented the first year of the BAU scenario in the economic analysis and a projection was already available.

A.1.1.2 Data supplied

The inventory data are managed by the NSW EPA using the 'Emissions Data Management System' (EDMS)[1]. NSW EPA interrogated the EDMS to generate two forms of emissions data for this project: (i) gridded data (2011 only) and (ii) so-called 'Emissions-to-Area'[2] summaries containing projections at five-year intervals. The gridded data for 2011 were used for the modelling of base-year concentrations, and the Emissions-to-Area reports were used to develop the BAU scenario.

Gridded emission inventory files for the NSW GMR in 2011 were supplied in The Air Pollution Model (TAPM[3]) format; the structure of the data is summarised in **Table A1**. The data were also separated into the emission source groups summarised in **Table A2**. The development of the emission inventories, and the in-built assumptions, are described in **NSW EPA (2012a-g)**.

It can be seen from **Table A2** that commercial sources were represented in different files. The commercial sector contained all individual business-specific commercial activities (*i.e.* point sources or fugitive sources such as service stations). The Domestic-Commercial source group contained all private residence emission sources (*i.e.* the 'Domestic' part) plus those commercial activities that are largely

[1] http://www.environment.nsw.gov.au/resources/air/tr9aei08181.pdf. EDMS is an overarching emission inventory database that links to individual source-specific databases.

[2] The Emissions-to-Area reports provide total annual emissions from each source in the inventory (based on a detailed source breakdown) and for specific administrative areas of the GMR.

[3] http://www.cmar.csiro.au/research/tapm/

driven by household/ domestic demand but are not attributable to particular premises. Examples include aerosol and solvent use, graphic arts supplies, and surface coatings.

Figure A1: Definition of Greater Metropolitan, Sydney, Newcastle and Wollongong regions (NSW EPA, 2012a)

Table A1: Structure of gridded emissions data for NSW

Area of coverage	NSW GMR
Cell size (grid resolution)	1 km x 1 km
Number of cells in x direction	210
Number of cells in y direction	273
Year	2011
Months	All
Days	Weekday and weekend
Temporal resolution	One hour
Substances	PM_{10}, $PM_{2.5}$, SO_2, NO_x

Table A2: Gridded emission inventory files supplied for the 2011 calendar year

File type	Emissions sources included
Point source emission file (*.pse*)	All point source emissions from the following source modules: ➢ Industrial ➢ Commercial
Area source emission file (*.ase*)	All fugitive emissions from the following source modules: ➢ Commercial fugitive ➢ Industrial fugitive ➢ Off-road mobile
Domestic source emission file (*.dse*)	All emissions from the following source module: ➢ Domestic/commercial
Motor vehicle emission file (*.mvse*)	All emissions from the following source module: ➢ Motor vehicles
Biogenic emission file (*.bse*)	All emissions from the following source module: ➢ Biogenic/geogenic

In addition, consideration had to be given to the specific sources for which abatement measures were being considered (see **Chapter 4** and **Appendix D**). In particular, separate gridded emission data were provided for the following area sources[4]:

- Within the industrial fugitive source group:
  - Coal dust
- Within the off-road mobile source group:
  - Non-road diesel engines
    - Commercial boats
    - Recreational boats
    - Off-road commercial vehicles and equipment
    - Industrial vehicles
  - Non-road spark-ignition engines
    - Commercial boats
    - Recreational boats
  - Diesel locomotives
  - Shipping
  - Industrial vehicles and equipment - Mine site diesel
- Within the domestic-commercial source group:
  - Non-road spark ignition engines
    - Domestic lawnmowers
    - Public lawnmowers
  - Wood heaters

[4] Emissions from these sources are distributed differently in space, and so were considered independently in terms of abatement. For example, reducing emissions from shipping should have relatively little effect on concentrations at inland locations.

These data were supplied by NSW EPA as annual totals by grid cell for each source. Separate monthly, weekly and daily profiles were also supplied to enable the emission data to be configured in an hourly format for use in TAPM. To reduce computational times the inventory data were aggregated to a 3 km x 3 km grid in TAPM, and the regional dispersion modelling and analysis were undertaken at this spatial resolution. An example of the gridded data is provided in **Figure A2**, which shows the total $PM_{2.5}$ emissions (in tonnes per year) from all sources in the modelled area[5] of the GMR during 2011. The gridded annual total PM_{10} and $PM_{2.5}$ emissions (aggregated to 3 km x 3 km) from the most important specific sources in the NSW GMR in 2011 are plotted in **Figures A3** to **A8**. Emissions from industrial point sources are not shown, as these were not provided in a gridded format.

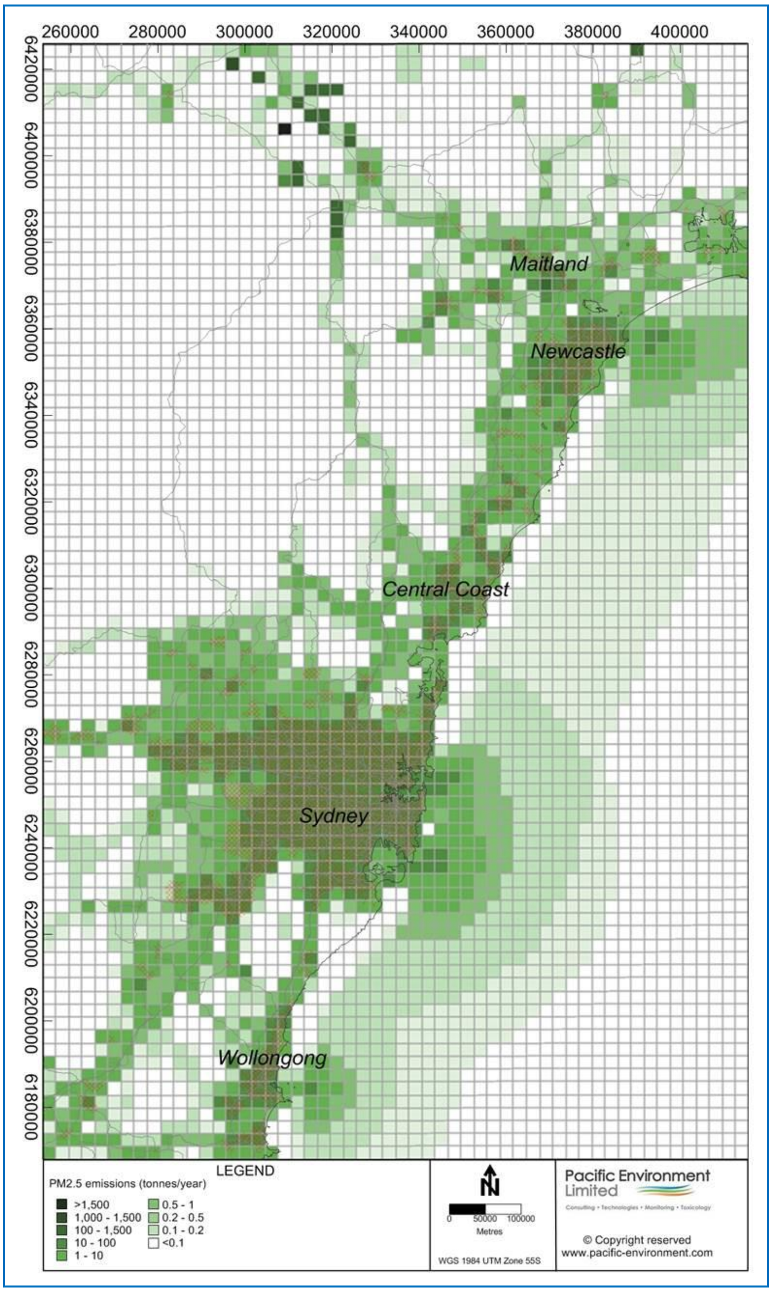

Figure A2: Gridded $PM_{2.5}$ emissions from all sources in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

[5] For the reasons explained in **Section A.1.3.3**, the modelled area was smaller than the inventory area.

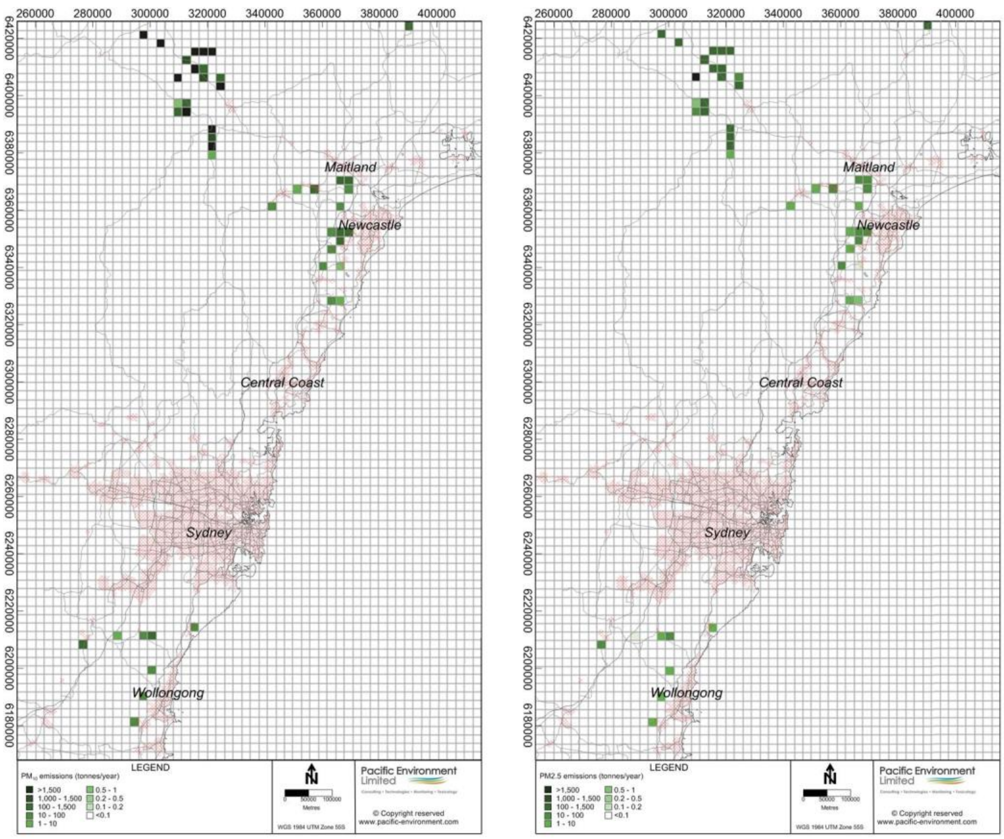

Figure A3: Gridded PM_{10} and $PM_{2.5}$ emissions from coal dust in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

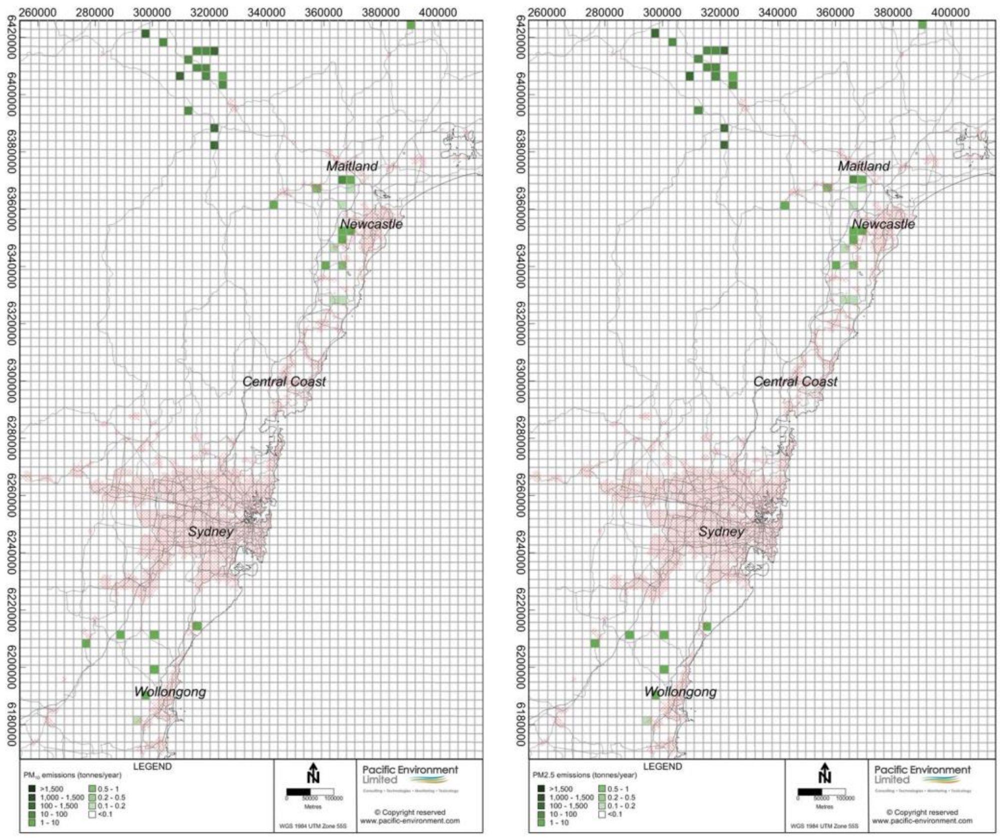

Figure A4: Gridded PM_{10} and $PM_{2.5}$ emissions from mine site diesel in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

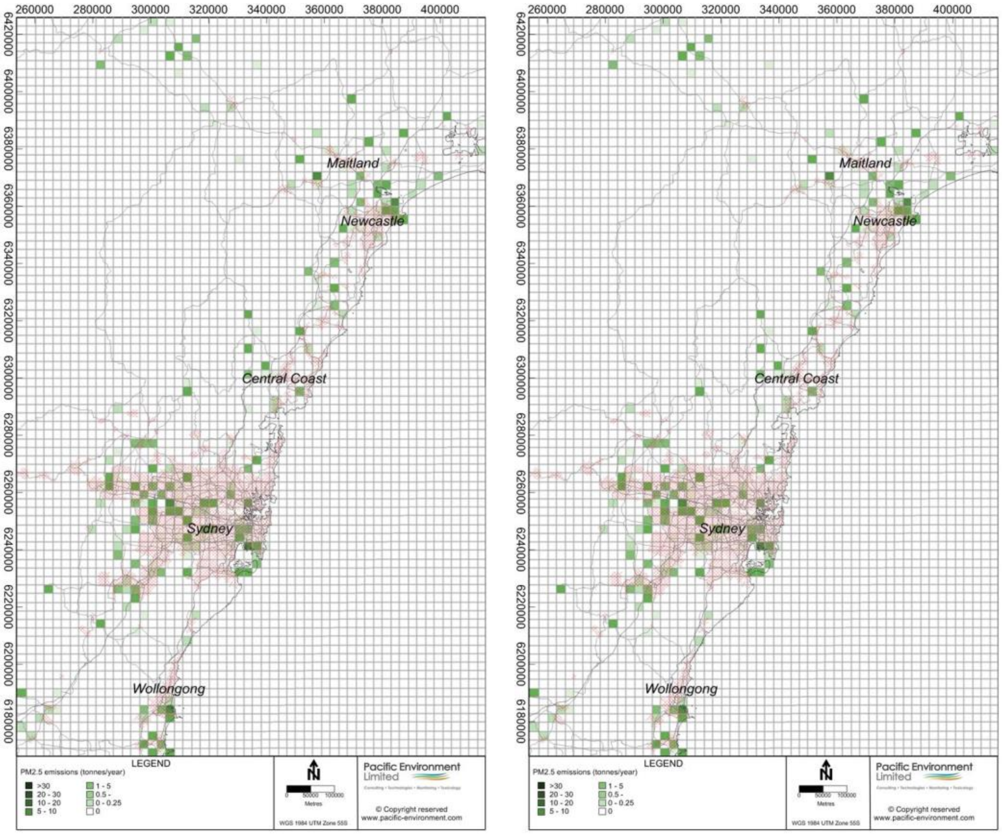

Figure A5: Gridded PM_{10} and $PM_{2.5}$ emissions from other industrial vehicles and equipment in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

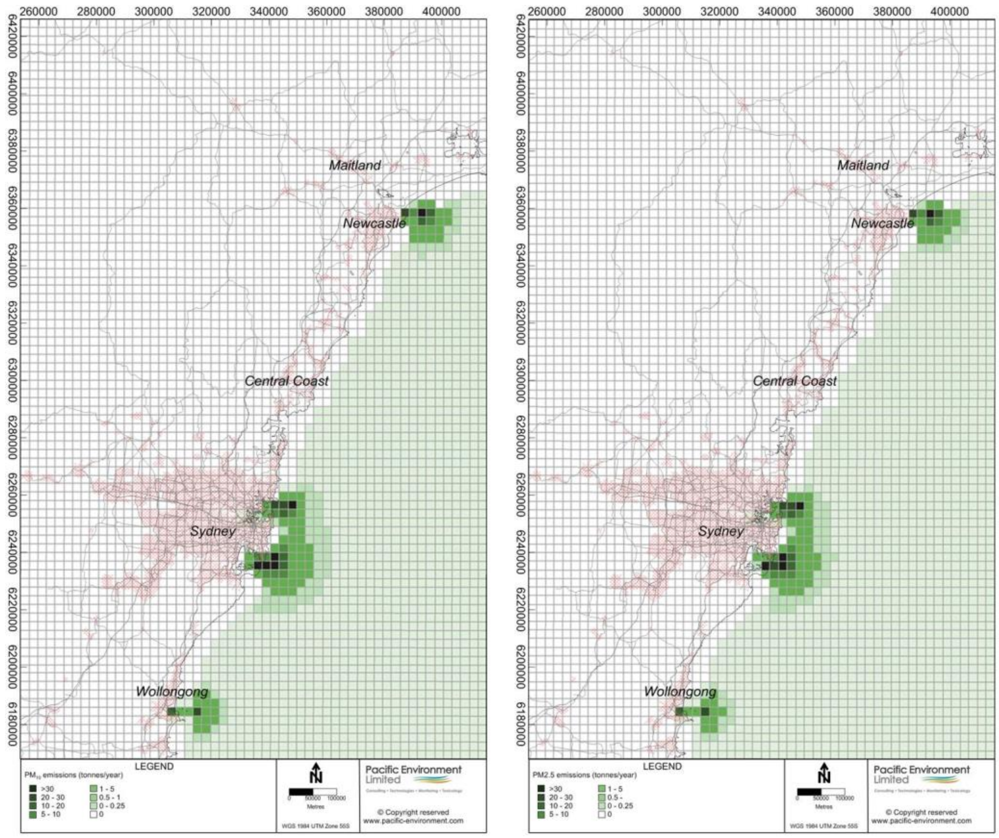

Figure A6: Gridded PM_{10} and $PM_{2.5}$ emissions from shipping in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

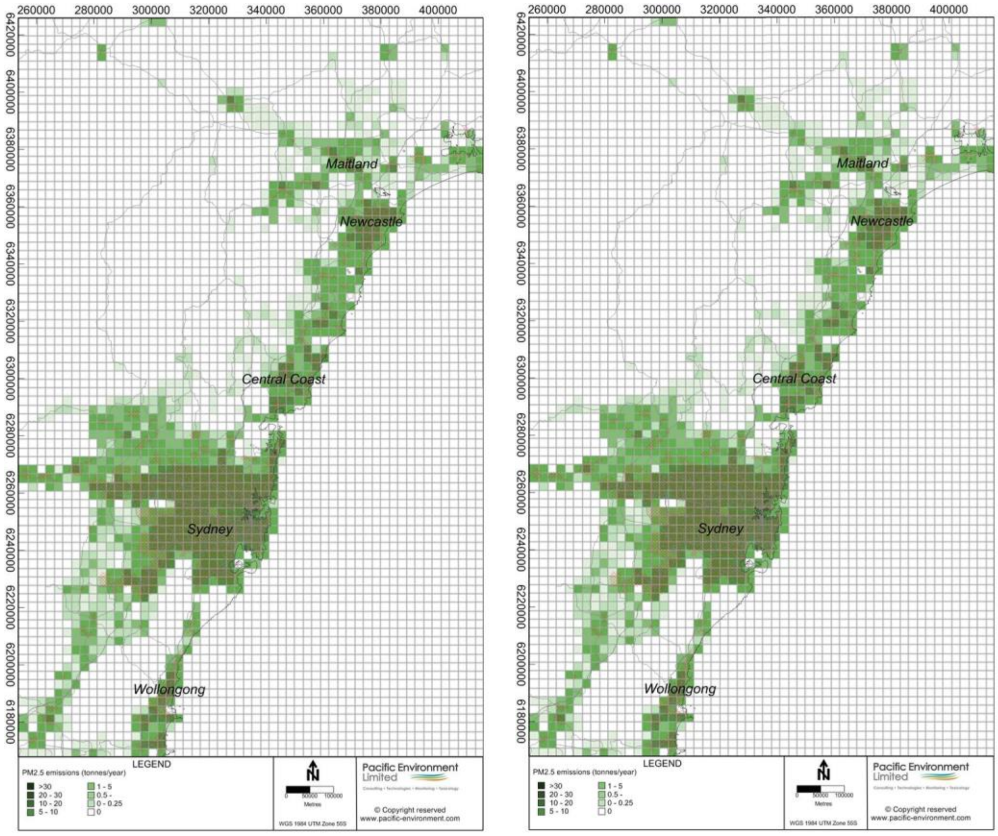

Figure A7: Gridded PM_{10} and $PM_{2.5}$ emissions from wood heaters in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

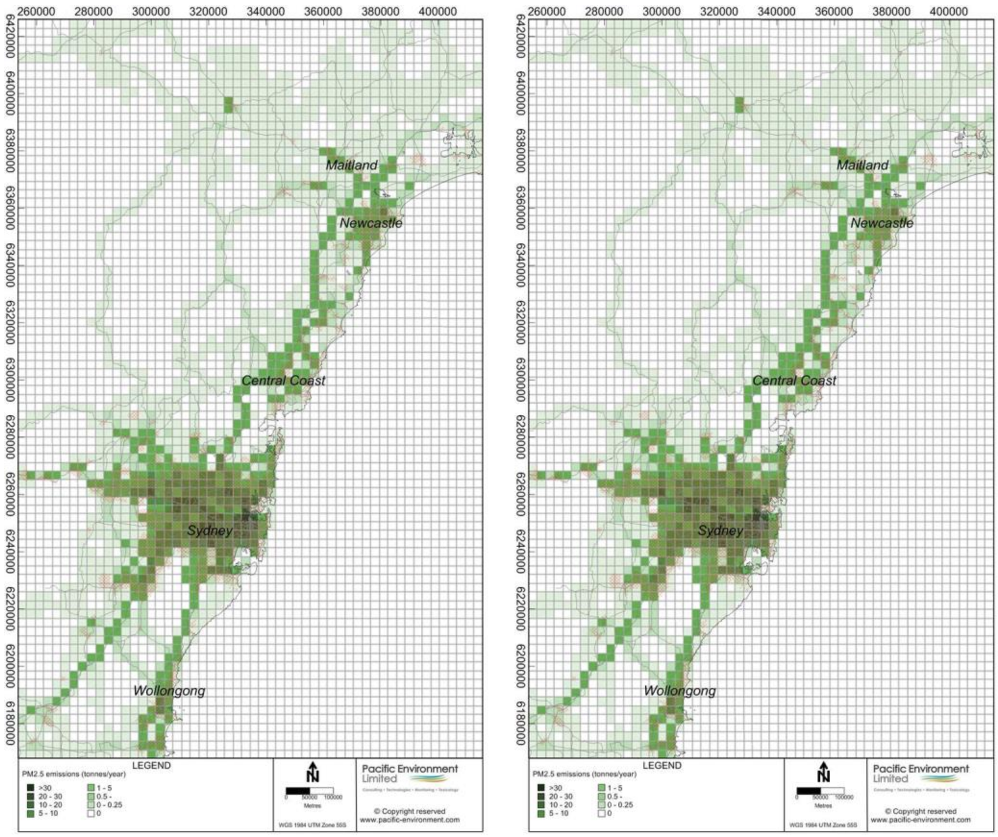

Figure A8: Gridded PM_{10} and $PM_{2.5}$ emissions from road vehicles in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

The relative importance of the different anthropogenic sectors to total emissions of PM_{10} and $PM_{2.5}$ in the GMR in 2011 is shown in **Figure A9** (based on the Emissions-to-Area reports). A distinction was made between point and area sources for the industrial and commercial sectors, although for clarity of presentation this distinction is not shown in the Figure. In 2011 area sources accounted for 87% of PM_{10} emissions and 63% of $PM_{2.5}$ emissions from all industrial sources.

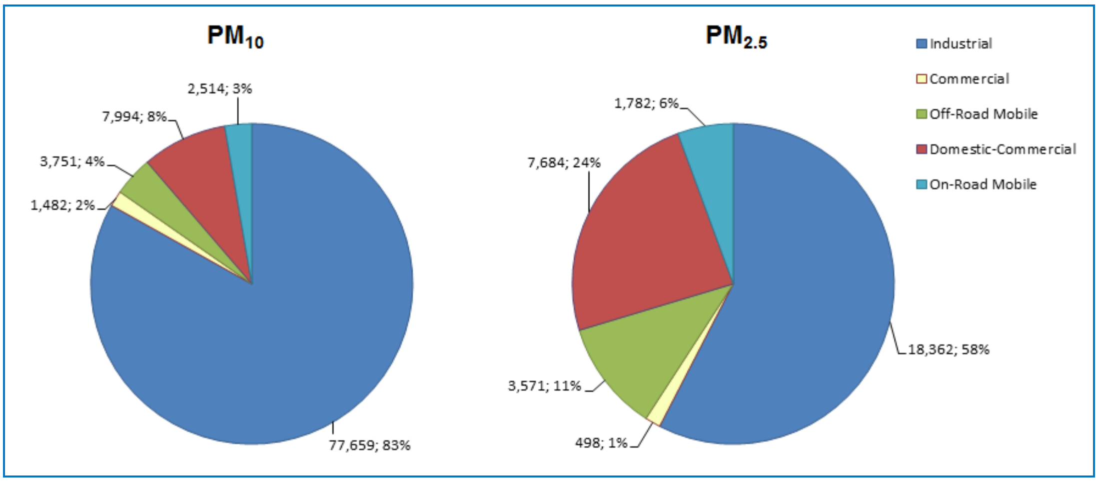

Figure A9: Source group contributions to anthropogenic PM_{10} and $PM_{2.5}$ emissions in the NSW GMR in 2011 (tonnes per year and percentage contributions).

The most important sector for both PM_{10} and $PM_{2.5}$ was industry. In the case of $PM_{2.5}$ the domestic/commercial sector was also important. Emissions from the three largest sectors – industry, domestic-commercial, and off-road mobile - are broken down further in **Figure A10** to **Figure A12**. In each case there was a single dominant emission-generating process. Emissions from industry were dominated by coal mining. Domestic/commercial emissions were dominated by domestic solid fuel burning (wood heaters). The main contributor to emissions from off-road mobile sources was industrial vehicles and equipment (which in NSW is principally equipment operating at coal mines).

Biogenic emissions were not included in the economic analysis. However, it is worth noting that particles of biogenic origin contributed significantly to total (natural and anthropogenic) emissions of both PM_{10} (26%) and $PM_{2.5}$ (19%) in the NSW GMR during 2011. **Figure A13** shows that the main contributor was marine aerosol, which accounted for 85% of biogenic/geogenic PM_{10} emissions and 56% of $PM_{2.5}$ emissions. Bushfires and prescribed burning were also large contributors to $PM_{2.5}$ emissions.

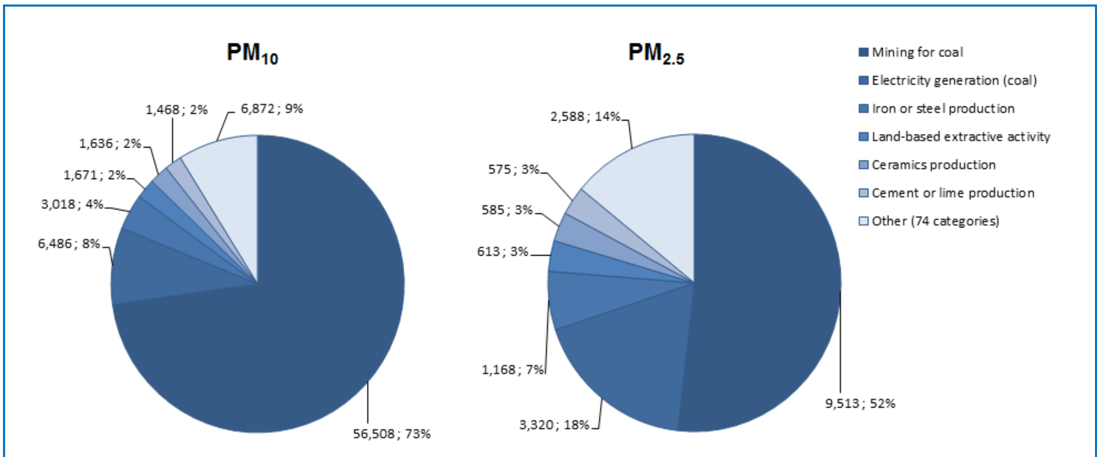

Figure A10: Annual PM_{10} and $PM_{2.5}$ emissions in the NSW GMR in 2011 – breakdown of industrial sector (tonnes per year and percentage contributions).

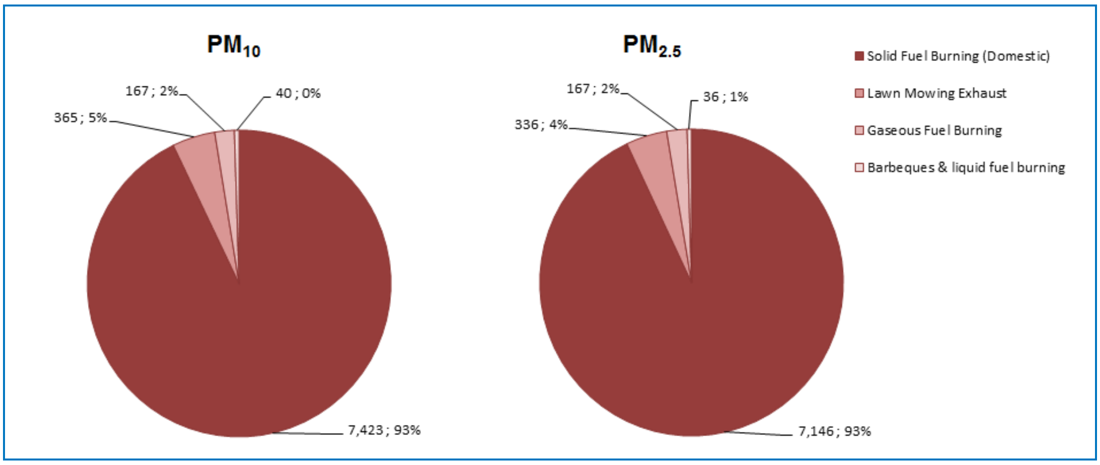

Figure A11: Annual PM_{10} and $PM_{2.5}$ emissions in the NSW GMR in 2011 – breakdown of domestic/commercial sector (tonnes per year and percentage contributions).

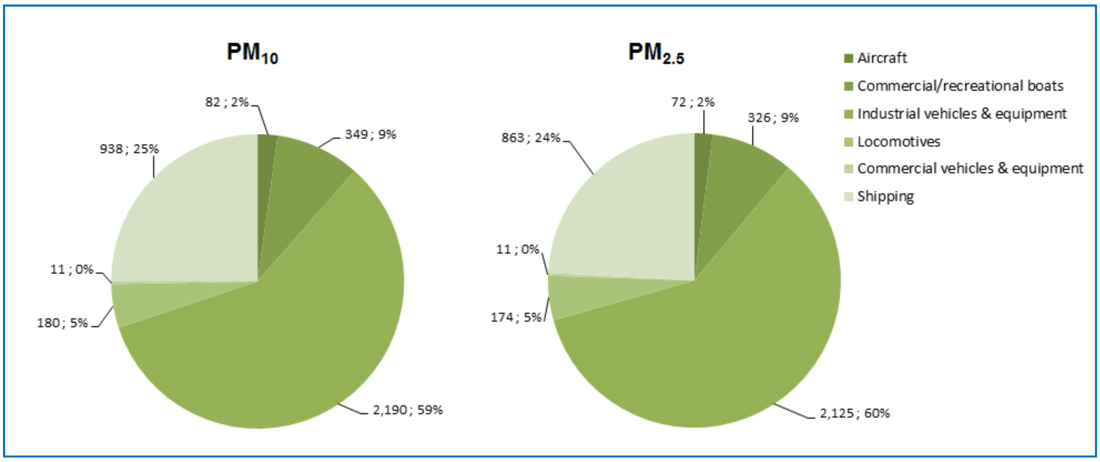

Figure A12: Annual PM_{10} and $PM_{2.5}$ emissions in the NSW GMR in 2011 – breakdown of off-road mobile sector (tonnes per year and percentage contributions).

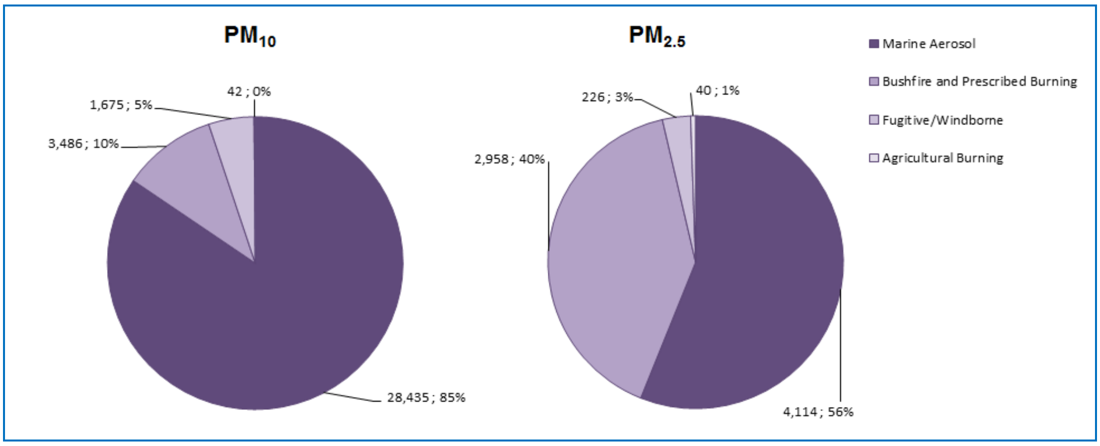

Figure A13: Annual PM_{10} and $PM_{2.5}$ emissions in the NSW GMR in 2011 – breakdown of biogenic/geogenic sector (tonnes per year and percentage contributions).

In **Figure A14** emissions of PM_{10} and $PM_{2.5}$ in the GMR are also broken down in terms of the specific sources that were modelled in the economic analysis.

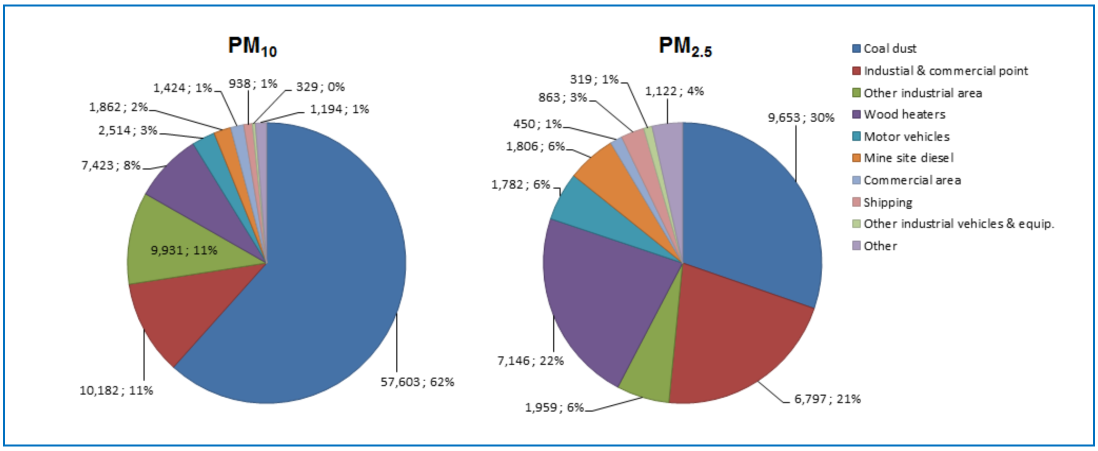

Figure A14: Annual PM_{10} and $PM_{2.5}$ emissions in the NSW GMR in 2011 – breakdown according to modelled sources.

For the cost-benefit analysis it was necessary to ensure that total emissions remained consistent with those reported for the NSW GMR emissions inventory. The specific sources that were modelled in the economic analysis are summarised in **Table A3** and **Table A4**. The sources shaded in grey were not modelled in TAPM, but were required for completeness. Some assumptions were required to infer the concentrations associated with these sources (see **Section A.1.3.7**).

Table A3: Annual PM_{10} emissions for sources modelled in TAPM – NSW GMR

Source code	Main model group	Specific source[a]			PM_{10} emissions (tonnes/year)					
					2011	2016	2021	2026	2031	2036
01	PSE	All industrial and commercial point sources			10,182	11,240	12,845	14,607	16,168	17,777
02	ASE	Industrial area	Coal dust (inc. small point source contrib.)		57,603	64,846	75,424	87,085	97,269	107,798
03			*Other industrial area*		9,931	9,767	9,927	9,999	10,198	10,366
04		*Commercial area*			1,424	1,331	1,206	1,298	1,400	1,534
05		Non-road diesel engines	Commercial boats		96	101	104	108	113	117
06			Recreational boats		1	1	2	2	2	2
07			Off-road commercial vehicles/equipment		11	12	13	14	14	15
08			Industrial veh. & equip.: mine site diesel		1,862	1,988	2,129	2,280	2,417	2,556
09			Industrial veh. & equip.: other		329	351	376	402	427	451
10		Non-road spark ignition engines	Commercial boats		103	108	112	116	121	125
11			Recreational boats		148	158	168	177	186	195
12		Diesel trains			180	193	206	219	233	246
13		Shipping			938	956	971	985	1,004	1,022
14		*Other off-road mobile (balance) (aircraft)*			82	97	114	132	147	164
15	DSE	Domestic	Spark ignition engines	Domestic lawnmowers	211	226	239	252	265	277
16				Public lawnmowers	153	161	168	174	184	193
17			Wood heaters		7,423	6,950	6,929	6,901	6,894	6,880
18			*Other domestic*		206	220	235	249	263	277
19	MVSE	Motor vehicles			2,514	2,293	2,181	2,189	2,222	2,323
Total anthropogenic emissions					**93,400**	**101,000**	**113,347**	**127,188**	**139,526**	**152,318**

Table A4: Annual $PM_{2.5}$ emissions for sources modelled in TAPM – NSW GMR

Source code	Main model group	Specific source			$PM_{2.5}$ emissions (tonnes/year) 2011	2016	2021	2026	2031	2036
01	PSE	All industrial and commercial point sources			6,797	7,307	8,151	9,067	9,896	10,747
02	ASE	Industrial area	Coal dust (inc. small point source contrib.)		9,653	10,867	12,639	14,593	16,300	18,065
03			*Other industrial area*		1,959	1,631	1,319	939	654	347
04		*Commercial area*			450	408	360	378	400	431
05		Non-road diesel engines	Commercial boats		94	98	101	105	109	113
06			Recreational boats		1	1	2	2	2	2
07			Off-road commercial vehicles/equipment		11	12	12	13	14	15
08			Industrial veh. & equip.: mine site diesel		1,806	1,928	2,065	2,212	2,345	2,479
09			Industrial veh. & equip.: other		319	340	364	390	414	438
10		Non-road spark ignition engines	Commercial boats		95	99	103	107	111	115
11			Recreational boats		136	146	154	163	171	179
12		Diesel trains			174	187	200	212	226	239
13		Shipping			863	879	894	906	924	940
14		*Other off-road mobile (balance) (aircraft)*			72	85	99	115	128	143
15	DSE	Domestic	Spark ignition engines	Domestic lawnmowers	194	208	220	232	244	255
16				Public lawnmowers	142	149	156	162	171	178
17			Wood heaters		7,146	6,690	6,670	6,643	6,637	6,623
18			*Other domestic*		202	216	230	244	258	272
19	MVSE	Motor vehicles			1,782	1,524	1,365	1,328	1,322	1,376
Total anthropogenic emissions					**31,897**	**32,775**	**35,103**	**37,810**	**40,325**	**42,957**

A.1.2 Primary anthropogenic emissions of PM_{10} and $PM_{2.5}$ in Victoria

A.1.2.1 Description of emissions inventory

The Victoria air emissions inventory was described by **Delaney and Marshall (2011)**. The inventory covers the whole state, and includes detailed information for the airsheds of Port Phillip (Melbourne and the surrounding area), the Latrobe Valley, Bendigo and Mildura (**Figure A15**).

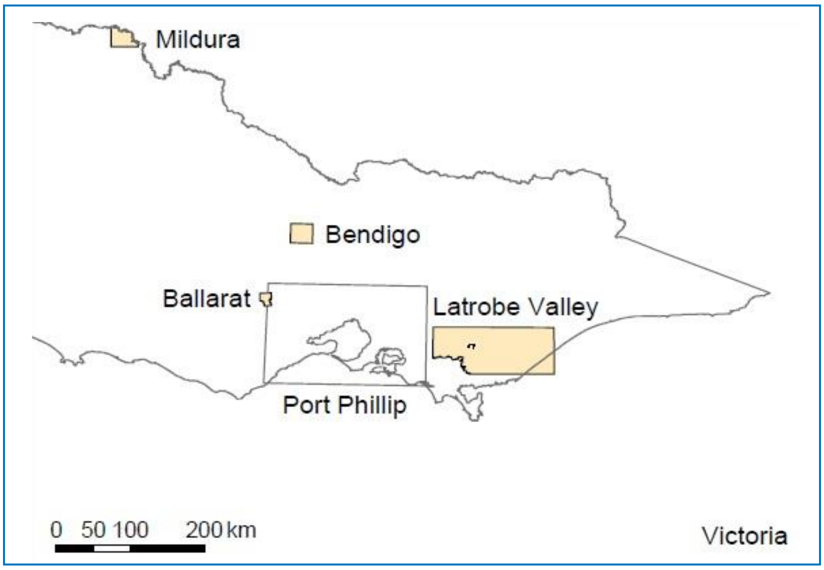

Figure A15: Coverage of Victoria emissions inventory (Delaney and Marshall, 2011)

The inventory contains data for substances that are relevant for PM formation (*i.e.* primary pollutants - PM_{10} and $PM_{2.5}$ and secondary pollutants – SO_2, SO_3, NO_x, NH_3 and VOCs). There is also a distinction between elemental carbon and organic carbon in PM. However, not all the substances in the inventory were relevant to the economic analysis.

A.1.2.2 Data supplied

Gridded emissions inventory data were supplied by EPA Victoria for a base year of 2006 and a projection year of 2030. The emission files for the 2006 base year were supplied in TAPM Chemical Transport Model (CTM) file format[6]. Different grid resolutions were used for Victoria (5 km x 5 km) and Port Phillip (1 km x 1 km), as defined in **Table A5**. Separate files were provided for seven different TAPM-CTM source groups (**Table A6**). The information in the industrial point source file was coded differently to that in all other files. The file had explicit X and Y coordinates for each point source, coded as a long header in the file which specified stack location, stack height, stack radius, *etc*. All the other files were presented as gridded data.

Table A5: Structure of gridded emissions data for Victoria

Grids	Grid 1	Grid 2
Area of coverage	Victoria	Port Philip Region
Cell size (grid resolution)	0.05° x 0.05° (approx. 5 x 5 km)	0.01 ° x 0.01 ° (approx. 1 x 1 km)
Number of cells in x direction	190	161
Number of cells in y direction	140	96
Year	2006	
Temporal resolution	One hour, based on varying profiles for month of the year, day of the week and hour of the day.	
Substances	PM_{10}, $PM_{2.5}$, NO_x, SO_2	

Table A6: Gridded emission inventory files supplied by EPA Victoria for the 2006 calendar year

File type	Emission sources included
Point source emissions (*.pse*)	All industrial point sources
Area source emissions (*.gse*)	All emissions from domestic and commercial sources, excluding wood heaters
Wood heater emissions (*.whe*)	All wood heater emissions from domestic sources (at a standard daily average temperature of 10°C)
Petrol vehicle emissions (*.vpx*)	Tailpipe, road dust, brake wear and tyre wear emissions from petrol vehicles
Diesel vehicle emissions (*.vdx*)	Tailpipe, road dust, brake wear and tyre wear emissions from diesel vehicles
LPG vehicle emissions (*.vlx*)	Tailpipe, road dust, brake wear and tyre wear emissions from LPG vehicles
Evaporative emissions from petrol vehicles (*.vpv*)[(a)]	Evaporative emissions from petrol vehicles

(a) Not relevant for PM emissions.

[6] As defined in Section 4.3 ('CTM Format Emission files', pages 32-35) of the Chemical Transport Model User Manual **(Cope and Lee, 2009)**.

The area source file actually contained a large number of different subcategories. These were:

- agricultural burning
- agricultural machinery
- aircraft
- architectural surface coatings
- automotive refinishing
- bakery
- barbecues
- bitumen
- commercial boats
- degreasing
- dry cleaning
- fertiliser and crops
- gas leakage
- gaseous fuel combustion
- graphic arts
- industrial surface coatings
- landfill
- lawnmowers
- liquid fuel combustion
- livestock
- locomotives
- pets and humans
- pleasure craft
- service stations
- solvent use
- sub-threshold fuel combustion
- waste combustion

Because of the large amount of time required to process the emission files and to run TAPM-CTM, it was not possible to model any of these specific source types separately. Consequently, we issued no requests to EPA Victoria for gridded emissions data for these source types. This is considered to be an important limitation of the modelling for Victoria.

The inventory data were supplied in a gridded format at the resolution described in **Table A5**, and were then imported into TAPM-CTM. Consistent with the NSW approach, the regional dispersion modelling (and subsequent analysis) was undertaken at a spatial resolution of 3 km x 3 km. Total annual $PM_{2.5}$ emissions in the modelled area are shown in **Figure A16**. The gridded PM_{10} and $PM_{2.5}$ emissions from the separate sources are plotted in **Figures A17** to **A20**. Again, emissions from industrial point sources are not shown, as these were not provided in a gridded format.

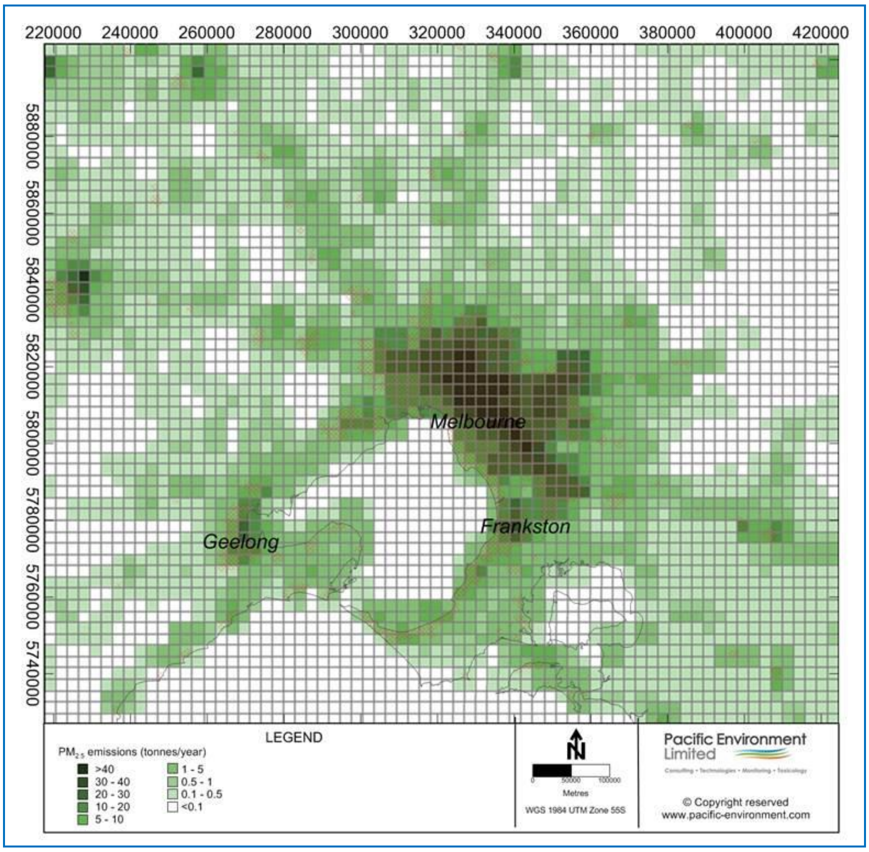

Figure A16: Gridded $PM_{2.5}$ emissions from all sources in the modelled area of the Port Phillip region during 2006 (3 km x 3 km grid)

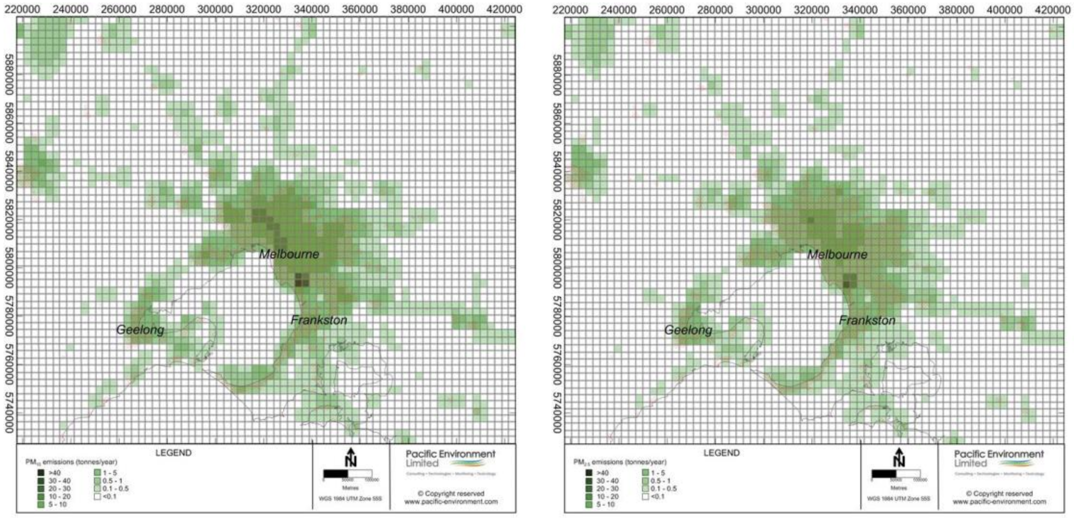

Figure A17: Gridded PM$_{10}$ and PM$_{2.5}$ emissions from area sources in the modelled are of the Port Phillip region during 2006 (3 km x 3 km grid)

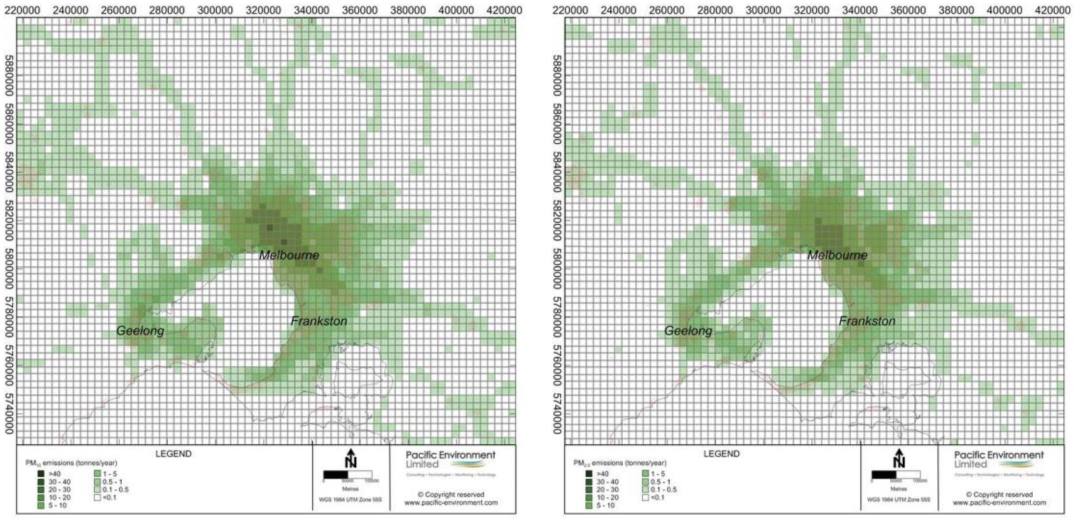

Figure A18: Gridded PM$_{10}$ and PM$_{2.5}$ emissions from diesel road vehicles in the modelled area of the Port Phillip region during 2006 (3 km x 3 km grid)

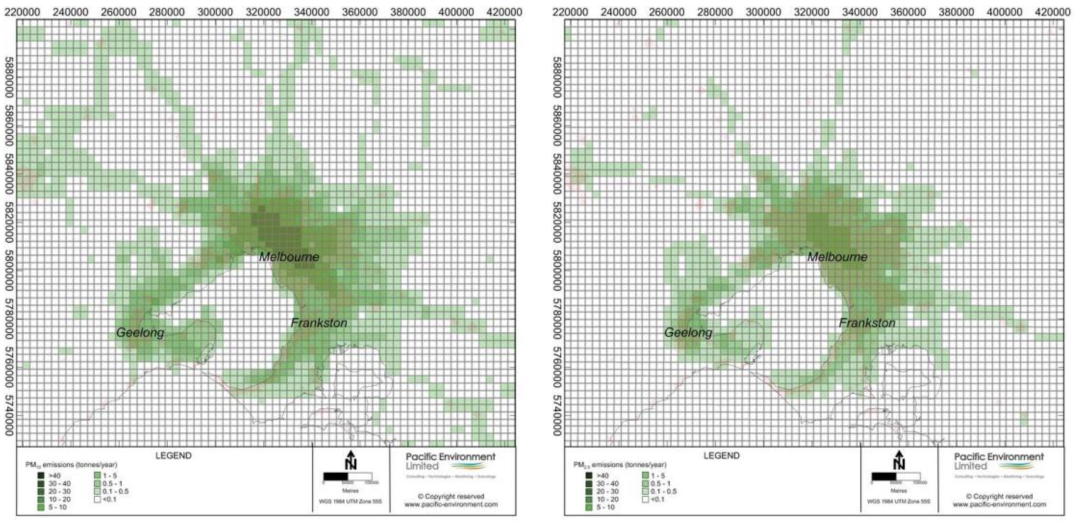

Figure A19: Gridded PM$_{10}$ and PM$_{2.5}$ emissions from petrol road vehicles in the modelled area of the Port Phillip region during 2006 (3 km x 3 km grid)

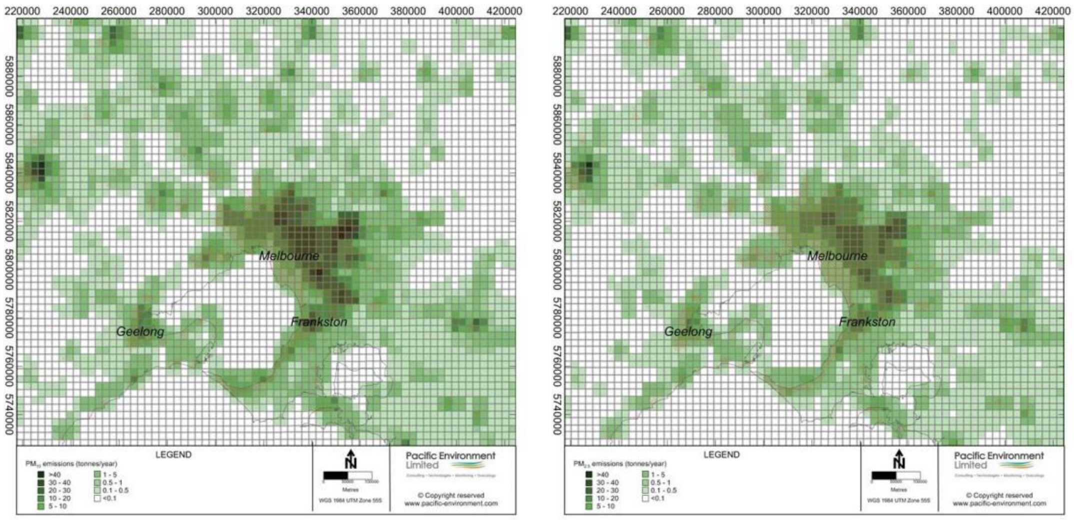

Figure A20: Gridded PM_{10} and $PM_{2.5}$ emissions from wood heaters in the modelled area of the Port Phillip region during 2006 (3 km x 3 km grid)

The relative importance of the different sectors to total anthropogenic emissions of PM_{10} and $PM_{2.5}$ in the modelled area of the Port Phillip region is shown in **Figure A21** (total PM_{10} = 20,425 tonnes/year; total $PM_{2.5}$ = 12,705 tonnes/year). As in NSW, the most important sectors for both PM_{10} and $PM_{2.5}$ were industry and domestic wood heaters. Road vehicles accounted for approximately a quarter of all anthropogenic PM_{10} and $PM_{2.5}$ emissions.

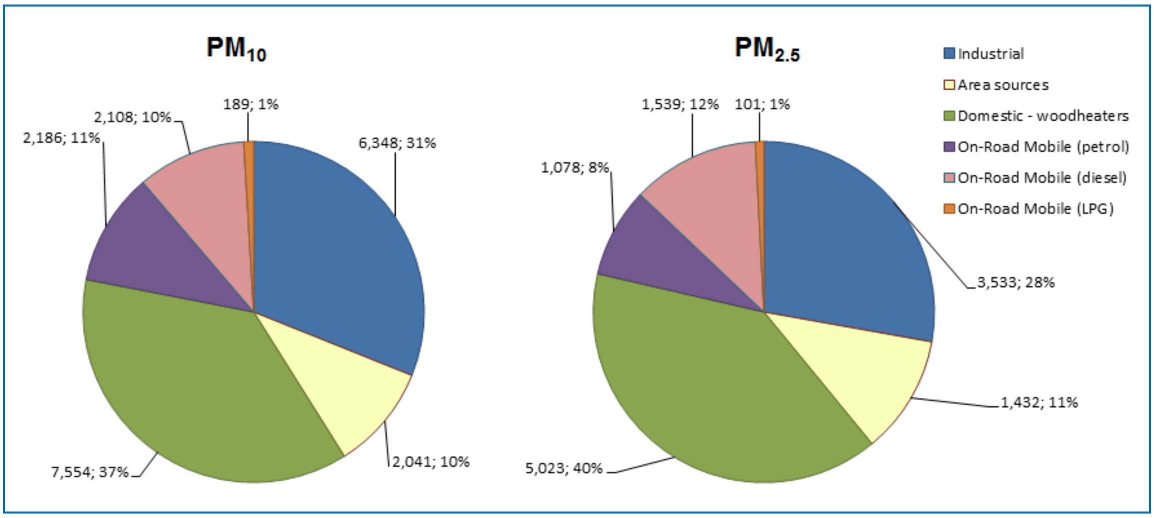

Figure A21: Source group contributions to anthropogenic PM_{10} and $PM_{2.5}$ emissions in the Port Phillip region in 2011 (tonnes per year and percentage contributions).

Total emissions from the specific sources that were modelled in the economic analysis are summarised in **Table A7** and **Table A8.**

Table A7: Annual PM_{10} emissions for sources modelled in TAPM-CTM – Victoria Port Phillip

Source code	Main model group	Specific source	PM_{10} emissions (tonnes/year)[a]					
			2011	2016	2021	2026	2031	2036
01	PSE	Industrial point sources	6,348	6,497	6,647	6,797	6,947	7,097
02	GSE	Area sources	2,041	2,220	2,400	2,579	2,758	2,938
03	MSE	Motor vehicles - petrol	2,186	2,205	2,225	2,244	2,263	2,282
04		Motor vehicles - diesel	2,108	1,976	1,844	1,712	1,579	1,447
05		Motor vehicles - LPG	189	173	158	143	127	112
06	WHE	Wood heaters	7,554	7,570	7,586	7,603	7,619	7,635
Total anthropogenic emissions			**20,425**	**20,643**	**20,860**	**21,077**	**21,294**	**21,511**

(a) Values estimated from data supplied by EPA Victoria for 2006 and 2030.

Table A8: Annual $PM_{2.5}$ emissions for sources modelled in TAPM-CTM – Victoria Port Phillip

Source code	Main model group	Specific source	$PM_{2.5}$ emissions (tonnes/year)[a]					
			2011	2016	2021	2026	2031	2036
01	PSE	Industrial point sources	3,533	3,668	3,804	3,939	4,075	4,210
02	GSE	Area sources	1,432	1,561	1,689	1,818	1,947	2,076
03	MSE	Motor vehicles - petrol	1,078	1,085	1,091	1,097	1,103	1,110
04		Motor vehicles - diesel	1,539	1,355	1,171	987	803	619
05		Motor vehicles - LPG	101	95	89	83	77	71
06	WHE	Wood heaters	5,023	5,033	5,044	5,055	5,066	5,076
Total anthropogenic emissions			**12,705**	**12,796**	**12,888**	**12,979**	**13,070**	**13,162**

(a) Values estimated from data supplied by EPA Victoria for 2006 and 2030.

A.1.3 Unadjusted primary anthropogenic PM_{10} and $PM_{2.5}$ concentrations

A.1.3.1 Overview

Regional air quality modelling is undertaken by the different Australian jurisdictions for policy development purposes, although the extent of the modelling varies considerably. NSW, Victoria and Queensland typically conduct regional air quality simulations using TAPM **(Bawden *et al.*, 2012)**. TAPM (Version 4) was also selected for the economic analysis to model primary anthropogenic PM_{10} and $PM_{2.5}$ concentrations (as well as NO_X and SO_2), primarily because the NSW and Victoria emission inventories were already available in TAPM format, thereby reducing the need for re-formatting of the inventory data.

Essentially, the gridded emissions inventories for the NSW GMR (year 2011) and Port Phillip region (year 2006) were used in conjunction with TAPM to determine ambient concentrations of primary anthropogenic PM_{10} and $PM_{2.5}$ on a regional scale, as illustrated in **Figure A22**. Concentrations were predicted separately for each sector of activity and each grid cell (a 3 km × 3 km output grid was used for both the NSW GMR and Port Phillip). It is worth noting that the spatial distribution of concentrations is not the same as that for emissions, as the concentration in any given grid cell is affected by emissions from other grid cells, and the modelling process allows for the transport of pollutants.

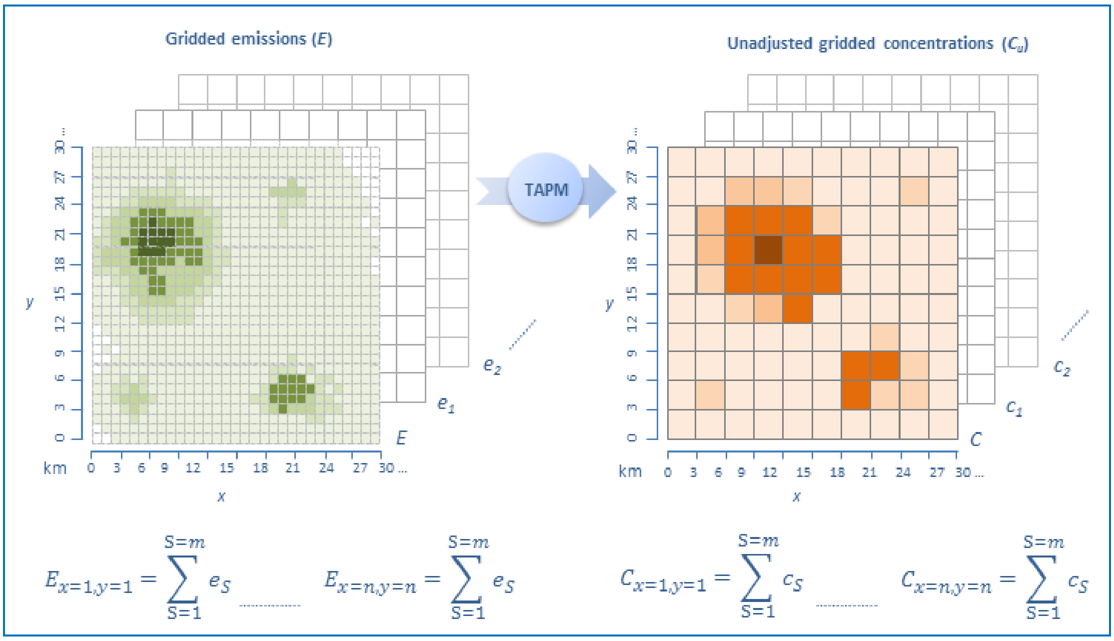

Figure A22: Prediction of unadjusted gridded PM concentrations (*E* = total emissions, e_S = emissions from sector *S*, *C* = total concentration, *c* = concentration for sector *S*)

A.1.3.2 Model selection

TAPM is a PC-based three-dimensional dispersion model produced by the CSIRO Division of Atmospheric Research **(Hurley, 2008)**. TAPM solves fluid dynamics and scalar transport equations to predict meteorology and pollutant concentrations. The model predicts the air flows that are important for local-scale air pollution, such as sea breezes and terrain-induced flows, against a background of synoptic-scale meteorology. It connects to Australian databases of terrain, vegetation, soil type, sea surface temperature and synoptic-scale meteorology. TAPM allows for inclusion of point emission sources (*e.g.* industrial stacks), gridded area sources (including motor vehicle and wood heater combustion), as well as gridded biogenic sources. TAPM is suitable for horizontal domain sizes below approximately 1,500 km by 1,500 km. Its performance has been verified for several regions in Australia.

The CTM add-on to TAPM is used for urban airsheds that require a more complex treatment of chemistry. Six chemistry schemes are available for use in the publically available TAPM-CTM model, such as the 'Lurmann-Carter-Coyner' and 'Carbon Bond (CB) 04' mechanisms **(Cope and Lee, 2009)**. TAPM-CTM includes modules for simulating the formation of secondary inorganic and organic aerosols, but as noted in **Section 3.1** these models do not appear to perform well at present.

The advantages and disadvantaged of TAPM have been summarised by **NZMFE (2004)**:

Advantages

- It is easy to use and completely self-contained, with good visualisation of model results.
- It requires no local data, although it has the ability to assimilate local surface meteorological data.
- It describes the effects of point, line and volume sources, simulates the effects of buildings on dispersion, and simulates chemical reactions between pollutants.

Disadvantages

- A high level of understanding of boundary-layer meteorology and pollution dispersion is needed to produce meaningful results.

- The maximum horizontal resolution of the meteorological model component of TAPM is of the order of 1 km. Care must be taken to ensure that the meteorological data are representative of the scales modelled by the meteorological model.

A.1.3.3 Model set-up and processing

For the NSW GMR, TAPM was set up and run in tracer mode[7]. Three domains were included, with each successively smaller domain being fully enclosed by the outer domain. The outer grid had a spacing of 15,000 m covering 1,800,000 km^2 including South Eastern Australia and parts of the Tasman Sea. The middle grid had a spacing of 7,000 m covering 392,000 km^2 including eastern NSW. The inner grid had a spacing of 3,000 m and covered the majority of the NSW GMR, approximately 72,000 km^2. The grid centroid was located in the Hawkesbury River region, near Mount White at 33°28" S, 151°12"E (-33.466°, 151.20°), approximately 43 km north of the centre of Sydney.

The inner-most domain (*i.e.* 3 km resolution) was utilised for the analysis, while the outer domains were included to ensure that emissions and meteorological effects from outside the inner domain were taken into account. To setup the model, the TAPM graphical user interface was used along with TAPM terrain and 'Ausynoptic' meteorological data.

Figure A23 shows the full extent of the area covered by the GMR emissions inventory, illustrating the 1 km x 1 km grid. Because of the restrictions on the size of the inner modelling domain within TAPM (maximum input (emission) grid extent comprising 40,000 grid points), it was not possible to model the whole inventory area. The Figure therefore also shows the smaller area (defined by the red box) which was modelled in TAPM at a resolution of 3 km x 3 km.

For Victoria TAPM with the CTM extension was used, and again three domains were included. The outer grid had a spacing of 18,000 m and covered 1,360,000 km^2, including Victoria, Bass Strait, Northern Tasmania and Southern NSW. The middle grid had a spacing of 9,000 m and covered 340,000 km^2, including central and southern Victoria and Bass Strait. The inner grid had a spacing of 3,000 m, and covered the 37,800 km^2 of the Port Phillip region. The grid centroid was located in the centre of Port Phillip Bay at 37°49" S, 144°58"E, approximately 21 km south-east of the centre of Melbourne.

Two emission grids were supplied by EPA Victoria: the Victoria grid (Grid 1) which was imported into the 18 km and 9 km domains, and the Port Phillip grid (Grid 2) which was imported into the 3 km domain. The inner-most grid - containing 60 x 70 grid points - was used for the analysis (**Figure A24**). As in NSW, the outer grids were included to ensure that the effects of emissions and meteorological conditions outside the analysis grid were taken into account. For this model only the dispersion of PM_{10} and $PM_{2.5}$ was required, and therefore a chemistry scheme was not used.

The emissions files for Victoria were categorised by month and emission source group. To reduce model run times, emissions from LPG vehicles (relatively small) were combined with those from area sources. Five model runs – representing the source groups - were required for each month. Thus, across the 12 months, 60 monthly model runs were required for $PM_{2.5}$ and 60 for PM_{10}.

More than 30 different chemical species and substances were identified in the files. PM_{10} and $PM_{2.5}$ were separated into several different components (*i.e.* elemental carbon, organic carbon, sulfate and other), and a distinction was made between the fine (< 2.5 µm) and coarse (2.5-10 µm) fractions. To simplify the modelling process for each PM metric (PM_{10} and $PM_{2.5}$), these components were combined additively. NO_X and SO_2 were also modelled as they were useful for the valuation of health impacts

[7] Tracer mode does not include chemistry. This assumption is valid for an evaluation of primary PM.

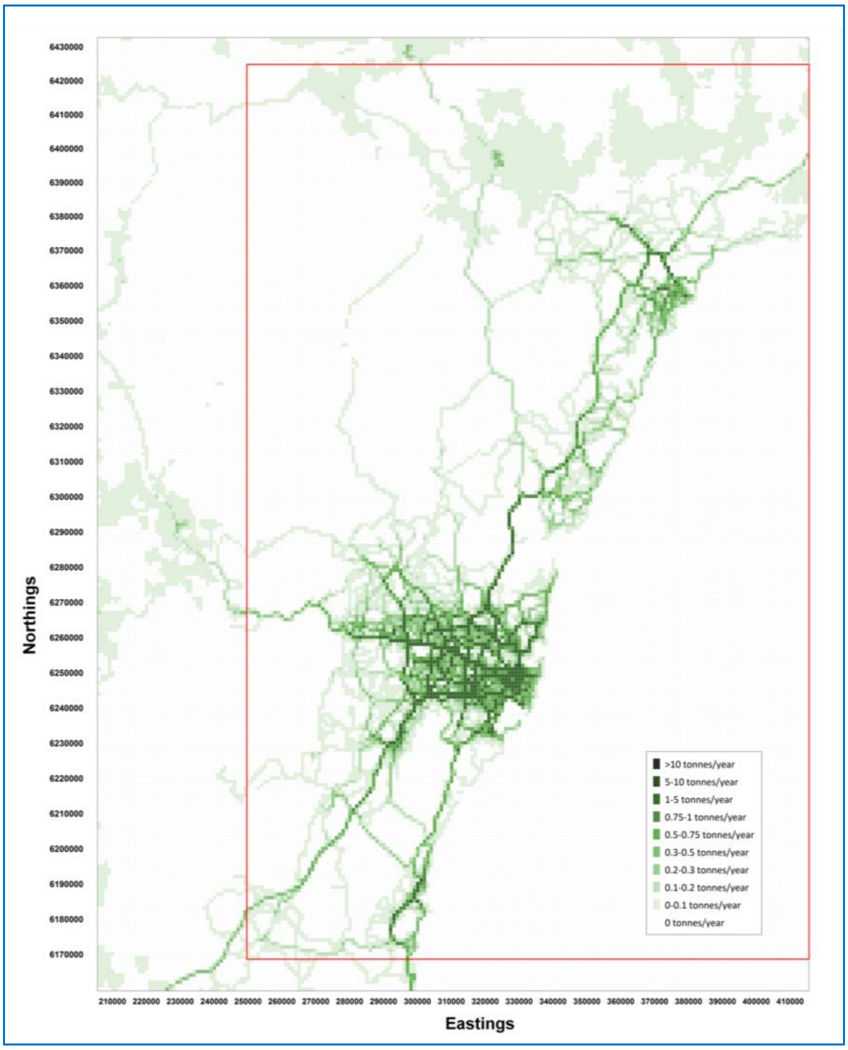

Figure A23: Emissions from motor vehicles in the NSW GMR (2011), illustrating the 1 km x 1 km inventory grid. The smaller area defined by the red box was modelled in TAPM at a resolution of 3 km x 3 km.

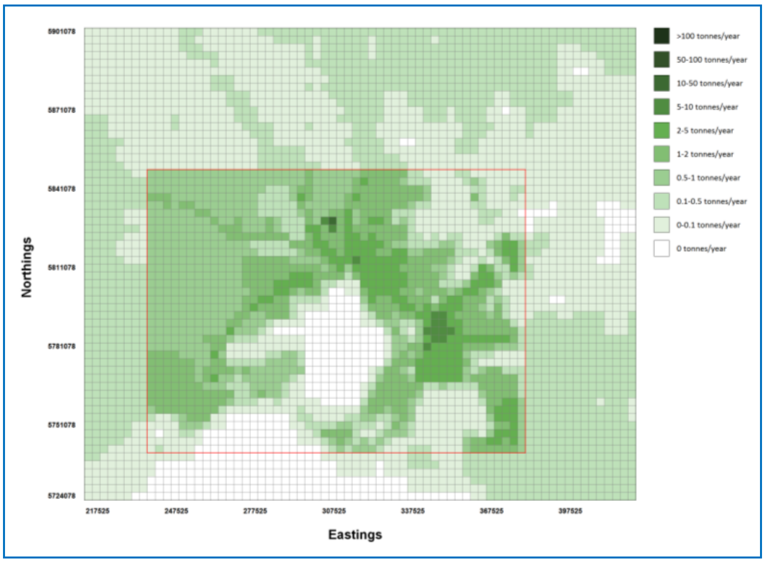

Figure A24: Emissions from area sources in the Victoria inventory (2006). The smaller area defined by the red box was modelled in TAPM at a resolution of 3 km x 3 km.

A.1.3.4 Meteorological data

For both modelled regions the required synoptic meteorological data were obtained from CSIRO.

A.1.3.5 Time periods

For both modelled regions PM_{10} and $PM_{2.5}$ concentrations were modelled as 24-hour average values for each day of the year and for each grid cell.

A.1.3.6 Modelling of source groups

Each individual source group was modelled separately in TAPM to allow a more detailed analysis and specific targeting for emission-reduction strategies. Non-anthropogenic PM emissions (*i.e.* from biogenic and geogenic sources) were modelled in TAPM but were not considered in the economic analysis.

The source groups modelled for NSW are shown in **Table A9**. Most sources were modelled directly in TAPM using the emission files supplied by NSW EPA. Pollutant concentrations relating to wood heaters were calculated using a wood heater emission (WHE) file. For some sources the gridded concentrations were obtained by scaling the results for sources which were likely to have a broadly similar spatial distribution. For example, emissions for 'other industrial area' sources in a given grid cell were obtained by scaling emissions from industrial point sources in the same cell according to the total emissions from the respective sources in the GMR.

Table A9: Source groups modelled in NSW

Model source file	Main source group	Source	Treatment	
			Modelled directly	Obtained by scaling
1	Industrial point	All	✓	
2	Area	Coal dust	✓	
3		Other industrial area		✓
4		Commercial area		✓
5		Non-road diesel engines: commercial boats	✓	
6		Non-road diesel engines : recreational boats	✓	
7		Non-road diesel engines: commercial vehicles	✓	
8		Industrial vehicles & equip.: mine-site diesel	✓	
9		Industrial vehicles & equip.: other	✓	
10		Non-road SI engines: commercial boats	✓	
11		Non-road SI engines: recreational boats	✓	
12		Diesel trains	✓	
13		Shipping	✓	
14		Other off-road mobile (air transport)		
15	Domestic-commercial	Spark ignition engines: domestic lawnmowers	✓	
16		Spark ignition engines: public lawnmowers	✓	
17		Wood heaters	✓	
18		Other domestic commercial		✓
19	Motor vehicles	All	✓	

The source groups modelled for Victoria are shown in **Table A10**.

Table A10: Source groups modelled in Victoria

Model source file	Source group
1	Industrial point sources
2	Area sources (all emissions from domestic and commercial sources, excluding wood heaters) and LPG vehicles
3	Wood heaters
4	Petrol vehicles
5	Diesel vehicles

A.1.3.7 Non-modelled sources

In the case of NSW, for conservation of mass it was necessary to infer the gridded concentrations for those sources that were not modelled explicitly. These sources, and the assumptions used, were as follows:

- *Other industrial area sources*. The concentrations for these sources were assumed to be spatially distributed in the same way as industrial point sources, and were calculated by scaling emissions from the latter in accordance with the ratio of total emissions in the GMR (*i.e.* other industrial area: industrial point).
- *Commercial area sources*. The concentrations for these sources were assumed to be spatially distributed in the same way as off-road commercial vehicles, and were scaling accordingly.
- *Other off-road mobile sources*. These sources were essentially aircraft flight operations (airport ground operations were covered by 'other industrial vehicles and equipment'). Given that no other modelling group had the same spatial distribution as air transport, the concentrations were set to zero. Moreover, emissions from the source group were relatively small overall, and a substantial proportion of emissions from aircraft are allocated to the layer of the atmosphere between ground level and around 1,000 metres. These emissions therefore have a relatively small impact on ground-level concentrations.
- *Other domestic sources*. The concentrations for these sources were assumed to be spatially distributed in the same way as domestic lawnmowers, and were scaled accordingly.

For Victoria, area source emissions, evaporative emissions and LPG exhaust emissions were expected to be quite low, and therefore the emission files for three groups were combined for dispersion modelling.

A.1.4 Adjusted primary anthropogenic PM_{10} and $PM_{2.5}$ concentrations

The results from TAPM were subject to a number of uncertainties. These included uncertainties in emission estimates, meteorological data and other model inputs, as well as overall model limitations. In a model 'calibration' process the predicted primary anthropogenic PM_{10} and $PM_{2.5}$ concentrations for the NSW and Victoria grids were adjusted to take account of these uncertainties. These steps in the calibration process are illustrated in **Figure A25**.

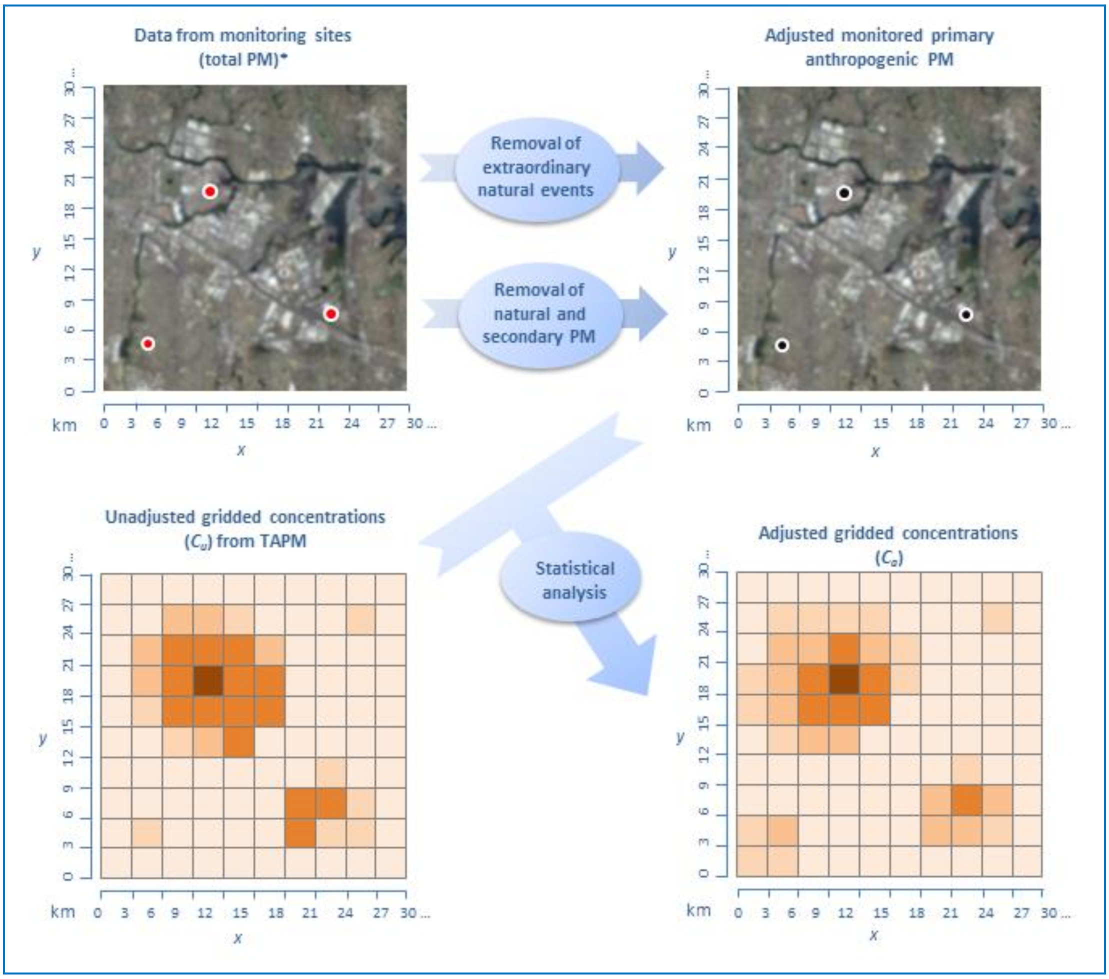

Figure A25: Model calibration – determination of gridded primary anthropogenic concentrations

The predicted PM concentrations from TAPM were scaled according to the corresponding measured values using the following steps:

- Selection of appropriate PM_{10} and $PM_{2.5}$ monitoring data.
- Adjustment of the PM_{10} and $PM_{2.5}$ monitoring data to ensure comparability with the model results, and to ensure that the importance of primary anthropogenic PM was not overestimated. This involved:
  - Removal of data for days with extraordinary natural events (bush fires and dust storms) and days with high concentrations as a result of other unusual activities near the monitoring sites.
  - Removal of natural and secondary PM (to leave the primary anthropogenic components).
- Adjustment of the model results according to the adjusted monitoring data using a statistical procedure.
- Scaling to ensure the long-term representativeness of the base year concentrations.

These steps are described in detail in **Appendix B**, and the annual mean results for specific sources are shown in **Figures A26** to **A39** below.

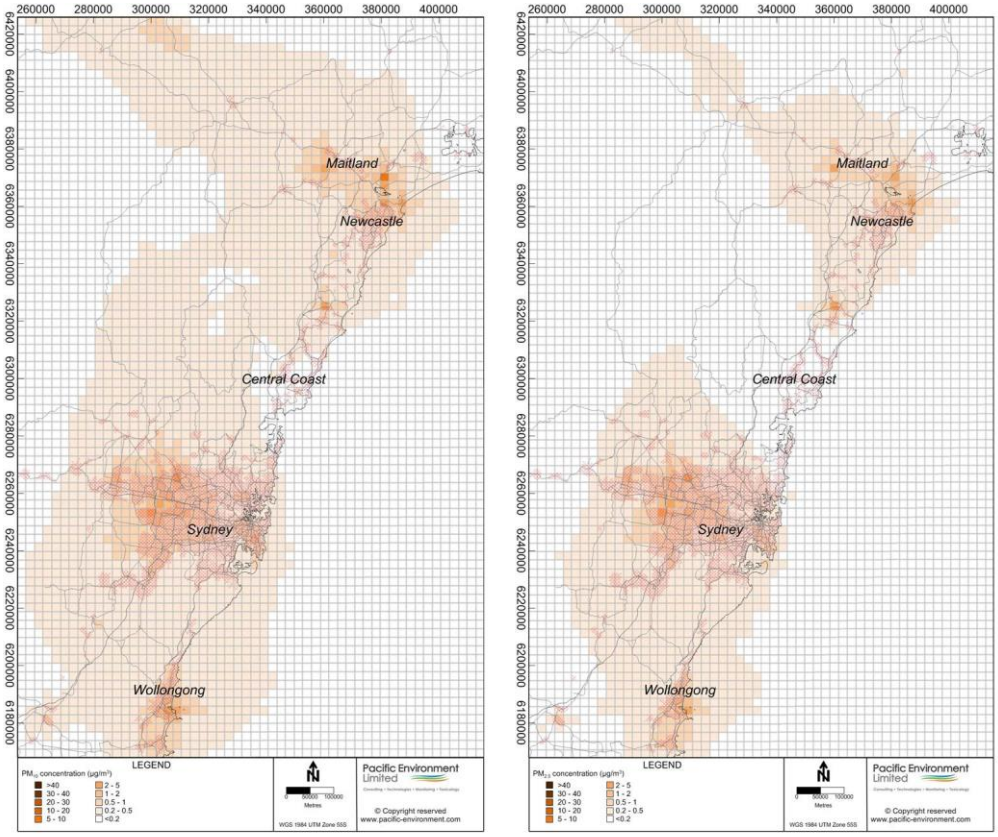

Figure A26: Gridded PM10 and PM2.5 concentrations from industrial point sources in in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

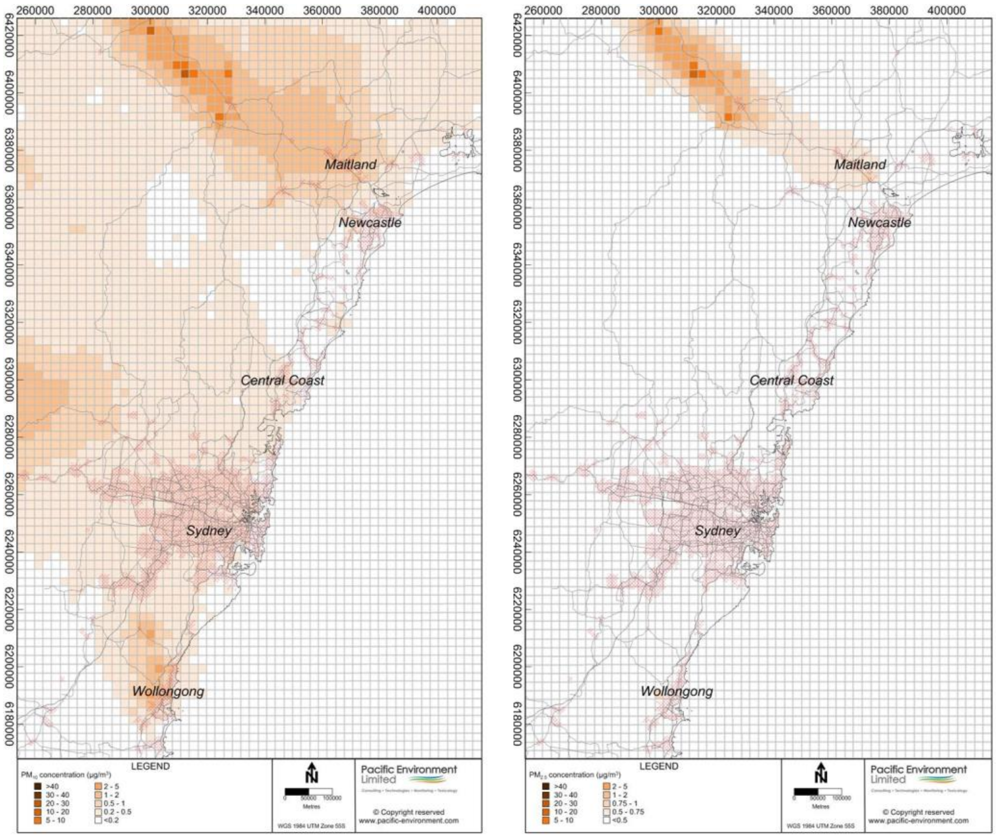

Figure A27: Gridded PM10 and PM2.5 concentrations from coal dust in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

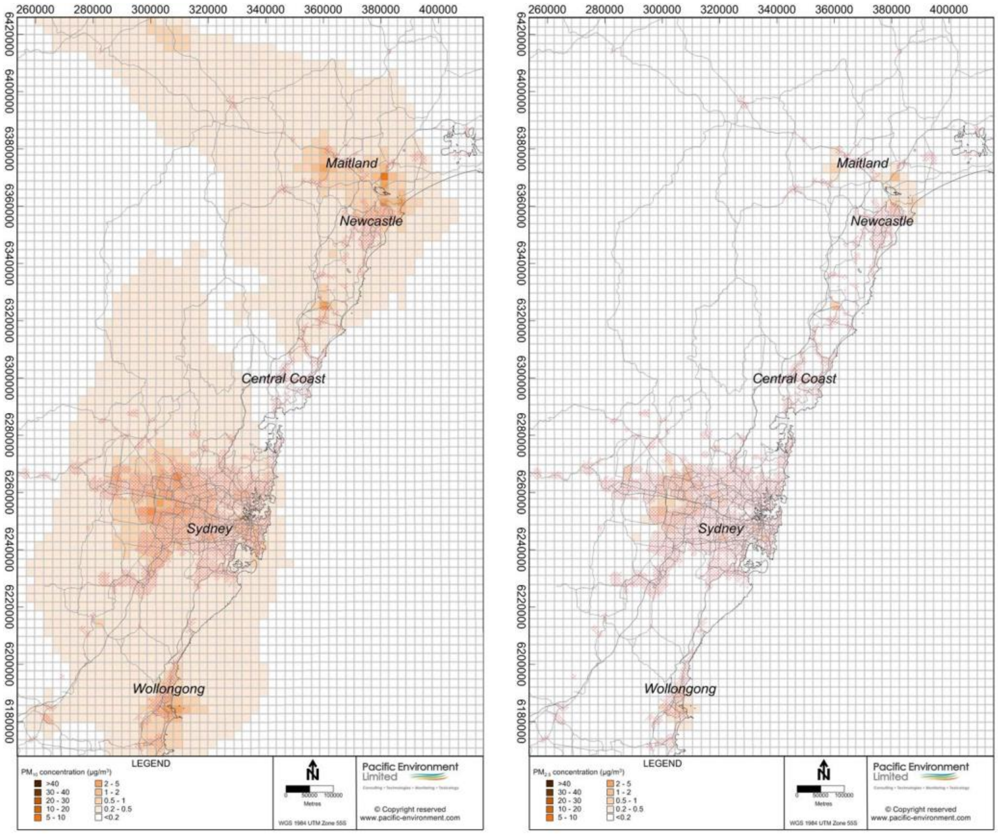

Figure A28: Gridded PM_{10} and $PM_{2.5}$ concentrations from other industrial area sources in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

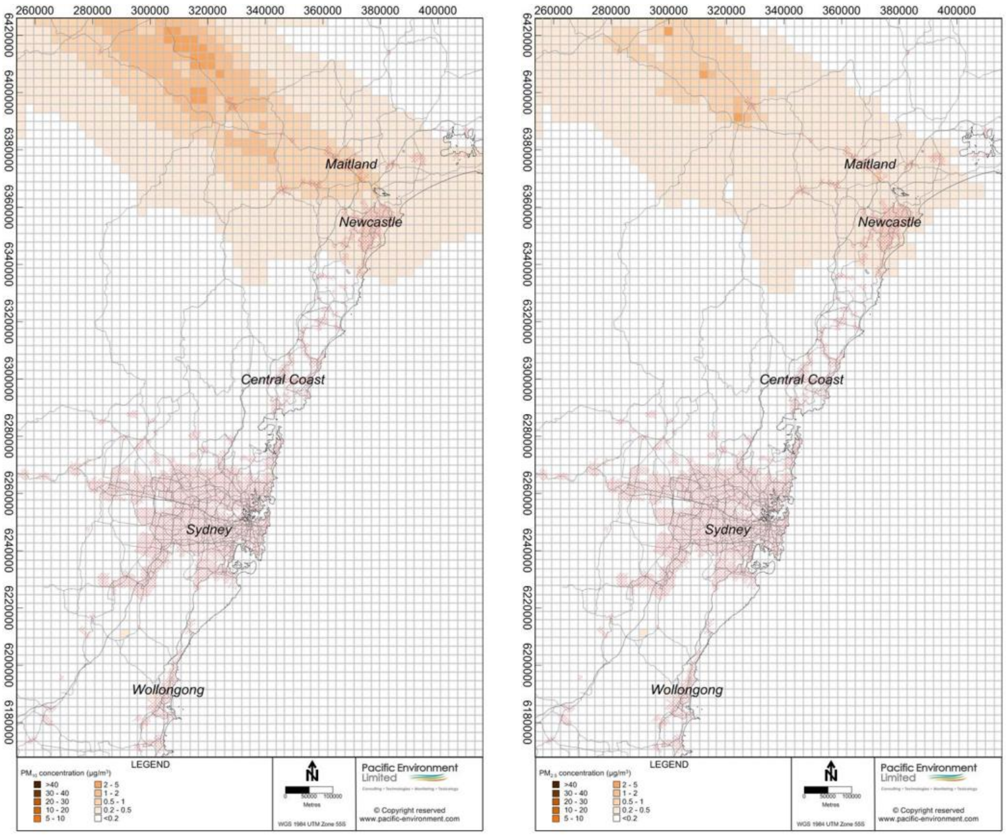

Figure A29: Gridded PM_{10} and $PM_{2.5}$ concentrations from mine site diesel in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

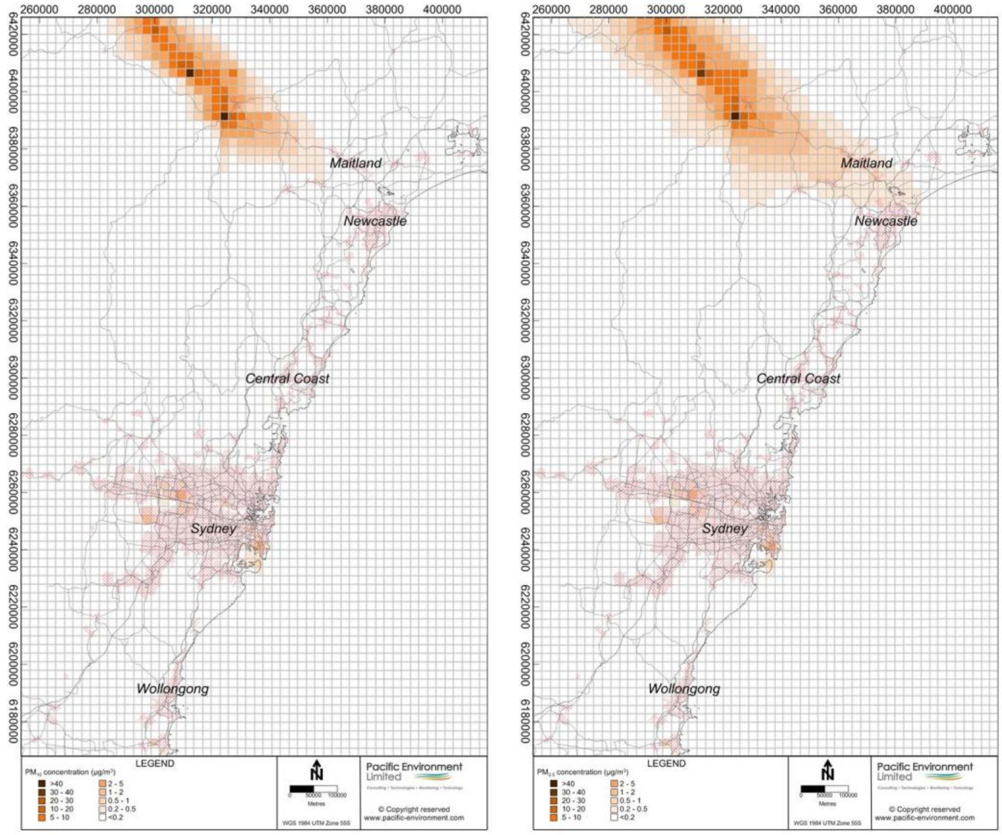

Figure A30: Gridded PM_{10} and $PM_{2.5}$ concentrations from other industrial vehicles and equipment in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

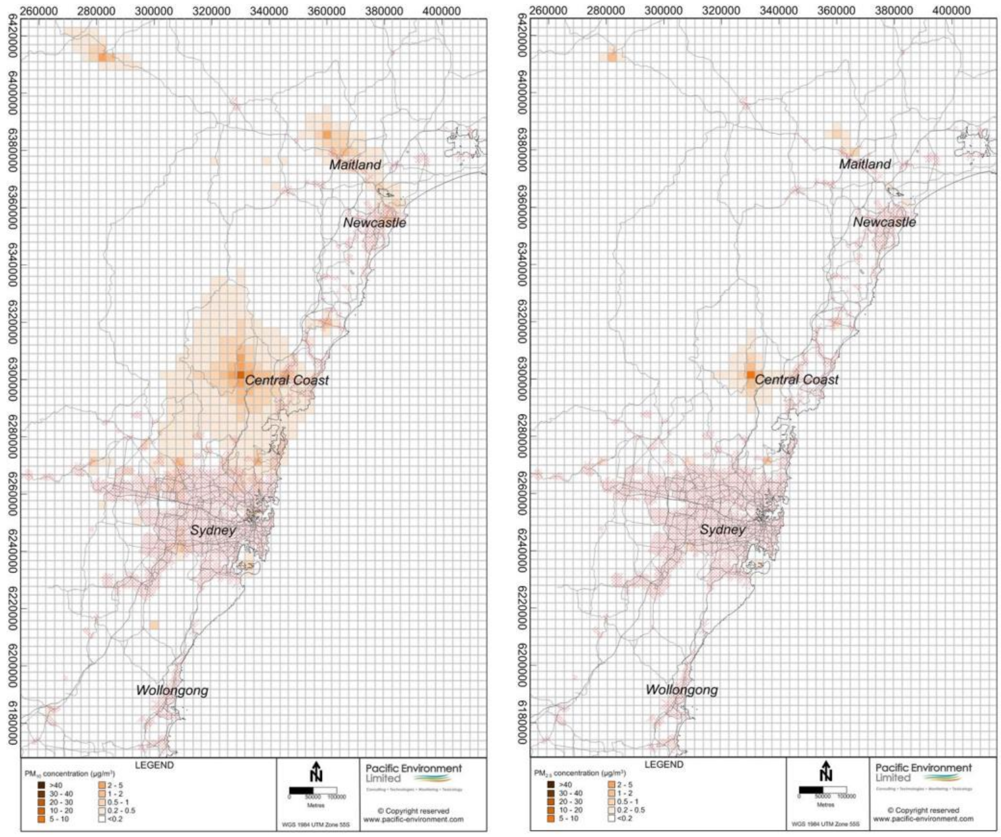

Figure A31: Gridded PM_{10} and $PM_{2.5}$ concentrations from commercial area sources in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

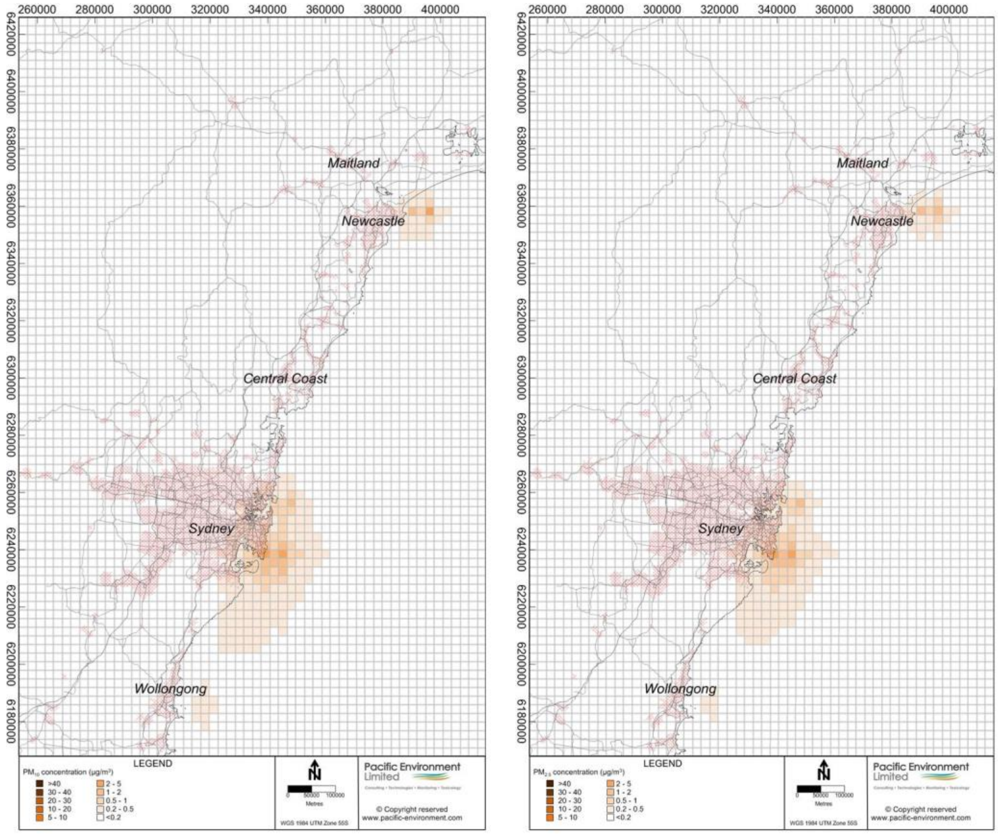

Figure A32: Gridded PM_{10} and $PM_{2.5}$ concentrations from shipping in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

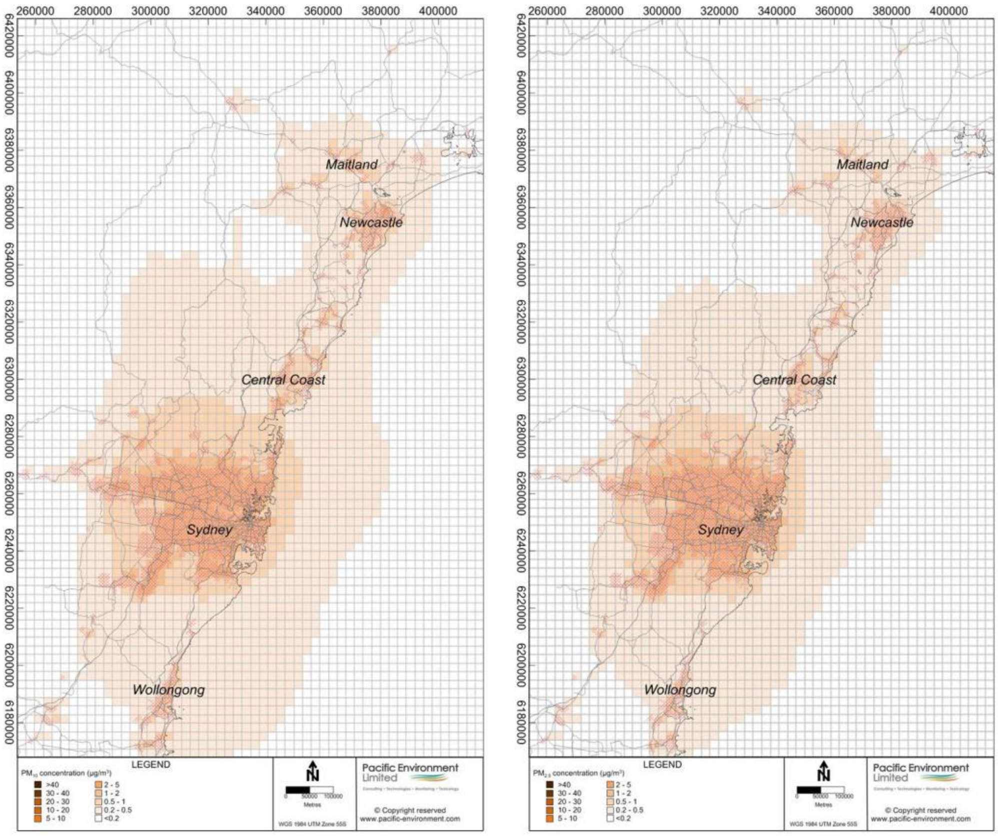

Figure A33: Gridded PM_{10} and $PM_{2.5}$ concentrations from wood heaters in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

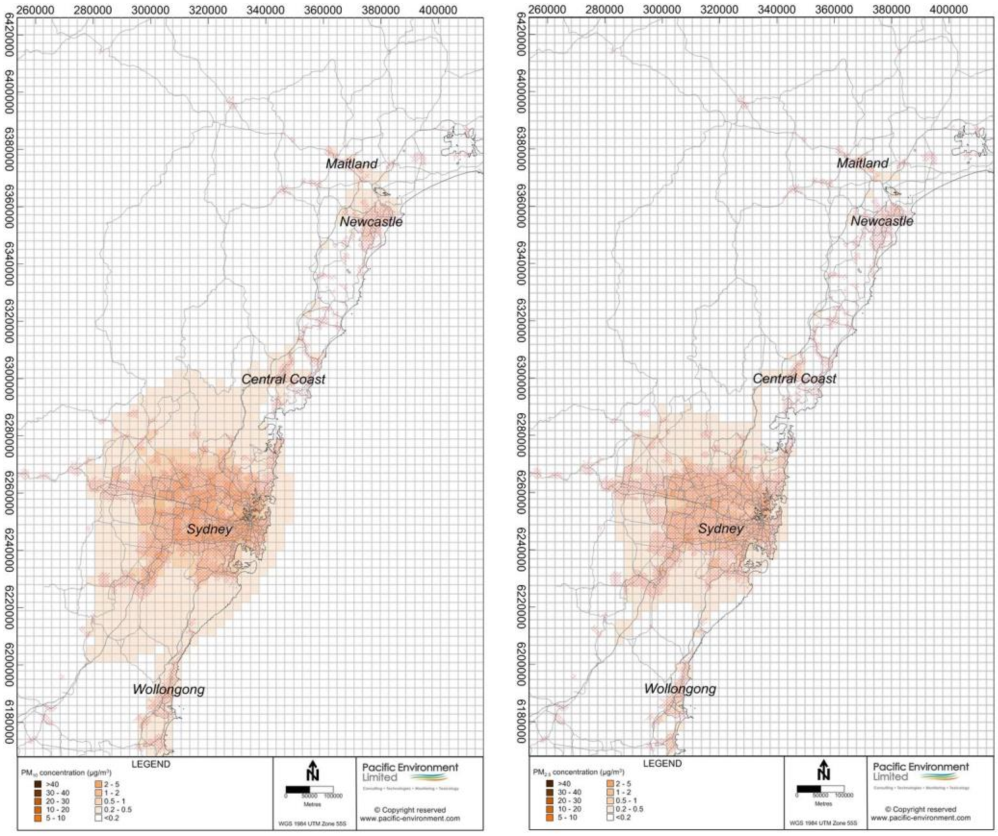

Figure A34: Gridded PM_{10} and $PM_{2.5}$ concentrations from road vehicles in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

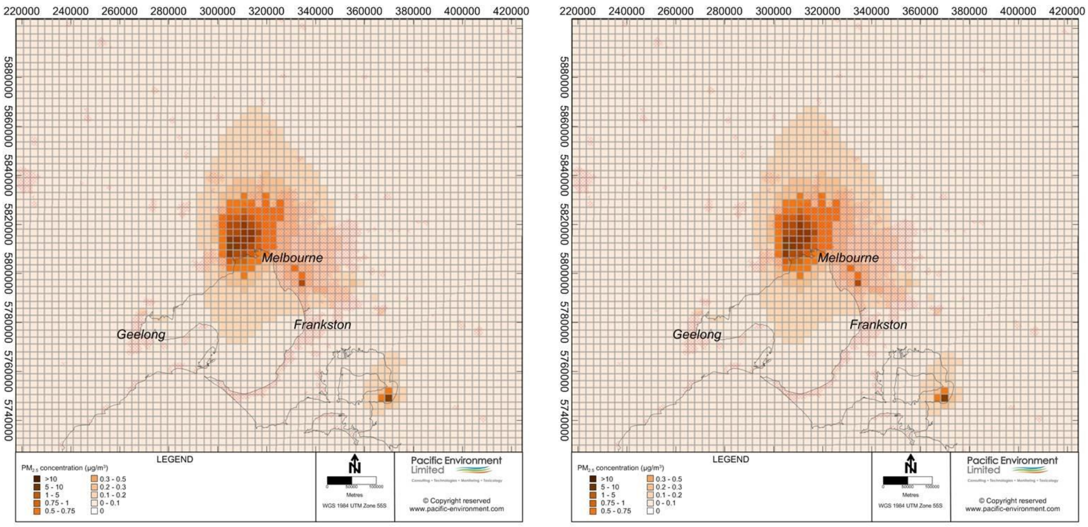

Figure A35: Gridded PM_{10} and $PM_{2.5}$ concentrations from industrial point sources in the modelled area of the Port Phillip region during 2006 (3 km x 3 km grid)

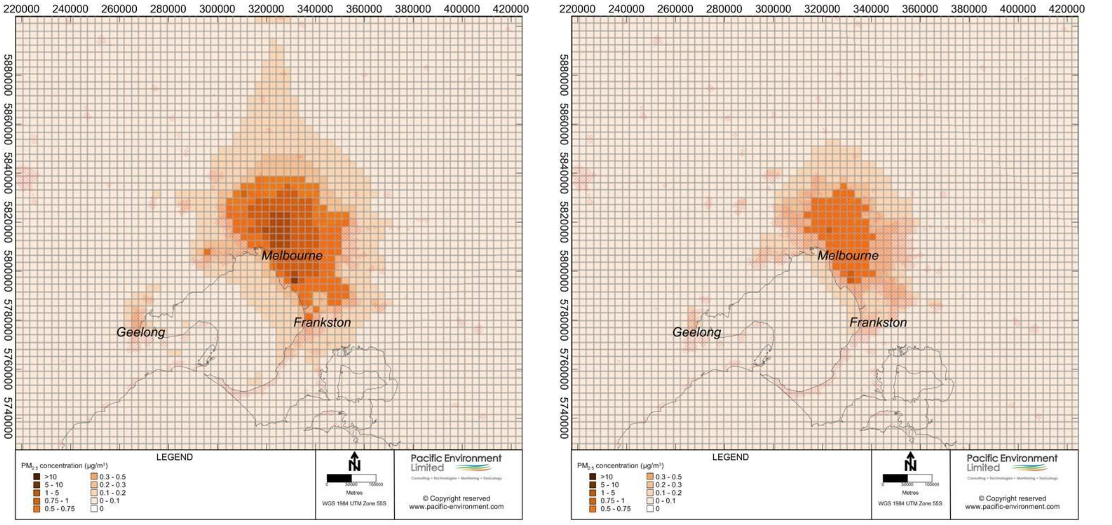

Figure A36: Gridded PM_{10} and $PM_{2.5}$ concentrations from area sources in the modelled area of the Port Phillip region during 2006 (3 km x 3 km grid)

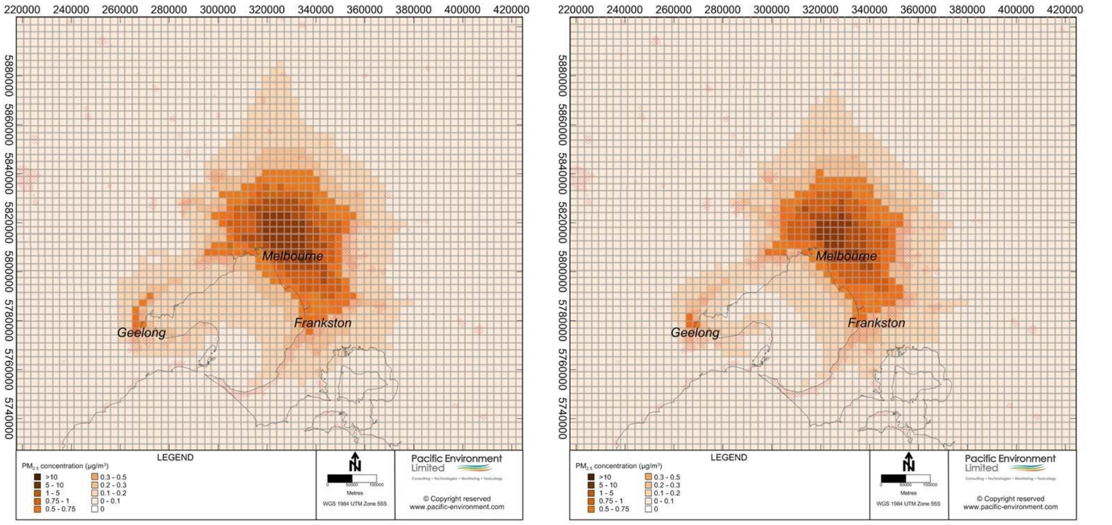

Figure A37: Gridded PM_{10} and $PM_{2.5}$ concentrations from diesel road vehicles in the modelled area of the Port Phillip region during 2006 (3 km x 3 km grid)

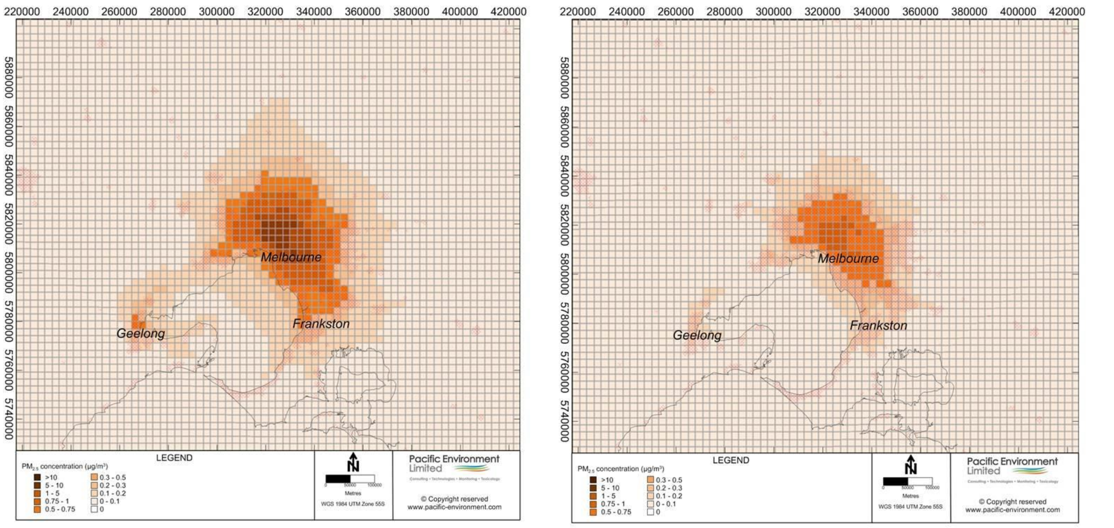

Figure A38: Gridded PM_{10} and $PM_{2.5}$ concentrations from petrol road vehicles in the modelled area of the Port Phillip region during 2006 (3 km x 3 km grid)

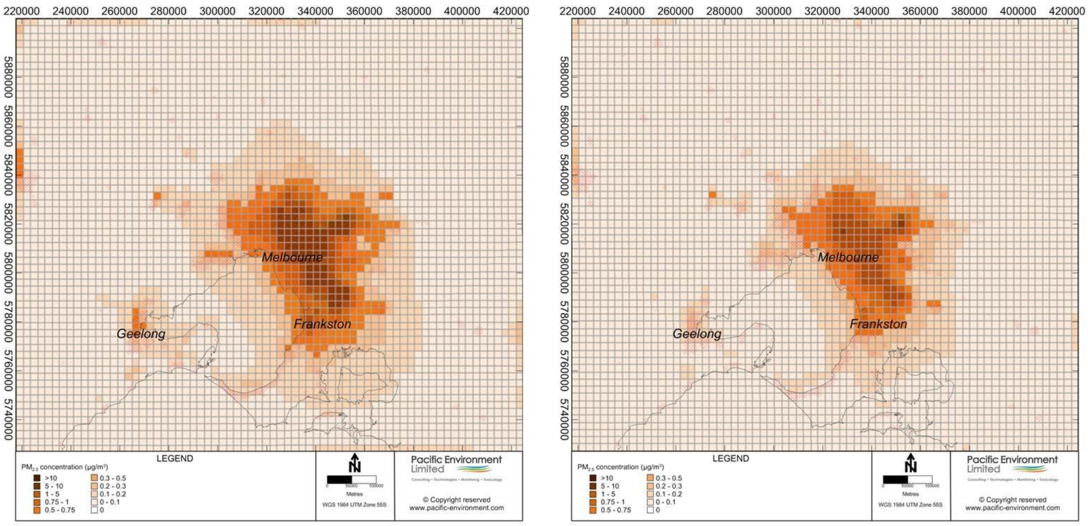

Figure A39: Gridded PM_{10} and $PM_{2.5}$ concentrations from wood heaters in the modelled area of the Port Phillip region during 2006 (3 km x 3 km grid)

A.1.5 Mapped natural and secondary PM_{10} and $PM_{2.5}$ concentrations

The annual mean natural and secondary PM_{10} and $PM_{2.5}$ components were mapped across the TAPM domains for NSW and Victoria in order to provide specific values for each grid cell. Gridding was performed using the kriging method, which produces an equally-spaced grid from irregularly spaced input data. For each grid cell the primary anthropogenic PM contributions for all sources were summated, and the natural and secondary PM components were added to the result (**Figure A40**). This gave the total annual mean concentration for comparison with air quality standards.

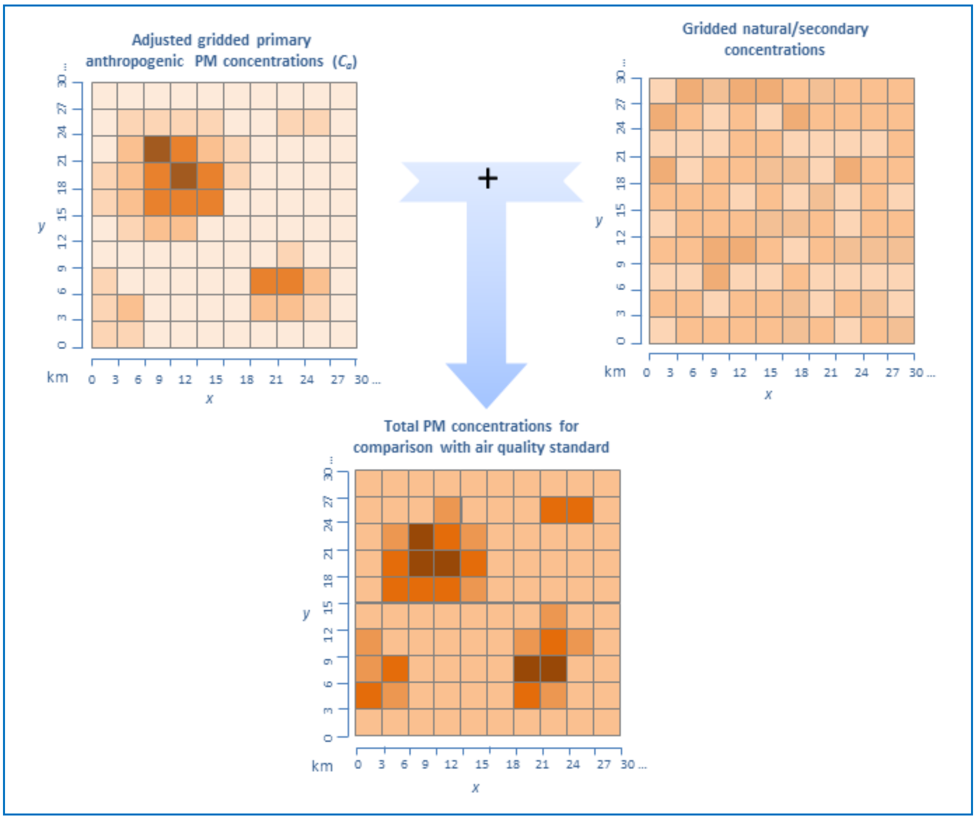

Figure A40: Determination of gridded total annual mean PM concentrations

An example of the result of this process for the annual mean PM_{10} concentration in NSW is shown in **Figure A41**. It can be seen that the highest PM_{10} concentrations were predicted in the Upper Hunter Valley region, primarily as a result of coal mining activities. The influence of emissions in the Hunter Valley was apparent across the GMR. PM_{10} concentrations were also elevated around the major population centres in the GMR.

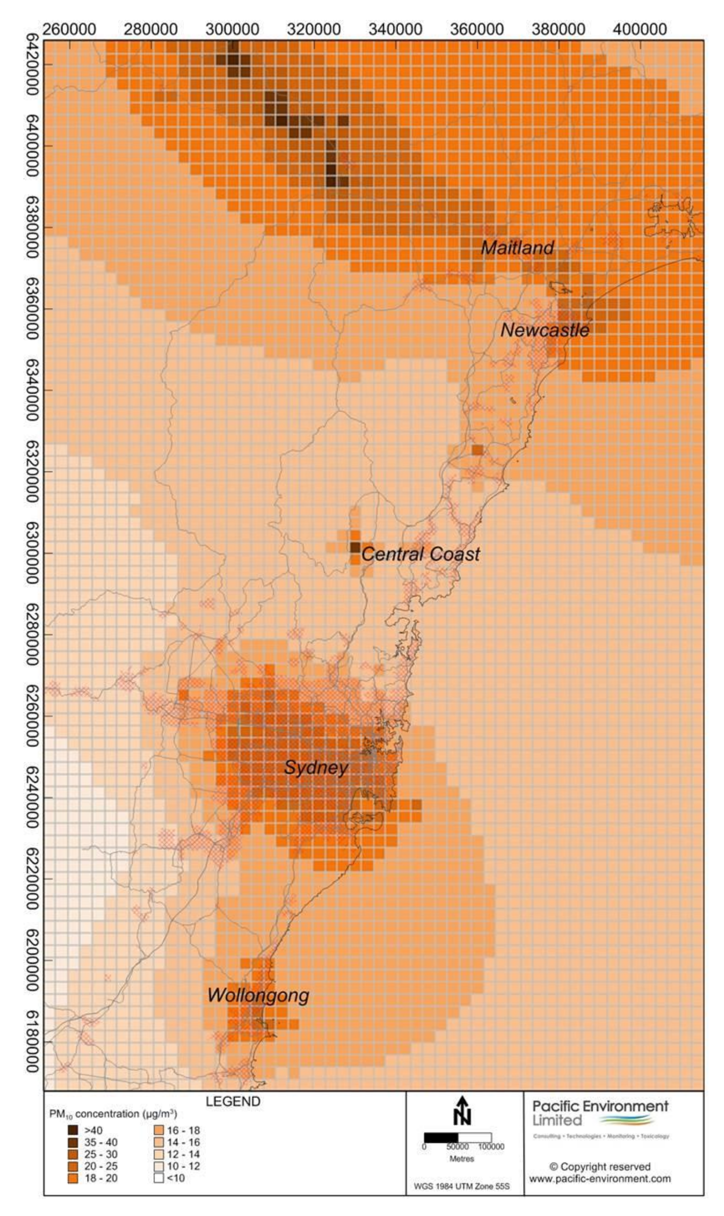

Figure A41: Gridded PM_{10} concentrations from all sources in the modelled area of the NSW GMR during 2011 (3 km x 3 km grid)

A.1.6 Relationships between emissions and concentrations for application

A.1.6.1 Investigation of a statistical approach

One of the original intentions of the project was to examine the emission and concentration data on a cell-by-cell basis, and to investigate the relationships between the two. A detailed statistical analysis was conducted using the data for Victoria, taking into account meteorological parameters as well as emissions from five different source groups. This effectively resulted in functions which related concentrations to emissions on a statistical basis. However, for Victoria the functions often resulted in counter-intuitive predictions. For example, a reduction in state-wide emissions from some sectors could lead to an increase in concentrations in a substantial proportion of grid cells. In addition, the air pollution modelling takes into account the transport of pollutants over distances that are larger than the dimensions of a grid cell. In other words, the concentration in any given grid cell is dependent not only on the emissions in that cell, but also the emissions in other cells (although this becomes less important as the size of the grid cell increases). This will also have contributed to the variability in the data in the statistical analysis. Moreover, the analysis was conducted using five source types, and the inclusion of many more source types (as in the case of NSW) would have rendered this approach extremely complex and impractical.

Because of these limitations we concluded that it would be hard to justify the application of such a method in the context of the economic analysis, and we therefore used an alternative approach (see **Section A.1.6.2**). However, further investigation of the statistical approach in the future could prove beneficial.

A.1.6.2 Scaling approach

For the economic analysis we adopted an approach in which the required level of abatement was determined by scaling the PM concentrations according to changes in emissions. In other words, if the total emissions from a source in a jurisdiction decreased by 50%, then the contribution of that source to the primary anthropogenic concentration in all relevant grid cells also decreased by 50%. However, the reliability of this approach depended on the extent to which the different sources could be represented spatially.

For each source group there is a spatial relationship between emissions and concentrations. Of course, this spatial relationship differs according to the source group (*e.g.* wood heaters, shipping), and therefore the contributions of the different source groups to the PM concentration will vary by location. In the case of NSW several different sources were modelled independently, and therefore these spatial relationships were maintained in the scaling approach. In Victoria the spatial relationships were maintained in some cases (*e.g.* wood heaters and road vehicles), but not in others. For example, a reduction in emissions from shipping was applied to all area sources. However, this was not considered to be a serious limitation, as wood heaters and road transport accounted for most of the emissions in Victoria (excluding industrial sources, for which abatement measures were not considered in the economic analysis anyway). In the other jurisdictions little spatial information on emissions was available, and therefore an overall scaling approach was applied.

One consequence of using gridded data for NSW and Victoria was that it was not possible to state any definitive overall emission reduction to enable compliance with a given air quality standard. This was because the required emission reduction depended upon the actual portfolio of abatement measures being implemented. For example, achieving compliance with an annual mean PM_{10} standard of 20 $\mu g/m^3$ in a particular grid cell could have required a reduction of *x* tonnes per year from road vehicles alone, but a reduction of *y* tonnes per year for wood heaters alone, depending on the extent to which the two sources affect the grid cell.

A.1.7 Population weighting

Gridded population data were supplied for the NSW GMR and for the Port Phillip region by NSW EPA and EPA Victoria respectively (some examples are provided in **Figures A42 and A43**). We determined overall average population-weighted concentrations for PM_{10} and $PM_{2.5}$ in each modelled area by weighting the modelled concentration in a given grid cell by the proportion of the population (in the modelled area) in that cell. This approach has been used in previous cost-benefit analyses in the UK and the US.

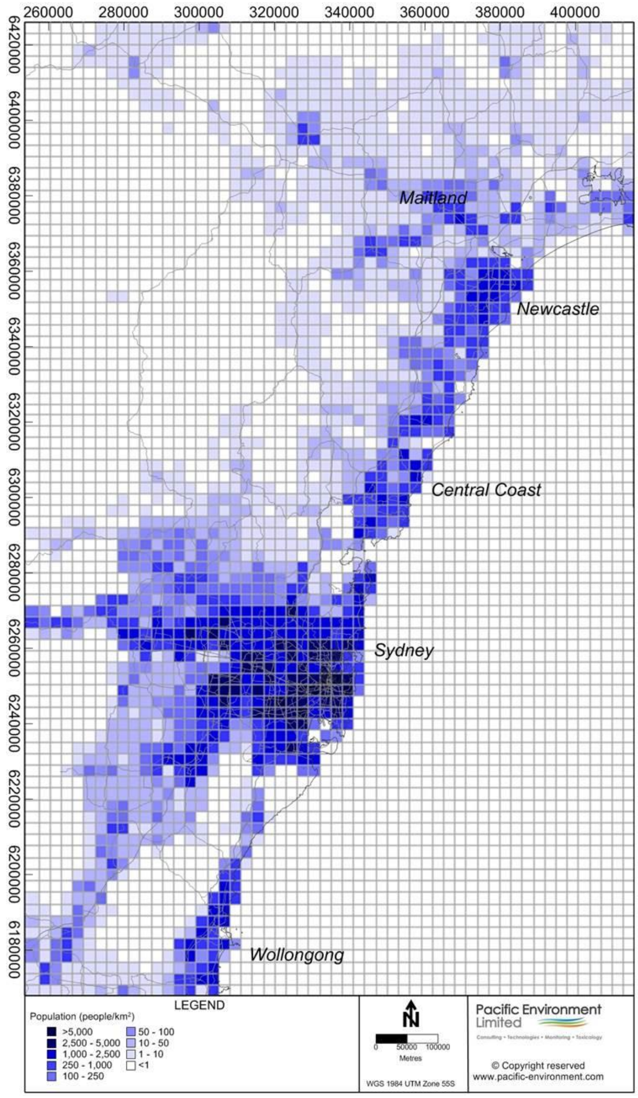

Figure A42: Population density in NSW GMR in 2011 (3 km x 3 km grid)

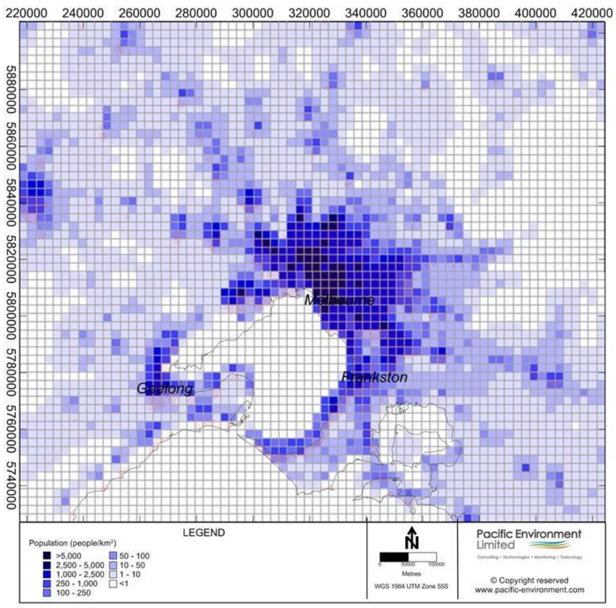

Figure A43: Population density in the Port Phillip region of Victoria in 2011 (3 km x 3 km grid)

This can be expressed mathematically as:

$$C_{PW,i} = \frac{\sum_{c=1}^{c=n}(c_{i,c} \times p_c)}{\sum_{c=1}^{c=n} p_c}$$

Where:

$C_{PW,i}$ = population-weighted concentration of pollutant ***i*** in modelled area (μg/m^3)

$c_{i,c}$ = concentration of pollutant ***i*** in grid cell ***c*** (μg/m^3)

p_c = population in grid cell ***c*** (people)

Little information on pollutant concentrations - and no detailed information on emissions - was available for the areas outside the NSW GMR and the Port Phillip region of Victoria. However, it was assumed that the areas modelled in TAPM contained a sufficient range of population densities, emission types and PM concentrations to enable us to conclude that compliance with air quality standards in the modelled areas would also ensure compliance in parts of NSW and Victoria that were outside these areas.

A.2 OTHER JURISDICTIONS

Because of the nature of the emission inventories and modelling efforts in the remaining jurisdictions - Queensland, South Australia, Western Australia, Tasmania, Northern Territory and ACT – our calculations were simpler than those for NSW and Victoria. The emission inventories for these jurisdictions were limited to the state capitals, were not suitable for air quality modelling[8], and in some cases were rather dated. The inventories for Tasmania, Northern Territory and ACT were especially limited. The emission sources in the different inventories were also named and characterised slightly differently, complicating the analysis. In some instances $PM_{2.5}$ was not reported. Where this was the case, $PM_{2.5}$:PM_{10} ratios for specific sources were taken from the NSW GMR Emissions-to-Area reports.

Consequently, for these other jurisdictions it had to be assumed that the state capitals would represent the most demanding conditions in terms of achieving compliance with air quality standards on a population-weighted basis. Whilst the emission reductions required for compliance with air quality standards at some specific locations outside the state capitals (*e.g.* in areas with mining) may have been relatively large, only a small proportion of the state population would have been affected. However, the available data (and resources) did not permit an assessment at this this level of detail.

A.2.1 Queensland (South-East Queensland)

A.2.1.1 Overview of inventory

The emissions inventory for the South-East Queensland (SEQ) region covered a land area of 23,316 km^2 which included the Sunshine Coast, Brisbane, Toowoomba and the Gold Coast (**Figure A44**). The latest publicly available inventory data for the region were published in 2004, and were based on activities that occurred in the calendar year 2000. The inventory methodology is described by **Queensland EPA (2004)**. The Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA) is currently updating the inventory **(DSITIA, 2012a),** but unfortunately the new data were not available in time for the economic analysis.

[8] Only total emission estimates (and not gridded data) were available.

Figure A44: South-East Queensland region (Queensland EPA, 2004)

The inventory included emissions data from the following:

- Biogenic sources (*e.g.* bushfires, trees and soil)
- Commercial businesses (*e.g.* quarries, service stations and smash repairers)
- Domestic activities (*e.g.* house painting, lawn mowing and wood heaters)
- Industrial premises (*e.g.* oil refineries, power stations and steelworks)
- Off-road mobile sources (*e.g.* aircraft, railways and recreational boats)
- On-road mobile sources

Notable emission sources that were not included in the 2000 inventory (in relation to PM) were marine aerosols and wheel-generated dust.

The inventory includes all criteria pollutants and grouped photochemical air pollutants, including PM_{10} and $PM_{2.5}$.

A.2.1.2 Emissions

In the original inventory, emission projections for some source groups were made for the years 2005 and 2011 based on population growth as well as anticipated changes in technology. In particular, the projections of emissions from motor vehicles were based on low and high population scenarios and the forecast implementation of motor vehicle emission controls **(Queensland EPA, 2004)**. The baseline inventory results and the projections to 2011 by main source group are shown in **Table A11**. Some assumptions were required to estimate values which were not provided by Queensland EPA (**Appendix C**).

Table A11: Anthropogenic emissions by source group and pollutant (SEQ)

Year	Source group	Emissions (tonnes/year)				
		PM_{10}	$PM_{2.5}$	NOx	SO_2	VOC
2000	Area sources	291	280	356	100	21,266
	Industrial and commercial	4,894	2,450	15,450	18,318	17,156
	Motor vehicles	2,249	2,173	60,579	1871	83,167
	Other mobile	831	803	9,104	4,147	5,550
	Total	**8,265**	**5,706**	**85,489**	**24,436**	**127,139**
2011	Area sources	439	423	563	136	31,940
	Industrial and commercial	8,463	3,999	24,416	28,555	26,733
	Motor vehicles	3,018[(a)]	2,136[(a)]	37,812	647	46,359
	Other mobile	1,121	1,085	12,559	5,442	9,388
	Total	**13,041**	**7,643**	**75,351**	**34,780**	**114,420**

(a) A non-exhaust PM component was added to the data, based on the non-exhaust: exhaust ratio from the NSW GMR inventory.

A.2.1.3 Population-weighted concentrations

The calculations of population-weighted PM_{10} and $PM_{2.5}$ concentrations in the SEQ region are shown in **Tables A12** and **A13** respectively.

Monitoring statistics for PM_{10} and $PM_{2.5}$ in the SEQ region were obtained from the following sources:

- The response to a questionnaire prepared for a previous NSW EPA project on the development of an exposure-reduction framework **(Bawden *et al.*, 2012; DSITIA, 2012a)**.
- The Queensland air monitoring report for 2011 **(DSITIA, 2012b)**.

In selecting suitable monitoring stations for the analysis we focussed as much as possible on generally representative upper bound (GRUB) stations or GRUB-type stations in predominantly residential areas. We considered that only monitoring stations within the boundary of the SEQ emissions inventory would be relevant.

The measurements were taken using a mixture of Tapered Element Oscillating Microbalance (TEOM) and TEOM-Filter Dynamic Measurement System (FDMS) instruments (the implications of this are briefly discussed in **Appendix B**). In the received PM_{10} data all non-FDMS TEOM measurements had already been temperature-corrected[9] for the loss of semi-volatile components, and therefore we made no further adjustments. Average values were determined over multiple years where the data allowed, although the time period covered in all cases was not consistent. Basic summary statistics were available for each year (*e.g.* annual mean, 98th percentile concentration), and under the circumstances these statistics were considered to be appropriate. The factors used to determine the primary anthropogenic and natural/secondary PM components were taken from the analysis of the NSW data (see **Appendix B**).

Population data for Local Government Areas (LGAs) in Queensland were obtained from the ABS web site[10].

[9] The PM_{10} data also included the standard manufacturer's adjustment (see **Appendix B**).

[10] http://www.abs.gov.au/ausstats/abs@.nsf/mf/3218.0/

Table A12: Calculation of population-weighted PM_{10} concentrations in SEQ region.

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	6th highest 24-hour average			Annual mean	6th highest 24-hour average
Mountain Creek	TEOM 1400	Residential	14.9[(a)]	28.4[(e)]	Sunshine Coast	316,858	16.0	29.9
Arundel	FDMS TEOM 1405	Residential	12.4[(b)]	30.2[(e)]	Gold Coast	513,954		
Flinders View	TEOM 1400	Industry/residential	14.9[(c)]	31.6[(e)]	Ipswich	172,147		
Brisbane CBD	TEOM 1400	CBD	16.8[(c)]	N/A	Brisbane	1,089,743		
Rocklea	FDMS TEOM 1405	Light industry /residential	17.3[(d)]	N/A	Brisbane	1,089,743		
			Factor to determine primary anthropogenic component (0.20)					
			Primary anthropogenic component				**3.2**	**6.0**
			Natural/secondary component				**12.8**	**23.9**

Notes:
(a) Average for 2002-2011
(b) Average for 2010-2011
(c) Average for 1998-2011
(d) Average for 1998-2010
(e) 2011 only

Table A13: Calculation of population-weighted $PM_{2.5}$ concentrations in SEQ region.

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	98th %ile 24-hour average			Annual mean	98th %ile 24-hour average
Arundel	FDMS TEOM 1405	Residential	5.1[(a)]	13.0[(b)]	Gold Coast	513,954	5.5	14.6
Rocklea	FDMS TEOM 1405	Light industry /residential	5.7[(c)]	15.3[(c)]	Brisbane	1,089,743		
			Factor to determine primary anthropogenic component (0.41)					
			Primary anthropogenic component				**2.2**	**6.0**
			Natural/secondary component				**3.2**	**8.6**

Notes:
(a) Average for 2010-2011
(b) 2011 only
(c) Average for 1998-2010

A.2.2 South Australia

A.2.2.1 Overview of inventory

The South Australian air emissions inventory was constructed in order to report emissions to the NPI, and was based on activity that occurred during the 1998/1999 period **(Ciuk, 2002)**. The area covered by the inventory is shown in **Figure A45**. It included the five major regional areas of South Australia. At the time, approximately 76% of the South Australia population resided in the study area. EPA South Australia also compiled a gridded air emissions inventory for the entire state covering motor vehicle emissions. The base year for the study was 2006. However, no gridded data were available for the economic analysis.

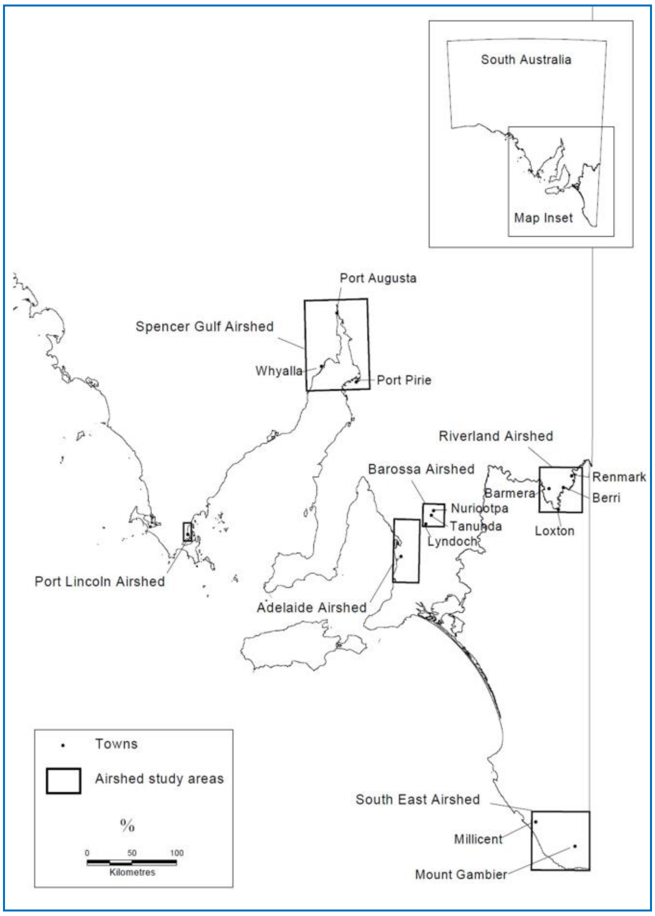

Figure A45: South Australia inventory area (Ciuk, 2002)

The inventory included emissions from the following anthropogenic sources:

- On-road mobile sources
- Off-road mobile sources (*e.g.* aircraft, railways and recreational boats)
- Area-based sources (service stations, paved roads, domestic fuel combustion)
- Sub-reporting threshold facilities (industrial and commercial facilities that do not report separately to the NPI)

The original South Australian emissions inventory was not suitable for regional air quality modelling. Several major sources (such as biogenic sources) were excluded, and the inventory was not designed with a high spatial resolution. However, the more recent motor vehicle inventory was designed to be model-ready **(Bawden *et al.*, 2012)**.

The original inventory covered a wide range of pollutants, including criteria pollutants, metal air toxics and organic air toxics. No emissions data were presented for $PM_{2.5}$. Additionally, no emission projections for 2011 or future years were provided.

A.2.2.2 Emissions

In the original inventory PM_{10} emissions were estimated for the base year 1998-1999, with no projections for other years. No data were reported for $PM_{2.5}$. Emissions in 2011 were therefore estimated based on the assumptions in **Appendix C**. The inventory results for the baseline year and projections to 2011 are shown in **Table A14**.

Table A14: Anthropogenic emissions by source group and pollutant in South Australia inventory

Year	Source group	Emissions (tonnes/year)				
		PM_{10}	$PM_{2.5}$	NOx	SO_2	VOC
1998/99	Commercial	200	-	2,600	200	2,960
	Domestic-commercial	1,570	-	503	66	16,176
	Industrial	2,907	-	7,714	2,059	2,930
	Mobile - road	6,170[(a)]	-	18,000	640	17,000
	Other mobile	210	-	1,182	386	161
	Other mobile	**11,057**	**-**	**29,999**	**3,352**	**39,227**
2011	Commercial	223	223	2,894	223	3,295
	Domestic-commercial	1,748	1,678	560	74	18,008
	Industrial	2,813	2,813	7,465	1,993	2,836
	Mobile - road	768[(b)]	546[(b)]	10,863	131	9,788
	Other mobile	209	206	1,566	385	183
	Other mobile	**5,761**	**5,466**	**23,348**	**2,806**	**34,110**

(a) Includes a paved road contribution which was removed for the analysis to ensure consistency between jurisdictions.

(b) A non-exhaust PM component was added to the data, based on the non-exhaust: exhaust ratio from the NSW GMR inventory.

A.2.2.3 Population-weighted concentrations

The calculations of population-weighted PM_{10} and $PM_{2.5}$ concentrations in the inventory are shown in **Tables A15** and **A16** respectively.

The monitoring stations that were selected were all GRUB sites in the airsheds covered by the emissions inventory. Monitoring statistics for PM_{10} and $PM_{2.5}$ during 2011 were obtained from the Air Monitoring Report for South Australia **(EPA South Australia, 2010)**. As the PM_{10} and $PM_{2.5}$ data from the TEOMs were unadjusted for temperature[11] a simple correction was used to account for the loss of semi-volatile components based on the NSW analysis. The factors used to determine the primary anthropogenic and natural/secondary PM components were also taken from the analysis of the NSW data (see **Appendix B**).

Population data for LGAs in the airshed were obtained from the ABS web site, as before.

[11] The PM_{10} data included the standard manufacturer's adjustment (see **Appendix B**).

Table A15: Calculation of population-weighted PM_{10} concentrations in the South Australia inventory area

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)(a)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	6th highest 24-hour average			Annual mean	6th highest 24-hour average
Adelaide Elizabeth Downs	TEOM	Residential area	15.5	32.1	Adelaide	1,140,725	16.0	31.9
Adelaide Netley	TEOM	Residential/light industrial area, heavy traffic	15.1	34.8	Adelaide	1,140,725		
Adelaide Kensington Gardens	TEOM	Residential area	16.3	24.8	Adelaide	1,140,725		
Adelaide Christie Downs	TEOM	Residential area	17.0	35.6	Adelaide	1,140,725		
Port Pirie, Oliver Street	TEOM	Residential/industrial	17.7	38.8	Port Pirie	17,593		
Whyalla, Schulz Park	TEOM	Residential/industrial	16.6	37.1	Whyalla	22580		
Notes: (a) Measured value upscaled (using a factor of 1.16) to account for loss of semi-volatile components.			*Factor to determine primary anthropogenic component (0.2)*					
			Primary anthropogenic component				**3.2**	**6.4**
			Natural/secondary component				**12.8**	**25.5**

Table A16: Calculation of population-weighted $PM_{2.5}$ concentrations in the South Australia inventory area

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)(a)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	98th %ile 24-hour average			Annual mean	98th %ile 24-hour average
Adelaide Netley	TEOM	Residential/light industrial area, heavy traffic	8.1	17.3	Adelaide	1,140,725	8.1	17.3
Notes: (a) Measured value upscaled (using a factor of 1.14) to account for loss of semi-volatile components.			*Factor to determine primary anthropogenic component (0.41)*					
			Primary anthropogenic component				**3.3**	**7.1**
			Natural/secondary component				**4.8**	**10.2**

A.2.3 Western Australia (Perth)

A.2.3.1 Overview of inventory

The first Perth airshed emissions inventory was compiled for the year 1992, with a later update based on the 1998/1999 period **(WA DEP, 2002)**. A diffuse emissions study for the airshed was subsequently undertaken for the 2004/2005 period **(SKM, 2006)**. The study area covered 8,600 km^2, and included the major population centres and emission sources in Western Australia (**Figure A46**). At the time of the original inventory approximately 70% of the Western Australia population resided in the Perth airshed.

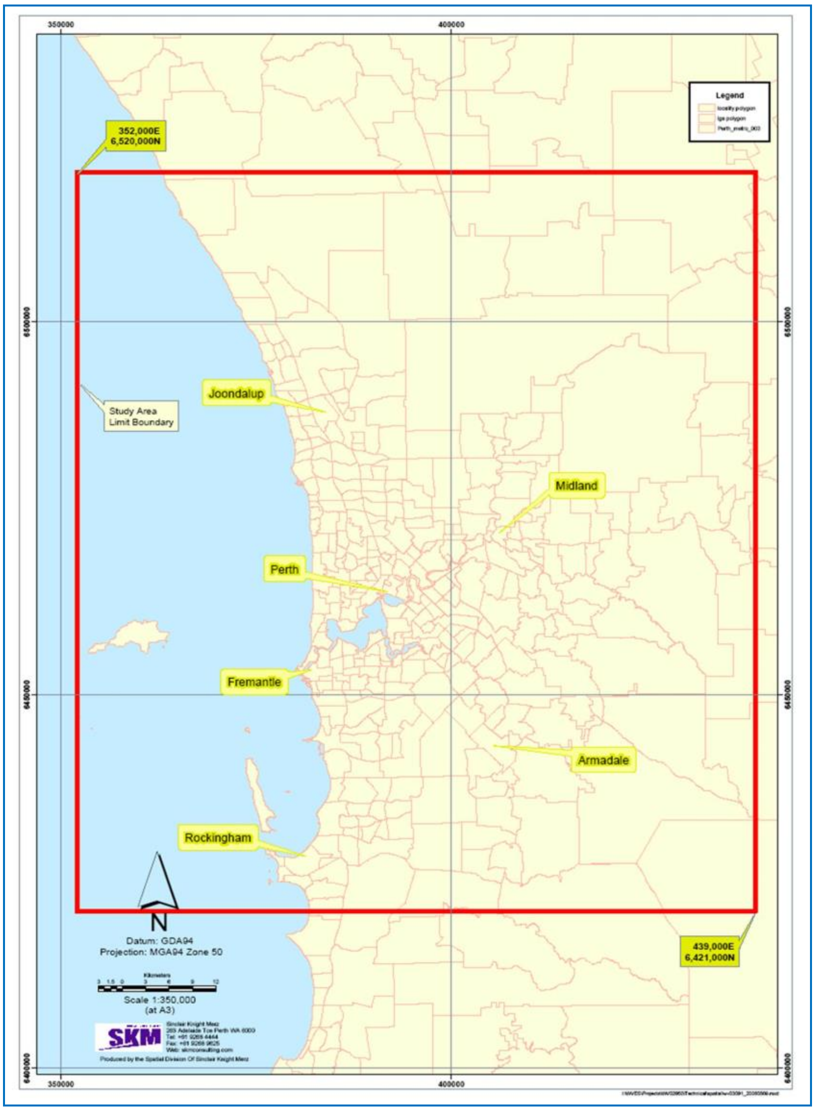

Figure A46: Perth airshed inventory area (SKM, 2006)

The Perth inventory included emissions data for the following:

- Biogenic sources (*e.g.* bushfires, trees)
- Commercial businesses (*e.g.* dry cleaning and smash repairers)
- Domestic activities (*e.g.* lawnmowers, aerosols and solvents and wood heaters)
- Off-road mobile sources (*e.g.* aircraft, railways and recreational boats)
- On-road mobile sources

Industrial emissions were reported to the NPI by individual industrial facilities.

The inventory included data for various pollutants, including criteria pollutants, metal air toxics and organic air toxics.

A.2.3.2 Emissions

The emission results for the inventory year and the projections to the baseline year of 2011 for the economic analysis are shown in **Table A17**. Emissions in 2011 were estimated based on the assumptions in **Appendix C**.

Table A17: Anthropogenic emissions by source group and pollutant – Perth inventory

Year	Source group	Emissions (tonnes/year)				
		PM_{10}	$PM_{2.5}$	NOx	SO_2	VOC
2004/05	Industrial-Commercial[a]	2,380	-	17,200	9,128	7,146
	Domestic-commercial	1,488	-	587	30	20,756
	Mobile - road	16,335[b]	-	16,302	191	13,404
	Off-road mobile	629	-	5,470	1,026	1,234
	Total	**20,832**	**-**	**39,559**	**10,375**	**42,540**
2011	Industrial-Commercial	2,380	2,380	17,200	9,128	7,146
	Domestic-commercial	1,786	1,715	705	36	24,912
	Mobile - road	514[c]	365[c]	9,838	39	7,718
	Off-road mobile	657	575	6,459	1,042	1,273
	Total	**5,337**	**5,036**	**34,201**	**10,245**	**41,048**

(a) Industrial-commercial data were provided for 2011.

(b) Original inventory included a paved road contribution which was removed for the analysis to ensure consistency between jurisdictions.

(c) A non-exhaust PM component was added to the data, based on the non-exhaust: exhaust ratio from the NSW GMR inventory.

A.2.3.3 Population-weighted concentrations

The calculations of population-weighted PM_{10} and $PM_{2.5}$ concentrations in the Perth inventory area are shown in **Tables A18** and **A19** respectively.

The monitoring stations used in the analysis were GRUB or GRUB-type sites in the inventory area. Monitoring statistics for PM_{10} and $PM_{2.5}$ in the Perth airshed were obtained from the Air Monitoring Report for Western Australia **(WA DEC, 2012)**, and from the response to the questionnaire for the NSW EPA exposure-reduction project. The TEOM data had not been temperature-corrected for the loss of semi-volatile components[12], and therefore adjustments based on the NSW data were applied. The factors used to determine the primary anthropogenic and natural/secondary PM components were also taken from the analysis of the NSW data (see **Appendix B**).

Again, population data for LGAs in the airshed were obtained from the ABS web site.

[12] Both the PM_{10} and $PM_{2.5}$ data included the standard manufacturer's correction (see **Appendix B**). For consistency with the other jurisdictions the manufacturer's correction for $PM_{2.5}$ was removed prior to the application of our own adjustment, whereas that for PM_{10} was retained.

Table A18: Calculation of population-weighted PM_{10} concentrations in Perth inventory area

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)[(a)]		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	6th highest 24-hour average			Annual mean	6th highest 24-hour average
Perth Caversham	TEOM	Metropolitan area	18.9[(b)]	35.5[(b)]	Greater Perth	1,832,114	18.7	35.7
Perth Duncraig	TEOM	Metropolitan area	18.0[(b)]	34.3[(b)]	Greater Perth	1,832,114		
Perth South Lake	TEOM	Metropolitan area	19.0[(b)]	37.4[(b)]	Greater Perth	1,832,114		
			Factor to determine primary anthropogenic component (0.2)					
			Primary anthropogenic component				**3.7**	**7.1**
			Natural/secondary component				**14.9**	**28.6**

Notes:
(a) Measured value upscaled (using a factor of 1.16) to account for loss of semi-volatile components.
(b) 2011 only

Table A19: Calculation of population-weighted $PM_{2.5}$ concentrations in Perth inventory area

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)[(a)]		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	98th %ile 24-hour average			Annual mean	98th %ile 24-hour average
Perth Caversham	TEOM	Metropolitan area	5.1[(b)]	9.6[(d)]	Greater Perth	1,832,114	5.5	11.9
Perth Duncraig	TEOM	Metropolitan area	6.2[(b)]	11.3[(d)]	Greater Perth	1,832,114		
Perth Quinns Rock	TEOM	Metropolitan area	5.0[(c)]	13.1[(d)]	Greater Perth	1,832,114		
Perth South Lake	TEOM	Metropolitan area	5.6[(c)]	13.7[(d)]	Greater Perth	1,832,114		
			Factor to determine primary anthropogenic component (0.41)					
			Primary anthropogenic component				**2.3**	**4.9**
			Natural/secondary component				**3.2**	**7.0**

Notes:
(a) Measured value adjusted to remove manufacturer's TEOM correction and then upscaled (using a factor of 1.14) to account for loss of semi-volatile components.
(b) Average for 1997-2010
(c) Average for 2006-2010
(d) 2011 only

A.2.4 Tasmania (Hobart)

A.2.4.1 Overview of inventory

Bawden *et al.* (2012) noted than no regional emissions inventory has been developed for Tasmania. Emissions were therefore taken from the NPI for 1999 (2010/11 in the case of industrial sources). The values were estimated by the Department of Primary Industry, Water and the Environment, Tasmania.

A.2.4.2 Emissions

The emissions data for 1999, and the projected values for the 2011 baseline for the economic analysis, are given in **Table A20**. Emissions in 2011 were estimated based on the assumptions given in **Appendix C**. Wood heaters are by far the largest contributor to emissions in the Hobart airshed. Correspondence from EPA Tasmania indicated that the emission estimate for 2011 used in the economic analysis was close to the value determined in a more recent survey **(Chelkowska, 2013)**.

Table A20: Anthropogenic emissions by source group and pollutant – Hobart airshed

Year	Source group	Emissions (tonnes/year)				
		PM_{10}	$PM_{2.5}$	NOx	SO_2	VOC
1999	Commercial	85	-	130	340	301
	Domestic-commercial	2,185	-	289	374	7,302
	Industrial[a]	131	-	796	1,668	28
	Mobile - road	1,180[a]	-	4,900	93	-
	Off-road mobile	20	-	1,050	10	419
	Total	**3,600**	**-**	**7,165**	**2,485**	**8,051**
2011	Commercial	93	93	143	373	331
	Domestic-commercial	2,398	2,304	317	410	8,015
	Industrial	105	105	639	1339	22
	Mobile - road	243[b]	172[b]	2,957	19	0
	Off-road mobile	20	19	1,348	12	429
	Total	**2,859**	**2,693**	**5,404**	**2,153**	**8,797**

(a) Includes a paved road contribution which was removed for the analysis to ensure consistency between jurisdictions.

(b) A non-exhaust PM component was added to the data, based on the non-exhaust: exhaust ratio from the NSW GMR inventory.

A.2.4.3 Population-weighted concentrations

The calculations of population-weighted PM_{10} and $PM_{2.5}$ concentrations in the Hobart airshed are shown in **Tables A21** and **A22** respectively. Monitoring data were taken from the GRUB monitoring site at Hobart New Town. In order to avoid using data from a single site, measurements were also obtained for the GRUB site at Launceston Ti Tree Bend, even though this was located outside the area covered by the emissions inventory. This was not considered to be a problem, given that the concentrations at the two sites were similar. The PM_{10} and $PM_{2.5}$ concentrations were taken from the most recent NEPM compliance report (for the year 2009) and the response to the NSW EPA exposure-reduction project questionnaire. All TEOM data had already been temperature-corrected[13], and therefore no further adjustments for the loss of semi-volatile components were made. The factors used to determine the primary anthropogenic and natural/secondary PM components were taken from the analysis of the NSW data (see **Appendix B**). It is worth noting that the primary anthropogenic contribution to the PM_{10} concentration is slightly lower than the primary anthropogenic contribution to the $PM_{2.5}$ concentration, which cannot be the case in reality. However, this was a consequence of the broad assumptions that were required in the assessment. Population data for Local Government Areas in the airshed were obtained from ABS.

[13] The PM_{10} data included the standard manufacturer's adjustment (see **Appendix B**).

Table A21: Calculation of population-weighted PM_{10} concentrations in Hobart and Launceston

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	6th highest 24-hour average[a]			Annual mean	6th highest 24-hour average
Launceston – Ti Tree Bend	TEOM	Light industry	12.7[b]	44.9[c]	Launceston	134,810	12.7	41.6
Hobart – New Town	TEOM	Residential	12.7[b]	35.7[c]	Hobart	76,018		
			Factor to determine primary anthropogenic component (0.2)					
			Primary anthropogenic component				**2.5**	**8.3**
			Natural/secondary component				**10.2**	**33.3**

Notes:
(a) 98th percentile.
(b) Average for 2009-2011
(c) Average for 2006-2009

Table A22: Calculation of population-weighted $PM_{2.5}$ concentrations in Hobart and Launceston

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	98th %ile 24-hour average			Annual mean	98th %ile 24-hour average
Launceston – Ti Tree Bend	Low-vol. samplers	Light industry	8.7[a]	33.2[b]	Launceston	134,810	8.1	30.3
Hobart – New Town	Low-vol. samplers	Residential	7.1[a]	25.2[b]	Hobart	76,018		
			Factor to determine primary anthropogenic component (0.41)					
			Primary anthropogenic component				**3.3**	**12.4**
			Natural/secondary component				**4.8**	**17.9**

Notes:
(a) Average for 2006-2011
(b) Average for 2006-2009

A.2.5 Northern Territory (Darwin)

A.2.5.1 Overview of inventory

Bawden *et al.* (2012) noted than no regional emissions inventory has been developed for the Northern Territory. The emission estimates were therefore taken from the NPI for 1999 (2010/11 in the case of industrial sources). These were estimated by the Northern Territory Department of Lands, Planning and Environment.

A.2.5.2 Emissions

The emissions data for 1999, and the projected values for 2011, are given in **Table A23**. Emissions in 2011 were estimated based on the assumptions in **Appendix C.**

Table A23: Anthropogenic emissions by source group and pollutant – Darwin airshed

Year	Source group	Emissions (tonnes/year)				
		PM_{10}	$PM_{2.5}$	NOx	SO_2	VOC
2000	Commercial	7	-	60	0	386
	Domestic-commercial	6	-	7	1	1,066
	Industrial	4	-	19	5	11
	Mobile - road	69	-	5,558	122	1,059
	Off-road mobile	55	-	650	228	288
	Total	**141**	**-**	**6,294**	**355**	**2811**
2011	Commercial	9	9	74	6	475
	Domestic-commercial	8	7	8	1	1,309
	Industrial	11	11	51	15	30
	Mobile - road	93[a]	66[a]	3,354	25	610
	Off-road mobile	54	52	832	212	304
	Total	**174**	**144**	**4,320**	**258**	**2,728**

(a) A non-exhaust PM component was added to the data, based on the non-exhaust: exhaust ratio from the NSW GMR inventory.

A.2.5.3 Population-weighted concentrations

The calculations of population-weighted PM_{10} and $PM_{2.5}$ concentrations in the Darwin airshed are shown in **Tables A24** and **A25** respectively.

PM_{10} and $PM_{2.5}$ concentrations in Darwin during 2011 were provided by the Northern Territory Environment Protection Authority. For the Casurina site a combination of TEOM and Partisol data were provided. No subsequent adjustments were therefore made to the data. The TEOM data supplied for the Palmerston site had not been temperature-corrected[14], and therefore an adjustment was applied. The factors used to determine the primary anthropogenic and natural/secondary PM components were taken from the analysis of the NSW data (see **Appendix B**). Again, the primary anthropogenic contribution to the PM_{10} concentration is very slightly lower than the primary anthropogenic contribution to the $PM_{2.5}$ concentration. Population data were obtained from ABS, as before.

[14] The PM_{10} data included the standard manufacturer's adjustment (see **Appendix B**).

Table A24: Calculation of population-weighted PM_{10} concentrations in Darwin and Palmerston

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m3)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	6th highest 24-hour average			Annual mean	6th highest 24-hour average
Darwin – Casurina	TEOM/Partisol	Light industry/residential	14.7[(a)]	34.1[(b)]	Darwin	77,259	17.0	39.6
Palmerston	TEOM		23.0[(b)(c)]	53.7[(b)(c)]	Palmerston	30,151		
Notes: (a) Average for 2004-2011; (b) 2011 only; (c) Measured value upscaled (using a factor of 1.16) to account for loss of semi-volatile components.			*Factor to determine primary anthropogenic component (0.2)*					
			Primary anthropogenic component				**3.4**	**7.9**
			Natural/secondary component				**13.6**	**31.7**

Table A25: Calculation of population-weighted $PM_{2.5}$ concentrations in Darwin and Palmerston

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	98th %ile 24-hour average			Annual mean	98th %ile 24-hour average
Darwin – Casurina	TEOM/Partisol	Light industry/residential	7.5[(a)]	24.7[(b)(c)]	Darwin	77,259	8.6	24.7
Palmerston	TEOM		11.4[(b)(c)]	N/A	Palmerston	30,151		
Notes: (a) Average for 2004-2011; (b) 2011 only; (c) Measured value upscaled (using a factor of 1.14) to account for loss of semi-volatile components.			*Factor to determine primary anthropogenic component (0.41)*					
			Primary anthropogenic component				**3.5**	**7.3**
			Natural/secondary component				**5.1**	**10.5**

A.2.6 ACT

A.2.6.1 Overview of inventory

For the ACT no regional air emission inventory data were available in the public domain beyond those estimates contained in the NPI database **(Bawden *et al.*, 2012)**. The emission estimates for 1999 (2010/11 in the case of industrial sources) were therefore taken from the NPI. These were based on data originally supplied by Environment ACT - Department of Urban Services, Canberra.

A.2.6.2 Emissions

The emissions data for 1999, and the projected values for 2011, are given in **Table A26**. Emissions in 2011 were estimated based on the assumptions in **Appendix C.**

Table A26: Anthropogenic emissions by source group and pollutant – Canberra

Year	Source group	Emissions (tonnes/year)				
		PM_{10}	$PM_{2.5}$	NOx	SO_2	VOC
1999	Commercial	8	-	92	0	894
	Domestic-commercial	733	-	247	205	5805
	Industrial	133	-	103	4	19
	Mobile - road	92	-	7400	100	6000
	Off-road mobile	-	-	120	12	14
	Total	**967**	**-**	**7,962**	**321**	**12,732**
2011	Commercial	10	10	108	26	1,052
	Domestic-commercial	863	863	291	242	6,836
	Industrial	133	133	103	217	12,041
	Mobile - road	124 [(a)]	88 [(a)]	4,466	20	3,455
	Off-road mobile	-	-	151	17	15
	Total	**1,130**	**1,094**	**5,119**	**523**	**23,398**

(a) A non-exhaust PM component was added to the data, based on the non-exhaust: exhaust ratio from the NSW GMR inventory.

A.2.6.3 Population-weighted concentrations

The calculations of population-weighted PM_{10} and $PM_{2.5}$ concentrations in the Canberra airshed are shown in **Tables A27** and **A28** respectively.

PM_{10} and $PM_{2.5}$ concentrations at the Canberra Monash and Civic GRUB sites during 2011 were provided by the ACT Government. PM_{10} and $PM_{2.5}$ were measured using the Beta Attenuation Monitor (BAM) and gravimetric reference methods respectively, and therefore no subsequent adjustments to the data were required. The factors used to determine the primary anthropogenic and natural/secondary PM components were taken from the analysis of the NSW data (see **Appendix B**).

Population data were obtained from the ABS web site.

Table A27: Calculation of population-weighted PM_{10} concentrations in Canberra

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	6th highest 24-hour average			Annual mean	6th highest 24-hour average
Canberra – Monash	BAM	Residential	10.4	31.9	Canberra	367,752	10.4	31.9
Canberra – Civic	BAM	CBD	8.7	21.5	Canberra	367,752		
			Factor to determine primary anthropogenic component (0.2)					
			Primary anthropogenic component				**2.1**	**6.4**
			Natural/secondary component				**8.3**	**25.5**

Table A28: Calculation of population-weighted $PM_{2.5}$ concentrations in Canberra airshed

Monitoring site	Monitoring method	Location type	Measured concentration (µg/m³)		LGA	Population	Population-weighted concentration (µg/m³)	
			Annual mean	98th %ile 24-hour average			Annual mean	98th %ile 24-hour average
Canberra - Monash	Ref. method	Residential	6.5	26.4[(a)]	Canberra	367,752	6.5	26.4
Notes: (a) Average for 2004-2011			*Factor to determine primary anthropogenic component (0.41)*					
			Primary anthropogenic component				**2.7**	**10.8**
			Natural/secondary component				**3.8**	**15.6**

A.3 SUMMARY OF ADJUSTMENTS TO CONCENTRATIONS

As explained in **Appendix B**, there are two ways in which the TEOM data can be adjusted: (i) a manufacturer's correction and (ii) a temperature adjustment. **Tables A29** and **A30** summarise the adjustments and upscaling factors that were applied to the TEOM data for PM_{10} and $PM_{2.5}$, and the annual mean concentrations before and after upscaling. For $PM_{2.5}$ in Western Australia the manufacturer's correction was removed prior to the application of the upscaling factor.

Table A29: Summary of TEOM adjustments – annual mean PM_{10} in 2011

Jurisdiction	Adjustments applied in received data		Upscaling factor of 1.16 applied in economic analysis	Population-weighted concentration	
	Manufacturer's correction ($1.03_x + 3$)	Temperature		Without upscaling factor (µg/m³)	With upscaling factor (µg/m³)
NSW	Yes	No	Yes	16.3	18.9
VIC	Yes	Yes	No	18.3	
QLD	Yes	Yes	No	16.0	
SA	Yes	No	Yes	13.8	16.0
WA	Yes	No	Yes	16.1	18.7
TAS	Yes	Yes	No	12.7	
NT	Yes	No	Yes[b]	16.1	17.0
ACT	N/A[a] (BAM data used)			10.4	

(a) N/A = not applicable
(b) Palmerston site only

Table A30: Summary of TEOM adjustments – annual mean $PM_{2.5}$ in 2011

Jurisdiction	Adjustments applied in received data		Upscaling factor of 1.14 applied in economic analysis	Population-weighted concentration	
	Manufacturer's correction ($1.03_x + 3$)	Temperature		Without upscaling factor (µg/m³)	With upscaling factor (µg/m³)
NSW	No	N/A[a]	Yes	6.1	6.9
VIC	No	N/A	Yes	5.4	6.2
QLD	N/A (FDMS-TEOM used)			5.5	
SA	No	N/A	Yes	7.1	8.1
WA	Yes	N/A	Yes	4.8[c]	5.5
TAS	N/A (Gravimetric method)			8.1	
NT	No	N/A	Yes[b]	8.2	8.6
ACT	N/A (Reference method used)			6.5	

(a) N/A = not applicable
(b) Palmerston site only
(c) Includes removal of manufacturer's adjustment

A.4 DISAGGREGATION OF EMISSION REDUCTIONS

In our economic analysis the emission reductions associated with abatement measures were quantified at the national level (see **Chapter 4** and **Appendix D**). In general the emission inventories and modelled areas were considerably smaller than the state areas. It was therefore necessary to (i) allocate the national emission reduction for each sector to the different jurisdictions, and (ii) determine, for each jurisdiction, the proportion of state-wide emissions in the inventory area. This firstly enabled the emission reductions to be correctly allocated to the inventory areas, and secondly allowed impacts in non-inventory areas to be taken into account (notably the determination of health benefits).

The level of coverage of each emissions inventory area (and in the case of NSW and Victoria the area modelled in TAPM) relative to the state as a whole in terms of different metrics and for the year 2011 is summarised in **Table A31**. No reliable data on emissions at the state level were available.

Table A31: Summary of data coverage

		Full jurisdiction - 2011 data							
		NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Area (km^2)[(a)]		801,315	227,416	1,734,175	985,338	2,531,564	67,914	1,352,176	2,351
Population (2011)[(b)]		7,211,468	5,534,526	4,474,098	1,638,232	2,352,215	511,195	231,331	367,752
Emissions (tonnes/year)	PM_{10}	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	$PM_{2.5}$	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		Inventory area - 2011 data							
		GMR	Port Phillip	SEQ	Greater Adelaide	Greater Perth	Greater Hobart	Greater Darwin	Canberra
Area (km^2)		57,330	N/A	22,420	2,024	8,613	2,500	7,650	1,288
Population (2011)[(c)]		5,432,935	N/A	3,050,000	1,198,467	1,600,000	216,276	129,062	367,752
Emissions (tonnes/year)	PM_{10}	93,400	N/A	13,041	5,761	5,968	2,859	174	1,130
	$PM_{2.5}$	31,897	N/A	7,643	5,466	5,667	2,693	144	1,094
		TAPM area - 2011 data							
		GMR	Port Phillip	SEQ	Greater Adelaide	Greater Perth	Greater Hobart	Greater Darwin	Canberra
Area (km^2)[(d)]		42,496	37,800	N/A	N/A	N/A	N/A	N/A	N/A
Population (2011)[(e)]		5,343,082	4,497,749	N/A	N/A	N/A	N/A	N/A	N/A
Emissions (tonnes/year)	PM_{10}	87,694	20,208	N/A	N/A	N/A	N/A	N/A	N/A
	$PM_{2.5}$	30,514	12,614	N/A	N/A	N/A	N/A	N/A	N/A

(a) Based on ABS regional profiles.
(b) Based on ABS regional population growth.
(c) From inventory reports or estimated from ABS population statistics.
(d) Calculated from size of model domain.
(e) Based on gridded population data supplied by NSW EPA and EPA Victoria.
N/A = not available

In NSW and Victoria, the area modelled in TAPM covered 74% and 81% of the respective state populations. For Queensland, South Australia and Western Australia the inventory areas included around 70% of the state populations. The Hobart inventory included 42% of the population of Tasmania, and the Darwin inventory included 56% of the Northern Territory population. It was assumed that the Canberra inventory effectively covered the whole ACT population.

The methods used to allocate emissions are described in **Sections A.4.1** and **A.4.2**.

A.4.1 Allocation of emission reductions to jurisdictions

The total Australia-wide emission reductions for each abatement measure were allocated *pro rata* to the states and territories using relevant indicators (*e.g.* current emissions, fuel use). It was assumed that the resulting state allocations would remain constant with time. The following data sources were utilised for this estimation:

- *Road vehicle exhaust*: Total vehicle kilometres travelled (VKT) (billion vehicle-kilometres) by state/territory, 1965 to 2012 **(BITRE, 2012)**.
- *Lawnmowers*: Emissions for 2011 in the state inventories.
- *Shipping*: Handling of international sea freight by Australian Ports **(BITRE, 2011)**.
- *Recreational boats*: Emissions during 2011 in the state inventories.
- *Commercial boats*: Assumed to be proportional to shipping.
- *Diesel trains*: Diesel consumption by rail transport, 1973 to 2010 (value for 2009/10 used) **(ABARES, 2011a)**.
- *Wood heaters*: Emissions during 2011 in the state inventories.
- *Coal dust and diesel engines used at coal mines*: Coal production in 2009/10 **(ABARES, 2011b)**.
- *Other non-road diesel engines*: Cost-benefit analysis of options to manage non-road diesel engine emissions **(ENVIRON and SKM-MMA, 2011)**.

The allocation of national emission reductions to the jurisdictions is given in **Table A32**.

Table A32: Allocation of PM_{10} and $PM_{2.5}$ emission reductions to jurisdictions

Source type		NSW	VIC	QLD	SA	WA	TAS	NT	ACT	Total
Road vehicle exhaust		29.5%	26.2%	21.1%	7.1%	11.3%	2.4%	0.9%	1.6%	100%
Shipping		15.1%	3.1%	24.3%	1.8%	52.7%	0.8%	2.2%	0.0%	100%
Non-road spark ignition engines	Lawnmowers	46.7%	15.0%	19.6%	6.9%	9.2%	1.3%	0.4%	0.9%	100%
	Recreational boats	47.3%	8.1%	32.7%	0.0%	6.7%	1.1%	4.0%	0.0%	100%
	Commercial boats	15.1%	3.1%	24.3%	1.8%	52.7%	0.8%	2.2%	0.0%	100%
Diesel trains		22.6%	13.7%	29.6%	4.6%	27.4%	1.9%	0.3%	0.0%	100%
Wood heaters		37.4%	29.4%	0.6%	8.5%	8.6%	11.7%	0.0%	3.8%	100%
Coal dust and mine-site diesel engines		35.3%	12.7%	49.6%	0.7%	1.6%	0.1%	0.0%	0.0%	100%
Other non-road diesel engines		24.9%	13.5%	21.1%	8.1%	27.6%	1.7%	3.1%	0.1%	100%

A.4.2 Proportion of state-wide emissions in inventory area

The assumptions used to allocate emissions to inventory and non-inventory areas are summarised below, and the proportions derived using these assumptions are given in **Table A33**. No emissions data for the full Victoria inventory area were available.

Coal dust and mine-site diesel

In NSW it was estimated that the GMR inventory only excluded 3% of NSW coal production (mainly in the Gunedah Basin), based on the statistics provided by **NSW EPA (2012e)** and **NSW DPI (2010)**.

For SEQ, PM_{10} emissions were taken from the emissions inventory. Black coal production was taken from **ABARES (2011b)**. An average ratio between PM_{10} emissions and coal production of 0.25 kg/tonne was obtained from the NSW inventory in order to estimate PM_{10} emissions from coal mining in Queensland. Using these data it was estimated that 4% of state-wide coal mine PM_{10} (and $PM_{2.5}$) emissions would occur in the SEQ inventory area.

For the other jurisdictions, emissions from coal mining in the inventory area were assumed to be zero.

Shipping, commercial boats and recreational boats

For NSW it was assumed that all shipping emissions would occur in the GMR inventory area. In the other jurisdictions emissions from shipping were allocated to the inventory area (state capital) and non-inventory areas using sea freight statistics from **BITRE (2011)**. The ratios for shipping were also applied to commercial boats. Emissions from recreational boats were either allocated on the basis of population (QLD, WA, TAS), assumed to be entirely in the inventory area (NSW, SA, NT), or assumed to be zero (ACT).

Commercial vehicles

In NSW data on VKT were available for the inventory area, and these were used to allocate emissions to inventory and non-inventory areas. Emissions in the other jurisdictions were allocated on the basis of population.

Other industrial vehicles and equipment

It was assumed that the NSW GMR inventory included 95% of emissions from other industrial vehicles and equipment. In the other jurisdictions the allocation was based on the PM_{10} emissions data used in the CBA by **ENVIRON and SKM-MMA (2011).** For the inventory areas the data for urban areas ('major' and other') were used, whereas for other areas the state balance was used.

Diesel trains

For NSW the split of emissions between the inventory area and the non-inventory area was based on the respective activity (in gross tonne-kilometres) from **NSW EPA (2012f)**. In Queensland we allocated emissions based on gross tonne kilometre data from **Queensland Rail (2012)**, which show that 20.1 billion gross tonne-kilometres of freight were carried in the state, of which one billion were in the SEQ region. For the other jurisdictions the PM_{10} emissions data from the NPI were used, except in the Northern Territory were track length was used as a proxy for allocating emissions between Darwin and the rest of the jurisdiction.

Lawnmowers

Emissions from domestic and public lawnmowers were allocated based on population.

Wood heaters

Emissions from wood heaters were allocated based on population.

Motor vehicles

Emissions from motor vehicles were allocated based on VKT and using data from **BITRE (2012)** and from the emission inventories.

Area planting

The effective emission reduction from the area planting of vegetation was assumed to occur entirely within each inventory area.

Table A33: Emissions in inventory/TAPM area as a proportion of state-wide emissions

Source type	Inventory/jurisdiction								TAPM/jurisdiction	
	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	NSW	VIC
Coal dust	0.97	N/A	0.04	0.00	0.00	0.00	N/A	N/A	0.88	0
Commercial boats (diesel)	1.00	N/A	0.11	0.86	0.05	0.07	1.00	N/A	0.98	0.98
Recreational boats (diesel)	1.00	N/A	0.68	1.00	0.68	0.42	1.00	N/A	0.96	0.81
Commercial vehicles	0.64	N/A	0.68	0.73	0.68	0.42	0.56	1.00	0.60	0.81
Industrial vehicles and equipment: mine site diesel	0.97	N/A	0.04	0.00	0.00	0.00	N/A	N/A	0.88	0
Industrial vehicles and equipment: other	0.95	N/A	0.36	0.31	0.19	0.67	0.15	1.00	0.83	0.81
Commercial boats (spark ignition)	1.00	N/A	0.11	0.86	0.05	0.07	1.00	N/A	0.96	0.98
Recreational boats (spark ignition)	1.00	N/A	0.68	1.00	0.68	0.42	1.00	N/A	0.96	0.81
Diesel trains	0.68	N/A	0.05	0.03	0.12	0.19	0.01	N/A	0.57	0.05
Shipping	1.00	N/A	0.11	0.86	0.05	0.07	1.00	N/A	0.99	0.98
Domestic lawnmowers	0.75	N/A	0.68	0.73	0.68	0.42	0.56	1.00	0.74	0.81
Public lawnmowers	0.75	N/A	0.68	0.73	0.68	0.42	0.56	1.00	0.74	0.81
Wood heaters	0.75	N/A	0.68	0.73	0.68	0.42	N/A	1.00	0.74	0.81
Motor vehicles	0.64	N/A	0.52	0.62	0.65	0.37	0.49	1.00	0.60	0.65
Area planting	1.00	N/A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

A.5 SOURCE CONTRIBUTIONS TO OVERALL EXPOSURE

In the modelled areas of NSW and Victoria it was possible to define the relative contributions of different sources to overall 'exposure' (including natural and secondary PM). This was calculated in terms of the sum-product of the $PM_{2.5}$ concentration and the affected population across all grid cells. These contributions were only calculated for the base year of 2011. Whilst it was not used in the economic analysis itself, this information is useful for guiding policy decisions.

The results are provided in **Tables A34** and **A35**, and show that exposure to natural and secondary $PM_{2.5}$ dominated the overall exposure in both modelled areas (especially in Victoria). This is essentially because every grid cell has a natural/secondary $PM_{2.5}$ component. For anthropogenic emissions in NSW the most important contributors were industrial point sources, wood heaters and motor vehicles. Motor vehicles and wood heaters were also the most important sources in Victoria.

Table A34: Contributions to $PM_{2.5}$ exposure in NSW modelled area

Source			Contribution (%) to total exposure in 2011 (BAU)
All industrial and commercial point sources			6.6%
Industrial area	Coal dust (including a small point source component)		2.8%
	Other industrial area		1.9%
Commercial area			0.8%
Non-road diesel engines	Commercial boats		0.4%
	Recreational boats		0.0%
	Off-road commercial vehicles and equipment		0.0%
	Industrial vehicles and equipment - mine site diesel		1.4%
	Industrial Vehicles & Equip (excl. mine site diesel)		1.8%
Non-road SI engines	Commercial boats		0.2%
	Recreational boats		0.2%
Diesel trains			0.7%
Shipping			1.9%
Other off-road mobile (balance)			0.0%
Domestic	SI engines	Domestic lawnmowers	0.5%
		Public lawnmowers	0.3%
	Wood heaters		16.3%
	Other domestic		0.5%
Motor vehicles			7.1%
Natural and secondary components			56.7%
TOTAL			**100.0**

Table A35: Contributions to $PM_{2.5}$ exposure in Victoria modelled area

Source	Contribution (%) to total exposure in 2011 (BAU)
All industrial point sources	1.3%
Area sources (including a small contribution from LPG vehicles)	4.4%
Motor vehicles – diesel	7.7%
Motor vehicles - petrol	4.5%
Wood heaters	7.7%
Natural and secondary components	74.3%
TOTAL	**100.0**

Appendix B ADJUSTMENT OF PM_{10} AND $PM_{2.5}$ CONCENTRATIONS

B.1 SELECTION OF PM_{10} AND $PM_{2.5}$ MONITORING DATA

The rationale for monitoring air pollution and the characteristics of the monitoring framework in Australia were described by **Bawden *et al.* (2012)**. Various methods are used to measure PM_{10} and $PM_{2.5}$, and these vary by jurisdiction. A summary of the methods used in each jurisdiction is provided in **Table B1**.

The actual monitoring stations in NSW and Victoria are listed in **Tables B2** to **B4**. Trend stations represent long-term monitoring trends, and are located at a nominated site for at least a decade. Trend sites are generally representative of regional population exposure and generally approximate the GRUB definition[15]. Performance stations are located at a site for at least five years and used to evaluate air quality against the NEPM. Campaign monitoring is conducted to determine whether longer-term monitoring is necessary elsewhere. There are currently more sites measuring PM_{10} than $PM_{2.5}$.

Table B1: Particulate matter monitoring methods used by jurisdictions

Jurisdiction	PM_{10}	$PM_{2.5}$
New South Wales	Gravimetric reference method TEOM	TEOM BAM
Victoria	TEOM	Gravimetric reference method TEOM
Queensland	FDMS TEOM, TEOM	FDMS TEOM, TEOM DOAS
Western Australia	TEOM	TEOM
South Australia	TEOM	TEOM
Tasmania	Gravimetric reference method TEOM Microcal air sampler DustTrak	Gravimetric reference method TEOM DustTrak
Australian Capital Territory	Gravimetric reference method BAM	Gravimetric reference method BAM
Northern Territory	Partisol dichotomous sampler TEOM	Partisol dichotomous sampler

Notes: TEOM: Tapered Element Oscillating Microbalance; FDMS: Filter Dynamic Measurement System; DOAS: Differential Optical Absorption Spectroscopy; BAM: Beta Attenuation Monitor

Table B2: $PM_{2.5}$ monitoring stations in NSW operated by ANSTO

Site	Location	Metric	Method	Purpose
Mascot	Urban site, close to Sydney CBD, Sydney International Airport and major arterial motorways	$PM_{2.5}$	Gravimetric filter, with compositional analysis	Research
Liverpool	Mixed urban/industrial site surrounded by urban housing and light industry			
Lucas Heights	Rural site 30 km SW of Sydney CBD, surrounded by bushland and minor roads			
Richmond	Mixed urban/rural site NW of Sydney - surrounded mainly by agricultural land			
Mayfield	Urban location in Newcastle, industrial hub			
Warrawong	Mixed urban industrial site in Wollongong			
Muswellbrook	Urban periphery			

[15] http://www.environment.nsw.gov.au/air/nepm/summary.htm

Table B3: PM monitoring stations in NSW (current NSW EPA sites only) (Bawden *et al.*, 2012)

Site	Metric	Method	Start year	Station type	Purpose	Location
Sydney						
Bringelly	PM_{10}	TEOM	1992	Trend	GRUB	Residential area
Chullora	PM_{10}	TEOM	2003	Trend	GRUB	
	$PM_{2.5}$	TEOM				
Earlwood	$PM_{2.5}$	TEOM	1998	Campaign	GRUB	
Liverpool	PM_{10}	TEOM	1990	Campaign	GRUB	Residential area
	$PM_{2.5}$	TEOM				
Macarthur	PM_{10}	TEOM	2003	Trend	GRUB	Residential area
Oakdale	PM_{10}	TEOM	1996	Performance	GRUB – NEPM compliance	Rural area
Prospect	PM_{10}	TEOM	2007	Trend	GRUB	
Richmond	PM_{10}	TEOM	1992	Trend	GRUB	Residential area
	$PM_{2.5}$	TEOM				
Rozelle	PM_{10}	TEOM	1978	Trend	GRUB	Residential area
St Marys	PM_{10}	TEOM	Pre-1994		GRUB	
Vineyard	PM_{10}	TEOM	1996		GRUB	
Lower Hunter						
Newcastle	PM_{10}	TEOM	1992	Trend	GRUB	CBD
Beresfield	PM_{10}	TEOM	1993	Campaign	GRUB	Semi-rural area
	$PM_{2.5}$	TEOM				
Wallsend	PM_{10}	TEOM	1994		GRUB	
	$PM_{2.5}$	TEOM	1992	Campaign	GRUB	
Illawarra						
Albion Park South	PM_{10}	TEOM	2005	Performance	GRUB – NEPM compliance	
Kembla Grange	PM_{10}	TEOM	1994	Performance	GRUB – NEPM compliance	Residential area
Wollongong	PM_{10}	TEOM	1993	Trend	GRUB	CBD
	$PM_{2.5}$	TEOM				
Regional NSW						
Albury	PM_{10}	TEOM	2000	Campaign	Population exposure - rural	Rural area
Bathurst	PM_{10}	TEOM	2000	Campaign	Population exposure – rural	Rural area
Dubbo	PM_{10}	TEOM		Campaign	Population exposure – rural	Rural area
Lismore	PM_{10}	TEOM		Campaign	Population exposure	Rural area
Orange	PM_{10}	TEOM		Campaign	Population exposure	Rural area
Tamworth	PM_{10}	TEOM	2000	Campaign	Population exposure - rural	Rural area
Wagga Wagga	PM_{10}	TEOM	2001	Campaign	Population exposure - rural	Rural area
Upper Hunter						
Merriwa	PM_{10}	TEOM	2012	Background	UHAQMN (Upper Hunter Air Quality Monitoring Network)	Rural area – coal mining
Wybong	PM_{10}	TEOM	2011	Small community	UHAQMN	Rural area – coal mining
Muswellbrook	PM_{10}	TEOM	2010	Large community	Population exposure	Rural area – coal mining
	$PM_{2.5}$	BAM	2010	Large community	Population exposure	
Muswellbrook NW	PM_{10}	TEOM	2011	Diagnostic	UHAQMN	Rural area – coal mining
Aberdeen	PM_{10}	TEOM	2011	Large community	Population exposure	Rural area – coal mining
Camberwell	PM_{10}	TEOM	2011	Small community	UHAQMN	Rural area – coal mining
	$PM_{2.5}$	BAM	2011	Small community	UHAQMN	
Jerrys Plains	PM_{10}	TEOM	2011	Small community	UHAQMN	Rural area – coal mining
Warkworth	PM_{10}	TEOM	2011	Small community	UHAQMN	Rural area – coal mining
Maison Dieu	PM_{10}	TEOM	2011	Small community	UHAQMN	Rural area – coal mining
Singleton	PM_{10}	TEOM	2010	Large community	Population exposure	Rural area – coal mining
	$PM_{2.5}$	BAM	2010	Large community	Population exposure	
Singleton NW	PM_{10}	TEOM	2011	Diagnostic	UHAQMN	Rural area – coal mining
Singleton South	PM_{10}	TEOM	2011	Background	UHAQMN	Rural area – coal mining
Bulga	PM_{10}	TEOM	2011	Small community	UHAQMN	Rural area – coal mining
Mt Thorley	PM_{10}	TEOM	2011	Diagnostic	UHAQMN	Rural area – coal mining

Table B4: PM monitoring stations in Victoria (current sites only) (Bawden *et al.*, 2012)

Site	Metric	Method	Start year	Station type	Location
Port Phillip					
Alphington	PM_{10}	TEOM	1994	Trend - GRUB	Residential/light industry
	$PM_{2.5}$	Grav. ref. method	2002		
	$PM_{2.5}$	TEOM	1996		
Box Hill[(a)]	PM_{10}	TEOM	1998	Trend	Residential
Brighton	PM_{10}	TEOM	1996	Performance: pop. average	Residential
Dandenong	PM_{10}	TEOM	1998	Performance: pop. average	Light industry
Deer Park[(a)]	PM_{10}	TEOM	2006	Trend	Residential
Footscray	PM_{10}	TEOM	1996	Trend - GRUB	Industrial/residential
	$PM_{2.5}$	Grav. ref. method	2002		
	$PM_{2.5}$	TEOM	1996		
Geelong South	PM_{10}	TEOM	2002	Trend - GRUB	Light industry/residential
Mooroolbark	PM_{10}	TEOM	2002	Performance: pop. average	Residential
Richmond	PM_{10}	TEOM	2001	Performance - GRUB	Residential
Latrobe Valley					
Traralgon	PM_{10}	TEOM	2002	Trend - GRUB	Residential

(a) Note that Box Hill and Deer Park are non-NEPM stations

Rural stations have been omitted from this analysis as the monitoring at those locations typically covered a 12 month period which crossed two calendar years, meaning the requirement for 75% data capture was not met in either year.

The reference method for monitoring $PM_{2.5}$ in Australia is the manual gravimetric method. The method is a non-continuous (batch), 1-day-in-3 technique that requires pre- and post-laboratory weighing. This introduces a significant time delay in data acquisition. However, the most common method for measuring and reporting PM_{10} and $PM_{2.5}$ concentrations in Australia is the TEOM.

The TEOM is an automated continuous particle monitor (for both PM_{10} and $PM_{2.5}$) that works by drawing air through a hollow tapered tube. The sampled air passes from the sampling inlet, through a filter, to a flow controller. As particles collect on the filter the mass changes, resulting in a change in the frequency of oscillation. The TEOM's microprocessor then calculates the mass concentration from the rate of mass accumulation on the filter and the flow rate through the flow controller. The main advantage of the TEOM is that concentrations are reported on a continuous basis. However, the TEOM has issues relating to the loss of semi-volatile components (these are considered in more detail later in this Appendix). The document *Technical paper no. 10: Collection and reporting of TEOM PM_{10} data* **(NEPC, 2001)** provides guidance on the handling of TEOM PM_{10} data to correct for these losses by way of an adjustment factor to generate equivalent information to the NEPM reference methods. These recommendations have not been implemented consistently by all jurisdictions, and this remains an area of concern for PM_{10} data **(NEPC, 2011a)**. Although they are not used in NSW and Victoria, it is worth noting that TEOMs equipped with the so-called FDMS compensate automatically for the loss of semi-volatile components.

B.1.1 New South Wales

The locations of the NSW monitoring sites that were selected for use in the analysis are shown in **Figure B1**. The monitoring sites are summarised in **Table B5**. Data for 2011 from 25 PM_{10} sites and nine $PM_{2.5}$ sites were obtained from NSW EPA. The monitoring stations operated by NSW EPA predominantly use TEOMs, with a small number of BAMs for $PM_{2.5}$ near mines. In addition, the Australian Nuclear Science and Technology Organisation (ANSTO) measures $PM_{2.5}$ (with compositional analysis) using a gravimetric filter method at seven sites in NSW. Data from these sites for the years 2005-2011 were obtained from the ANSTO web site[16].

[16] http://www.ansto.gov.au/discovering_ansto/what_does_ansto_do/live_weather_and_pollution_data/aerosol_sampling_program

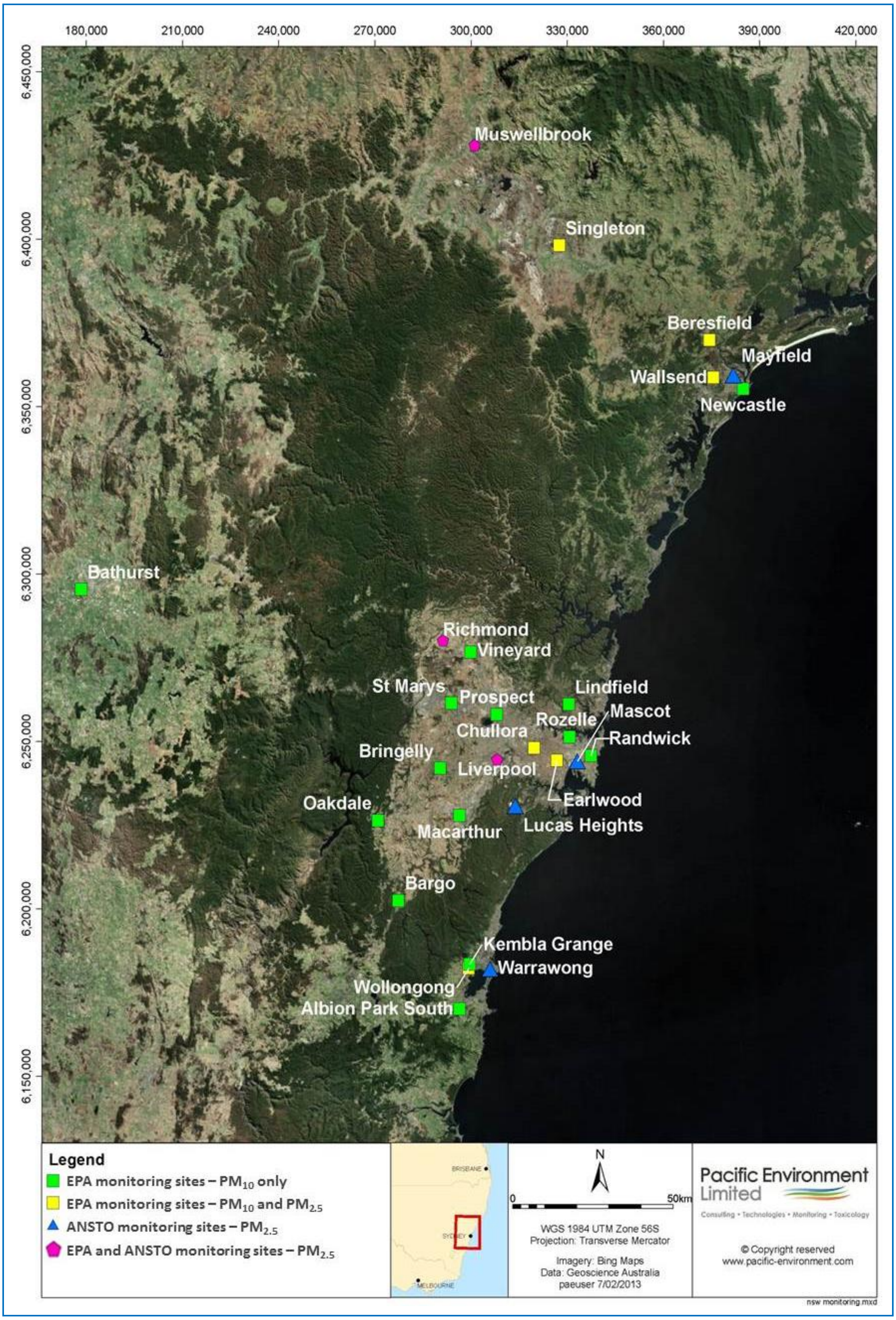

Figure B1: NSW monitoring sites (Bathurst site is outside modelled area)

Table B5: PM monitoring data used in NSW analysis

Metric	NSW EPA sites (data for 2011)		ANSTO sites (data for 2005-2011)
PM_{10}	Beresfield (TEOM) Chullora (TEOM) Earlwood (TEOM) Liverpool (TEOM) Richmond (TEOM) Wallsend (TEOM) Wollongong (TEOM) Muswellbrook (TEOM) Singleton (TEOM) Rozelle (TEOM) Randwick (TEOM) Lindfield (TEOM) Bringelly (TEOM)	Newcastle (TEOM) Tamworth (TEOM)[(a)] Kembla Grange (TEOM) Bargo (TEOM) Albury (TEOM)[(a)] St Marys (TEOM) Vineyard (TEOM) Bathurst (TEOM)[(a)] Macarthur (TEOM) Oakdale (TEOM) Albion Park South (TEOM) Prospect (TEOM)	-
$PM_{2.5}$	Beresfield (TEOM) Chullora (TEOM) Earlwood (TEOM Liverpool (TEOM Richmond (TEOM	Wallsend (TEOM) Wollongong (TEOM) Muswellbrook (BAM) Singleton (BAM)	Mascot (filter) Liverpool (filter) Lucas Heights (filter) Richmond (filter) Mayfield (filter) Warrawong (filter) Muswellbrook (filter)

(a) Outside TAPM area, and thus not used in model calibration

B.1.2 Victoria

The locations of the monitoring sites in the Port Phillip region that were used in the analysis are shown in **Figure B2**, and the sites are summarised in **Table B6**. Data for nine PM_{10} sites and two $PM_{2.5}$ sites were obtained from EPA Victoria. As in NSW, the monitoring is mostly undertaken using TEOMs. Gravimetric filter measurements - high-volume air samplers (HVAS) or Partisol samplers - are also deployed at some locations. Continuous monitoring of $PM_{2.5}$ is only conducted at Alphington and Footscray. The PM_{10} and $PM_{2.5}$ data for the sites listed in **Table B6** were supplied in hourly-average format by EPA Victoria. These hourly data were subsequently aggregated (midnight to midnight) to obtain 24-hour averages to be consistent with the AAQ NEPM.

Table B6: PM monitoring data used in Victoria analysis

Metric	EPA Victoria sites (data for 2006)	
PM_{10}	Alphington (TEOM)[(a)] Box Hill (TEOM) Brighton (TEOM) Dandenong (TEOM) Footscray (TEOM)[(a)]	Mooroolbark (TEOM) Richmond (TEOM) RMIT (TEOM)[(a)] Geelong South (TEOM [(a)]
$PM_{2.5}$	Alphington (TEOM)[(b)]	Footscray (TEOM)[(b)]

(a) Data from HVAS available for comparison
(b) Data from Partisol sampler available for comparison

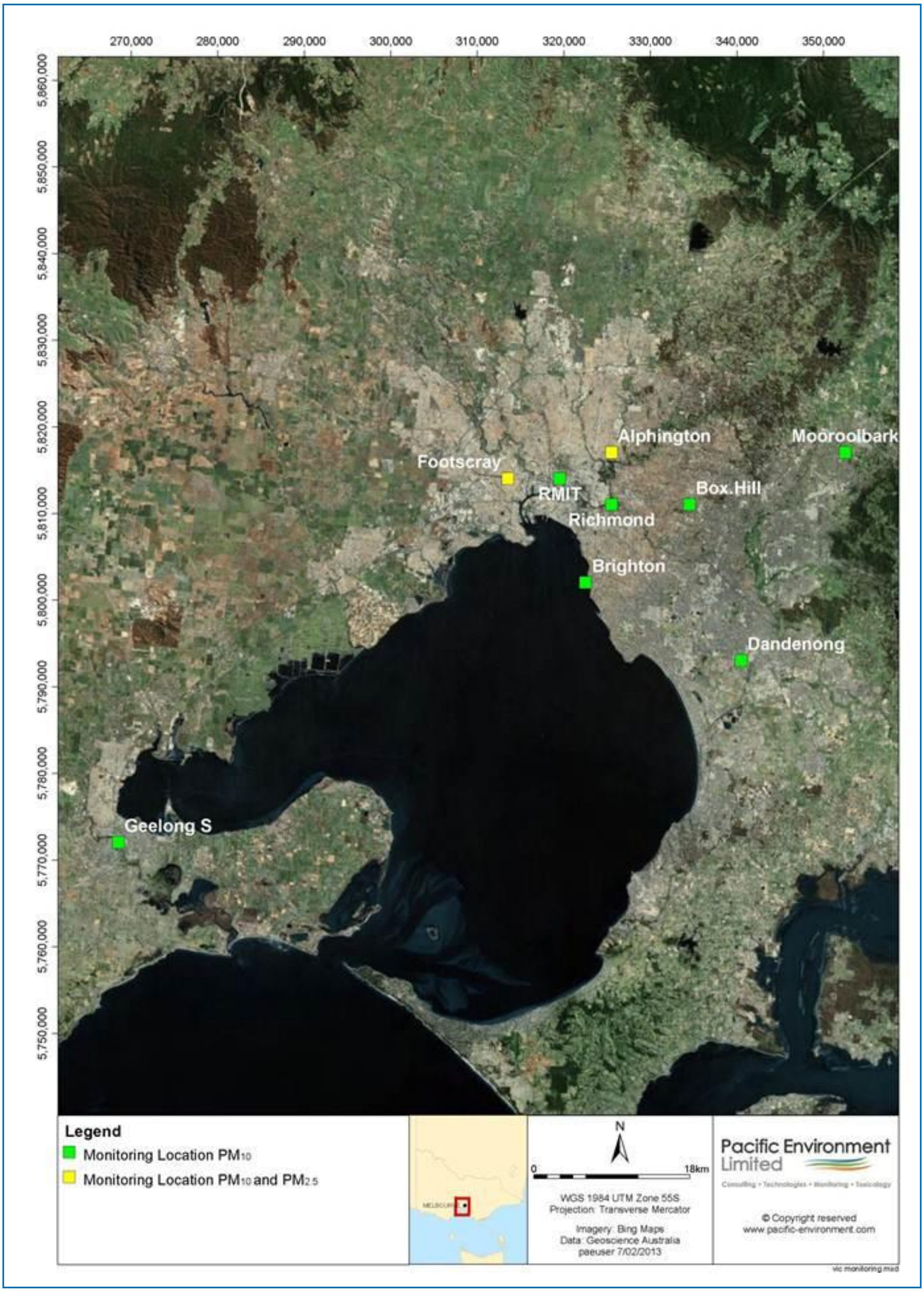

Figure B2: Victoria monitoring sites (all EPA)

B.2 ADJUSTMENT OF MONITORING DATA – TREATMENT OF EXTRAORDINARY NATURAL EVENTS

Extraordinary natural events - bushfires and dust storms - tend to result in high concentrations of PM. Such events were excluded from the PM monitoring data for the purpose of model adjustment. The monitoring data were removed for all days on which bushfires, dust storms or other unusual events affected the study areas.

Satellite observation data (Terra-MODIS[17] images) and other records (such as NEPM compliance reports) were analysed to identify bushfires for the periods of interest (2011 for NSW, and 2006 for Victoria).

In the case of NSW, no regional bushfire events were observed in the satellite data archive. This is likely to be linked to the observation that 2011 was a particularly high-rainfall *La Niña* year **(BOM, 2012)**, with relatively few fires. It was subsequently confirmed by NSW EPA that regional natural events did not result in any exceedances of air quality standards in 2011, although information on local fires affecting the monitoring sites was provided by NSW EPA (**Table B7**). The EPA monitoring data for each day affected were excluded from the analysis. No dust storm events were identified in NSW during 2011.

The ANSTO data were not modified, as only monthly summaries were available. However, the data corresponding to the dust storm of September 2009 were excluded from the analysis.

Table B7: NSW EPA monitoring sites and time periods affected by fires and other events

Monitoring site	Date and time	PM metric	Comment
Bringelly	15/11/2011 12:00	PM_{10}	Hazard reduction burning
Chullora	02/02/2011	PM_{10}	Unknown
	01/03/2011	PM_{10}	Local construction
	10/03/2011 4:00	PM_{10}	Hazard reduction burn Killarney Heights
	03/08/2011	PM_{10}	Local construction
	15/11/2011 12:00	$PM_{2.5}$	Hazard reduction burning
	15/11/2011 12:00	PM_{10}	Hazard reduction burning
Earlwood	12/08/2011 22:00	$PM_{2.5}$	Stolen car on fire next to monitoring site
	15/11/2011 12:00	$PM_{2.5}$	Hazard reduction burning
Liverpool	15/11/2011 12:00	$PM_{2.5}$	Hazard reduction burning
	15/11/2011 12:00	PM_{10}	Hazard reduction burning
Macarthur	15/11/2011 12:00	PM_{10}	Hazard reduction burning
Oakdale	15/11/2011 12:00	PM_{10}	Hazard reduction burning
Richmond	14/04/2011 7:00	$PM_{2.5}$	Hazard reduction burning - smoke from fires
	14/04/2011 7:00	PM_{10}	Hazard reduction burning - smoke from fires
Vineyard	14/04/2011 7:00	PM_{10}	Hazard reduction burning - smoke from fire

For Victoria, the satellite images revealed that there were major bushfire events during January and most of December 2006 (**Figure B3**). Additional information on bushfire smoke affecting the Port Phillip airshed was obtained by running backward trajectories originating over the airshed. Use was made of the HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory)[18] model, an online system initially

[17] MODIS = Moderate Resolution Imaging Spectroradiometer (http:// http://earthobservatory.nasa.gov)

[18] http://ready.arl.noaa.gov/HYSPLIT.php

developed by the US National Oceanic and Atmospheric Administration and the Australian Bureau of Meteorology for computing air parcel trajectories.

Figure B3: Terra-MODIS image of bushfires over Victoria during December 2006. Melbourne is located at the bottom left of the image (source: http://earthobservatory.nasa.gov).

Figure B4 shows that air parcels passing over Melbourne on 21 December 2006 originated over bushfire areas the previous night. Confirmations of these events, plus local fire events and dust storms during 2006, were identified from the NEPM Compliance Report **(EPA Victoria, 2007)**. Where a bushfire smoke plume was clearly seen to be advected into the airshed of interest, or there was a local fire or dust storm, the ambient air quality monitoring data for the corresponding day was excluded from the analysis.

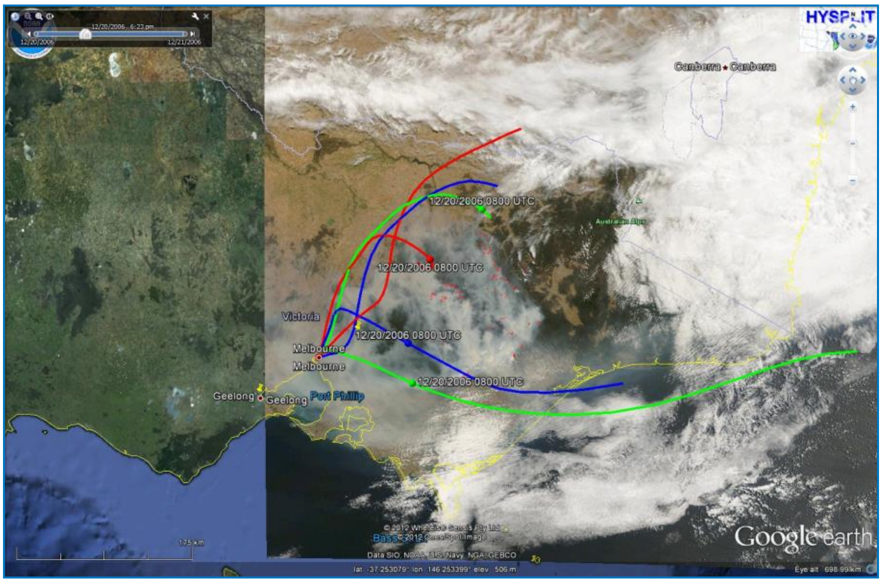

Figure B4: Back trajectories originating over Melbourne passing across bushfire regions: 21 December 2006.

The events affecting the monitoring sites in Victoria are listed in **Table B8**. The EPA monitoring data on each affected date were excluded from the analysis.

Table B8: EPA Victoria monitoring sites and time periods affected by fires and other events

Monitoring site	Date	PM metric	Comment
Geelong South	20 Jan 2006	PM_{10}	Dust storm
All	25-28 Jan 2006	$PM_{2.5}$, PM_{10}	Bush fire
Geelong South	11 apr 2006	PM_{10}	Dust storm
All	28 Apr 2006	$PM_{2.5}$, PM_{10}	Hazard reduction burning
Geelong South	1 Sep 2006	PM_{10}	Dust storm
All	12 Oct 2006	$PM_{2.5}$, PM_{10}	Dust storm
Dardenong	11 Nov 2006	PM_{10}	Dust storm
Footscray	11 Dec 2006	PM_{10}	Local fire

B.3 ADJUSTMENT OF MONITORING DATA - REMOVAL OF NATURAL AND SECONDARY PM COMPONENTS

B.3.1 Approach

The TAPM predictions included only primary anthropogenic PM, whereas the monitoring data also included other components. There was therefore a requirement to isolate primary anthropogenic PM[19] in the ambient measurements to provide a like-with-like comparison and to ensure that the importance of human activity was not under- or over-estimated in the modelling. Thus, natural primary particles and all secondary components (both natural and anthropogenic) needed to be 'removed' from the total measured PM_{10} and $PM_{2.5}$) prior to any comparison with model predictions. This process required knowledge of PM composition and the effects of different measurement methods. It was also necessary to determine the contribution of natural and secondary PM for subsequent addition to the primary anthropogenic contribution for direct comparison with the air quality standards.

As noted earlier, most of the PM monitoring sites in NSW and Victoria employ TEOMs. It is known that the operational method of the TEOM (the use of a heated sample inlet) results in the loss of semi-volatile secondary organic aerosol (SOA) and secondary ammonium nitrate (**Grover *et al.*, 2005**). Consequently, the TEOM mainly measures (i) primary anthropogenic PM, (ii) natural salts, (iii) mineral dusts and (iv) secondary sulfate. Components (ii) to (iv) therefore had to be subtracted from the TEOM data for the TAPM calibration.

It should be noted that there are two ways in which the TEOM data can be adjusted:

- Firstly, in the case of PM_{10} there is an internal manufacturer's correction. As part of the USEPA PM_{10} equivalency programme this correction was introduced to account for the measurement differences between the TEOM sampler and the high-volume reference method. This internal factor is incorporated into all TEOM PM_{10} analysers sold in Australia, and is given by $TEOM_{raw} * 1.03 + 3\ \mu g/m^3$. In Western Australia this adjustment is also applied to the $PM_{2.5}$ data.
- Secondly, *AAQ NEPM PRC Technical Paper No. 10* provides a basis for the removal of bias due to the loss of volatile components in TEOM PM_{10} measurements **(NEPC, 2001)**. Under this protocol the PM_{10} daily average data are multiplied by a factor which varies linearly from 1.4 at daily mean temperatures less than or equal to 5°C, to 1.0 at temperatures equal to or greater than

[19] It could be argued that a more conventional approach would have been to model all PM components and leave the monitoring data unadjusted. However, the approach to treating natural and secondary PM, and hence the overall effect, would have been the same. We have focused on the isolation (and presentation) of anthropogenic PM for transparency.

15°C. This method is an alternative to the application of a site-specific adjustment based on co-located TEOM and HVAS instruments. Again, it is not applied consistently across jurisdictions. For example, it is applied to the PM_{10} data from TEOMs in Victoria, but not in NSW. Slightly different approaches were therefore required for the two jurisdictions.

There is likely to be an element of double counting in the application of these adjustments.

The PM components that are modelled and measured by the TEOM are summarised in **Table B9**, with the required primary anthropogenic components being shaded in blue. The Table is applicable to both PM_{10} and $PM_{2.5}$, the main difference being the relative contributions of the different components; for example, PM_{10} tends to contain proportionally more material produced by natural mechanical processes (including wind-blown soil and sea-salt).

A smaller number of measurement sites in NSW use approaches other than the TEOM (*i.e.* BAM and filter measurements). The PM components that are modelled and are measured by non-TEOM instruments are summarised in **Table B10**. A different adjustment of the monitoring data was therefore required where these instruments were used, as they retain secondary inorganic and organic PM. In such cases, all non-primary anthropogenic PM had to be subtracted from the total PM to derive the 'measured' primary anthropogenic PM.

Table B9: PM components measured by TEOM and modelled

Natural/ anthropogenic	Primary/ secondary	Organic/ inorganic	Component	Measured	Modelled
Natural	Primary	Inorganic	Marine aerosol	Yes	No
			Wind-blown mineral dust	Yes	No
		Organic	Solid vegetal material	Yes	No
	Secondary	Organic	Aerosol derived from biogenic VOCs	No[a]	No
Anthropogenic	Primary	Inorganic	Mineral dust (*e.g.* from mining)	Yes	Yes
			Abrasion products (*e.g.* tyre and brake wear)	Yes	Yes
			Elemental carbon (*e.g.* diesel exhaust)	Yes	Yes
		Organic	Organic carbon (*e.g.* combustion sources)	No[a]	Yes
	Secondary	Inorganic	Ammonium nitrate (some sodium nitrate)	No	No
			Ammonium sulfate	Yes	No
		Organic	Organic carbon	No[a]	No

(a) Assuming that all organic carbon is removed by the TEOM.

Table B10: PM components measured by non-TEOM instruments and modelled

Natural/ anthropogenic	Primary/ secondary	Organic/ inorganic	Component	Measured	Modelled
Natural	Primary	Inorganic	Marine aerosol	Yes	No
			Wind-blown mineral dust	Yes	No
		Organic	Vegetal material	Yes	No
	Secondary	Organic	Biogenic aerosol	Yes	No
Anthropogenic	Primary	Inorganic	Mineral dust (*e.g.* mining)	Yes	Yes
			Abrasion products (*e.g.* tyre and brake wear)	Yes	Yes
			Elemental carbon (*e.g.* diesel exhaust)	Yes	Yes
		Organic	Organic carbon (*e.g.* diesel exhaust)	Yes	Yes
	Secondary	Inorganic	Ammonium nitrate (some sodium nitrate)	Yes	No
			Ammonium sulfate	Yes	No
		Organic	Organic carbon	Yes	No

The analyses for NSW and Victoria are described in more detail below. The $PM_{2.5}$ method was developed before the PM_{10} method, as more compositional information was available for $PM_{2.5}$. It is accepted that there will be a significant degree of uncertainty given the spatial and temporal variation in the various components. However, an effort was made to take this variation into account as far as possible.

B.3.2 New South Wales – $PM_{2.5}$

There have been relatively few studies of PM composition - and in particular SOA - in Australia. For NSW the approach to adjusting the various measurements was based primarily on the monitoring data published by ANSTO. ANSTO has been sampling $PM_{2.5}$ – mainly along the east coast of Australia - since 1991. During this time fine particles have been routinely collected at selected urban, rural and industrial sites. $PM_{2.5}$ has been collected on filters every Wednesday and Sunday over a 24-hour period, with subsequent analysis using ion beam analysis techniques. Positive matrix factorisation has also been used to characterise particles and to identify sources. This long-term aerosol sampling study is the only one of its kind taking place in Australia **(ANSTO, 2010)**.

$PM_{2.5}$ composition data for the ANSTO sites are available from the ANSTO web site, and the following components (as well as total mass) are reported:

- Sulfate (stated as '$NHSO_4$')
- 'Soil'
- 'Salt'
- Organic carbon
- Black (elemental) carbon
- Metals (K, Fe, Zn and Pb)

Ammonium sulfate is one of the largest components of $PM_{2.5}$ at the ANSTO sites. Between 1998 and 2008 the average ammonium sulfate concentration at 10 sites was 25% (range 18-31%) **(ANSTO, 2008)**. According to ANSTO the residual mass (i.e. the total less the sum of the above components) is likely to be mainly water and nitrates[20].

For each ANSTO site, data were analysed for the period 2005-2011 to generate the following:

- An estimate of primary anthropogenic $PM_{2.5}$ (in µg/m^3).
- An estimate of natural and secondary $PM_{2.5}$ (in µg/m^3).
- Primary anthropogenic $PM_{2.5}$ as a percentage of total measured $PM_{2.5}$ (for application to TEOM data).
- Primary anthropogenic $PM_{2.5}$ as a percentage of total measured $PM_{2.5}$ (for application to non-TEOM data).
- The ratio between natural/secondary $PM_{2.5}$ and primary anthropogenic $PM_{2.5}$.

Monthly average data were used at each site (based on the 24-hour measurements), and for each site and month the data were averaged over all years (2005-2011).

B.3.2.1 Estimation of primary anthropogenic $PM_{2.5}$

Primary anthropogenic $PM_{2.5}$ was estimated using the equation:

[20] ANSTO does not report nitrates, as these are not well retained on the Teflon filters that are used. The total mass may therefore be under-reported.

$$PM_{2.5\,(P/A)} = PM_{2.5\,(total)} - PM_{2.5\,(NHSO4)} - PM_{2.5\,(soil)} - PM_{2.5\,(salt)} - PM_{2.5\,(SOA)} - PM_{2.5\,(nitrate)}$$

Where:

$PM_{2.5\,(P/A)}$	=	mass concentration of primary anthropogenic $PM_{2.5}$
$PM_{2.5\,(total)}$	=	total measured $PM_{2.5}$ mass concentration
$PM_{2.5\,(NHSO4)}$	=	mass concentration of 'NHSO$_4$' component of $PM_{2.5}$ (assumed to be equivalent to secondary sulfate)
$PM_{2.5\,(soil)}$	=	mass concentration of 'soil' component of $PM_{2.5}$ (assumed to be equivalent to wind-blown mineral dust)
$PM_{2.5\,(salt)}$	=	mass concentration of 'salt' component of $PM_{2.5}$ (assumed to be equivalent to marine aerosol)
$PM_{2.5\,(SOA)}$	=	mass concentration of secondary organic aerosol component of $PM_{2.5}$
$PM_{2.5\,(nitrate)}$	=	mass concentration of nitrate component of $PM_{2.5}$

The mass concentrations were in µg/m^3. The sulfate, soil and salt components were taken directly from the ANSTO data.

> ***NB:*** *The 'soil' component is likely to include a significant anthropogenic contribution. However, no information was available to allow this to be isolated. Consequently, it was assumed that all 'soil' was natural wind-blown dust, rather than anthropogenic dust (again, to reduce the likelihood of overestimation of primary anthropogenic PM). Moreover, in the absence of data, water was effectively assigned to primary anthropogenic PM. Further consideration of water content was beyond the scope of the analysis.*

The SOA component was estimated using the elemental carbon '(EC) tracer' method, as outlined by, for example, **Seguel *et al.* (2009)** and **Keywood *et al.* (2011)**. Carbonaceous material is a major component of $PM_{2.5}$, comprising between 20% and 90% of $PM_{2.5}$ in urban areas **(Keywood *et al.*, 2011)**. A distinction can be made between EC and organic carbon (OC). Particulate EC is predominantly of primary origin, being emitted from incomplete combustion. OC is derived from primary emission sources such as coal combustion, road vehicle exhaust and biomass burning **(Cachier *et al.*, 1989; Duan et al., 2005)**, but also through atmospheric chemical conversion processes to form SOA **(Pankow, 1994; Duan *et al.*, 2005)**. The EC tracer method is based on the assumption that measured EC is predominantly of primary origin and can therefore be used as a tracer for measured primary OC emissions **(Duan *et al.*, 2005)**. As both EC and OC are produced by incomplete combustion, the EC tracer method requires an understanding of the OC:EC ratio for primary sources **(Keywood *et al.*, 2011)**. The basis of this method is that SOA is estimated by the ratio of primary OC:EC, assuming primary OC:EC is a constant value **(Duan *et al.*, 2005**; **Seguel *et al.* 2009)**. However, primary OC:EC ratios are source- and meteorology-dependant with, for example, the OC:EC ratio increasing to high values during bushfire events **(Keywood *et al.*, 2011)**. Consequently, **Duan *et al.* (2005)** recommended using the minimum OC:EC ratio of ambient aerosol as the primary OC:EC ratio when calculating SOA . The following equation was used to estimate SOA:

$$OC_{sec} = OC_{tot} - [EC_{tot} \times (OC{:}EC)_{min}]$$

Where:

OC_{sec}	=	secondary organic (carbon) aerosol mass
OC_{tot}	=	total measured organic carbon mass
EC_{tot}	=	total measured elemental carbon mass
$(OC{:}EC)_{min}$	=	minimum OC:EC ratio of ambient aerosol

As noted earlier, there are relatively few data on secondary nitrates from monitoring campaigns in Australia. Here, the secondary nitrate component of $PM_{2.5}$ was estimated based on the four-city study by **Chan *et al.* (2008)** in which, on average, secondary nitrates contributed about 7% of the mass of the $PM_{2.5}$ samples at urban and suburban sites. This 7% value was used to determine the nitrate component at all ANSTO sites and for all months. This approach is supported by the finding by **Chan *et al.* (2008)** that secondary nitrates was distributed evenly within each city, and that the average contribution of secondary nitrates to fine particles was rather uniform in different seasons rather than being higher in winter (as found in other studies). It was suggested that this could be due to the low-humidity conditions in winter in Australian cities, which makes the partitioning of the particle phase less favourable in the NH_4NO_3 equilibrium. Consequently, primary anthropogenic $PM_{2.5}$ was assumed to include elemental carbon, the non-SOA component of organic carbon, the metals, and any residual mass.

The results for two ANSTO sites - Mascot and Lucas Heights - are shown in **Figures B4** and **B5**. The Figures give the monthly average (all years) contributions of the different components to the total $PM_{2.5}$ mass concentration, highlighting the primary anthropogenic component which is comparable to the TAPM output. The Figures illustrate the complexities associated with the spatial treatment of the monitoring data. For example, at the urban Mascot site there was a strong seasonal variation in the primary anthropogenic contribution, with a peak in the primary anthropogenic component during the winter months, whereas at the more rural Lucas Heights site there was not. Conversely, for natural and secondary PM the seasonal variation was greater at the Lucas Heights site.

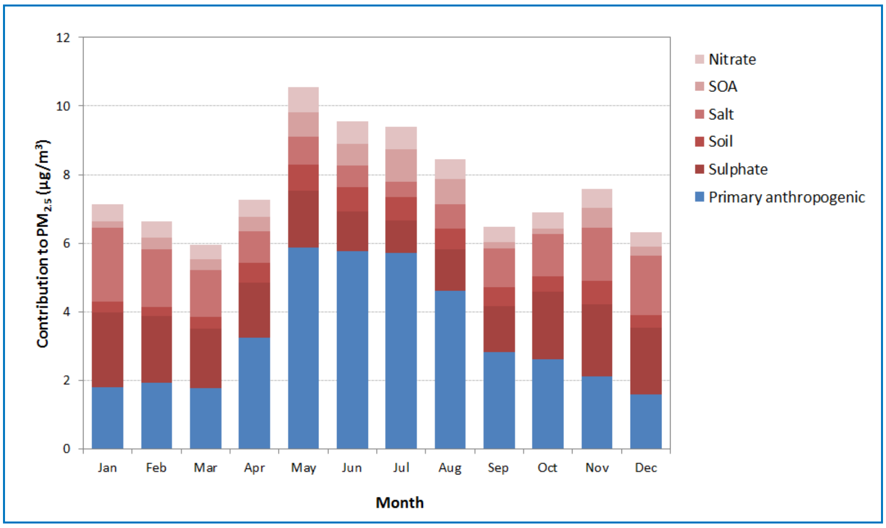

Figure B4: Contributions of different components to $PM_{2.5}$ mass concentration at Mascot site (average for period 2005-2011)

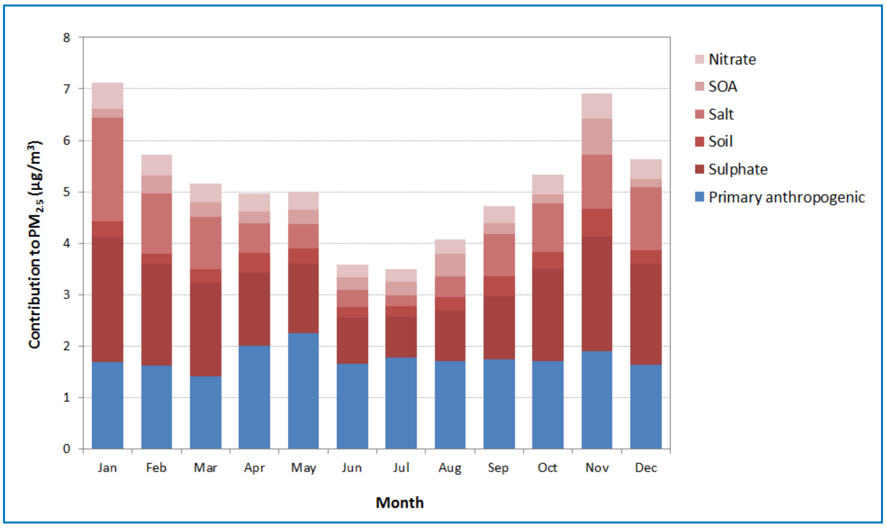

Figure B5: Contributions of different components to $PM_{2.5}$ mass concentration at Lucas Heights site (average for period 2005-2011)

Figure B6 shows the contributions of each component, averaged over all sites and years. The contribution of primary anthropogenic sources ranged from a low of around 20% in the summer months to a high of around 50% in the winter months; this is consistent with the findings of **Cope (2012)** for the Westmead site. The sulfate component, on the other hand, had a low of around 15% in the summer and a high of around 30% in the winter. The salt component ranged from less than 10% in winter to more than 20% in summer. Soil and SOA each generally contributed less than 10% to the $PM_{2.5}$ mass in any given month. The first study to determine the specific contribution of SOA to $PM_{2.5}$ in an Australian urban context (Melbourne) was by **Keywood *et al.* (2011)**, in which SOA was also estimated indirectly using the EC tracer method. The median annual SOA concentration was found to be 1.1 µg/m^3, representing 13% of $PM_{2.5}$. The SOA fraction of $PM_{2.5}$ was greatest during the autumn and early winter months. The findings here are similar to those of the Keywood study. As noted above, the nitrate component was fixed at 7%. Because of the month-to-month variation in the components, the $PM_{2.5}$ data from the NSW EPA monitoring sites were adjusted on a monthly basis.

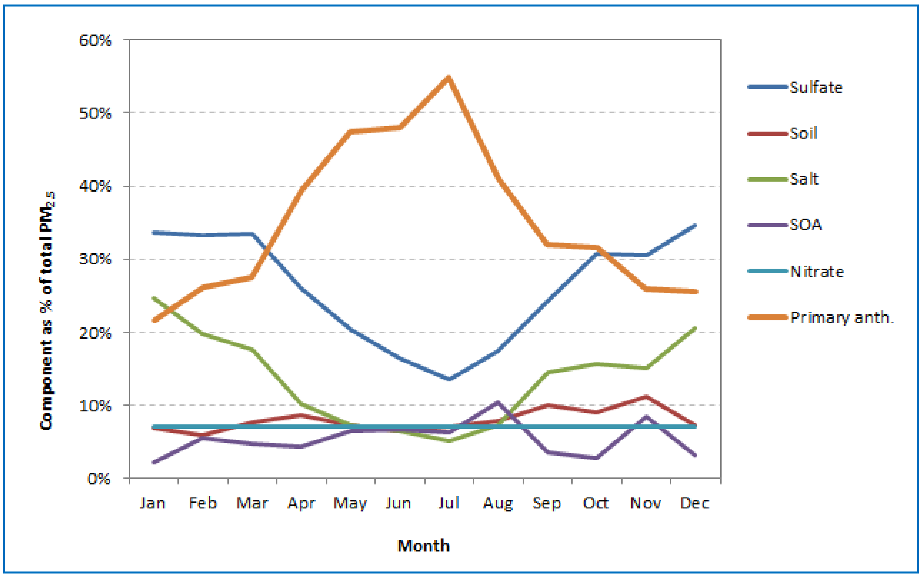

Figure B6: Contributions of different components to $PM_{2.5}$ mass concentration at all ANSTO sites (average for period 2005-2011)

B.3.2.2 Estimation of natural and secondary $PM_{2.5}$

The natural and secondary $PM_{2.5}$ components were required for a subsequent step in the analysis (calculation of total concentration for comparison with air quality standards). The average (all years) contribution of natural and secondary $PM_{2.5}$ at each ANSTO site and during each month was determined by subtracting the primary anthropogenic $PM_{2.5}$ (described above) from the total measured $PM_{2.5}$ mass.

B.3.2.3 Primary anthropogenic particles as a percentage of total measured $PM_{2.5}$

The ANSTO data were subsequently used to determine scaling factors to be applied at NSW EPA monitoring sites to estimate primary anthropogenic $PM_{2.5}$ from measured $PM_{2.5}$ mass. The scaling factors were developed for both TEOM and non-TEOM measurements. The results for the different ANSTO sites and different months are shown in **Figures B7** and **B8**. It is reiterated that these values are not derived *from* TEOM and non-TEOM instruments, but are for *application to* the data from them.

The TEOM scaling factors are higher than those for non-TEOM instruments, since the loss of semi-volatile PM components in the former means that primary anthropogenic PM forms a higher fraction of the measured mass (the total $PM_{2.5}$ filter mass was, on average, 14% higher than the TEOM-equivalent $PM_{2.5}$

mass calculated in the study). It can again be seen that there was substantial month-to-month variation in the scaling factors. There was also variation between sites. However, there was no clear geographical trend in the data, and therefore an average monthly profile for all sites was used in the analysis.

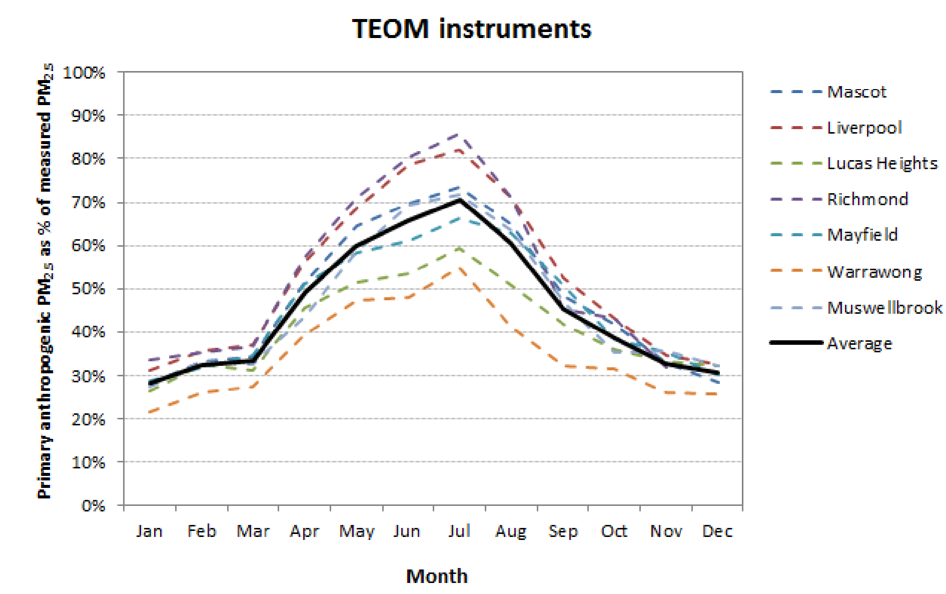

Figure B7: Primary anthropogenic $PM_{2.5}$ as a percentage of measured $PM_{2.5}$ (applicable to TEOM instruments, $PM_{2.5}$ only)

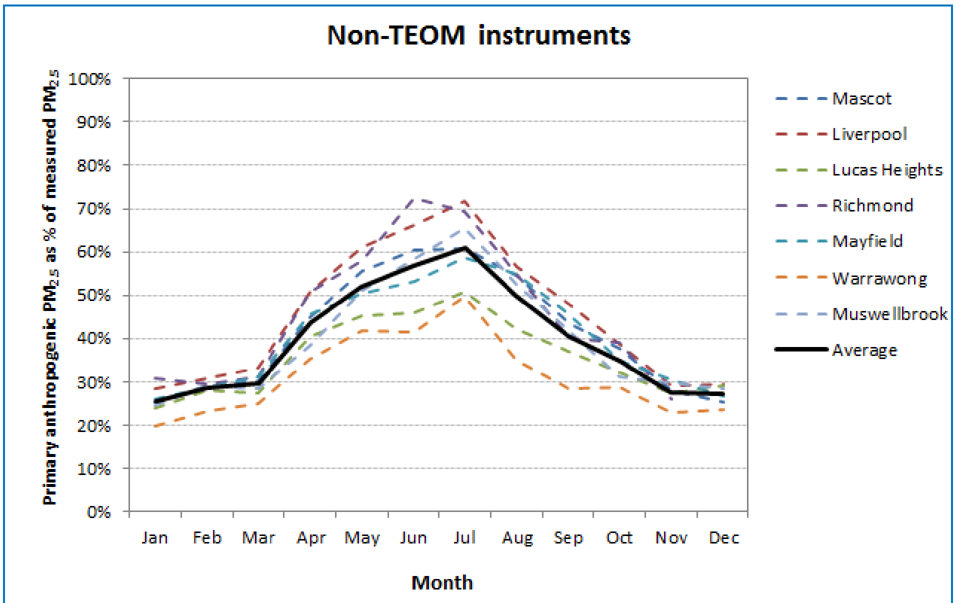

Figure B8: Primary anthropogenic $PM_{2.5}$ as a percentage of measured $PM_{2.5}$ (applicable to non-TEOM instruments, $PM_{2.5}$ only)

B.3.2.4 Ratio between natural/secondary $PM_{2.5}$ and primary anthropogenic $PM_{2.5}$

The ratio between natural/secondary $PM_{2.5}$ and primary anthropogenic $PM_{2.5}$ was required to determine the actual natural and secondary components from the TEOM data. This value was calculated separately for each ANSTO site and each month (**Figure B9**). Again, there was considerable seasonal variation in the data, but in general terms there was a good level of consistency across the sites. Consequently, the results were averaged over all sites, and the final ratios are shown in **Table B11**. These ratios were applied to the primary anthropogenic components in the NSW EPA TEOM $PM_{2.5}$ data on a month-by-month basis.

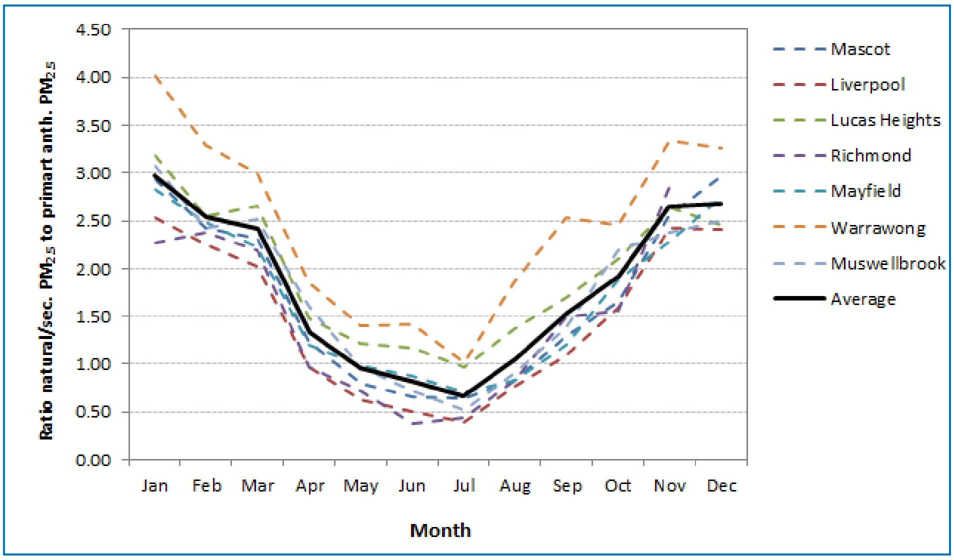

Figure B9: Ratio between natural/secondary $PM_{2.5}$ and primary anthropogenic $PM_{2.5}$ for all ANSTO sites

Table B11: Ratio between natural/secondary $PM_{2.5}$ and primary anthropogenic $PM_{2.5}$

Month	Ratio between natural/secondary $PM_{2.5}$ to primary anthropogenic $PM_{2.5}$ (average for 7 ANSTO sites between 2005 and 2011)
Jan	2.98
Feb	2.54
Mar	2.42
Apr	1.33
May	0.96
Jun	0.82
Jul	0.67
Aug	1.06
Sep	1.53
Oct	1.92
Nov	2.64
Dec	2.68

B.3.3 New South Wales - PM_{10}

Although PM_{10} mass concentration data were available for 25 sites in NSW, there was relatively little compositional information. A simpler series of adjustments was therefore applied based on a combination of the ANSTO $PM_{2.5}$ data, the co-located PM_{10} and $PM_{2.5}$ measurements at the EPA sites, and the literature. NSW EPA does not adjust the TEOM PM_{10} data to allow for the loss of semi-volatile components, and therefore allowance had to be made for this. The steps in the calculation are given below.

1. Scaling factors were applied to the different natural/secondary $PM_{2.5}$ components obtained from the ANSTO data (each site and month) to give the corresponding contributions (in µg/m^3) to PM_{10}. These scaling factors are given in **Table B12**. The scaling factors for salt, soil, sulfate and nitrate were derived from the 'four city' results reported by **Chan *et al.* (2008)**. It should be noted that the use of data from this single study is likely to be a significant source of uncertainty in the PM_{10} estimates. It was also assumed that all SOA would be in the $PM_{2.5}$ fraction, based on the literature. For example, **Hinds (1999)** states that SOA is rarely found in the coarse mode under ambient conditions, and in smog chamber experiments **Liu *et al.* (2009)** found that SOA created by isoprene photo-oxidation was predominantly in the form of particles with a diameter of less than 2.5 µm. The PM_{10} contribution for each component was then averaged over all ANSTO sites and all months.

Table B12: Scaling factors for determining contributions of natural/secondary particles to PM_{10}

Component	$PM_{10}/PM_{2.5}$ mass ratio	Annual mean contribution to PM_{10} (µg/m^3)
'Salt'	4.1	3.7
'Soil'	12.5[(a)]	6.7
'Sulfate'	2.3[(b)]	3.9
'Nitrate'	5.5[(b)]	2.6
SOA	1.0	0.4
	TOTAL	**17.2**

(a) This increases the importance of soil in the analysis for PM_{10}. The assumption that these particles are of natural origin may be overly conservative.

(b) These values may be high. For example, for a wide range of monitoring sites in Europe **Putaud *et al.* (2010)** reported broadly similar percentage contributions of nitrate to the fine ($PM_{2.5}$) and coarse ($PM_{2.5\text{-}10}$) size fractions, with $PM_{2.5}$ accounting for between around 40% and 90% of PM_{10}. In the Chan study the overall average $PM_{2.5}$ contribution was 38%. **Putaud *et al.* (2010)** also pointed out, however, that most of the particulate nitrate was observed in the coarse mode during pollution episodes.

2. A 'TEOM-equivalent' $PM_{2.5}$ mass ($PM_{2.5\ (TEOM\ eq.)}$) was estimated from the ANSTO data using the equation:

$$PM_{2.5\ (TEOM\ eq.)} = PM_{2.5\ (total)} - PM_{2.5\ (SOA)} - PM_{2.5\ (nitrate)}$$

   The values for the TEOM-equivalent $PM_{2.5}$ mass were determined for each ANSTO site and each month, and then averaged over all sites and months. The resulting $PM_{2.5}$ value was 5.9 µg/m^3.

3. An overall annual average $PM_{10}/PM_{2.5}$ ratio was calculated for the NSW EPA monitoring sites having co-located PM_{10} and $PM_{2.5}$ measurements. This value – which was quite consistent (range = 2.9 to 3.6) - was determined to be 3.2. The TEOM-equivalent $PM_{2.5}$ mass was multiplied by the 3.2 factor to give TEOM-equivalent PM_{10}. The resulting PM_{10} value was 18.9 µg/m^3.

4. Primary anthropogenic PM_{10} was calculated by subtracting the sulfate, soil and salt components (14.2 µg/m^3 in total) from the TEOM-equivalent PM_{10}. This resulted in a value of 4.7 µg/m^3.

5. An annual average 'downscaling' factor of 0.25 (4.7 µg/m³ / 18.9 µg/m³) was calculated to generate primary anthropogenic PM_{10} from the TEOM measurements at each of the NSW EPA monitoring sites. A substantial proportion of primary anthropogenic PM_{10} is combustion-derived $PM_{2.5}$. It was therefore considered appropriate to superimpose the monthly variation profile from **Figure B7** (normalised to the annual average proportion) on the primary anthropogenic component.

6. An 'upscaling' factor of 1.16 was calculated to give the total PM_{10} for comparison with the air quality standards from the measured PM_{10}. This value was calculated as the sum of all components (salt + soil + sulfate + nitrate + SOA + primary anthropogenic = 21.9 µg/m³) divided by the TEOM-equivalent PM_{10} (18.9 µg/m³).

7. Each daily 24-hour average PM_{10} concentration at each NSW EPA monitoring site was multiplied by monthly-varying downscaling proportion to give the primary anthropogenic contribution.

8. Total PM_{10} for comparison with the air quality standards was then calculated by multiplying the TEOM-measured PM_{10} by 1.16, and then the natural/secondary component was calculated as the difference between the total and the primary anthropogenic component.

B.3.4 Victoria – $PM_{2.5}$

$PM_{2.5}$ data were only available for two sites in Victoria (Alphington and Footscray). At these sites $PM_{2.5}$ is measured using both a TEOM and a Partisol. The Partisol measurements are only obtained every third day.

The TEOM data from Victoria were used in the analysis. EPA Victoria does not apply any temperature adjustment to the TEOM $PM_{2.5}$ data to allow for the loss of volatile components, as set out in the AAQ NEPM PRC Technical Paper No. 10 **(NEPC, 2001)**. This appears to be confirmed by the comparison in **Figure B10**. Therefore, the TEOM data for each site were scaled up according to the Partisol data, and using the gradients of the regression fits in the Figure (*i.e.* 1.56 for Alphington and 1.3 for Footscray). The split between primary anthropogenic and natural/secondary PM from the ANSTO filter data was then applied to the adjusted TEOM measurements on a month-by-month basis.

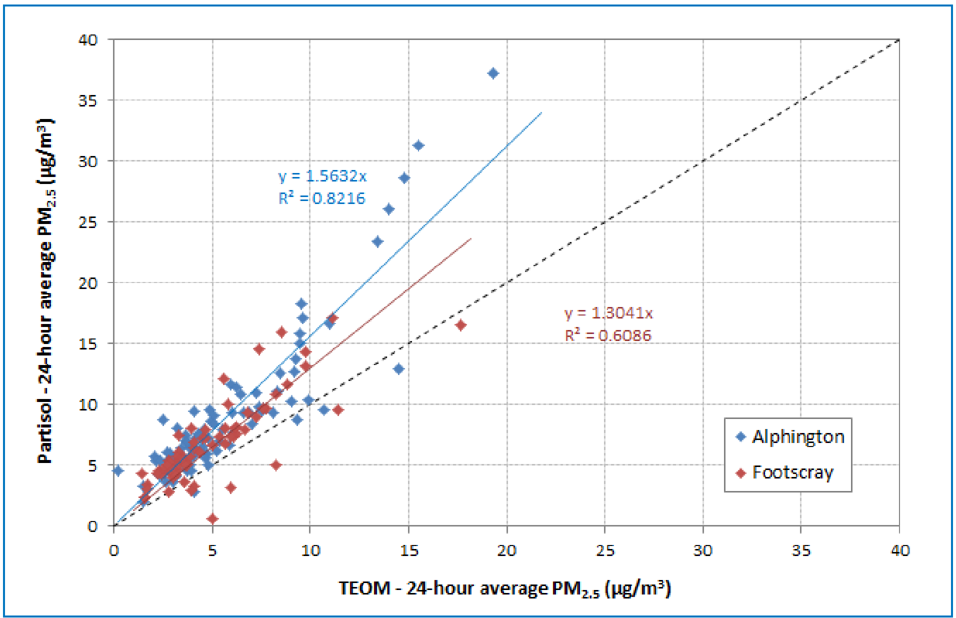

Figure B10: Comparison between 24-hour average $PM_{2.5}$ measured by Partisol and TEOM (data for 2006). The regression fits are forced through zero.

B.3.5 Victoria – PM_{10}

The TEOM PM_{10} data from EPA Victoria were used in the analysis. For PM_{10} EPA Victoria does apply the TEOM temperature adjustment for the loss of volatile components, as set out in the AAQ NEPM PRC Technical Paper No. 10 **(Walsh, 2012a)**. This approach is supported by a comparison between the TEOM and HVAS data for PM_{10} at four sites in Victoria, which revealed an approximate 1:1 relationship between the two instruments (**Figure B11**).

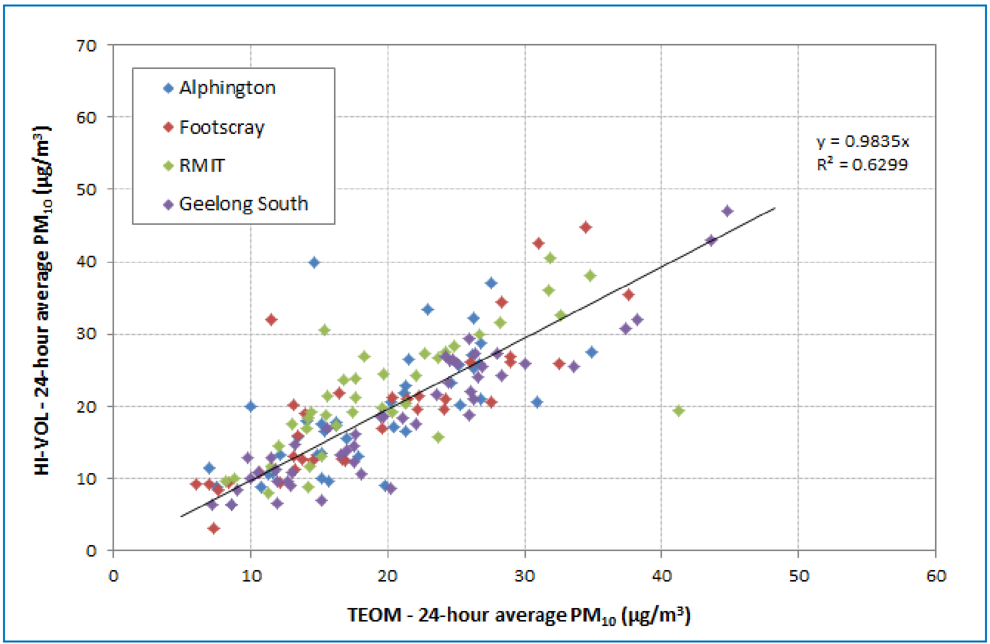

Figure B11: Comparison between PM_{10} measured using a Hi-Vol sampler and PM_{10} measured using a TEOM at four monitoring sites in Victoria (data for 2006)

The steps in the calculation are given below:

1. The scaling factors from **Table B12** were applied as described for PM_{10} in NSW.

2. The total annual mean $PM_{2.5}$ (filter) mass for the ANSTO sites (6.8 µg/m³) was multiplied by the PM_{10}:$PM_{2.5}$ ratio of 3.2 to give an equivalent filter mass for PM_{10}. The resulting PM_{10} value was 21.6 µg/m³.

3. Primary anthropogenic PM_{10} was calculated by subtracting the sulfate, soil, salt, nitrate and SOA components (17.2 µg/m³ in total) from the total PM_{10} mass. This resulted in a value of 4.4 µg/m³.

4. Annual average downscaling factor of 0.2 (4.4 µg/m³ / 21.96 µg/m³) was calculated to generate primary anthropogenic PM_{10} from the TEOM data at each of the EPA Victoria monitoring sites. As in the case of NSW, it was considered appropriate to superimpose the monthly variation profile from **Figure B7** on the annual mean primary anthropogenic component.

5. Each daily 24-hour average PM_{10} concentration at each EPA Victoria monitoring site was multiplied by the monthly-varying downscaling factor to give the primary anthropogenic contribution. The natural/secondary component was calculated as the difference between the total and the primary anthropogenic component.

B.3.6 Summary of results for the primary anthropogenic component

The proportion of measured PM mass that was assumed to be primary anthropogenic PM is summarised in **Table B13**. Again, these values are based upon the assumption that the soil (and salt) components of the ANSTO data are natural in origin. It could be argued that the primary PM contributions obtained by this method are rather low, and would underestimate primary anthropogenic PM close to major sources (such as highways). Nevertheless, the findings are not inconsistent with those in the literature. For example, in the UK **Laxen *et al.* (2010)** noted that primary anthropogenic PM (from all sources) probably contribute less than 25% to urban background $PM_{2.5}$ concentrations. Moreover, for the economic analysis it was more important to underestimate primary anthropogenic PM than to overestimate it (which would lead to an underestimation of abatement costs in the economic analysis).

Table B13: Proportion of primary anthropogenic particles in measured PM mass

Period	Corrected TEOM data or gravimetric filter data		Uncorrected TEOM data	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Jan	0.13	0.26	0.15	0.28
Feb	0.14	0.28	0.18	0.33
Mar	0.15	0.29	0.18	0.33
Apr	0.22	0.44	0.27	0.49
May	0.26	0.52	0.33	0.60
Jun	0.29	0.57	0.36	0.66
Jul	0.31	0.61	0.39	0.71
Aug	0.25	0.50	0.33	0.61
Sep	0.20	0.41	0.25	0.45
Oct	0.17	0.35	0.21	0.38
Nov	0.14	0.28	0.18	0.33
Dec	0.14	0.27	0.17	0.30
Annual average	0.20	0.41	0.25	0.47

B.3.7 Adjusted monitoring data

The relevant descriptive statistics for the adjusted monitoring data for PM_{10} and $PM_{2.5}$ are given in **Table B14** to **Table B17**. Separate statistics are provided for the total concentration, the primary anthropogenic contribution and the natural/secondary contribution.

> ***NB**: Within the constraints of the economic analysis the annual average value of the natural/secondary contribution defines the lower limit for any new air quality standard. This is not quite the case for the 24-hour average, as the maximum primary anthropogenic and natural/secondary components will not tend to coincide in time. The values presented in the Tables therefore suggest that some of the hypothetical standards will be exceedingly difficult to meet, such as 12 µg/m³ and 16 µg/m³ for annual mean PM_{10}.*

Table B14: Adjusted PM_{10} monitoring data for NSW (totals may differ due to rounding)

Site		Year	Total PM_{10} (µg/m³)		Primary anthropogenic PM_{10} (µg/m³)		Natural and secondary PM_{10} (µg/m³)	
Ref	Name		Annual mean	6th highest 24-hour average[(a)]	Annual mean	6th highest 24-hour average[(a)]	Annual mean	6th highest 24-hour average[(a)]
N_EPA_01	Beresfield	2011	20.0	43.2	4.3	10.0	15.6	33.0
N_EPA_02	Chullora	2011	22.4	50.1	4.9	13.2	17.5	41.2
N_EPA_03	Earlwood	2011	20.9	46.9	4.4	10.4	16.4	39.6
N_EPA_04	Liverpool	2011	20.8	42.7	3.9	9.1	16.9	33.5
N_EPA_05	Richmond	2011	15.1	34.3	3.1	8.5	12.0	27.4
N_EPA_06	Wallsend	2011	16.5	32.9	3.5	7.5	13.1	28.0
N_EPA_07	Wollongong	2011	19.7	44.3	4.0	8.9	15.7	38.4
N_EPA_08	Muswellbrook	2011	22.4	46.7	4.7	10.4	17.7	36.7
N_EPA_09	Singleton	2011	23.0	52.9	5.0	12.5	18.0	45.0
N_EPA_10	Rozelle	2011	19.2	37.9	4.1	8.8	15.2	31.6
N_EPA_11	Randwick	2011	18.5	36.1	3.9	8.6	14.6	30.7
N_EPA_12	Lindfield	2011	15.4	32.0	3.2	6.6	12.2	26.1
N_EPA_13	Bringelly	2011	18.2	44.0	3.8	10.1	14.4	34.3
N_EPA_14	Newcastle	2011	22.1	45.9	4.6	9.8	17.6	39.8
N_EPA_16	Kembla Grange	2011	19.5	47.8	4.0	9.9	15.5	40.4
N_EPA_17	Bargo	2011	15.0	36.9	3.1	9.1	11.8	27.8
N_EPA_19	St Marys	2011	17.1	38.5	3.5	9.7	13.5	30.3
N_EPA_20	Vineyard	2011	16.2	35.1	3.4	8.1	12.8	27.9
N_EPA_22	Macarthur	2011	15.2	33.2	3.1	7.1	12.1	26.6
N_EPA_23	Oakdale	2011	12.2	29.0	2.5	6.7	9.7	24.6
N_EPA_24	Albion Park South	2011	15.8	38.7	3.2	7.5	12.6	33.6
N_EPA_25	Prospect	2011	18.3	37.1	3.9	8.9	14.4	31.9

(a) To take into account the five exceedances permitted by the AAQ NEPM.

Table B15: Adjusted $PM_{2.5}$ monitoring data for NSW

Site		Year	Total $PM_{2.5}$ (µg/m³)		Primary anthropogenic $PM_{2.5}$ (µg/m³)		Natural and secondary $PM_{2.5}$ (µg/m³)	
Ref	Name		Annual mean	Maximum 24-hour average	Annual mean	Maximum 24-hour average	Annual mean	Maximum 24-hour average
ANSTO_01	Mascot	avg. 2005-11	7.7	28.3	3.3	-	4.4	-
ANSTO_02	Liverpool	avg. 2005-11	8.3	33.7	4.0	-	4.3	-
ANSTO_03	Lucas Heights	avg. 2005-11	5.1	18.7	1.8	-	3.4	-
ANSTO_04	Richmond	avg. 2005-11	6.6	28.9	3.1	-	3.5	-
ANSTO_05	Mayfield	avg. 2005-11	7.0	21.0	2.9	-	4.1	-
ANSTO_06	Warrawong	avg. 2005-11	6.4	22.5	1.9	-	4.5	-
ANSTO_07	Muswellbrook	avg. 2005-11	6.0	18.7	2.4	-	3.6	-
N_EPA_01	Beresfield	2011	6.3	21.0	2.4	7.9	3.9	15.7
N_EPA_02	Chullora	2011	6.9	28.8	2.7	14.3	4.3	16.1
N_EPA_03	Earlwood	2011	6.1	27.7	2.5	14.1	3.7	13.6
N_EPA_04	Liverpool	2011	6.7	34.0	2.7	17.3	4.1	16.6
N_EPA_05	Richmond	2011	5.2	35.6	2.0	13.5	3.2	23.4
N_EPA_06	Wallsend	2011	5.6	18.6	2.1	7.8	3.4	13.2
N_EPA_07	Wollongong	2011	5.4	21.1	2.0	9.6	3.4	15.3
N_EPA_08	Muswellbrook	2011	9.1	28.3	4.0	15.3	5.2	14.1
N_EPA_09	Singleton	2011	7.6	21.5	3.1	12.2	4.5	14.7

Table B16: Adjusted PM_{10} monitoring data for Victoria

Site		Year	Total PM_{10} (µg/m³)		Primary anthropogenic PM_{10} (µg/m³)		Natural and secondary PM_{10} (µg/m³)	
Ref	Name		Annual mean	6th highest 24-hour average	Annual mean	6th highest 24-hour average	Annual mean	6th highest 24-hour average
V_EPA_01	Alphington	2006	18.9	34.7	3.7	9.0	15.2	27.2
V_EPA_02	Box Hill	2006	17.6	34.2	3.5	8.2	14.1	28.4
V_EPA_03	Brighton	2006	14.6	31.0	2.9	7.9	11.6	24.1
V_EPA_04	Dandenong	2006	22.3	44.4	4.5	11.9	17.8	33.9
V_EPA_05	Footscray	2006	19.8	40.5	4.0	9.9	15.8	34.1
V_EPA_06	Mooroolbark	2006	22.1	43.5	4.5	12.0	17.6	34.1
V_EPA_07	Richmond	2006	19.1	35.8	3.9	9.0	15.2	28.2
V_EPA_08	RMIT	2006	19.1	38.5	4.1	9.4	15.0	29.6
V_EPA_09	Geelong South	2006	20.3	43.6	4.0	9.6	16.3	35.3

Table B17: Adjusted $PM_{2.5}$ monitoring data for Victoria

Site		Year	Total $PM_{2.2}$ (µg/m³)		Primary anthropogenic $PM_{2.5}$ (µg/m³)		Natural and secondary $PM_{2.5}$ (µg/m³)	
Ref	Name		Annual mean	Maximum 24-hour average	Annual mean	Maximum 24-hour average	Annual mean	Maximum 24-hour average
V_EPA_01	Alphington	2006	8.8	34.0	3.6	19.3	5.2	16.4
V_EPA_05	Footscray	2006	6.8	23.6	2.8	13.5	4.0	16.7

B.4 MODEL PERFORMANCE AND ADJUSTMENT

B.4.1 Model performance

The performance of TAPM at predicting primary anthropogenic PM_{10} and $PM_{2.5}$ concentrations was examined at each monitoring site in NSW (2011) and Victoria (2006). For each monitoring site the following information was examined:

A. Monthly average primary anthropogenic PM from TAPM and monthly average primary anthropogenic PM from the measurements.

B. The contributions of the different anthropogenic emission sources to the modelled annual mean PM concentration at the monitoring site.

C. Quantile-quantile (Q-Q) plots of the 24-hour average predictions and measurements. These illustrated the performance of the model in different concentration ranges.

The results for NSW and Victoria are discussed separately in **Sections B.4.1.1** and **B.4.1.2** respectively.

B.4.1.1 New South Wales

The performance of TAPM for PM_{10} and $PM_{2.5}$ is illustrated in **Figures B12** to **B21** below.

PM10 concentrations

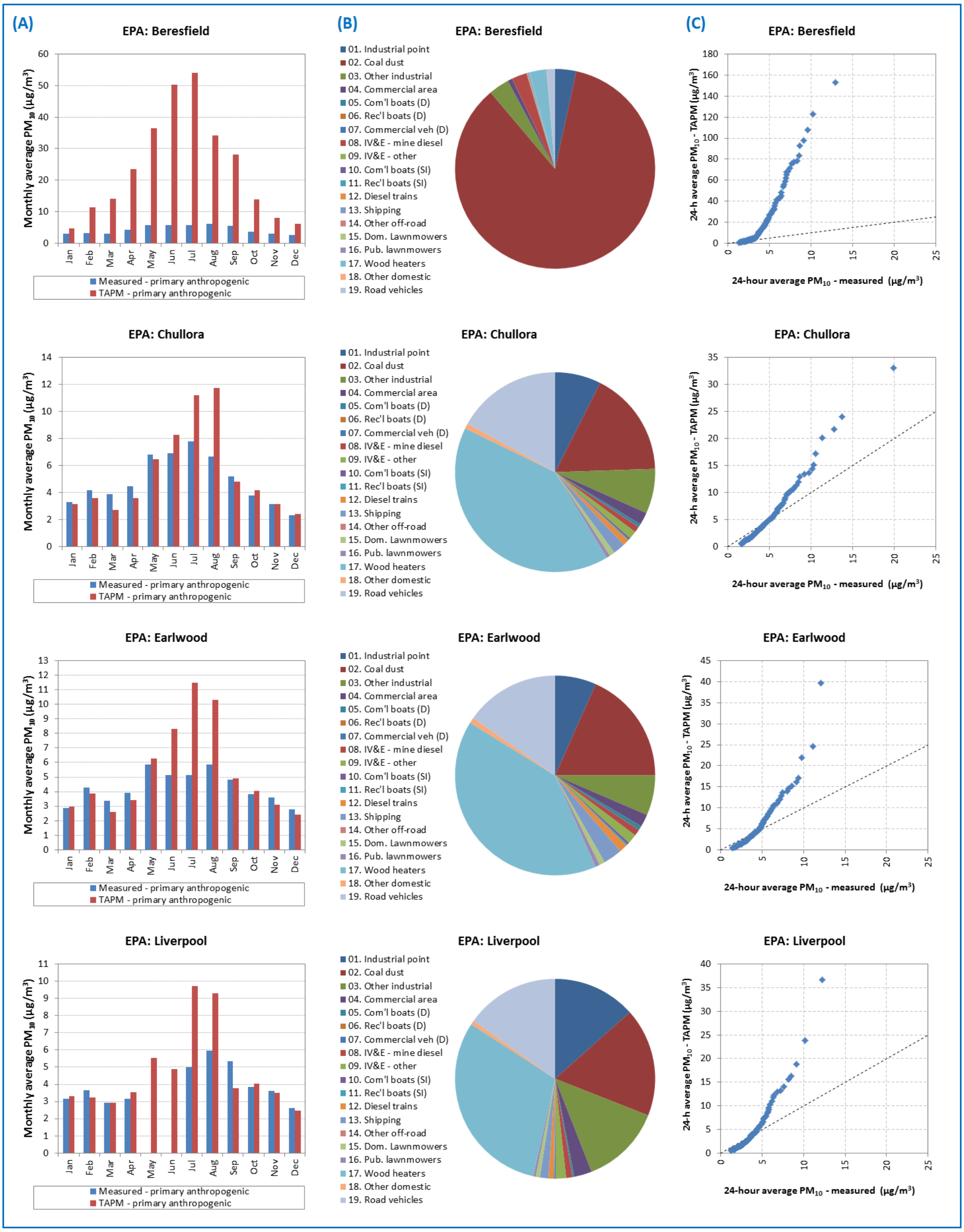

Figure B12: Model performance: PM10 at Beresfield, Chullora, Earlwood and Liverpool sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

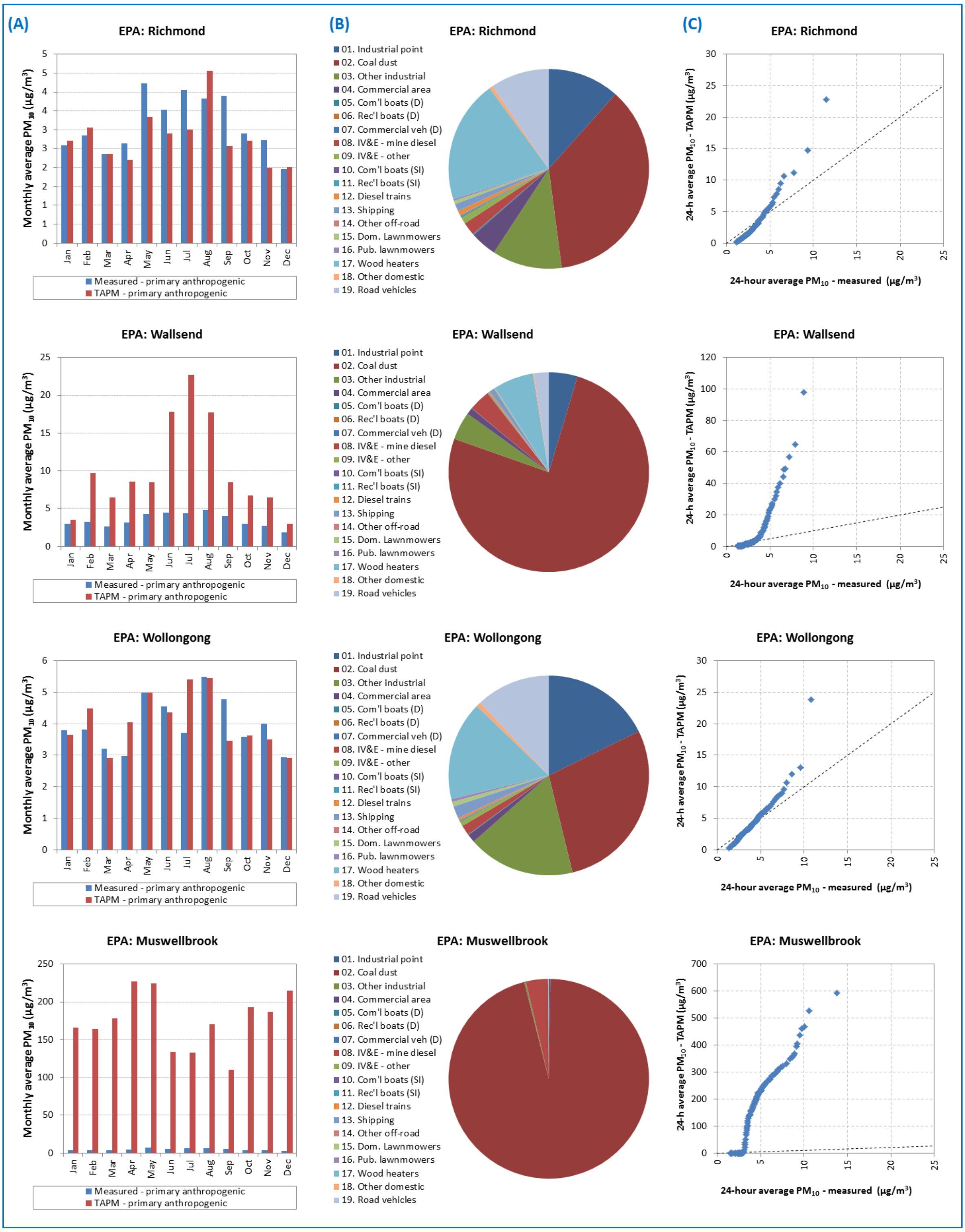

Figure B13: Model performance: PM_{10} at Richmond, Wallsend, Wollongong and Muswellbrook sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

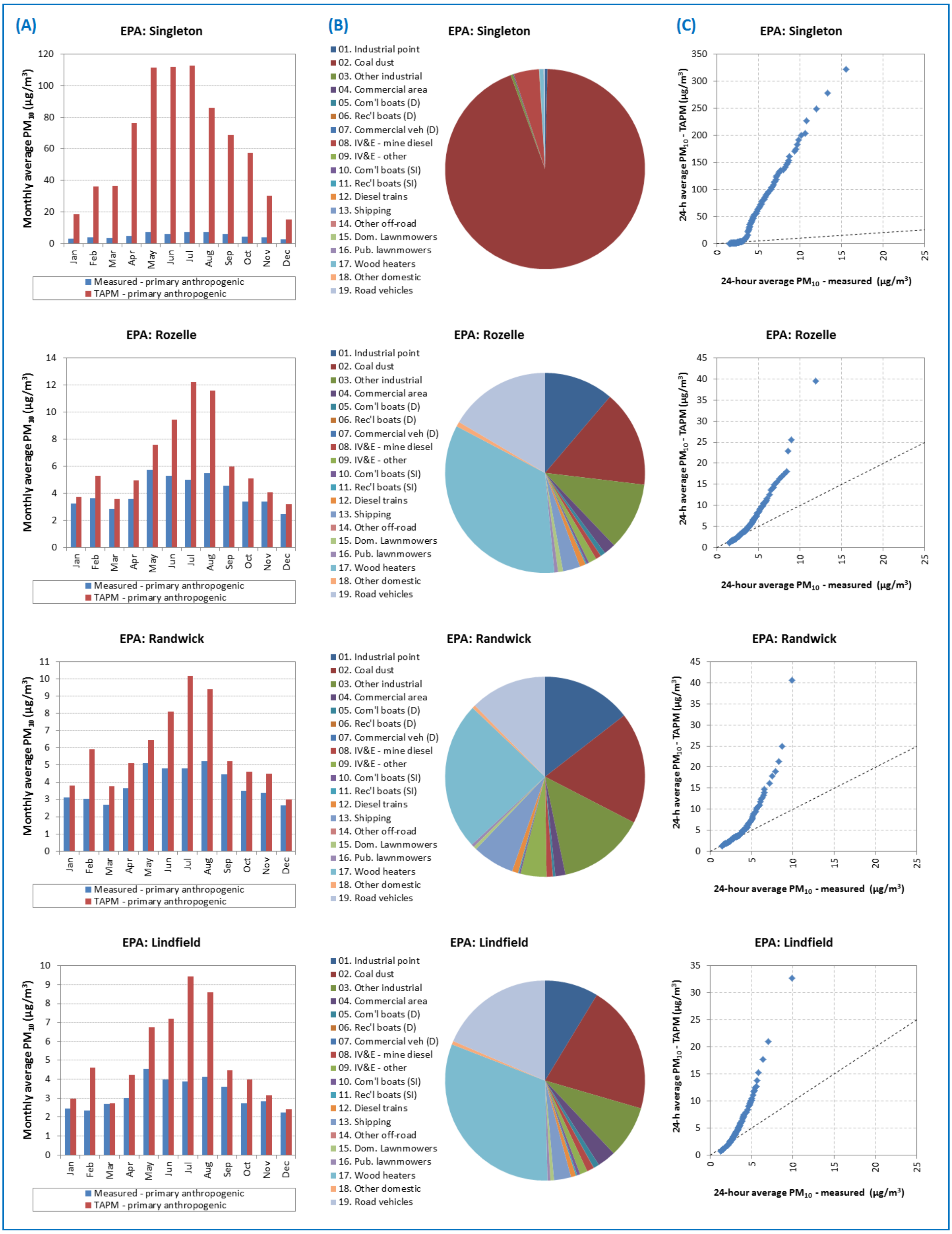

Figure B14: Model performance: PM_{10} at Singleton, Rozelle, Randwick and Lindfield sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

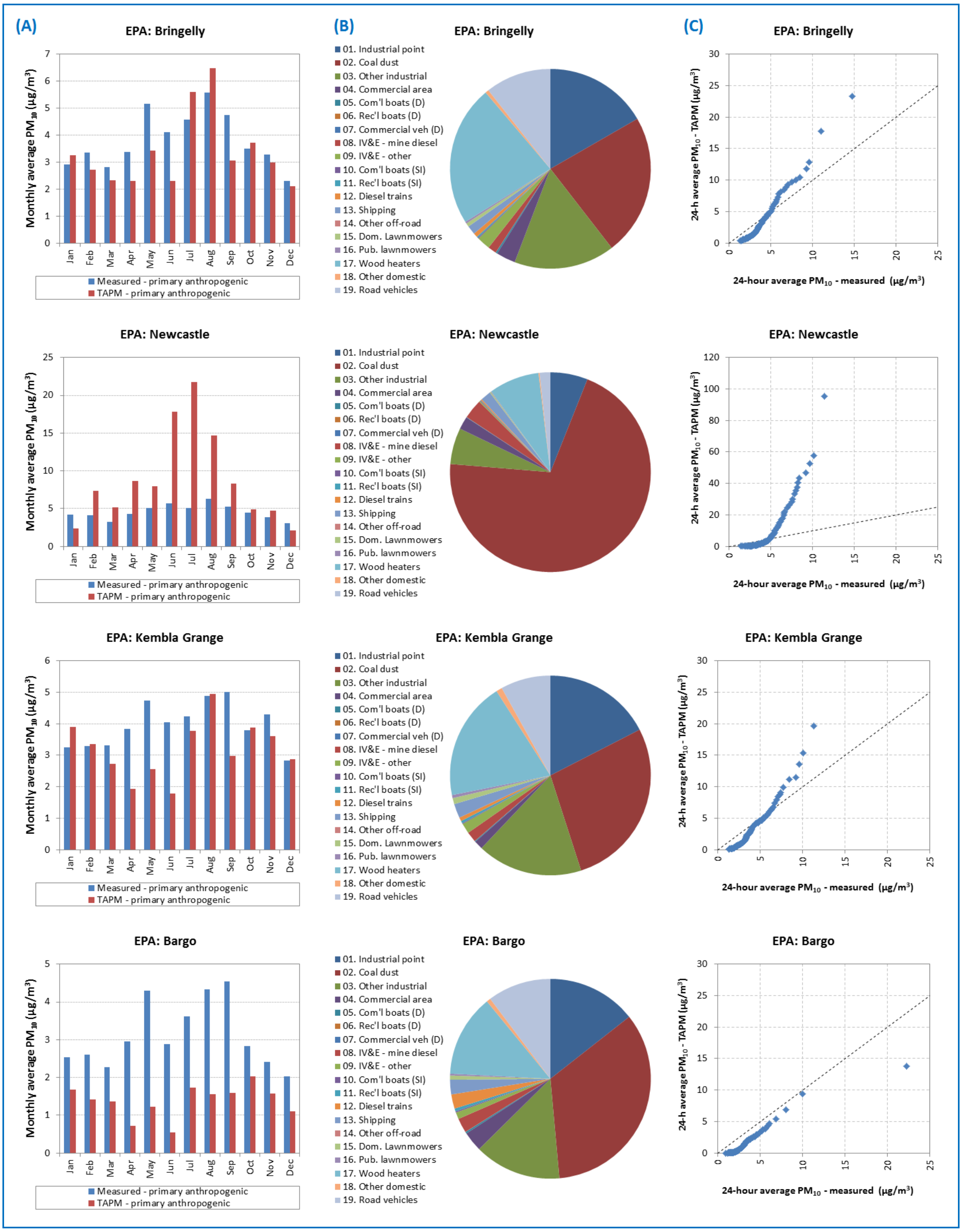

Figure B15: Model performance: PM$_{10}$ at Bringelly, Newcastle Kembla Grange and Macarthur sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

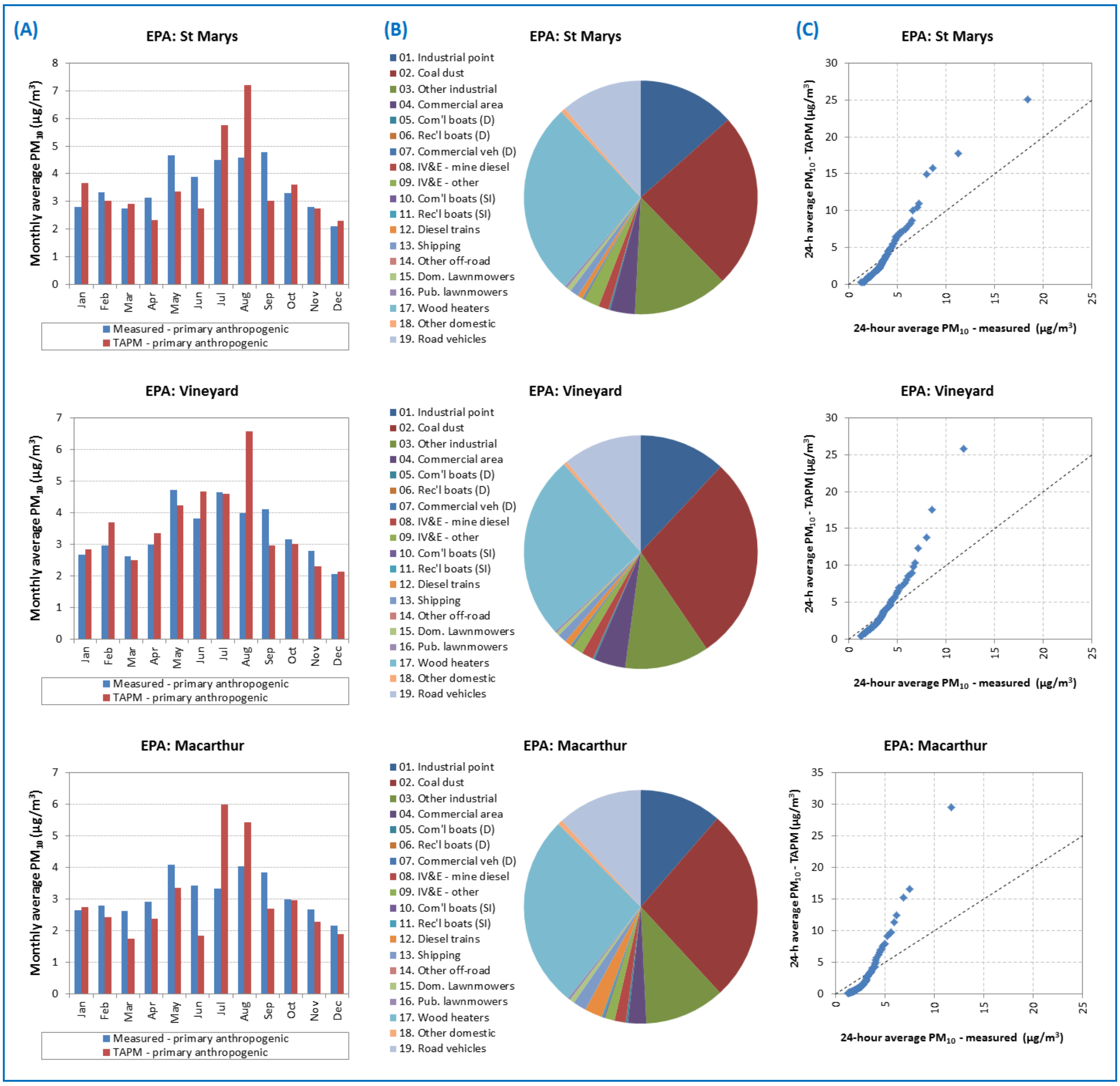

Figure B16: Model performance: PM10 at St Marys, Vineyard and Macarthur sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

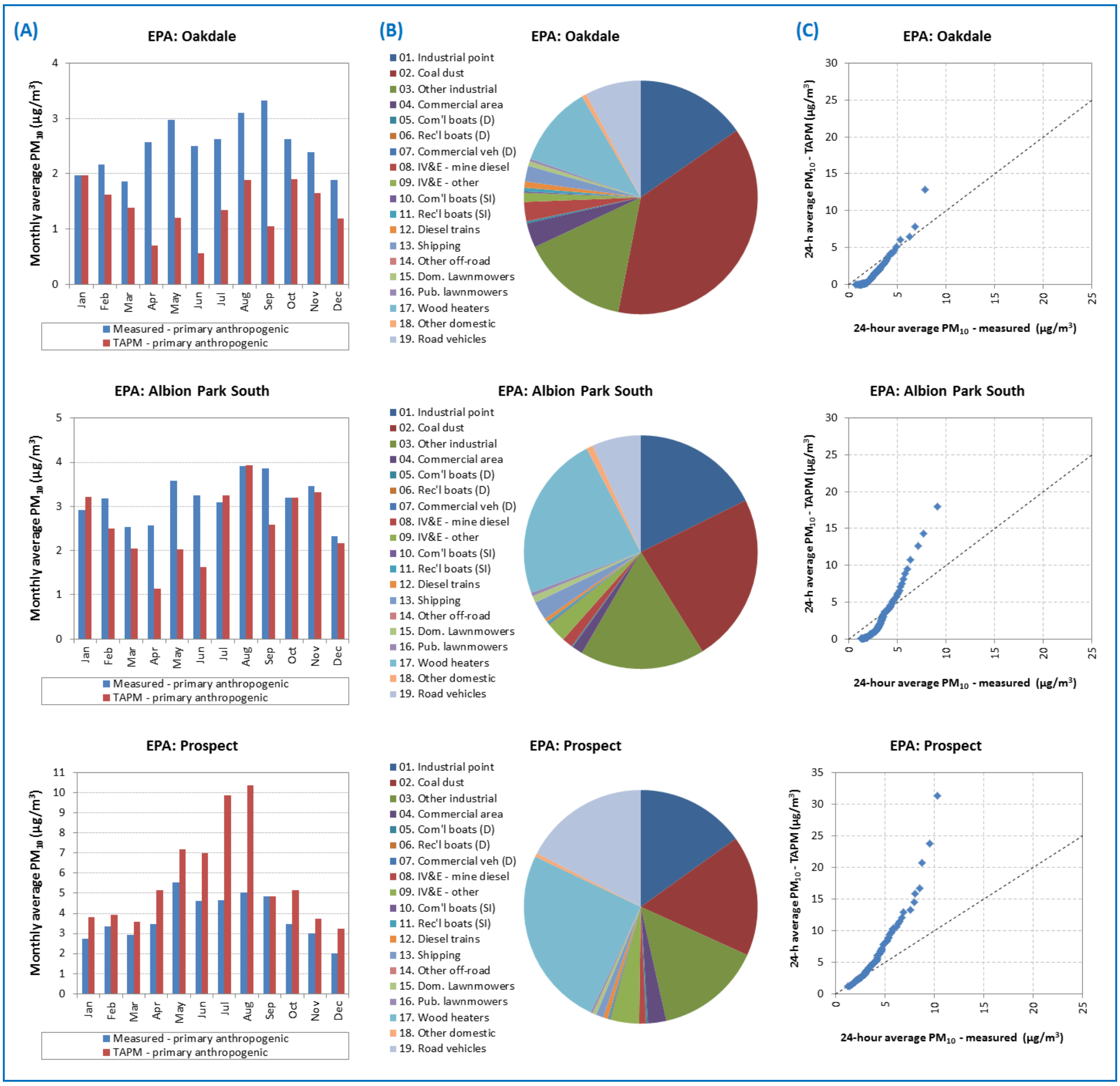

Figure B17: Model performance: PM_{10} at Oakdale, Albion Park south and Prospect sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

PM2.5 concentrations

Figure B18: Model performance: $PM_{2.5}$ at Mascot, Liverpool, Lucas Heights and Richmond sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

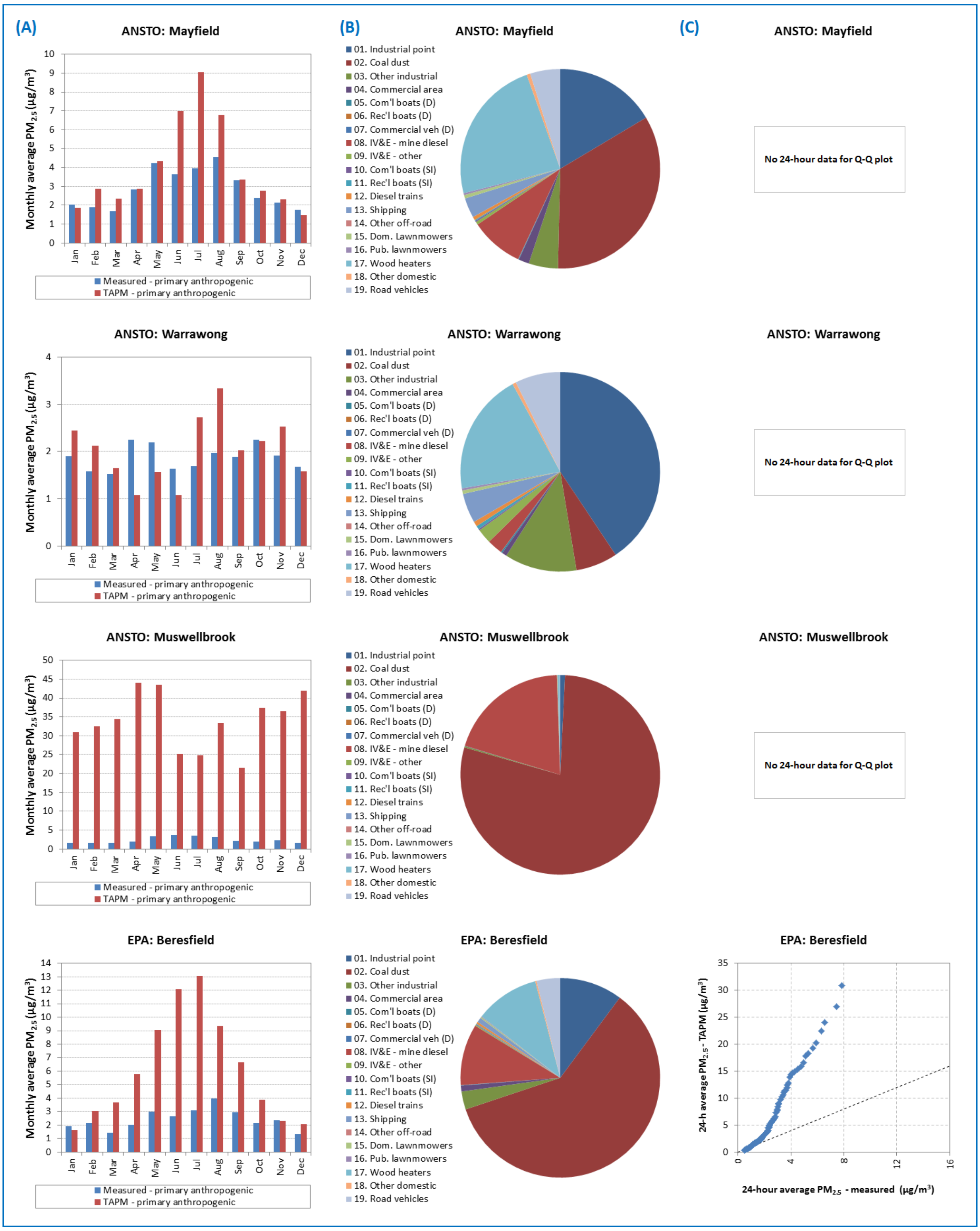

Figure B19: Model performance: $PM_{2.5}$ at Mayfield, Warrawong, Muswellbrook and Beresfield sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

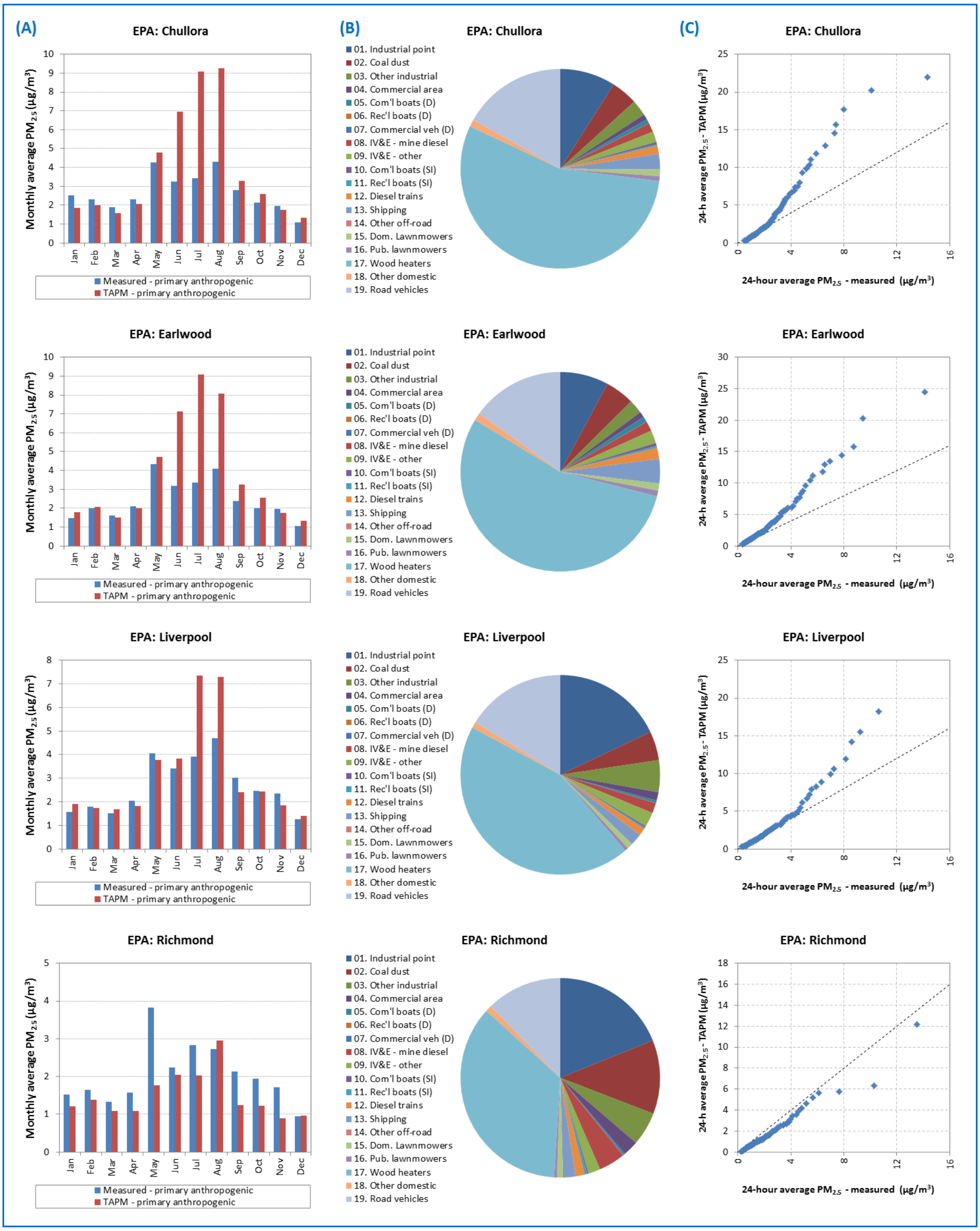

Figure B20: Model performance: $PM_{2.5}$ at Chullora, Earlwood, Liverpool and Richmond sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

Figure B21: Model performance: $PM_{2.5}$ at Wallsend, Wollongong, Muswellbrook and Singleton sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

The performance varied greatly from site to site, although there were some patterns in the data. In **Table B18** the monitoring sites are grouped according to TAPM performance, based on a visual inspection of the graphs. Whilst at some monitoring sites the model performed well, at most sites the performance was 'average' or 'poor'.

Table B18: Model performance by monitoring site in NSW (primary anthropogenic PM only)

Performance	Characteristics of model performance	Site(s)	
		PM_{10}	$PM_{2.5}$
'Good'	(A) Good agreement between monthly average predictions and measurements. (B) No common pattern in terms of sources/ (C) Over-prediction at highest concentrations. Other comments: With exception of Mascot, sites in Illawarra or outer Sydney.	Richmond Wollongong Bringelly	Mascot[b] Warrawong[b]
'Average'	(A) Tendency towards an over-prediction, but only in winter months. (B) Largest contributions from wood heaters and/or coal mine dust. (C) Increasing over-prediction with increasing concentration. Other comments: wide range of locations.	Chullora Earlwood Liverpool Rozelle Randwick Lindfield Newcastle St Marys[a] Vineyard[a] Macarthur[a] Prospect	Lucas Heights[b] Mayfield[b] Chullora Earlwood Liverpool Wallsend Wollongong
	(A) General under-prediction, especially in winter. (B) Coal mine dust or wood heaters largest single source. (C) Generally good agreement of 24-hour values. Other comments: With exception of Liverpool, sites in Illawarra or outer Sydney.	Oakdale Albion Park South Kembla Grange Bargo	Liverpool[b] Richmond Richmond[b]
'Poor'	(A) Very large over-prediction in all months. (B) Dominated by coal mine dust and mine-site diesel. (C) Very large over-prediction of 24-hour values, except at lowest concentrations. Other comments: Sites in Hunter Valley coal-mining region.	Beresfield Wallsend Muswellbrook Singleton	Beresfield[b] Muswellbrook[b] Muswellbrook Singleton

(a) Over-prediction in some months

(b) ANSTO sites

Whilst at some sites there were under-predictions of concentrations, over-predictions were more common. Different factors could have contributed to the model over-prediction, possibly in combination. For example:

1. The monitoring sites may not be entirely representative of the areas being modelled in TAPM, and concentrations may be affected by local factors.

2. The process for adjusting the monitoring data resulted in an underestimation of primary anthropogenic particles. However, as noted earlier, it was considered important to avoid overestimation.

3. The emission factors used for the different sources do not accurately reflect real-word emissions, or the assumptions when modelling emissions do not match those used to isolate primary anthropogenic PM in the measurements. For example, emission factors may include both solid particles and condensable material (e.g. organic carbon). The latter may have been characterised as SOA in the measurement adjustment process. However, the NSW emission inventory has been subjected to a rigorous quality assurance process.

4. There may be limitations to the simulation method in TAPM.

5. The meteorology data used in TAPM may not have been representative of the monitoring sites.

Each source modelled contributed (to a greater or lesser extent) to the general over-estimation of concentrations. However, in most cases there were two clear reasons for average or poor performance, as described next.

Firstly, there was a clear over-prediction of the contributions from coal mine dust - especially for PM_{10} - in all months. This was most extreme for the sites in the Upper Hunter Valley (Muswellbrook and Singleton), but it also strongly affected the sites in the Lower Hunter Valley. In Muswellbrook the modelled annual mean PM_{10} concentration (primary anthropogenic component only) was 175 µg/m³, whereas the measured primary anthropogenic concentration was just 4.7 µg/m³ and the measured total concentration was 22.3 µg/m³. Information on air quality in communities in the Upper and Lower Hunter Valley regions is provided by the NSW EPA's Upper Hunter Air Quality Monitoring Network (UHAQMN). An examination of the UHAQMN data revealed that the annual mean total PM_{10} concentration measured at Muswellbrook was not atypical of the concentrations across the region. Complete data for the UHAQMN sites were not available for 2011, but the average PM_{10} concentrations for sites having around five months' worth of data ranged from around 17 µg/m³ to around 25 µg/m³. During 2012 the highest reported 24-hour average PM_{10} concentration in 2012 was around 89 µg/m³ (at the Mount Thorley site) and the highest annual mean $PM_{2.5}$ concentration was around 10 µg/m³ (at the Muswellbrook site) **(NSW EPA, 2013)**. Clearly this was not an issue with the method used in the economic analysis to isolate the primary component, but involved a systematic over-prediction of PM from coal mines. Indeed, the general scale of the over-prediction was so large, that most grid cells across the NSW GMR were affected, even where one would expect there to be little contribution from coal mining activity (*e.g.* Rozelle).

Secondly, there was a clear over-prediction of concentrations in the winter months due to the contribution from domestic wood heaters.

These discrepancies were investigated in some detail. Several possible explanations for the general over-predictions were considered, as summarised below.

Vertical mixing

For NSW TAPM was set up with default options of emissions mixed vertically within the first model level of the atmosphere (to 10 m). It was apparent that the use of the default value was contributing significantly to the over-prediction, and it was therefore increased. The extent of the mixing was increased to a value of 100 m, equating to the first three vertical model levels. This allowed the emissions to spread further up into the atmosphere, and allowed them to be dispersed more easily, thus reducing any unrealistic trapping within the lower levels. This change reduced the predicted ground-level concentrations by approximately 50%, bringing them closer to the monitored values.

'Pit retention' in coal mines

Most activities at coal mines occur within the pit, and it is likely that a fraction of the emitted PM will not escape from the pit. Therefore, the concentrations associated with coal mine activities where scaled down using an 'escape fraction' to account for this effect. The NPI emission estimation technique manual suggests the use of a 5% control for PM_{10} pit retention. Another method taken from the Industrial Source Complex (ISC) model user guide **(USEPA, 1994)** involves computing an escape fraction, and is based on the following equation **(Winges and Cole, 1986)**:

$$Escape\ Fraction = \frac{1}{1 + {V_g}/{0.029 \times WS}}$$

Where:

$\boldsymbol{V_g}$ is the gravitational settling velocity

WS is the wind speed

0.029 is the proportionality constant in the relationship between flux from the pit and the product of wind speed and concentration in the pit **(Thompson, 1994)**.

Taking a meteorological extract for the Hunter Valley, the use of hourly escape fractions resulted in a pit retention effect of <1-3.1% for $PM_{2.5}$ and 1.4-60.4% for PM_{10}. On average the pit retention is less than 1% for $PM_{2.5}$ and around 7% for PM_{10} which is negligible compared with the size of the over-prediction. However, it would be reasonable to assume additional pit retention due to particles being trapped in the pit under stable conditions and a low-wind-speed threshold.

Wind-speed dependency

Emissions from coal mines in the Hunter Valley would primarily be the result of open cut mining activities. These coal mine sources can be separated into three classes covering all dust emission sources for which there are emission factor equations for open-cut mines:

- Wind erosion sources where emissions vary with the hourly average wind speed according to the cube of the wind speed. These sources would include stockpiles and exposed areas.
- Loading and dumping operations where emissions vary with wind speed to the power of 1.3. This is due to the impact wind has on these activities as they move materials.
- All other sources where emissions are assumed to be independent of wind speed (including hauling via trucks).

The proportion of emissions in each of these categories was assumed to be:

- 0.732 for emission sources that are independent of wind speed.
- 0.135 for emission sources that depend on wind speed (such as loading and dumping).
- 0.133 for wind erosion sources.

These factors were based on a detailed analysis of mine dust inventories undertaken as part of the Mount Arthur North Environmental Impact Statement (EIS) **(URS, 2000)**, and have subsequently been accepted as appropriate and routinely applied to subsequent air quality impact assessments for mining operations over the past eleven years.

Scaling for wind erosion reduced predicted ground level concentrations by 3-11% at the monitoring sites (see examples in **Table B19**). Scaling the emissions by both wind erosion and wind sensitivity resulted in a 5-19% reduction in annual predicted ground level concentrations at the monitoring sites. Although this scaling didn't bring emissions within the range of the monitored values, they incorporated realistic features of open cut coal mines into the reported NPI emissions.

Table B19: Comparison of predicted annual mean PM_{10} concentrations for scaling methods (only affected sites are shown)

Site name	Site ID	Annual mean PM_{10} concentration (µg/m³)		
		Coal mine PM_{10}	Scaled for wind erosion only	Scaled for wind erosion and wind speed sensitivity
Beresfield	EPA_01	23	22	22
Wallsend	EPA_06	9	8	8
Muswellbrook	EPA_08	216	197	185
Singleton	EPA_09	76	70	66
Newcastle	EPA_14	7	7	7

Met modelling year

Table B20 shows that for all four years modelled the predicted annual mean ground level concentrations are comparable across all monitoring sites. It can be seen that 2011 has only slightly lower concentrations than the other years across the year.

Table B20: Comparison of predicted annual mean PM_{10} concentrations for meteorological years 2008-2011.

Site name	Site ID	Annual mean PM_{10} concentration (µg/m³)			
		2008	2009	2010	2011
Beresfield	EPA_01	22.5	23.7	20.7	20.8
Chullora	EPA_02	2.5	2.6	2.7	2.8
Earlwood	EPA_03	2.5	2.7	2.8	2.8
Liverpool	EPA_04	3.5	3.8	3.8	3.7
Richmond	EPA_05	1.8	2.0	2.1	2.3
Wallsend	EPA_06	8.0	9.7	7.5	8.6
Wollongong	EPA_07	2.0	2.1	2.2	2.2
Muswellbrook	EPA_08	175.8	161.8	191.8	193.2
Singleton	EPA_09	79.7	75.7	76.8	68.6
Rozelle	EPA_10	2.7	2.7	2.8	3.0
Randwick	EPA_11	4.7	4.7	5.1	5.0
Lindfield	EPA_12	2.7	2.6	2.8	3.0
Bringelly	EPA_13	3.4	4.0	3.7	4.0
Newcastle	EPA_14	6.6	8.4	6.5	7.2
Kembla Grange	EPA_16	3.1	3.3	3.5	3.7
Bargo	EPA_17	0.9	1.0	1.1	1.1
St Marys	EPA_19	3.3	3.7	3.8	4.1
Vineyard	EPA_20	2.8	2.6	2.9	3.2
Macarthur	EPA_22	1.9	2.0	2.1	2.3

Comparing the wind speed and wind direction against the scaled concentrations (**Figure B22**) it is apparent that higher ground level concentrations (GLCs) are associated with wind speeds around 1 m/s, no rainfall and north-westerly winds. Additionally they appear to occur when the mixing height is low. Looking at the diurnal cycle of the concentrations (**Figure B23**) it is very clear that the particles are building up overnight in the stable conditions and dispersing better during the day.

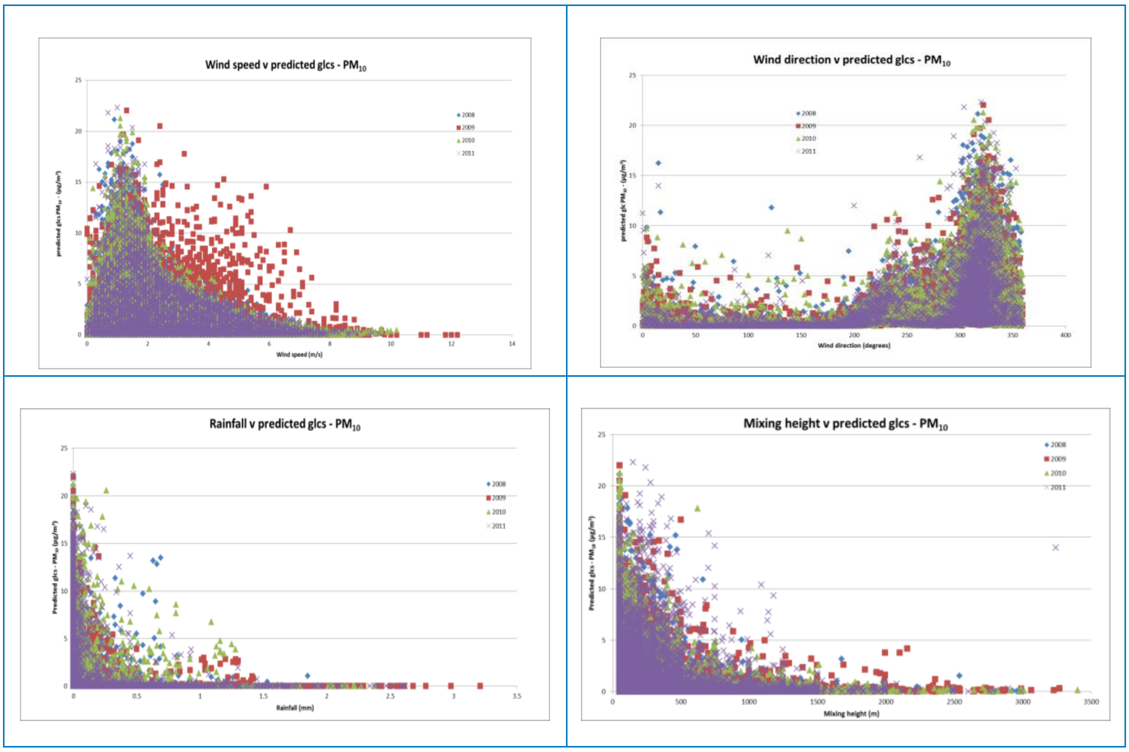

Figure B22: Comparison of wind speed, wind direction and mixing height against hourly predicted PM_{10} GLCs (2008-2011).

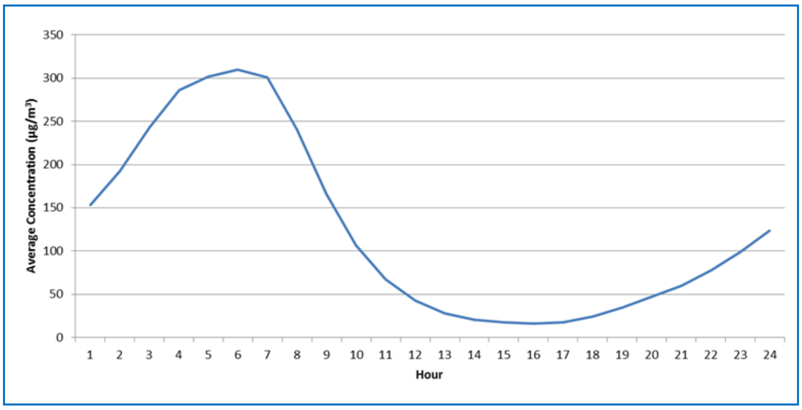

Figure B23: Comparison of 24-hour average predicted GLCs for meteorological years 2008-2011.

B.4.1.2 Victoria

The performance of TAPM for PM_{10} and $PM_{2.5}$ at the Victoria monitoring sites is illustrated in **Figures B24** to **B26**. For most of the monitoring sites in Victoria there was an over-prediction of PM_{10} in most or all months, with this being most pronounced in winter. The one site which showed a different monthly pattern for PM_{10} was Geelong South, where there was under-prediction in all months, especially in summer. With exception of Geelong South, the Q-Q plots showed that 24-hour concentrations were over-predicted across the concentration range. Wood heaters were the predominant source at Alphington, Box Hill, Brighton, Dandenong, Mooroolbark, and Geelong South, whereas industrial point sources dominated at Footscray. There was no single dominant source at the RMIT and Richmond sites. $PM_{2.5}$ was only monitored at two sites (Alphington and Footscray), and the patterns for these sites were similar to those for PM_{10} at the same sites.

PM10 concentrations

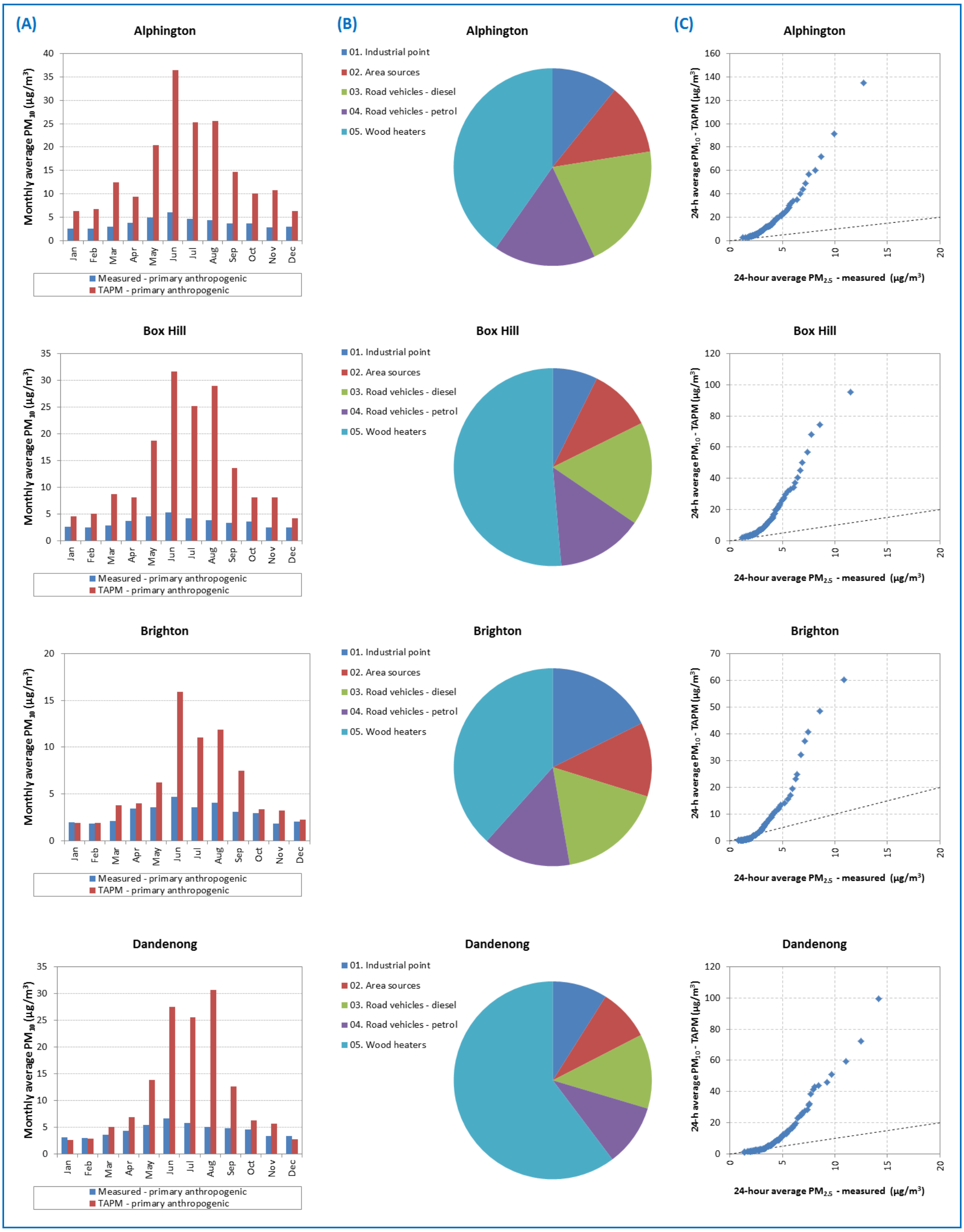

Figure B24: Model performance: PM10 at Alphington, Box Hill, Brighton and Dandenong sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

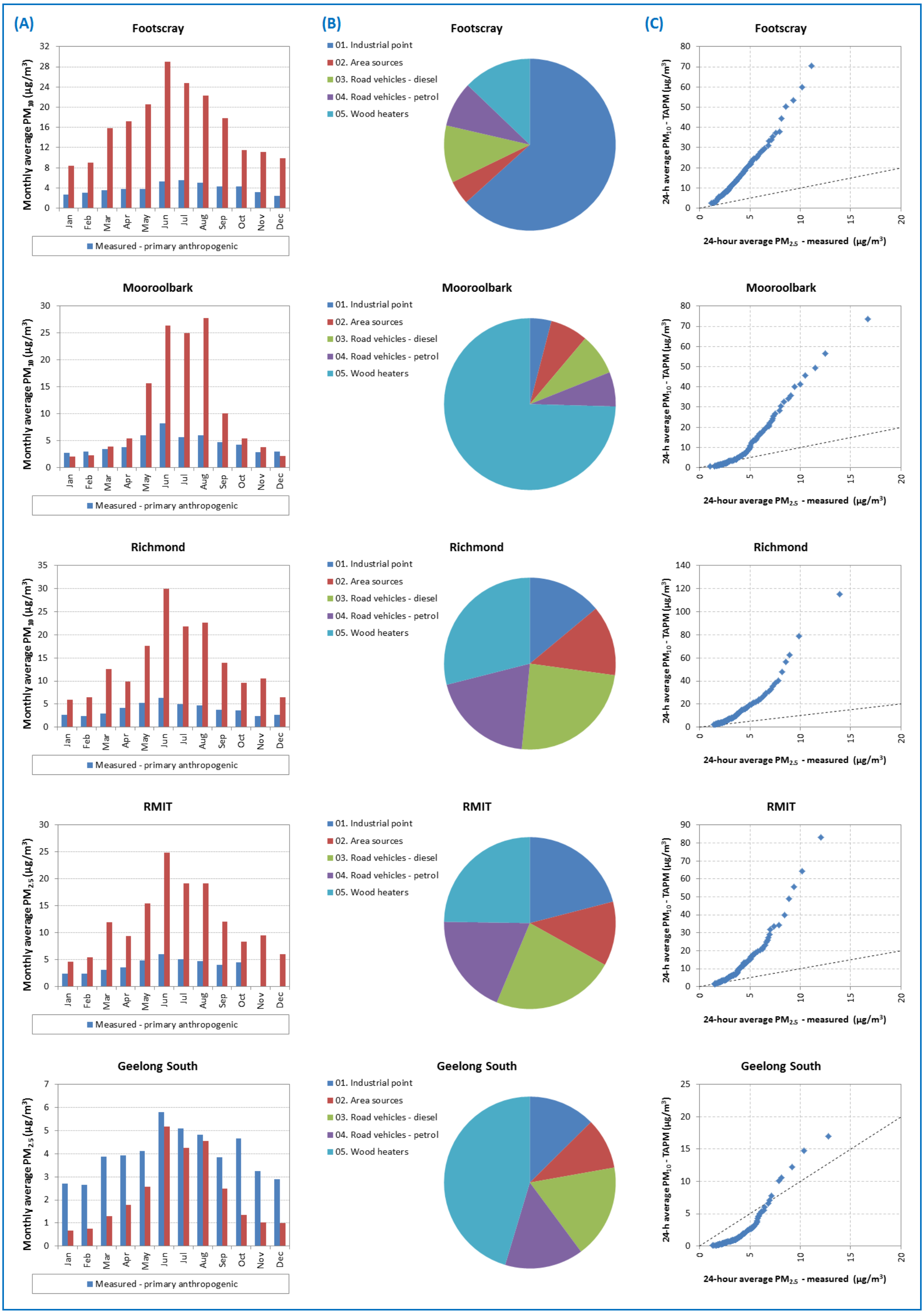

Figure B25: Model performance: PM_{10} at Footscray, Mooroolbark, Richmond, RMIT and Geelong South sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

PM2.5 concentrations

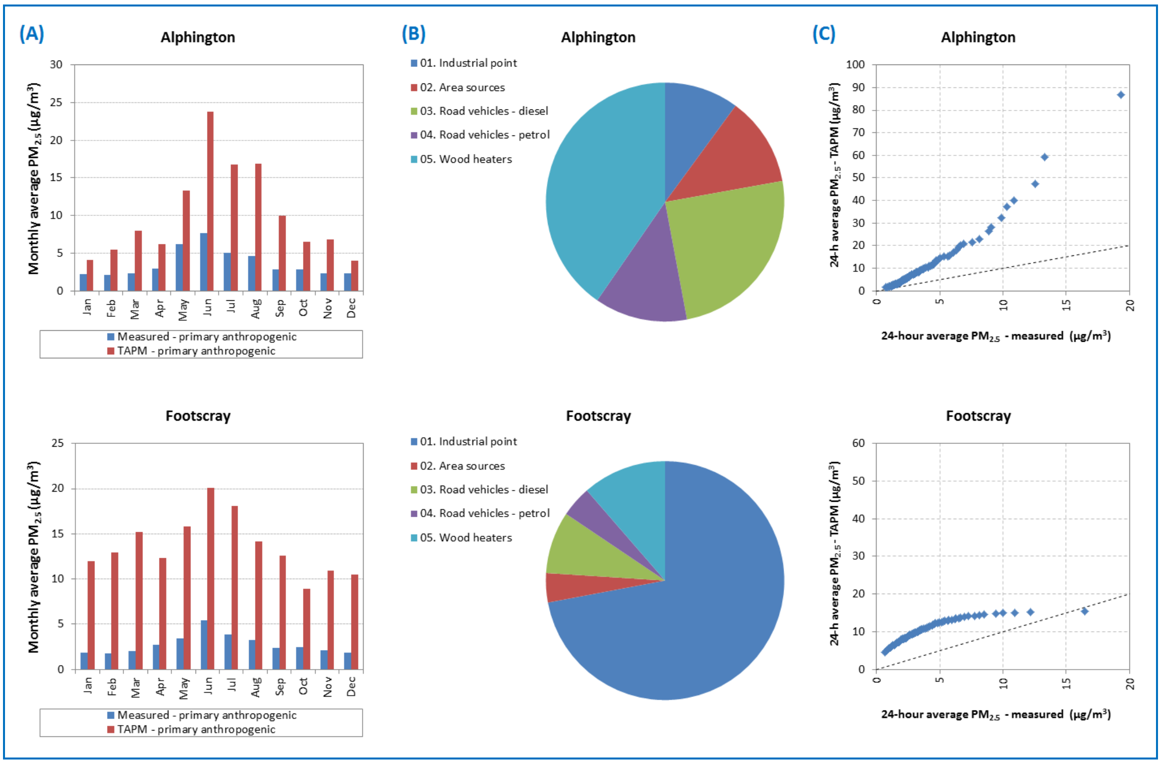

Figure B26: Model performance: $PM_{2.5}$ at Alphington and Footscray sites (A = monthly average concentration, B = source contributions, C = Q-Q plot)

B.4.2 Model adjustment

Given the complexities of the modelling, the wide range of monitoring sites considered, and the varying performance of TAPM for different sites, a pragmatic approach was used to ensure that the modelling more accurately reflected the reality of the measurements across the whole modelling domain.

The model adjustment process was based upon the calculation of the root mean square error (RMSE) on the annual mean concentrations across all monitoring sites. The value of RMSE was calculated as follows:

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2}$$

Where:

RMSE	=	root mean square error concentration (µg/m³)
n	=	number of sites
P_i	=	predicted annual mean concentration at site ***i*** (µg/m³)
O_i	=	observed (measured) annual mean concentration at site ***i*** (µg/m³)

The minimum RMSE was determined by varying model calibration factors (multiples of the modelled concentrations) for coal mines, mine site diesel and wood heaters in combination.

Coal mine dust and mine site diesel were adjusted by the same proportion. A cursory examination of the predictions indicated that these two sources would have to be reduced by at least 80%. The model calibration factor was therefore varied between 0.20 and zero in increments of 0.01 (the same factor was used for both). A smaller reduction was required for wood heaters, and the model calibration factor varied between 1.00 and 0.30 in steps of 0.01. The Q-Q plots indicated that TAPM generally provided reliable 24-hour average predictions below 5 µg/m³ for PM_{10} and below 2 µg/m³ for $PM_{2.5}$. Therefore, only the 24-hour concentrations above these values were adjusted. All combinations of scaling factors (1,400 in total) were tested, and the minimum RMSE determined.

The approach used for the Victoria sites was similar to that described in **Section B.4.1.1** for NSW. The main difference was that in Victoria the values of the scaling factors were influenced disproportionately by three sites in areas of relatively low population density: Dandenong, Mooroolbark and Geelong South. In order to avoid very low scaling factors for all sites, these three sites were excluded from the analysis.

The results of the adjustment process – the overall model calibration factors - are summarised in **Table B22**. The improvement in the predictions for one site (Singleton in NSW) is shown in **Figure B27**.

Table B22: Model calibration factors

Jurisdiction	Source	PM_{10}	$PM_{2.5}$
NSW	Coal dust/mine site diesel	0.02[(a)]	0.08[(b)]
	Wood heaters	0.37[(a)]	0.67[(b)]
Victoria	Industrial point	0.20[(b)]	0.10
	Area sources	0.50[(b)]	0.40
	Road vehicles - diesel	0.50[(b)]	0.50
	Road vehicles - petrol	0.50[(b)]	0.50
	Wood heaters	0.20[(b)]	0.20

(a) Only applied to 24-hour average concentrations (per source) >5 µg/m³
(b) Only applied to 24-hour average concentrations (per source) >2 µg/m³

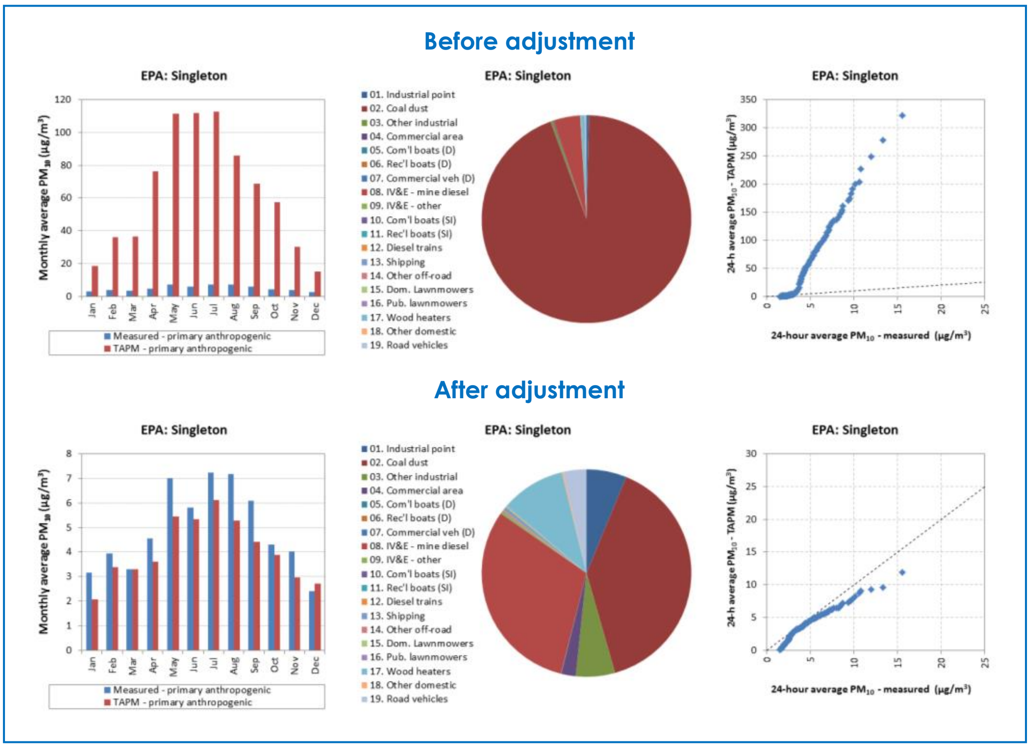

Figure B27: PM_{10} at Singleton NSW, before and after adjustment

B.4.3 Correction to ensure representative base year concentrations

A further consideration was the representativeness of the modelled years. In other words, how representative were 2011 (NSW) and 2006 (Victoria) in terms of the prevailing multi-year concentrations in the two jurisdictions? For NSW in 2011, a critical factor was the occurrence of successive Southern Oscillation (La Niña) events in 2010–11 and 2011–12. These events were two of the most significant in Australia's recorded meteorological history. The La Niña events were associated with record rainfall over much of Australia, and April 2010 to March 2012 was Australia's wettest two-year period on record **(BOM, 2012)**. This is reflected in the PM monitoring data. For all the NSW EPA monitoring sites during the period 2006-2012, **Figure B28** shows the ratio between the annual mean concentration measured in a given year and the annual mean concentration measured in 2011. Separate results are provided for PM_{10} and $PM_{2.5}$. The corresponding plot for Victoria, with concentrations shown relative to 2006, is given in **Figure B29**.

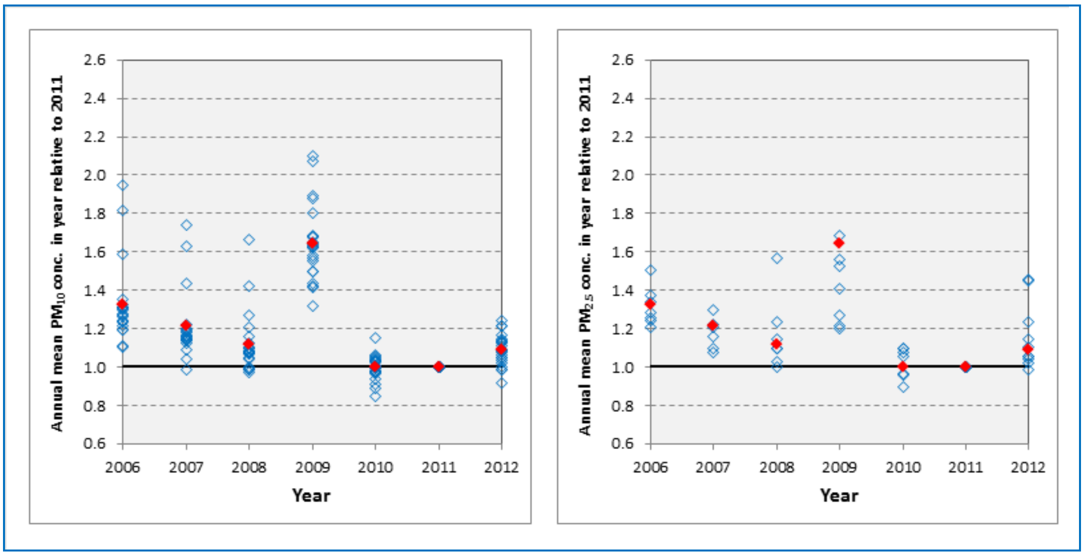

Figure B28: PM_{10} and $PM_{2.5}$ concentrations at NSW EPA monitoring sites in the years from 2006 to 2012, relative to 2011. The blue points are the individual monitoring sites, and the red points are the average ratios over all site.

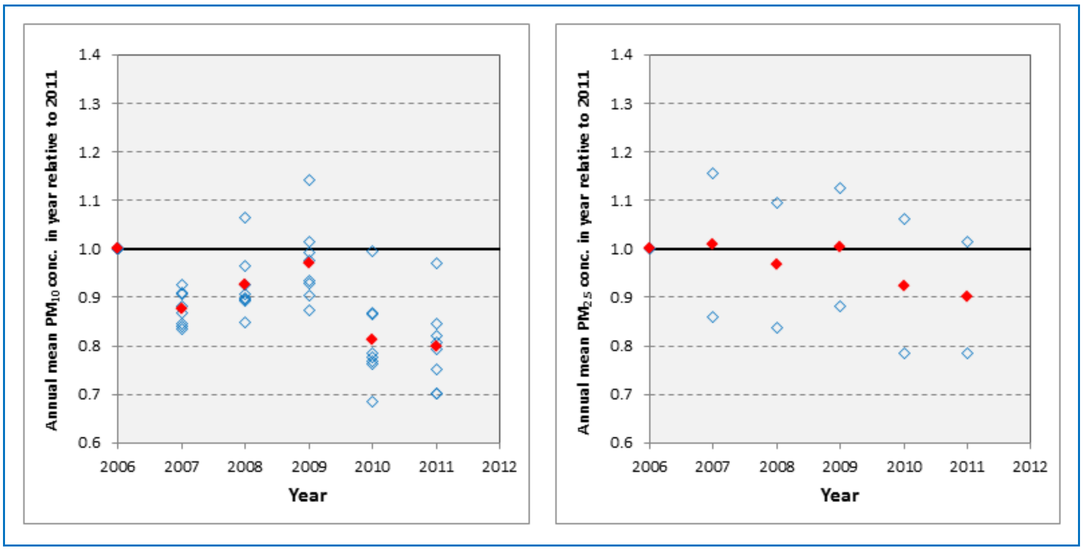

Figure B29: PM_{10} and $PM_{2.5}$ concentrations at EPA Victoria monitoring sites in the years from 2006 to 2011, relative to 2006. The blue points are the individual monitoring sites, and the red points are the average ratios over all site.

For NSW it is immediately clear the PM concentrations in 2011 were lower than in the other years (although similar to those in 2010). In addition, concentrations in 2009 were substantially higher than those in the other years. 2009 was the warmest year on record for the state of NSW, and annual average rainfall for the state was low at 484 mm. There were also several significant regional dust storms in 2009. Similarly, in Victoria the average PM_{10} and $PM_{2.5}$ concentrations were, in most cases, higher than those in the subsequent years.

Additional concentration adjustments for PM_{10} and $PM_{2.5}$ were therefore applied to avoid the bias associated with the selection of a single base year. The ratios are also shown in **Table B23**. For NSW overall average factors of 1.20 and 1.18 were applied to the modelled concentrations of PM_{10} and $PM_{2.5}$ respectively. The corresponding factors for Victoria were 0.90 and 0.97.

Table B23: Base year bias adjustments

Year	NSW- Annual mean concentration bias in year relative to 2011 (average for all sites)		VIC Annual mean concentration bias in year relative to 2006 (average for all sites)	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
2006	1.33	1.32	*1.00*	*1.00*
2007	1.21	1.18	0.88	1.01
2008	1.12	1.17	0.93	0.97
2009	1.65	1.41	0.97	1.00
2010	1.00	1.02	0.81	0.92
2011	*1.00*	*1.00*	0.80	0.90
2012	1.09	1.16	-	-
Overall average	**1.20**	**1.18**	**0.90**	**0.97**

In the other jurisdictions we used multi-year averages to determine the concentration in the base year, and therefore no further adjustments of this type were made.

Appendix C EMISSION AND CONCENTRATION PROJECTION METHODS

C.1 PROJECTION METHODS

C.1.1 Emission projection methods

Population projections for the states and capitals were used for several aspects of the analysis. The projections were taken from **ABS (2008)** (**Figure C1**). For industrial sources, where emissions data were unavailable for future years, we obtained estimates using scaling factors based on economic growth. The economic metric that was considered to be the most appropriate was the 'gross value added' (GVA) by industry from ABS Catalogue 5220.0 (*Australian National Accounts - State Accounts*)[21]. This breaks the economy down into 20 sectors, and provides historical data for the period 1990-2012. GVA is a chain volume measure. An average annual change[22] in GVA over this period was determined for each state and for each type of industry, and the resulting value was applied to future years. For most inventories we used the value for 'manufacturing', although separate scaling factors were derived for some specific industries (notably mining). Some examples of the values used are shown in **Figure C2**.

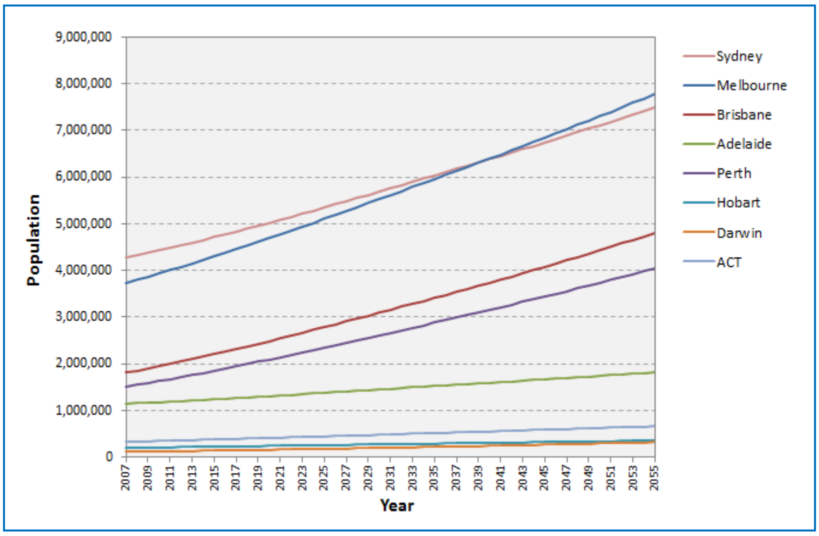

Figure C1: Projected population for main state conurbations (ABS, 2008)

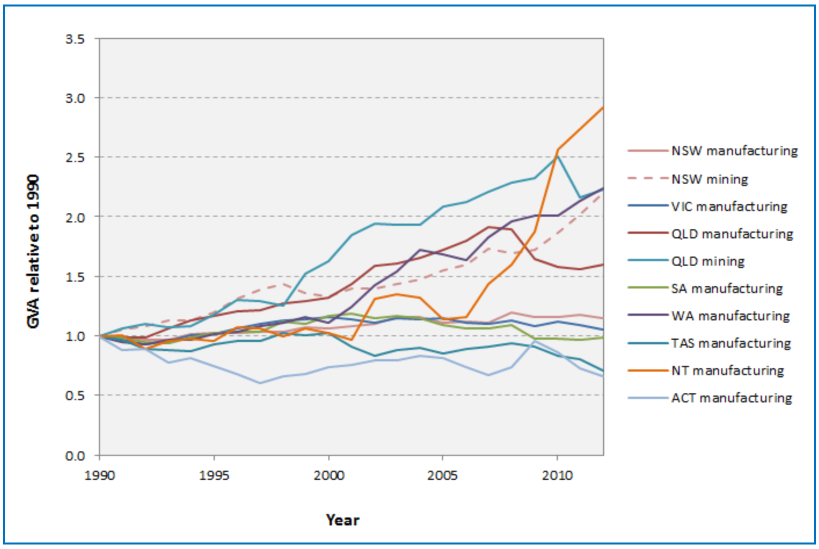

Figure C2: GVA relative to 1990 (ABS, 2012b)

[21] http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5220.02010-11

[22] Calculated as a geometric mean.

For road vehicles and other mobile sources, emissions of PM_{10} and $PM_{2.5}$ for any missing years were obtained using national emission projections from **BITRE (2010)**. **Figure C3** shows the BITRE projections for PM_{10} emissions from different road vehicle categories. The data refer only to exhaust emissions. Emissions from non-exhaust sources (tyre wear, brake wear and road surface wear) were assumed to vary in proportion to projected travel and transport (vehicle-kilometres), again taken from **BITRE (2010)**. Because exhaust emissions from road vehicles are expected to continue to decrease in the future as a result of improved emission-control and fleet turnover, and because (uncontrolled) non-exhaust emissions will increase in line with travel and transport, PM emissions (especially PM_{10}) will be increasingly dominated by the non-exhaust component. This is a problem for policymakers, as few control technologies for non-exhaust particles are currently foreseen.

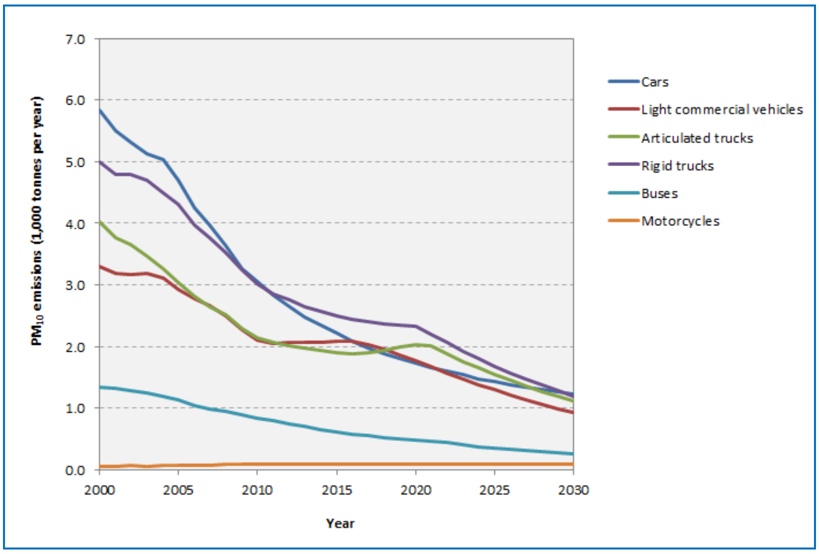

Figure C3: Projections of exhaust PM_{10} emissions from different road vehicle categories in Australia (BITRE, 2010)

The BITRE projections for national PM_{10} emissions from rail transport, maritime shipping and aviation are shown for the period 2000-2030 in **Figure C4**. BITRE predicted a significant growth in emissions from rail transport in the future, whereas for maritime transport and aviation there is little net change in emissions between 2000 and 2030.

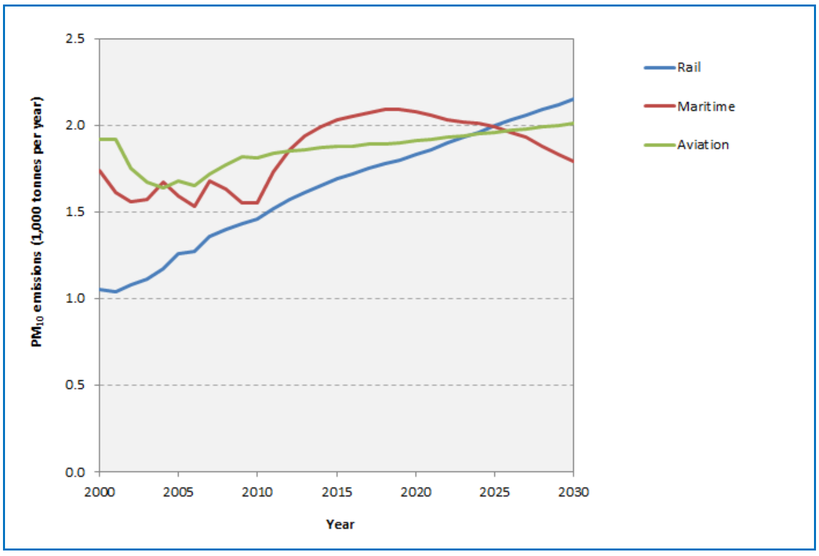

Figure C4: Projections of PM_{10} emissions from other transport modes in Australia (BITRE, 2010)

C.1.2 Concentration projection method

In all jurisdictions it was assumed that future primary anthropogenic concentrations would change in direct proportion to future anthropogenic emissions. Emission scaling factors for PM_{10} and $PM_{2.5}$ in all years (relative to 2011) were therefore derived by the project team. These emission scaling factors were then used to determine future-year concentrations. In NSW and Victoria each modelled source was treated separately, and for each source type the scaling factors were assumed to apply equally to all grid cells. The scaling factors for projections were developed from the larger emissions inventory domain rather than the smaller TAPM domain. In the other jurisdictions only total emissions were considered.

To determine annual mean concentrations in future years the scaling factors were simply applied to the annual mean concentration in 2011. A similar approach was used for 24-hour concentration metrics in the other jurisdictions. In other words, we also applied the emission scaling factors to determine the 6th highest PM_{10} and maximum $PM_{2.5}$ concentrations in future years.

For the 24-hour calculations in NSW and Victoria a more sophisticated approach was possible, whereby the 2011 concentrations were adjusted on a daily basis for each grid cell (**Figure C5**).

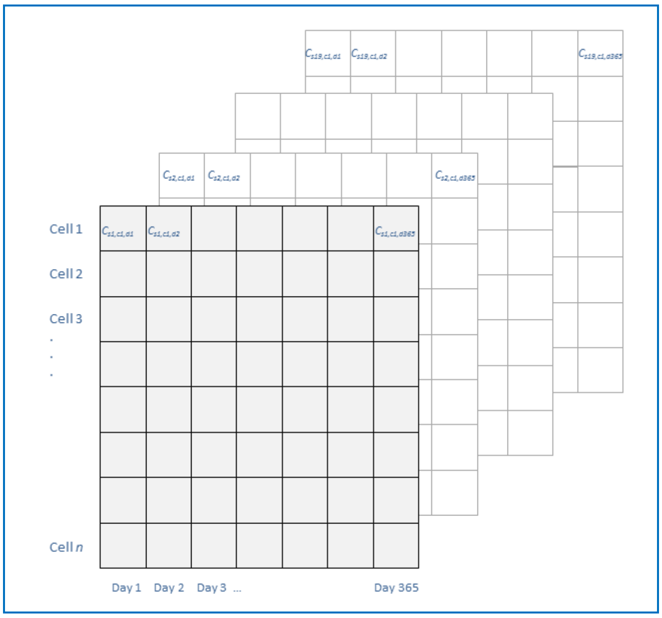

Figure C5: Calculation of 24-hour concentrations in NSW GMR and Port Phillip region

The total 24-hour concentration in a given grid cell on the first day of the year was calculated by summating the contributions from all sources (19 different sources were considered for NSW):

$$C_{24,c,y,d} = \sum_{s=1}^{s=19} c_{c,s,d,2011} \times YSF_{y,s} \times ASF_{y,s}$$

Where:

$C_{24,c,y,d}$	=	total 24-hour concentration in cell ***c*** on day ***d*** in year ***y***
s	=	source
$c_{c,s,d,2011}$	=	24-hour concentration for source ***s*** in cell ***c*** on day ***d*** in 2011
$YSF_{y,s}$	=	year scaling factor for year ***y*** and source ***s***
$ASF_{y,s}$	=	abatement scaling factor for year ***y*** and source ***s*** (set to zero for BAU scenario)

The emission reductions associated with the different portfolios of abatement measures were also applied at this stage, although for the BAU scenario the emission reductions were set to zero.

A fixed (annual mean) contribution from natural and secondary particles was added to each grid cell. The relevant metrics for PM_{10} (the sixth highest 24-hour concentration) and $PM_{2.5}$ (the maximum 24-hour concentration) were then determined for each grid cell from the results.

This calculation was computationally very intensive, and therefore by necessity the 24-hour evaluation was narrower in scope (fewer years were assessed).

C.2 NEW SOUTH WALES GMR

C.2.1 Data supplied

Emission projections at five-year intervals from 2011 to 2036 were already available for the majority of emission sources and by local government area from the latest NSW GMR emissions inventory **(NSW EPA, 2012a-f)**. The data included in the Emissions-to-Area reports generated by NSW EPA are summarised in **Table C1**. Relatively little work was therefore required on the NSW projections.

Table C1: Parameters included in the 'Emissions to Area' reports

Parameter	Selection
Substances included	➢ TSP ➢ NO_x ➢ CO ➢ NH_3 ➢ PM_{10} ➢ NO ➢ SO_2 ➢ SO_3 ➢ $PM_{2.5}$ ➢ NO_2 ➢ VOCs ➢ H_2SO_4
Years	➢ 2011 ➢ 2021 ➢ 2031 ➢ 2016 ➢ 2026 ➢ 2036
Modules	➢ Industrial ➢ On-road mobile ➢ Commercial ➢ Biogenic/Geogenic ➢ Off-road mobile ➢ Domestic/Commercial

C.2.2 Projection methodology and assumptions in BAU scenario

Emissions in the baseline inventory year (2008) were projected for the period 2011-2036 using multiplicative growth factors and control factors. This work was undertaken by NSW EPA. For NSW the BAU emission scenarios for each main source group were based on current economic or demographic forecasting, taking into account natural growth in population and activity, and scheduled air improvement actions.

C.2.2.1 Industrial, commercial and domestic-commercial sources

The emission projection methodologies for the following source groups are described in the reports for the NSW GMR inventory:

- ➢ Industrial point sources **(NSW EPA, 2012e)**
- ➢ Commercial sources **(NSW EPA, 2012c)**
- ➢ Domestic-commercial sources **(NSW EPA, 2012d)**

Separate projection factors were specified for specific activities within these source groups.

The NSW GMR projection methodologies mainly involve the application of energy projection data for Australian and New Zealand Standard Industrial Classification (ANZSIC) categories or the application of population forecasts from the ABS. Data from the following sources were used by NSW EPA to develop the projection factors:

- Energy (primary or final) projections for ANZSIC categories published by the Australian Bureau of Agricultural and Resource Economics **(ABARE, 2006)**
- Dwelling growth **(TDC, 2009)**
- Population growth **(TDC, 2009)**
- Vehicle-kilometres travelled growth **(TDC, 2009)**

For different types of industrial and commercial activity, emission-control factors were taken from the Regulatory Impact Statement (RIS) for the proposed Clean Air Regulation 2010[23].

For domestic-commercial sources, emissions for wood heaters were adjusted by NSW EPA using control factors which accounted for the uptake of wood heaters complying with AS/NZS 4013:1999[24] and the retirement of older, non-compliant wood heaters. The NSW EPA also developed a stock model for wood heaters[25]. No other sources included controls.

C.2.2.2 Mobile sources – off road

The projection methodology for off-road mobile source emissions between 2009 and 2036 is described in **NSW EPA (2012f)**. The emission projections were derived based on (in most cases) final/primary energy consumption by industry and fuel in NSW **(ABARE, 2006)** or (in the case of recreational boats) total dwelling growth in the GMR **(TDC, 2009)** (**Table C2**).

Table C2: Surrogate variables used for projection of off-road mobile emissions

Source type	Projection factor surrogate
Aircraft (flight operations)	Final energy consumption for air transport using petroleum
Aircraft (ground operations)	Final energy consumption for air transport using petroleum
Commercial boats	Final energy consumption for agriculture, commercial & services and domestic water transport using petroleum
Commercial off-road vehicles and equipment	Final energy consumption for agriculture, manufacturing & construction and mining using liquid petroleum gas, petroleum and natural gas
Industrial off-road vehicles and equipment	Final energy consumption for manufacturing & construction and mining using liquid petroleum gas, petroleum and natural gas
Locomotives	Final energy consumption for rail transport using petroleum
Recreational boats	Total dwelling growth
Ships	Final energy consumption for international water transport using petroleum

C.2.2.3 Mobile sources - road transport

The projection methodology used in the NSW GMR road transport inventory is described in Appendix B of **NSW EPA (2012g)**. The projections took into account the following:

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[23] http://www.environment.nsw.gov.au/resources/air/10504caris.pdf

[24] *Domestic solid fuel burning appliances - Method for determination of flue gas emission* http://infostore.saiglobal.com/store2/Details.aspx?ProductID=375908

[25] Documented in *Economic Appraisal of Wood Smoke Control Measures* http://www.environment.nsw.gov.au/resources/air/WoodsmokeControlReport.pdf

- The future vehicle fleet age distribution. Assumptions were made regarding the emissions performance of the fleet based on promulgated and proposed future emission standards relative to the emission data for the current fleet.
- Vehicle-kilometres travelled (VKT), which is a measure of transport activity. The total VKT by vehicle type from 2008 to 2036 used for the emission projections was provided by the NSW Bureau of Transport Statistics (BTS). VKT was estimated by BTS using the Strategic Transport Model (for passenger vehicles) and the Freight Movement Model (for commercial vehicles).

C.2.2.4 Interpolation and projections beyond 2036

In NSW emissions data were obtained for the years 2016, 2021, 2026, 2031 and 2036. Emissions for the intervening years were determined by linear interpolation. Emissions for the years 2036 to 2055 were determined using the methods described in **Section C1.1**. Emissions from mining (coal dust and mine site diesel) were scaled using an historical (1990-2012) annual change in GVA for the sector (+3.6% per annum), whereas for all other industrial commercial sources an annual change in GVA for manufacturing (+0.6% per annum) was used **(ABS, 2012b)**. Emissions from all other sectors were scaled in line with the NSW population from **ABS (2008)**.

C.3 VICTORIA (PORT PHILLIP)

C.3.1 Data supplied

The only projection year included in the Victoria emissions inventory was 2030, and the gridded emission files for 2030 were supplied to Pacific Environment by EPA Victoria. An interpolation/extrapolation approach was therefore used to determine emissions in the years required for the economic analysis.

C.3.2 Projection methodology and assumptions in BAU scenario

The 2030 emissions inventory was generated by EPA Victoria by modifying the 2006 inventory to represent the expected changes in each sector. Important changes between 2006 and 2030 included a general reduction in exhaust emissions from road vehicles and a general increase in all population-related emissions (domestic & commercial sources). The ABS **(ABS, 2008)** predicts that the population of Melbourne will grow by 50% between 2006 and 2030. Over the Port Phillip region, population growth is estimated to be 45%. The assumptions used in the development of the 2030 inventory were also supplied **(Walsh, 2012b)**, and are summarised below for each sector. In all cases the projection methodology was based on emissions in the whole inventory domain.

C.3.2.1 Industrial sources

Growth rates in the industry sector were based on industry projections to 2018, with the same growth rates assumed to be valid out to 2030. EPA Victoria predicted significant changes to the power generation sector by 2030. It was assumed that most electrical power will be generated using natural gas, brown coal, co-generation and tri-generation. Smaller amounts of power will be generated using wind, black coal, hydro-electric, biomass (from landfill), liquid fuels and solar **(Walsh, 2012b)**.

C.3.2.2 Area sources

As noted earlier, the area source emissions file supplied by EPA Victoria included many different individual types of sources. Information on the projection methodology was not available for all specific sources. However, some details were available for mobile off-road sources, rail and shipping.

Across Victoria, diesel passenger train travel was predicted to grow by 20% between 2006 and 2030. Growth in shipping and rail freight was expected, and activity at Victorian ports was assumed to increase in line with freight projections. The sulfur content of shipping fuels was assumed to remain constant **(Walsh, 2012b)**.

For agricultural and heavy industrial engines and equipment, growth was taken to be a function of the longer life spans of agricultural engines and equipment, and emissions were also calculated based on the progressive introduction of US emission standards **(Walsh, 2012b)**.

C.3.2.3 Wood heaters

EPA Victoria assumed that emissions from certain domestic and commercial sectors – such as domestic fuel consumption - would increase with population growth, although other factors were taken into account. For example, **ABS (2006)** provided projections which suggested a decrease in *per capita* consumption of wood as people switch to electricity and natural gas for heating. The net effect is that there is little change in total wood combustion between 2006 and 2030 **(Walsh, 2012b)**.

C.3.2.4 Road transport sources

Between 2006 and 2030 EPA Victoria predicted significant changes in vehicles, fuels and the level of transport activity, including both freight and passenger transport. It was assumed that diesel and petrol will still be widely used in 2030, along with less common fuels (natural gas and biofuels). Increasing numbers of hybrid and electric vehicles are expected, although these will remain a small fraction of the fleet. Hydrogen and biodiesel use are not expected to become significant before 2050 **(Walsh, 2012b)**.

Unit emissions for individual vehicles are expected to decrease as a result of new emission standards, but the total amount of travel (vehicle-kilometres) is expected to increase. Overall, the effect of the new standards is expected to outweigh the growth in travel, so total vehicle exhaust emissions should decrease by 2030. It is assumed that the fleet-turnover rate will remain constant. The resuspension of dust from sealed roads is also included in the inventory, and is linked to traffic activity **(Walsh, 2012b)**.

C.3.2.5 Interpolation and projection beyond 2030

Emissions of PM_{10} and $PM_{2.5}$ in the years required for the economic analysis were determined from the EPA Victoria data for 2006 and 2030 using linear interpolation. The total change in emissions from each source group between 2006 and 2030 was calculated, and the result was divided by the number of intervening years to give an annual emission rate increment/decrement. The resulting values are given in **Table C3**.

Table C3: Annual increments/decrements for sources in the Victoria emissions inventory

Source group	Annual change in emissions (tonnes per annum per annum)	
	PM_{10}	$PM_{2.5}$
Industrial sources	30.0	27.1
Area sources	33.3	24.0
Wood heaters	2.5	1.6
Petrol vehicles	1.8	0.0
Diesel vehicles	-44.3	-51.2
LPG road vehicles	-3.0	-1.1

Emissions for the years 2031 to 2055 were determined using the methods described in **Section C1.1**. Emissions from industry were scaled using an historical (1990-2012) annual change in GVA for manufacturing (+0.2% per annum) **(ABS, 2012b)**. Emissions from area sources, wood heaters and motor vehicles were scaled in line with the Victoria population from **ABS (2008)**.

C.4 OTHER JURISDICTIONS

The projection methods for the other jurisdictions are summarised in **Table C4**.

Table C4: Emission projection methods in other jurisdictions

<table>
<tr><th>Jurisdiction</th><th>Source group</th><th>Projection method from base year to 2036 (proxy used)</th><th>Projection method from 2036 to 2055 (proxy used)</th></tr>
<tr><td rowspan="4">QLD</td><td>Industrial-commercial</td><td colspan="2">Historical[a] annual change in GVA for manufacturing in QLD (+2.2% per annum)</td></tr>
<tr><td>Mining</td><td colspan="2">Historical[a] annual change in GVA of +3.7% was used</td></tr>
<tr><td>Area sources</td><td colspan="2">Brisbane population[b]</td></tr>
<tr><td>Road transport & other modes</td><td>National PM_{10} emissions by mode[c]</td><td>Brisbane population[b]</td></tr>
<tr><td rowspan="4">SA</td><td>Industrial</td><td colspan="2">Historical[a] annual change in GVA for manufacturing in SA (-0.1% per annum)</td></tr>
<tr><td>Commercial</td><td colspan="2">Adelaide population[b]</td></tr>
<tr><td>Domestic-commercial</td><td colspan="2">Adelaide population[b]</td></tr>
<tr><td>Road transport & other modes</td><td>National PM_{10} emissions by mode[c]</td><td>Adelaide population[b]</td></tr>
<tr><td rowspan="3">WA</td><td>Industrial-commercial</td><td colspan="2">Perth population[b]</td></tr>
<tr><td>Domestic-commercial</td><td colspan="2">Perth population[b]</td></tr>
<tr><td>Road transport & other modes</td><td>National PM_{10} emissions by mode[c]</td><td>Perth population[b]</td></tr>
<tr><td rowspan="3">TAS</td><td>Industrial-commercial</td><td colspan="2">Historical[a] annual change in GVA for manufacturing in Tasmania (-1.5% per annum)</td></tr>
<tr><td>Domestic-commercial</td><td colspan="2">Hobart population[b]</td></tr>
<tr><td>Road transport & other modes</td><td>National PM_{10} emissions by mode[c]</td><td>Hobart population[b]</td></tr>
<tr><td rowspan="3">NT</td><td>Industrial-commercial</td><td colspan="2">Historical[a] annual change in GVA for manufacturing in NT (+5% per annum)</td></tr>
<tr><td>Domestic-commercial</td><td colspan="2">Darwin population[b]</td></tr>
<tr><td>Road transport & other modes</td><td>National PM_{10} emissions by mode[c]</td><td>Darwin population[b]</td></tr>
<tr><td rowspan="3">ACT</td><td>Industrial</td><td colspan="2">Historical[a] annual change in GVA for manufacturing in ACT (-1.9% per annum)</td></tr>
<tr><td>Commercial, domestic- commercial</td><td colspan="2">Canberra population[b]</td></tr>
<tr><td>Road transport & other modes</td><td>National PM_{10} emissions by mode[c]</td><td>Canberra population[b]</td></tr>
</table>

(a) 1990-2012, from **ABS (2012b)**

(b) From **ABS (2008)**

(c) From **BITRE (2010)**

Appendix D ANALYSIS OF POTENTIAL NEW ABATEMENT MEASURES

D.1 ANALYSIS: EXISTING MEASURES CURRENTLY BEING ASSESSED

Here, the term 'existing measures' refers to the abatement initiatives that currently being considered through Council of Australian Governments (COAG) processes.

D.1.1 Non-road diesel engines

D.1.1.1 Background

Non-road diesel engines (examples include cranes, excavators, dozers and heavy forklifts) are a significant contributor to air pollution in Australia. For example, several types of non-road diesel sources feature amongst the top ten anthropogenic emitters of NO_X and PM_{10} in the NSW GMR **(NSW EPA, 2012a)**. Market segments, and the types of non-road diesel engines used in each segment, are listed in **Table D1** below. This list is derived from **ENVIRON and SKM-MMA (2011)**, but is not exhaustive.

Table D1: Types of non-road diesel engines and equipment in use in Australia

Market segment	Engine/equipment description
Industrial (industrial, commercial, construction, mining)	Engines for construction and mining equipment
	Engines for industrial pumps
	Engines for 'other' industrial equipment[(a)]
	Engines for miscellaneous industry applications
	Tractors (expected to include airport equipment)
	Forklifts
	Cranes and lifting equipment
	Heavy construction, mining, industrial and commercial equipment (e.g. loaders, rollers, dumpers)
Agricultural	Engines for pumps and irrigation
	Engines for agricultural vehicles
	Engines for 'other' agricultural applications[(b)]
	Agricultural tractors
	Combine-harvester-threshers
	Windrowers
	Self-propelled sprayers
	Balers
Power generation (various markets)	Power gen drives - prime power
	Power gen drives - standby power
	Power gen drives - marine auxiliary
	Power gen sets - prime power
	Power gen sets - standby power
	Power gen sets - marine auxiliary
	Power gen sets - miscellaneous
Lawn and garden	Ride-on or tractor lawn mowers
Light commercial	Welders, air compressors, pressure washers
Marine (<37 kW)	Propulsion engines for pleasure boats (<37 kW)
	Propulsion engines for work boats (<37 kW)
	Propulsion engines for fishing boats (<37 kW)
	Marine propulsion engines (not specified) (<37 kW)
Forestry	Log skidders

(a) Includes engines for waste removal equipment, road sweeping and cleaning equipment, hydraulic power packs and welding sets.
(b) Includes engines for hay making machinery, oil tresses, lawn and garden outdoor power equipment.
Source: Table 9, **ENVIRON and SKM-MMA (2011)**

Whilst the diesel engines used in road vehicles are required to meet strict emissions limits, non-road diesel engines are not subject to any emissions standards. Moreover, the emission performance of non-road diesel engines sold in Australia lags behind the performance of those sold in the EU and the US. The so-called 'Stage IV' standards enter into force in the EU in 2014, whereas 'Tier 4' standards in the US are being phased-in from 2008 to 2015.

ENVIRON and SKM-MMA (2011) undertook a CBA which considered the phased introduction of overseas emission limits for non-road diesel engines in Australia through federal government regulation, a NEPM, or voluntary standards. The results of the study, together with preliminary scoping work have been used to assess the costs and benefits of abatement from the non-road diesel sector through the implementation of EU/US standards in Australia.

Whilst the data and methods applied in the scoping work (which only deals with non-road diesel engine standards) and the economic analysis (which had broader sectoral coverage) were similar, differences in factors such as choice of base year and population assumptions led to slightly different results. Specifically, the economic analysis adopted a finer spatial resolution (higher precision) for the states of NSW and Victoria but a coarser resolution in the remaining states (lower precision) compared with the scoping work.

ENVIRON and SKM-MMA (2011) modelled four sets of policy options (1, 2, 3 and 4). Options 1A, 1B and 1C represented alternative base cases (outcomes expected if no further action is taken) for comparison with options representing policy intervention. Options 2A and 2B assumed harmonisation of standards through Commonwealth regulation. Options 3A and 3B assumed harmonisation of standards through a NEPM[26]. Option 4 assumed voluntary action and industry agreements (self-regulation). The distinction between Commonwealth regulation (Options 2A and 2B) and a NEPM (Option 3A and 3B) is that the former is enacted (or amended) at a federal level and applies to the sale of new engines, whereas in the latter a NEPM obliges each State and Territory to adopt NEPM provisions in their own jurisdiction, under their own legislation. Thus, under a NEPM engine suppliers may need to deal with multiple regulatory agencies **(ENVIRON and SKM-MMA, 2011)**.

ENVIRON and SKM-MMA (2011) concluded that a variant of harmonisation with US standards (through Commonwealth regulation or NEPM) in which engines having a power rating of less than 19 kW were excluded had the highest net present value (NPV) of benefits. This was because these engines were found to produce only 2% of emissions but had very high compliance costs.

These two options - Commonwealth regulation for harmonisation to US standards (excluding engines less 19kW) and a NEPM for harmonisation to US standards (again excluding engines less 19kW) - were selected for inclusion in this economic analysis. It should be noted that that whilst the policy option considered relates to US standards, the US and EU standards are being harmonised.

D.1.1.2 Timeframe

The scoping work modelling built upon the work of **ENVIRON and SKM-MMA (2011)**, and suggested a stepwise approach to policy implementation:

- Under the Commonwealth regulation option, Tier 3 / Stage 3a standards would be implemented in 2015 and Tier 4 final / Stage 3b/Stage 4 standards would be implemented in 2018 for new engines/equipment with a power rating of more than 19 kW.
- The NEPM policy options mirror those of the Commonwealth regulation, with the exception that a delay in implementation is assumed.

[26] In order for a NEPM to be used to set limits, the National Environment Protection Council Act 1994 would need to be amended.

The economic analysis in the CRIS scoping work is based on stock projections to 2035 and declining residual health benefits (and associated operational costs and fuel savings) out to 2055 to reflect the long lifetime of the equipment.

D.1.1.3 PM emission reductions

The CRIS scoping work provided emission reductions for $PM_{2.5}$ which were used directly in our analysis. To estimate PM_{10} emission reductions we assumed that 97% of PM_{10} from this type of source can be classified as $PM_{2.5}$ (this ratio is used for off-road industrial vehicles and equipment in the NSW GMR Inventory).

The resulting reductions in emissions are shown in **Figure D1.** Consistent with the source study, the levels of compliance (and therefore the emission reductions) are higher under the Commonwealth regulation options than under the NEPM options. The emission reductions peak in 2035, coinciding with a peak in sales of lower-emitting engines compared with the situation without harmonisation. The gradual increase in the emission reduction reflects the increasing stock of less emissions-intensive engines compared with the BAU case. Estimated emission reductions tail off as engines gradually reach the end of their lives.

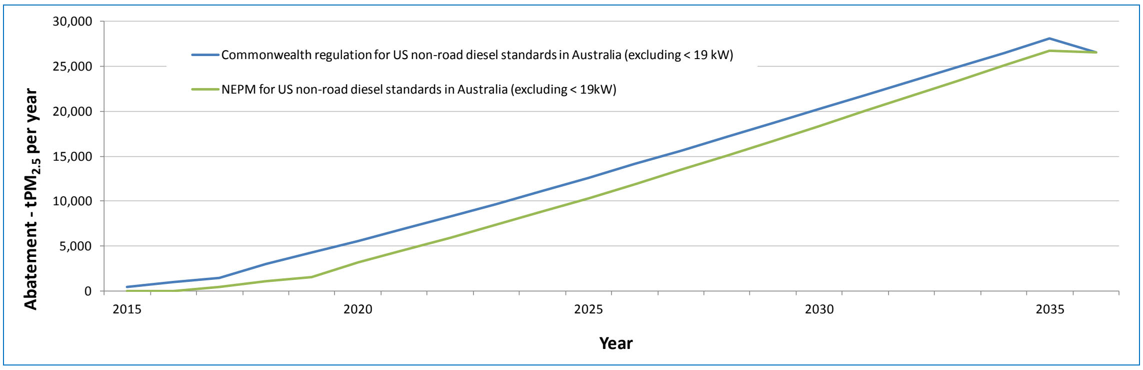

Figure D1: $PM_{2.5}$ emission reductions for non-road diesel engine measures

D.1.1.4 Co-benefits and dis-benefits

ENVIRON and SKM-MMA (2011) also estimated the associated emission reductions for NO_X, as shown in **Figure D2.** The implementation of emission standards is also estimated to result in reductions in fuel consumption and emissions of CO_2, VOCs and SO_2. VOC and SO_2 benefits are small relative to particle and fuel efficiency impacts and were assumed to have zero value. CO_2 reductions are acknowledged but not quantified as some sectors affected by standards are currently covered by an ETS and the resulting uncertainty in measuring benefits.

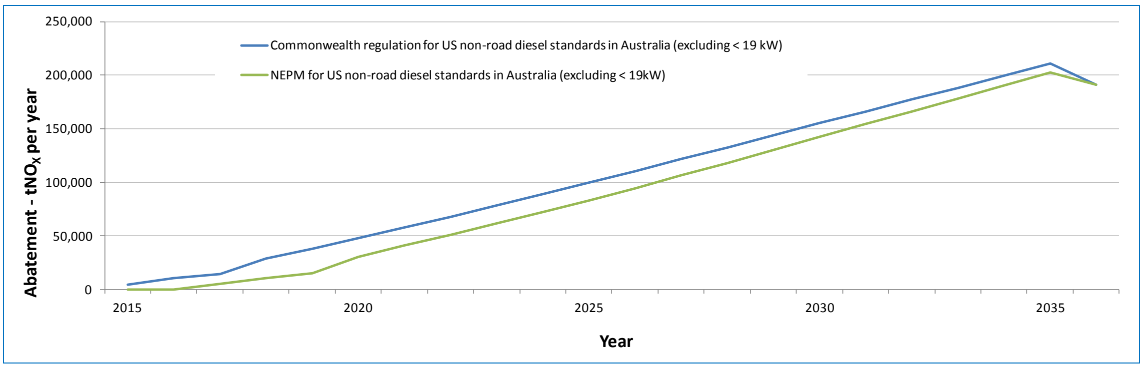

Figure D2: NO_X emission reductions for non-road diesel engine measures

D.1.1.5 Costs

As with emission reductions, the costs of compliance with emission standards for both government and non-government (in this case industry) stakeholders were taken from the scoping work. Specifically, this work provided the following:

- Additional costs associated with engine purchase.
- Increased operation and maintenance costs associated with low-emission engines.
- Industry compliance costs.
- Government administration costs.
- Costs associated with changes in fuel consumption[27].

The main resulting costs are shown in **Figures D3** and **D4**. Costs peak in 2035, coinciding with a peak in sales of lower-emitting engines compared with the situation without harmonisation. The gradual increase in costs reflects the increasing stock of less emissions-intensive engines compared with the BAU scenario. Beyond 2035 ongoing maintenance costs and fuel efficiency benefits are maintained.

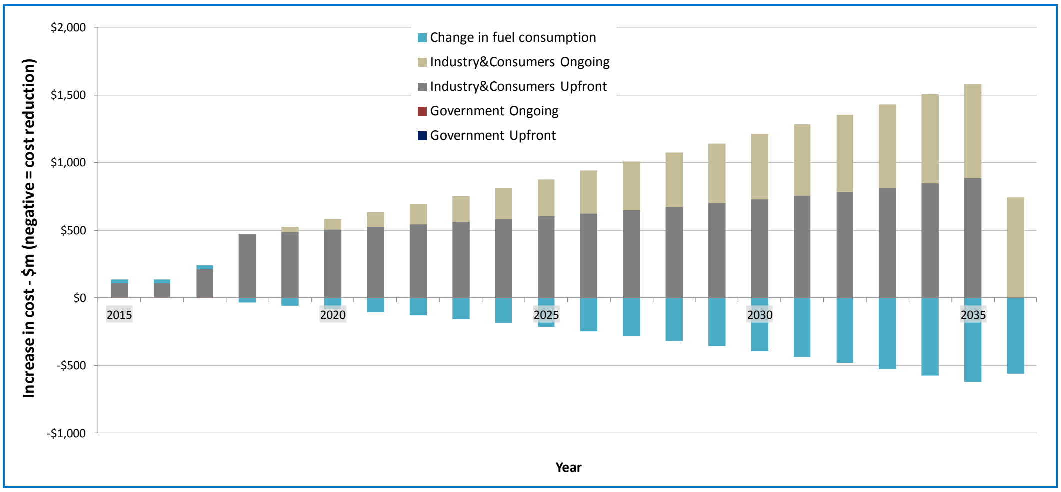

Figure D3: Costs of Commonwealth regulation for US non-road diesel engine standards in Australia (excl. < 19 kW)

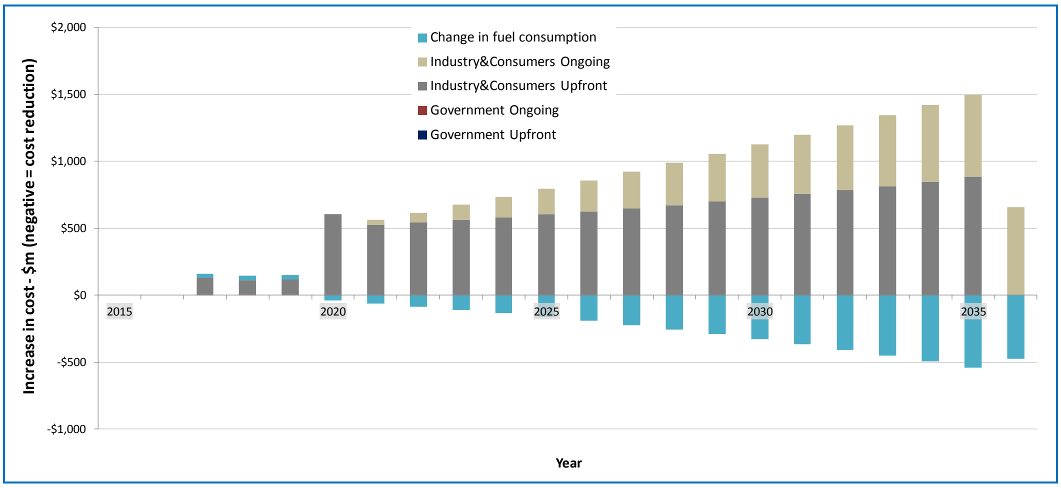

Figure D4: Costs of NEPM for US non-road diesel engine standards in Australia (excl. < 19 kW)

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[27] There is estimated to be an *increase* in fuel consumption resulting from the move from non-compliant or Tier 1 engines to Tier 3 in the early years of the scheme, and a reduction in fuel consumption from the move to Tier 4 engines of around 2.5% (5% gross fuel efficiency benefits offset by 2.5% due to the installation of DPFs and associated fuel additive requirements).

The results indicate that the two variants were very similar with respect to cost-effectiveness and emission reductions. Therefore, while they are considered as two separate options within the cost-effectiveness analysis they are referred to as a single policy ('US non-road diesel engine standards in Australia (excluding < 19kW)') within the economic analysis.

D.1.1.6 Uncertainty in estimates

Two key sensitivities were investigated in the scoping work. These were the level of uptake of more efficient engines in the reference (counterfactual) case and costs of new engines (up to 10% lower or higher). The existing level of analysis undertaken for this abatement measure is higher relative to other measures, and therefore a narrower band of uncertainty was used for the economic analysis. The sensitivity ranges used for the economic analysis are provided in **Table D2**.

Table D2: Sensitivity parameters for non-road diesel engine measures

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Emission reductions	-7.5%
Measure less cost-effective compared with central assumptions	Costs to industry & consumers	+7.5%
Measure more cost-effective compared with central assumptions	Emission reductions	+7.5%
Measure more cost-effective compared with central assumptions	Costs to industry & consumers	-7.5%
Fuel efficiency lower than expected	Fuel efficiency	2.25% (-10%)
Fuel efficiency higher than expected	Fuel efficiency	2.75% (+10%)

D.1.2 Wood heaters

D.1.2.1 Background

Despite targeted jurisdictional programmes to reduce emissions from in-service wood heaters, studies have shown that there is considerable scope for further reductions **(BDA Group, 2013; AECOM, 2011)**. There is a large health burden associated with PM emissions from wood heaters that extends beyond that experienced by wood heater owners/users (*i.e.* externalities) to the broader community. Currently there is an Australian Standard for wood heater emissions (4 g of particulate matter per kg of wood burnt) for new wood heaters.

BDA Group (2013) detailed CRIS policy measures that are designed to reduce emissions from wood heaters. These measures included various combinations of actions (relating to both emissions and efficiency), compliance, and in-service measures with a focus on nationally consistent and more stringent standards. Specifically, the following policy combinations were analysed:

- Policy combination 1: National audit and targeted education programmes.
- Policy combination 2: National audit, education and targeted replacement incentive programmes.
- Policy combination 3: Inclusion of certified emission performance on heater compliance plates, education and audit programmes.
- Policy combination 4: Inclusion of certified emission performance on heater compliance plates, a star rating labelling scheme, education and audit programmes.

- Policy combination 5: Inclusion of certified emission performance on heater compliance plates, a star rating labelling scheme, education and audit programmes and a 60% efficiency standard.
- Policy combination 6: A compliance and education program, 60% efficiency standard and 3 g/kg emission standard.
- Policy combination 7: A compliance and education program, 60% efficiency standard and 3 g/kg emission standard and in-service measures.
- Policy combination 8: A compliance and education program, 65% efficiency standard and 3 g/kg emission standard and in-service measures.
- Policy combination 9: A compliance and education program, 60% efficiency standard and 1.5 g/kg emission standard and in-service measures.

D.1.2.2 Timeframe

In the CRIS BDA chose the period 2011 to 2030 for the assessment of costs and benefits, and assumed a policy measure introduction date of 2012, with various phase-in periods for measures to be effective but with emission reductions beginning to accrue in 2013. For our economic analysis we have assumed that all options would be introduced from 2017 to allow adequate policy lead time, and will operate until 2036.

D.1.2.3 Emission reductions

Reductions in PM_{10} emissions were provided in the BDA CRIS, and these were used directly in the economic analysis, with implementation delayed according to the revised timeframe. Ideally, new modelling would be undertaken to estimate more precisely the effect of the time lag, but this was beyond the scope of the economic analysis. Where such adjustments and assumptions would be required - and would cause further uncertainty in the estimates - this was accounted for in the sensitivity analysis. It is worth noting that the regulatory impact analysis is now considering the results of consultation and the outcomes may change.

The resulting emission reductions for PM_{10} are shown in **Figure D5**. The emission reductions provided in the BDA CBA were quantified in tonnes of PM_{10}. To estimate $PM_{2.5}$ emission reductions from wood heaters it was assumed that $PM_{2.5}$ comprises 96% of PM_{10}, consistent with international data (size fractions for fireplaces and wood stoves in California Emission Inventory and Reporting System **(CEIDARS, 2008)**.

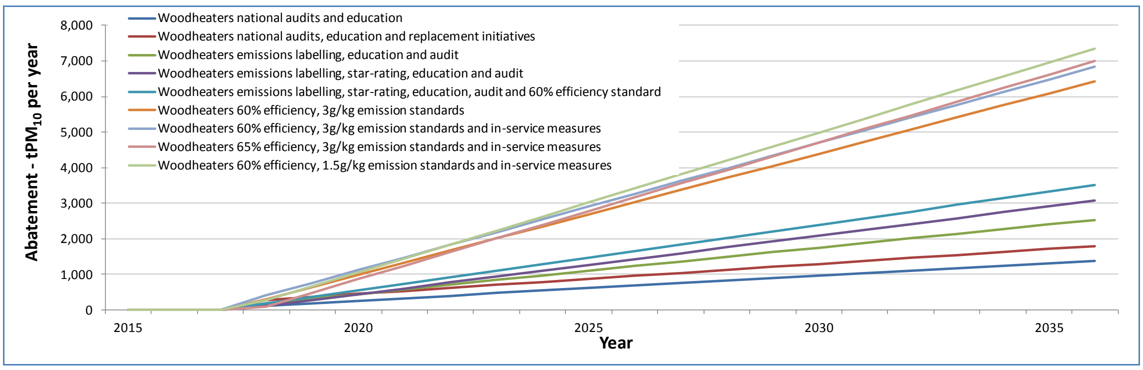

Figure D5: PM_{10} reductions for wood heater emissions standard measures

Benefits were captured over 20 years. This was consistent with the source study, which adopted a 20-year time horizon for both costs and benefits. While there may be some long-lived benefits arising from measures for wood heater standards, these are not expected to be significant given the average physical lifetime of 15 years for wood heater appliances **(Todd, 2003)**.

Therefore, the time period was not extended beyond 20 years to account for long-lived emission reductions, as has been done for some measures for which this effect is likely to be more relevant. As a result, emission reductions were considered to be zero after 2036 (consistent with the methodology used in the source study).

The gradual increase in the size of the emission reduction reflects the increasing stock of relatively 'low-emission' wood heaters compared with the BAU scenario.

D.1.2.4 Costs

Costs relating to the implementation of wood heater measures (**Figure D6**) were derived from **BDA Group (2013)**, and specific details relating to cost assumptions were taken from the underlying CBA for the CRIS **(BDA Group, 2006)**. In particular, the CRIS provided the costs of options as a present value over 20 years.

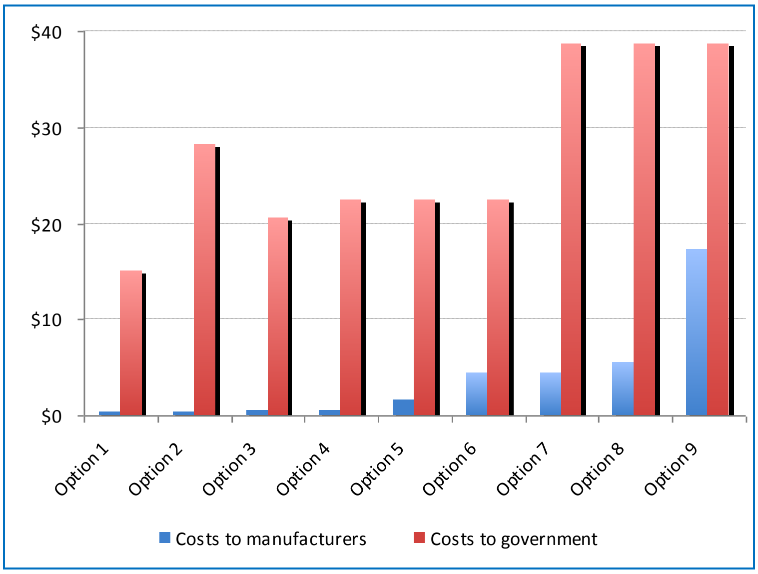

Figure D6: Cost of wood heater emissions standards measures ($m PV)

The present value (aggregate) of costs was disaggregated, drawing from raw cost data contained in the CRIS relating to the following:

- Research and development costs
- Star rating
- National audits
- State audits
- National testing and certification
- Compliance plate labelling
- Education
- Replacement incentives
- Other in-service regulations
- National regulatory framework costs

Consistent with the treatment in **BDA Group (2013)**, industry costs are predominantly upfront (as opposed to ongoing):

> "*The estimated costs to manufacturers range from $240,000 under Option 1 (for improvements to heaters to comply with the existing standard and any re-testing required where heaters fail) to $17m under Option 9 (primarily heater model development costs to meet an efficiency standard of 60% as well as an emission limit of 1.5 g/kg)*" **(BDA Group, 2013)**.

Also consistent with the treatment in **BDA Group (2013)**, price impacts have not been estimated and therefore costs to industry & consumers primarily relate to research, development and testing:

"Price effects have not been incorporated into the analysis and we have assumed no change in the base case assumption of continued sales of around the 25,000. However, our analysis assumes a reduction of up to 28% in the number of models that would be available, and this would lead to changes in market shares held by different manufacturers." **(BDA Group, 2013).**

Detailed costs have been provided in **BDA Group (2013)**[28], and have not been reproduced here. According to these data, upfront and ongoing costs for both government and industry stakeholders over a 20-year period were derived (**Figures D7** to **D15**). The profile of costs in **Table D3** shows the spreading of upfront costs over a phase-in period, followed by equivalent ongoing costs each year. Phase in periods were derived from **BDA Group (2013)**[29].

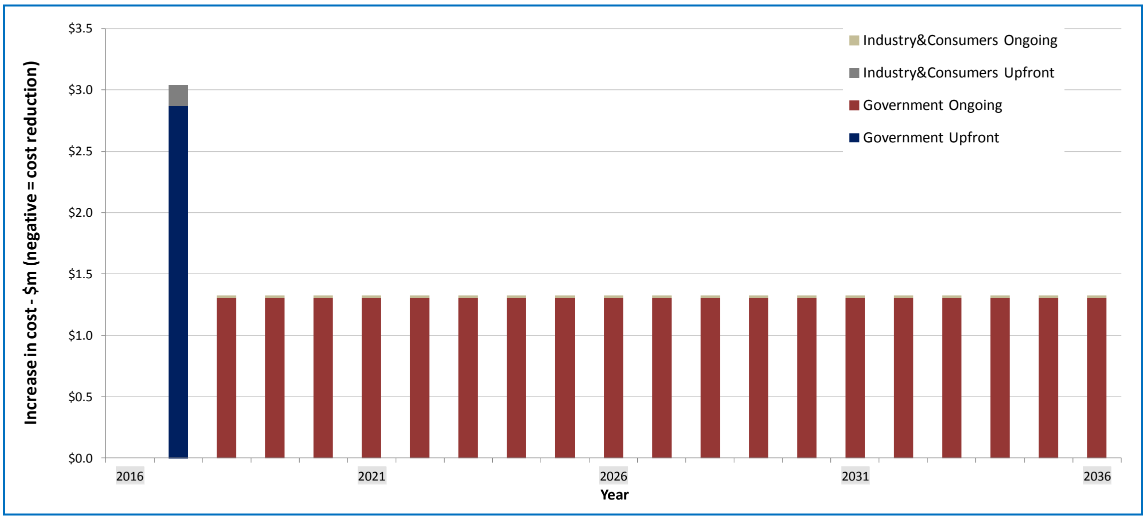

Figure D7: Cost of wood heater national audits and education

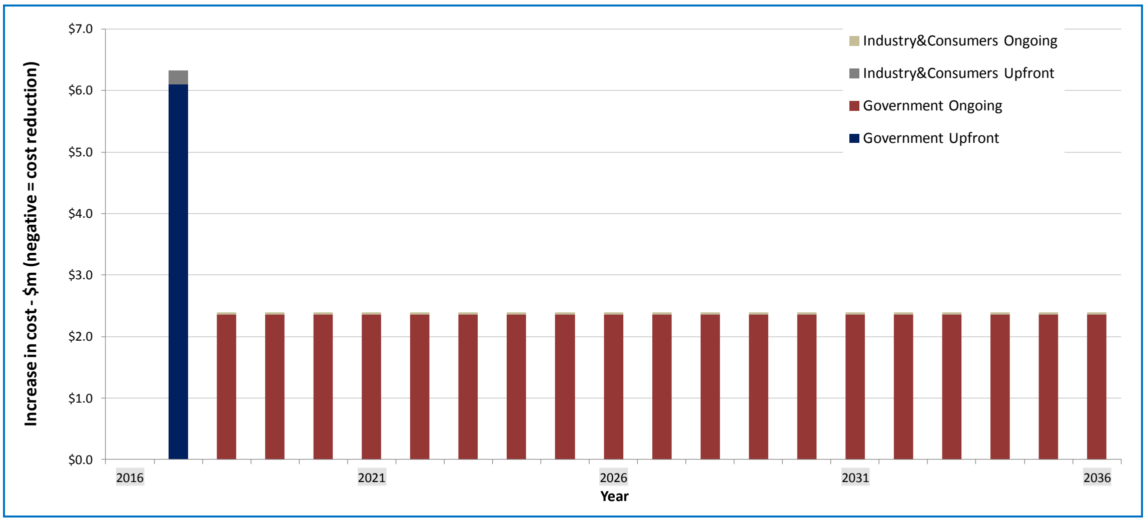

Figure D8: Cost of wood heater national audits, education and replacement initiatives

[28] See Appendix 7 of **BDA Group (2013)**.
[29] See Table 6.2 of **BDA Group (2013)**.

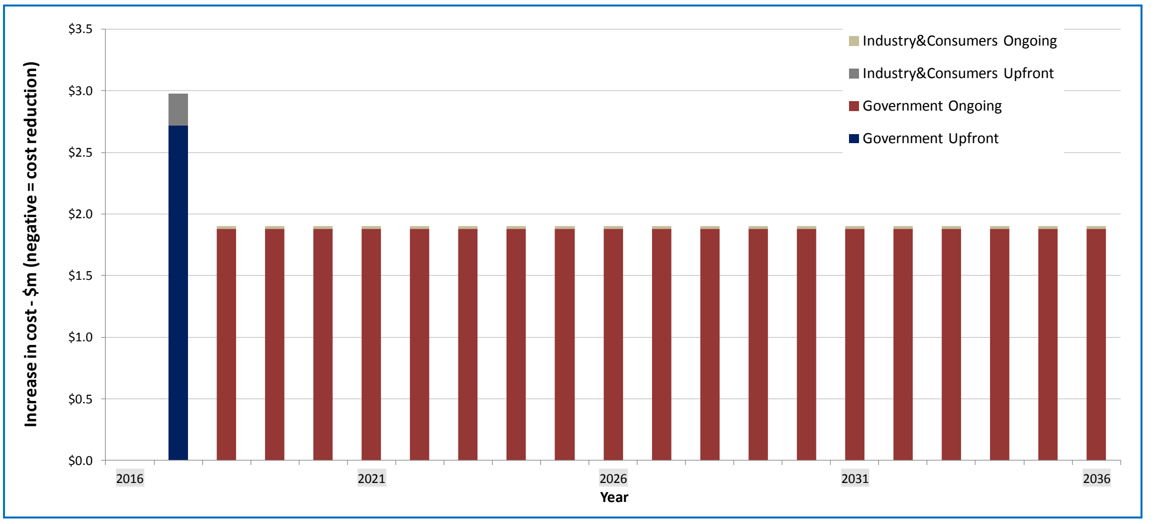

Figure D9: Cost of wood heater emissions labelling, education and audit

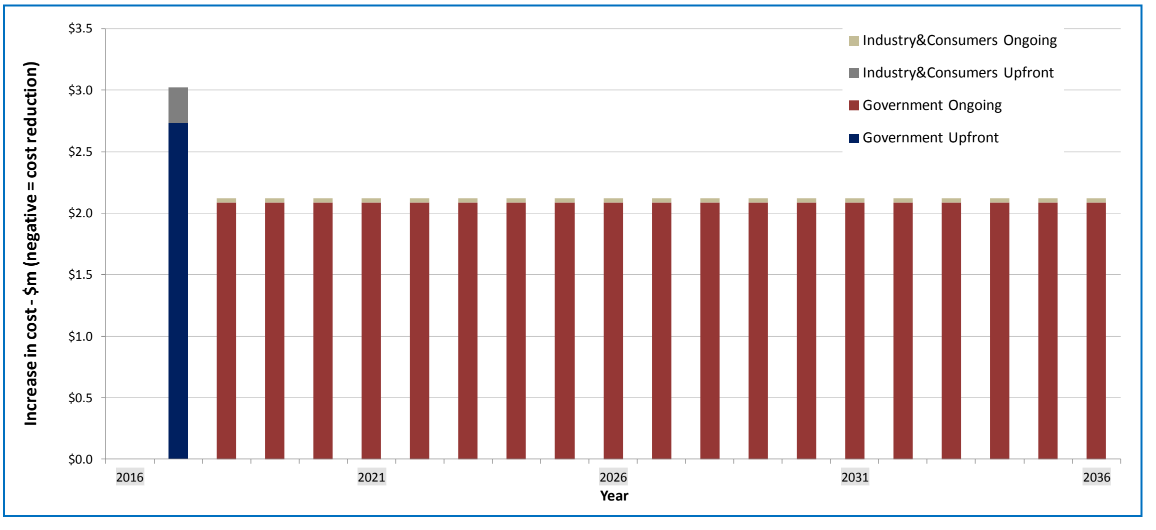

Figure D10: Cost of wood heaters emissions labelling, star-rating, education and audit

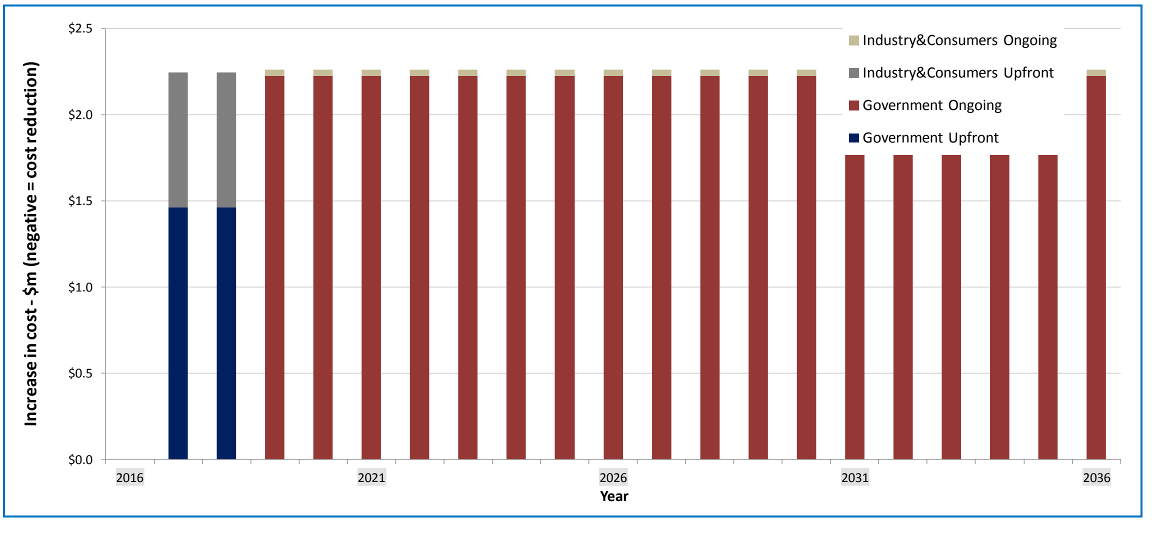

Figure D11: Cost of wood heater emissions labelling, star-rating, education, audit and 60% efficiency standard

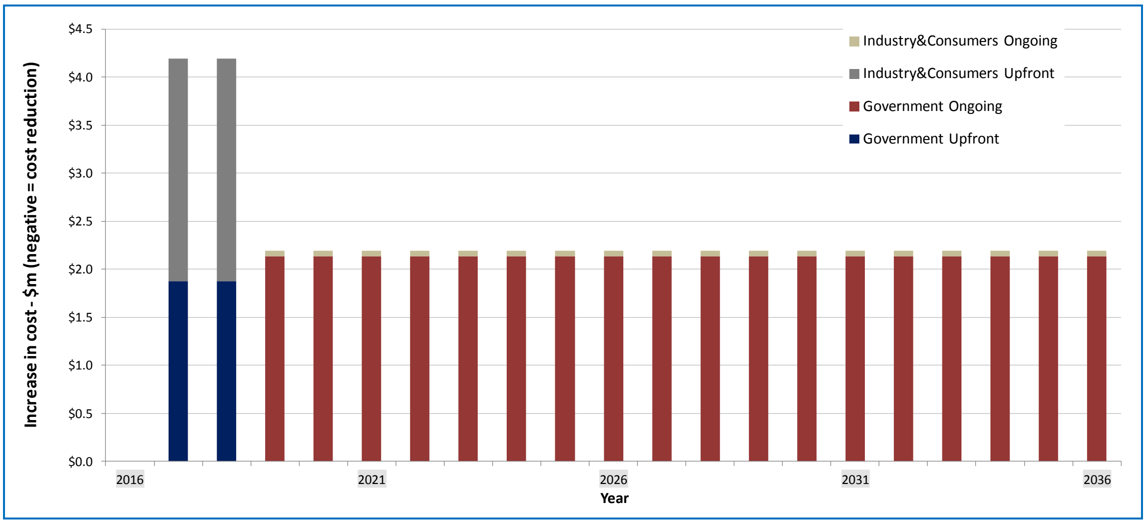

Figure D12: Cost of wood heater 60% efficiency, 3 g/kg emission standards

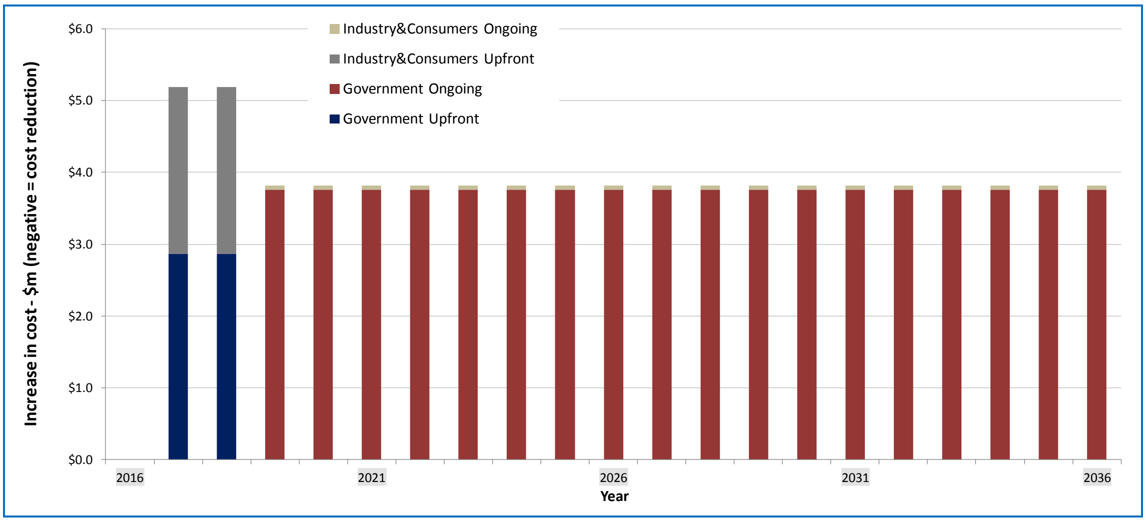

Figure D13: Cost of wood heater 60% efficiency, 3 g/kg emission standards and in-service measures

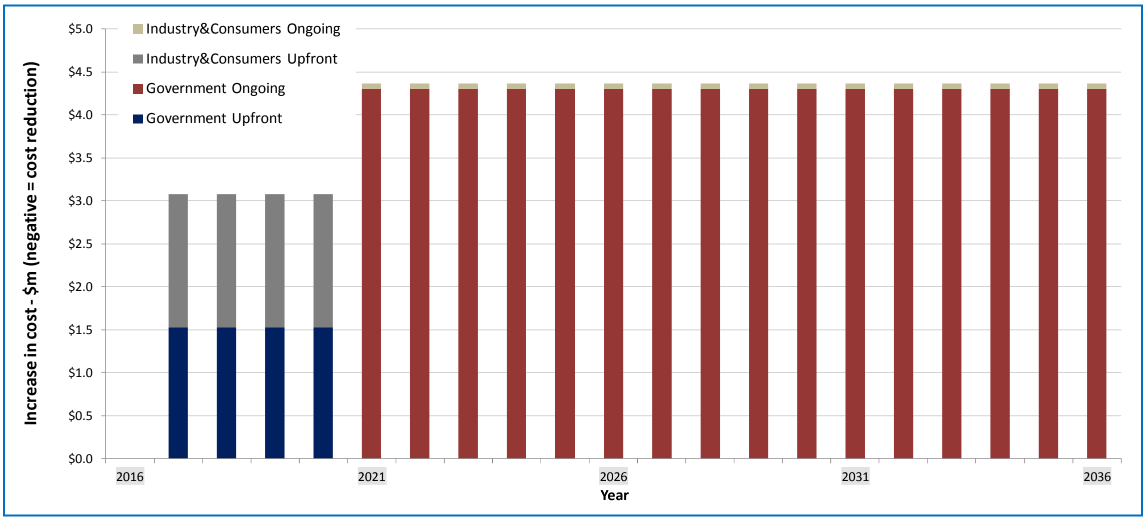

Figure D14: Cost of wood heater 65% efficiency, 3 g/kg emission standards and in-service measures

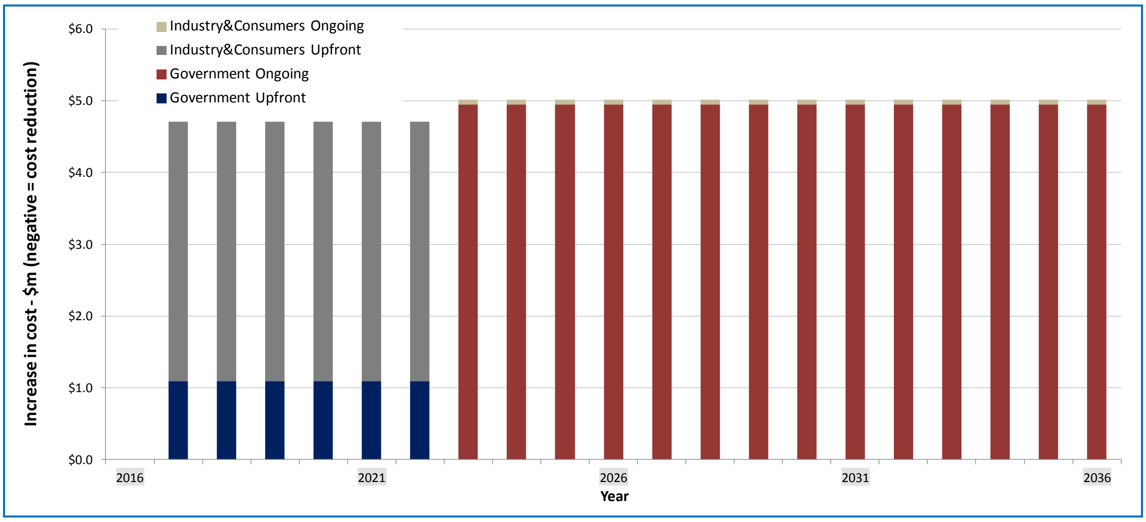

Figure D15: Cost of wood heater 60% efficiency, 1.5 g/kg emission standards and in-service measures

Table D3: Phase in periods for wood heater measures (Source: Table 6.2, BDA Group (2013))

New measure	Phase-in period
Emissions labelling (star)	1 year
National Star Rating Scheme	1 year
3 g/kg & 60%	2 years
3 g/kg & 65%	4 years
1.5 g/kg & 60%	6 years

D.1.2.5 Co-benefits and dis-benefits

No estimate of the impact on CO_2 was included in our economic analysis. The impact of wood heaters on CO_2 is largely dependent on the extent to which the wood used is sourced from sustainable sources.

D.1.2.6 Uncertainty in estimates

The sensitivity analysis undertaken in the CRIS suggested that the results were sensitive to the level of retail compliance with the standards. In particular, the estimated net benefits of options 6, 7, 8 and 9 were approximately 10% to 20% higher when 100% retail compliance with standards was assumed, as opposed to the base case assumption of 40%.

The results were also sensitive to the assumption about the relationship between design standards and 'real-world' (operational) emissions. Specifically, name-plate emissions ratings assume certain behaviour in operating wood heaters, whereas actual behaviour may result in higher emissions. A range of 'pass through' standards was tested for Option 6 (chosen as it would be most sensitive to this parameter given the Option had the highest emission reduction for new measures (85%)). Estimated net benefits varied by a range of approximately 50% for pass-through levels, ranging from 0% to 100%.

Efficacy of education was a key sensitivity, resulting in an estimated 90% reduction in benefits from Option 2 if education was assumed to have no impact.

Finally, the results for replacement programs were found to be sensitive to the assumptions about replacement of stock in the counterfactual (comparison case). In particular, the benefits of Option 2 were estimated to decrease by 40% if it was assumed that all units would have been replaced regardless of the measures, instead of 50%.

Whether a measure produces overall net benefits is not sensitive to assumptions, but the level of benefits is. In the absence of more detailed information, the sensitivity parameters in **Table D4** were used for the economic analysis.

Table D4: Sensitivity parameters for wood heater standard measures

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Emission reductions	-20%
Measure less cost-effective compared with central assumptions	Costs	+20%
Measure more cost-effective compared with central assumptions	Emission reductions	+20%
Measure more cost-effective compared with central assumptions	Costs	-20%

D.1.3 Non-road spark ignition engines

D.1.3.1 Background

Non-road spark ignition engines (which include lawnmowers, outdoor hand-held equipment, outboard engines and personal watercraft) are high polluters relative to their size **(EPHC, 2010)**. The following non-road spark ignition engines and equipment contribute to air pollution in Australia **(EPHC, 2010)**:

- Small non-road spark ignition engines and equipment rated below 19 kW used in household equipment and commercial applications, which include:
  - Lawn and garden equipment
  - Utility vehicles (*e.g.* ride-on mowers)
- Marine spark ignition engines and vessels, which include:
  - Outboard engines
  - Personal watercraft

However, there are currently no national regulations restricting emissions from this source. Emission management options are being assessed through COAG processes with reference to the most recent US standards published in November, 2010[30]. Various scenarios were modelled by MMA for the underlying CBA **(MMA, 2008)**. This modelling was extended to include two additional scenarios **(MMA, 2009)** developed in consultation with industry and other stakeholders. These two additional scenarios were selected for inclusion in this economic analysis. These were:

- Scenario 1a:
  - US 2010 outboard exhaust and evaporative emission standards from the US EPA final rule implemented in Australia in 2012.
  - US 2010 personal water craft exhaust and evaporative emission standards from the US EPA final rule implemented in Australia in 2012.
  - US Phase 2 gardening equipment exhaust and US EPA final rule evaporative emission standards implemented in Australia in 2012.

[30] The Final Rule regarding emissions from marine engines and vessels and small non-road engines and equipment was promulgated in 2008, but several amendments to the Final Rule (and therefore the most recent US standard) were published in November, 2010.

- Scenario 2a:
  - US 2006 outboard exhaust emissions standards from the US EPA final rule implemented in Australia in 2012, and US 2010 exhaust and evaporative emission standards from the US EPA final rule implemented in Australia in 2015.
  - US 2006 personal water craft exhaust emissions standards from the US EPA final rule implemented in Australia in 2012, and US 2010 exhaust and evaporative emission standards from the US EPA final rule implemented in Australia in 2015.
  - US Phase 2 gardening equipment emission standards implemented in Australia in 2012 and US gardening equipment evaporative emission standards from the USEPA final rule implemented in Australia in 2015.

D.1.3.2 Timeframe

As above, the MMA modelling assumed a policy measure introduction date of 2012. For the economic analysis we have assumed that all options would be introduced from 2015 to allow adequate policy lead time, and would continue until 2035.

D.1.3.3 Emission reductions

The modelling results from the **MMA (2009)** study were provided to the project team by the Department of Sustainability, Environment, Water, Population and Communities (DSEWPAC). These included the annual emission reductions for PM, as well as the pollutants NO_X, CO, HC and CO_2. Again, the emission reductions were 'lagged' for the revised timeframe with the arising lack of precision and uncertainty accounted for in the sensitivity analysis.

Emission reductions were provided for PM_{10} and it was assumed that $PM_{2.5}$ comprises 90% of PM_{10}, consistent with international data: size fractions for gasoline engines in **CEIDARS (2008)**. The PM_{10} reductions are shown in **Figure D16**.

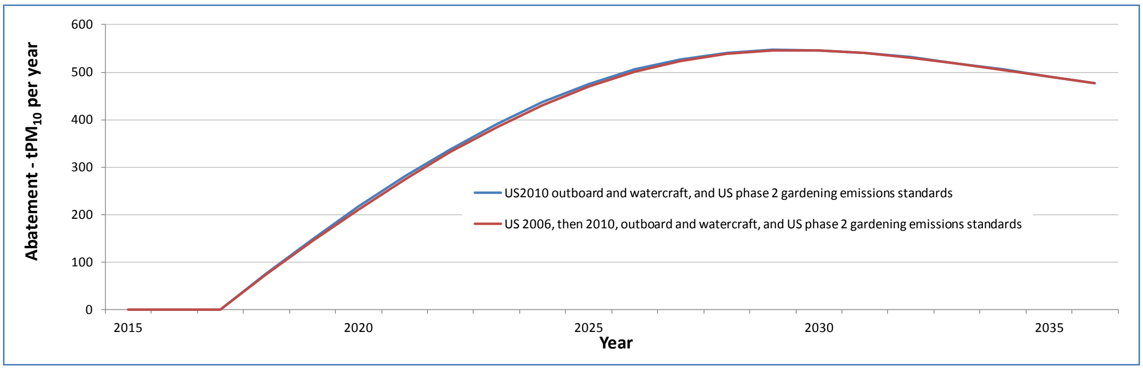

Figure D16: PM_{10} reductions for non-road spark ignition engine standards measures

The gradual increase in the size of the emission reduction reflects the increasing stock of relatively low-emission engines compared with the BAU scenario. Emission reductions begin to decline as the replaced stock reaches the end of its life. The emission reductions for US 2010 outboard and watercraft, and US phase 2 gardening emissions standards are marginally higher than US 2006, then 2010, outboard and watercraft, and US phase 2 gardening emission standards, due to the earlier compliance with US2010 outboard and watercraft standards.

Some residual emissions reductions continue to accrue from this measure beyond the policy implementation period until 2053 due to the ongoing emissions benefit of new cleaner equipment, specifically there is an ongoing tail of:

- Watercraft and outboard emissions reductions to 17 years from last year of expenditure (average life based on **MMA (2009)**).
- Garden equipment emission reductions to 10 years **(NSW DEC, 2004)** from the last year of expenditure.

D.1.3.4 Co-benefits and dis-benefits

Changes to emissions of NO_X were also derived from these data. Notably, NO_X emissions are expected to increase through the implementation of measures as four stroke engines replace two stroke engines. However, there are offsetting reductions in VOC, CO_2 and CO. These co-benefits (and dis-benefits) are not quantified as they are minor relative to particulate reductions. Reductions in fuel consumption are expected and these are discussed in costs (below).

D.1.3.5 Costs

MMA (2009) provided a comparison of costs and benefits of measures compared with the BAU scenario expressed as present value (aggregate) for the categories of service costs, expenditure costs, fuel costs[31] and health costs. Service and fuel costs were considered as ongoing costs of measures, whereas expenditure costs were considered as upfront costs. Government compliance and administration costs were not estimated in the study. For our economic analysis these were assumed to be the same order of magnitude as non-road diesel engine measures ($5 million per year).

Two sets of estimates (zero elasticity and non-zero elasticity) were provided by MMA. The former assumes that there is no change in sales resulting from an increase in engine purchase cost. The latter assumes some demand response (a reduction in sales). The former was selected for inclusion in our economic analysis as it overcomes issues associated with the non-zero elasticity assumption. In particular, a reduction in sales is likely to lead to a loss of profits for engine suppliers (loss of producer surplus) and loss of enjoyment of engines by consumers (loss of consumer surplus). These effects have not been estimated by MMA in either scenario. However, avoided expenditure, service and fuel costs directly resulting from reduced sales have been accounted for. Therefore, while these effects are expected to be marginal, the zero elasticity (no change in sales) assumption provides a more internally consistent scenario.

Due to the absence of more detailed data, costs expressed as present values were annualised into equal annual amounts. While this simplification is imprecise, the margin of error introduced in doing so is reflected in sensitivity analysis.

Figures from **MMA (2009)[32]** were the primary source of cost assumptions, as shown in **Table D5**.

Adoption of US standards is estimated to result in high expenditure and service costs, but lower fuel costs. Improved fuel consumption is due to the replacement of less fuel efficient 2-stroke engines with 4-stroke engines together with evaporative emission requirements under US emission standards.

While expenditure and service costs are estimated to increase under implementation of standards (due to higher engine purchase and maintenance costs), fuel costs are estimated to decrease. This results in negative ongoing costs for consumers, so much so that it offsets any positive costs, resulting in the measure estimated to be of negative cost to society, even without accounting for health benefits. Admittedly, the 'smoothing' of costs over the 20-year period causes some distortion as the actual cost profile would in reality result in greater front-loading of purchase costs and back-loading of fuel savings. Notwithstanding these distortions, fuel savings are estimated to be significant.

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[31] Estimated fuel savings were significant. However, the measure currently assumes no increase in oil price. The absence of such a price increase, all else being equal, would lead to a conservative estimate of fuel savings (and therefore net present value benefits).

[32] Table A-1 of **MMA (2009)**.

Table D5: Non-road spark ignition engine standards costs (2008 $m PV) (SKM-MMA, 2009)

Option	Scenario name	Service costs	Expenditure costs	Fuel costs
Business as Usual (BAU)	Outboard engine costs in BAU	2,606	4,873	3,938
	Personal watercraft costs in BAU	97	316	281
	Garden equipment costs in BAU	1,610	7,818	7,203
Final rule standard scenarios	Outboard engine costs in Scenario 1a	2,710	5,203	3,744
	Outboard engine costs in Scenario 2a	2,707	5,194	3,747
	Personal watercraft costs in Scenario 1a	97	326	263
	Personal watercraft costs in Scenario 2a	97	326	265
	Garden equipment costs in Scenario 1a	1,611	7,772	6,765
	Garden equipment costs in Scenario 2a	1,611	7,767	6,765

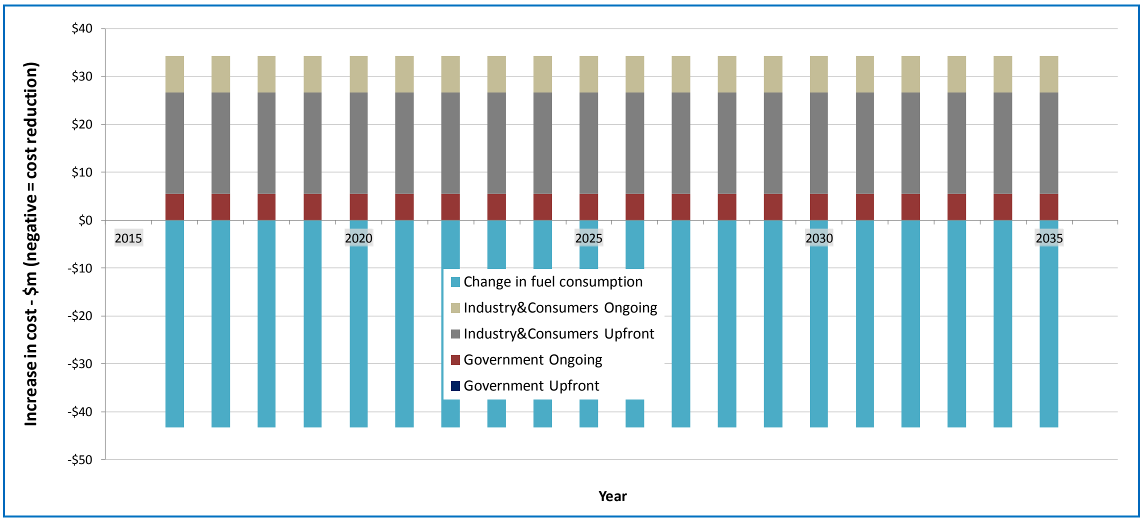

Figure D17: Cost of US2010 outboard and watercraft and US phase 2 gardening emission standards

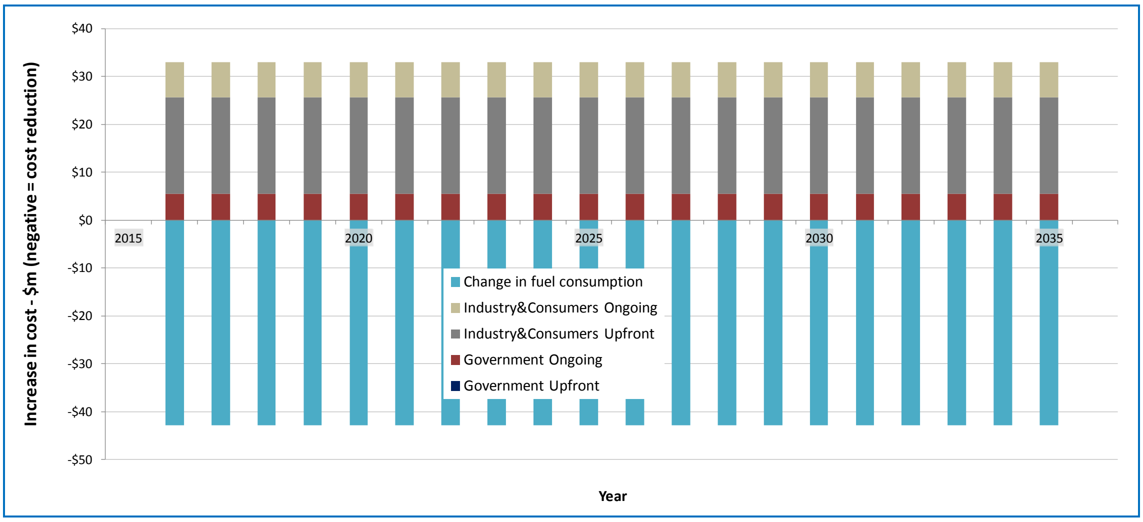

Figure D18: Cost of US 2006, then 2010, outboard and watercraft and US phase 2 gardening emission standards

D.1.3.6 Uncertainty in estimates

The MMA analysis included testing of the sensitivity of results to assumptions relating to price elasticity of demand and nominal interest rates (see Appendix A of **MMA (2009)**). While this economic analysis will undertake global sensitivity analyses for discount rates, the sensitivity of results to changes in elasticity is relevant.

Assuming a non-zero price elasticity results in greater health benefits, albeit marginally (about 5%). However, all industry costs reduce as fewer units are sold. As previously mentioned, this ignores any loss of producer surplus or consumer surplus.

While we consider that more exhaustive sensitivity testing could have been conducted, a significant amount of analysis on the measure, relative to other measures analysed in the economic analysis has been conducted to date. Therefore a similar sensitivity range is recommended, consistent with that chosen for non-road diesel engines. The sensitivity parameters are summarised in **Table D6**.

Table D6: Sensitivity parameters for non-road spark ignition engine measures

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Emission reductions	-10%
Measure less cost-effective compared with central assumptions	Costs to industry & consumers	+10%
Measure more cost-effective compared with central assumptions	Emission reductions	+10%
Measure more cost-effective compared with central assumptions	Costs to industry & consumers	-10%

D.2 ANALYSIS: ADDITIONAL MEASURES

D.2.1 Diesel trains

D.2.1.1 Background

Australia does not regulate emissions from new or re-manufactured locomotives, nor are there substantive programs addressing emissions from in-service locomotives **(ENVIRON, 2012)**. ENVIRON reviewed a range of potential measures for reducing locomotive emissions, following reviews of standards, policies and programs in the US, EU and Canada. Of the measures analysed, two which were assessed to be the most cost-effective (replacement of new locomotives with US Tier 4 standards and a driver assistance system for line haul locomotives), together with a third, more extensive variant of the first (including accelerated replacement of existing locomotives with US Tier 4 standards) were analysed in this economic analysis. The ENVIRON study calculated cost-effectiveness (expressed as A$/tonne of PM_{10}) of the selected measures as:

- $50,080 for requiring new locomotives to meet US Tier 4 standards.
- $145,157 for accelerated old line locomotive replacement to achieve US Tier 4 standards requiring new locomotives to meet US Tier 4 standards.
- $16,120 for the implementation of driver assistance software systems for line haul locomotives.

ENVIRON provided aggregate cost and emission-reduction figures over a 20-year period (*e.g.* total cost, average emission reductions). The assumed policy start date was not specified. Key assumptions taken from **ENVIRON (2012)** are provided in **Table D7**.

Table D7: Key assumptions relating to diesel train measures (ENVIRON, 2012)

Assumption	Value
Capital cost for implementing driver assistance system	$25,000 per locomotive
Annual maintenance and support fee	$2,000 per locomotive
Fuel savings[(a)]	Described as 10% fuel savings and diesel costs of $1 per litre. Fuel savings not provided in dollar terms but provided net cost per locomotive of $16,000 over 20 years, capital and annual costs as provided above implies fuel savings of -$2,450 per locomotive year.
Number of new line haul locomotives expected	871
Number of existing line haul locomotives	921
Timeframe for uptake of new locomotives	20 years
Increase in capital costs for new Tier 4 locomotive	$500,000
Increase in maintenance & fuel costs for Tier 4 locomotive	$10,000 per year
Replacement of existing line haul locomotives	$5.25 million ($4-6.5 million) per locomotive to be replaced
Total PM_{10} and NO_x reduction (per year) from driver assistance systems for line haul locomotives	113 tPM_{10} and 4,810 tNO_x
Total PM_{10} and NO_x reduction (per year) from Tier 4 standards for new locomotives	304 tPM_{10} and 8,344 tNO_x
Total PM_{10} and NO_x reduction (per year)from accelerated replacement of old line haul locomotives and for new locomotives to Tier 4 standards	629 tPM_{10} and 25,749 tNO_x

(a) Measure currently assumes no increase in oil price. The absence of such a price increase, all else being equal, would lead to a conservative estimate of fuel savings (and therefore net present value benefits).

For replacement of new locomotives, it was assumed that the total new fleet of 871 locomotives would be replaced over 20 years with an equal number replaced each year. Notwithstanding data limitations, while the actual time profile of replacement may be more varied, the results would be similar. Accelerated replacement of existing fleet would occur over five years.

D.2.1.2 Timeframe

The measures were assumed to be implemented with effects beginning from 2015, a slightly slower turnover of stock of 22 years compared with 20 years assumed in **ENVIRON (2012)**, and continuation out to 2036.

D.2.1.3 Emission reductions

The estimated emission reductions derived from **ENVIRON (2012)** are provided in **Figure D19**. ENVIRON provided estimated emissions for PM_{10} size fractions and consistent with the study it was assumed that $PM_{2.5}$ emissions comprise 97% of PM_{10} emissions **(ENVIRON, 2012)**. The profile of emission reductions reflects a gradual phase in of measures as described above. Note some emissions and benefits accrue beyond 2036 out to 2055 due to the long lived nature of diesel trains.

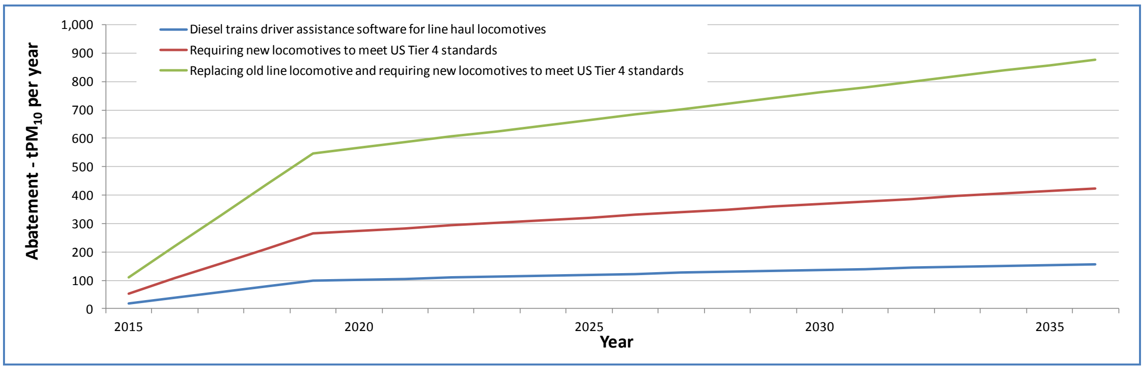

Figure D19: PM reductions for diesel train measures

D.2.1.4 Co-benefits and dis-benefits

The ENVRON study provided estimated reductions in NO_X. Our estimates, derived from figures provided in the study, are shown in **Figure D20**.

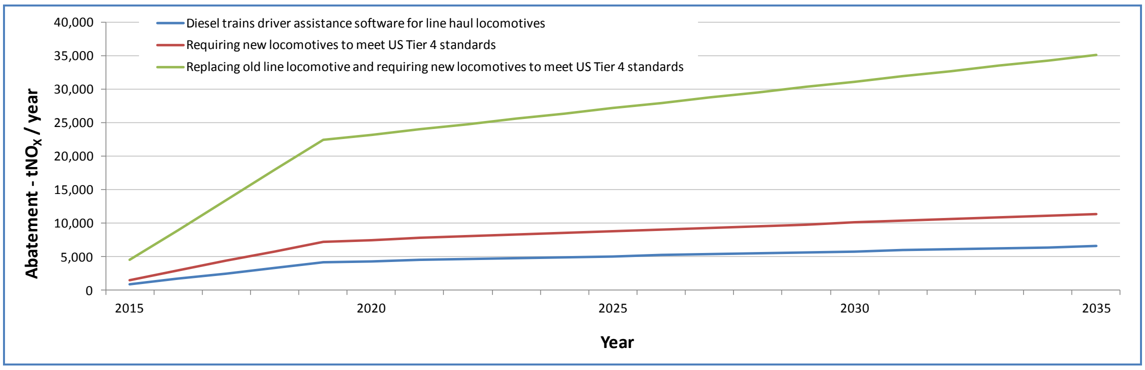

Figure D20: NO_X reductions for diesel train measures

Fuel efficiency benefits are associated with the driver assistance programme (indicated below). There are potential CO_2 reductions, but these are not quantified due to the same uncertainties that arise as with non-road diesel engines.

D.2.1.5 Costs

Cost estimates provided by the ENVIRON study included:

- Changes in capital expenditure
- Changes in operating expenditure
- Changes in maintenance costs
- Fuel savings

Notably, for driver assistance systems fuel savings exceeded other ongoing costs.

Government costs (*e.g.* regulation) were not provided in the source study. An allowance for government administration costs to oversee the measures of two full time equivalents (FTE) at approximately $100,000 per FTE per year was made.

The costs used in our economic analysis are shown in **Figures D21** to **D23**. Higher capital costs are incurred in the first five years as existing line haul locomotives are fitted with the software in addition to the higher costs associated with new line haul locomotives. Following this initial period, the remaining 15 years of the first 20-year period include fitting of software to new line haul locomotives only. Increase in operating costs (and fuel efficiency savings) reflect the increase in installations over time. Capital costs are higher for new locomotives that are compliant with US Tier 4 standards. As cumulative installations grow, higher operating costs, as described above, are incurred. In addition to the costs in the previous chart, requiring accelerated replacement of old line haul locomotives in addition to new locomotives results in significantly higher capital costs ('front loaded' over 5 years for the existing 921 line haul locomotives).

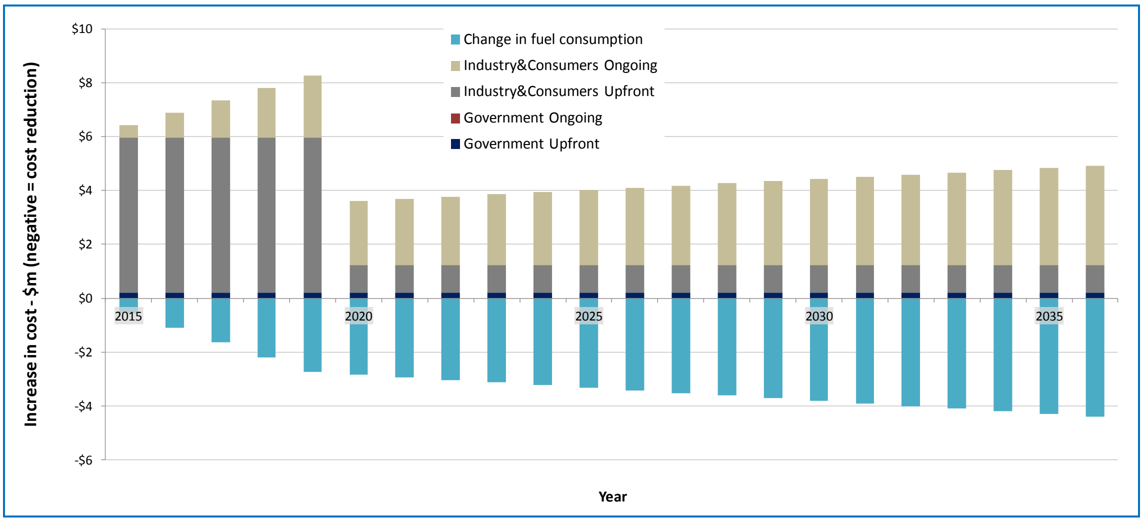

Figure D21: Cost of diesel trains driver assistance software for line haul locomotives

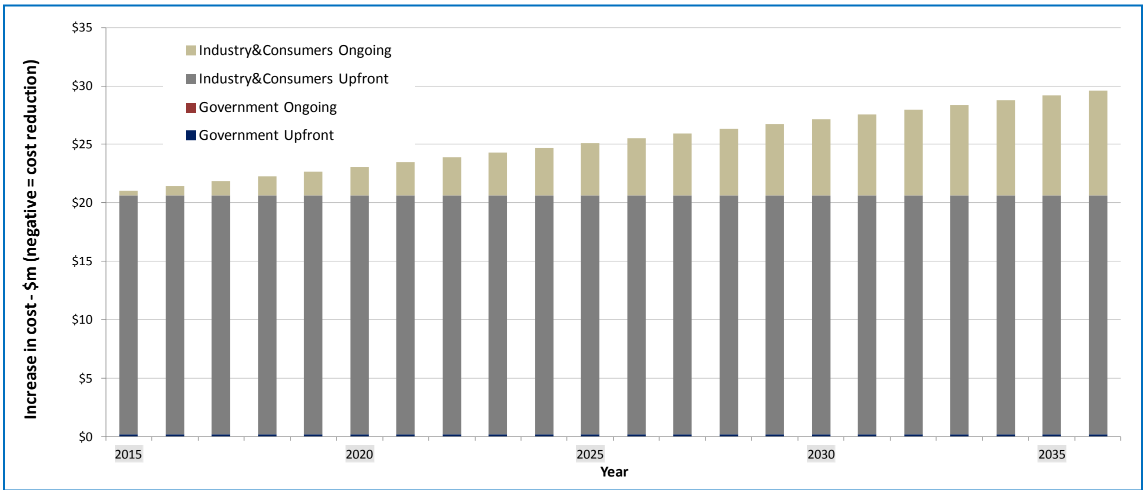

Figure D22: Cost of requiring new locomotives to meet US Tier 4 standards

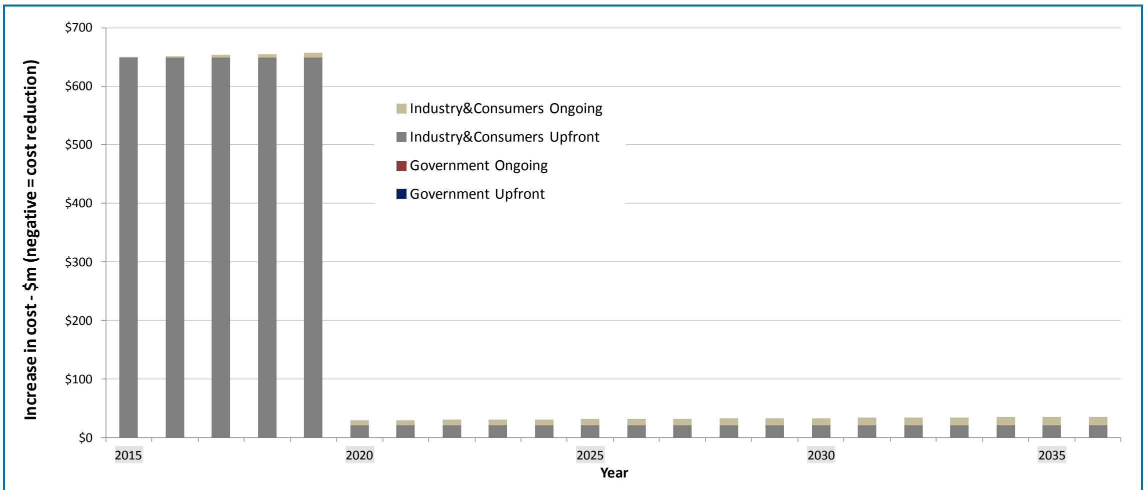

Figure D23: Cost of replacing old line locomotives and requiring new locomotives to meet US Tier 4 standards

D.2.1.6 Uncertainty in estimates

The presentation of results of emission reductions and cost-effectiveness in the study, with uncertainties drawn from source studies, demonstrates relatively moderate confidence in precise emissions and cost estimates. For some measures a 50% range (+/- 25%) is presented for cost-effectiveness, while a lower range is presented for emissions of approximately 20% (+/- 10%) for some measures. The sensitivity ranges for this economic analysis are given in **Table D8**.

Table D8: Sensitivity parameters for diesel trains measures

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Emission reductions	-10%
Measure less cost-effective compared with central assumptions	Costs	+30%
Measure more cost-effective compared with central assumptions	Emission reductions	+10%
Measure more cost-effective compared with central assumptions	Costs	-30%

D.2.2 In-service diesel equipment

D.2.2.1 Background

In addition to emissions standards for new diesel equipment, measures designed to reduce emissions from existing in-service diesel equipment in urban areas were briefly analysed. NSW EPA provided the project team with emission reductions and cost estimates related to the installation of pollution-reduction devices such as DPFs for in-service equipment under its Clean Machine program. This potential measure assumes a national rollout of the NSW Clean Machine Program, with a notional subsidy of $4.2 million over four years (subsidising on average 70% of costs) to encourage retrofit of emission-reduction equipment. Data for the analysis were drawn from the NSW Clean Machine Program[33] and the CBA of non-road diesel engine measures undertaken by **ENVIRON and SKM-MMA (2011)**.

D.2.2.2 Timeframe

A programme to install pollution reduction devices on in-service diesel equipment is assumed to start in 2015 and run until 2019.

D.2.2.3 Emission reductions

Consistent with experience form the NSW Clean Machine Program, retrofits were assumed to deliver average PM_{10} reductions of 29 kg per year per machine. The number of machines estimated to be retrofitted was derived from the average cost of retrofits, and by assuming an even profile of uptake over the four-year lifetime of the program, with uptake commencing in 2015. The resulting emission reductions for PM_{10} are shown in **Figure D24**. As it was assumed that retrofits would be targeted at relatively older equipment an average 10-year life per unit was assumed. It was also assumed that $PM_{2.5}$ comprises 95% of PM_{10} emissions from combustion sources[34].

Emissions reductions increase as more DPFs are fitted and then decreases as equipment reaches the of end of its life (in 10 years).

[33] http://www.environment.nsw.gov.au/air/nonroaddiesel.htm
[34] California Air Resources Board (CARB) Emissions Inventory (www.arb.ca.gov/)

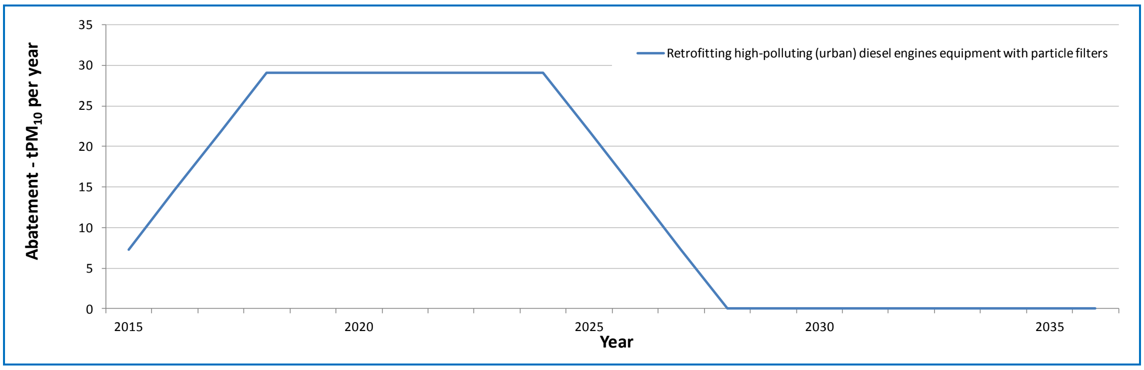

Figure D24: PM reduction from retrofitting high-polluting (urban) diesel engines with DPFs

D.2.2.4 Co-benefits and dis-benefits

The use of DPFs may also result in a slight increase in NO_X emissions and fuel consumption. These effects are marginal and therefore have not been quantified. However, such effects are incorporated in the sensitivity range.

D.2.2.5 Costs

An average per machine installation cost of $5,930 was derived from the NSW Clean Machine program. Assuming 70% of costs are funded by government with the remaining 30% by industry and making an order of magnitude allowance for government administration costs (2.5 FTE) at approximately $100,000 per FTE per year), costs were estimated as shown below. Costs are incurred over the 4 year life of the program.

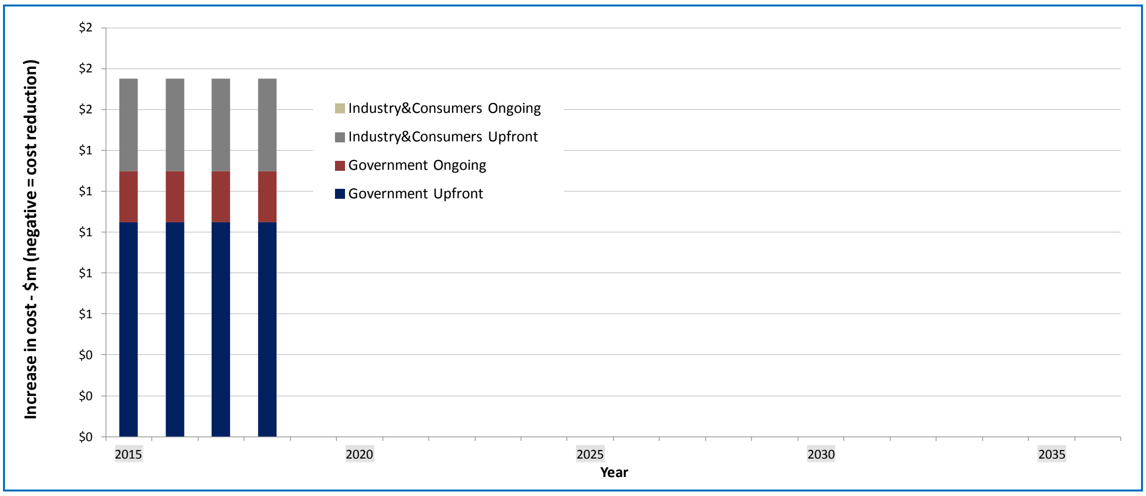

Figure D25: Cost of retrofitting high-polluting (urban) diesel engines with DPFs

D.2.2.6 Uncertainty in estimates

Cost-effectiveness of individual machine retrofits in the NSW Clean Machine Program varies significantly (estimated by NSW EPA to vary from $8/kg to $619/kg).

For the sensitivity analysis, a wide range of cost estimates is proposed to reflect uncertainty. Note that keeping the programme size and estimated reductions per machine fixed, flexing this parameter automatically varies the level of emission reductions (higher cost per machine results in lower total installations and therefore lower total emission reductions.

Table D9: Sensitivity parameters for retrofits to in-service diesel equipment

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Cost	+40%
Measure less cost-effective compared with central assumptions	Emission reductions	Automatically lower number of installations due to higher cost
Measure more cost-effective compared with central assumptions	Cost	-40%
Measure more cost-effective compared with central assumptions	Emission reductions	Automatically higher number of installations due to lower cost

D.2.3 Shipping

D.2.3.1 Background

PAE Holmes (2011) undertook a preliminary study for potential mitigation measures to reduce air pollution in NSW Ports, centred on reducing emissions from shipping. Emissions from ports are increasing as freight traffic rises with shipping being by far the largest fraction of this contribution. Measures to reduce pollution from shipping may be cost-effective relative to others. PAE Holmes recommended that better understanding be gained of priorities, potential measures and their costs and benefits by considering relevant actions being undertaken by the Port of Los Angeles and Long Beach in California as part of their 'Clean Air Action Plan'. Two measures have been considered and analysed as part of this economic analysis. These include:

- Mandatory low-sulfur (0.1%) fuel at berth from 2017 (currently fuel sulfur is 2.7%).
- Memorandum of Understanding (MOU) with port operators and ship owners to reduce vessel speed for ocean transits to and from harbours from 2015.

Ships generally use low quality fuel with relatively high sulfur content **(PAEHolmes, 2011)**. EU ports require mandatory use of low sulfur (0.1% by mass or less) fuel in ship auxiliary engines and auxiliary boilers if berthed for more than two hours, or the use of exhaust gas scrubbers to achieve equivalent results **(PAEHolmes, 2011)**. The effects of using low sulfur fuel include reductions in PM, NO_x and SO_2 emissions.

Reduced fuel consumption and emissions are associated with vessel speed reduction **(PAEHolmes, 2011)**. A voluntary MOU would involve the shipping industry to negotiate an agreement to reduce vessel speed within a reduced speed zone. A negotiated agreement would allow the industry to determine levels of speed reduction and extent of the reduced speed zone so as to maximise cost-effectiveness.

Analysis of potential emission reductions and cost-effectiveness of measures was based on findings of the **PAE Holmes (2011)** report and the following sources (extrapolating the NSW analysis to the whole of Australia where required):

- Ship boiler numbers for GMR from NSW EPA inventory **(NSW EPA, 2012f)**.
- BTRE forecasts of ship movements through Australia to 2024-25 **(BTRE, 2006)**.
- Other publically available sources (*e.g*. Marine Diesel Oil Price[35]).

In contrast to other sectors where measure options are seen as mutually exclusive, for the purposes of the economic analysis it was assumed that shipping measures could be complementary (both the low-sulfur and MOU options could be implemented simultaneously).

[35] http://www.bunkerindex.com/prices/asia.php

D.2.3.2 Timeframe

For this economic analysis, it has been assumed that low-sulfur at berth will be mandatory from 2017 to 2036, and that a MOU between port operators and ship owners to reduce vessel speed for ocean transits to and from harbours will be in place from 2015 to 2036.

D.2.3.3 Emission reductions

For low-sulfur fuel, emission reductions in the NSW GMR for PM_{10}, $PM_{2.5}$, NO_X and SO_2 were provided in **PAE Holmes (2011).** From these, emission reductions per ship boiler were derived and scaled assuming national coverage. Additionally, reductions were assumed to increase in line with expected emissions increases from shipping as projected under BAU.

Emission reductions from a MOU for speed reductions were derived from the PAE Holmes study. That is, a 20% reduction in particulate emissions was estimated to result from a 10% reduction in speed with a consequent increase in costs to ship owners of $425 per ship movement. Further, estimated ship movements of 32,500 in the year of implementation, rising in line with estimated BAU shipping emissions increases and an 80% participation rate were used to estimate emission reductions.

PM_{10} and $PM_{2.5}$ reduction estimates for low-sulfur fuel and MOU for speed reduction measures are shown **in Figures D26** and **D27**.

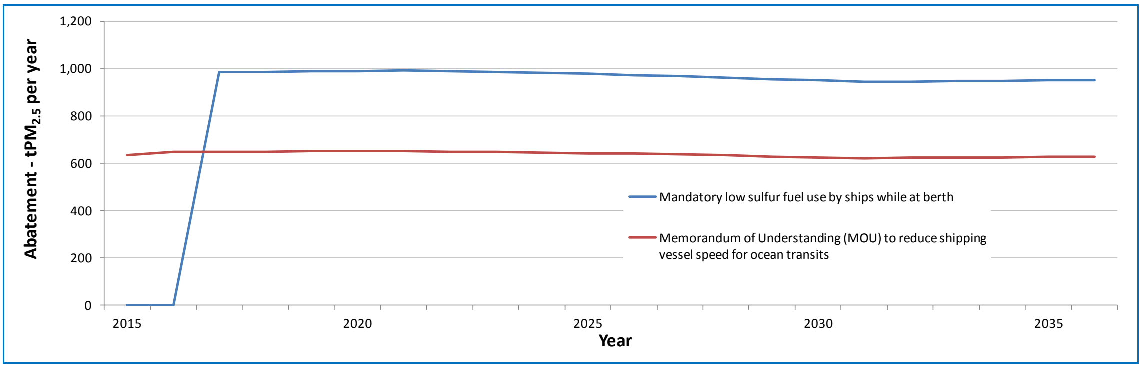

Figure D26: $PM_{2.5}$ reductions from shipping measures

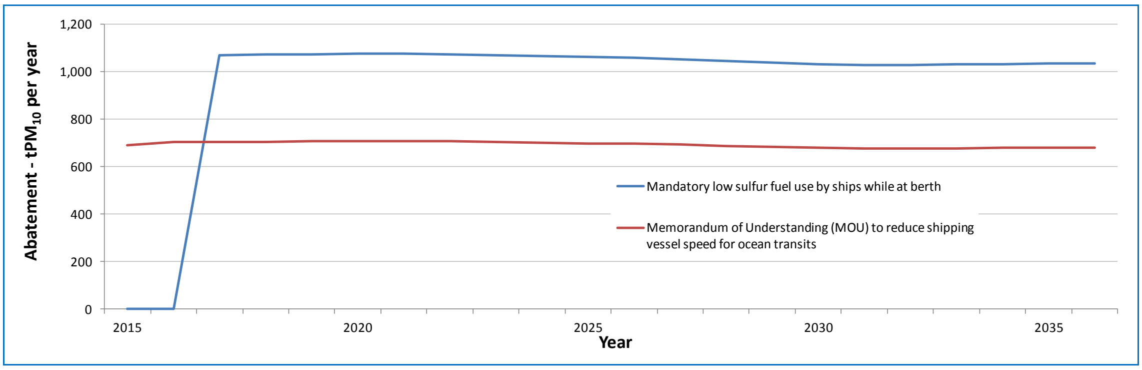

Figure D27: PM_{10} reductions from shipping measures

D.2.3.4 Co-benefits and dis-benefits

Reductions in NO_X were derived using the methodology described above. The estimates are presented in **Figure D28**. There are also fuel efficiency and CO_2 benefits from the vessel speed measure. These values are not calculated in this analysis. Benefits of SO_2 pollution, (i.e. the quantum (tonnes) which may be estimated), are not included in the analysis as these are estimated to be minor relative to benefits resulting from particulate and NO_x reduction.

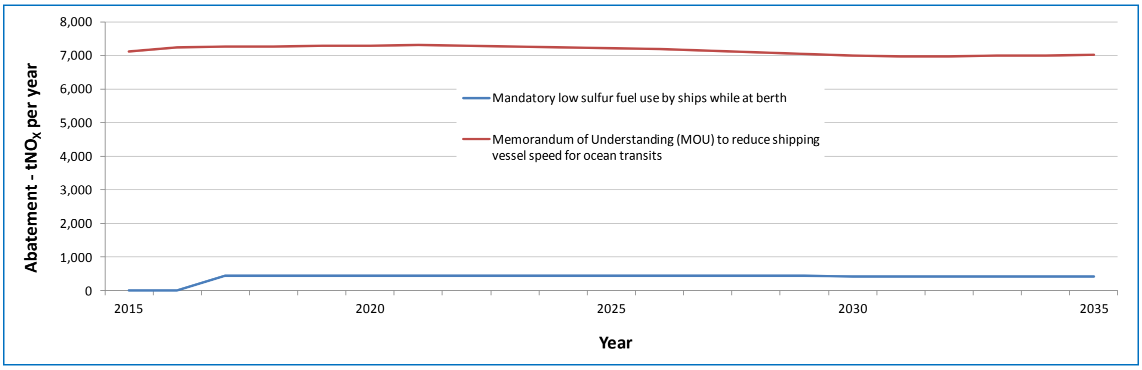

Figure D28: NO_X reductions from shipping measures

D.2.3.5 Costs

For low-sulfur fuel, estimated boiler retrofit costs, derived from **PAE Holmes (2011)** of $20,400 per boiler were assumed. Additionally, estimated fuel consumption at berth was derived from the NSW EPA inventory and combined with current marine diesel oil prices[36] and an expected 50% increase in fuel costs for low-sulfur fuel, reflecting that low sulfur fuel costs at least 50% more than conventional fuel **(PAE Holmes, 2011)** to derive ongoing costs of this measure.

Finally, order of magnitude costs for government regulatory design and administration ($1million and 5 FTE per year) were assumed. Costs of a MOU for speed reduction were estimated assuming an increase in costs to ship owners of $425 per ship movement **(PAE Holmes, 2011)** and estimated BITRE ship movement numbers as described above. Governments costs equivalent to that for the low-sulfur fuel option were assumed.

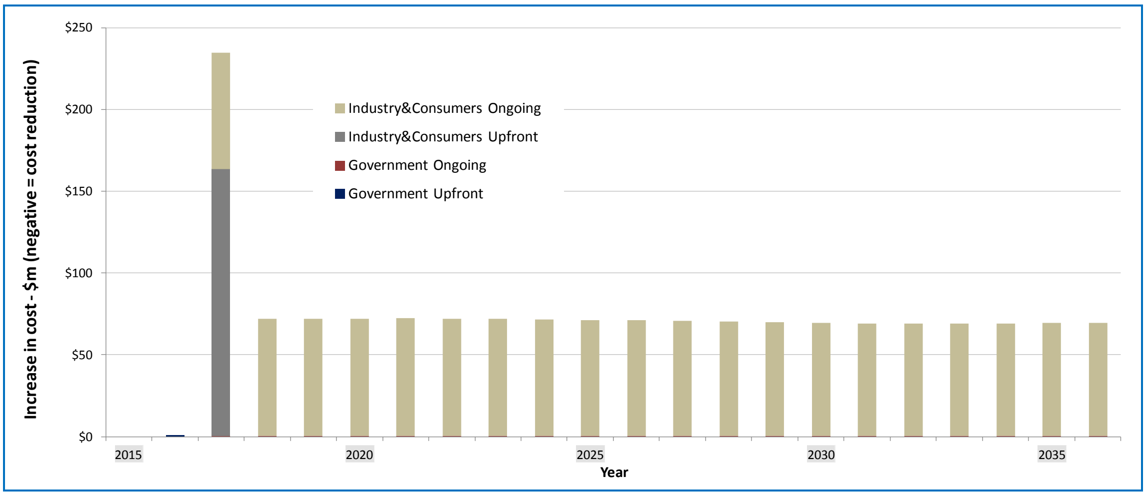

Figure D29: Cost of mandatory low-sulfur fuel use by ships while at berth

[36] http://www.bunkerindex.com/prices/asia.php

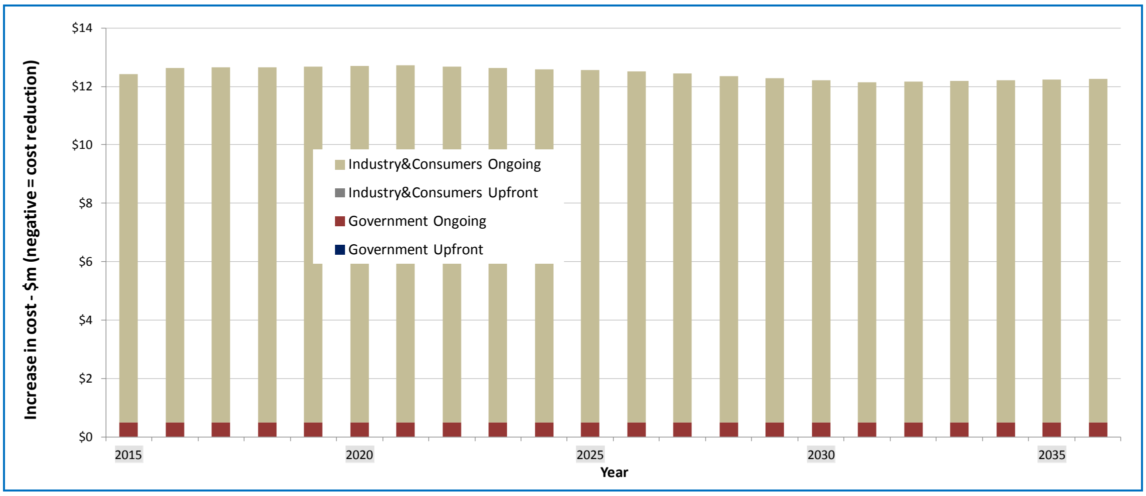

Figure D30: Cost of Memorandum of Understanding (MOU) to reduce shipping vessel speed for ocean transits

D.2.3.6 Uncertainty in estimates

For low-sulfur fuel, a wide range of cost of retrofit estimates (($6,800 - $34,000 per retrofit) were provided in **PAE Holmes (2011).** Uncertainty in estimated emission reductions is unknown. Uncertainty in costs estimates of a MOU for speed reduction are similarly uncertain, with an estimated increase in costs for ship owners (per ship movement) provided in **PAE Holmes (2011)** ranging from $250 to $600. Similar to low-sulfur fuel, uncertainty in estimated emission reductions is unknown. Sensitivity parameters for both measures in this economic analysis are given in **Table D10**.

Table D10: Sensitivity parameters for shipping measures

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Cost	+50%
Measure less cost-effective compared with central assumptions	Emission reductions	-50%
Measure more cost-effective compared with central assumptions	Cost	+50%
Measure more cost-effective compared with central assumptions	Emission reductions	-50%

D.2.4 Coal dust

D.2.4.1 Background

Concern over the health impacts of PM emissions and air quality issues associated with coal mining have prompted recent studies into exploring measures to reduce PM emissions from coal mine operations. **Katestone Environmental (2011)** undertook a benchmarking study, reviewing international best practice for control of coal mine particle emissions and the scope for adoption of such practices in NSW. The study considered the impact of adopting what appear to be the most cost-effective measures for PM_{10} and $PM_{2.5}$ emissions at NSW coal mines. The most cost-effective controls were found to be:

- Controlling wind erosion from exposed areas through rehabilitation.
- Use of fabric filters or enclosure of drill rigs.
- Controlling wind erosion of overburden through rehabilitation.

- A range of possible measures for unpaved roads including application of suppressants, conversion to conveyors or the use of larger haul trucks.
- Use of fabric filters or enclosure of 'Run of Mine' hoppers receiving coal from trucks.
- Controlling wind erosion from coal stockpiles through application of suppressants or watering.
- Watering while bulldozing coal.

Following the study further analysis on potential emission reductions from actual NSW coal mines through implementation of these measures has been undertaken and preliminary results provided to the project team. Therefore the figures in the economic analysis reflect a more focussed set of measures from **Katestone Environmental (2011)** and data from NSW coal mines. The analysis found that measures for unpaved roads, overburden and wind erosion provide the greatest opportunities potentially achieving >80%, >50% and >20% reduction from the baseline respectively.

D.2.4.2 Timeframe

For the economic analysis, measures were assumed to be effective from 2016 to 2036. However, some emissions reductions were assumed to continue to accrue beyond 2036 to 2046 as it is expected that measures that entail changes in capital equipment will continue to deliver emissions reduction while this equipment is in service.

D.2.4.3 Emission reductions

Analysis undertaken for NSW EPA indicates that adoption of unpaved roads, overburden and wind erosion controls is estimated to result in a reduction of 26.1% of PM_{10} and 19.4% of $PM_{2.5}$ emissions from NSW coal mines. These estimates were extrapolated to Australian coal mine emissions using coal production by state figures from **ABARES (2010)**. Additionally, annual emission reductions were increased over time in line with projected increases in coal dust emissions under BAU.

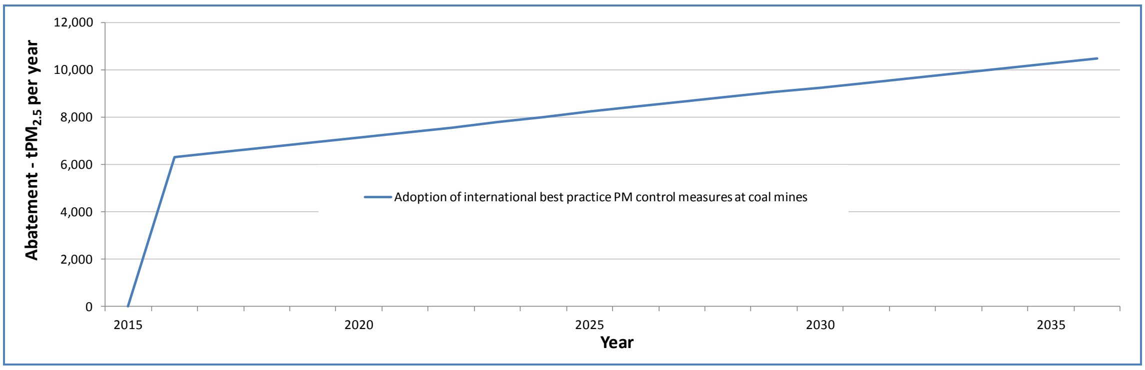

Figure D31: $PM_{2.5}$ reduction from adoption of international best practice PM control measures at coal mines

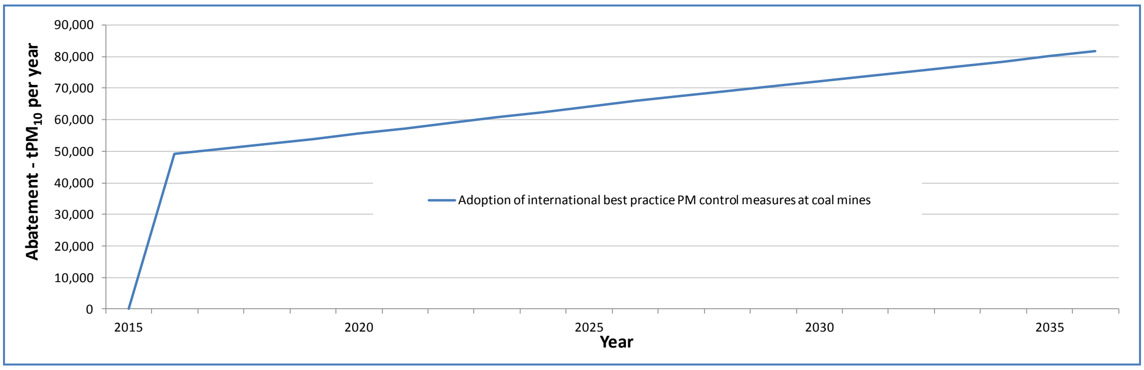

Figure D32: PM_{10} reduction from adoption of international best practice PM control measures at coal mines

Approximately 10% of the total cost of the coal dust measures relates to capital charges for the purchase of equipment. Equipment is assumed to have an average remaining life of 10 years. Therefore, some emissions reductions are maintained compared to what there would be assuming full continued best practice (10% in 2037, gradually declining to 0% by 2046).

D.2.4.4 Co-benefits and dis-benefits

Controlling wind erosion from exposed areas was found to reduce the cost of coal mine operations by reducing the cost of current watering control measures **(Katestone Environmental, 2011)**. An estimate for this benefit is not included in this economic analysis.

D.2.4.5 Costs

Katestone Environmental (2011) found the present value of the most cost-effective measures to be $164 million per annum in NSW (this figure was scaled to provide a national estimate), and the cost of unpaved roads, overburden and wind erosion measures represented approximately 70% of this total. This cost was disaggregated into upfront and ongoing components, using additional assumptions supplied to the project team by Katestone; that is, assuming a 7.8% real discount rate, a capital recovery period of 20 years and that capital costs account for 10% of the total cost (incurred in the first year of the measure). Order of magnitude estimates of costs to government of approximately $1 million and five FTE per year at $100,000 per year were assumed for implementing regulations and ongoing administration respectively. The resulting cost estimates for the economic analysis are shown in **Figure D33**.

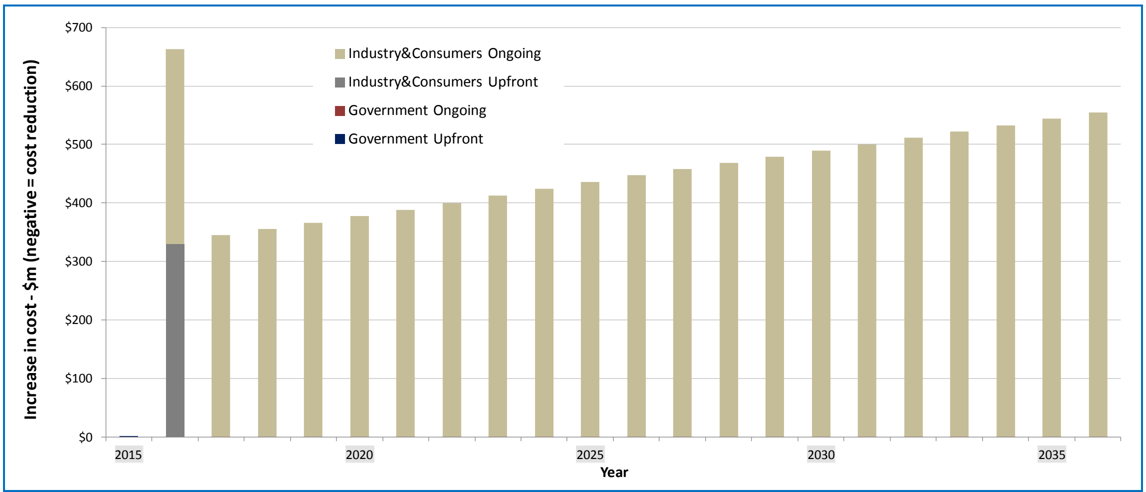

Figure D33: Cost[37] of adoption of international best practice PM control measures at coal mines

D.2.4.6 Uncertainty in estimates

Uncertainty in source assumptions is not known to the project team, although the further analysis undertaken to estimate potential emission reductions from actual NSW coal mines provides relatively higher confidence to emission reduction and cost estimates. The sensitivity parameters for coal mine control measures in this economic analysis are given in **Table D11**.

[37] Government costs are not visible as they are minimal in comparison to industry costs.

Table D11: Sensitivity parameters for coal mine best practice measures

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Cost	+10%
Measure less cost-effective compared with central assumptions	Emission reductions	-10%
Measure more cost-effective compared with central assumptions	Cost	+10%
Measure more cost-effective compared with central assumptions	Emission reductions	-10%

D.2.5 Light commercial vehicles

D.2.5.1 Background

Two measures for reducing emissions from the existing light commercial fleet have been analysed and included in the economic analysis. These were:

- Adopting behaviour change ('eco-driving') in the national light commercial vehicle (LCV) fleet to maximise fuel economy by operating the engine more efficiently and minimising engine idling, thereby reducing emissions. This measure would extend Western Australia's programs such as 'CleanRun'.
- Targeted maintenance of high polluting vehicles detected using remote sensing technology that provides instantaneous feedback to drivers on emissions performance of their vehicles.

The CleanRun trial used a range of tools to encourage drivers to avoid unnecessary idling. The trial concluded that behaviour change achieved through Community-Based Social Marketing - that is, encouraging behaviour change using social psychology to discover and overcome barriers associated with behaviour change - were both cost-effective and significantly reduced emissions. Tools included stickers, signs and posters prompting drivers to avoid unnecessary idling and addressing 'myths' about idling (seen as barriers to behaviour change) and electronic message reminders to drivers, Based on evaluation results and feedback from drivers, the trials also developed a model that could be adopted within the broader transport industry.

Remote sensing technology involves monitoring of vehicle emissions at roadside monitoring sites and using a 'Smart Sign' to provide instantaneous feedback to drivers who have just passed the site. Vehicles with poor emissions performance would then have the opportunity to participate in voluntary vehicle servicing. Maintenance can also deliver fuel consumption benefits in addition to reducing emissions.

D.2.5.2 Timeframe

For PM abatement through behaviour change, an estimated rollout to 2% of Australia's approximately 2.5 million LCV fleet (Australian Bureau of Statistics) was assumed. The behaviour change campaign was assumed to occur in 2015, with adoption by industry in 2016 and ongoing benefits were assumed to 2036, reflecting retention of behaviour by drivers.

The estimated emission reductions for remote sensing of LCVs were based on the assumptions that 10% of poor-performing vehicles would participate, and 15% of these would be feasible to repair. Repair was estimated to reduce emissions by 60%[38]. The measure was assumed to be effective from 2015 to 2017, with ongoing emissions reduction to 2026, reflecting the average lifetime of affected vehicles.

D.2.5.3 Emission reductions

An evaluation of the CleanRun initiative by **WA DEC (2008)** estimated emission reductions achieved through behaviour change by analysing self-reported data on idling reductions by drivers and emissions performance of the vehicles involved. Through this method, potential emission reductions per vehicle are given in **Table D12**.

Table D12: Emission reductions from behaviour change per light commercial vehicle

Pollutant	Estimated annual emission reduction
CO_2	560 kg
NO_x	3.5 kg
CO	850 g
PM	2 g

Fuel savings were estimated, using a similar method, as 200 litres per vehicle per year.

Due to the absence of more specific studies for potential emission reductions from remote sensing and targeted maintenance, plausible intuitive assumptions were required to provide an estimate of the scope for this measure.

Potential emission reductions through maintenance of LCVs only was estimated using indicative estimates for an Isuzu NPR 300 model[39] **(BCI, 2008)** as representative of emissions before repair, assuming an average of 10 hours per day of vehicle use over the year and an estimated 60% reduction in emissions through repair.

NSW EPA has provided assumptions to the project team relating to the proportion of vehicles opting into schemes and the proportion suitable for repair. A precise estimation of participation was beyond the scope of this study, however the assumptions provided are plausible and uncertainty is captured in the sensitivity analyses. Assumptions provided by NSW EPA and adopted in this economic analysis were:

- 2% of total LCVs in Australia participate in behaviour change;
- 10% of LCVs in Australia volunteer for maintenance through remote sensing (with 15% of these being able to repaired), effectively capturing 1.5% of LCVs.

Finally, potential emission reductions from behaviour change were decreased annually in line with estimated annual decrease in exhaust emissions from motor vehicle under BAU projections.

Emission reductions were held constant for remote sensing, with an average remaining life of 10 years being assumed for participating vehicles as the measures are expected to target a significantly higher proportion of older vehicles. $PM_{2.5}$ size fractions were assumed to comprise 95% of PM_{10} emissions for combustion source emissions **(CEIDARS, 2008)**.

[38] In order to comply with increasingly stringent type approval limits for exhaust PM emissions, DPFs on diesel LCVs will become more common in the future. DPFs virtually eliminate exhaust PM. It is therefore assumed that vehicles will be identified as having 'high' PM emissions where there has been a failure of the DPF. DPF failure is a gradual process, and the condition of the DPFs in the fleet will vary widely. It is therefore not straightforward to give a definitive fleet-average emission reduction for the identification and repair of a faulty DPF. The 60% value takes into account the fact that vehicles identified as having high emissions should typically have DPFs in a 'worse than average' state, although it is acknowledged that there are no supporting data.
[39] Model is estimated to emit 0.015 grams of PM per hour.

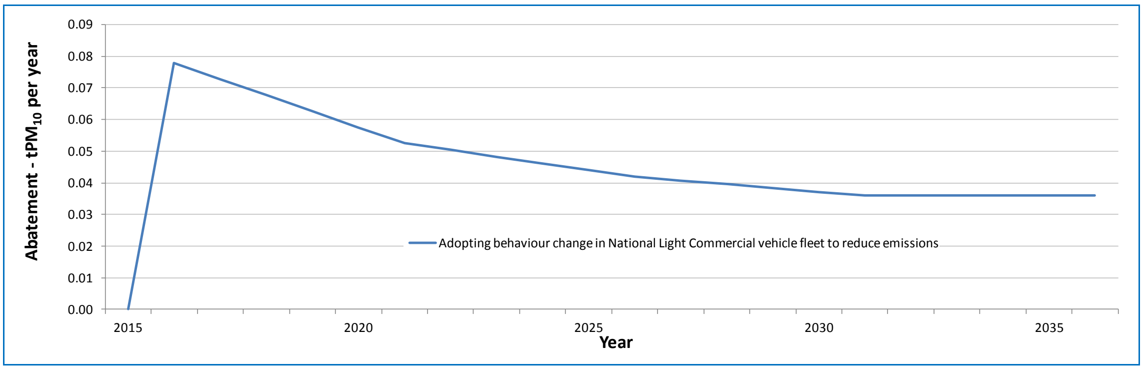

Figure D34: PM reductions from adopting behaviour change in national light commercial vehicle fleet

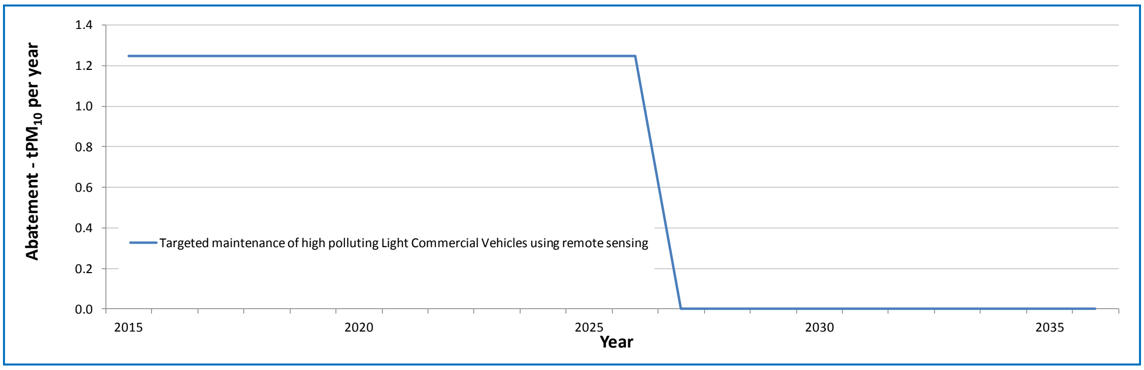

Figure D35: PM reductions from targeted maintenance using remote sensing

D.2.5.4 Co-benefits and dis-benefits

Assuming the methodology described above, reductions in NO_X and CO_2 were estimated as shown in **Figures D36** and **D37.** Additional fuel savings of 200 litres per vehicle per year (as above) were estimated for behaviour change, together with a diesel price assumption of $1.50 per litre. Fuel savings were considered possible (but un-estimated) through remote sensing and targeted maintenance of all vehicles.

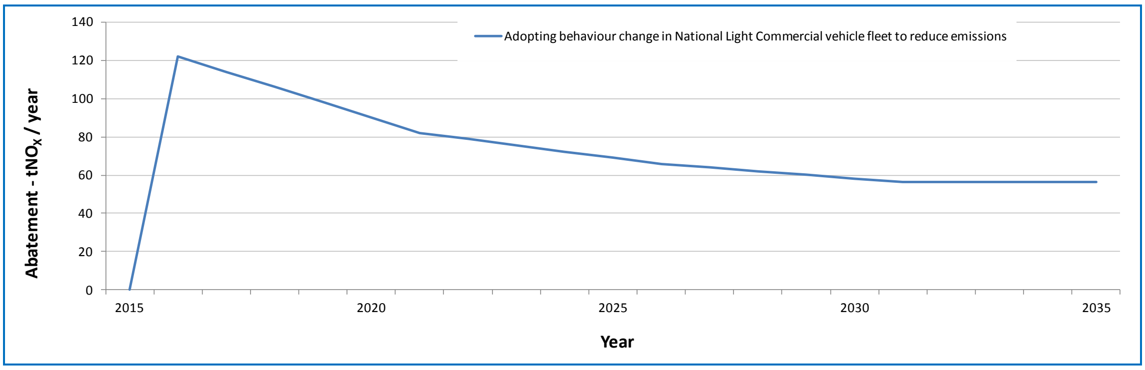

Figure D36: NO_X reductions from behaviour change

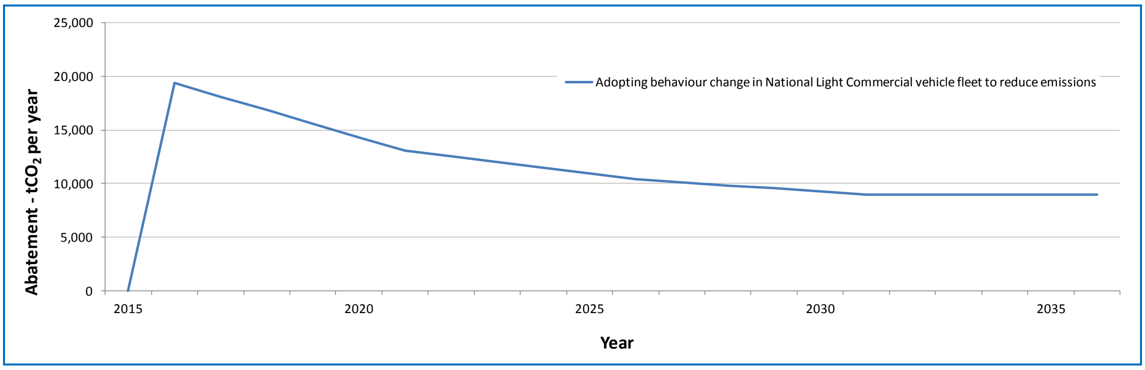

Figure D37: CO_2 reductions from behaviour change

D.2.5.5 Costs

In addition to cost assumptions provided above, order of magnitude government costs were assumed as $2.5 million for a national behaviour change programme (equating to approximately $50 per vehicle), $1 million for implementation costs associated with remote sensing as well as $200,000 per state (for equipment) spread over three years.

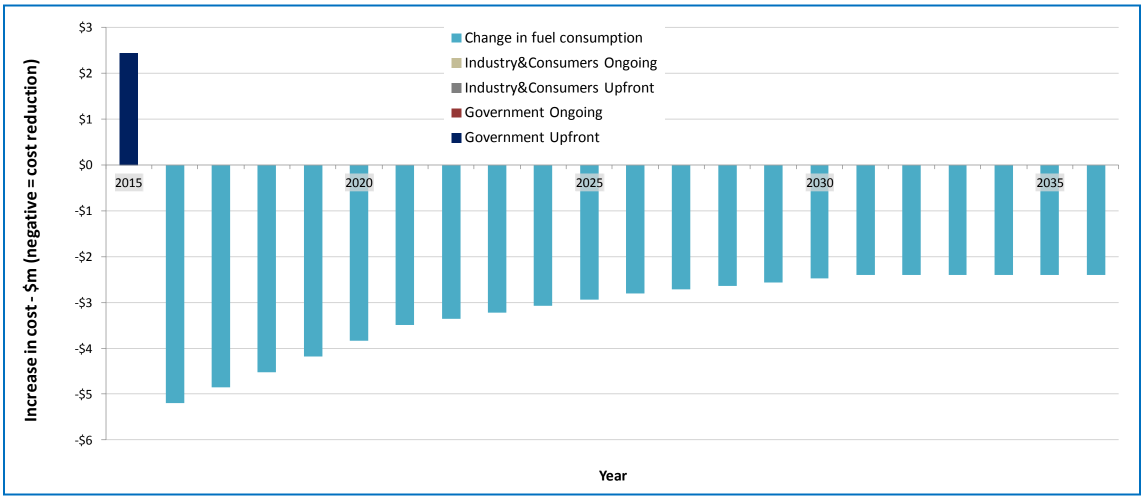

Figure D38: Cost of adopting behaviour change in national light commercial vehicle fleet

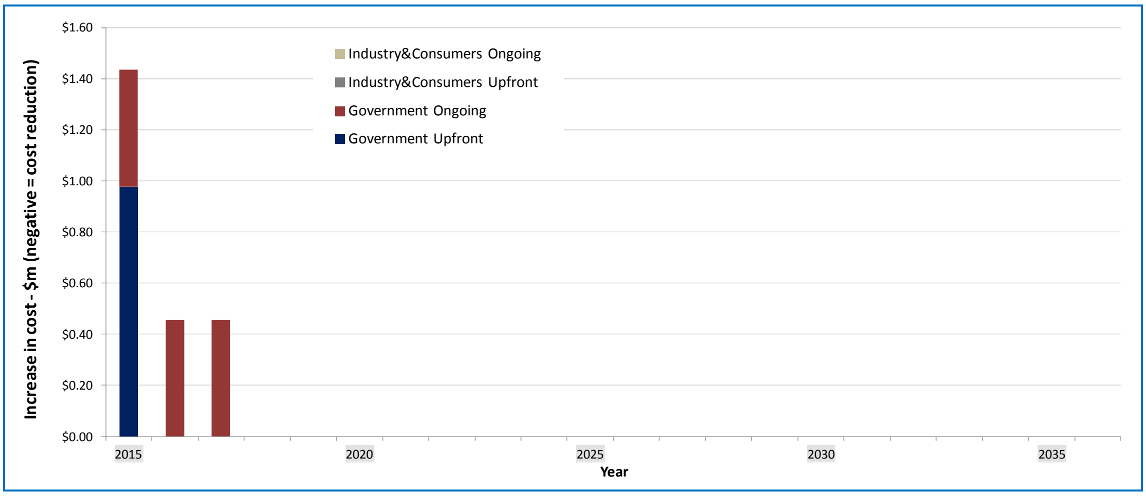

Figure D39: Cost of targeted maintenance of high-polluting light commercial vehicles using remote sensing

D.2.5.6 Exclusion of behaviour change from economic analysis

It is apparent from the results above that the fuel consumption benefits of behaviour change far outweigh those of particulate matter. Ignoring fuel efficiency benefits, the measure is not cost-effective for PM reduction alone (a $2.5 million programme resulting in approximately 0.05 tPM_{10} abatement per year).

Fuel savings for this measure are significant and the project team considers that the policy would primarily be driven by this benefit. Therefore, while this policy is expected to have significant (non-particulate) benefits it has not been included in the economic analysis.

D.2.5.7 Uncertainty in estimates

Many of the assumptions for LCV measures, while informed through other studies, have a high degree of uncertainty. To reflect the significant uncertainty in estimates, sensitivity parameters for LCV measures in this economic analysis are recommended as follows.

Table D13: Sensitivity parameters for LCV measures

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Cost	+50%
Measure less cost-effective compared with central assumptions	Emission reductions	-50%
Measure more cost-effective compared with central assumptions	Cost	+50%
Measure more cost-effective compared with central assumptions	Emission reductions	-50%

D.3 ANALYSIS: OTHER MEASURES

D.3.1 High polluting vehicles – penalties and incentives

D.3.1.1 Background

Data from the NSW M5 East Air Quality Improvement program[40], which entails a combination of penalties and incentives to reduce pollution from gross-polluting vehicles, was used to estimate the potential of operating similar schemes in all State Jurisdictions.

Through penalties and incentives, the scheme would encourage the installation of DPFs to grossly polluting vehicles to reduce emissions. For example as of 1 March 2013, trucks with poor emissions performance face a fine of $2,000 for the first two offences and $2,000 plus an automatic three month suspension of the vehicle's registration after a third offence. Under the program, the NSW Government will pay up to 50% of costs (up to $10,000) to assist with engine repairs and fitting DPFs. The scheme is supported through a 'smoky vehicle camera/video system' that facilitates detection of smoky vehicles, with subsequent contact with vehicle owners through the sending of letters to encourage participation in the repair and retrofit program.

[40] http://www.rta.nsw.gov.au/environment/cleanerair/improvementprogram/index.html

D.3.1.2 Timeframe

The measure was assumed to be effective from 2015-2018.

D.3.1.3 Emission reductions

The emission reduction from the fitting of a DPF was assumed to be 4.5 kg PM_{10} per vehicle per year **(SKM, 2010)**. $PM_{2.5}$ was assumed to comprise 95% of PM_{10} emissions for combustion source emissions[41]. Emissions reductions increase as more DPFs are fitted and then decreases as vehicles reach the end of their lives (in 10 years). From the M5 East study it was assumed that there would be 2,781 grossly polluting vehicles in Australia.

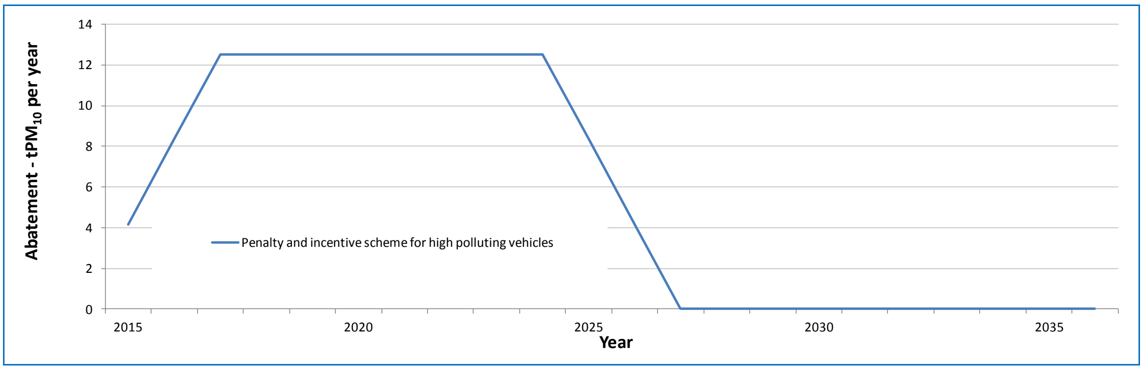

Figure D40: PM reductions from penalty and incentive scheme for high-polluting vehicles

D.3.1.4 Co-benefits and dis-benefits

The use of DPFs may result in a slight increase in fuel consumption and NO_X emissions. These were not estimated, as they were considered to be within the range of values used to test sensitivity.

D.3.1.5 Costs

The following assumptions, derived primarily from the M5 East Air Quality Improvement programme were made:

- An average cost of $7,800 per vehicle for purchase and installation of DPFs.
- $5 million for 50% subsidy towards purchase and installation of DPFs on vehicles.
- Assumption of 2,781 estimated grossly polluting vehicles in Australia.
- $4 million in total performance monitoring costs spread over a programme duration of 3 years.
- An average assumed lifetime of 10 years per vehicle given that the measure is expected to target older vehicles.

The results of adopting the cost assumptions described above are shown in **Figure D41**.

[41] CARB emissions inventory (www.arb.ca.gov/).

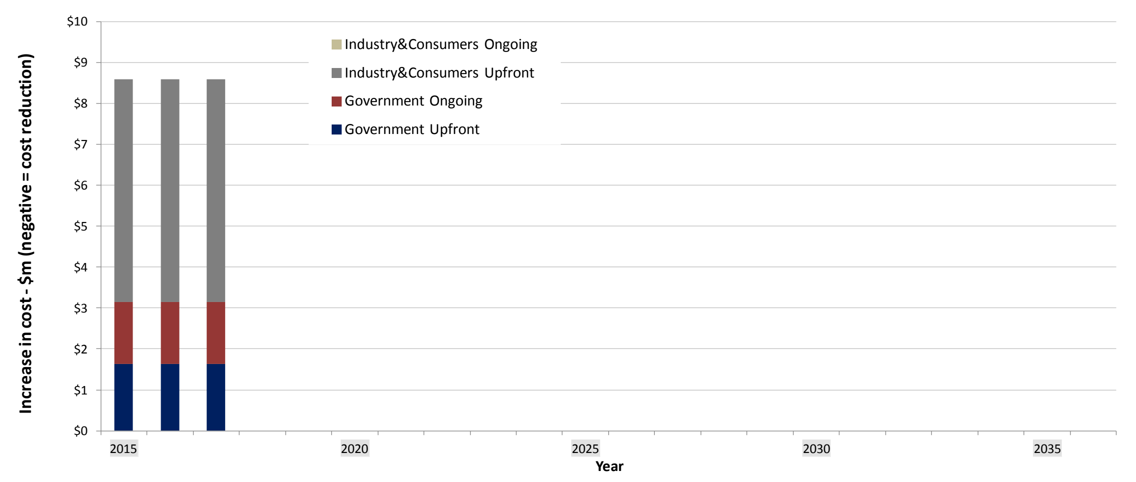

Figure D41: Cost of penalty and incentive scheme for high-polluting vehicles

D.3.1.6 Uncertainty in estimates

As with LCV measures, many of the assumptions for this measure, while informed through other studies, have a degree of uncertainty. Such assumptions were required to assess the potential costs and benefits of the measures. To reflect the significant uncertainty in estimates, sensitivity parameters for this measure in this economic analysis are shown in **Table D14**.

Table D14: Sensitivity parameters for high polluting vehicles measure

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Cost	+50%
Measure less cost-effective compared with central assumptions	Emission reductions	-50%
Measure more cost-effective compared with central assumptions	Cost	+50%
Measure more cost-effective compared with central assumptions	Emission reductions	-50%

D.3.2 Mine site diesel

D.3.2.1 Background

Section D.2.4 presented costs and emission reductions of abatement opportunities relating to dust from coal mine operations. Additional to these, analysis has been undertaken for the costs and emission reductions possible from addressing in-service diesel emissions at coal mines. Specifically, the costs and emissions reductions possible through a Pollution Reduction Program (PRP) or licence conditions at mine sites were considered.

D.3.2.2 Timeframe

This measure requires coal mine operators to produce a procurement plan that pursues conformance with latest EU/US non-road diesel engine emission standards (Tier 4) over time, with the intent of reducing emissions from in-service diesel at mine sites. The programme would begin in 2016 and is assumed to operate till 2036.

It was assumed that mine operators would achieve compliance through retrofit of existing equipment, given that much of this equipment will still have significant remaining useful life. Therefore, costs derived from the NSW Clean Machine Program (which also involves retrofit to existing diesel equipment) were used. Two tranches of capital investment (one in 2015 and one in 2025) were assumed.

The primary sources for assumptions underpinning the estimates were:

- NSW 2008 EPA Inventory to obtain a profile of industrial vehicle emissions at NSW coal mines (specifically, 1,747 $tPM_{2.5}$ and 26,416 tNO_X are estimated to be emitted from off-road vehicles at NSW coal mines);
- ABARE's coal production by state figures to extrapolate NSW calculations to a national scale (NSW coal mining volumes are 36% of national); and
- The NSW Clean Machine Program for estimated costs of achieving compliance through retrofit (costs of $20,605 per $tPM_{2.5}$ over 10 years are assumed).

D.3.2.3 Emission reductions

Emission reductions (**Figure D42**) were conservatively estimated at 50%, achievable through a PRP or licence conditions effective from 2016. This assumed a mix of emissions performance of existing equipment being replaced with Tier 4 engines. Typically moving from Tier 0 to Tier 2 level emissions may achieve greater than 90% emission reductions and moving from Tier 3-level to Tier 4-level emissions is likely to achieve greater than 90% reduction (**NSW EPA[42]**). $PM_{2.5}$ size fractions were assumed to comprise 97% of PM_{10} emissions (ratio for off-road industrial vehicles and equipment in the NSW GMR Inventory).

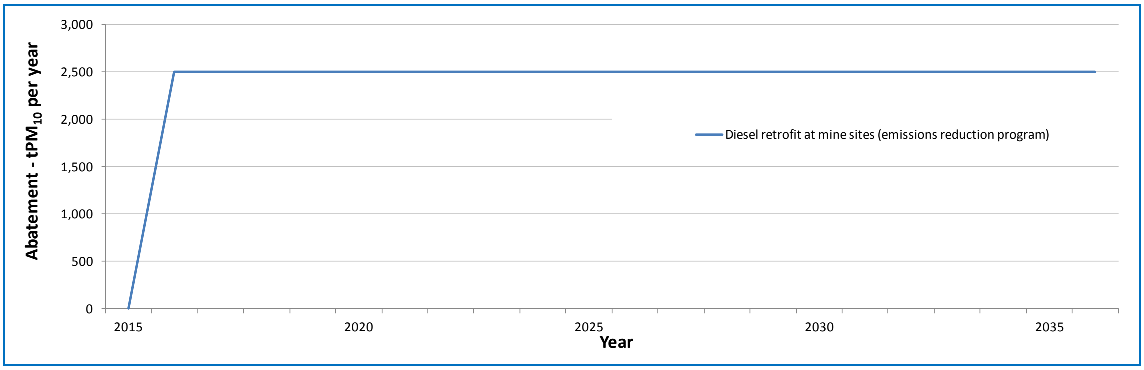

Figure D42: PM reductions from mine-site diesel measure

D.3.2.4 Co-benefits and dis-benefits

No co-benefits were identified for this measure.

D.3.2.5 Costs

Based on compliance cost assumptions consistent with the NSW Clean Machine Program and order of magnitude government administration costs of 2.5 FTE per year at $100,000 per FTE, cost estimates for this measure are shown in **Figure D43**. The cost of complying with the PRP or licence conditions is modelled to be incurred as two tranches (the first in 2015 and the second in 2025), allowing industry to defer part of the compliance until the second tranche and thereby reducing the cost impact on industry. Government administration (ongoing) costs are not visible on the chart as they are far outweighed by costs to industry.

[42] Derived from analysis undertaken by the NSW EPA for the Minerals Council.

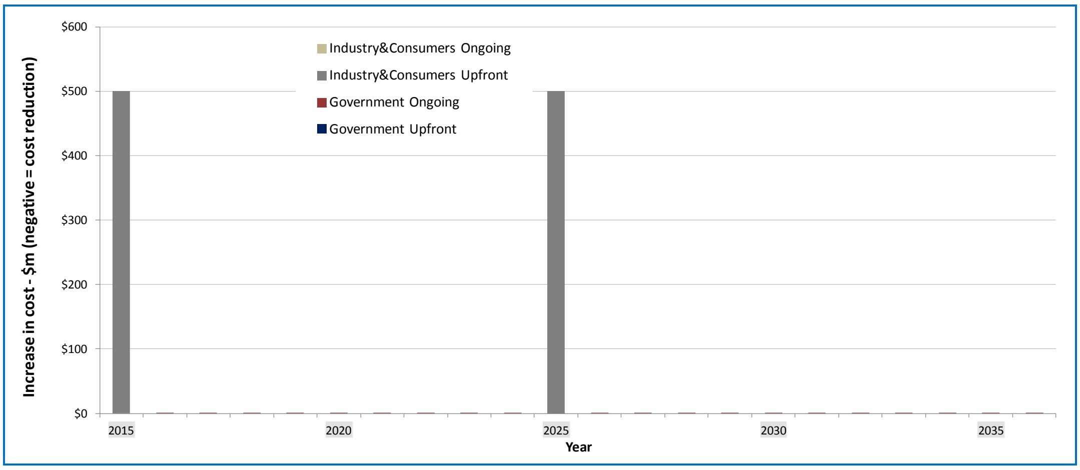

Figure D43: Cost of diesel retrofit at mine sites

D.3.2.6 Uncertainty in estimates

Cost-effectiveness of individual machine retrofits in the NSW Clean Machine Program varies significantly (estimated by NSW EPA to vary from $8/kg to $619/kg). As with the diesel retrofit measure, for the sensitivity analysis of coal mine diesel, a wide range of cost estimates is proposed to reflect uncertainty.

Emissions reductions of 50% being achieved through compliance were assumed. However, this is likely to be a conservative assumption. Recent analysis of coal mine emission-reduction measures undertaken by the NSW EPA suggests greater reductions (approximately 90%) are possible. Therefore sensitivity parameters (**Table D15**) are proposed that reflect the greater 'upside' for emission reductions than 'downside'.

Table D15: Sensitivity parameters for mine-site diesel measure

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Cost	+50%
Measure less cost-effective compared with central assumptions	Emission reductions	40% emission reduction from baseline
Measure more cost-effective compared with central assumptions	Cost	-50%
Measure more cost-effective compared with central assumptions	Emission reductions	90% emission reduction from baseline

D.3.3 In-service wood heaters

D.3.3.1 Background

In addition to the nine policy combination options modelled from the BDA report **(BDA Group, 2013)** (in **Section D.1.2**) the consultants examined options assessed in a report for NSW EPA **(AECOM, 2011)**. The NSW study focussed on in-service wood heater options and considered various combinations of the following individual options:

(I) A ban on the sale and installation of new wood heaters

(II) Stricter efficiency and emission limits for all new wood heaters

(III) Removal of wood heaters at sale of house or within 7 years

(IV) Regulation for a maximum moisture content on firewood sold

(V) A levy on new wood heaters

(VI) A general licensing levy to install a wood heater

(VII) A levy on solid fuel for sale

(VIII) Cash incentives to take up and use an alternative form of heating

Of these options (II) and (VIII) are already covered, at least in part, by the options presented in the BDA report. Options (I), (III) and (V) were assessed as having the highest net benefit and may therefore warrant further consideration.

We note however, that the costs associated with these options (in particular loss of consumer surplus for Options (I) and (V) are likely be substantially greater than assessed in the NSW EPA study (especially outside of metropolitan areas). Further, because Options (I) and (V) are blunt instruments they are likely to face strong community opposition.

Noting these points, Option (III) is the option most likely to warrant further consideration as an alternative to some of the options assessed in the BDA report. It would be most applicable to introduction only in priority airsheds (as per Policy combination 2 assessed in the BDA report). Additionally, option (IV) may warrant further consideration as a low-cost option.

D.3.3.2 Timeframe

Two options for addressing emissions from in-service wood heaters have therefore been analysed:

- Phase out of wood heaters. Specifically, requiring wood heaters to be removed or rendered inoperable on the sale of a house (assumed to turn over every seven years). Implementation of such regulations would result in new owners having to install more efficient wood heaters or alternative heating systems following purchase of the house.
- Regulating the moisture content of wood fuel to be less than 20%. Doing so, would require drying of wood fuel for up to 12 months and therefore may result in a rise in the cost of wood fuels.

Phase-out of wood heaters was considered to be mutually exclusive to the measures derived from **BDA Group (2013)**. However, regulation of moisture content could be complementary to the **BDA Group (2013)** measures. While on face value, a complete wood heater phase-out appears to be superior to all wood heater measures with respect to both emission reductions and costs, in reality a phase out may not be practical.

The original study assumed a commencement date of 2012 and measurement of costs and benefits to 2030 (i.e. 19 years of emissions reductions). In the economic analysis, measures are assumed to begin in 2018 to allow adequate policy lead time and operate till 2036.

D.3.3.3 Emission reductions

Emission reductions from phase out and moisture content regulation were derived from **AECOM (2011)** (**Figure D44**), scaled to a national level (a scaling factor of 1.56 was used comparing 273,203 wood heaters in NSW **(AECOM, 2011)** with 579,976 wood heaters nationally **(BDA Group, 2013)** and with introduction of a lag to implementation such that measures are considered to be effective from 2016.

As with the other wood heater measures, to estimate $PM_{2.5}$ reductions it was assumed that $PM_{2.5}$ comprised 96.3% of PM_{10}. This was consistent with the data on the size fractions for fireplaces and woodstoves in **CEIDARS (2008)**. The resulting estimates of emissions reductions are shown in **Figure D45**.

The emission reductions derived from **AECOM (2011)** were estimated over 20 years. Emission reductions for wood heater phase-out increase as more wood heaters are out of operation compared with the BAU scenario. Emission reductions for the regulation of moisture content decline over time relative to the BAU scenario.

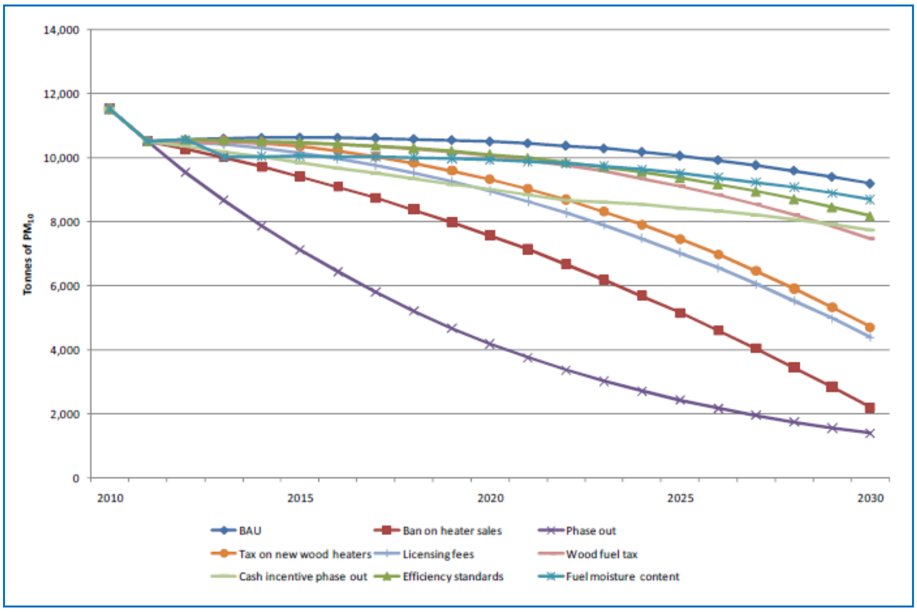

Figure D44: Emissions from in-service wood heaters measures (AECOM, 2011)

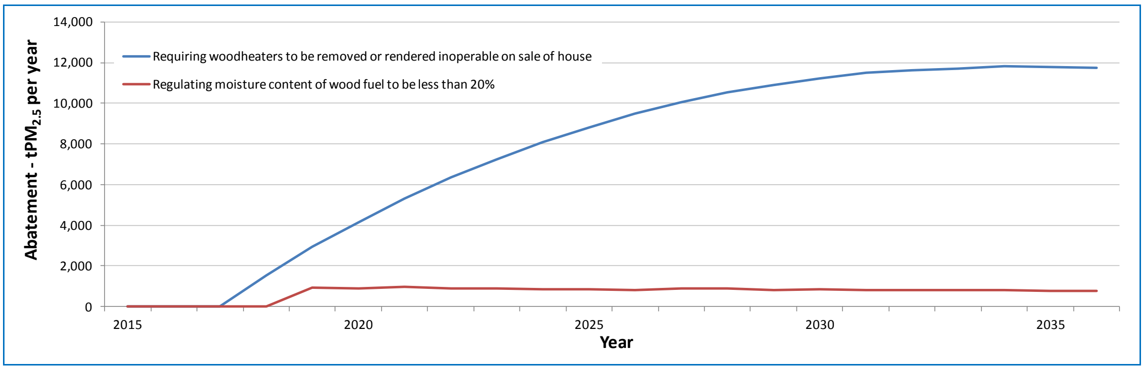

Figure D45: PM reduction from in-service wood heaters measures

D.3.3.4 Co-benefits and dis-benefits

Any decreased wood heater use is likely to result in a compensating increase in use of electric and gas heating. On face value, this could lead to an increase in GHG emissions. However, alternative forms of heating are not necessarily more CO_2-intensive. The impact of wood heaters on CO_2 is largely dependent on the sustainability of the supply of wood used. For these reasons no estimate on the impact on CO_2 is included in this economic analysis.

D.3.3.5 Costs

AECOM (2011) provided the following NSW cost data, also adopted in this study:

- Implementation of regulations ($100,000)
- Administration of regulations ($70,000)
- Education ($70,000)
- Loss of profitability to the industry ($3.1 million NPV over 20 years)
- Business administration ($57,200 per year)
- Loss of consumer surplus ($19.3 million per year)

Costs from the study, were scaled to a national level, resulting in the cost estimates shown in **Table D16**.

Table D16: Costs of in-service wood heaters measures

Cost assumption	Phase out	Moisture content
Implementation of regulations	$155,822	$155,822
Administration of regulations	$109,076	$109,076
Education	$109,076	$109,076
Loss of profitability to the industry	$4,830,496 NPV over 20 years	$0
Business administration	$89,130 per year	$89,130 per year
Loss of consumer surplus	$30,073,731 NPV over 20 years	$0

Many components of the government costs provided in **AECOM (2011)** relate to items that are likely to be incurred towards the beginning of the scheme (either prior to implementation or in the first year). Therefore, government costs are largely front-loaded, and uncertainty in treatment of costs is captured through the sensitivity range.

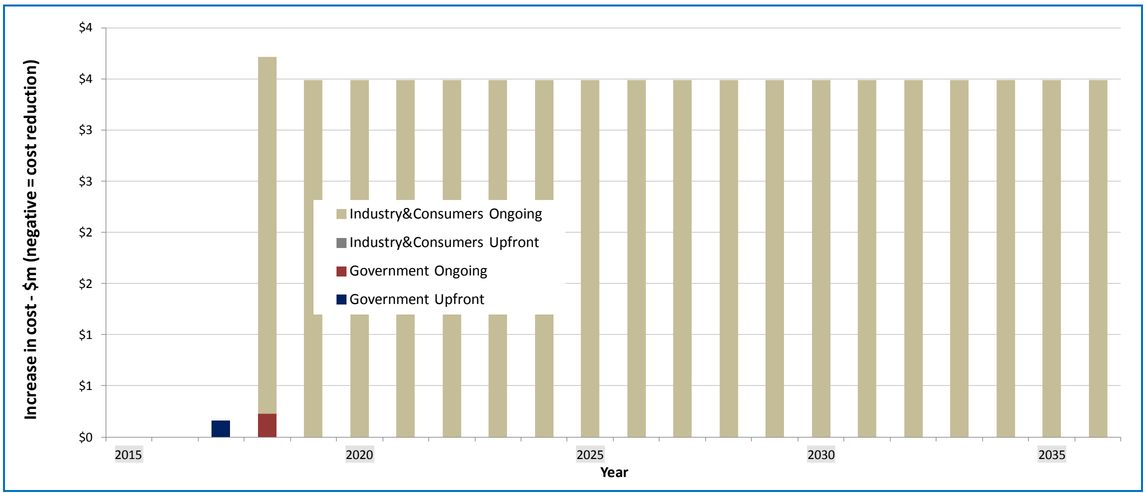

Figure D46: Cost of requiring wood heaters to be removed or rendered inoperable on sale of house

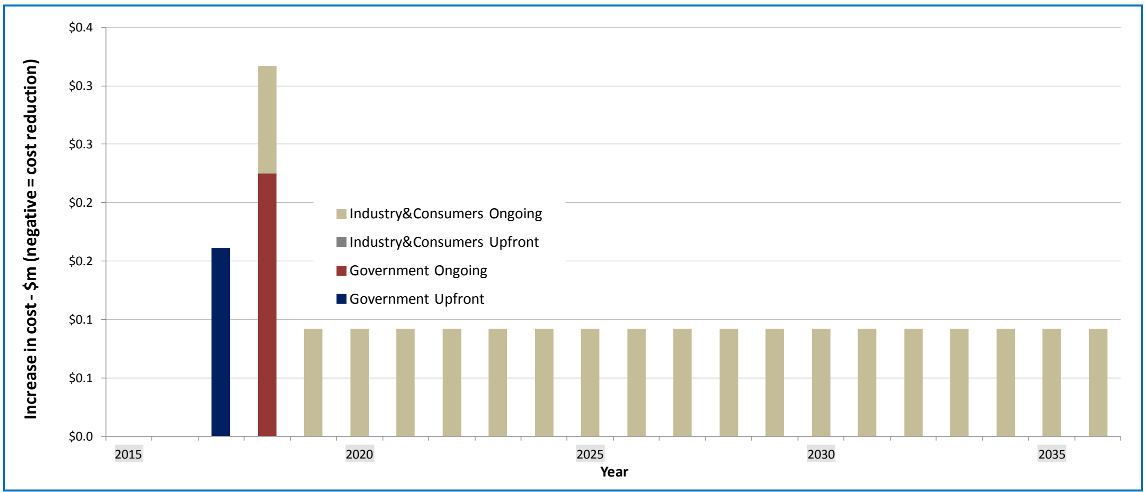

Figure D47: Cost of regulating moisture content of wood fuel to be less than 20%

D.3.3.6 Uncertainty in estimates

The project team have not undertaken a detailed audit of the assumptions and methods used to derive costs and emissions reductions estimates by **AECOM (2011).** However, in our opinion there is scope to increase some cost items which appear to represent somewhat of a lower bound (*e.g.* no loss of profitability or consumer surplus from moisture content regulation despite there being a possibility of price impacts). Sensitivity ranges similar to wood heater measures derived from **BDA Group (2013)** but adjusted for additional 'upside' in cost estimates are proposed (**Table D17**).

Table D17: Sensitivity parameters for in-service wood heaters measures

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Cost	+30%
Measure less cost-effective compared with central assumptions	Emissions reductions	-20%
Measure more cost-effective compared with central assumptions	Cost	-20%
Measure more cost-effective compared with central assumptions	Emissions reductions	-20%

D.3.4 Vegetation

D.3.4.1 Background

Experiments and model calculations have indicated that vegetation can reduce concentrations of, and exposure to, airborne particles and other pollutants. The use of vegetation as a PM-abatement option has been included in the economic analysis because it is, in general, feasible in the short-term (*i.e.* there are few technological barriers).

The application and study of vegetation in the context of reducing pollution takes three main forms:

- Barriers, such as the planting of trees and shrubs alongside busy roads.
- Area-wide planting, such as increasing the vegetation ground cover in urban areas.
- 'Green roofs' or 'green walls' in cities.

However, additional research was required to develop this option, in contrast to other options where assumptions were available to be extracted directly from existing studies. In a review we considered the ways in which vegetation can remove pollution from the atmosphere, and the literature on effectiveness and cost in terms of the types of application listed above. A comprehensive review of the literature on the role of vegetation in this context was beyond the scope of the project, and the aim was to determine indicative values for use in the economic analysis.

The assumptions used in the economic analysis are summarised in **Table D18**. Again, it should be noted that few data have been reported for different particle sizes, and the data for area planting and green roofs only relate to PM_{10}. However, in the absence of detailed data on size-related effects, it is assumed that the values for PM_{10} are also applicable to the removal of $PM_{2.5}$. More research is needed on species effects on particulate matter in general, and on $PM_{2.5}$ specifically.

Table D18: Summary of pollutant-removal assumptions for economic analysis

Type of vegetation	Location type		Removal rate (g/m²/year)				
	City centres	Other areas	PM_{10}	CO	NO_2	SO_2	O_3
Barrier	No	No	**Not quantified**				
Area planting[(a)]	No	**Yes**	**6.5** [0.01-19.7]	**0.8** [0.1-1.9]	**2.1** [0.4-6.3]	**1.0** [0.2-2.4]	**4.5** [0.8-7.6]
Green roofs/walls[(b)]	**Yes**	No	**1.5** [0.4-3.2]	**0.3** [-]	**1.9** [1.5-2.3]	**0.6** [-]	**3.7** [2.9-4.5]

(a) Median and range calculated for trees from the data for 55 US cities presented by **Nowak *et al.* (2006)**.
(b) Estimated values for grasses from literature

Vegetation barriers have been excluded from the economic analysis, partly due to the inconclusive results in the literature and partly to the difficulty of parameterising barriers in a meaningful way for the analysis. Green roofs are unlikely to be driven by PM reductions (due to the costs discussed below).

D.3.4.2 Timeframe

Area planting has been considered for inclusion. Plantings are assumed to be undertaken between 2015 and 2019 (over five years) through an approximately $900 million[43] programme. Ongoing benefits are calculated, as a conservative estimate, for 25 years (up to 2044).

D.3.4.3 Costs

The cost assumptions for the economic analysis are summarised in **Table D19**. For green roofs, assuming the average initial cost (A$230/ m²), an annual cost ($A10/ m²), a 7% real discount rate, a PM removal rate of 1.6 g/ m²/year and ignoring replacement costs provides an indicative cost-effectiveness of the measure as approximately $10 million per tonne of PM over 20 years. Notwithstanding possible co-benefits such as reductions in building energy use, this measure is unlikely to be driven by air quality issues and is therefore not considered for inclusion in the economic analysis.

Table D19: Summary of cost assumptions for economic analysis

Type of vegetation	Cost		
	Initial cost [range]	Annual maintenance cost [range]	Replacement cost [range]
Area planting	Establishment - **2,000** [1,000-3,000] (A$/Ha) Land Value – **840,000** (A$/Ha) Water – **2** [1.6 to 2.5] ML/Ha at $2000/ML	-	-
Green roofs	**230** [99-394] (A$/m²)	**10** [8-13] (A$/Ha)	**40** (A$/Ha)

[43] The scale of funding required reflects the significant costs of land purchase (or opportunity costs). A notional figure has been used for the purposes of understanding the costs and benefits of the measure and does not necessarily reflect an amount of government funding that is feasible.

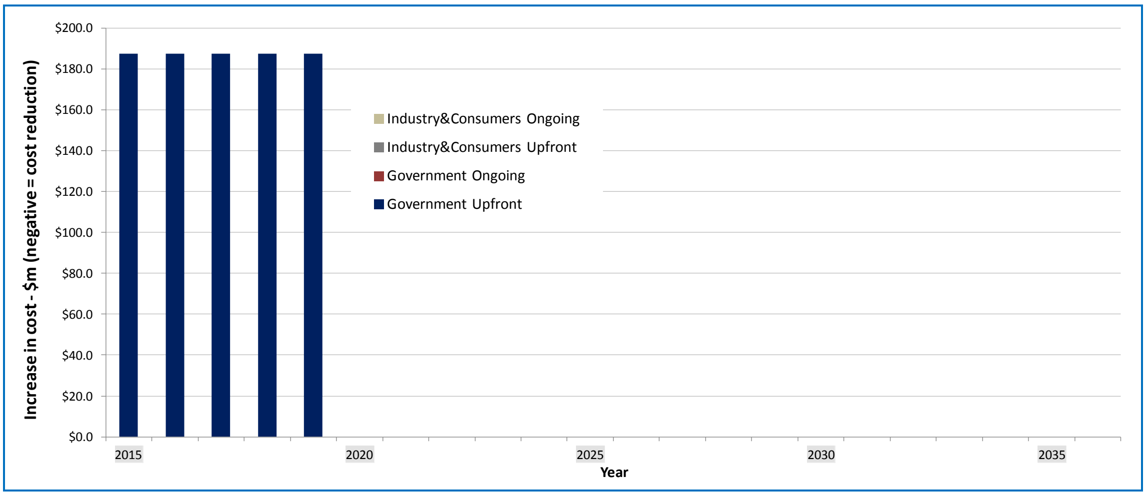

Figure D48: Cost of area-wide planting to remove PM from the atmosphere

D.3.4.4 Emissions Removal

The area identified as being plantable is one of the most important but uncertain input assumptions to these types of analyses. The potential area of coverage for area planting will vary greatly from location to location. Area planting is likely to be more effective around conurbations. The area of Australian conurbations is provided in **Table D20 (Aust *et al.*, 2013)**.

Table D20: Area of conurbations

SUA code	SUA name	Area (km²)
1030	Sydney	4,064
2011	Melbourne	5,679
3001	Brisbane	5,065
4001	Adelaide	2,024
5009	Perth	3,367
6003	Hobart	1,213
7002	Darwin	295
8001	Canberra - Queanbeyan	482

GHG abatement studies[44] conducted by MJA for Victorian local councils which included consideration of area planting as a carbon sequestration mechanism indicate an assumption of 0.5% of area provides a proxy for suitable area. Assuming a more conservative assumption of 0.05% of area is suitable for area planting provides an estimate of total area of 11,095 km^2 across Australia.

The measure is assumed to be effective from 2015 but with a gradual increase in plantings to total area over a period of five years. Resulting estimates of emissions reductions are shown in **Figure D49**.

In the absence of detailed data on size-related effects, it is assumed that the values for PM_{10} are also applicable to the removal of $PM_{2.5}$. More research is needed on species effects on particulate matter in general, and on $PM_{2.5}$ specifically. While such a simplification potentially adds to the margin of error in estimates overall, this is recognised in the sensitivity analysis.

[44] Private, unpublished, studies undertaken by MJA (*e.g.* recently for the City of Casey completed in 2012).

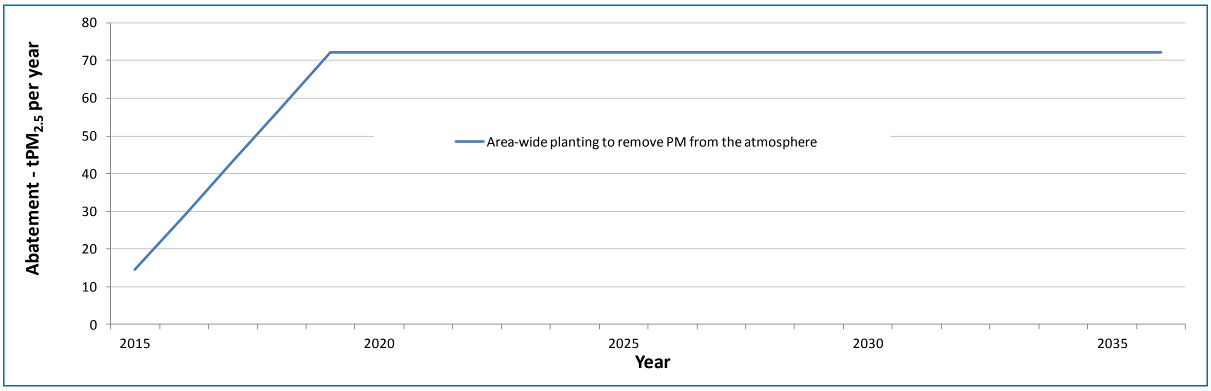

Figure D49: PM reduction from Area-wide planting to remove PM from the atmosphere

D.3.4.5 Co-benefits and dis-benefits

Estimates of reduction in NO_X are derived from estimates of pollutant removal rates described in Section D.3.4.4. Emissions reductions gradually increase over time in line with increase in cumulative plantings over the five year period.

Area planting also provides carbon sequestration benefits. Indeed the study conducted by **CSIRO (2011)** was for area planting as a basis for carbon sequestration. Rate of assumed carbon sequestration in the study varied from five to 20 t CO_2/ha/year. A central assumption of 12.5 tCO_2/ha/year has been adopted for the economic analysis.

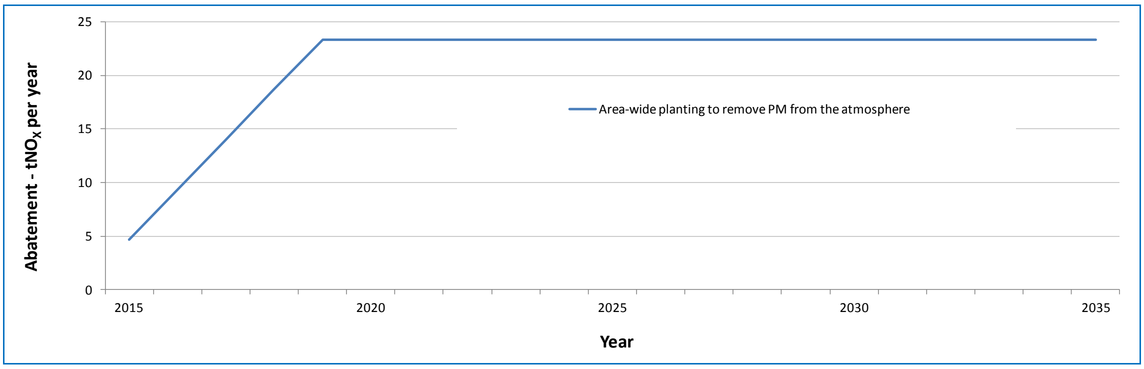

Figure D50: NO_X reductions from area-wide planting to remove PM from the atmosphere

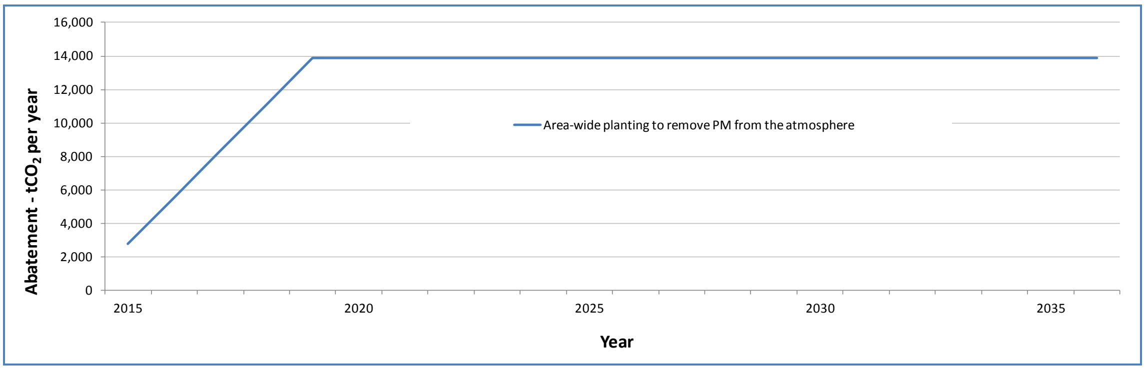

Figure D51: CO_2 reductions from area-wide planting to remove PM from the atmosphere

D.3.4.6 Uncertainty in estimates

The relative size of the sensitivity ranges for area planting in the economic analysis are proposed to approximately mirror the range of cost and emissions removal estimates in the source literature, where the uncertainty in pollutant removal efficacy is notably much higher.

Table D21: Sensitivity parameters for area planting measures

Sensitivity	Sensitivity variable	Value
Measure less cost-effective compared with central assumptions	Cost	-50%
Measure less cost-effective compared with central assumptions	Emissions reductions	-80%
Measure more cost-effective compared with central assumptions	Cost	+50%
Measure more cost-effective compared with central assumptions	Emissions reductions	+80%

D.4 OTHER MEASURES CONSIDERED BUT NOT INCLUDED IN ECONOMIC ANALYSIS

D.4.1 Electric Vehicles

The transition to a vehicle fleet with a greater proportion of electric vehicles (EVs) has the potential to reduce PM and other emissions currently being emitted from exhaust sources. **AECOM (2009)** assessed the economic viability of EVs on behalf of the NSW Department of Environment and Climate Change. The study found long-term net benefits to society associated with the uptake of electric vehicles through the reduction of GHG emissions and air pollution.

However, around 81 % of $PM_{2.5}$ emissions from petrol passenger vehicles in NSW arise from non-exhaust sources. This may have resulted in an overestimation of air pollution benefits calculated by AECOM. EV policy will not be driven primarily by air quality concerns. Due to the significant upfront infrastructure requirements, the fact that support for EVs is likely to be driven by other factors (primarily climate change), and potential inaccuracy in air quality calculation benefits in previous studies, this measure has not been included for analysis in this economic analysis.

Note that expected PM reductions from agreed Australian Design Rule emission standards for new petrol and diesel road vehicles are included the BAU emissions base case for this economic analysis.

D.4.2 Improved planned burning

The smoke produced by wildfires can adversely affect air quality and visibility. Fire and land managers have statutory responsibilities to effectively manage smoke, and to balance competing fire management and air quality management obligations. Effective smoke management involves understanding where sensitive areas are located and having a sound knowledge of fire behaviour and meteorological processes. Fire fighting authorities and land managers can use this knowledge to minimise bushfire smoke impacts.

Managing air quality impacts via **improved planned burning** was raised by the Air TOG members as an area of particular interest. Whilst an assessment of the full impacts of planned burning itself (as opposed to not implementing it) was beyond the scope of this project, consideration was given to reducing the impacts of planned burning through the use of modelling and public warnings. The likely effectiveness and cost of this approach were assessed with reference to a system being trialled by the NSW Rural Fire Service (RFS).

NSW RFS has developed a computer-based software system that provides a forecast of smoke dispersion associated with hazard reduction burns. The software automates a process using meteorological software, air pollution software (TAPM) and GIS mapping software. The model produces a series of maps at various points in time which display the forecast particulate matter (PM_{10} or $PM_{2.5}$) at 10 m in height. The smoke plume model provides various inputs into TAPM, including the location of the burn, the fuel load, the time of the burn and the size of the burn. The system is designed to provide fire managers with greater accuracy regarding the forecast of smoke dispersion, thus enabling them to provide better information to communities on potential smoke dispersion and actions that can be taken to reduce exposure, with prioritisation of sensitive areas. NSW RFS currently runs TAPM in-house, at an estimated cost of $20,000 per annum.

Residents around the hazard reduction burn areas are reminded to take precautions, including:

- Keep doors and windows closed to prevent smoke entering homes.
- If they have asthma or lung conditions, reduce outdoor activities if smoke levels are high and if shortness of breath or coughing develops, take reliever medicine or seek medical advice.

Similar advice is provided by EPA Victoria[45] in relation to bushfires in general.

Potential scenarios for evaluating the effects of improved planned burning therefore include:

- The use of a predictive system to ensure that, based on meteorological conditions, the plume of smoke from a planned burn would be directed away from an area of relatively high population density to an area of relatively low population density. This would involve changing the timing of the burn to allow for, say, a change in wind direction.
- Issuing better targeted air pollution warnings to encourage people to stay indoors during planned burns (with the assumption of a high level of uptake or enforcement).

However, it was not possible to investigate these scenarios in any detail within the framework of the economic analysis. Firstly, given that the NSW RFS system is still being trialled there are no accurate figures on its effectiveness. Secondly, the process of evaluation in the economic analysis is based on the concept of reducing primary anthropogenic PM emissions, whereas for improved planned burning no such allocation was possible. Thirdly, the investigation of improved planned burning would require a review of the literature to identify appropriate information (such as indoor:outdoor ratios for PM concentrations), and this was considered impractical given the timeframe of the economic analysis.

A basic analysis was performed on the hourly PM_{10} and $PM_{2.5}$ monitoring data (TEOM) for NSW in 2011 to estimate the effects of planned burning on annual mean concentrations. The planned burns that affected the monitoring data at specific sites during 2011 were identified by NSW EPA **(Betts, 2012)**. Each planned burn was assumed to last for 36 hours, and the monitoring data for these hours were excluded. The annual mean concentration with the planned burning period excluded was then compared with the annual mean concentration with the planned burning period included. These results of this exercise are shown in **Table D22** and **Table D23** for PM_{10} and $PM_{2.5}$ respectively.

It can be seen that **avoiding planned burning altogether** would only have a very limited impact on annual mean concentrations. The reductions in the annual mean concentrations of PM_{10} and $PM_{2.5}$ *per planned burn* were 0.13 µg/m³ and 0.07 µg/m³ respectively. Whilst the peak one-hour average concentrations during the planned burning periods were typically an order of magnitude higher than the annual mean, only one or two planned burns affected the data at each monitoring site during 2011. It was therefore concluded that improved planned burning would tend to have a very small impact on long-term population-weighted exposure to PM_{10} and $PM_{2.5}$, and was not considered further in the analysis.

[45] http://www.epa.vic.gov.au/your-environment/air/bushfires-and-air-quality

Table D22: Reduction in PM_{10} concentration with removal of planned burning

Monitoring station	Annual mean PM_{10} concentration (μg/m³)			Number of planned burns in 2011	Approx. reduction in annual mean per planned burn avoided (μg/m³)
	With planned burning	Without planned burning	Reduction in annual mean without burning		
Bringelly	15.91	15.69	0.22	1	0.22
Chullora	19.86	19.72	0.14	2	0.07
Liverpool	18.19	18.00	0.19	1	0.19
MaCarthur	13.16	13.10	0.06	1	0.06
Oakdale	10.67	10.53	0.15	1	0.15
Richmond	13.19	13.05	0.14	1	0.14
Vineyard	14.01	13.95	0.06	1	0.06
				Average	**0.13**

Table D23: Reduction in $PM_{2.5}$ concentration with removal of planned burning

Monitoring station	Annual mean $PM_{2.5}$ concentration (μg/m³)			Number of planned burns in 2011	Approx. reduction in annual mean per planned burn avoided (μg/m³)
	With planned burning	Without planned burning	Reduction in annual mean without burning		
Chullora	5.97	5.93	0.03	1	0.03
Earlwood	5.39	5.38	0.01	1	0.01
Liverpool	5.89	5.79	0.10	1	0.10
Richmond	4.65	4.50	0.14	1	0.14
				Average	**0.07**

Appendix E MARGINAL ABATEMENT COST CURVES FOR JURISDICTIONS

Marginal Abatement Cost Curves (MACCs) for each jurisdiction are presented in the following Sections. The order of measures (ranked from most cost-effective on the left to least on the right of the curve) is the same for each jurisdiction. However, the proportions of emissions reduction by measure for each of the jurisdictions differ due to the relative size (and in some cases existence) of sectors containing the emitting sources.

The coal dust best practice measure provides the largest expected emissions reduction (both $PM_{2.5}$ and PM_{10} but the latter to a greater extent) in NSW, VIC and QLD. Non-road diesel engine standards dominate the SA, WA and NT MACCs. Wood heater measures provide the largest emission reductions for TAS and the ACT.

E.1 NSW

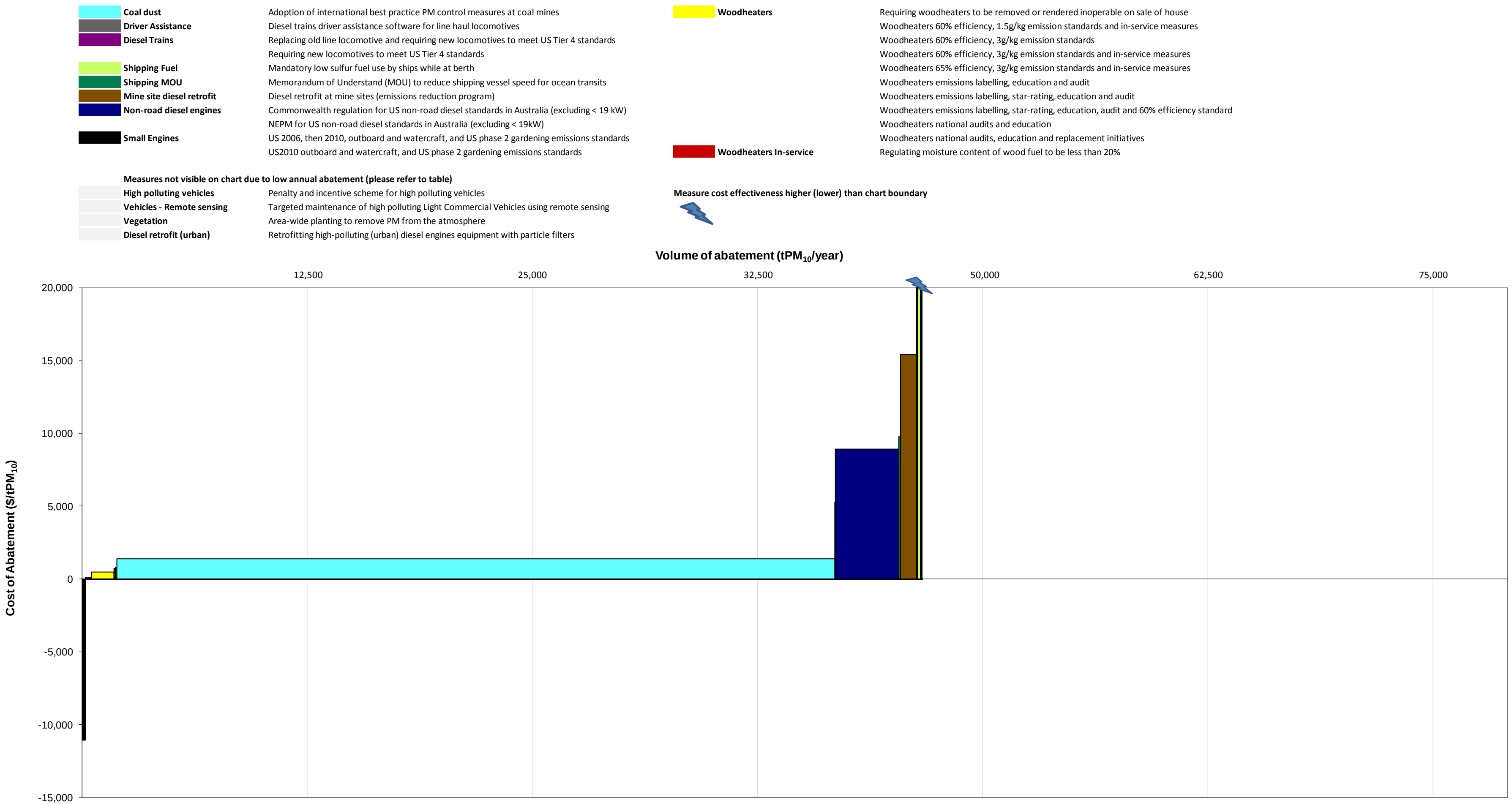

Figure E1: PM_{10} NSW MACC

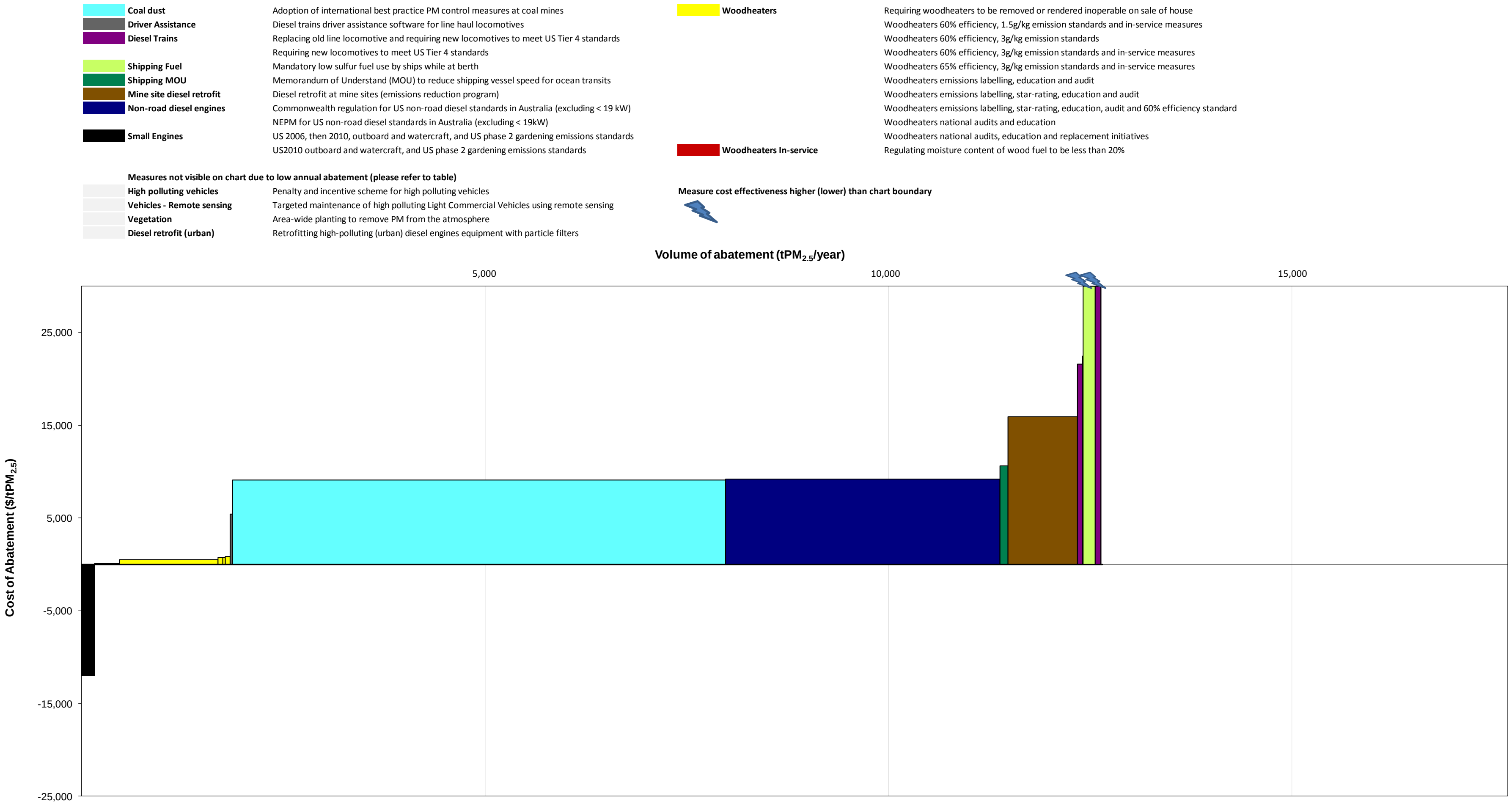

Figure E2: PM$_{2.5}$ NSW MACC

Table E1: NSW PM_{10} MACC data

Measure	Marginal cost ($/t$PM_{10}$)	Abatement (tPM_{10}/year)	Incremental abatement (tPM_{10}/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,065	173	173
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,003	174	1
Regulating moisture content of wood fuel to be less than 20%	95	330	330
Wood heaters 60% efficiency, 3g/kg emission standards	480	1,258	1,258
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	711	1,325	67
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	715	1,352	27
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	819	1,421	70
Adoption of international best practice PM control measures at coal mines	1,397	39,874	39,874
Diesel trains driver assistance software for line haul locomotives	5,263	26	26
US non-road diesel standards in Australia (excluding <19kW)	8,915	3,511	3,511
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	9,779	104	104
Diesel retrofit at mine sites (emissions reduction program)	15,416	883	883
Requiring new locomotives to meet US Tier 4 standards	20,950	69	69
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	21,781	7	7
Mandatory low sulfur fuel use by ships while at berth	46,049	159	159
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	102,666	143	74
Targeted maintenance of high-polluting LCVs using remote sensing	151,072	0	0
Penalty and incentive scheme for high polluting vehicles	192,661	3	3
Area-wide planting to remove PM from the atmosphere	407,418	19	19

Table E2: NSW $PM_{2.5}$ MACC data

Measure	Marginal cost ($/t$PM_{2.5}$)	Abatement (t$PM_{2.5}$/year)	Incremental abatement (t$PM_{2.5}$/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,963	160	160
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,815	161	1
Regulating moisture content of wood fuel to be less than 20%	99	318	318
Wood heaters 60% efficiency, 3g/kg emission standards	499	1,211	1,211
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	739	1,276	65
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	742	1,302	26
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	850	1,369	67
Diesel trains driver assistance software for line haul locomotives	5,426	25	25
Adoption of international best practice PM control measures at coal mines	9,115	6,110	6,110
US non-road diesel standards in Australia (excluding <19kW)	9,191	3,406	3,406
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	10,632	96	96
Diesel retrofit at mine sites (emissions reduction program)	15,893	857	857
Requiring new locomotives to meet US Tier 4 standards	21,598	67	67
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	22,455	7	7
Mandatory low sulfur fuel use by ships while at berth	50,066	146	146
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	105,841	139	72
Targeted maintenance of high-polluting LCVs using remote sensing	158,922	0	0
Penalty and incentive scheme for high polluting vehicles	202,673	3	3
Area-wide planting to remove PM from the atmosphere	407,418	19	19

E.2 VICTORIA

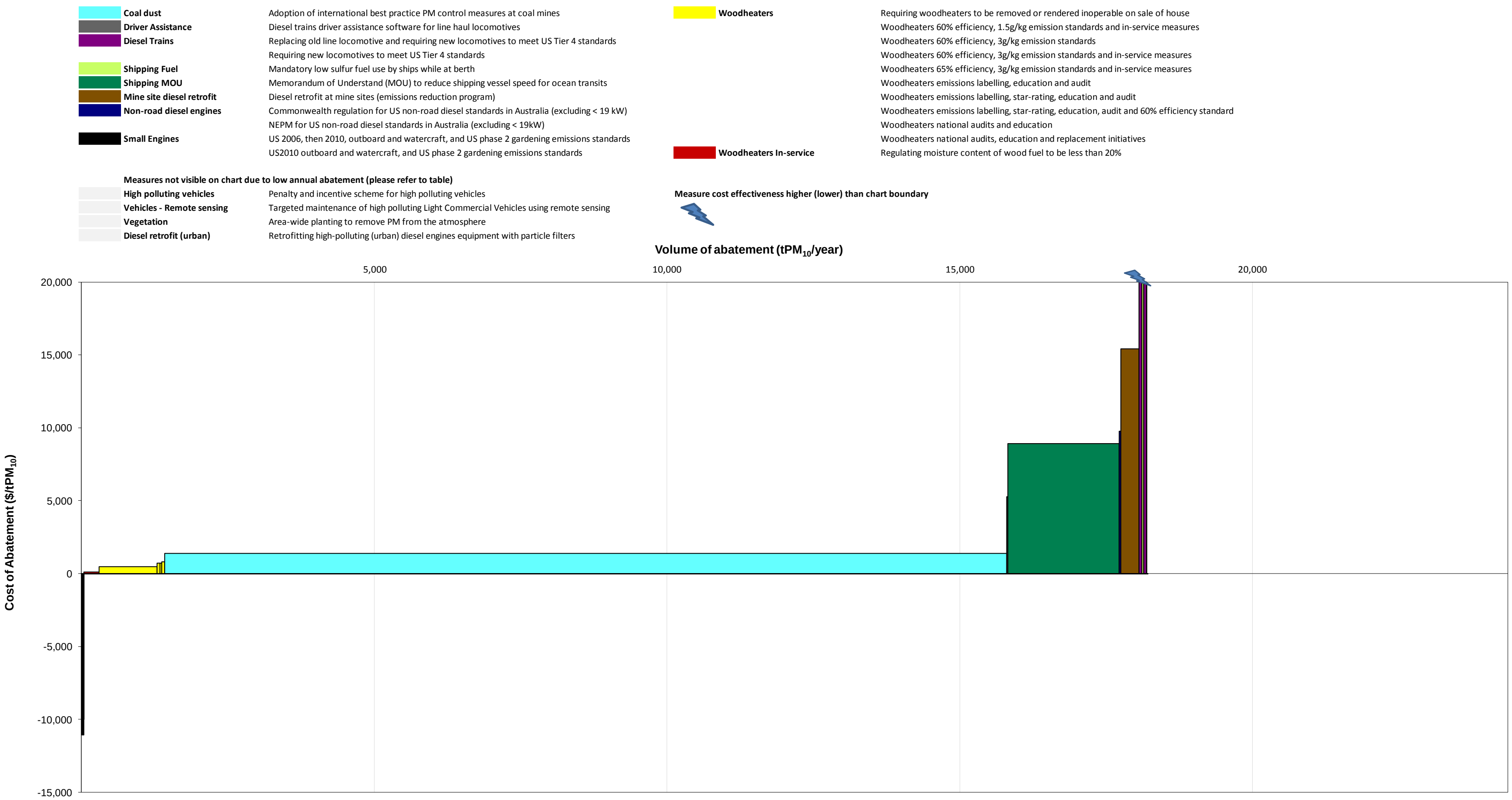

Figure E3: PM_{10} VIC MACC

Coal dust	Adoption of international best practice PM control measures at coal mines	**Woodheaters**	Requiring woodheaters to be removed or rendered inoperable on sale of house
Driver Assistance	Diesel trains driver assistance software for line haul locomotives		Woodheaters 60% efficiency, 1.5g/kg emission standards and in-service measures
Diesel Trains	Replacing old line locomotive and requiring new locomotives to meet US Tier 4 standards		Woodheaters 60% efficiency, 3g/kg emission standards
	Requiring new locomotives to meet US Tier 4 standards		Woodheaters 60% efficiency, 3g/kg emission standards and in-service measures
Shipping Fuel	Mandatory low sulfur fuel use by ships while at berth		Woodheaters 65% efficiency, 3g/kg emission standards and in-service measures
Shipping MOU	Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits		Woodheaters emissions labelling, education and audit
Mine site diesel retrofit	Diesel retrofit at mine sites (emissions reduction program)		Woodheaters emissions labelling, star-rating, education and audit
Non-road diesel engines	Commonwealth regulation for US non-road diesel standards in Australia (excluding < 19 kW)		Woodheaters emissions labelling, star-rating, education, audit and 60% efficiency standard
	NEPM for US non-road diesel standards in Australia (excluding < 19kW)		Woodheaters national audits and education
Small Engines	US 2006, then 2010, outboard and watercraft, and US phase 2 gardening emissions standards		Woodheaters national audits, education and replacement initiatives
	US2010 outboard and watercraft, and US phase 2 gardening emissions standards	**Woodheaters In-service**	Regulating moisture content of wood fuel to be less than 20%

Measures not visible on chart due to low annual abatement (please refer to table)

High polluting vehicles	Penalty and incentive scheme for high polluting vehicles
Vehicles - Remote sensing	Targeted maintenance of high polluting Light Commercial Vehicles using remote sensing
Vegetation	Area-wide planting to remove PM from the atmosphere
Diesel retrofit (urban)	Retrofitting high-polluting (urban) diesel engines equipment with particle filters

Measure cost effectiveness higher (lower) than chart boundary

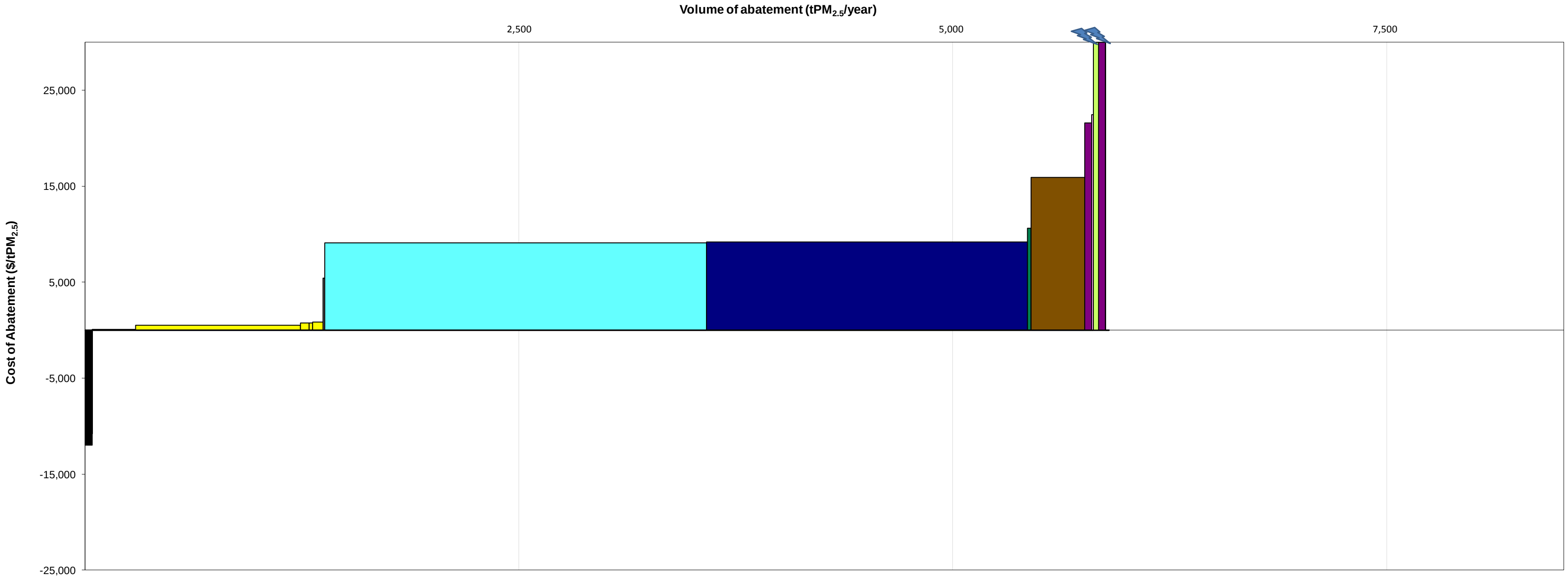

Figure E4: $PM_{2.5}$ VIC MACC

Table E3: VIC PM_{10} MACC data

Measure	Marginal cost ($/t$PM_{10}$)	Abatement (tPM_{10}/year)	Incremental abatement (tPM_{10}/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,065	47	47
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,003	47	0
Regulating moisture content of wood fuel to be less than 20%	95	260	260
Wood heaters 60% efficiency, 3g/kg emission standards	480	990	990
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	711	1,043	53
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	715	1,064	21
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	819	1,118	55
Adoption of international best practice PM control measures at coal mines	1,397	14,381	14,381
Diesel trains driver assistance software for line haul locomotives	5,263	16	16
US non-road diesel standards in Australia (excluding <19kW)	8,915	1,907	1,907
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	9,779	21	21
Diesel retrofit at mine sites (emissions reduction program)	15,416	319	319
Requiring new locomotives to meet US Tier 4 standards	20,950	42	42
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	21,781	6	6
Mandatory low sulfur fuel use by ships while at berth	46,049	33	33
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	102,666	87	45
Targeted maintenance of high-polluting LCVs using remote sensing	151,072	0	0
Penalty and incentive scheme for high polluting vehicles	192,661	3	3
Area-wide planting to remove PM from the atmosphere	407,418	17	17

Table E4: VIC $PM_{2.5}$ MACC data

Measure	Marginal cost ($/t$PM_{2.5}$)	Abatement (t$PM_{2.5}$/year)	Incremental abatement (t$PM_{2.5}$/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,963	44	44
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,815	44	0
Regulating moisture content of wood fuel to be less than 20%	99	250	250
Wood heaters 60% efficiency, 3g/kg emission standards	499	953	953
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	739	1,004	51
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	742	1,024	20
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	850	1,077	53
Diesel trains driver assistance software for line haul locomotives	5,426	15	15
Adoption of international best practice PM control measures at coal mines	9,115	2,204	2,204
US non-road diesel standards in Australia (excluding <19kW)	9,191	1,849	1,849
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	10,632	20	20
Diesel retrofit at mine sites (emissions reduction program)	15,893	309	309
Requiring new locomotives to meet US Tier 4 standards	21,598	41	41
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	22,455	6	6
Mandatory low sulfur fuel use by ships while at berth	50,066	30	30
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	105,841	84	43
Targeted maintenance of high-polluting LCVs using remote sensing	158,922	0	0
Penalty and incentive scheme for high polluting vehicles	202,673	3	3
Area-wide planting to remove PM from the atmosphere	407,418	17	17

E.3 QUEENSLAND

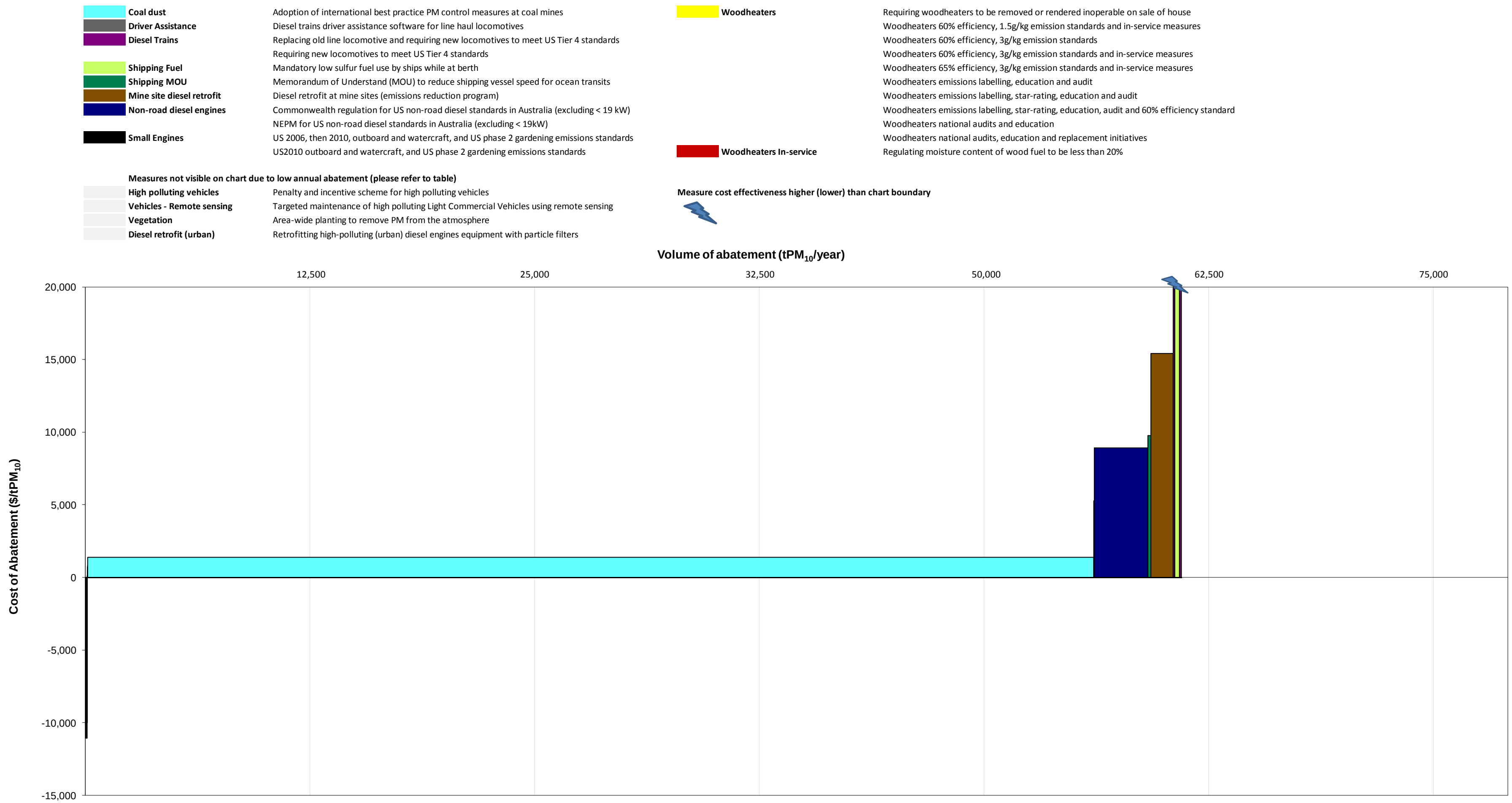

Figure E5: PM$_{10}$ QLD MACC

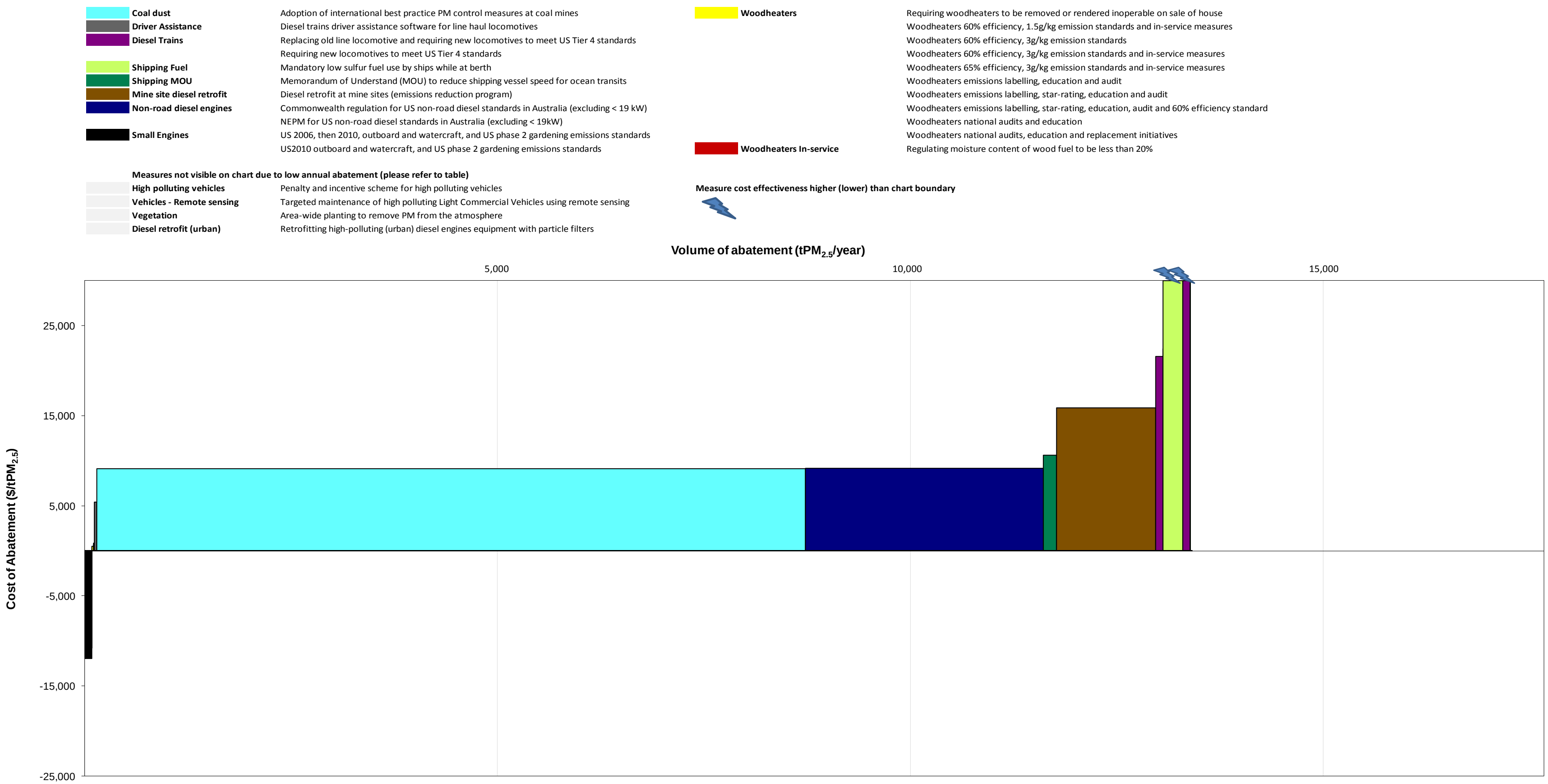

Figure E6: PM$_{2.5}$ QLD MACC

Table E5: QLD PM_{10} MACC data

Measure	Marginal cost ($/t$PM_{10}$)	Abatement (tPM_{10}/year)	Incremental abatement (tPM_{10}/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,065	99	99
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,003	100	1
Regulating moisture content of wood fuel to be less than 20%	95	6	6
Wood heaters 60% efficiency, 3g/kg emission standards	480	21	21
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	711	22	1
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	715	23	0
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	819	24	1
Adoption of international best practice PM control measures at coal mines	1,397	55,976	55,976
Diesel trains driver assistance software for line haul locomotives	5,263	34	34
US non-road diesel standards in Australia (excluding <19kW)	8,915	2,977	2,977
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	9,779	169	169
Diesel retrofit at mine sites (emissions reduction program)	15,416	1,240	1,240
Requiring new locomotives to meet US Tier 4 standards	20,950	90	90
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	21,781	5	5
Mandatory low sulfur fuel use by ships while at berth	46,049	256	256
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	102,666	187	97
Targeted maintenance of high-polluting LCVs using remote sensing	151,072	0	0
Penalty and incentive scheme for high polluting vehicles	192,661	2	2
Area-wide planting to remove PM from the atmosphere	407,418	14	14

Table E6: QLD $PM_{2.5}$ MACC data

Measure	Marginal cost ($/t$PM_{2.5}$)	Abatement (t$PM_{2.5}$/year)	Incremental abatement (t$PM_{2.5}$/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,963	92	92
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,815	92	1
Regulating moisture content of wood fuel to be less than 20%	99	5	5
Wood heaters 60% efficiency, 3g/kg emission standards	499	20	20
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	739	22	1
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	742	22	0
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	850	23	1
Diesel trains driver assistance software for line haul locomotives	5,426	33	33
Adoption of international best practice PM control measures at coal mines	9,115	8,577	8,577
US non-road diesel standards in Australia (excluding <19kW)	9,191	2,887	2,887
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	10,632	155	155
Diesel retrofit at mine sites (emissions reduction program)	15,893	1,203	1,203
Requiring new locomotives to meet US Tier 4 standards	21,598	88	88
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	22,455	5	5
Mandatory low sulfur fuel use by ships while at berth	50,066	236	236
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	105,841	181	94
Targeted maintenance of high-polluting LCVs using remote sensing	158,922	0	0
Penalty and incentive scheme for high polluting vehicles	202,673	2	2
Area-wide planting to remove PM from the atmosphere	407,418	14	14

E.4 SOUTH AUSTRALIA

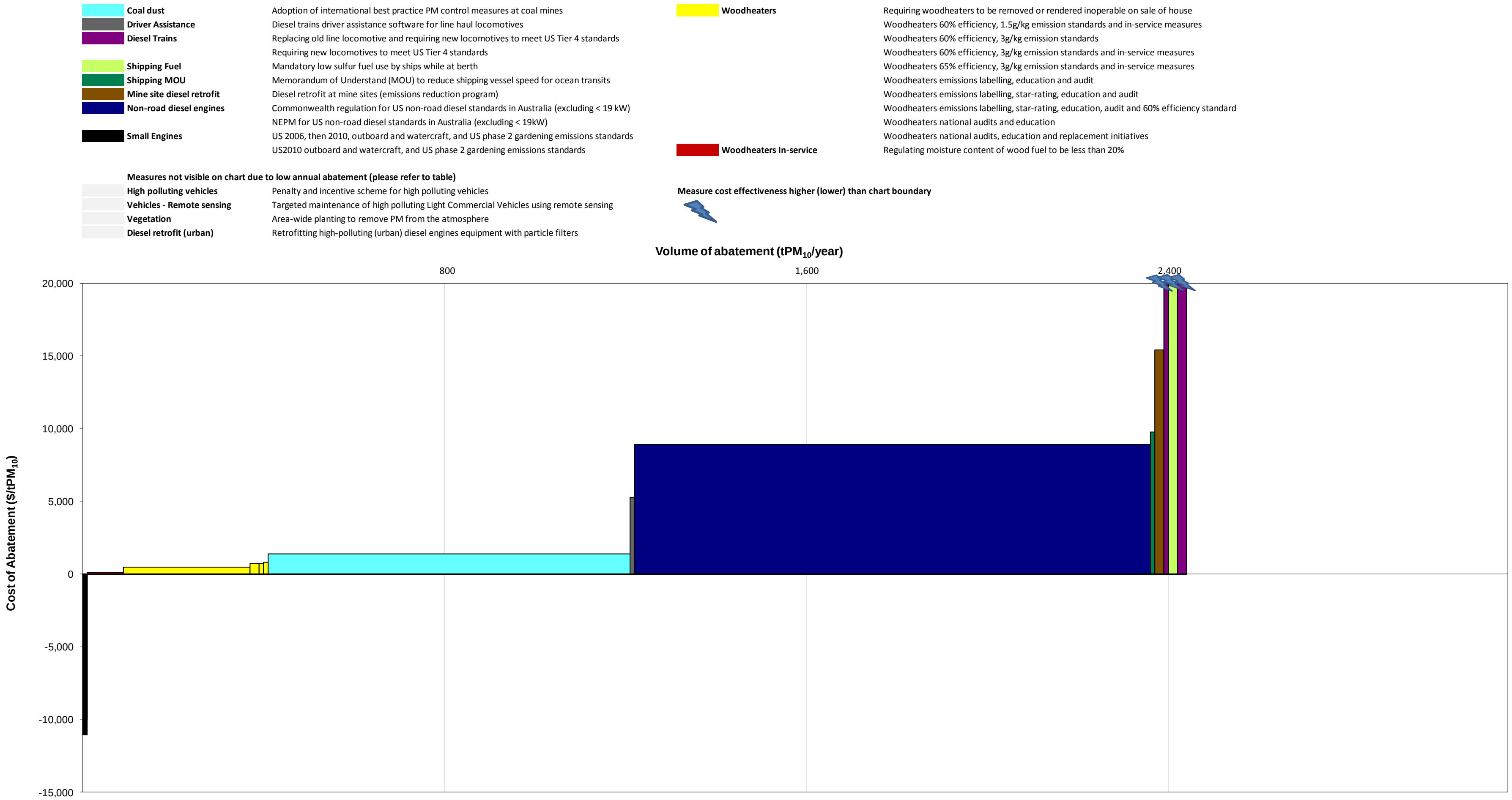

Figure E7: PM_{10} SA MACC

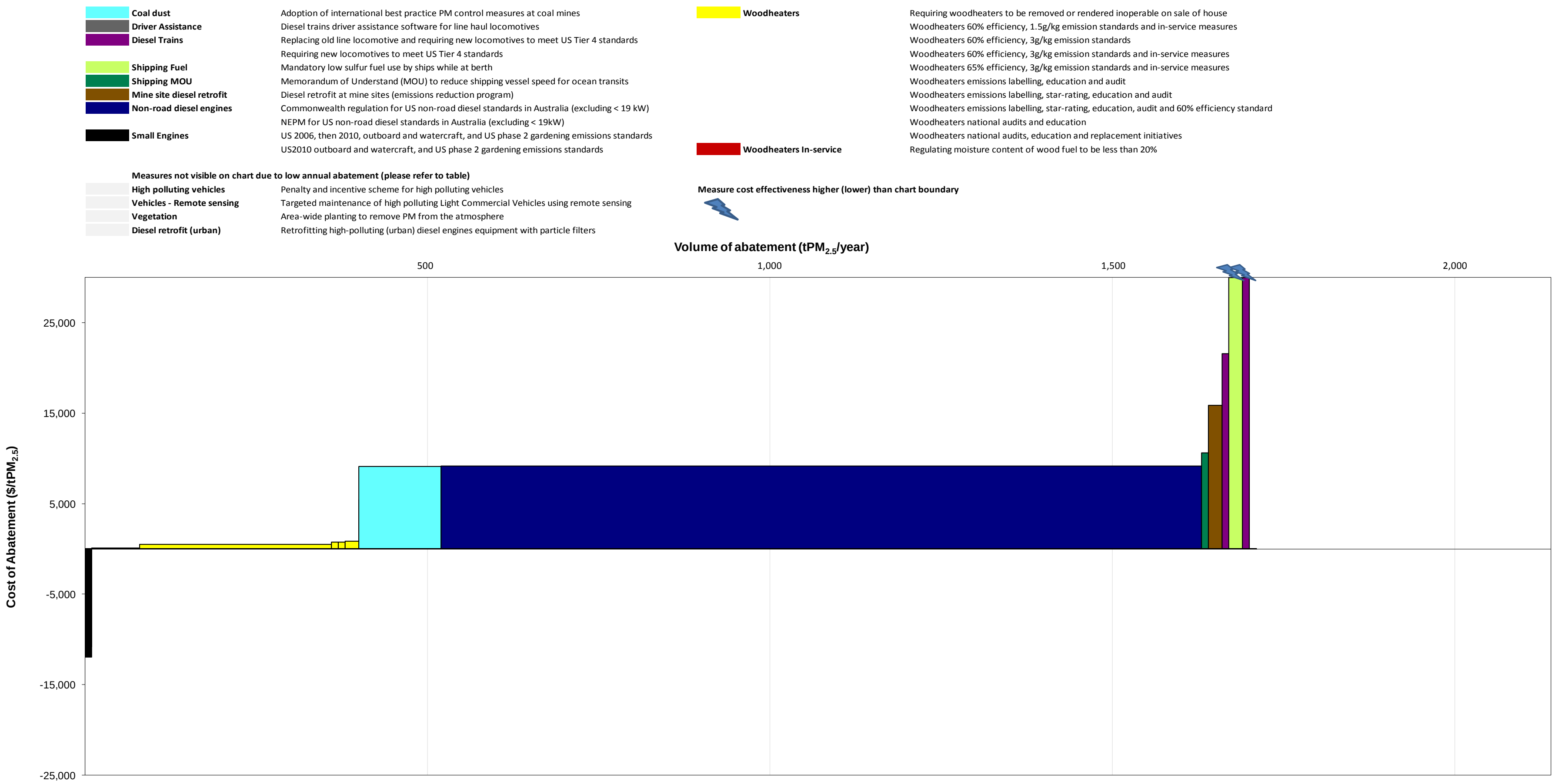

Figure E8: $PM_{2.5}$ SA MACC

Table E7: SA PM_{10} MACC data

Measure	Marginal cost ($/t$PM_{10}$)	Abatement (tPM_{10}/year)	Incremental abatement (tPM_{10}/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,065	18	18
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,003	18	0
Regulating moisture content of wood fuel to be less than 20%	95	75	75
Wood heaters 60% efficiency, 3g/kg emission standards	480	286	286
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	711	301	15
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	715	308	6
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	819	323	16
Adoption of international best practice PM control measures at coal mines	1,397	803	803
Diesel trains driver assistance software for line haul locomotives	5,263	5	5
US non-road diesel standards in Australia (excluding <19kW)	8,915	1,138	1,138
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	9,779	13	13
Diesel retrofit at mine sites (emissions reduction program)	15,416	18	18
Requiring new locomotives to meet US Tier 4 standards	20,950	14	14
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	21,781	2	2
Mandatory low sulfur fuel use by ships while at berth	46,049	19	19
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	102,666	29	15
Targeted maintenance of high-polluting LCVs using remote sensing	151,072	0	0
Penalty and incentive scheme for high polluting vehicles	192,661	1	1
Area-wide planting to remove PM from the atmosphere	407,418	5	5

Table E8: SA $PM_{2.5}$ MACC data

Measure	Marginal cost ($/t$PM_{2.5}$)	Abatement (t$PM_{2.5}$/year)	Incremental abatement (t$PM_{2.5}$/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,963	17	17
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,815	17	0
Regulating moisture content of wood fuel to be less than 20%	99	72	72
Wood heaters 60% efficiency, 3g/kg emission standards	499	276	276
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	739	290	15
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	742	296	6
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	850	311	15
Diesel trains driver assistance software for line haul locomotives	5,426	5	5
Adoption of international best practice PM control measures at coal mines	9,115	123	123
US non-road diesel standards in Australia (excluding <19kW)	9,191	1,104	1,104
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	10,632	12	12
Diesel retrofit at mine sites (emissions reduction program)	15,893	17	17
Requiring new locomotives to meet US Tier 4 standards	21,598	14	14
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	22,455	2	2
Mandatory low sulfur fuel use by ships while at berth	50,066	18	18
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	105,841	28	14
Targeted maintenance of high-polluting LCVs using remote sensing	158,922	0	0
Penalty and incentive scheme for high polluting vehicles	202,673	1	1
Area-wide planting to remove PM from the atmosphere	407,418	5	5

E.5 WA

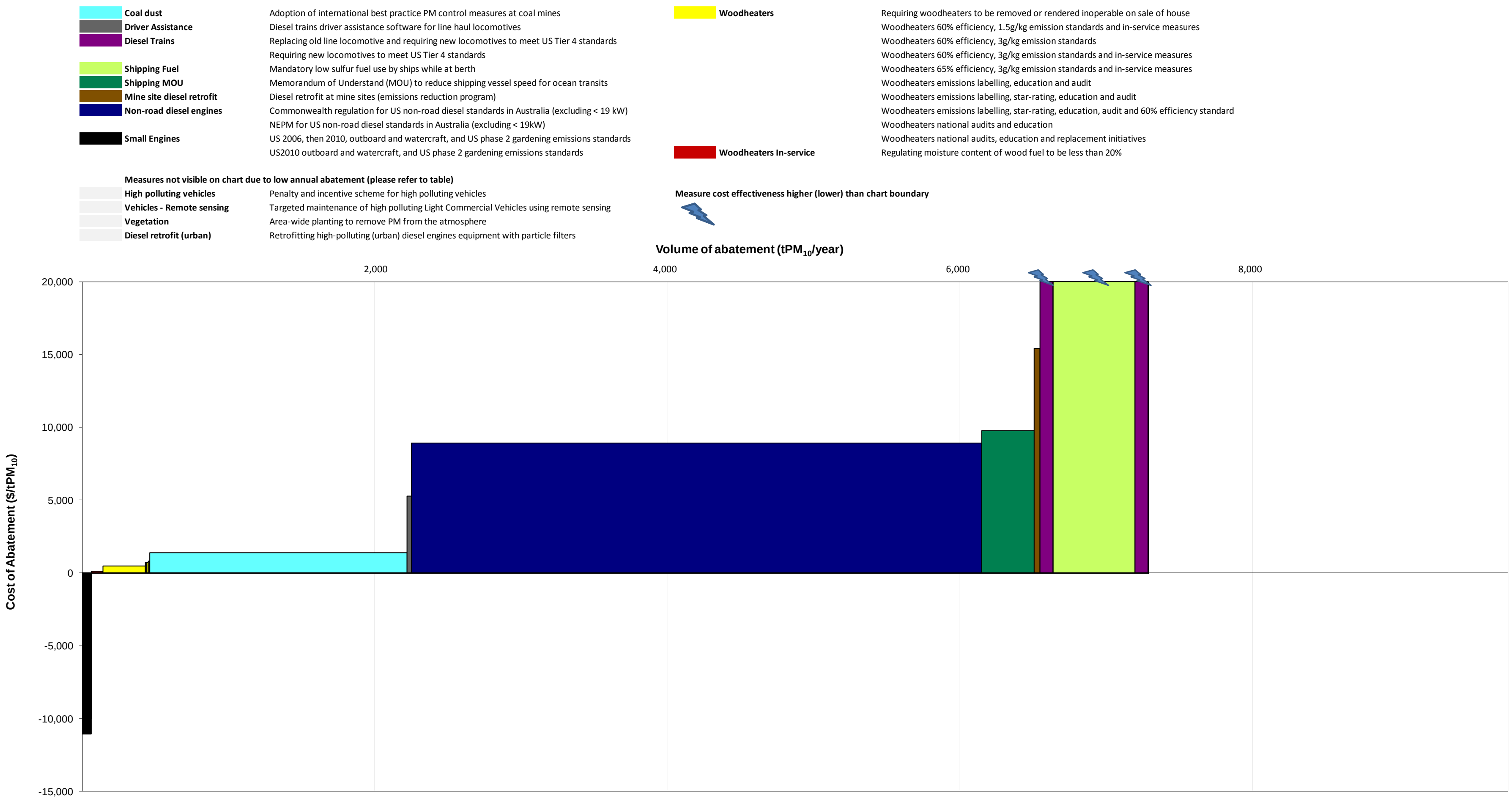

Figure E9: PM$_{10}$ WA MACC

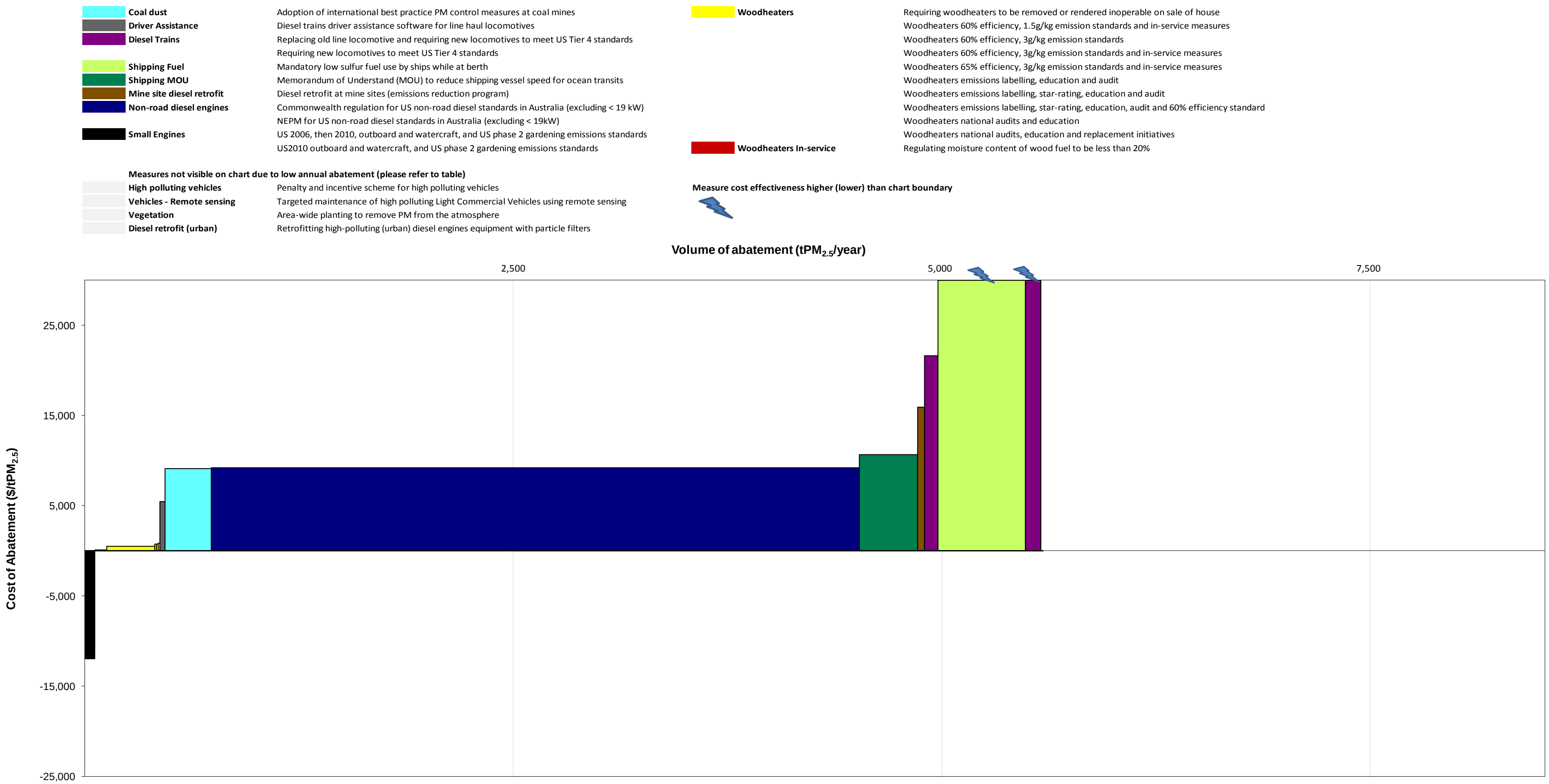

Figure E10: $PM_{2.5}$ WA MACC

Table E9: WA PM_{10} MACC data

Measure	Marginal cost ($/t$PM_{10}$)	Abatement (tPM_{10}/year)	Incremental abatement (tPM_{10}/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,065	68	68
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,003	68	0
Regulating moisture content of wood fuel to be less than 20%	95	76	76
Wood heaters 60% efficiency, 3g/kg emission standards	480	288	288
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	711	303	15
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	715	309	6
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	819	325	16
Adoption of international best practice PM control measures at coal mines	1,397	1,755	1,755
Diesel trains driver assistance software for line haul locomotives	5,263	31	31
US non-road diesel standards in Australia (excluding <19kW)	8,915	3,898	3,898
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	9,779	366	366
Diesel retrofit at mine sites (emissions reduction program)	15,416	39	39
Requiring new locomotives to meet US Tier 4 standards	20,950	84	84
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	21,781	3	3
Mandatory low sulfur fuel use by ships while at berth	46,049	556	556
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	102,666	173	90
Targeted maintenance of high-polluting LCVs using remote sensing	151,072	0	0
Penalty and incentive scheme for high polluting vehicles	192,661	1	1
Area-wide planting to remove PM from the atmosphere	407,418	7	7

Table E10: WA $PM_{2.5}$ MACC data

Measure	Marginal cost ($/t$PM_{2.5}$)	Abatement (t$PM_{2.5}$/year)	Incremental abatement (t$PM_{2.5}$/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,963	63	63
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,815	63	0
Regulating moisture content of wood fuel to be less than 20%	99	73	73
Wood heaters 60% efficiency, 3g/kg emission standards	499	277	277
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	739	292	15
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	742	298	6
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	850	313	15
Diesel trains driver assistance software for line haul locomotives	5,426	30	30
Adoption of international best practice PM control measures at coal mines	9,115	269	269
US non-road diesel standards in Australia (excluding <19kW)	9,191	3,781	3,781
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	10,632	336	336
Diesel retrofit at mine sites (emissions reduction program)	15,893	38	38
Requiring new locomotives to meet US Tier 4 standards	21,598	81	81
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	22,455	3	3
Mandatory low sulfur fuel use by ships while at berth	50,066	511	511
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	105,841	168	87
Targeted maintenance of high-polluting LCVs using remote sensing	158,922	0	0
Penalty and incentive scheme for high polluting vehicles	202,673	1	1
Area-wide planting to remove PM from the atmosphere	407,418	7	7

E.6 TASMANIA

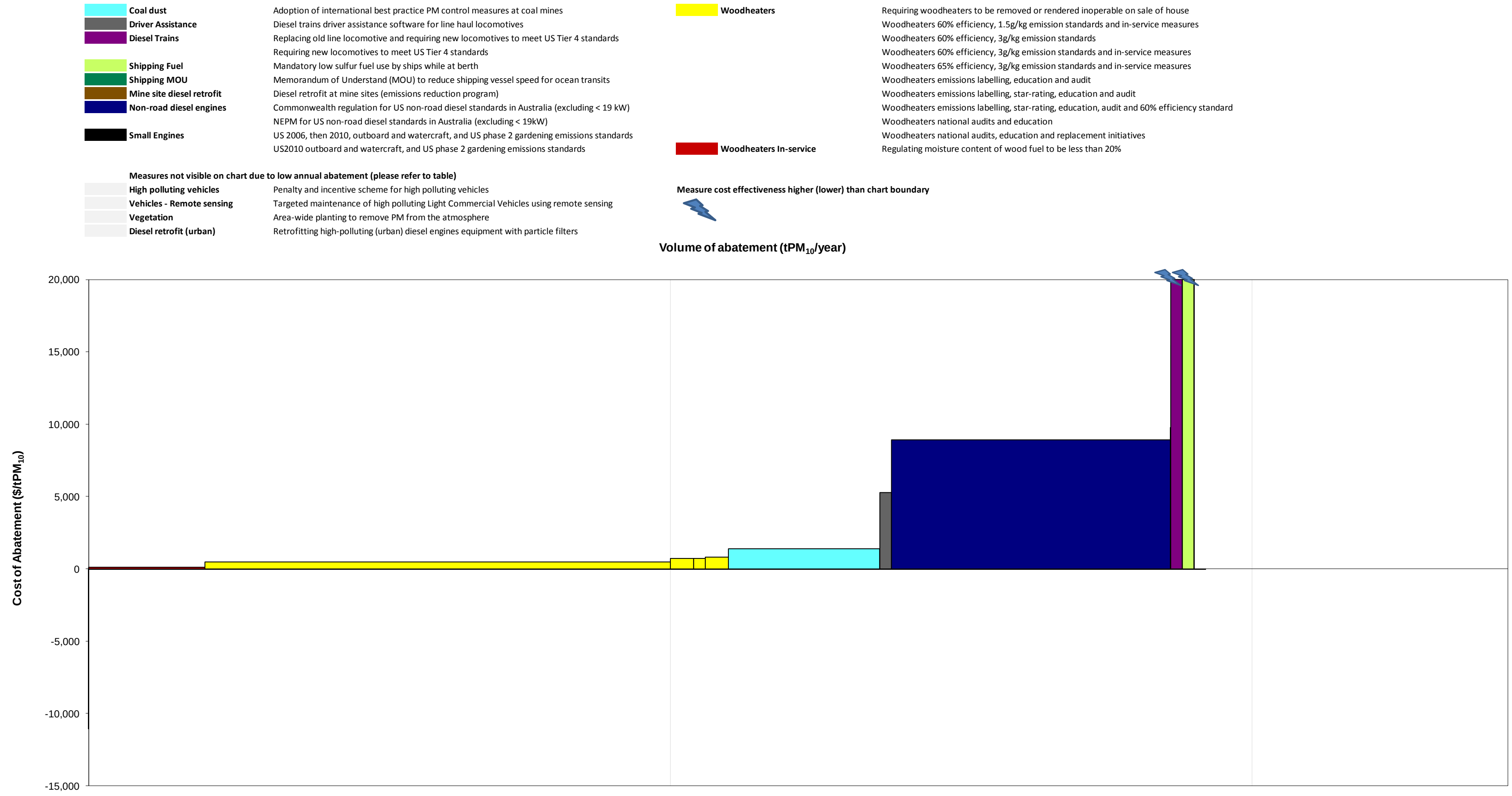

Figure E11: PM_{10} TAS MACC

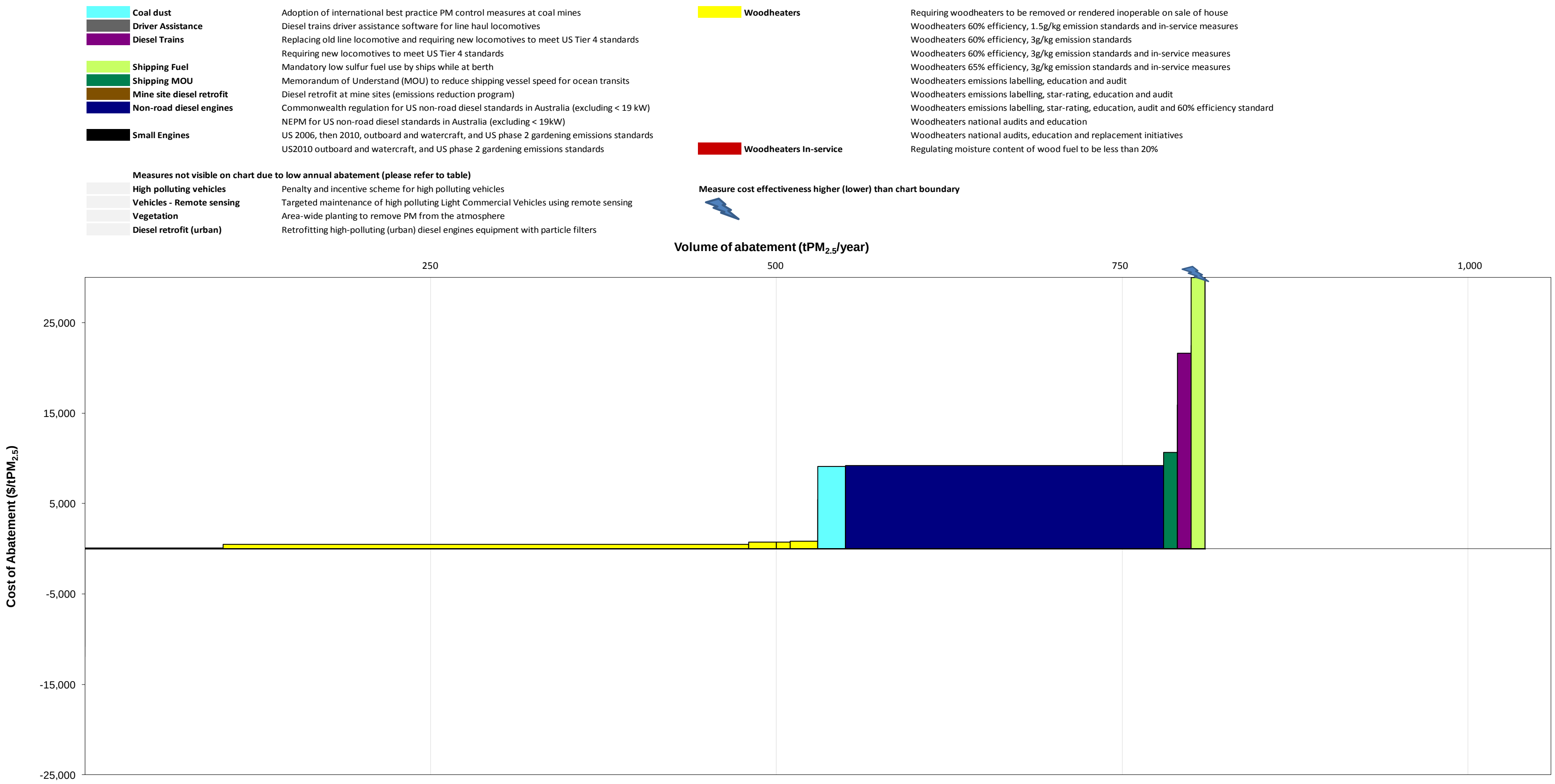

Figure E12: $PM_{2.5}$ TAS MACC

Table E11: TAS PM_{10} MACC data

Measure	Marginal cost ($/t$PM_{10}$)	Abatement (tPM_{10}/year)	Incremental abatement (tPM_{10}/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,065	5	5
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,003	5	0
Regulating moisture content of wood fuel to be less than 20%	95	104	104
Wood heaters 60% efficiency, 3g/kg emission standards	480	395	395
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	711	416	21
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	715	425	8
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	819	446	22
Adoption of international best practice PM control measures at coal mines	1,397	134	134
Diesel trains driver assistance software for line haul locomotives	5,263	2	2
US non-road diesel standards in Australia (excluding <19kW)	8,915	240	240
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	9,779	5	5
Diesel retrofit at mine sites (emissions reduction program)	15,416	3	3
Requiring new locomotives to meet US Tier 4 standards	20,950	6	6
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	21,781	1	1
Mandatory low sulfur fuel use by ships while at berth	46,049	8	8
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	102,666	12	6
Targeted maintenance of high-polluting LCVs using remote sensing	151,072	0	0
Penalty and incentive scheme for high polluting vehicles	192,661	0	0
Area-wide planting to remove PM from the atmosphere	407,418	2	2

Table E12: TAS $PM_{2.5}$ MACC data

Measure	Marginal cost ($/t$PM_{2.5}$)	Abatement (t$PM_{2.5}$/year)	Incremental abatement (t$PM_{2.5}$/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,963	4	4
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,815	4	0
Regulating moisture content of wood fuel to be less than 20%	99	100	100
Wood heaters 60% efficiency, 3g/kg emission standards	499	380	380
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	739	401	20
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	742	409	8
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	850	430	21
Diesel trains driver assistance software for line haul locomotives	5,426	2	2
Adoption of international best practice PM control measures at coal mines	9,115	21	21
US non-road diesel standards in Australia (excluding <19kW)	9,191	232	232
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	10,632	5	5
Diesel retrofit at mine sites (emissions reduction program)	15,893	3	3
Requiring new locomotives to meet US Tier 4 standards	21,598	6	6
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	22,455	1	1
Mandatory low sulfur fuel use by ships while at berth	50,066	7	7
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	105,841	12	6
Targeted maintenance of high-polluting LCVs using remote sensing	158,922	0	0
Penalty and incentive scheme for high polluting vehicles	202,673	0	0
Area-wide planting to remove PM from the atmosphere	407,418	2	2

E.7 NORTHERN TERRITORY

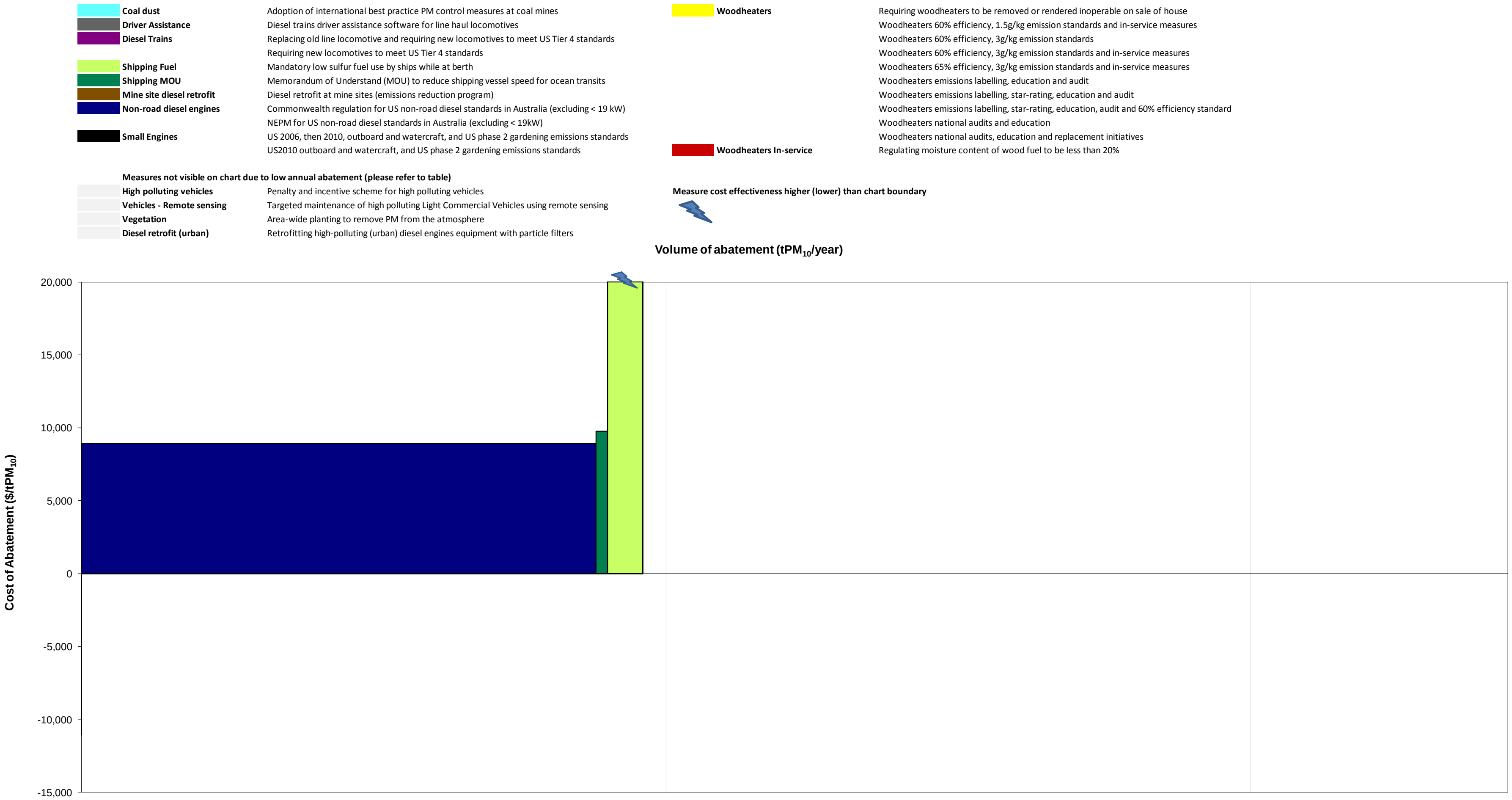

Figure E13: PM_{10} NT MACC

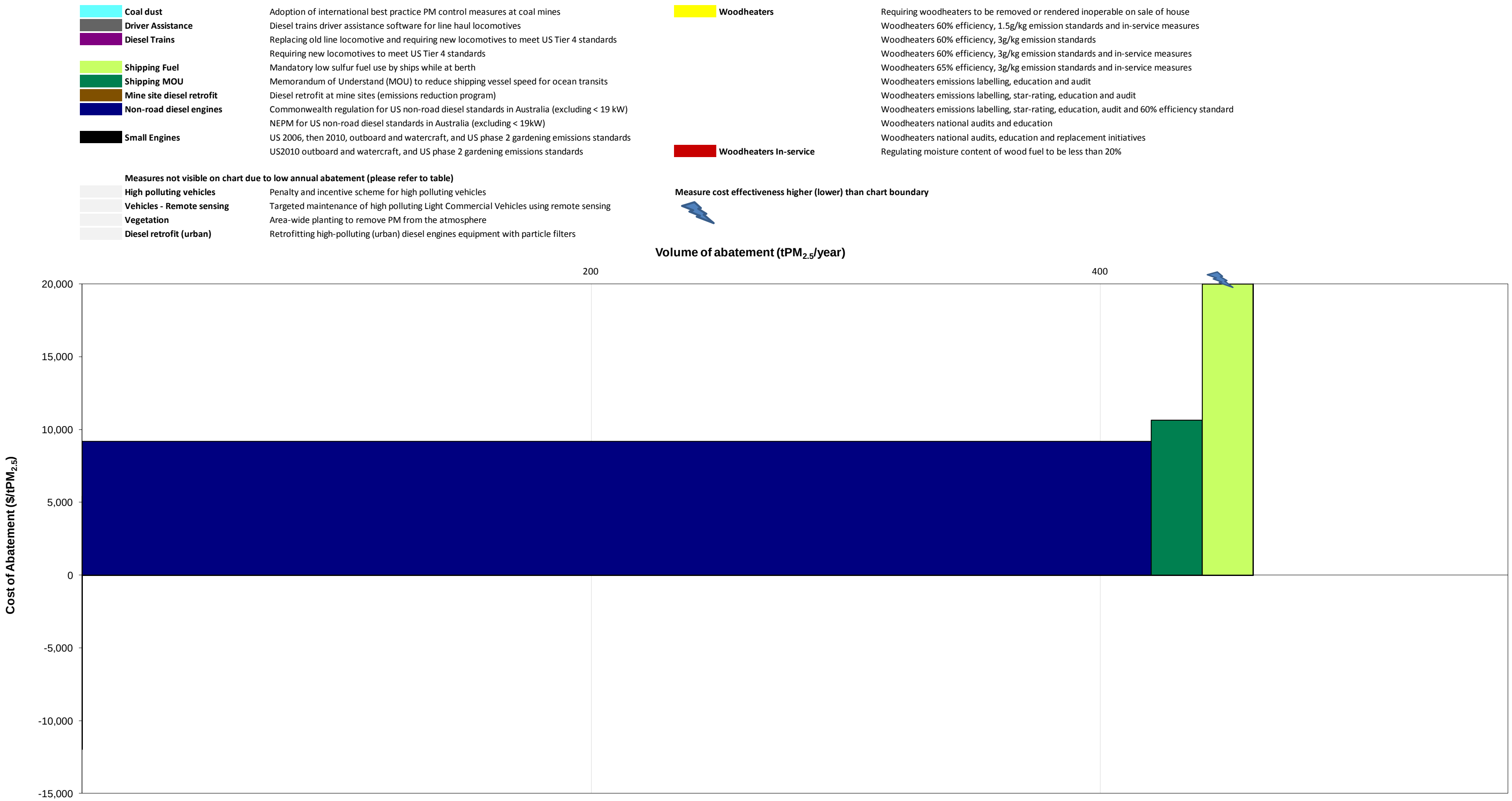

Figure E14: $PM_{2.5}$ NT MACC

Table E13: NT PM_{10} MACC data

Measure	Marginal cost ($/t$PM_{10}$)	Abatement (tPM_{10}/year)	Incremental abatement (tPM_{10}/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,065	7	7
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,003	7	0
Diesel trains driver assistance software for line haul locomotives	5,263	0	0
US non-road diesel standards in Australia (excluding <19kW)	8,915	436	436
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	9,779	15	15
Requiring new locomotives to meet US Tier 4 standards	20,950	1	1
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	21,781	0	0
Mandatory low sulfur fuel use by ships while at berth	46,049	23	23
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	102,666	2	1
Targeted maintenance of high-polluting LCVs using remote sensing	151,072	0	0
Penalty and incentive scheme for high polluting vehicles	192,661	0	0
Area-wide planting to remove PM from the atmosphere	407,418	1	1

Table E14: NT $PM_{2.5}$ MACC data

Measure	Marginal cost ($/t$PM_{2.5}$)	Abatement (t$PM_{2.5}$/year)	Incremental abatement (t$PM_{2.5}$/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,963	6	6
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,815	6	0
Diesel trains driver assistance software for line haul locomotives	5,426	0	0
US non-road diesel standards in Australia (excluding <19kW)	9,191	423	423
Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	10,632	14	14
Requiring new locomotives to meet US Tier 4 standards	21,598	1	1
Retrofitting high-polluting (urban) diesel engines equipment with particle filters	22,455	0	0
Mandatory low sulfur fuel use by ships while at berth	50,066	21	21
Replacing old locomotives and requiring new locomotives to meet US Tier 4 standards	105,841	2	1
Targeted maintenance of high-polluting LCVs using remote sensing	158,922	0	0
Penalty and incentive scheme for high polluting vehicles	202,673	0	0
Area-wide planting to remove PM from the atmosphere	407,418	1	1

E.8 ACT

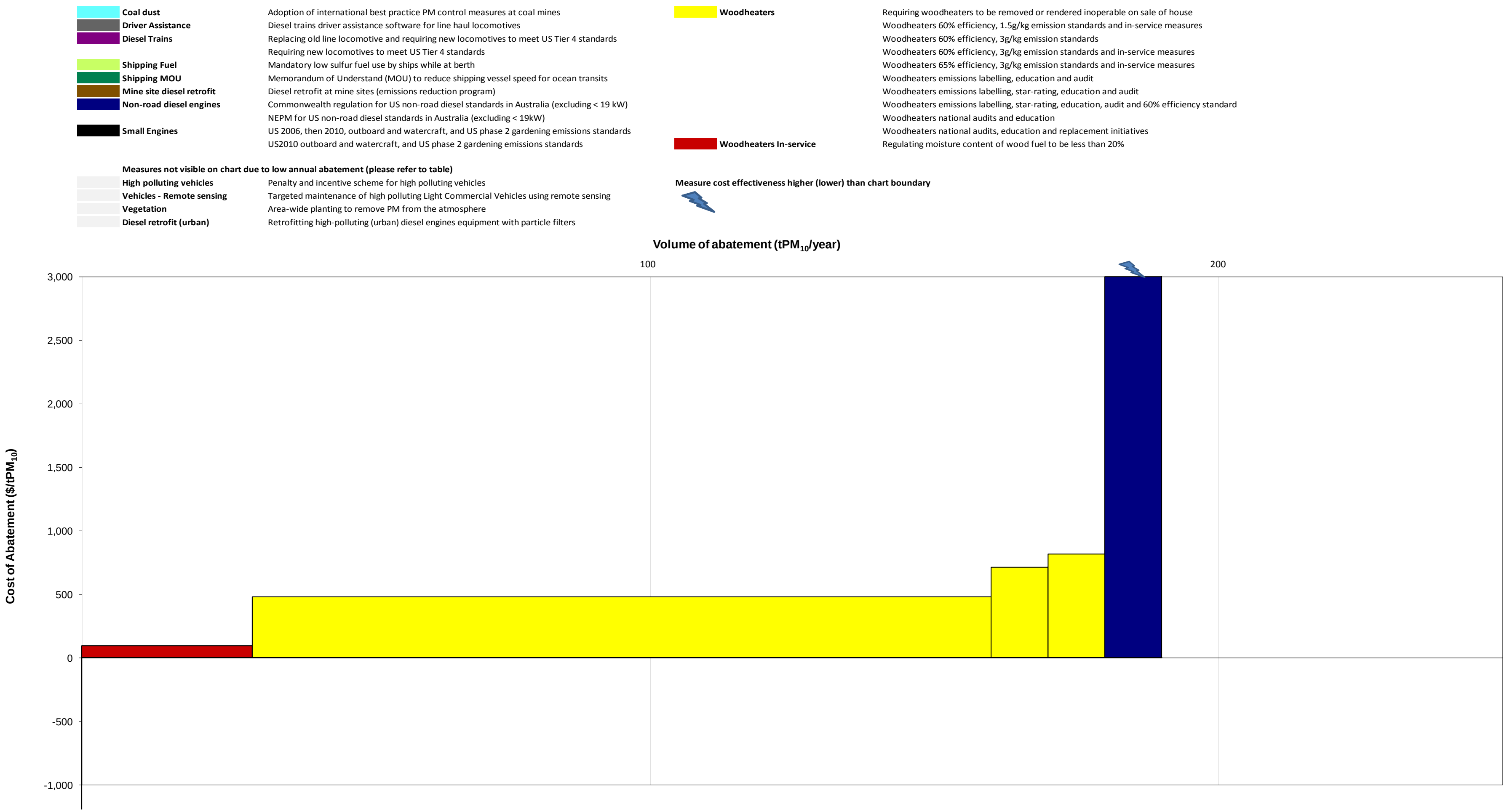

Figure E15: PM_{10} ACT MACC

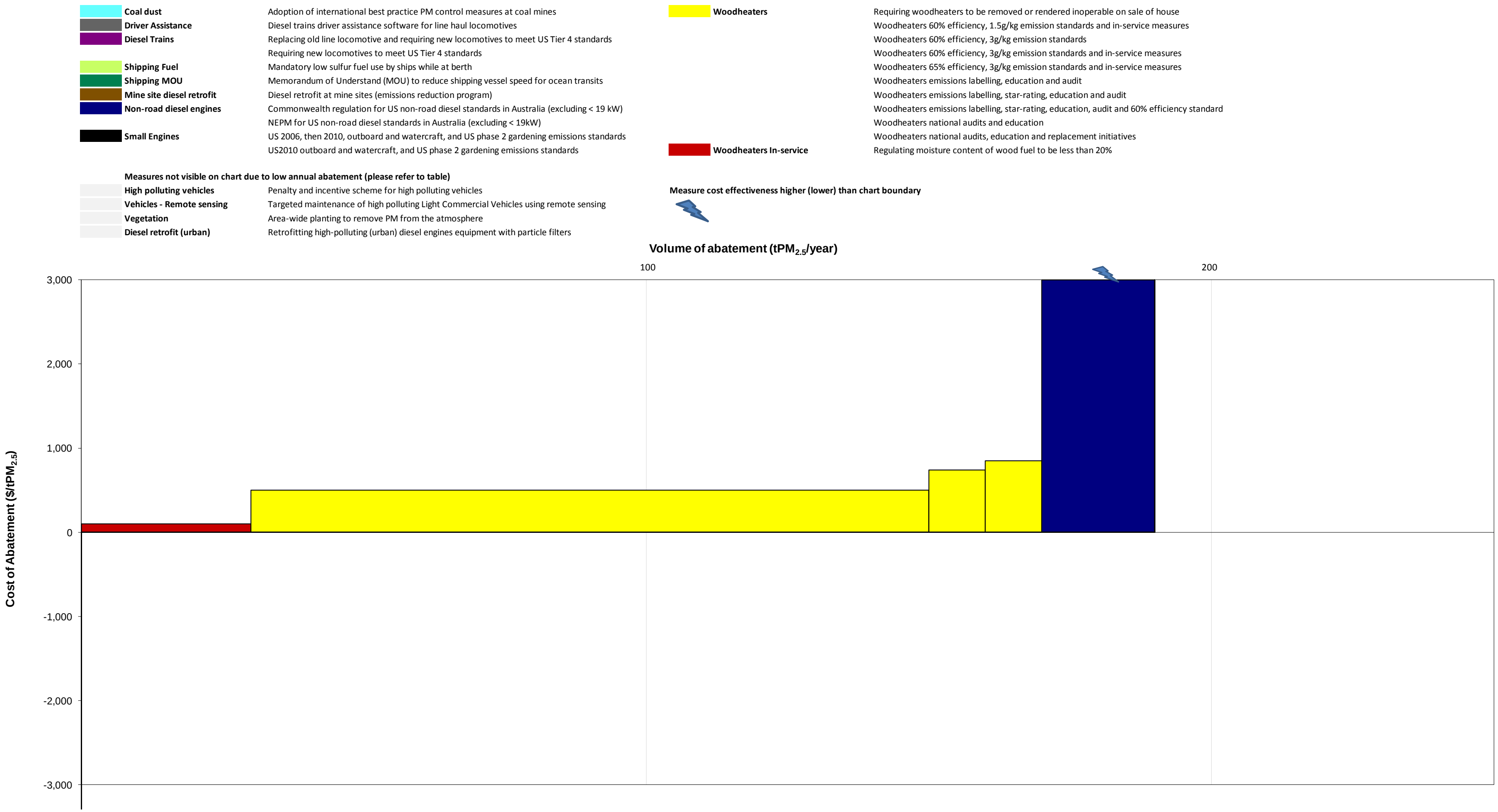

Figure E16: $PM_{2.5}$ ACT MACC

Table E15: ACT PM_{10} MACC data

Measure	Marginal cost ($/t$PM_{10}$)	Abatement (tPM_{10}/year)	Incremental abatement (tPM_{10}/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,065	2	2
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,003	2	0
Regulating moisture content of wood fuel to be less than 20%	95	34	34
Wood heaters 60% efficiency, 3g/kg emission standards	480	129	129
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	711	136	7
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	715	139	3
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	819	146	7
US non-road diesel standards in Australia (excluding <19kW)	8,915	16	16
Targeted maintenance of high-polluting LCVs using remote sensing	151,072	0	0
Penalty and incentive scheme for high polluting vehicles	192,661	0	0
Area-wide planting to remove PM from the atmosphere	407,418	1	1

Table E16: ACT $PM_{2.5}$ MACC data

Measure	Marginal cost ($/t$PM_{2.5}$)	Abatement (t$PM_{2.5}$/year)	Incremental abatement (t$PM_{2.5}$/year)
US 2006 & 2010 outboard and watercraft, and US phase 2 gardening emissions stand.	-11,963	2	2
US2010 outboard and watercraft, and US phase 2 gardening emissions standards	-10,815	2	0
Regulating moisture content of wood fuel to be less than 20%	99	33	33
Wood heaters 60% efficiency, 3g/kg emission standards	499	124	124
Wood heaters 65% efficiency, 3g/kg emission standards and in-service measures	739	131	7
Wood heaters 60% efficiency, 3g/kg emission standards and in-service measures	742	134	3
Wood heaters 60% efficiency, 1.5g/kg emission standards and in-service measures	850	141	7
US non-road diesel standards in Australia (excluding <19kW)	9,191	16	16
Targeted maintenance of high-polluting LCVs using remote sensing	158,922	0	0
Penalty and incentive scheme for high polluting vehicles	202,673	0	0
Area-wide planting to remove PM from the atmosphere	407,418	1	1

Appendix F DAMAGE COST METHOD FOR NO_X

F.1 BACKGROUND

NO_X emissions are responsible for various adverse impacts on health and the environment. These include the following **(Uherek *et al.*, 2010)**:

- Effects on health of NO_2, both directly and through the formation of secondary pollutants (*e.g.* ozone and the nitrate component of secondary PM).
- Impaired atmospheric visibility through the absorption of visible light.
- Acidification and eutrophication.
- Radiative forcing of climate, again through the formation of secondary PM and tropospheric ozone, and impacts on the carbon cycle.

Where a strategy for reducing PM emissions will also lead a reduction of NO_X emissions, this could be a significant co-benefit. To quantify the health benefits of reduced PM emissions we have used the unit damage costs from **Aust *et al.* (2013).** However, **Aust *et al.* (2013)** did not derive unit damage costs for NO_X in Australia because of the difficulties associated with transferring these from other countries. Here, a method has been developed for valuing NO_X emissions in Australia based on the existing information in the literature. Because of limitations on available data, the method only addresses the role of NO_X in contributing to the health impacts of secondary PM.

As with PM, it was necessary to transfer NO_X damage costs from overseas studies, although the range of values in the literature was wide. Annualised damage costs (*i.e*. the annual damage costs for an emission of one tonne of pollutant in one year) were available for the UK and the EU. For the UK **Defra (2011)** gave an average value of £875 per tonne of NOx emitted (equating to around $A1,400 at 2011 prices). For the EU-25, the CAFE programme reported values ranging[46] from €4,400 to €12,000 at 2010 prices (around $A6,000 to $A16,000 at 2011 prices) **(AEA, 2005)**. The UK value in CAFE ranged from €4,000 to €10,000. The unit damage costs varied between individual countries by an order of magnitude. The CAFE values were higher than the Defra value (both absolutely and relative to PM) as they included trans-boundary pollution, which significantly increased population-weighted exposure. It is also worth noting that the Defra costs for the UK relate to secondary PM, whereas the EU costs also include ozone. However, according to **Watkiss *et al.* (2008)** ozone-related costs are likely to be small compared with those for secondary PM. For the United States **Fann *et al.* (2009)** presented unit damage cost of between $US5,000 and $13,000 at 2006 prices. The damage costs for specific areas of the United States suggest a significant amount of inter-regional and intraregional variability. In the regulatory analysis for non-road diesel engines **USEPA (2004)** used an average unit damage cost for NO_X of around $US1,000 at 2002 prices, with a relatively high PM:NO_X ratio (around 10:1) which may be related in part to transboundary (inter-state) pollution. The costs of air pollutants in the Vancouver, British Columbia region of Canada were estimated by **RWDI (2006)**. The unit damage cost used for NO_X was $C934 at 2005 prices.

Primarily because of the presence of an existing method for transferring the Defra damage costs for PM from the UK to Australia **(Aust *et al.*, 2013)**, the NOx damage costs from Defra were also selected for use in the economic analysis. This ensured a broadly consistent approach in the economic analysis. Moreover, the years of life lost (YOLL) and hospital admission numbers used to calculate impacts in the Defra study were readily available. The Defra damage costs for NOx relate to the effects of secondary PM on mortality and hospital admissions (respiratory and cardio-vascular). There are no direct NO_2 or ozone components.

[46] The range takes account of variation in the method used to value mortality, reflecting the use of the median and mean estimates of the value of a life year and value of statistical life.

F.2 METHOD

The main challenge when transferring the UK damage costs to Australia was to take into account - in a simple but logical manner - the formation of secondary nitrate in Australia and its likely impact on population exposure (given the difference between the UK and Australia in terms of the spatial distribution of population). Given the potential differences in nitrate formation between the UK and Australia, and the lack of detailed information on nitrates in Australia (including the absence of a model for secondary PM), only a broad-brush approach was possible. The approach we used is explained below.

The report *Damage Costs for Air Pollution* **(Watkiss *et al.*, 2008)** sets out how the unit damage costs for NO_x in the UK are calculated. Regional-level impacts dominate the damage costs associated with secondary pollutants. Defra do not therefore state area-specific NOx values but only one single UK national value. The national unit damage costs stated in **Watkiss *et al.* (2008)** have a PM:NOx ratio of around 50:1, which is essentially driven by the difference in YOLL per tonne (2.1 for PM compared with 0.04 for NO_X). In fact, the approaches for PM and NOx are slightly different in that the PM value is an average for transport in the UK, whereas the NO_X value is an average for all sources[47]. The PM:NO_X ratio is high because of the difference in population-weighted exposure for a primary (PM) and secondary PM (in this case the nitrate component of secondary PM). In other words, only a fraction of the emitted NO_X is converted into nitrate, and this conversion occurs over time and distance. NO_X emission sources typically contribute to secondary PM at varying distances (typically tens to hundreds of kilometres) downwind from a source. The exposure to nitrates therefore tends to occur away from urban areas. As a consequence, there is also a reasonably even distribution of secondary PM on a regional scale, with fewer differences between urban and rural areas than for primary particles **(Laxen *et al.*, 2010)**. In the case of PM derived from transport, a large proportion of the total emission occurs in areas of high population density. According to **Watkiss (2013)**, the PM:NO_X cost ratio is even higher for London (around 200:1), as these differences are exacerbated.

In Australia the population is typically concentrated along a narrow coastal strip. Whilst population densities in inner cities can be high, these fall off more rapidly with distance compared with the UK, Europe and the United States. Consequently, a large fraction of total nitrate will form outside cities in areas of low population density (inland) or zero population density (offshore). This situation can be contrasted with the US, where tens of millions of people at the regional level are exposed to nitrates. Moreover, the UK, Europe and the US also have high background concentrations of the precursors of nitrate (in particular ammonia from anthropogenic sources) whereas Australia does not. It is therefore likely that NO_X damage costs for Australia will be much lower than in the UK or US. We based our approach on the assumption that the PM:NO_X cost ratio of 50:1 would be suitable for Australia, with a range of 10:1 to 100:1 for sensitivity testing.

The values for the health metrics for PM and NO_X that are relevant here are summarised in **Table F1**. The Australian value of life year (VOLY) (central estimate for 2011 from **Aust *et al.* (2013)**), and the unit costs for hospital admissions from **Jalaludin *et al.* (2011)** are given in **Table F2**. In **Table F3** the values from **Tables F1** and **F2** are combined. Based on the totals, the PM:NO_X ratio is 52.5. For PM **Aust *et al.* (2013)** derived a unit damage cost for $PM_{2.5}$ of \$280/tonne/person/km^2. Dividing this by 52.5 gave a value for NOx of \$5.30/tonne/person/km^2.

[47] PM from non-transport sources (*e.g.* domestic, power generation, agriculture, *etc.*) has a lower damage cost than transport PM in the UK analysis, so the ratio is lower (e.g. industry has a factor of 25:1 PM: NO_X). An average UK ratio for all sources is probably around 20:1 **(Watkiss, 2013)**.

Table F1: Values of health metrics for NOx emissions in the UK (Watkiss *et al.*, 2008)

Health metric	PM value	NO_X value[(a)]	Units
Change in mortality from chronic exposure per tonne of pollutant	2.1	0.04	YOLL $tonne^{-1}$
Change in respiratory hospital admissions from chronic exposure per tonne of pollutant	0.017	0.00035	$tonne^{-1}$
Change in cardio-vascular hospital admissions from chronic exposure per tonne of pollutant	0.017	0.00035	$tonne^{-1}$

(a) For secondary PM

Table F2: Australian values for health metrics

Metric	Value ($) at 2011 prices	Source
Mortality (VOLY)	$288,991	**Aust *et al.* (2013)**
Respiratory hospital admission	$5,706	**Jalaludin *et al.* (2011)**
Cardio-vascular hospital admission	$9,670	**Jalaludin *et al.* (2011)**

Table F3: Unit damage costs for PM and NOx in the UK in $A at 2011 prices

Health metric	Unit damage cost (A$ per tonne)	
	PM	NOx
Mortality	$606,881	$11,560
Respiratory hospital admissions	$97	$2
Cardio-vascular hospital admissions	$164	$3
TOTAL	**$607,142**	**$11,565**

It was then necessary to define suitable regions (with corresponding population densities) to which this population density-specific damage cost could be applied. The spatial distribution of population is more even in the UK than in Australia. Secondary nitrate in the UK will affect a larger number of people than secondary PM in Australia. For this reason, care must be taken when adjusting damage cost values. It was not appropriate to take the original UK values and adjust them using high-resolution local population density for specific areas of Australia. We decided to define unit damage costs for two types of location in each jurisdiction: (i) the main metropolitan area and (ii) all other areas. The results – the values that were used in the economic analysis - are shown in **Table F4**.

It should be noted that the method presented above gives a first approximation of damage costs for NO_X and will require considerable refinement in the future. A detailed assessment (with the modelling of secondary PM formation) is ultimately needed to understand the nitrate (and other secondary) components of PM in Australia, the types of aerosol species present, the background concentrations of other pollutants involved (*e.g.* ammonia) and the regional scale photochemical production of particulate nitrate.

Table F4: Unit damage costs for NO_X used in economic analysis

State	Area name	Constituent SUAs: SUA code	SUA name	SUA area (km²)	SUA 2011 Population	SUA 2011 pop. density (people/km²)	Total area (km²)	Total 2011 population	Total 2011 pop. density (people/km²)	Unit 2011 damage costs (A$/tonne)
NSW	Greater Sydney	1030	Sydney	4,064	4,028,525	991	4,630	4,333,280	936	4,992
		1009	Central Coast	566	304,755	538				
	Other NSW	-	-	-	-	-	795,710	2,505,659	3.1	17
VIC	Greater Melbourne	2011	Melbourne	5,679	3,847,567	677	6,508	3,930,407	604	3,221
		2012	Melton	266	47,670	179				
		2001	Bacchus Marsh	196	17,156	87				
		2009	Gisborne - Macedon	367	18,014	49				
	Other VIC	-	-	-	-	-	221,045	1,398,984	6.3	34
QLD	Greater Brisbane	3001	Brisbane	5,065	1,977,316	390	5,065	1,977,316	390	2,082
	Other QLD	-	-	-	-	-	1,725,267	2,422,741	1.4	7
SA	Greater Adelaide	4001	Adelaide	2,024	1,198,467	592	2,024	1,198,467	592	3,158
	Other SA	-	-	-	-	-	982,154	398,107	0.4	2
WA	Greater Perth	5009	Perth	3,367	1,670,952	496	3,472	1,699,754	490	2,611
		5005	Ellenbrook	105	28,802	276				
	Other WA	-	-	-	-	-	2,523,102	266,801	0.1	1
TAS	Greater Hobart	6003	Hobart	1,213	200,498	165	1,213	200,498	165	882
	Other TAS	-	-	-	-	-	66,805	294,851	4.4	24
NT	Greater Darwin	7002	Darwin	295	106,257	360	295	106,257	360	1,921
	Other TAS	-	-	-	-	-	1,347,905	105,691	0.1	0.4
ACT	Greater Canberra	8001	Canberra - Queanbeyan	482	391,643	813	482	391,643	813	4,334
	Other ACT	8000	Not in any Significant Urban Area	1,914	1,662	0.9	1,914	1,662	0.9	5

Appendix G METHOD FOR IMPACT PATHWAY APPROACH

G.1 QUANTIFICATION OF HEALTH OUTCOMES

A simplified[48] impact pathway-type approach was followed for the locations covered by both the Health Risk Assessment (HRA) project and the state emissions inventories. These locations are listed in **Table G1**.

Table G1: Locations covered by impact pathway approach

Jurisdiction	HRA Location	Economic analysis location(s)
NSW	Illawarra	Wollongong SUA
	Lower Hunter	Newcastle SUA
	Sydney	Sydney SUA
	Upper Hunter	Muswellbrook & Singleton SUAs
VIC	Geelong	Geelong SUA
	Melbourne	Melbourne SUA
QLD	South East QLD (including Brisbane)	SEQ airshed
SA	Adelaide	Adelaide airshed
WA	Perth	Perth airshed
TAS	Hobart	Hobart airshed
NT	Darwin	Darwin airshed
ACT	Canberra	Canberra airshed

G.1.1 Identification of health endpoints

The first step in the impact pathway approach was to identify suitable metrics for evaluating the benefits of improved air quality (*i.e.* health endpoints and other outcomes) (Task 3.1 in **Figure 2.2**). For health impacts the work built upon the results of the HRA project **(Frangos and DiMarco, 2012)**.

As part of the AAQ NEPM review the NEPC commissioned an expert review of epidemiology studies on air pollution and health effects **(Jalaludin and Cowie, 2012)**. The aim of the review was to identify health endpoints and the associated concentration-response functions (CRFs)[49], thus informing the exposure assessment and risk characterisation for the HRA project. The review documented health endpoints for PM_{10} and $PM_{2.5}$ (amongst other pollutants), and the associated CRFs.

Additionally, Pacific Environment recently investigated valuation methodologies for air pollution on behalf of NSW EPA **(Aust *et al.*, 2013)**. The work included a review of the major international methods used for health impact assessment. In economic terms, the review found that mortality due to chronic exposure to PM accounted for almost all (>90%) of the economic impacts of air pollution.

After consideration of the above, we selected the following specific health endpoints for use in the economic analysis:

- Mortality (all-cause) due to long-term exposure to $PM_{2.5}$

[48] The approach was simpler than that used in the UK and the EU, in that we did not consider factors such as time lags and the effect of annual pollution 'pulses'.

[49] A CRF (reported by epidemiological studies) is an empirical relationship between the concentration of PM and the observed health endpoint of interest (for example, hospital admissions for respiratory disease) in a population. There is a concentration-response relationship with PM and many health outcomes where the health risk increases or decreases with varying exposure to both PM_{10} and $PM_{2.5}$.

- Morbidity due to short-term exposure:
  - Hospital admissions for all causes of respiratory disease ($PM_{2.5}$)
  - Hospital admissions for cardiovascular disease ($PM_{2.5}$)
  - Hospital admissions for cardiac disease (PM_{10})
  - Emergency department visits for asthma ($PM_{2.5}$)

These endpoints were largely consistent with those used in the HRA conducted by Golder Associates **(Frangos and DiMarco, 2012)**, following in turn the recommendations of **Jalaludin and Cowie (2012)**. Different age groups were also taken into account. However, there were some notable differences:

- A method for calculating YOLL was also presented by **Frangos and DiMarco (2012)**. However, due to concerns about the robustness of this method we did not calculate YOLL for the economic analysis.
- **Frangos and DiMacro (2012)** provided data on mortality due to acute exposure to PM. Although mortality is also associated with 24-hour increases in PM, it is not the most sensitive endpoint. Mortality endpoints associated with large episodes of incremental increases in 24-hour PM are captured by the chronic exposure analysis. Acute exposure to PM is more likely to be associated with morbidity, such as asthma attacks and other respiratory distress. Therefore, to avoid the double-counting of effects (and for consistency with the damage cost approach) we followed what has become standard practice, and did not include acute effects alongside mortality due to chronic exposure.
- Similarly, with regards to morbidity only the impact of PM on hospitalisation for all causes of respiratory disease was used and not individual causes of respiratory disease hospitalisation (in particular, we excluded hospital admissions due to pneumonia and bronchitis).

We considered our approach to be a conservative one, in that it was designed to avoid the overestimation of health impacts and the associated benefits.

G.1.2 Quantification of benefits

The next step was to quantify the health endpoints for each of the hypothetical air quality standard scenarios (Task 3.2 in **Figure 2.2**). Health benefits were determined for the estimated changes in PM concentration from the BAU scenario to those resulting from different policy and abatement measures over the period from 2011 to 2055. In short, the estimation of the magnitude of health benefits attributable to reducing ambient PM to the hypothetical scenario levels was based on the following factors:

1. CRFs from the identified epidemiological studies that relate changes in ambient concentrations of PM to the selected health effects. The CRFs were sourced from **Jalaludin and Cowie (2012)**.
2. The baseline incidence of the health effects of interest for each study location. Baseline incidences for the selected health outcomes (year 2010) were sourced from **Frangos and DiMarco (2012)** and scaled from 2010 to 2055 using scaling factors based on population projections for the corresponding locations **(ABS, 2008)** to estimate future year health outcome events for each location. It was therefore assumed that health outcome baseline rates *per capita* would remain constant.
3. The difference in modelled BAU concentrations and the hypothetical air quality standard scenarios for all PM metrics.

Long-term (mortality) benefits were estimated for all HRA locations using modelled annual mean PM concentration changes for the different scenarios from 2010 until 2055. Because of the lengthy calculation involved, short-term (morbidity) benefits were calculated using the 24-hour PM concentrations for the target year of 2036 only, and just for the HRA locations in NSW.

For consistency with the health risk assessment project, changes in health outcomes (both annual and 24-hour) were calculated using the following equation for each location:

$$\Delta Y = Y_{base} \times (e^{\beta \Delta C} - 1)$$

Where:

ΔY is the change in the health outcome

Y_{base} is the baseline health incidence (either annual or 24-hour, as appropriate)

β is a coefficient

ΔC is the change in PM_{10} or $PM_{2.5}$ concentration

Table G2 summarises the health endpoints and associated CRFs used in this project. For each location and each health outcome the baseline incidence is given in **Table G3**, and the corresponding affected population is shown in **Table G4**. The total population is also provided in **Table G4**.

Table G2: Health endpoints and beta coefficients used in this study. The outcomes shaded in grey were calculated but not used in the analysis to avoid double counting.

Averaging period	PM metric	Health outcome	Age group	Coefficient (β)
Long-term: Mortality				
Annual[a]	PM_{10}	Mortality (all cause)	30+ years	0.004
	$PM_{2.5}$	Mortality (all cause)	30+ years	0.006
Short-term: Mortality				
24 hour[b]	PM_{10}	Mortality (all cause)	30+ years	0.002
	$PM_{2.5}$	Mortality (all cause)	30+ years	0.0023
Short-term: Morbidity				
24 hour[b]	PM_{10}	Hospital admissions – all respiratory	0-1 years	0.003
		Hospital admissions – all respiratory	15-64 years	0.003
		Hospital admissions – all respiratory	65+ years	0.003
		Hospital admissions – cardiac disease	65+ years	0.0019
		Hospital admissions – pneumonia and bronchitis	65+ years	0.0013
		Emergency department visits - asthma	1-14 years	0.002
	$PM_{2.5}$	Hospital admissions – all respiratory	0-1 years	0.006
		Hospital admissions – all respiratory	15-64 years	0.003
		Hospital admissions – all respiratory	65+ years	0.004
		Hospital admissions – cardiovascular disease	65+ years	0.003
		Hospital admissions – pneumonia and bronchitis	65+ years	0.0053
		Emergency department visits - asthma	1-14 years	0.0015

(a) Calculated for all HRA locations

(b) Calculated only for HRA locations in NSW

Table G3: Baseline (annual) incidence for health outcomes (2010)

Jurisdiction	Location	Mortality: all cause (30+ years)	Hospital admissions: All respiratory (0-1 years)	All respiratory (15-64 years)	All respiratory (65+ years)	Cardiovascular disease (65+ years)	Cardiac disease (65+ years)	Pneumonia & bronchitis (65+ years)	Emergency visits: asthma (1-14 years)
NSW	Illawarra	3,276	377	2,790	3,246	7,860	5,234	925	1,054
	Lower Hunter	4,300	385	3,080	2,322	7,953	5,514	948	1,043
	Sydney	25,490	4,581	23,171	22,456	52,125	35,701	6,164	9,482
	Upper Hunter	823	N/A	N/A	N/A	N/A	N/A	N/A	N/A
VIC	Geelong	2,220	165	2,022	1,799	4,675	3,010	508	635
	Melbourne	23,057	2,613	25,474	24,006	54,536	37,264	8,525	8,309
QLD	South-East QLD	13,701	2,807	22,631	26,648	70,539	54,595	7,527	78
SA	Adelaide	9,154	1,436	9,738	9,084	21,740	15,311	2,704	3,147
WA	Perth	9,026	335	3,808	3,520	4,030	108	1,694	2,085
TAS	Hobart	1,753	100	1,135	1,038	2,688	1,756	279	276
NT	Darwin	396	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ACT	Canberra	1,616	236	2,324	1,692	4,745	2,679	622	706

Table G4: Affected populations for health outcomes, and total population (2010)

Jurisdiction	Location	Mortality: all cause (30+ years)	Hospital admissions: All respiratory (0-1 years)	All respiratory (15-64 years)	All respiratory (65+ years)	Cardiovascular disease (65+ years)	Cardiac disease (65+ years)	Pneumonia & bronchitis (65+ years)	Emergency visits: asthma (1-14 years)	Total population
NSW	Illawarra	166,309	3,233	177,034	43,682	43,682	43,682	43,682	49,545	273,494
	Lower Hunter	230,734	4,522	241,822	62,341	62,341	62,341	62,341	64,093	372,778
	Sydney	2,610,100	58,818	2,926,562	575,038	575,038	575,038	575,038	776,761	4,337,179
	Upper Hunter	130,080	4,522	136,174	32,854	32,854	32,854	32,854	40,203	213,753
VIC	Geelong	157,386	2,988	162,713	41,337	41,337	41,337	41,337	45,287	252,325
	Melbourne	2,342,627	50,271	2,679,829	511,888	511,888	511,888	511,888	676,514	3,918,502
QLD	South-East QLD	543,991	36,001	1,565,072	557,829	557,829	557,829	557,829	505,544	2,664,446
SA	Adelaide	741,558	14,077	802,986	185,607	185,607	185,607	185,607	198,686	1,201,356
WA	Perth	984,449	21,835	1,142,243	207,674	207,674	207,674	207,674	300,356	1,672,108
TAS	Hobart	128,526	2,626	138,074	31,871	31,871	31,871	31,871	36,859	209,430
NT	Darwin	64,996	N/A	N/A	N/A	N/A	N/A	N/A	N/A	127,756
ACT	Canberra	201,242	4,648	247,690	36,809	36,809	36,809	36,809	60,732	349,879

G.2 MONETISATION OF BENEFITS

G.2.1 Health benefits - mortality

G.2.1.1 Background

Mortality outcomes arising from changes in air pollution may be expressed as lives lost and/or years of life lost. To monetise these outcomes, estimates for the Value of a Statistical Life (VSL) and Value of a Statistical Life Year (VOLY) are required

[50]. In addition to selecting a central estimate for VSL and VOLY, appropriate lower and upper bound estimates were determined for the sensitivity analysis. A review was therefore undertaken of the literature relating to the monetisation of mortality, and in particular the sources of information on VSL and VOLY. The literature and the estimates for the relevant metrics, as well as issues raised and relevance to the economic analysis, are discussed below.

G.2.1.2 Literature review

Methodology for Valuing the Health Impacts of Changes in Particle Emissions (Aust et al., 2013)

This work involved the development of a robust general valuation methodology for changes in air pollution to replace the previous *ad hoc* assessments. The report provided a summary of approaches taken by overseas jurisdictions, an analysis of Australian needs and conditions, a review of the literature on secondary particles, and the development of a methodology for estimating health costs associated with changes in PM in NSW and Australia. The summary of international approaches from the report is reproduced in **Table J5**. **Aust *et al.* (2013)** also summarised estimates from Australian studies. These have varied but largely used damage costs from international studies (with some adjustments for Australian conditions).

Aust *et al.* (2013) recommended the use of an Australian VOLY of $288,991 (in 2011 prices), with low and high estimates of $178,211 and $390,138 respectively, to be consistent with **NEPC (2011b)** and **ASCC (2008)** (see below).

It is worth noting the different approaches used to estimate how mortality outcomes are valued into the future. Future mortality benefits are contingent on assumptions relating to:

- Whether VSL should increase over time, as society's willingness to pay for a life saved increases in line with economic factors such as *per capita* gross domestic product (GDP) growth or labour productivity, referred to as an 'uplift' factor.
- The discount that ought to apply to a life saved in the future to compare it with a life saved today (to reflect that in a CBA future benefits are typically discounted compared to nearer term benefits), referred to as a 'discount' factor.

The UK Air Quality Strategy Review's economic framework (mentioned in **Table G5**) applied an uplift of 2% per year, effectively assuming that the value of life increases over time. **Aust *et al.* (2013)** recommended the adoption of the same value in Australia. Whilst we are not aware of any precedent in Australian studies, the rationale for applying such an uplift factor also applies to Australia, as the value of life (heavily influenced by the value of production) is likely to increase over time, as reflected through increasing income or *per capita* GDP.

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[50] VSL is defined broadly as the marginal dollar value of a human life, while VOLY is defined broadly as the marginal dollar value of a year of healthy human life. The VOLY is particularly important in practical applications, since most interventions and regulation are aimed at averting injuries and disease, and most of these are not immediately fatal **(ASCC, 2008)**.

Table G5: Summary of international approaches to value of life (Aust *et al.*, 2013)

Aspect	CAFÉ (AEA, 2005)	UK Air Quality Strategy Review (Defra, 2007)	USEPA Fann *et al.* (2009)
General approach	Impact pathway and damage cost	Impact pathway and damage cost	Impact pathway (damage costs for SO_2 and NO_x)
Pollutants considered	Primary and secondary	Primary and secondary	Primary and secondary
Emission inventory	Various	NAEI – 11 sectors including point source, agriculture and transport	USEPA NEI - point, non-point, on-road, non-road, and event
Approach for air quality	Detailed models (RAINS)	Detailed national models (plus EMEP)	Detailed air quality models (CMAQ)
Population assumptions and inputs	Detailed population and life tables	Detailed population and life tables	Detailed population and life tables
Mortality - chronic analysis of PM	$PM_{2.5}$, 6% hazard rate, all equally causal, no lag between exposure and effect, annual pulse, using life tables	PM_{10}, 6% hazard rate, all equally causal, various lag effects, life tables (UK specific), annual pulse and sustained pollution changes	$PM_{2.5}$, 6% hazard rate, all equally causal, lag distribution
Morbidity	Infant mortality Chronic bronchitis Respiratory hospital admissions Cardiac hospital admissions Restricted activity days Respiratory medication use Lower respiratory symptom days	Respiratory and cardio-vascular hospital admissions only	Infant mortality Bronchitis: chronic and acute Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Non-fatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma/respiratory exacerbations (asthmatic population)
Application of health functions (% of baseline rates, values per population).	Various	Baseline rates	Baseline rates
Functions used for estimating health endpoints	Pope *et al.* (1995, 2002) for chronic effects	Pope *et al.* (1995, 2002) for chronic effects	Pope *et al.* (1995, 2002) for chronic effects
Valuation of health endpoints	VSL and VOLY (€120,000 at 2000 prices)	VOLY(£29,000 at 2010 prices)	VSL (US$5.5 million)
Overall economic framework	Current prices, no uplift or discounting.	Current prices, then uplift at 2% per year, followed by declining discount rate starting at 3.5%.	Projected real income growth (split by endpoint, but not specified). Real discount rates of 3% and 7%.

The Health of Nations: The Value of a Statistical Life (ASCC, 2008)

The Australian Safety and Compensation Council published a review of the international literature on values of human life **(ASCC, 2008)**. The aim of the review was to identify a VSL and a VOLY for use in Australia. The study also included a consultation process with government stakeholders. Various issues related to the use of VSL were presented, including the following:

- The difficulties in adjusting VSL to account for the utility of health states (that is, quality adjusted or disability adjusted value of life) and the benefit of adopting a consistent approach where adjustment weights are agreed by international experts.
- The potential pitfalls of adopting a WTP approach to estimating VSL where, for example, the values individuals attribute to saving their own life may be influenced by seemingly irrational behaviour rather than would be expected under a neoclassical economic framework.
- The fact that investments in health and safety result in positive and negative externalities (benefits or drawbacks for third parties outside of the parties directly associated with the transaction) and is therefore a domain for government intervention and regulation.

ASCC recommended a VSL and a VOLY for use in the context of air quality:

- An average VSL of $6 million (at 2006 prices).

- This equated to a VOLY of $252,014 using a discount rate of 3% over an estimated 40 years of remaining life expectancy.
- A sensitivity range of $3.7 million to $8.1 million (at 2006 prices), which is wider than the range of estimates from the analysis of selected VSL studies undertaken by ASCC, but recommended due to the significant variability in estimates.

Due to the detailed consideration of such issues, we consider the ASCC recommendations to be robust estimates for mortality benefits associated with reductions in air pollution.

Evaluating the Health Impacts of Ethanol Blend (Orbital and CSIRO, 2008)

Orbital and CSIRO (2008) estimated the human health benefits of adopting ethanol-blended fuels for selected Australian fleets, using a statistical value of a human life of $7m. The study required estimates of the value of human life and also provided support for estimates produced by **ASCC (2008)**.

A Methodology for Cost-Benefit Analysis of Ambient Air Pollution (Jalaludin et al., 2009)

Jalaludin *et al.* (2009) critically evaluated the methodology and uncertainty associated with CBAs in terms of four aspects: (i) measurement of ambient air pollution, (ii) identification of health effects, (iii) identification of concentration-response functions and (iv) monetary valuation of the health effects. A number of Australian and international CBAs were reviewed. Key issues discussed in the report that are relevant to the current study included:

- Only one of the CBAs reviewed **(DEFRA, 2007)** quantified both long-term and short-term premature mortality whereas typically only long-term exposure is quantified.
- Concentration response functions for long-term effects are preferred to those for short-term effects.
- WTP was the preferred method for valuing life in all the reviewed CBA reports, except for a Bureau of Transport and Regional Economics study **(BTRE, 2005)**, where the human capital method was used.
- Life years lost is a preferred measure to lives lost and should be estimated where feasible and practicable.

The paper also supported **ASCC (2008**) as a reliable source for the estimate of value of life (p. 242) - "*A figure of A$6.0 million (range: A$3.7 million to A$8.1 million; 2006 dollar values) for a VOSL may be used in Australia until further VOSL studies are undertaken and published*".

Establishing a Monetary Value for Lives Saved: Issues and Controversies (Abelson, 2008)

This study, undertaken for the Office of Best Practice Regulation (OBPR), sought to assess whether the expenditure on health and safety in Australia was appropriate and to determine quantitative measures for value of life and health. The study also noted the issues surrounding value of life estimates derived from either stated preference (where individuals express their WTP for life) or revealed preference (where individuals' WTP may be inferred by analysing purchasing or employment decisions) methods. Such issues included that rationality does not always hold, individuals have imperfect information, values of human life accrue not just to the individual but also third parties (e.g. individuals' employers) and that values of life involve ethical judgments.

The study recommended a value of life of $3-4 million (2008 dollars). This was done by reference to selected international studies but an exact method (e.g. meta-analysis) was not used to derive these estimates.

Methodology for setting air quality standards in Australia (NEPC, 2011b)

NEPC (2011b) recommended a framework for the setting of air quality standards in Australia. A methodology was developed to address the wide variety of approaches and diversity of stakeholder views surrounding previous air quality standard setting processes. The methodology provided guidance for hazard assessment, exposure assessment, risk characterisation and policy considerations, and NEPC recommended the VSL and VOLY values from **ASCC (2008)**.

Draft Preliminary Cost Benefit Analysis (Wilson et al., 2011b)

The preliminary CBA by **Wilson *et al.* (2011b)** adopted value-of-life estimates recommended by **NEPC (2011b)**, in turn based on **ASCC (2008)**[51]. For the current economic analysis we have arrived at a broadly similar conclusion for the value of a life. However, we also adjusted the estimate (expressed in 2006 dollars) to the value of the base year of the study (2011) and recommend the application of an uplift factor for future years (derived from ABS estimates of GDP growth per capita over the last 50 years), to reflect increasing WTP for lives saved over time.

G.2.1.3 Values and assumptions for economic analysis

The assumed values for VSL and/or VOLY have by far the largest influence on the monetary benefits of any new air quality standards, and therefore fundamentally affect the results of the economic analysis. A number of previous studies on value of life, both overseas and in Australia, have been undertaken and have produced a range of estimates for the two metrics. The studies have also highlighted the issues relating to the derivation and application of the values.

Many of the studies have recommended that a consistent figure should be used in future studies, and that sensitivity ranges should be applied to account for significant variance in estimates. We agree with these recommendations, and propose to adopt value-of-life estimates (**Table G6**) that have been recommended and supported for use in the context of setting air quality standards. However, we also consider that an uplift factor should be applied to reflect that WTP for lives saved is likely to increase over time, in line with increases in the general standard of living and/or income. The full sensitivity range (VSL of $3.7 million to $8.1 million (2006 dollars)) is proposed for sensitivity testing of portfolios, however this has been derived from a very wide diversity of studies, and therefore a range of +/- 25% is proposed for individual measures. The full VSL sensitivity range translates to a VOLY range of $178,211 to $390,138 with a central estimate of $288,991 (2011 dollars). This is consistent with **Aust *et al.* (2013)** and provides a robust test due to its significant range between lower and upper bound estimates.

Table G6: Assumptions for estimating mortality benefits in economic analysis

Assumption	Value	Source(s)
VSL – central estimate	$6.0 million (2006 dollars)	**NEPC (2011b)** **ASCC (2008)** **Jalaludin *et al.* (2009)** **Wilson *et al.* (2011b)**
VSL – sensitivity range	$3.7 million to $8.1 million (2006 dollars)	As above
VOLY – central estimate	$288,991 (2011 dollars)	**Aust et al. (2013)**
VOLY – sensitivity range	$178,211 to $390,138 (2011 dollars)	**Aust et al. (2013)**
Uplift factor	2.1% per year	Derived from ABS estimates of real GDP growth *per capita* over the last 50 years.
Discount rate	3%, 7% or 10% (based on sensitivity – must be consistent with discount rate applied to other items in the economic analysis)	

[51] The report (p.34) states: 'Given the COAG guidelines and the present theoretical overview of VSL frameworks, the CBA measurement of chronic mortality effects and acute mortality effects should be based on the VSL life of $6 million, as described in the NEPC standards setting consultation draft (NEPC 2009)'.

It should be noted that the selected VSL and VOLY figures derived from the literature assume that a 3% discount rate is applied to life years saved in the future. The VOLY is used in this economic analysis (as life years saved estimates are used) and, to be consistent with previous Australian studies **(ENVIRON and SKM-MMA, 2011; BDA Group, 2013; MMA, 2009)**, a central discount rate of 7% is recommended (with a sensitivity range of 3% to 10%). Estimates of health benefits in this analysis are therefore based on a more conservative use of discount rate.

G.2.2 Health benefits - morbidity

G.2.2.1 Background

Various morbidity endpoints associated with PM emissions were considered in the study. These included:

- Hospital admissions for all respiratory illnesses
- Hospital admissions for cardiovascular illnesses
- Hospital admissions for cardiac failure
- Chronic and acute bronchitis
- Emergency visits for asthma attacks
- Restricted activity days
- Work loss days

Again, appropriate values were determined through a review of the literature.

G.2.2.2 Literature review

Reviews of overseas and Australian air pollution health impacts studies (including **AEA, 2005; Beer, 2002; CIE, 2005; Coffey, 2003; Defra, 2007; NSW EPA, 1997; Watkiss *et al.*, 2008**) undertaken by **Aust *et al.* (2013)** and for this study indicated that the costs associated with the morbidity endpoints listed above tend to be low relative to mortality costs.

Of the morbidity health endpoints listed above, valuation estimates have been provided in this study for the following:

- Hospital admissions for respiratory illnesses
- Hospital admissions for cardiovascular illnesses
- Hospital admissions for cardiac failure
- Hospital admissions associated with acute bronchitis and pneumonia
- Emergency visits for asthma attacks

While the impact of days away from work ('lost productivity' in **Section G.2.2.3**) associated with hospitalisations and emergency visits has been estimated, the exclusion of 'restricted activity days' and 'work loss days' (due to sickness but not hospital or emergency visits) reflects the fact that data relating to these health end points have not been provided through the HRA.

Estimates for Europe **(AEA, 2005)** suggest that restricted activity days and lost work days are potentially significant air pollution health impacts relative to other morbidity outcomes. However, overall morbidity benefits were estimated to be miniscule (< 0.1%) in comparison with mortality health impacts in the impact pathway analysis and therefore this exclusion is noted but is not expected to affect results.

G.2.2.3 Values and assumptions for economic analysis

For each of the morbidity health endpoints, the main potential costs are:

- The reduced quality of life associated with the illness (pain, suffering).
- Resource costs associated with hospitalisation or emergency department visits.
- Lost productivity associated with hospitalisation.

Valuation estimates for each of these are discussed in turn below.

Reduced quality of life

Estimates of the value of reduced quality of life were derived using a method adopted for use in Australia by **Mathers *et al.* (1999)** and further considered by **Abelson (2003)**. This method derives quality of life indices for a wide range of illnesses ranging from 0 (deceased) to 1 (perfect health), drawing on clinical views of health status derived through expert surveys **(Southard *et al.*, 1997)**. These indices are then used to derive daily (acute morbidity) or annual (chronic morbidity) costs by applying them to the current estimate of the VOLY. These costs provide estimates of the amounts per day or per year that individuals are willing to pay to avoid acute or chronic conditions respectively. In the case of the morbidity health end points associated with PM emissions, these are acute conditions and therefore costs are estimated daily. Estimates for the relevant health endpoints are provided in **Table G7**. Note high and low estimates for respiratory, and cardiovascular endpoints are the same, as ranges for these are not provided in the literature.

Table G7: Estimated quality of life values for morbidity health endpoints

Health Endpoint	Quality of life index		Cost of health endpoint ($/day)[(a)]		Total cost of health endpoint ($)	
	High	Low	Low	High	Low	High
Respiratory	0.836	0.836	130	130	325	649
Cardiovascular	0.822	0.822	141	141	296	719
Cardiac including cardiac failure	0.822	0.605	141	313	550	2596
Acute bronchitis & pneumonia	0.868	0.627	105	295	439	2363
Asthma	0.970	0.770	24	182	6	364

(a) Based on a VOLY of $288,991 and an average duration of condition

Hospitalisation costs

Hospitalisation costs were estimated using national data on hospital admission and costs compiled by the Australian Institute of Health and Welfare **(AIHW, 2012)**. The AIHW data indicate that the average daily cost for each additional patient admitted to an Australian public hospital treating acute conditions in 2010-11 was approximately $1,380 per day.

The other key (but less certain) variable influencing morbidity valuations is the length of hospital admission. Australian hospital admission data compiled by AIHW indicate that the average durations of admissions were (depending on state, hospital type and severity of condition):

- respiratory – 2.5 to 5.0 days
- cardiovascular – 2.1 to 5.1 days
- cardiac – 3.9 to 8.3 days
- bronchitis and pneumonia– 4.2 to 8.0 days

These values are generally less than comparable data on length of hospital stay provided for the UK (presented in **DEFRA, 2007**). Estimates of the length of stay for asthma emergency department visits are less certain still. The AIHW data indicate that the average duration of stay for emergency department visits of a semi-urgent or urgent nature is approximately 6 hours. However, some of these visits extend to overnight stays with an average duration of 2 days.

Compiling the data on daily hospital costs and duration of admission provides low and high estimates for each admission associated with the morbidity health endpoints, as set out in **Table G8**.

Table G8: Estimated hospitalisation costs for morbidity health endpoints

Health Endpoint	Duration of admission (days)		Cost per admission ($)	
	Low	High	Low	High
Respiratory	2.5	5	3,450	6,900
Cardiovascular	2.1	5.1	2,898	7,038
Cardiac including cardiac failure	3.9	8.3	5,382	11,454
Acute bronchitis & pneumonia	4.2	8	5,796	11,040
Asthma	0.25	2	345	2,760

Lost productivity

Lost productivity is estimated based on costs of work days lost due to hospitalisation and emergency visits, based on ABS average weekly earnings data. Average daily earnings for all employees (fulltime and part time) are estimated at $151/ day (averaged over a 7 day week). Assuming lost earnings apply for the same duration as hospital admissions and that lost work days will only apply to admissions in the 15-64 age category, **Table G9** gives the following estimates of costs associated with lost work days for different health end points.

Table G9: Estimated costs lost productivity for morbidity health endpoints

Health Endpoint	Work days lost		Cost of endpoint ($)	
	Low	High	Low	High
Respiratory	2.5	5	378	755
Cardiovascular	1.7	2.4	317	770
Cardiac including cardiac failure	3.9	8.3	589	1,253
Acute bronchitis & pneumonia	1.5	3.9	634	1,208
Asthma	0	0	-	-

Total admission costs

The various costs for the three health endpoints were combined to give the cost estimates per hospital/ emergency department admission in **Table G10**. Note that for outcomes specific to the under 15 and/or 65+ age groups there is assumed to be no cost from work days lost and for cardiac including cardiac failure a straight average of estimated cost of work days lost (applicable to working age population) and nil (applicable to non-working age population) is assumed.

The low and high respiratory, cardiovascular, cardiac and bronchitis estimates presented here lie in the low to mid points of ranges of estimates provided in the preliminary CBA **(Wilson *et al.*, 2011b)** and the methodology for valuing health impacts of particle emissions undertaken recently for the NSW EPA

(Aust *et al.* 2013) [52]. The asthma attack estimates presented here are significantly greater than those provided in the preliminary CBA, noting however that the estimates presented here relate only to emergency department visits, whereas the estimates in the preliminary CBA are for all asthma attacks. A midpoint of the low and high estimates is proposed as the central estimate of morbidity costs for use in the economic analysis.

Table G10: Estimated total costs for morbidity health endpoints

Health Endpoint	Total cost		
	Low	High	Median (applied in economic analysis)
Asthma (emergency)	351	3,124	1,738
Cardiovascular (65+)	3,194	7,757	5,475
Cardiac including cardiac failure	6,226	14,676	9,991
Respiratory (<15, 65+)	3,775	7,549	5,662
Respiratory (15 - 64)	4,152	8,304	6,228
Acute bronchitis (65+)	6,235	13,403	9,819

52 Noting an earlier comment that the length of stay for hospital admissions used here are significantly less than data from the United Kingdom used in the other studies.

Appendix H CONCENTRATION PROFILES WITH AND WITHOUT ABATEMENT (ALL FEASIBLE)

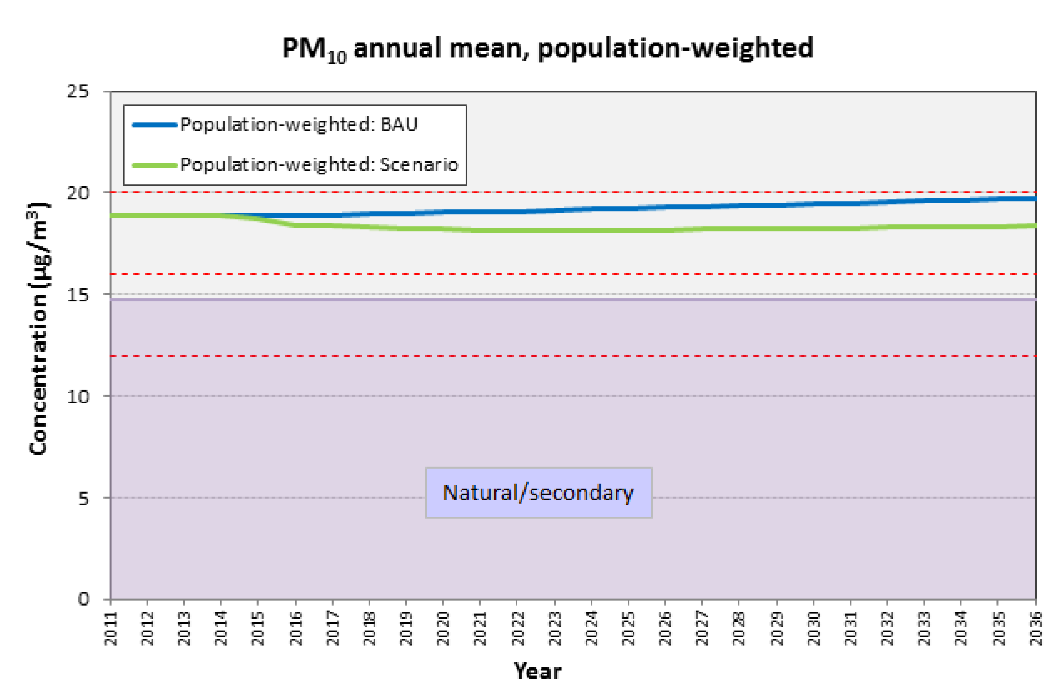


Figure H1: Projections of population-weighted PM_{10} concentrations in NSW (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

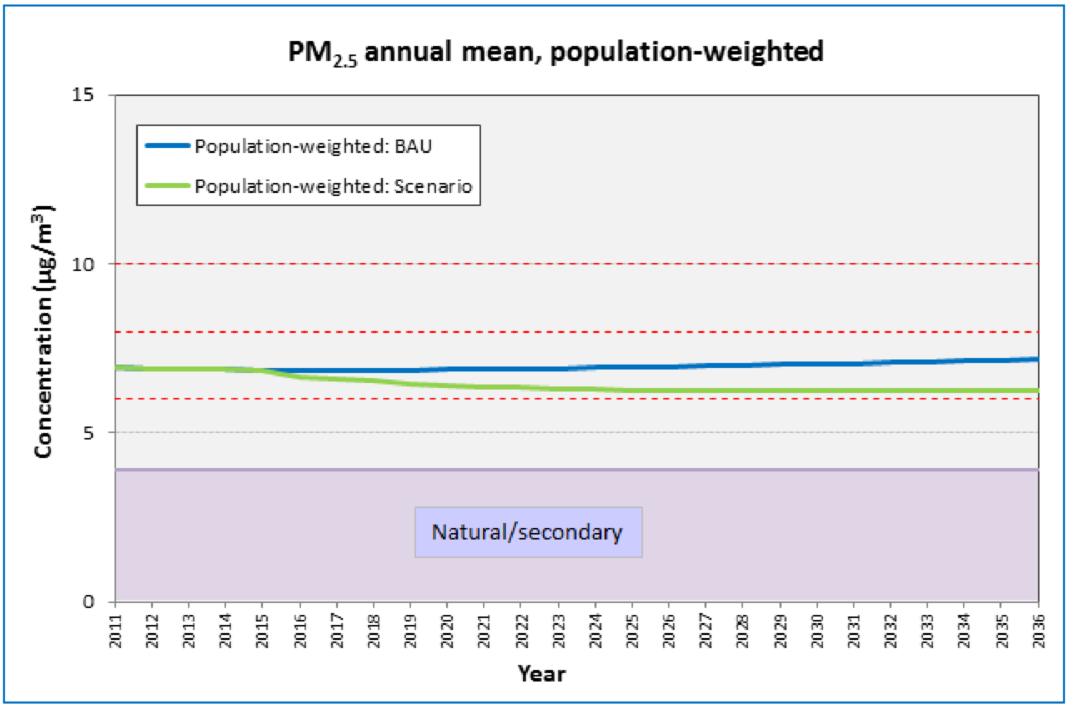


Figure H2: Projections of population-weighted $PM_{2.5}$ concentrations in NSW (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

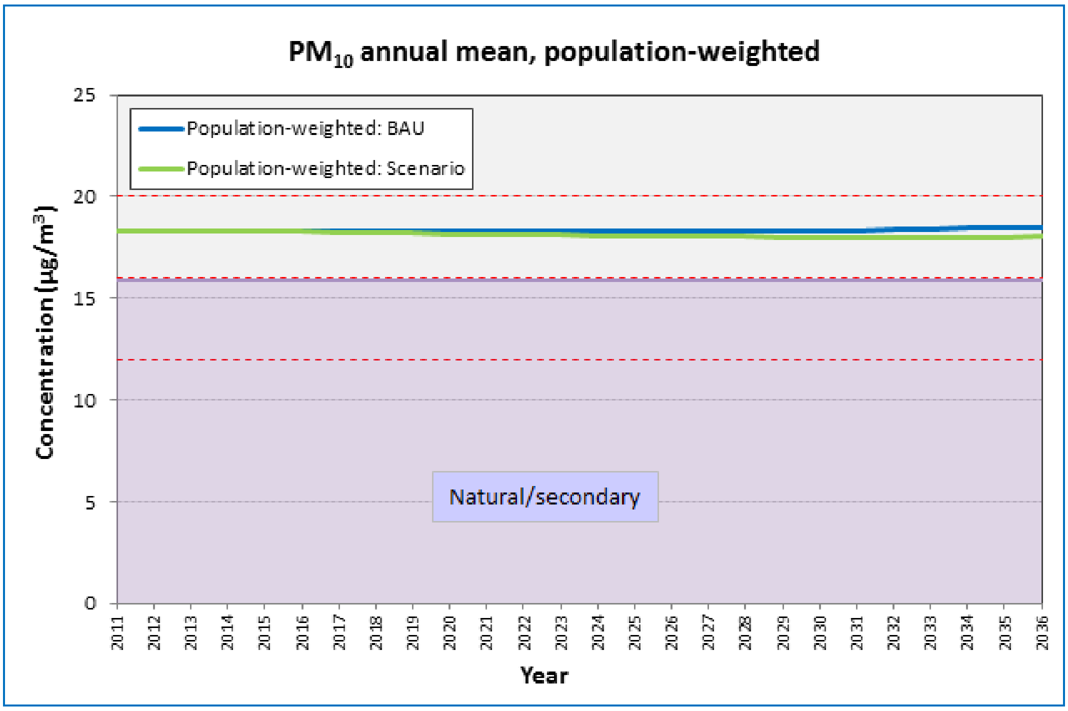


Figure H3: Projections of population-weighted PM_{10} concentrations in Victoria (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

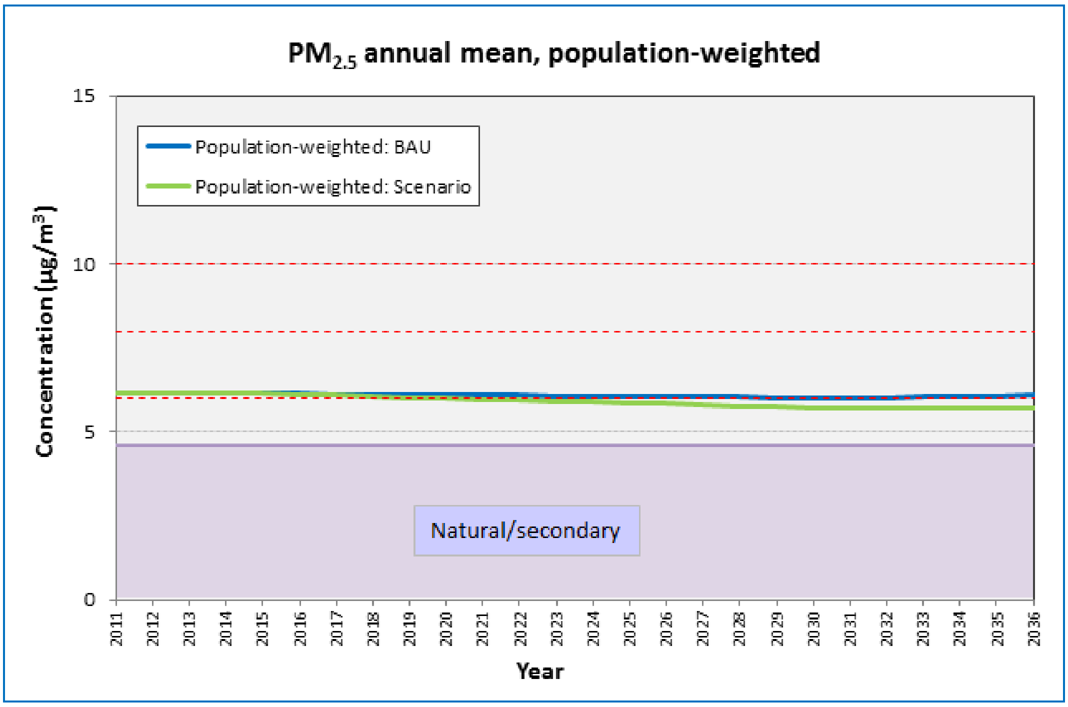


Figure H4: Projections of population-weighted $PM_{2.5}$ concentrations in Victoria (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

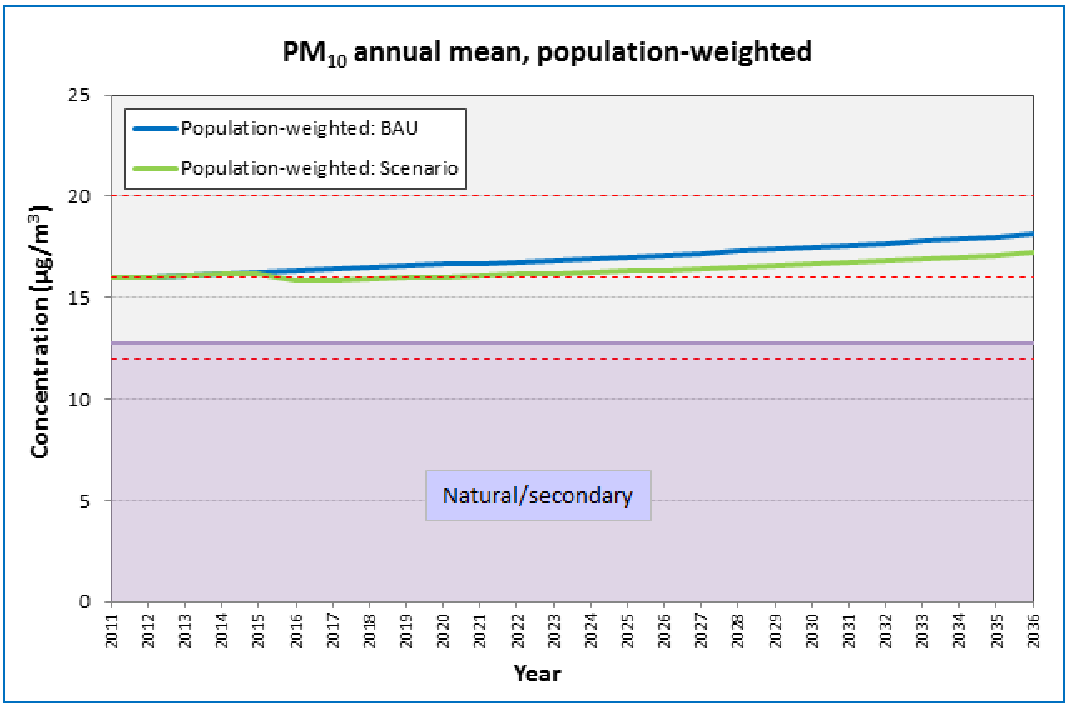


Figure H5: Projections of population-weighted PM_{10} concentrations in Queensland (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

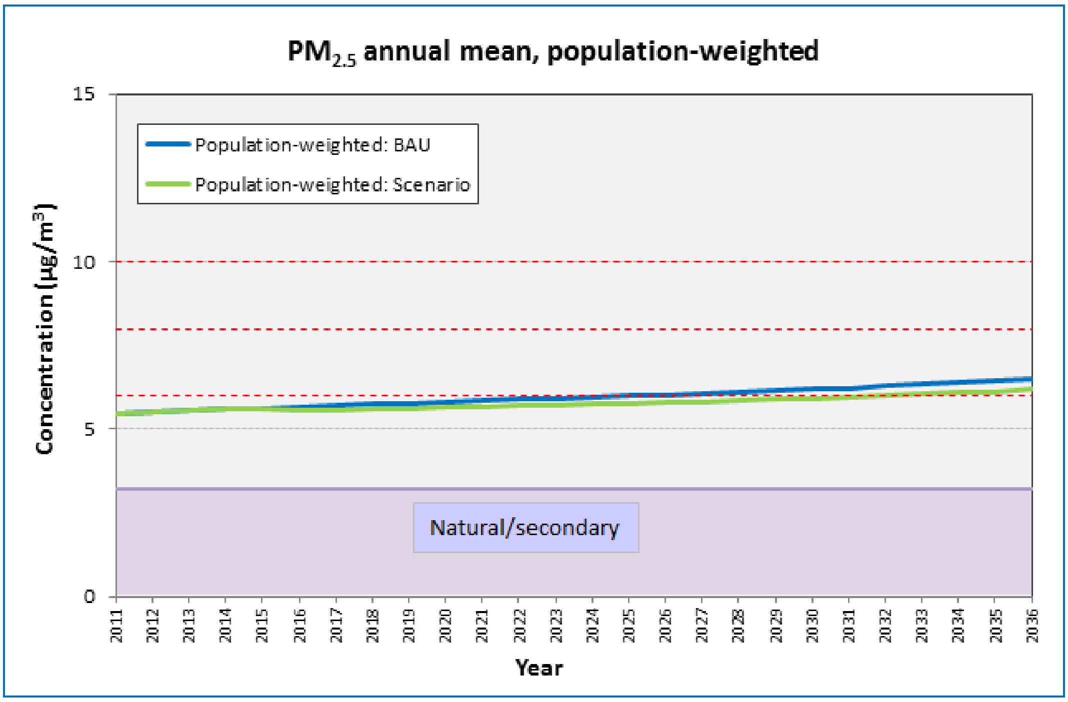


Figure H6: Projections of population-weighted $PM_{2.5}$ concentrations in Queensland (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

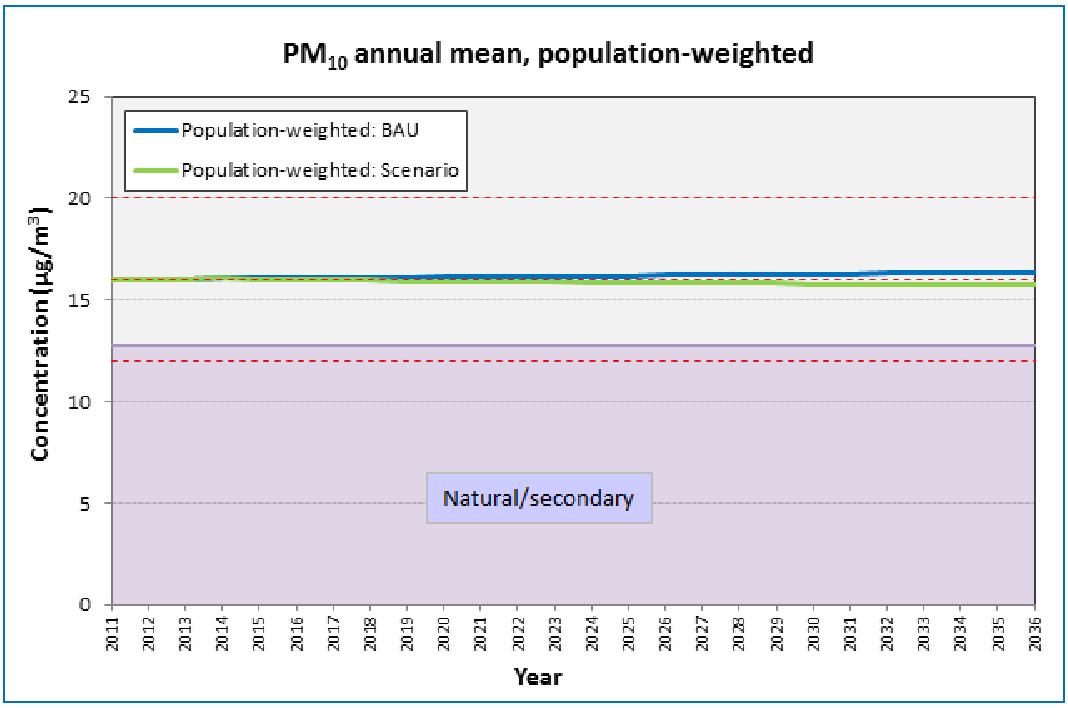


Figure H7: Projections of population-weighted PM_{10} concentrations in South Australia (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

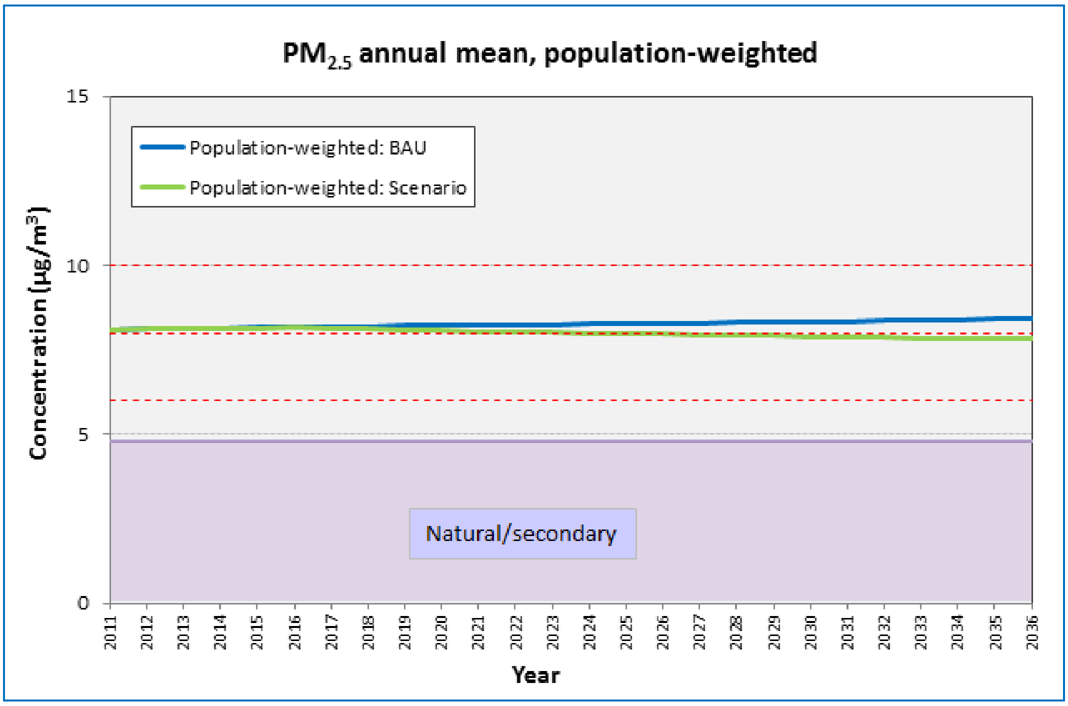


Figure H8: Projections of population-weighted $PM_{2.5}$ concentrations in South Australia (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

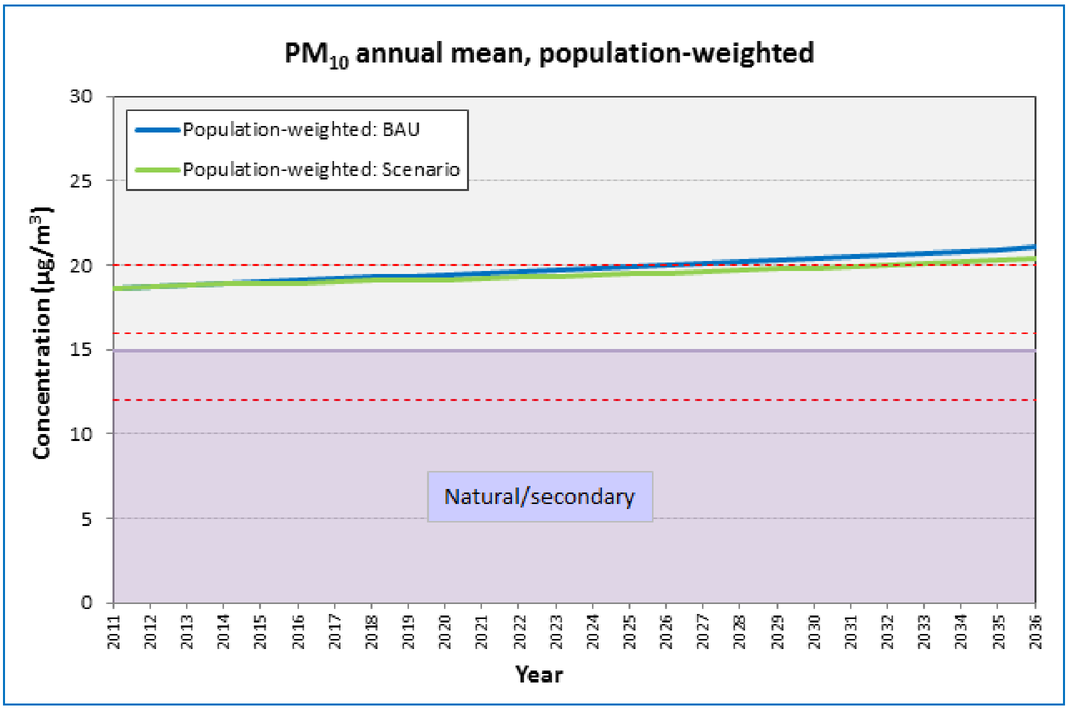


Figure H9: Projections of population-weighted PM_{10} concentrations in Western Australia (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

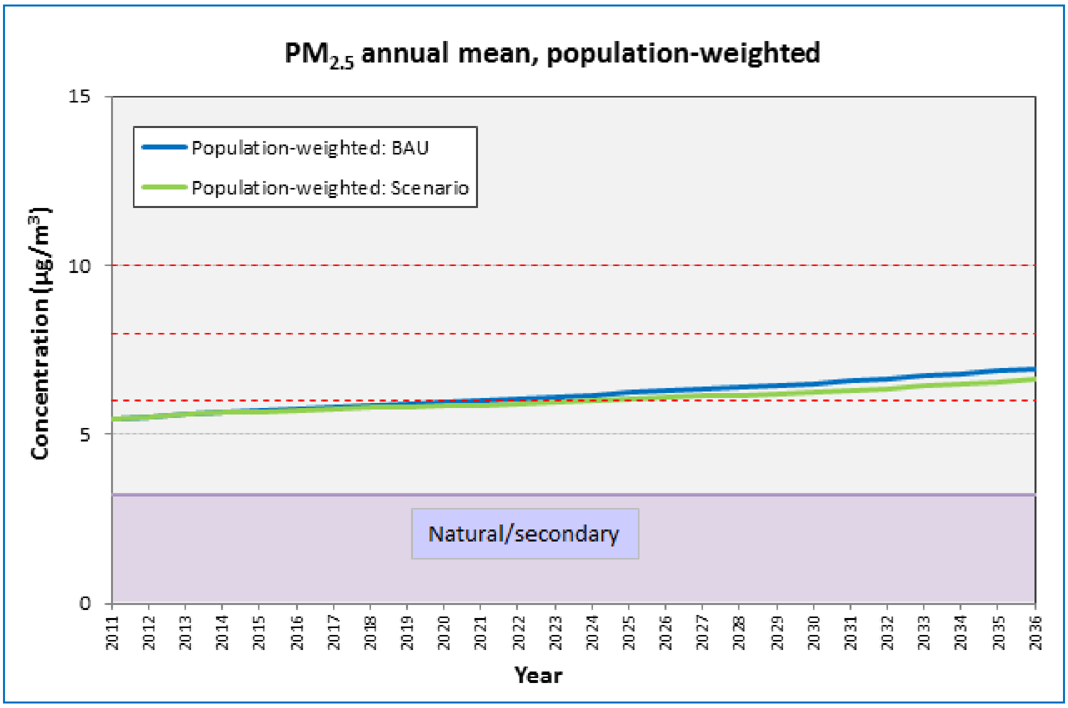


Figure H10: Projections of population-weighted $PM_{2.5}$ concentrations in Western Australia (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

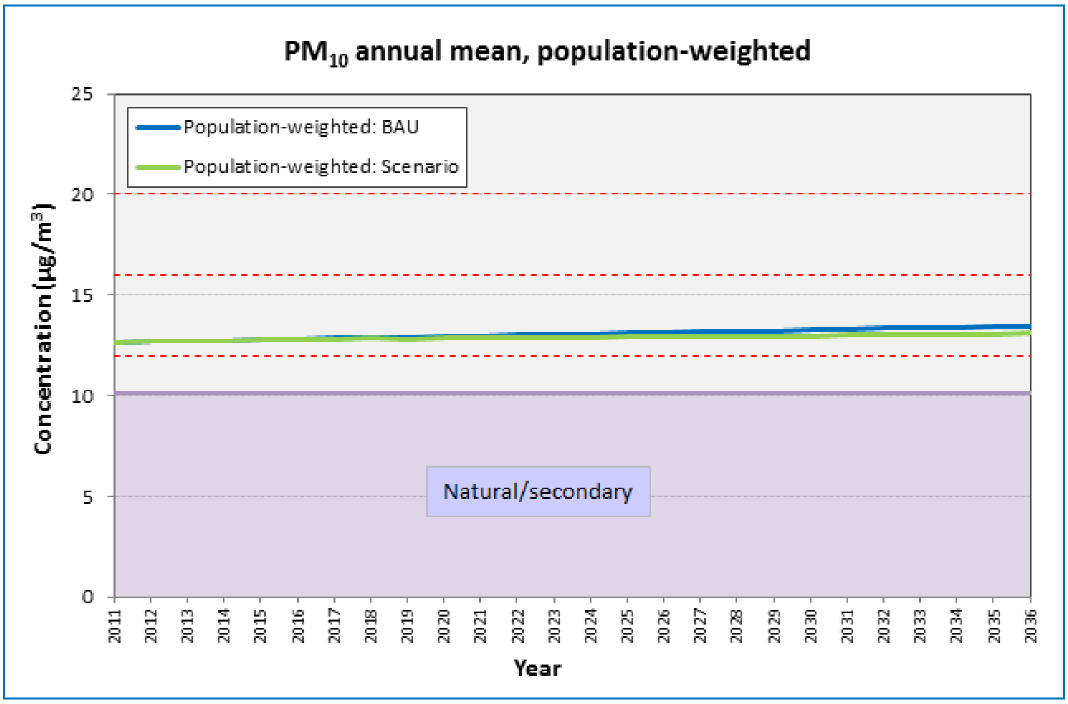


Figure H11: Projections of population-weighted PM_{10} concentrations in Tasmania (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

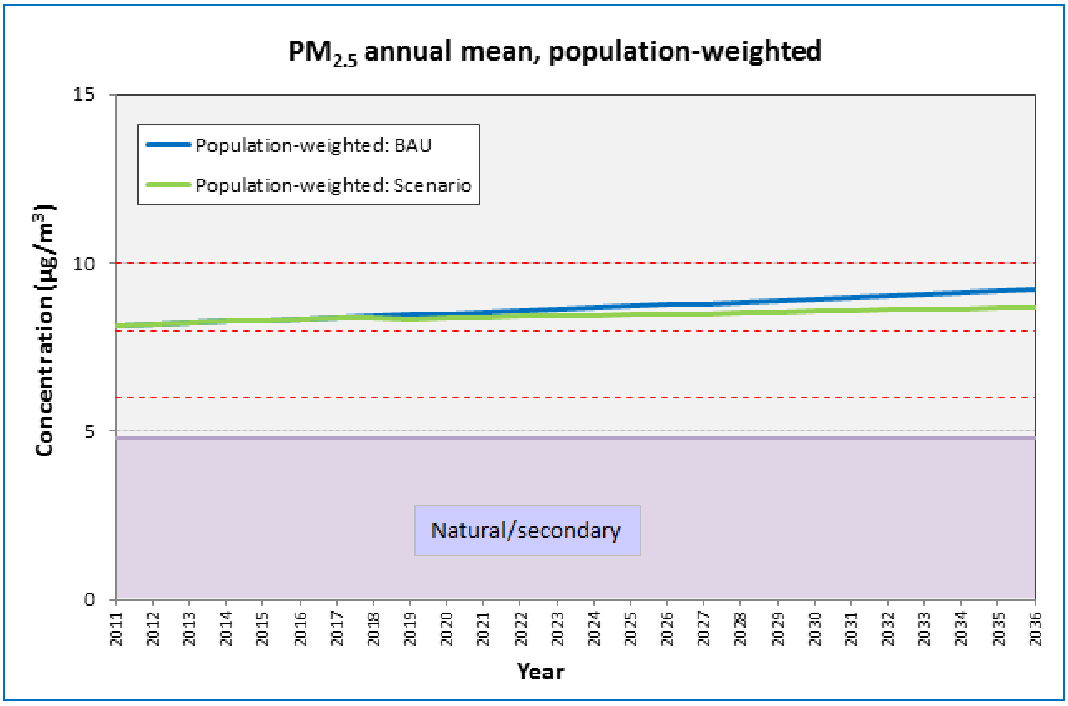


Figure H12: Projections of population-weighted $PM_{2.5}$ concentrations in Tasmania (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

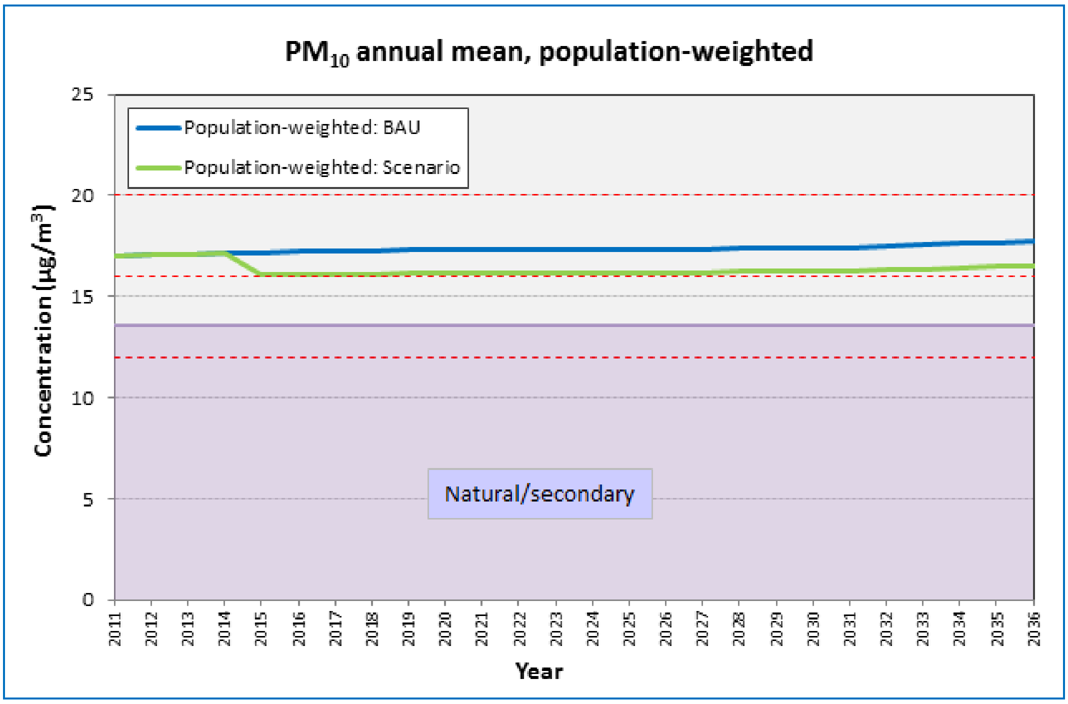


Figure H13: Projections of population-weighted PM_{10} concentrations in Northern Territory (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

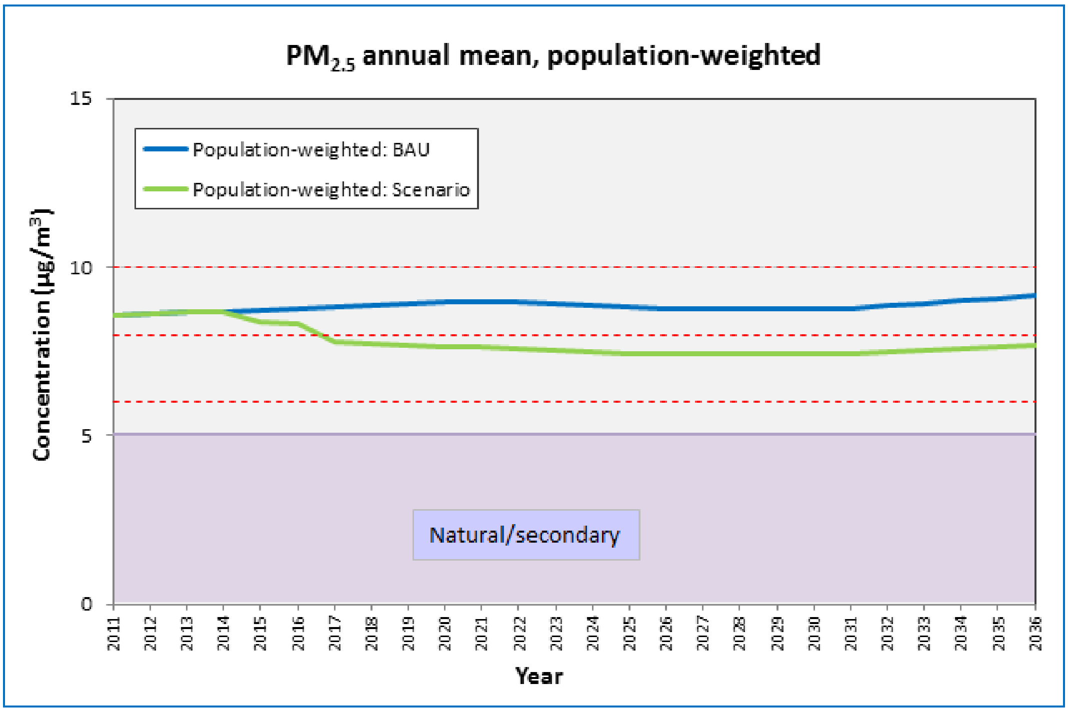


Figure H14: Projections of population-weighted $PM_{2.5}$ concentrations in Northern Territory (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

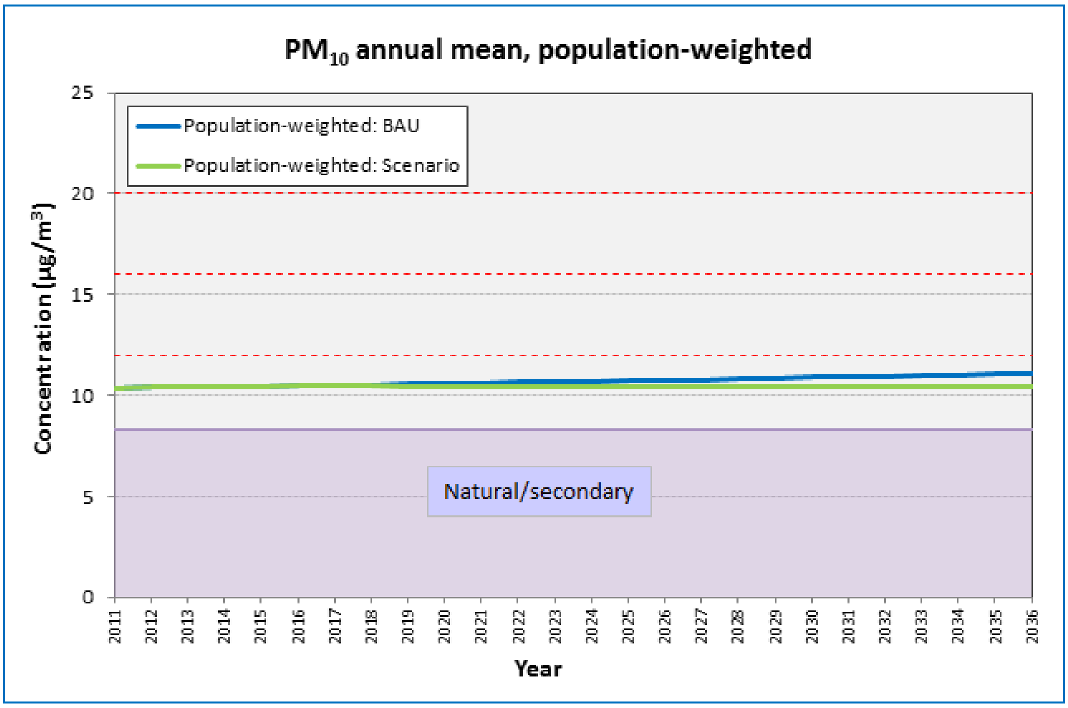


Figure H15: Projections of population-weighted PM_{10} concentrations in ACT (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

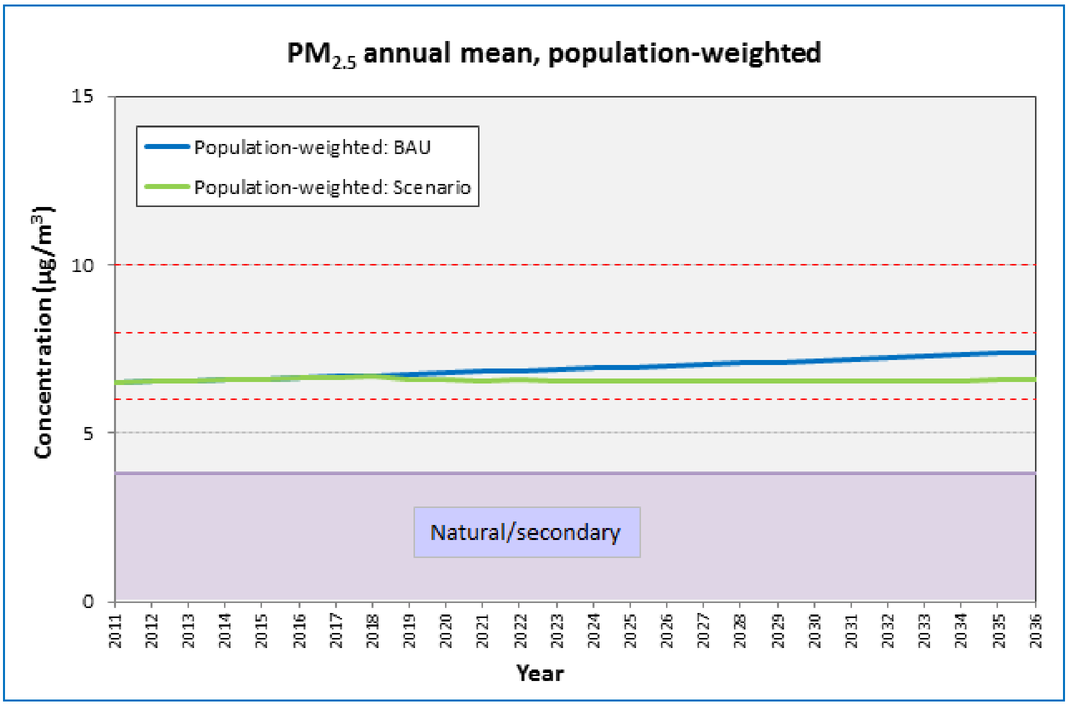


Figure H16: Projections of population-weighted $PM_{2.5}$ concentrations in ACT (scenario = all feasible abatement measures, red dashed lines = air quality standards, purple line = natural/secondary component)

Appendix I SENSITIVITY ANALYSIS

I.1 OVERVIEW

Five types of sensitivity analysis were performed in order to test how the results would vary based on alternative sets of assumptions. Specifically, we tested the sensitivity of the results to the following:

- The cost and emissions assumptions for the abatement measures.
- The discount rate.
- The assumptions relating to growth in emissions under the BAU scenario (Western Australia was used as a representative example of a jurisdiction with higher growth).
- The assumption relating to the value of life years saved.
- The method used to monetise the benefit of emission reductions.

The rationale for, and results of, these sensitivity tests are presented below.

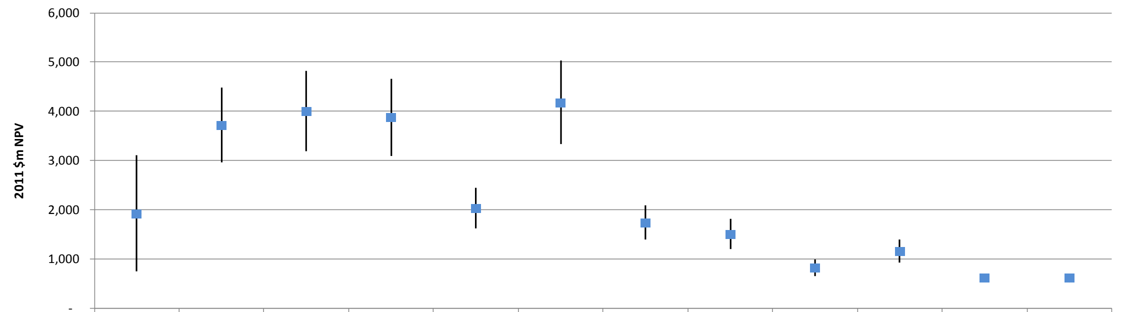
I.2 SENSITIVITY OF RESULTS TO COST AND EMISSIONS ASSUMPTIONS

I.2.1 Purpose of sensitivity test

The analysis of abatement measures drew from a wide variety of existing studies and additional research. The underlying studies varied in their degree of detail, and specificity in relation to the abatement options that were ultimately modelled for the economic analysis. Therefore, we selected different sensitivity ranges for each individual abatement measure to reflect the degree of confidence in the central assumptions (outlined in **Chapter 4**). These sensitivity assumptions provided a range, from the most pessimistic or 'lower bound' assumptions for costs, emissions and co-benefits to the most optimistic or 'upper bound'. Generally, we had a higher level of confidence in the assumptions relating to the measures for which previous CBAs have been conducted (*i.e.* all of the 'existing' measures), or where data from a current programme were provided (*e.g.* adoption of best practice dust controls at coal mines).

I.2.2 Results

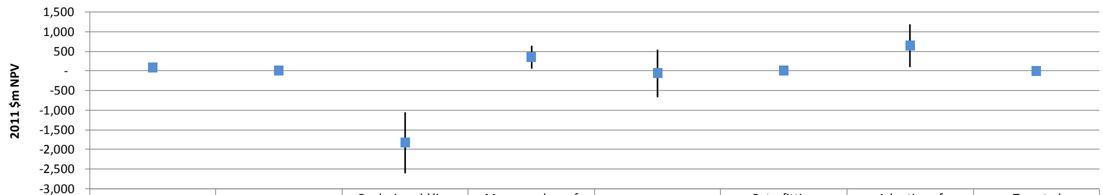
Figure I1 shows the sensitivity of the NPV for existing measures to the assumptions for cost and emissions. All of the existing measures maintain a positive NPV across the sensitivity range, with wood heater measures generally having the highest NPVs in the central case.



	Non-road diesel standards	W.heaters 60% efficiency, 3g/kg	W.heaters 60% efficiency, 3g/kg and in-service	W.heaters 65% efficiency, 3g/kg and in-service	W.heaters labelling, star-rating, education, audit and 60% efficiency	W.heaters 60% efficiency, 1.5g/kg and in-service measures	W.heaters labelling, star-rating, education and audit	W.heaters labelling, education and audit	W.heaters national audits and education	W.heaters national audits, education and replacement initiatives	Non-road spark ignition engine standards - Phased	Non-road spark ignition engine standards
Upper Bound	3,102	4,474	4,813	4,663	2,439	5,028	2,097	1,806	994	1,399	701	699
Lower Bound	750	2,970	3,188	3,089	1,615	3,328	1,387	1,194	655	919	539	534
Central	1,922	3,722	4,001	3,876	2,027	4,178	1,742	1,500	825	1,159	620	616

Figure I1: Sensitivity of NPV for existing measures to cost and emissions assumptions

The sensitivity of the NPV for additional measures to the assumptions for cost and emissions is provided in **Figure I2**. The sign of the NPV of some additional measures changes depending on the sensitivity setting. Under the lower-bound assumptions, requiring new locomotives to meet US Tier 4 standards has a negative NPV, whereas the measure has a positive NPV under the central settings. Compared with most other measures, diesel trains have a higher proportion of emissions in non-urban areas with low population density, leading to a marginally positive NPV under the central assumptions. Under the lower-bound assumptions, where costs are assumed to be high and emission reductions low, the costs exceed the benefits. Under the upper-bound assumptions, mandatory low-sulfur fuel use by ships while at berth and targeted maintenance of high-polluting LCVs using remote sensing have positive NPVs, whereas this is not expected to be the case under central assumptions. The measures have relatively low cost-effectiveness. However, if cost-effectiveness is higher than expected, the benefits of implementation could exceed the costs.



	Diesel trains driver assistance software for line haul locomotives	Requiring new locomotives to meet US Tier 4 standards	Replacing old line locomotive and requiring new locomotives to meet US Tier 4 standards	Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	Mandatory low sulfur fuel use by ships while at berth	Retrofitting high-polluting (urban) diesel engines equipment with particle filters	Adoption of international best practice PM control measures at coal mines	Targeted maintenance of high polluting Light Commercial Vehicles using remote sensing
Upper Bound	106	95	-1,061	640	554	14	1,196	1
Lower Bound	54	-93	-2,609	62	-677	3	91	-2
Central	80	1	-1,835	352	-61	6	643	-1

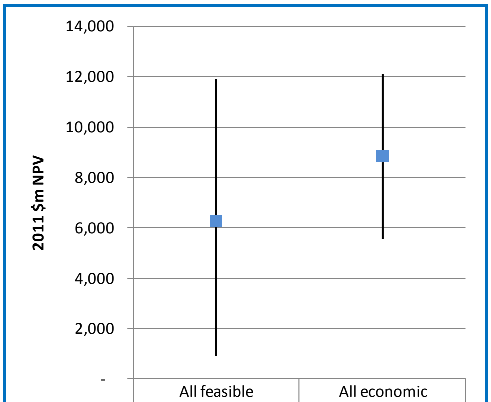
Figure I2: Sensitivity of NPV for additional measures to cost and emissions assumptions

Figure I3 shows the sensitivity of the NPV for other measures to the assumptions for cost and emissions. Similarly, under the upper-bound assumptions diesel retrofit at mine sites and the penalty and incentive scheme for high-polluting vehicles have positive NPVs. This is not expected to be the case under the central assumptions because there is a lower population benefiting from mine-site retrofits and a penalty and incentive scheme has relative low cost-effectiveness. However, if the cost-effectiveness of both is higher than in the central case then the benefits of implementation would exceed the costs.

	Diesel retrofit at mine sites (emissions reduction program)	Penalty and incentive scheme for high polluting vehicles	Area-wide planting to remove PM from the atmosphere	Regulating moisture content of wood fuel to be less than 20%	Requiring woodheaters to be removed or rendered inoperable on sale of house
Upper Bound	489	4	-101	1,241	12,685
Lower Bound	-520	-23	-918	827	8,438
Central	-145	-9	-510	1,034	10,563

Figure I3: Sensitivity of NPV for other measures to cost and emissions assumptions

The sensitivity tests for the 'all feasible measures' and 'all economic measures' portfolios to cost and emissions assumptions are shown in **Figure I4**. The two portfolios constructed for the economic analysis maintain positive NPVs across the cost and emission sensitivity ranges, This is also the case for compliance with air quality standards (**Table I1**).



	All feasible	All economic
Upper Bound	11,927	12,121
Lower Bound	899	5,556
Central	6,271	8,834

Figure I4: Sensitivity of NPVs for 'all feasible and 'all economic' portfolios to cost and emissions assumptions

Table I1: Net benefit of compliance with air quality standards (sensitivity to cost and emissions assumptions)

Pollutant	Averaging period and metric	Concentration (µg/m³)	Central NPV (2011 $m)	Upper Bound NPV (2011 $m)	Lower Bound NPV (2011 $m)
PM_{10}	1 year	20.0	**$6,389**	**$12,045**	**$1,017**
		16.0	Not feasible to meet through primarily national measures		
		12.0	Not possible to meet due to natural/secondary PM component		
$PM_{2.5}$	1 year	10.0	Already met in BAU		
		8.0	**$6,464**	**$12,120**	**$1,092**
		6.0	Not feasible to meet through primarily national measures		
PM_{10}	24 hours (6th highest value)	50.0	Already met in BAU		
		40.0	**$6,616**	**$12,272**	**$1,244**
		30.0	Not possible to meet due to natural/secondary PM component		
$PM_{2.5}$	24 hours (98th percentile)	25.0	**$6,940**	**$12,596**	**$1,568**
		20.0	Not feasible to meet through primarily national measures		
		15.0	Not possible to meet due to natural/secondary PM component		

The emissions gap calculated under the central case was applied for both the lower-bound and upper-bound cases. Whilst emissions reduction are expected to be lower/higher in the lower/upper-bound cases, the response to air quality standards (and therefore the gap to be bridged) is modelled on the basis of expected emissions reductions.

It should be stated that the pessimistic lower-bound scenario is extreme, in that it is assumed that all measures have higher costs and lower emission reductions than assumed under the central scenario. In reality, it is unlikely that following implementation the performance for all measures in a diverse portfolio will be lower than anticipated; it is more likely that some measures will perform worse than expected while others will perform better.

Consistent with the portfolio theory, this result provides an argument for selecting a diverse portfolio, where the underperformance of individual measures can be offset by better than anticipated performance from others, thus reducing economic risk as well as the risk of not meeting mandated air quality standards.

I.3 SENSITIVITY OF RESULTS TO DISCOUNT RATE

I.3.1 Purpose of sensitivity test

The discount rate in a CBA accounts for time preference of costs and benefits. For example, assuming a 7% discount rate, a $1 million cost today is equivalent in a CBA to a $1.4 million cost in five years' time, as it is assumed that if the cost was deferred by five years then the interest that could have been earned by investing that $1m (often referred to as the opportunity cost of capital) would be $0.4 million. The choice of a discount rate is important for the analysis of options where the time profile of costs is different to that for benefits. The Office of Best Practice Regulation **(Australian Government, 2010)** requires using a 7% discount rate and recommends a sensitivity range of 3% to 10%.

I.3.2 Results

The sensitivity tests for the 'all feasible measures' and 'all economic measures' portfolios to the discount rate assumptions are shown in **Figure I5**. The two portfolios maintain positive NPVs over the discount rate sensitivity range. The NPV of compliance with air quality standards also remains positive within the discount rate sensitivity range (**Table I2**).

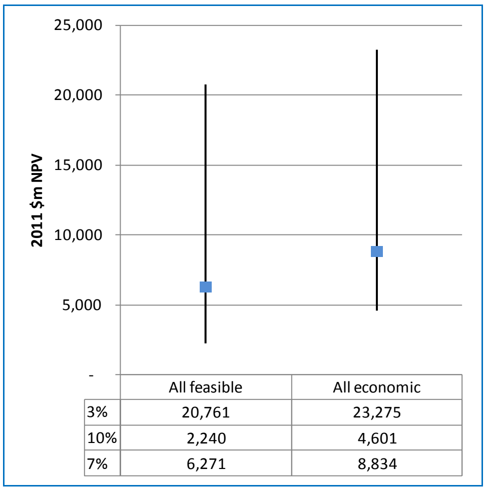


Figure I5: Sensitivity of 'all feasible and 'all economic' portfolio NPVs to discount rate assumption

Table I2: Net benefit of compliance with air quality standards (sensitivity to discount rate assumptions)

Pollutant	Averaging period and metric	Concentration (µg/m³)	7% discount rate NPV (2011 $m)	3% discount rate NPV (2011 $m)	10% discount rate NPV (2011 $m)
PM_{10}	1 year	20.0	**$6,389**	**$32,978**	**$6,444**
		16.0	Not feasible to meet through primarily national measures		
		12.0	Not possible to meet due to natural/secondary PM component		
$PM_{2.5}$	1 year	10.0	Already met in BAU		
		8.0	**$6,464**	**$33,107**	**$6,496**
		6.0	Not feasible to meet through primarily national measures		
PM_{10}	24 hours (6th highest value)	50.0	Already met in BAU		
		40.0	**$6,616**	**$33,374**	**$6,599**
		30.0	Not possible to meet due to natural/secondary PM component		
$PM_{2.5}$	24 hours (98th percentile)	25.0	**$6,940**	**$33,949**	**$6,820**
		20.0	Not feasible to meet through primarily national measures		
		15.0	Not possible to meet due to natural/secondary PM component		

I.4 SENSITIVITY OF RESULTS TO GROWTH RATE FOR INDUSTRY IN WESTERN AUSTRALIA

I.4.1 Purpose of sensitivity test

The gap analysis in **Chapter 6** indicted that overall compliance with some of the hypothetical air quality standards in Australia was influenced by whether they could be achieved in Western Australia. In the Perth airshed inventory, emissions are strongly influenced by the industrial sector (see **Chapter 3**), and the results were sensitive to the assumed growth rate in emissions from this sector between 2011 and 2036. An examination of the data from the NPI showed that the activity in the airshed that is responsible for the bulk of $PM_{2.5}$ emission is electricity generation. In the central estimate we therefore assumed that industrial emissions would grow in line with population, using an average annual growth rate of 2.3% **(ABS, 2008)**. The sensitivity of the results for Western Australia to this assumption was examined using the more pessimistic assumption that industrial emissions would increase in line with historical growth in the manufacturing sector (3.7%) per year. For the optimistic case we used a growth rate for industry of 0.8% (based on symmetry around the central estimate).

I.4.2 Results

The results of the sensitivity test are given in **Table I3**. The assumed growth in the BAU emission estimates for Western Australia has a minor impact on the NPVs. This is because it only affects the scale of gap measures required. NPVs are higher under higher growth assumptions, since a larger emissions gap provides greater impetus to implement cost-effective abatement measures. The NPVs for the 24-hour standards of 40 µg/m³ for PM_{10} and 25 µg/m³ for $PM_{2.5}$, and annual standard of 8 µg/m³ for $PM_{2.5}$, are unaffected, as gap measures are only required in Tasmania.

Table I3: Net benefit of compliance with air quality standards (sensitivity to WA growth assumption)

Pollutant	Averaging period and metric	Concentration (µg/m³)	2.3% growth NPV (2011 $m)	3.7% growth NPV (2011 $m)	0.8% growth NPV (2011 $m)
PM_{10}	1 year	20.0	**$6,389**	**$6,726**	**$6,271**
		16.0	Not feasible to meet through primarily national measures		
		12.0	Not possible to meet due to natural/secondary PM component		
$PM_{2.5}$	1 year	10.0	Already met in BAU		
		8.0	**$6,464**	**$6,464**	**$6,464**
		6.0	Not feasible to meet through primarily national measures		
PM_{10}	24 hours (6th highest value)	50.0	Already met in BAU		
		40.0	**$6,616**	**$6,616**	**$6,616**
		30.0	Not possible to meet due to natural/secondary PM component		
$PM_{2.5}$	24 hours (98th percentile)	25.0	**$6,940**	**$6,940**	**$6,940**
		20.0	Not feasible to meet through primarily national measures		
		15.0	Not possible to meet due to natural/secondary PM component		

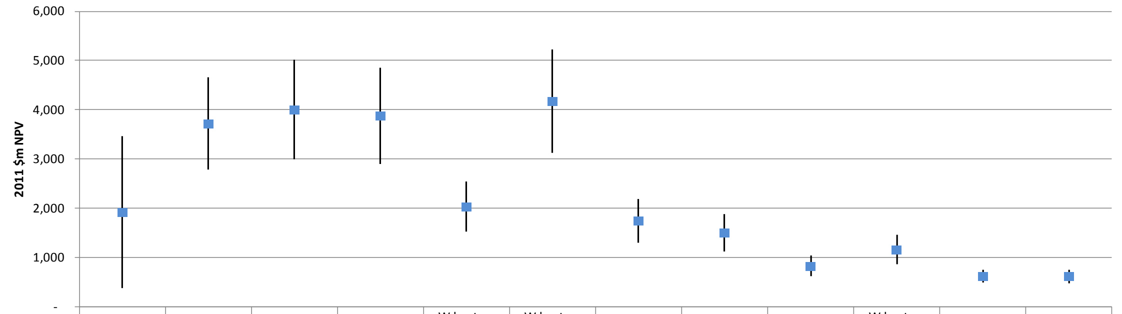
I.5 SENSITIVITY OF RESULTS TO VALUE OF LIFE YEAR

I.5.1 Purpose of sensitivity test

ASCC (2008) recommended a range of values for mortality benefits. This range ($3.7 million to $8.1 million, with a central estimate of $6.0 million (in 2006 dollars) for VSL) reflects a wide variability of estimates from the meta-analysis of studies. This translates to a VOLY (ultimately used in the damage cost approach) of $178,211 to $390,138 with a central estimate of $288,991 (this is consistent with **Aust *et al.* (2013)**). This range has been applied to the 'all economic measures' and 'all feasible measures' portfolios, and is relatively wide due to the diversity of studies used in the meta-analyses. A range of +/- 25% was applied for individual measures. It should be noted that the range of population density in Australia was taken into account in all benefit calculations through the use of the damage cost method. The VOLY itself is independent of population density.

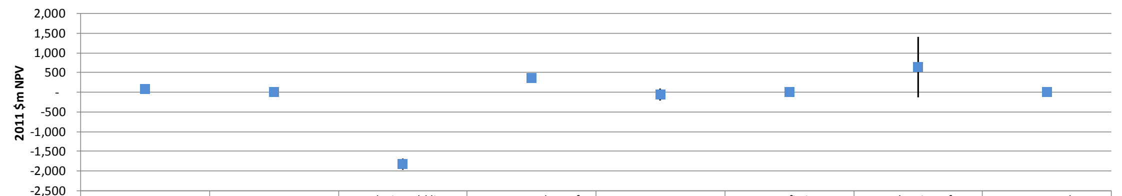
I.5.2 Results

The sensitivity results for individual measures are shown in **Figure I6** to **Figure I8**. Measures with positive (or negative) NPVs maintain positive (or negative) NPVs throughout the sensitivity range with the exception of coal dust measures at coal mines (becomes marginally negative) and US Tier 4 standards for new diesel trains.



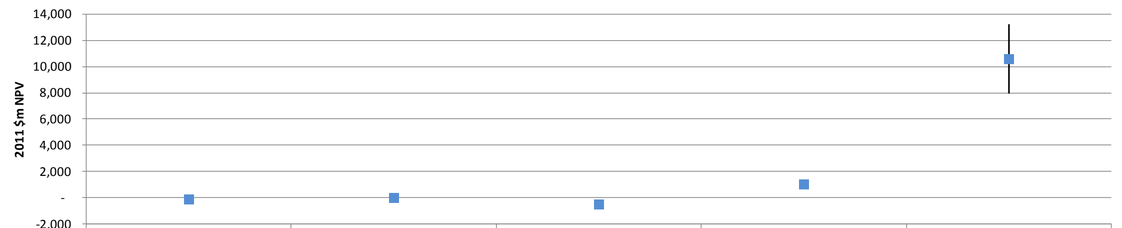
	Non-road diesel standards	W.heaters 60% efficiency, 3g/kg	W.heaters 60% efficiency, 3g/kg and in-service	W.heaters 65% efficiency, 3g/kg and in-service	W.heaters labelling, star-rating, education, audit and 60% efficiency	W.heaters 60% efficiency, 1.5g/kg and in-service measures	W.heaters labelling, star-rating, education and audit	W.heaters labelling, education and audit	W.heaters national audits and education	W.heaters national audits, education and replacement initiatives	Non-road spark ignition engine standards - Phased	Non-road spark ignition engine standards
High VOLY	3,470	4,657	5,008	4,852	2,538	5,232	2,181	1,879	1,034	1,454	755	753
Low VOLY	375	2,787	2,993	2,899	1,516	3,124	1,302	1,121	616	864	485	480
Central	1,922	3,722	4,001	3,876	2,027	4,178	1,742	1,500	825	1,159	620	616

Figure I6: Sensitivity of NPV for existing measures to VOLY assumption



	Diesel trains driver assistance software for line haul locomotives	Requiring new locomotives to meet US Tier 4 standards	Replacing old line locomotive and requiring new locomotives to meet US Tier 4 standards	Memorandum of Understand (MOU) to reduce shipping vessel speed for ocean transits	Mandatory low sulfur fuel use by ships while at berth	Retrofitting high-polluting (urban) diesel engines equipment with particle filters	Adoption of international best practice PM control measures at coal mines	Targeted maintenance of high polluting Light Commercial Vehicles using remote sensing
High VOLY	106	61	-1,695	468	85	9	1,414	-0
Low VOLY	55	-58	-1,975	236	-208	4	-128	-1
Central	80	1	-1,835	352	-61	6	643	-1

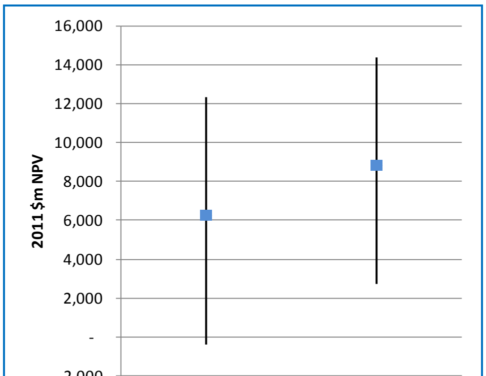
Figure I7: Sensitivity of NPV for additional measures to VOLY assumption



	Diesel retrofit at mine sites (emissions reduction program)	Penalty and incentive scheme for high polluting vehicles	Area-wide planting to remove PM from the atmosphere	Regulating moisture content of wood fuel to be less than 20%	Requiring woodheaters to be removed or rendered inoperable on sale of house
High VOLY	-37	-7	-481	1,293	13,210
Low VOLY	-253	-12	-538	775	7,916
Central	-145	-9	-510	1,034	10,563

Figure I8: Sensitivity of NPV for other measures to VOLY assumption

The sensitivity tests for the 'all feasible measures' and 'all economic measures' portfolios to the VOLY assumptions are shown in **Figure I9**. The all economic portfolio maintains positive NPVs over the sensitivity range. However, the all feasible scenario is marginally negative. It should however be noted that the all feasible portfolio used represents the lower end of NPV benefits as it incorporates some measures which are not economic. Measures considered in the Report were assessed on the basis that they may potentially benefit from a national approach or framework. However, the impact of population and emissions growth over the period to 2036 has meant some notional non-economic measures have necessarily been included to assess hypothetical standards. In practice such measures are unlikely to progress.



	All feasible	All economic
High VOLY	12,343	14,393
Low VOLY	-379	2,745
Central	6,271	8,834

Figure I9: Sensitivity of 'all feasible and 'all economic' portfolio NPVs to VOLY assumption

As a consequence, the NPV of compliance with air quality standards is estimated using the 'all economic' portfolio, with additional state-based measures (where these are expected to be economic) adopted (**Table I4**) based on existing Australian air pollution abatement studies. The state-based measures for the all economic case were the same as for the all feasible case (just of a higher magnitude). The state-based measures were industrial emission limits (Western Australia) and extended wood heater measures (Tasmania and ACT).

Table I4: Net benefit of compliance with air quality standards (sensitivity to VOLY assumption and using all economic portfolio)

Pollutant	Averaging period and metric	Concentration (µg/m³)	Central VOLY NPV (2011 $m)	High VOLY NPV (2011 $m)	Low VOLY NPV (2011 $m)
PM_{10}	1 year	20.0	**$8,952**	**$14,570**	**$2,799**
		16.0	Not feasible to meet through primarily national measures		
		12.0	Not possible to meet due to natural/secondary PM component		
$PM_{2.5}$	1 year	10.0	Already met in BAU		
		8.0	**$9,027**	**$14,657**	**$2,861**
		6.0	Not feasible to meet through primarily national measures		
PM_{10}	24 hours (6th highest value)	50.0	Already met in BAU		
		40.0	**$9,178**	**$14,864**	**$2,951**
		30.0	Not possible to meet due to natural/secondary PM component		
$PM_{2.5}$	24 hours (98th percentile)	25.0	**$9,510**	**$15,315**	**$3,152**
		20.0	Not feasible to meet through primarily national measures		
		15.0	Not possible to meet due to natural/secondary PM component		

I.6 SENSITIVITY OF RESULTS TO MONETISATION METHOD

I.6.1 Purpose of sensitivity test

The impact pathway approach resulted in health benefit estimates that were approximately 1.5 times higher than those for the damage cost approach (see **Appendix G**) applied in this Report. This comparison was only performed for selected locations. To estimate the effect of potentially higher health benefits a multiplying factor of 1.5 was applied to the total damage cost estimates (across Australia).

I.6.2 Results

The NPVs obtained using the health benefits derived from the impact pathway approach (**Table I5**) were \$8.6-\$8.8 billion higher than those estimated by the damage cost approach.

Table I5: Net benefit of compliance with air quality standards (increasing health benefits based on impact pathway approach)

Pollutant	Averaging period and metric	Concentration (µg/m³)	NPV (2011 \$m)
PM_{10}	1 year	20.0	**\$14,964**
		16.0	Not feasible to meet through primarily national measures
		12.0	Not possible to meet due to natural/secondary PM component
$PM_{2.5}$	1 year	10.0	Already met in BAU
		8.0	**\$15,058**
		6.0	Not feasible to meet through primarily national measures
PM_{10}	24 hours (6th highest value)	50.0	Already met in BAU
		40.0	**\$15,290**
		30.0	Not possible to meet due to natural/secondary PM component
$PM_{2.5}$	24 hours (98th percentile)	25.0	**\$15,729**
		20.0	Not feasible to meet through primarily national measures
		15.0	Not possible to meet due to natural/secondary PM component