Pacific Environment

Appendix A: Air quality study

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Document control

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Contents

1 Introduction

1.1 Objectives of the air quality study

A detailed air quality study was conducted to support the Impact Statement on the pollutants sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3) in the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM). This Appendix presents the technical approach used in the air quality study, and the results obtained.

The overall aim of the air quality study was to generate the necessary air quality inputs for the health risk assessment (HRA) and cost-benefit analysis (CBA) elements of the full Impact Statement. The study considered the current air quality standards in the AAQ NEPM, as well as a number of proposed alternative (more stringent) standards. It included an assessment of pollutant concentrations and exceedances of air quality standards, with historical trends based on air quality monitoring data and future projections based on modelling for NSW and Victoria. The future projections included a 'Business-as-Usual' (BAU) scenario and an 'Abatement Package' scenario, the latter involving the implementation of a single package of emission-reduction measures.

1.2 Current and proposed air quality standards

The current and proposed AAQ NEPM standards for SO_2, NO_2 and O_3 are shown in Table 1-1, Table 1-2 and Table 1-3 respectively. The current standards are identified with light blue shading. The proposed standards were identified through a review of the international literature and regulations, including the World Health Organization (WHO) Air Quality Guidelines, the United States Environmental Protection Agency (USEPA) National Ambient Air Quality Standards (NAAQS), and the standards that have been adopted in other leading countries. The proposed standards were then endorsed for assessment by the (then) Air Thematic Oversight Group (Air TOG), comprising members from all Australian jurisdictions. Specific considerations of this literature review included the ongoing need for a standard for annual mean SO_2 (which is included in the AAQ NEPM but is not widely used internationally), and the need for a rolling-average 8-hour standard for O_3 (which is used internationally but is not in the AAQ-NEPM).

Table 1-1: Current and proposed AAQ NEPM standards (SO_2)

Pollutant	Averaging period	Concentration (ppb)	Source
SO_2	1-hour	75	Air TOG
		100	Air TOG
		150	Air TOG
		200	AAQ NEPM
	24-hour	7	Air TOG
		20	Air TOG
		40	Air TOG
		80	AAQ NEPM
	Annual	10	Air TOG
		20	AAQ NEPM

Table 1-2: Current and proposed AAQ NEPM standards (NO_2)

Pollutant	Averaging period	Concentration (ppb)	Source
NO_2	1-hour	40	Air TOG
		80	Air TOG
		97	Air TOG
		120	AAQ NEPM
	Annual	10	Air TOG
		19	Air TOG
		30	AAQ NEPM

Table 1-3: Current and proposed AAQ NEPM standards (O_3)

Pollutant	Averaging period	Concentration (ppb)	Source
O_3	1-hour	70	Air TOG
		85	Air TOG
		100	AAQ NEPM
	4-hour	60	Air TOG
		70	Air TOG
		80	AAQ NEPM
	8-hour	47	Air TOG
		55	Air TOG
		60	Air TOG
		70	Air TOG

1.3 General methodology

The following sections provide a general overview of the methodology for the air quality study. Additional methodological details are provided in the relevant sections of this Appendix.

1.3.1 Historical trends in air quality

The assessment of historical trends in pollutant concentrations and exceedances of air quality standards was based on monitoring data for the period between 2003 and 2016. This covered all the airsheds ('major cities' and other significant 'regional centres') that were considered in the HRA and for which adequate monitoring data were available. The analysis established the level of compliance[a] with the current and proposed AAQ NEPM standards in each airshed.

1.3.2 Future projections of air quality

Future projections of air quality were determined for specific years (2016, 2021, 2031 and 2040). The projections were based primarily on air quality modelling for the Greater Metropolitan Region (GMR)

[a] Where reference is made to 'compliance' in this Appendix, unless stated otherwise it refers to the comparison between measured/predicted pollutant concentrations and current/proposed air quality standards. It does not refer to the requirements of the AAQ NEPM, such as monitoring or reporting.

of NSW and the Port Phillip Region (PPR) of Victoria, with a simpler approach being used for the other Australian airsheds. Pollutant concentrations and exceedances of air quality standards were determined for the projection years in the modelled airsheds. This part of the study also included the assessment of future air quality under the BAU and Abatement Package scenarios. The steps taken are summarised below.

1.3.2.1 Emission projections

For each airshed, future emissions of SO_2, NO_2 and volatile organic compounds (VOCs) (as O_3 precursors) from 2016 to 2040 were estimated for both the BAU and Abatement Package scenarios. The assumptions used to define the emission projections in the BAU scenario – including the legislation in place, the measures that will be implemented, and the predicted growth in activity – are described in Section 3.

For the Abatement Package scenario the work included:

- A literature review of potential additional abatement measures.
- The evaluation of key emission sources in the major cities and regional centres to identify where specific abatement measures may be applicable.
- The calculation of the emission reductions for the relevant abatement measures in the airsheds where compliance with the current and proposed standards was considered to be unlikely under the BAU scenario. This was used as an input to the CBA, and specifically the multi-criteria analysis (MCA) employed to define the Abatement Package scenario (see Appendix C).
- The calculation of the overall emission-reduction potential for the measures included in the Abatement Package scenario.

1.3.2.2 Dispersion modelling

It is important to note that two different approaches were used in the CBA to assess the monetary benefits of implementing the Abatement Package, depending on the jurisdiction:

- Where air quality modelling was used to predict pollutant concentrations for future years, a detailed ‘impact pathway’ approach was applied. This was the case for the airsheds in NSW and Victoria.
- For the other jurisdictions a ‘damage cost’ approach was used, based on predicted changes in emissions in future years. For these airsheds air quality modelling was not undertaken.

These two approaches are described in more detail Appendix C, and the air quality aspects are summarised below.

Airsheds with modelling

Detailed air quality modelling was conducted for the following regions:

- NSW: The Greater Metropolitan Region (GMR), which included Sydney, Newcastle and Wollongong.
- Victoria: The Port Phillip Region, which included Melbourne and Geelong, and the Latrobe Valley.

These regions of NSW and Victoria were selected for the following reasons:

- They had the most up-to-date atmospheric emission inventories.
- They had previously used photochemical modelling to understand air pollution.
- They represented a cross-section of locations affected by the emission sources relevant to the pollutants being considered in the review (i.e. urban, rural, agricultural, mining, industry).
- They included the range of atmospheric behaviour across the Australian cities and states.

Different air quality models were used to determine the fate and transport of emissions in NSW and Victoria. The modelling for NSW was conducted using the CCAM-CTM dispersion model, whereas the modelling for Victoria was based on the TAPM-CTM dispersion model. These models were consistent with those used by the regulatory agencies in each state, and were considered the most suitable, sophisticated and representative models for those states at the time of the study. It was beyond the scope of the study to develop new models.

Airsheds with no modelling

For the other airsheds, where modelling was not undertaken, the emission reductions estimated for the Abatement Package were projected into the future. Attainment of the current and proposed standards was estimated using a comparative method (for NO_2 and SO_2 only). This was then used to inform the damage cost calculations in the CBA. Given the complex nature of O_3 formation and removal, it was not possible to apply such an approach this pollutant.

1.4 Structure of Appendix

The structure of this Appendix is as follows:

- Analysis of the historical trends in air quality in major cities and some regional locations, based on ambient air quality monitoring data (Section 2).
- Emission projections (Section 3).
- Air quality modelling and projections (Section 4).
- Study findings and recommendations (Section 5).

2 Historical trends in air quality

2.1 Overview

Ambient air quality monitoring data for SO_2, NO_2 and O_3 from 2003 to 2016 were analysed to provide context with respect to historical trends in Australian airsheds, and to identify any airsheds that might be unable to comply with the current or proposed standards in future years.

Trends in air quality were assessed for the major urban airsheds and regional centres for which extensive time series of monitoring data were available. The geographic extents of these locations are summarised in Table 2-1. The data included in the analysis were provided by EPA Victoria, and consisted of the measurements reported by the jurisdictions under the current requirements of the AAQ NEPM. Data verification and validation were undertaken by EPA Victoria. Details of the files received, and the sites and data analysed[b], are provided in Annexure A.

Table 2-1: Airshed definitions for assessment of monitoring data

Jurisdiction	Airshed
New South Wales (NSW)	Greater Sydney, Newcastle, Wollongong
Victoria (VIC)	Port Phillip Region (Melbourne metropolitan area and Geelong), Latrobe Valley
Queensland (QLD)	South-East Queensland (Brisbane city and suburbs, Sunshine Coast, Gold Coast, and Ipswich), Townsville, Gladstone
South Australia (SA)	Adelaide metropolitan area
Western Australia (WA)	Perth metropolitan area
Northern Territory (NT)	Darwin metropolitan area
Australian Capital Territory (ACT)	Canberra city and suburbs

The analysis examined historical compliance with the current and proposed standards for each pollutant, based solely on the numerical values of the standards (i.e. different potential forms of the standards, such as the number of allowable exceedance, were not considered). The detailed results are presented in Annexure B (section B.1).

2.2 Sulfur dioxide

2.2.1 Concentrations

For SO_2 the monitoring stations established under the AAQ NEPM are not as extensive as for the other pollutants. The data show that SO_2 concentrations are generally low, and below the current AAQ NEPM standards (i.e. 200 ppb for the 1-hour average, 80 ppb for the 24-hour average, and 20 ppb for the annual average), except in areas impacted by industrial sources (see below).

[b] Consistent with the requirements of the AAQ NEPM, only monitoring stations/years with at least 75% data availability (i.e. the proportion of the year with valid data) were used to calculate annual averages. However, even where a station/year had less than less than 75% data availability, exceedances of short-terms air quality standards were still taken into account.

Figure 2-1 shows the measured maximum 1-hour SO_2 values for the major cities. The peaks in the Perth data are associated with a monitoring site located in a community that is affected by industrial emissions. The measurements for the Port Phillip Region were also influenced by large industrial sources at two of the AAQ NEPM monitoring stations. Maximum 1-hour SO_2 concentrations for the regional centres are presented in Figure 2-2. The concentrations in some of these areas were higher than those in the major cities, although Townsville had particularly low concentrations. The measurements from the Mount Isa station (not shown) had much higher SO_2 concentrations than the other regional centres due to large smelter operations.

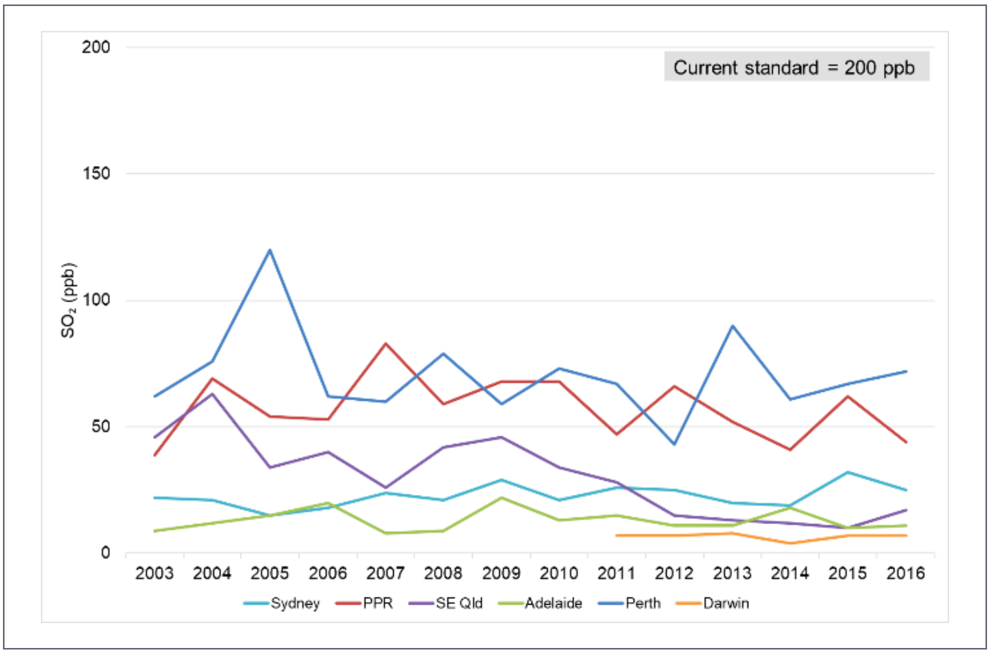

Figure 2-1: Maximum 1-hour SO_2 for major cities

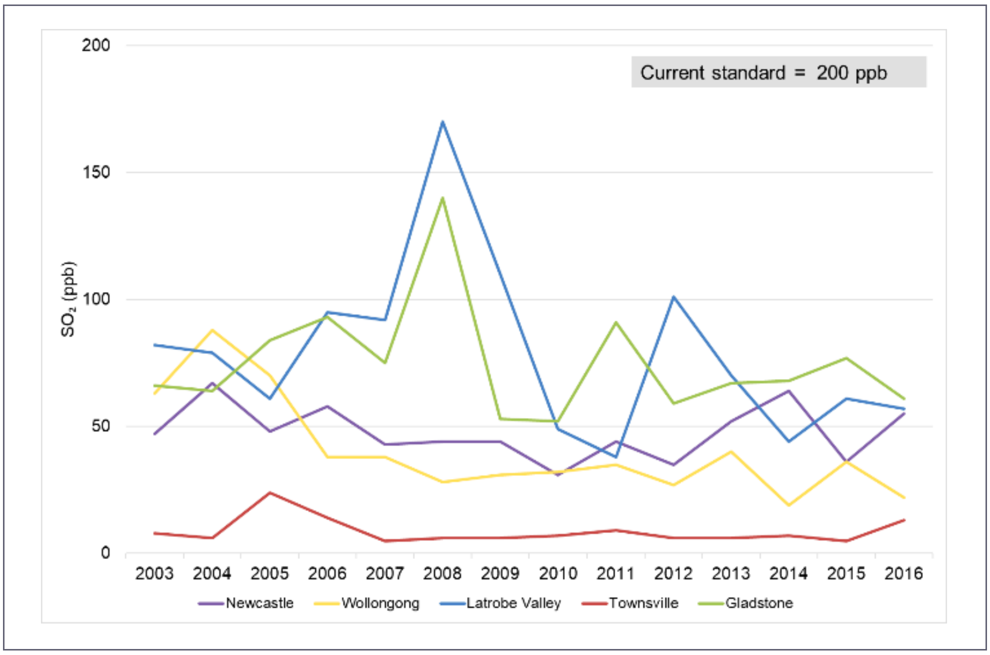

Figure 2-2: Maximum 1-hour SO_2 for regional centres

The maximum 24-hour average SO_2 concentrations in the major cities are shown in Figure 2-3. The peak for the Port Phillip Region in 2009-2010 was associated with a community site located close to an industrial complex. Figure 2-4 shows the maximum 24-hour concentrations for the regional centres. As with the 1-hour data, the SO_2 concentrations were higher than those observed in the major cities, and the peaks in the data were due to industrial sources.

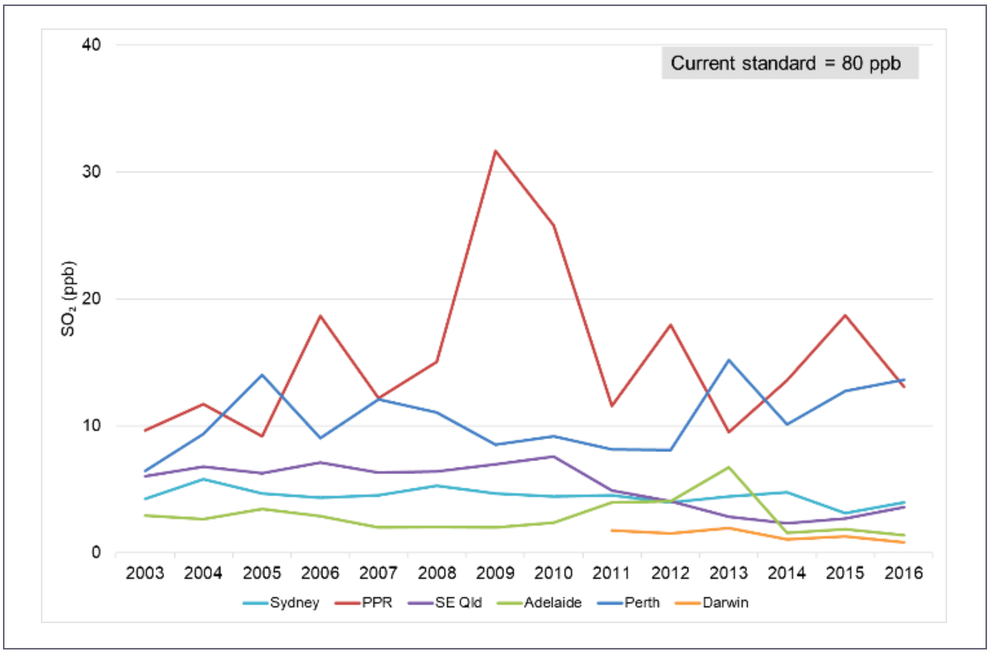

Figure 2-3: Maximum 24-hour SO_2 for major cities

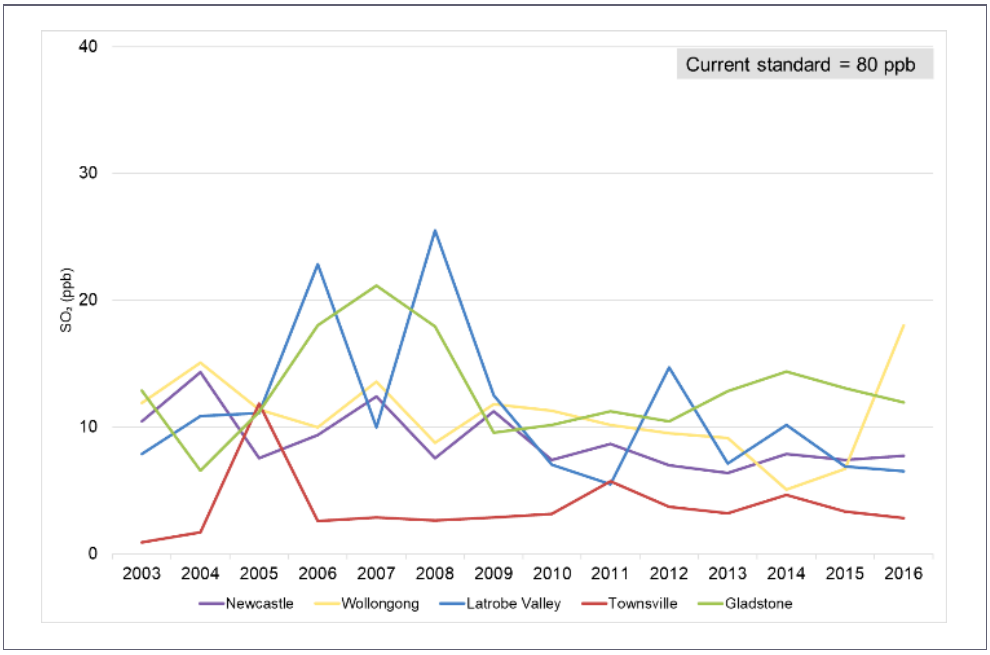

Figure 2-4: Maximum 24-hour SO_2 for regional centres

From Figure 2-5 it can be seen that annual average SO_2 concentrations in the major cities were low, indicating that any periods with high concentrations were infrequent. For the regional centres, Figure 2-6 shows that the concentrations were broadly similar, with the exception of Townsville where again they tended to be relatively low.

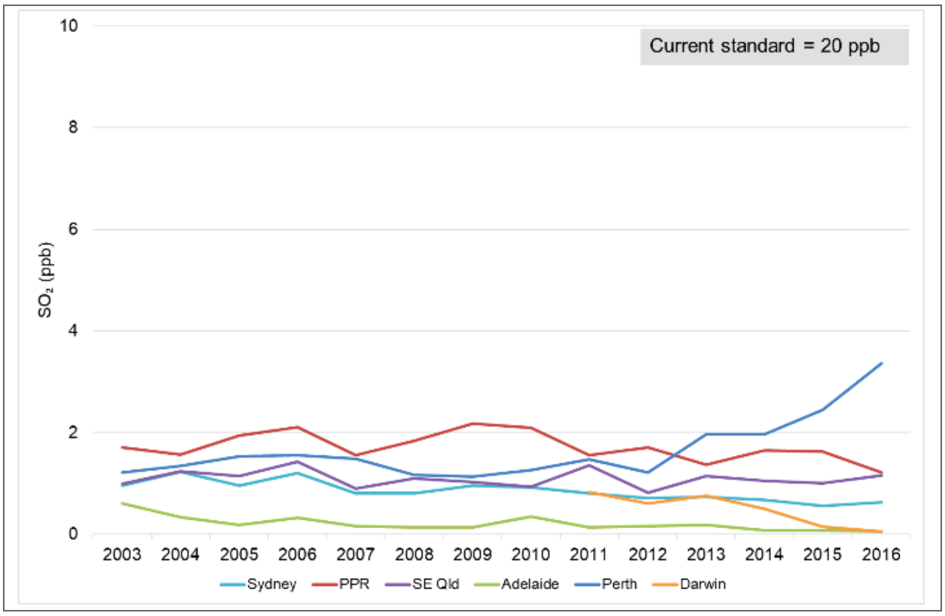

Figure 2-5: Annual average SO_2 for major cities

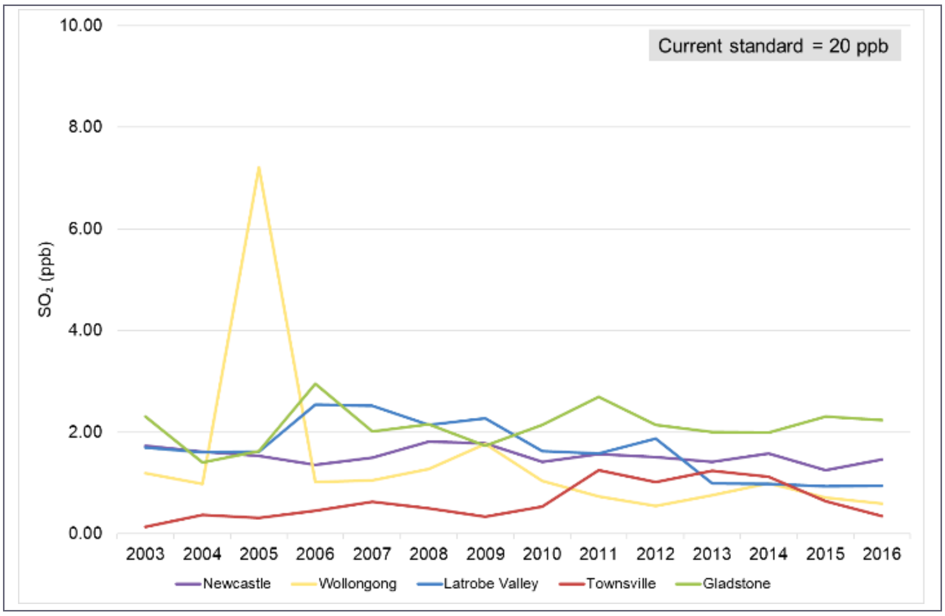

Figure 2-6: Annual average SO_2 for regional centres

Overall, there were no consistent long-term trends in the data for any of the SO_2 averaging periods, although there was a general downward trend in maximum 1-hour SO_2 in South-East Queensland and Wollongong, a general downward trend in annual mean SO_2 in the Latrobe Valley, and a general upward trend in annual mean SO_2 in Perth after 2012.

2.2.2 Exceedances of standards

For the 1-hour and 24-hour SO_2 standards the total numbers of unique[c] exceedance days across all stations (for the period between 2003 and 2016) were determined. In the case of the annual mean standards, the total number of monitoring stations exceeding then standards were calculated. The results are summarised in Table 2-2 (major cities) and Table 2-3 (regional centres), with exceedances

[c] This is the total number of exceedance days for all monitoring stations in an airshed, excluding any 'duplication' of exceedances across different stations on the same day.

for the more recent period between 2010 and 2014, as used in the HRA, being shown for comparison. The current standards are identified with light blue shading.

Table 2-2: Historical exceedances of current and proposed SO_2 standards in major cities

Standard		Exceedances between 2003 and 2016 (2010-2014 in brackets)						
		NSW: Sydney	VIC: Port Phillip Region	QLD: S-E Queensland	SA: Adelaide	WA: Perth	NT: Darwin	ACT: Canberra
1-hour		Total number of unique exceedance days						
	75	- (-)	1 (-)	- (-)	- (-)	5 (1)	- (-)	- (-)
	100	- (-)	- (-)	- (-)	- (-)	1 (-)	- (-)	- (-)
	150	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
	200	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
24-hour		Total number of unique exceedance days						
	7	- (-)	112 (47)	2 (1)	- (-)	71 (14)	- (-)	- (-)
	20	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
	40	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
	80	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
Annual		Total number of monitoring stations exceeding standard						
	10	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
	20	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)

Table 2-3: Historical exceedances of current and proposed SO_2 standards in regional centres

Standard		Exceedances between 2003 and 2016 (2010-2014 in brackets)				
		NSW: Newcastle	NSW: Wollongong	VIC: Latrobe Valley	QLD: Townsville	QLD: Gladstone
1-hour		Total number of unique exceedance days				
	75	- (-)	1 (-)	9 (2)	- (-)	9 (1)
	100	- (-)	- (-)	3 (1)	- (-)	- (-)
	150	- (-)	- (-)	1 (-)	- (-)	- (-)
	200	- (-)	- (-)	- (-)	- (-)	- (-)
24-hour		Total number of unique exceedance days				
	7	19 (9)	32 (18)	17 (5)	- (-)	120 (67)
	20	- (-)	- (-)	1 (-)	- (-)	- (-)
	40	- (-)	- (-)	- (-)	- (-)	- (-)
	80	- (-)	- (-)	- (-)	- (-)	- (-)
Annual		Total number of monitoring stations exceeding standard				
	10	- (-)	- (-)	- (-)	- (-)	- (-)
	20	- (-)	- (-)	- (-)	- (-)	- (-)

The analysis shows that the current 1-hour standard (200 ppb) and 24-hour standard (80 ppb) have been achieved in all jurisdictions. Under existing conditions, the results indicate the following for the proposed standards:

- For most airsheds there is the potential for a limited number of exceedances of the proposed 1-hour standard for SO_2 of 75 ppb in future years, particularly in regional areas with industrial activity. Compliance with the other proposed standards (100 ppb and 150 ppb) should generally be achievable, possibly with some local intervention.
- For several airsheds it will be a challenge to comply with the proposed 24-hour standard for SO_2 of 7 ppb in future years, whereas compliance with the other proposed standards (20 ppb and 40 ppb) should generally be achievable, possibly with some local intervention.
- For annual mean SO_2 there has been historical compliance with the most stringent proposed standard of 10 ppb in all airsheds.

This suggests that abatement measures focussing on specific emission sources in the more constrained airsheds, rather than national measures, will be more appropriate for delivering air quality improvements.

2.3 Nitrogen dioxide

2.3.1 Concentrations

Figure 2-7 shows the trend in maximum 1-hour NO_2 between 2003 and 2016 in the major cities. The peak for Canberra in 2008 was associated with a bushfire event. As with SO_2, there was no strong trend in the data between 2003 and 2016. In recent years (2010-2016) NO_2 concentrations in most jurisdictions have been relatively stable.

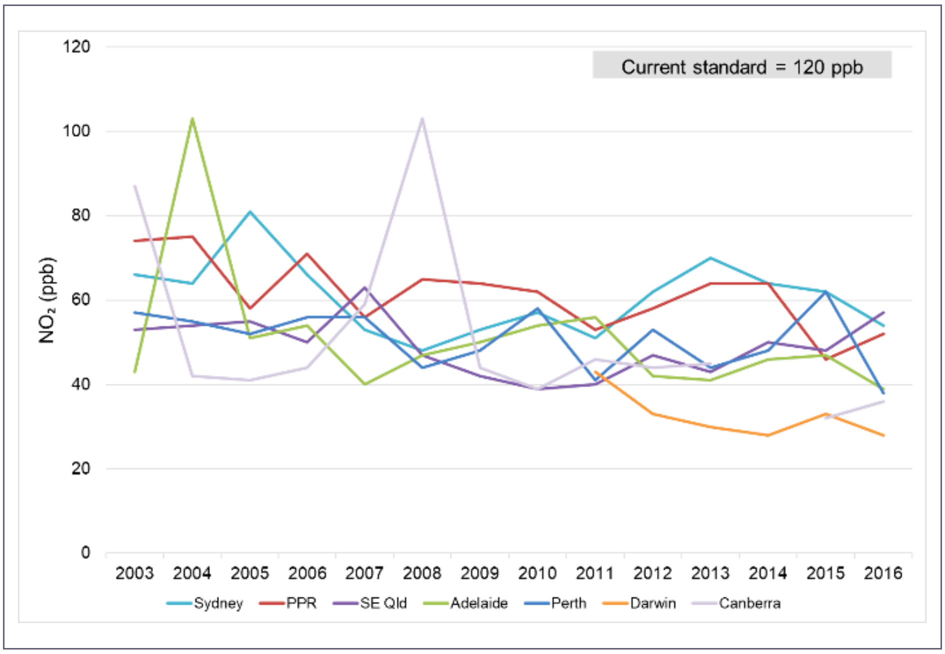

Figure 2-7: Maximum 1-hour NO_2 for major cities

The maximum 1-hour NO_2 concentrations in the regional centres are shown in Figure 2-8. These were generally lower than those in the major cities. This is probably indicative of the impact of motor vehicle emissions on ambient NO_2 concentrations in the major cities. No clear long-term trend in the data was apparent.

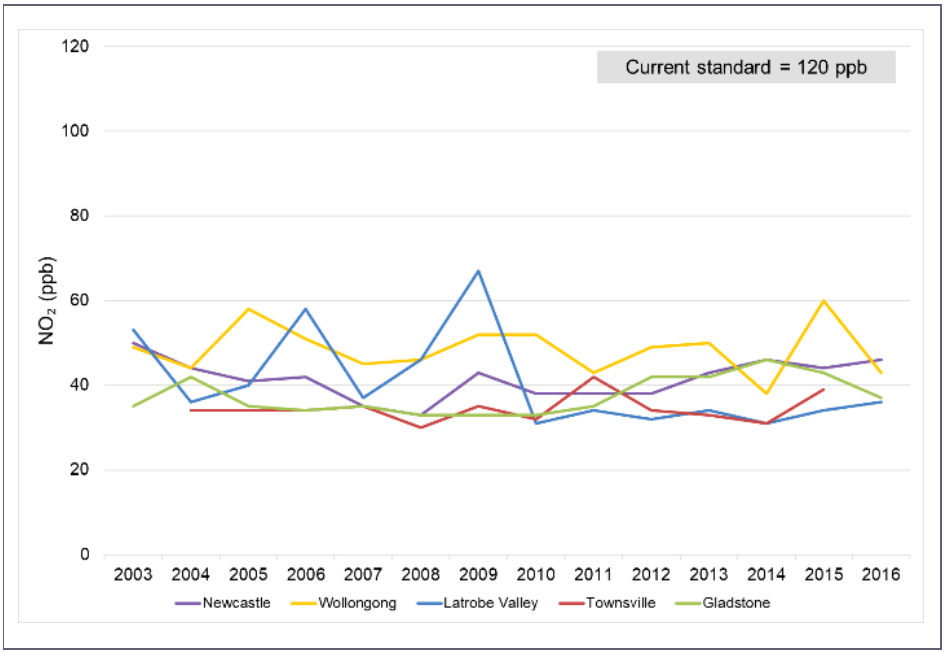

Figure 2-8: Maximum 1-hour NO_2 for regional centres

It is evident from Figure 2-9 that there was quite a wide range of annual average NO_2 concentrations in the major cities. In several cities there has been a general but gradual downward trend in annual average NO_2. In the Port Phillip Region there was a downward step change in concentration after 2006 when the RMIT station was closed. The RMIT station was in Melbourne's CBD and the NO_2 concentrations it measured were heavily influenced by road traffic.

For the other cities there was no clear trend in the data. From Figure 2-10 it can be seen that there was also no trend in the annual average NO_2 concentrations in the regional centres.

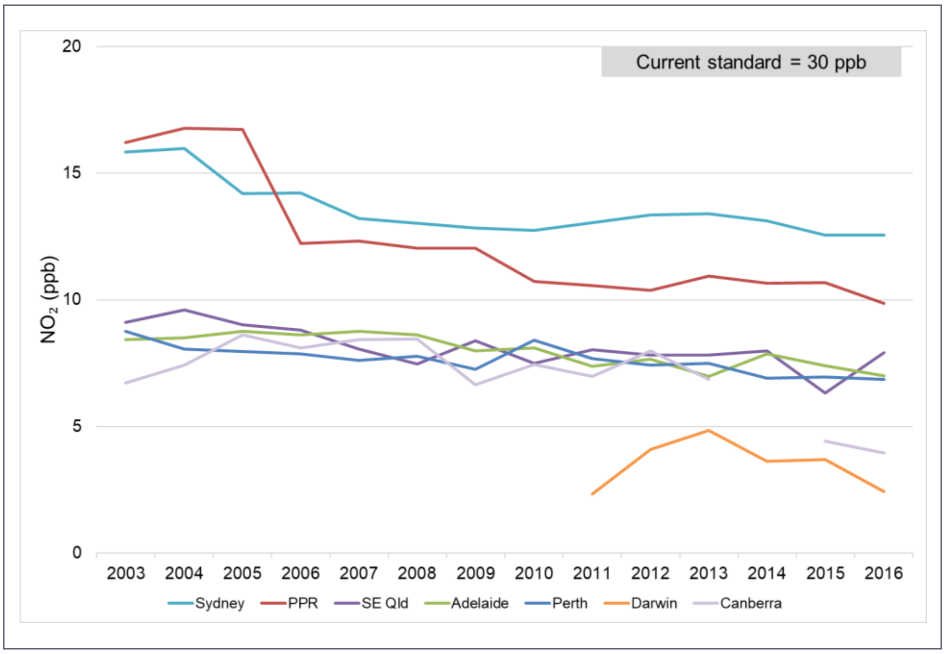

Figure 2-9: Annual average NO_2 for major cities

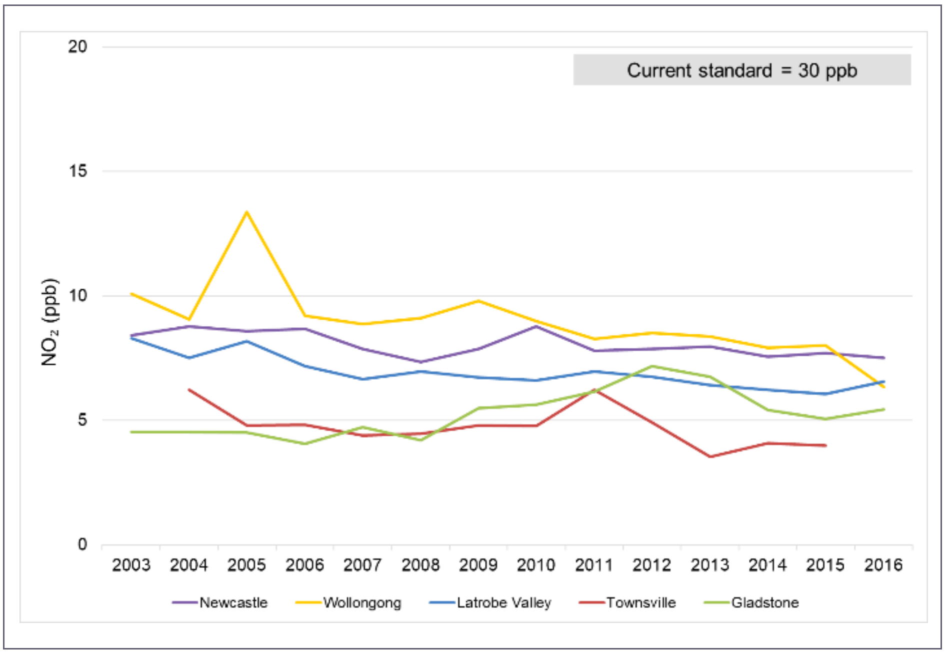

Figure 2-10: Annual average NO_2 for regional centres

2.3.2 Exceedances of standards

The exceedances of the current and proposed NO_2 standards in the major cities and regional centres are summarised in Table 2-4 and Table 2-5 respectively. All measured NO_2 concentrations in both the major cities and regional centres were below the current AAQ NEPM standards (120 ppb for the 1-hour average, and 30 ppb for the annual average, show with light blue shading).

Table 2-4: Historical exceedances of current and proposed NO_2 standards in major cities

Standard		Exceedances between 2003 and 2016 (2010-2014 in brackets)						
		NSW: Sydney	VIC: Port Phillip Region	QLD: S-E Queensland	SA: Adelaide	WA: Perth	NT: Darwin	ACT: Canberra
1-hour		Total number of unique exceedance days						
	40	376 (106)	267 (46)	73 (16)	40 (14)	78 (19)	1 (1)	30 (3)
	80	1 (-)	- (-)	- (-)	1 (-)	- (-)	- (-)	3 (-)
	97	- (-)	- (-)	- (-)	1 (-)	- (-)	- (-)	1 (-)
	120	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
Annual		Total number of monitoring stations exceeding standard						
	10	54 (18)	25 (7)	- (-)	- (-)	- (-)	- (-)	- (-)
	19	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
	30	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)

Table 2-5: Historical exceedances of current and proposed NO_2 standards in regional centres

Standard		Total exceedances between 2003 and 2016 (2010-2014 in brackets)				
		NSW: Newcastle	NSW: Wollongong	VIC: Latrobe Valley	QLD: Townsville	QLD: Gladstone
1-hour		Total number of unique exceedance days				
	40	17 (6)	63 (18)	3 (-)	1 (1)	6 (4)
	80	- (-)	- (-)	- (-)	- (-)	- (-)
	97	- (-)	- (-)	- (-)	- (-)	- (-)
	120	- (-)	- (-)	- (-)	- (-)	- (-)
Annual		Total number of monitoring stations exceeding standard				
	10	- (-)	2 (-)	- (-)	- (-)	- (-)
	19	- (-)	- (-)	- (-)	- (-)	- (-)
	30	- (-)	- (-)	- (-)	- (-)	- (-)

Under existing conditions, the results indicate that for the most urbanised airsheds it will be a significant challenge to comply with the proposed 1-hour standard for NO_2 of 40 ppb in future years. Compliance with the proposed standards of 80 ppb and 97 ppb should generally be possible in all airsheds. All jurisdictions would be likely to achieve continued compliance with the current 120 ppb standard.

There have been no exceedances of the proposed standard of 19 ppb for annual mean NO_2, but exceedances of the proposed standard of 10 ppb in Sydney, the Port Phillip Region and Wollongong.

2.4 Ozone

2.4.1 Concentrations

The measurements for O_3 revealed that exceedances of the current AAQ NEPM standards (100 ppb for the 1-hour average, and 80 ppb for the rolling 4-hour average) occurred at most locations and in most years. This was particularly evident in the data for Sydney.

Figure 2-11 shows the maximum 1-hour O_3 concentrations in the major cities. A number of the peak concentrations were associated with large bushfires, such as the 2006 events in the Port Phillip Region and Canberra. For Sydney there was a slight downward trend in the data from 2003 to 2016. For all other cities no clear trend was apparent. The maximum 1-hour O_3 concentrations in the regional centres are shown in Figure 2-12. The influence of bushfires on O_3 concentrations can be seen in the data for the Latrobe Valley in 2006 and 2009, where significant events occurred in the region, although again no clear overall trends were apparent.

The maximum (rolling) 4-hour average O_3 concentrations for the major cities are presented in Figure 2-13. There was a slight downward trend in the Sydney data. For all other cities there was no clear trend in the data. The corresponding data for the regional centres are shown in Figure 2-14. Although exceedances of the current AAQ NEPM standard occurred, again no clear trend in the data was apparent.

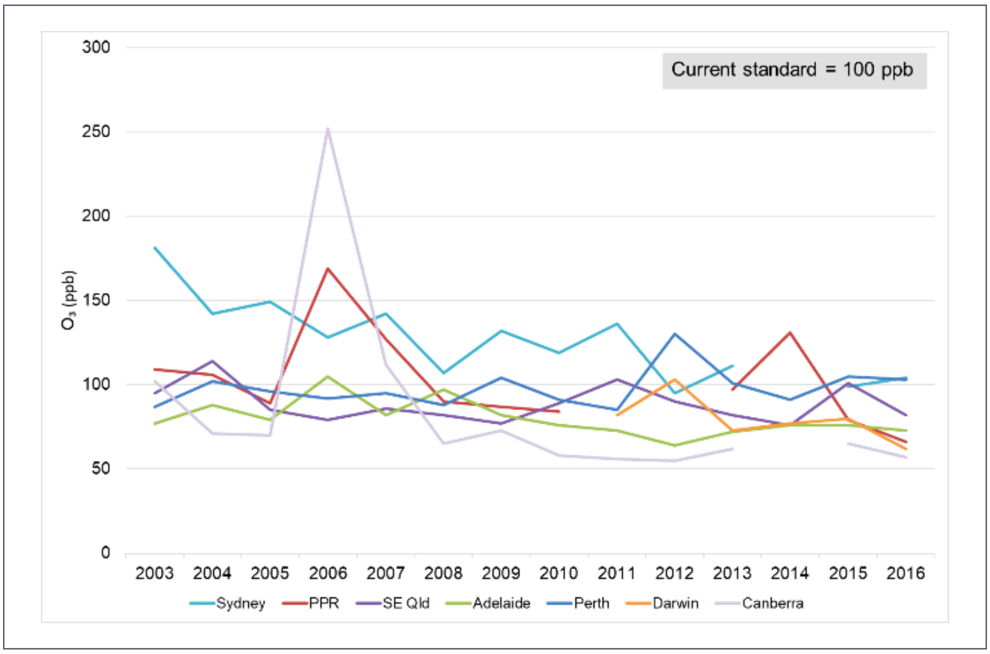

Figure 2-11: Maximum 1-hour O_3 for major cities

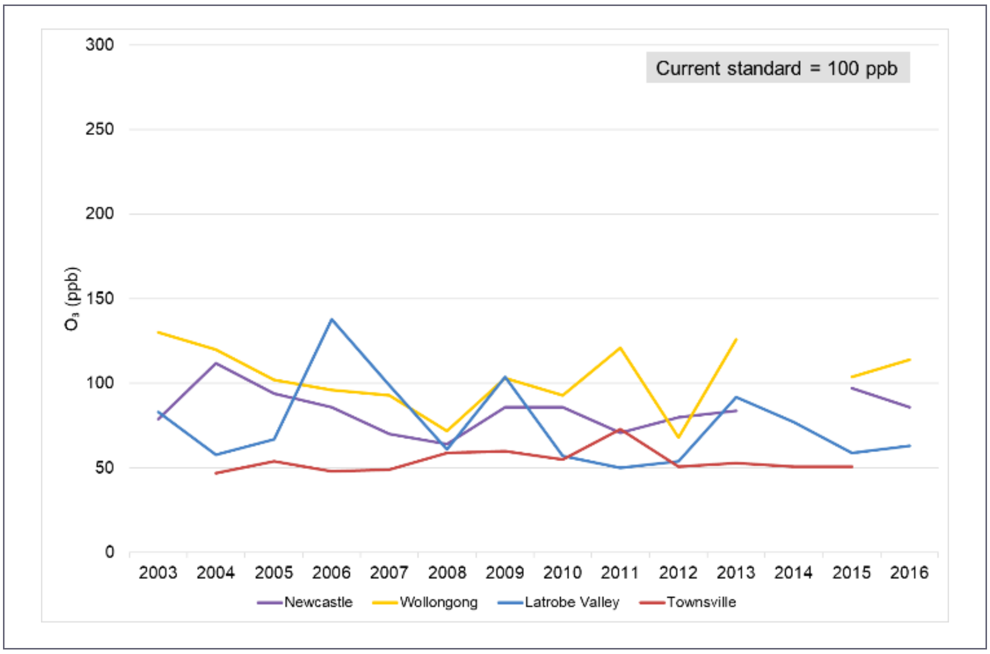

Figure 2-12: Maximum 1-hour O_3 for regional centres

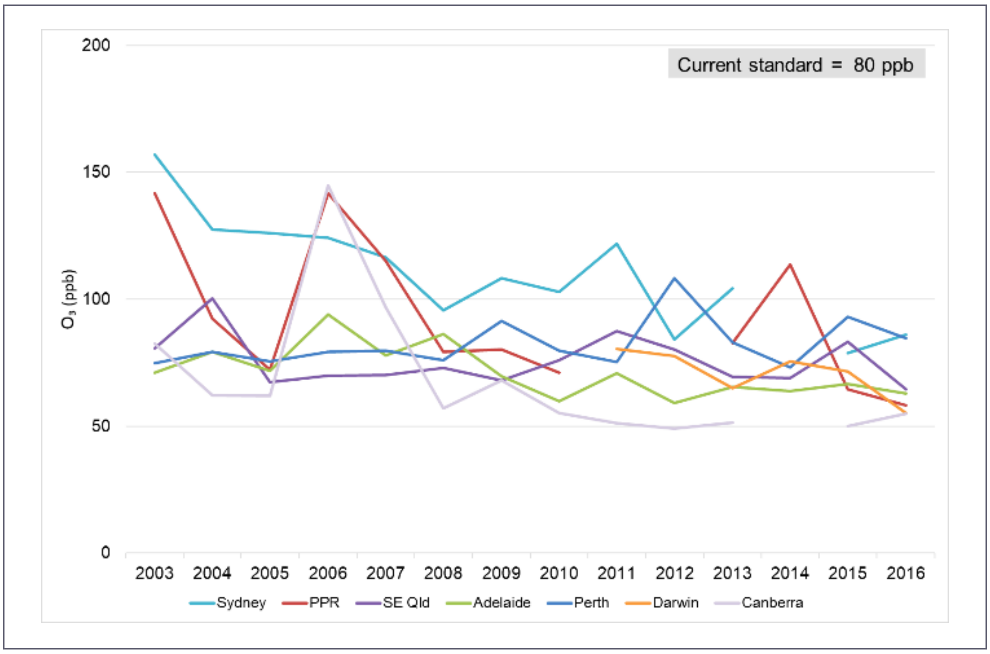

Figure 2-13: Maximum rolling 4-hour average O_3 for major cities

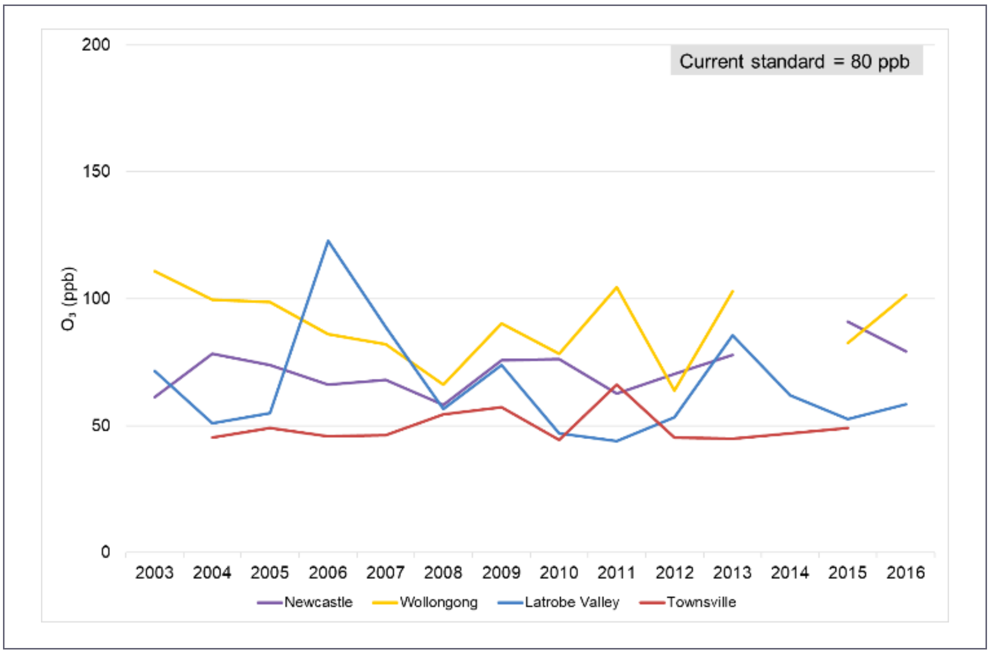

Figure 2-14: Maximum rolling 4-hour average O_3 for regional centres

There is currently no standard for 8-hour O_3 in the AAQ NEPM. However, internationally there are examples of standards for this averaging period. The introduction of an 8-hour standard has been considered in this Impact Statement, and therefore an analysis of the maximum rolling 8-hour average data has been included here. The data for the major cities in Figure 2-15 do not reveal any clear long-term trend in the data. The influence of bushfires can be seen in the years of high bushfire activity (e.g. 2006 in Melbourne and Canberra). The corresponding data for the regional centres are shown in Figure 2-16. As shown by the peak in 2006 for the Latrobe Valley, the influence of bushfires can be seen. Again, there was no clear long-term trend.

In summary, with the exception of Sydney, where there was a slight downward trend between 2003 and 2016, there has been no clear long-term trend in O_3 concentrations (1-hour, 4-hour and 8-hour maximum) in the airsheds. In years where there were significant bushfires, the influence on peak O_3 concentrations has been apparent.

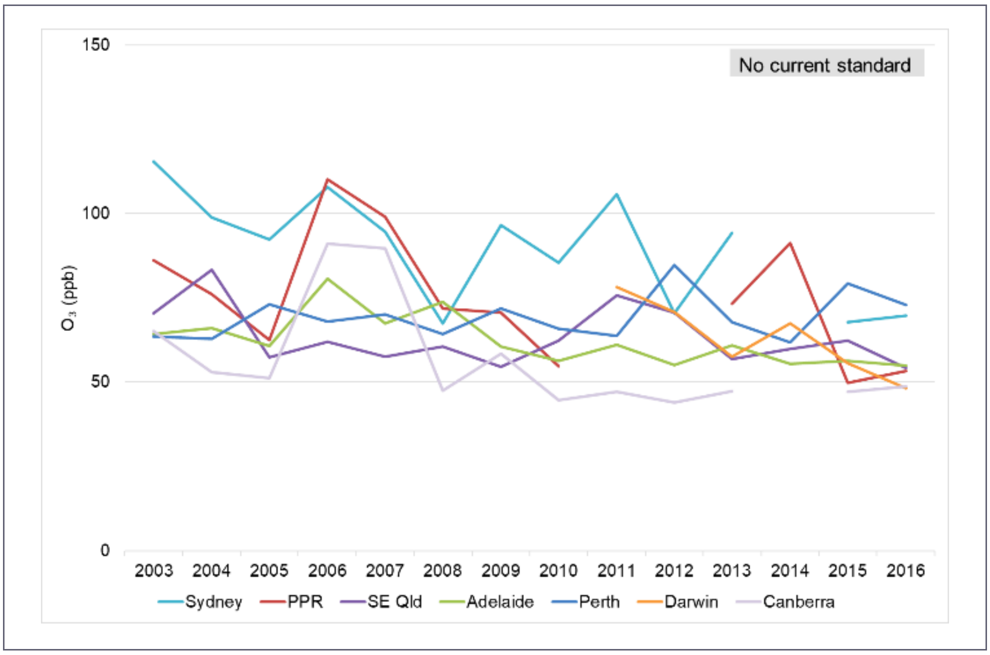

Figure 2-15: Maximum rolling 8-hour average O_3 for major cities

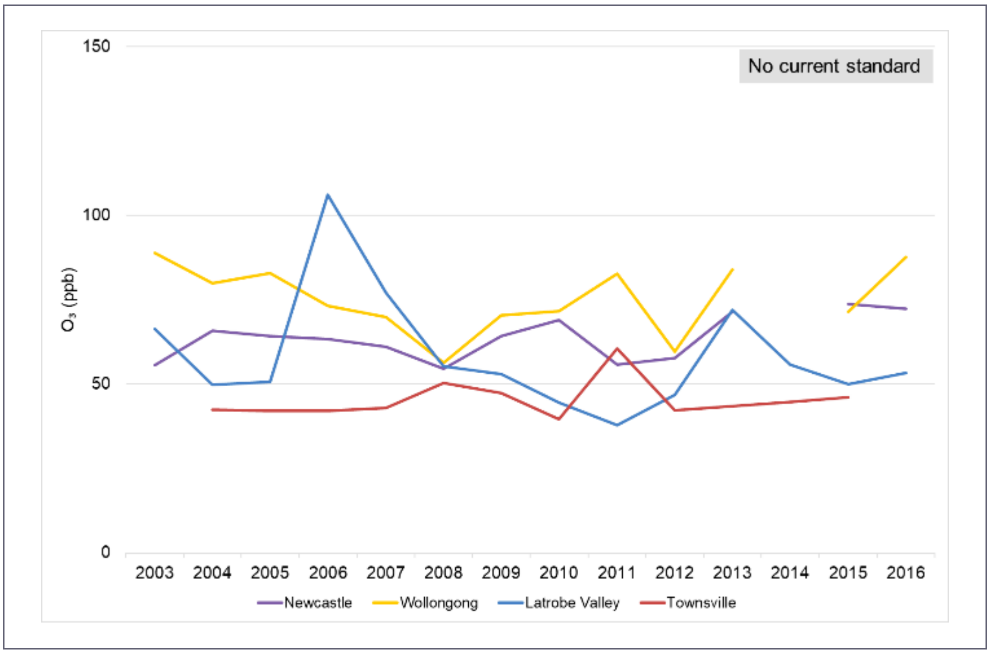

Figure 2-16: Maximum rolling 8-hour average O_3 for regional centres

2.4.2 Exceedances of standards

The O_3 exceedances between 2003 and 2016 (and 2010-2014) are summarised for the major cities and regional centres in Table 2-6 and Table 2-7 respectively.

Between 2003 and 2016 most jurisdictions experienced exceedances of both the current 1-hour and 4-hour NEPM standards (identified with light blue shading), most notably in Sydney, Wollongong, the Port Phillip Region and Perth. From 2010 to 2014 there were few exceedances outside these airsheds.

For a proposed 1-hour standard of 85 ppb, the situation was similar to that for the current standard. However, the only airsheds where the proposed standard of 70 ppb could be met across all years were Canberra and Gladstone.

Two alternative proposed 4-hour standards have been considered as part of this study (70 ppb and 60 ppb). The monitoring data show that the 70 ppb standard was only achieved across all years in Canberra, Townsville and Gladstone. The 60 ppb standard was only achieved across all years in Canberra and Gladstone.

Four proposed 8-hour standards were considered in this review (70 ppb, 60 ppb, 55 ppb and 47 ppb). Based on the monitoring data for recent years the 70 ppb standard was met in Canberra and Adelaide, as well as in the regional centres of Newcastle, Townsville and Gladstone. In Sydney, Wollongong, the Port Phillip Region and Perth, the lower standards were exceeded in most years.

In summary, the proposed O_3 standards have generally not been achieved historically, indicating that abatement measures would be required in the future.

Table 2-6: Exceedances of current and proposed O_3 standards in major cities

Standard		Exceedances between 2003 and 2016 (2010-2014 in brackets)						
		NSW: Sydney	VIC: Port Phillip Region	QLD: S-E Queensland	SA: Adelaide	WA: Perth	NT: Darwin	ACT: Canberra
1-hour		Total number of unique exceedance days						
	70	335 (108)	100 (22)	89 (25)	34 (6)	179 (59)	19 (18)	14 (-)
	85	145 (36)	24 (7)	16 (7)	3 (-)	33 (12)	2 (2)	9 (-)
	100	67 (13)	9 (1)	4 (1)	1 (-)	9 (3)	1 (1)	5 (-)
Rolling 4-hour		Total number of unique exceedance days						
	60	386 (113)	134 (29)	104 (30)	41 (8)	194 (69)	39 (38)	20 (-)
	70	197 (54)	48 (11)	24 (9)	9 (1)	57 (19)	11 (10)	7 (-)
	80	95 (23)	18 (6)	6 (3)	2 (-)	11 (6)	1 (1)	3 (-)
Rolling 8-hour		Total number of unique exceedance days						
	47	600 (184)	278 (55)	230 (66)	119 (36)	357 (119)	163 (153)	39 (1)
	55	300 (93)	113 (21)	50 (19)	24 (6)	127 (44)	42 (41)	9 (-)
	60	190 (58)	67 (14)	18 (7)	11 (2)	65 (20)	20 (20)	4 (-)
	70	62 (16)	20 (5)	5 (3)	2 (-)	8 (3)	3 (3)	2 (-)

Table 2-7: Unique exceedance days for current and proposed O_3 standards in regional centres

Standard		Exceedances between 2003 and 2016 (2010-2014 in brackets) NSW: Newcastle	NSW: Wollongong	VIC: Latrobe Valley	QLD: Townsville	QLD: Gladstone
1-hour		Total number of unique exceedance days				
	70	42 (15)	87 (22)	22 (4)	1 (1)	- (-)
	85	9 (2)	32 (9)	6 (1)	- (-)	- (-)
	100	1 (-)	16 (4)	4 (-)	- (-)	- (-)
Rolling 4-hour		Total number of unique exceedance days				
	60	63 (19)	106 (24)	17 (2)	3 (3)	- (-)
	70	19 (3)	45 (12)	10 (1)	0 (-)	- (-)
	80	1 (-)	23 (6)	4 (1)	0 (-)	- (-)
Rolling 8-hour		Total number of unique exceedance days				
	47	151 (53)	177 (49)	69 (12)	9 (5)	- (-)
	55	49 (14)	86 (21)	21 (2)	4 (4)	- (-)
	60	22 (4)	49 (13)	10 (1)	1 (-)	- (-)
	70	5 (-)	23 (7)	2 (1)	- (-)	- (-)

3 Emission projections

3.1 Overview

To understand future air quality in each airshed, projections of annual atmospheric emissions[d] for the period 2015 to 2040 were calculated based on existing emission inventories. The inventory area definitions were, in some cases, slightly different from those used in the analysis of the monitoring data. Emission projections were defined for both the BAU and Abatement Package scenarios, with the abatement measures being implemented from 2020 onwards. Some examples of the projections, in this case for sectoral emissions of NO_X in South-East Queensland, are shown in Figure 3-1 (BAU) and Figure 3-2 (Abatement Package). All the emission projections are presented in Annexure D.

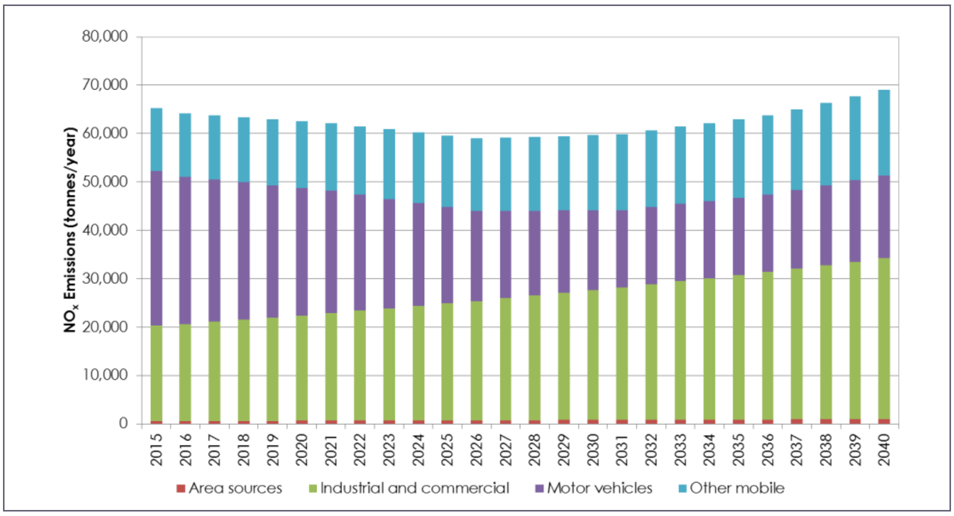

Figure 3-1: South-East Queensland BAU scenario NO_X emission projections

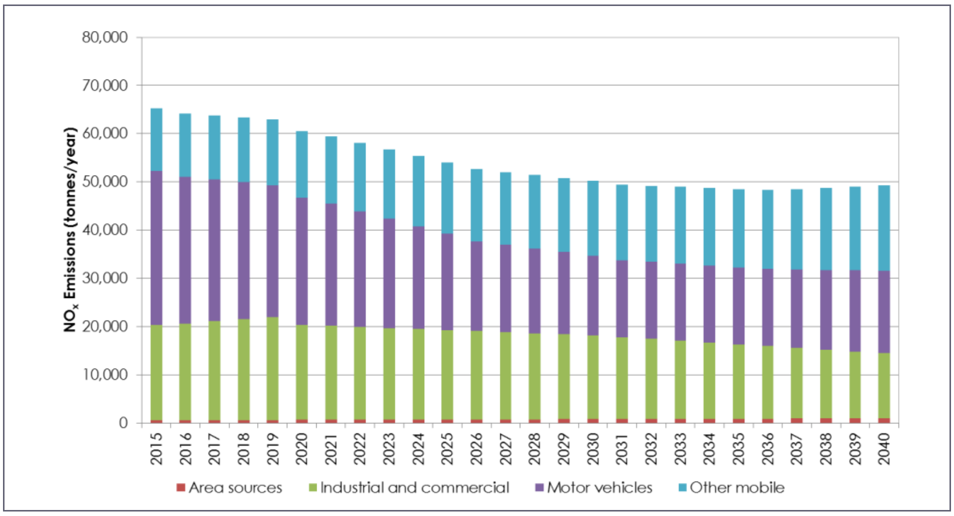

Figure 3-2: South-East Queensland Abatement Package scenario NO_X emission projections

[d] Tonnes of pollutant emitted in the airshed per year.

3.2 Projection methods

3.2.1 Business-as-Usual scenario

To construct the BAU scenario the official state emission inventory projections were referenced where possible[e]. Otherwise, reference was made to the information contained within the National Pollutant Inventory (NPI). The projections took into account the likely changes in major emission sources within each airshed.

In the BAU scenario the official projections were used for sources that would not be affected by changes in legislation. However, adjustments were made to some sources, as explained in the sections below. Whilst there have been some legislative changes that would affect emission sources, such as the modification of shipping fuels to be progressively lower in sulfur (MARPOL), these were not included in the BAU scenario. This was either because the legislation was specific to highly localised emission sources and did not provide a significant reduction in the airshed inventory, or because the original inventory was not provided with sufficient detail to incorporate the emission reductions.

It is worth noting that other emission datasets were made available during the study. However, consideration was given to maintaining consistency with the data sources referenced during the review of the AAQ NEPM standards for particulate matter. Compatibility of datasets for the required analysis, and data coverage, were also taken into account when selecting data for inclusion, as well as considering the validation and published status of the work.

3.2.1.1 New South Wales and Victoria

The most recent official emission inventory for the NSW GMR was compiled for a 2008 base year (NSW EPA, 2012), and the inventory data were supplied by NSW OEH for this study. This version of the inventory was also used in the Sydney Particle Study to investigate the characteristics of particles in Sydney (Cope et al., 2014), and the motor vehicle emission estimates were updated in the Review of Fuel Quality Standards Act (Kinrade et al., 2016). The inventory contained projections for the years 2011, 2016, 2021, 2026, 2031 and 2036.

Victoria's most recent official emission inventory was compiled in 2006 (Delaney and Marshall, 2011). This inventory was used in the Future Air Quality in Victoria study to understand the potential air quality issues in the future and to propose methods to reduce air pollution (EPA Victoria, 2013). The inventory contained emission estimates for the years 2006 and 2030. A linear interpolation was assumed for years between 2006 and 2030, and then extrapolated for years after 2030 using population data.

In the BAU scenario these official projections for NSW and Victoria were used for sources that would not be affected by changes in legislation or, in the case of industrial sources, closure. However, adjustments were made to the following sources in the BAU scenario:

- *Motor vehicles*. It was assumed that Australia would continue on the path of alignment with international legislation, with the adoption of the Euro 6 fuel specifications in 2019. The Australian fleet was assumed to continue to grow in size, with proportional increases in all fleet categories. The sulfur content of both petrol and diesel was assumed to be 10 ppm

[e] The emission source categories were identified by the reference material, and may not have been universal or consistent between jurisdictions.

(this assumes that fuel sulfur content would be harmonised with the EU (Euro 6), with the sulfur content of petrol being reduced from 50 ppm)[f].

- *Wood heaters*. Emissions from wood heaters were modified to take into account the Australian Government's December 2015 decision on the future management of this emission source.
- *Non-road spark-ignition engines and equipment*. For these, emissions were modified to account for the Australian Government's December 2015 policy decision on the future management of this emission source.
- *Selected industries with known closure dates*. These were removed from the inventory post-closure date.

3.2.1.2 Other jurisdictions

The BAU emission inventories for the other jurisdictions were based on the following published data sources provided by EPA Victoria:

- The 2000 South-East Queensland emissions inventory (Queensland EPA, 2004).
- The 1998/1999 Perth emission inventory (WA DEP, 2003).
- The latest NPI data (2014/2015) for industrial and commercial sources in Adelaide, Canberra, Hobart, Gladstone, and Darwin.
- The NPI diffuse source data for Adelaide, Canberra, Hobart, Gladstone, and Darwin, which were assumed to be for 1999/2000.

The projections for the other jurisdictions were calculated as follows:

- Industry was projected using averaged economic gross value added (GVA) data for different groups of industry.
- Motor vehicle and other mobile source emissions were projected using the data from the Bureau of Infrastructure, Transport and Regional Economics (BITRE) (Kinrade et al., 2016).
- Domestic and commercial sources were projected using population projections.

3.2.2 Abatement Package scenario

Achieving compliance with the proposed air quality standard for SO_2, NO_2 and O_3 would, in some cases, require the introduction of new abatement measures to reduce emissions from specific sectors.

Individual abatement measures were not modelled separately, but as a package. The package approach was necessary given that the pollutants being assessed are associated with complex photochemical reactions, and whilst individual measures could be evaluated the results for multiple individual measures could not sensibly be combined.

[f] The understanding at the time of the study was that Euro 6 fuels would be implemented in 2019. Given that this decision has been delayed, the BAU scenario is now out of date for the near-future projections. However, it is considered likely that that the sulfur content of petrol in Australia will be reduced in the medium-to-long term.

3.2.2.1 Review of potential additional abatement measures

An extensive review was conducted of potential additional abatement measures to inform the MCA, targeting emissions of SO_2, NO_2 and VOCs (as a precursor of O_3 formation). The additional abatement measures considered in the study were sourced from the following:

- A list of abatement measures and associated references provided by the Air TOG.
- Other references and options, with a focus on published material during the last 5 years.

The list of references covered in the literature review is provided in Annexure C.

The additional abatement measures were reviewed individually, and their potential contribution to reducing emissions was provided as an input to the MCA.

3.2.2.2 Estimated abatement for compliance with proposed air quality standards

To understand the likely abatement needed in the future to achieve airshed compliance with the proposed standards, the airsheds identified as being potentially constrained, either currently or in the future, were reviewed. An analysis was undertaken to estimate the potential emission load in each airshed in future years and, in turn, the estimated amount of abatement (emission load reduction) that would probably be required to achieve the standards in the future.

Several steps were applied in the analysis. The long-term ambient monitoring data (2009 – 2013/14) were reviewed to derive an emission-load-to-ambient-concentration ratio (SO_2, NO_2, and VOCs as a precursor for O_3). This ratio was used to estimate ambient concentrations for the years corresponding to the modelling years (i.e. 2021, 2031 and 2040), based on the emission projections.

Using the 2011-2014 compliance status for the airshed as a basis, the emission reduction required (SO_2, NO_2 and VOCs) was calculated for each airshed. The required emission reduction was then applied to the 2021, 2031 and 2040 projections.

For SO_2 and NO_2, a 2016 base load emission for the airshed was determined. It was assumed that the emission base load had to be achieved for the 2040 projections (including abatements) in order to achieve compliance with an air quality standard. To avoid overly conservative results, it was further assumed that compliance would be estimated based on the 98^{th} percentile of the maximum of the monitoring data for 2006-2014. This difference was calculated as a percentage reduction required. The calculated percentage reduction required was multiplied by the 2016 emission projections to give the 2016 base load.

To calculate future year emission loads, it was assumed that the relative percentage breakdown of emissions from sectors would remain stable with time in the BAU scenario, based on 2013/2014 data for industry. The abatement emission load reduction was applied to the relevant years, and the outcome was compared with the base load emissions. It was considered that, if the 2040 projected emissions with abatements were less than the calculated 2016 base load emissions, then compliance could be assumed to be achieved with the abatements applied.

For O_3, it was necessary to vary the approach. Based on monitoring data, a reduction in ambient O_3 concentration (expressed in ppb) was calculated for the lowest proposed O_3 standard for the 1-hour, 4-hour and 8-hour O_3 periods (see Table 1-1). Using an equivalence approach, it was assumed "*for every 1,000 tonne of VOCs reduced, 1 ppb reduction of O_3 could be achieved*". This reduction was calculated by comparing the 2040 VOCs projected emissions with abatements and the 2016 VOC emissions to determine the VOC reduction in tonnes. With the determined VOC reduction, the change in O_3 was then estimated based on the stated relationship. In this approach, the O_3 ppb reduction was calculated based on the available monitoring.

The yearly projected emissions for the BAU and Abatement Package scenarios, and for the timeframe 2016 to 2040, were made available as an input to the MCA.

3.2.2.3 Definition of Abatement Package

From an air quality perspective, the MCA considered the effectiveness, efficiency and appropriateness of individual abatement measures (refer to the CBA in Appendix C). The MCA delivered a suite of emission-reduction measures (the Abatement Package) that was applied to all airsheds consistently. The Abatement Package included eight prioritised measures (noting that one of these was common to both SO_2 and NO_2):

- SO_2
  - De-SO_X and gas capture storage standards for non-gas-fired power stations.
  - De-SOx at petrol refineries.
  - De-SOx at iron and steel production facilities.
- NO_2
  - De-NO_x and gas capture storage standards for non-gas-fired power stations.
  - Non-road diesel engines improved emission controls.
  - Industry NOx control technology – cement, iron and steel and aluminium industry.
- VOCs
  - VOCs control for solvent aerosol use. This assumed a regulatory requirement for reduction or reformulation in consumer aerosol products.
  - Improved surface coating standards. This assumed a regulatory requirement for reduction or reformulation in surface coating products.
  - On-board refuelling vapour recovery. This assumed a regulatory requirement for on-board emission control systems to capture fuel vapour from the fuel tank during vehicle refuelling. It is important to note that vehicles imported from the USA are already at this specification (2019-2020). However, the majority of imports to Australia do not currently meet this specification, so regulatory change is essential to achieve market penetration.

For the SO_X and NO_X abatement measures it was assumed that there would be a regulatory requirement for the implementation of control technology retrospectively for existing operations/engines, and setting of expectations for future facilities/engines. It was considered that the measures affecting power generation or industry would only have a direct benefit for the local population due to nature of dispersion.

Further details of the individual measures making up the Abatement Package are presented in Annexure C.

3.2.2.4 Emission reductions for the Abatement Package

For the measures in the Abatement Package, the associated emission reductions for Melbourne and Sydney were determined specifically, and then incorporated into the inputs for the dispersion modelling. For the airsheds identified as being potentially constrained with respect to a given standard, a further analysis was undertaken to assess the influence of the Abatement Package in assisting the airshed in meeting the standard in future years.

Projected emissions for the Abatement Package scenario were derived out to 2040. Assumptions were made with respect to the implementation of abatement within all airsheds. These assumptions were as follows:

- Abatement uptake was assumed to be 20% in 2020, followed by a linear reduction in emissions to 50% uptake by 2030, and then another linear reduction in emissions to 100% uptake in 2040. This therefore provided a twenty-year time horizon for assessing implementation.
- For airsheds dominated by a limited number of emission sources (i.e. less than three sources) a 0% emission reduction was applied in 2020, then a linear reduction to 100% uptake by 2030.
- Industry closure or shutdown was taken into account for specific airsheds where this could be confirmed with certainty. That is, emissions relating to an affected facility were removed from the emission inventory from the date of projected shutdown.
- For non-road diesel emissions, the abatement uptake was assumed to be 0% in 2020, followed by linear reductions in emissions to 2030 and 2040 (ENVIRON, 2010). The reductions in emissions took into account the projected vehicle fleet changes and vehicle kilometres travelled.

3.3 SO_2 emission projections

The SO_2 emission projections are shown in Annexure D, Section D.1.

In Sydney the majority of SO_2 emissions are from the industrial and off-road mobile sectors, with total emissions in the BAU scenario being forecast to increase by around 30% between 2011 and 2040. The Abatement Package was predicted to have a variable impact on SO_2 emissions in the future, most notably leading to a substantial reduction in industrial emissions between 2021 and 2031. There was, however, a further projected growth in emissions beyond 2031, although in 2040 the total SO_2 emission remained around 30% lower than the BAU scenario.

In the Lower Hunter (Newcastle) and Illawarra (Wollongong) regions, SO_2 emissions were dominated by industrial sources. In the Lower Hunter total emissions were projected to increase by around 45% between 2011 and 2040 in the BAU scenario. The Abatement Package was projected to give a marked reduction in emissions between 2021 and 2040, with total emissions being around 60% lower than under the BAU scenario in 2040. In the Illawarra total emissions were projected to increase slightly between 2011 and 2040, with the Abatement Package resulting in total emissions being around 75% lower than under the BAU scenario in 2040.

Emissions of SO_2 in the Port Phillip Region and the Latrobe Valley were again dominated by industrial sources. In the Port Phillip Region there was already forecast to be a pronounced reduction in emissions between 2016 and 2031 in the BAU scenario, with a more gradual reduction between 2031 and 2040. The Abatement Package resulted in a further reduction in emissions by 2040, such that by 2040 the commercial sector was predicted to be the dominant source of SO_2. In the Latrobe Valley the Abatement Package would counteract a projected growth in emissions in the BAU scenario after 2031, with emissions in 2040 being around 90% lower than in the BAU scenario.

In south-East Queensland there was predicted to be a substantial increase (around 50%) in SO_2 emissions between 2016 and 2041 under the BAU scenario. The Abatement Package resulted in emissions by 2040 being similar to those in 2021, but emissions in the region were increasing towards the end of the time frame of the projections.

There was a noticeable step-wise reduction in the projected emissions in Perth as a result of the Abatement Package, and this was associated with the abatement of a single dominant industrial point source in the airshed.

In the Adelaide, Hobart, Darwin and Canberra airsheds the Abatement Package was projected to have little to no distinguishable impact on SO_2 emissions.

3.4 NO_x emission projections

The NO_X emission projections are shown in Annexure D, Section D.2.

In Sydney emissions were mainly from the on-road mobile, off-road mobile and industrial sectors. Emissions were projected to decrease between 2011 and 2031, but then increase between 2031 and 2040. The Abatement Package had a relatively small impact on reducing NO_x emissions, and its effectiveness over time would not be sustained.

As with SO_2, emissions of NO_X in the Lower Hunter and Illawarra regions were strongly influenced by industrial sources. In the Lower Hunter, emissions of NO_X in the BAU scenario were projected to increase by around 20% between 2011 and 2040.The Abatement Package had a noticeable impact on reducing NO_x emissions, and it retained its effectiveness over time, such that by 2040 emissions were estimated to be around 40% lower than in the BAU scenario. For Illawarra in the BAU scenario, emissions of NO_X were projected to be relatively stable in the future. The Abatement Package had a noticeable impact on reducing NO_x emissions between 2021 and 2031, although the projected emissions remained stable from 2031 onwards.

In the Port Phillip Region the main contributors to NO_X emissions are on-road mobile, industrial and domestic-commercial sources. Emissions after 2021 were projected to be quite stable. The Abatement Package had little impact on reducing NO_x emissions. In the Latrobe Valley region, the Abatement Package did have a marked impact on reducing industrial NO_X emissions, with emissions being around 50% lower than in the BAU scenario by 2040.

For South-East Queensland emissions for NO_X were split between industrial-commercial, on-road and other mobile sources. The Abatement Package had a noticeable impact on reducing industrial emissions, but had little to no discernible impact on road vehicle emissions. By 2040, total emissions with the Abatement Package were around 25% lower than in the BAU scenario.

In Adelaide, NO_X emissions in the BAU scenario were projected to decrease between 2016 and 2031, but then remain quite stable after 2031. The Abatement Package also has a noticeable impact on reducing industrial emissions, but not emissions from the other main sectors (on-road mobile and commercial). By 2040, total emissions with the Abatement Package were around 25% lower than in the BAU scenario.

For Perth the Abatement Package has a noticeable impact on reducing industrial emissions, and retained its effectiveness over time. The Abatement Package has little to no discernible impact on emissions from the on-road mobile sector.

For the Hobart and Canberra airsheds, the Abatement Package was projected to have little to no distinguishable impact on NO_x emissions.

For Darwin the Abatement Package reduced industrial emissions, although emissions were still predicted to have a year-on-year increase in emissions beyond 2031.

3.5 VOC emission projections (as proxy for ozone)

O_3 is formed by the reaction of NO_x, a large group of VOCs and other compounds in the presence of sunlight. The combustion of fuel in vehicles is a key source of both NO_x and VOCs, and is therefore important in the consideration of O_3 formation. The rate at which O_3 is formed is limited by the amount of sunlight and the amount of NO_x and VOCs available, and the reactivity of the VOCs in a specific airshed. The formation of O_3 is therefore unique to each airshed, and applying a universal O_3 Abatement Package scenario may not lead to the same results in each airshed. In some areas, the changes to the NOx and VOC emissions may cause increases in O_3 concentrations.

It is also important to note that the content of VOC emission inventories varied across the airsheds. For example, biogenic sources were not included in some inventories. Similarly, the VOC source categories varied across the airsheds. When making comparisons, it is especially important to limit the interpretation to comparing the change within, rather than across, airsheds.

The VOC emission projections are shown in Annexure D, Section D.3.

In Sydney the main source of VOCs was the domestic-commercial sector. In the BAU scenario total emissions were predicted to decrease slightly overall between 2011 and 2040. The Abatement Package has a noticeable impact, reducing VOC emissions from domestic and commercial sources, but it had little to no impact on emissions from the other sectors. By 2040, total VOC emissions with the Abatement Package were around 25% lower than in the BAU scenario.

In the Lower Hunter and Illawarra regions, biogenic sources and domestic-commercial activity were the main contributors to VOC emissions, with emissions being quite stable with time. The Abatement Package reduced VOC emissions from domestic and commercial sources in the two airsheds, but the overall decreases in total emissions were quite small. The Abatement Package had little to no impact on emissions from the other sectors.

The main sources of VOCs in the Port Phillip Region were domestic and commercial activity. The Abatement Package had a marked impact on emissions from these sectors. However, it had little to no impact on the other sectors. By 2040, total VOC emissions with the Abatement Package were around 25% lower than in the BAU scenario.

For Latrobe Valley, the package had a noticeable impact on reducing VOC emissions from domestic and commercial sources. The Abatement Package had little to no impact on the other source categories, and emissions remained relatively stable over time.

For South-East Queensland the Abatement Package has a noticeable impact on reducing VOC emissions from area sources. It has little to no impact on the other source categories.

In Adelaide, Perth, Darwin and Canberra the Abatement Package had a noticeable impact on reducing emissions from domestic and commercial sources. It had little to no impact on the other VOC emission source categories.

The Abatement Package has no noticeable impact on emissions in Hobart.

4 Air quality projections

4.1 Methodology

4.1.1 General framework

The overall modelling framework used in the air quality study is shown in Figure 4-1. For NSW and Victoria an impact pathway approach - involving integrated modelling of emissions, air quality, and health impacts - was used to quantify the health costs of air pollution. This maximised the accuracy with which the benefits of the Abatement Package could be monetised. For the other jurisdictions a simpler approach had to be used, and this had an inherently higher uncertainty.

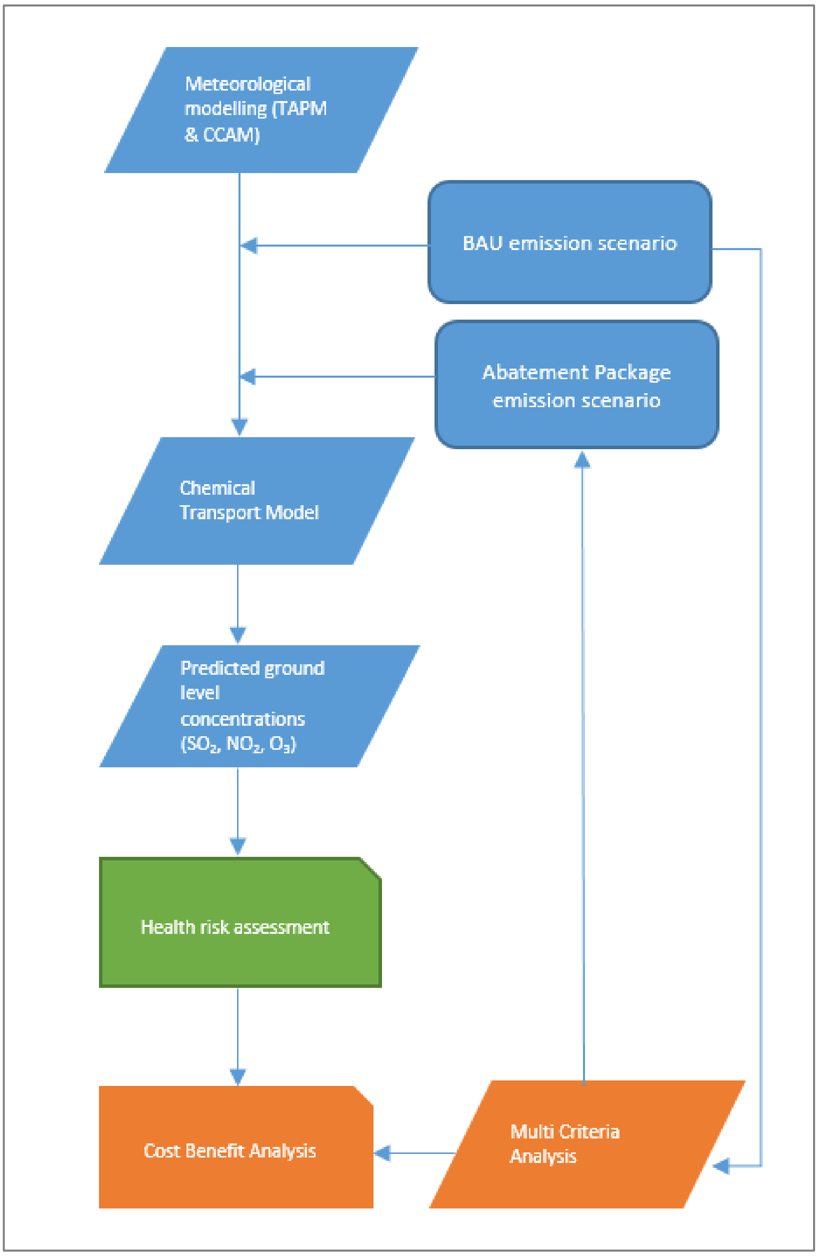

Figure 4-1: Overview of SO_2, NO_2 and O_3 modelling system for NSW and Victoria

The key steps in the air quality studies for NSW and Victoria included:

- The development of representative BAU and Abatement Package scenarios.
- The estimation of emissions for the scenarios based on ambient monitoring trends, inventories and population projections.
- Atmospheric dispersion modelling for the scenarios.
- Interpretation of the results, expressed as ground-level concentrations of pollutants.

Further steps included a co-analysis of concentration data and hospital admissions data (morbidity and mortality) as the basis of an HRA for each scenario, and the subsequent use of the HRA as an input to the CBA.

Different air quality models were used in NSW and Victoria, and these were consistent with those used by the regulatory agencies in each state. The models were validated, and were considered the most sophisticated and accurate ones available at the time of the study.

Each air quality modelling system consisted of a prognostic meteorological model (CCAM for NSW and TAPM for Victoria), an air emissions inventory, a chemical transport model (CTM), and post-processing routines. Complex chemical reaction mechanisms were used to predict how the airsheds responded to different emission scenarios.

4.1.2 Reduced number of modelled months

The impact pathway approach required the air quality outputs to be produced for a 12-month period. Due to the complex atmospheric chemistry and physics embedded in the TAPM-CTM and CCAM-CTM models, as well as their large domain size, the run time for a single month was three days using 12 Intel Xeon 3.5 GHz processors. To manage the computing requirements, a four-month modelling approach was applied to each scenario and year (2016, 2021, 2031, 2040). The modelled months, and the months they were used to represent, are shown in Table 4-1.

Table 4-1: Modelled Months and Interpolated Months

Modelled month	Representative months
January	December and February
April	March and May
July	June and August
October	September and November

The four modelling months were selected based on (but not limited to):

- Data availability (e.g. input data were incomplete for some months).
- Monthly patterns in concentrations (i.e. ensuring that maximum and minimum pollutant concentrations were captured).
- Seasonal trends in meteorology and air pollution.

Data analysis and transformation of the remaining eight months was undertaken to create a representative annual dataset.

In terms of ground-level concentrations, there was a consistent seasonal pattern for the NSW Greater Metropolitan Region (GMR) and Victorian (Port Phillip region) airsheds. The seasonal patterns in concentrations of NO_2 and O_3 in NSW, based on long-term monitoring data, are shown in Figure 4-2 and Figure 4-3 respectively. The corresponding seasonal patterns in concentrations for NO_2 and O_3 in Victoria are shown in Figure 4-4 and Figure 4-5 respectively.

In winter, reduced mixing in the atmosphere is common because of stronger and more frequent temperature inversions. Therefore, pollutants like NO_2 are more prone to be trapped in a shallow layer near ground level and accumulate. This is often compounded by calm conditions (little or no wind), further limiting dispersion of the pollutants.

Higher pollutant concentrations in winter months are also affected by other factors. For instance, in terms of vehicular emissions, vehicle cold starts in winter lead to longer periods of incomplete combustion and longer warm-up times for engines and catalytic converters, which generate higher emissions and thus ambient concentrations (Figure 4-2 and Figure 4-4). Other emission sources (such as domestic wood heating) become more prevalent in the airshed inventory during winter months.

In summer months, elevated ground level O_3 concentrations can be observed since O_3 is formed primarily from photochemical reactions between VOCs and NO_x in the presence of sunlight (Figure 4-3 and Figure 4-5). As a result, it was important to model the summer months to capture the highest ambient O_3 concentrations for the purposes of the study.

4.1.3 Emission inventories and scaling

Emission inventories are divided into sectors such as mobile, industrial, commercial, domestic and biogenic. Each sector contributes to O_3 production, but to an extent that is not linearly related to its relative contribution to total emissions. The formation of O_3 is complex in several ways. The photochemistry of O_3 is highly non-linear, and the relationship between concentrations of the two precursors (NO_x and VOCs) and resulting maximum O_3 concentration is best described as a function of both NOx, and the VOC:NOx ratio. The emissions contributing to the urban plume, and hence the O_3 concentration, vary in both space and time (DECCW, 2010). They are distributed very unevenly through the urban area, and vary throughout the day.

The management of air quality therefore needs to consider the relative significance of the various sectors, the distribution of emissions from each sector in space and time, and the potential impacts of any changes in emissions on ground-level concentrations.

In order to investigate the impacts of changes in emissions, the study adopted the emission-scaling approach used by DECCW (2010) to assess the changes in not only in O_3 but also NO_2 and SO_2. Each emission sector was scaled according to the projected emission as well as the base case emission. The emissions of NO_x, CO, PM_{10} and VOCs were changed for each scenario using scaling factors in the CTM input files. The scaling factors were applied to all sources over the whole grid. In addition, the files contained gridded emission apportionment ratios for each of the three grids, i.e. Australia grid, State grid (Victoria and NSW) and the inner most grid (Port Phillip and GMR).

Industrial SO_2 emissions could not be adjusted in the model configuration files. Therefore, emission files were only used to scale SO_2 emissions for the following:

- Wood heaters
- General area sources
- Diesel vehicles, petrol vehicles, other vehicles, and fuel loses through volatility.

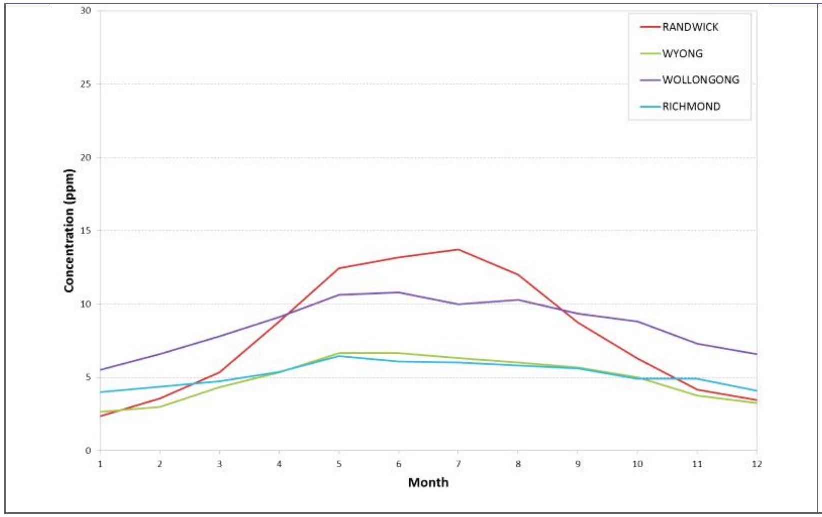

Figure 4-2: Monthly average NO_2 concentration in Sydney GMR (2005-2015; NSW OEH, 2015)

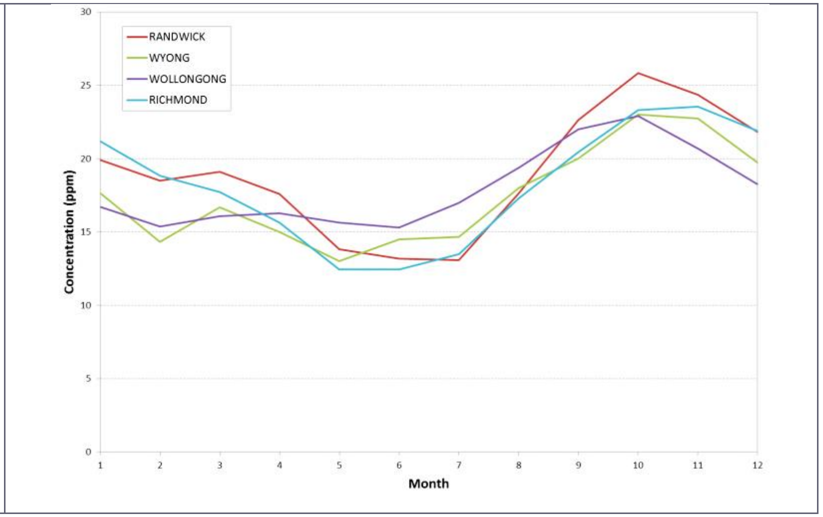

Figure 4-3: Monthly average O_3 concentration in Sydney GMR (2005-2015; NSW OEH, 2015)

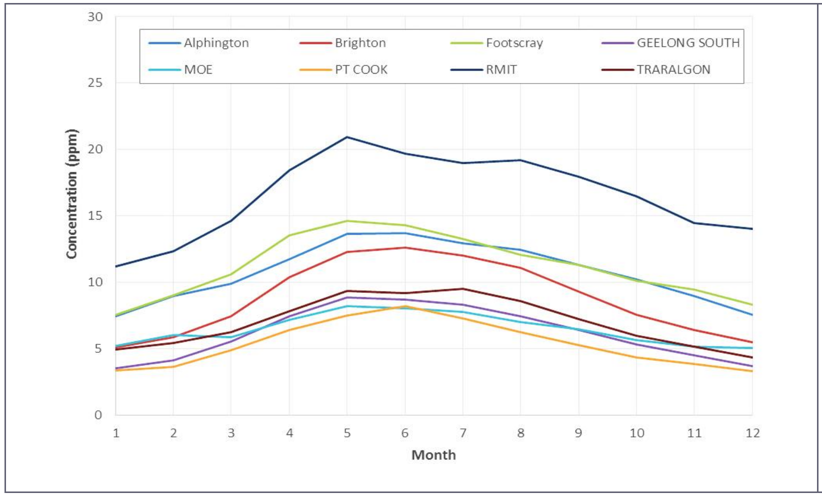

Figure 4-4: Monthly average NO_2 concentration in Victoria (2003-2014)

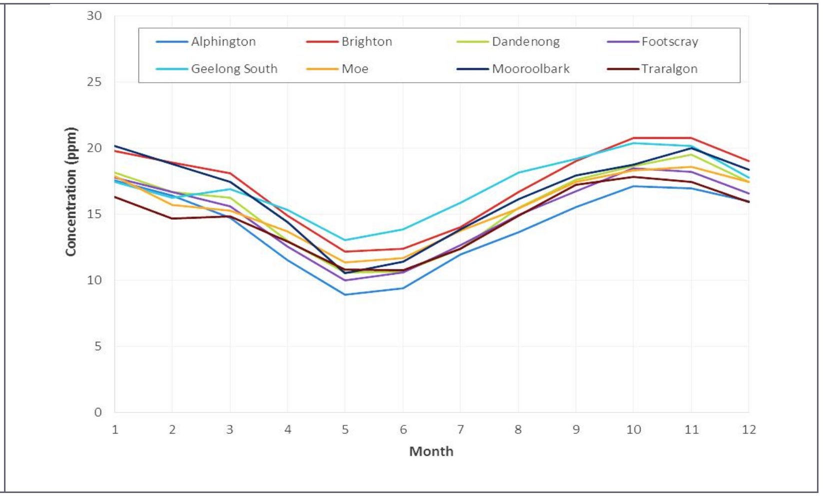

Figure 4-5: Monthly average O_3 concentration in Victoria (2003-2014)

To understand SO_2 emissions from industry, emissions were modelled as tracers with no chemistry and no other emission sources operating. The resulting concentrations for industrial sources were relatively conservative, as SO_2 removal chemistry was not considered. The outputs were then scaled based on the SO_2 industry emission inventory changes to determine ground-level concentrations. These results were then combined with the model outputs for the other sectors to determine total SO_2 concentrations. This method resulted in general reductions in concentrations across the whole modelling grid, where as in reality the largest reductions will occur near industrial facility locations. This means that, in some locations, SO_2 concentrations will have been greatly overestimated, while at others it will have been underestimated, depending on the locations of the industrial sources.

4.1.4 Model outputs for the health risk assessment

The dispersion modelling was performed to inform the HRA. The statistics provided for the HRA are stated in Table 4-2. In general, a dispersion model should typically predict concentrations within a factor of two compared with equivalent monitored data for a specific averaging period or statistic. Longer averaging statistics (i.e. annual average) are considered to be more reliable than short term statistics (e.g. 1-hour average) (USEPA, 2005).

Table 4-2: Modelled outputs for HRA

Parameter and statistics provided by pollutant		
SO_2	NO_2	O_3
Daily 1-hour average maximum	Daily 1-hour average maximum	Daily 1-hour maximum
Daily 24-hour average	Daily 24-hour average	Daily 4-hour average maximum
Annual average	Annual average	Daily 8-hour average maximum

The statistics for the HRA were required for every year from 2016 to 2040. For each modelled year, the statistics were based directly on model outputs. The concentrations for non-modelled years were predicted using a linear interpolation between the modelled years, except for the years 2016 to 2019 for the Abatement Package scenario. This is because it was assumed that the first year that the abatement activities would show emission reductions was 2020. For the Abatement Package the statistics for the years 2016 - 2019 were therefore the same as those in the BAU scenario.

The HRA statistics were determined for current and historical monitoring locations, except for select locations that were installed purely to monitor significant industrial sources that have been shut down prior to 2016 (Figure 4-7 and Figure 4-6).

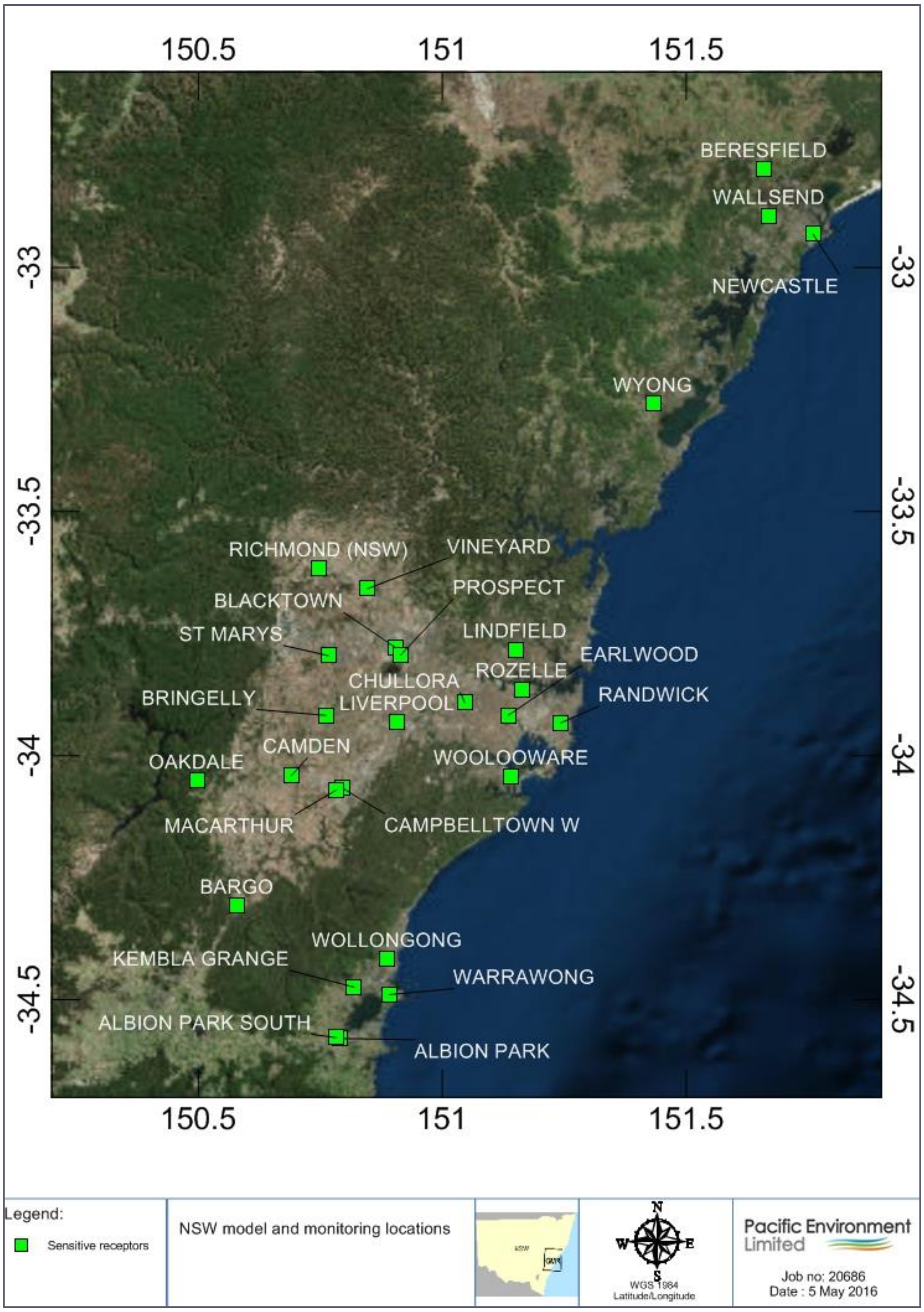

Figure 4-6: NSW model domain and monitoring locations

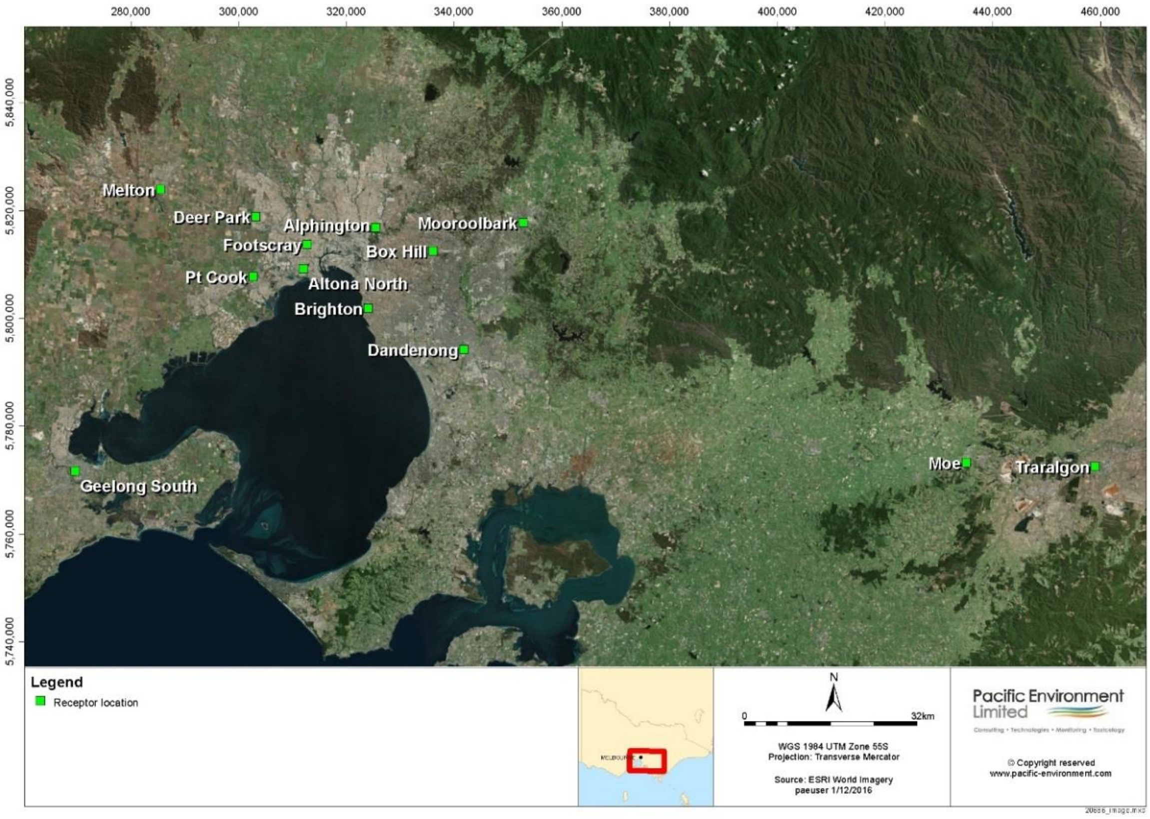

Figure 4-7: Victoria model domain and monitoring locations

4.2 Air quality modelling

4.2.1 New South Wales approach

4.2.1.1 Meteorological modelling

In NSW the meteorological modelling used the Conformal-Cubic Atmospheric Model (CCAM), a global stretched grid atmospheric simulation model which has been used extensively to downscale from synoptic to the mesoscale (McGregor and Dix, 2008). In this study, CCAM was run for the year between July 2010 and June 2011, a representative meteorological period from modelling studies (Cope et al., 2014).

4.2.1.2 Chemical transport modelling

The Chemical Transport Model (CTM) component of the NSW model was similar to that used in Victoria (Section 4.2.2.2). The CCAM-CTM modelling system was developed by CSIRO, and has been validated in NSW (e.g. Duc et al., 2016). The model emission input files for the GMR emission inventory were provided by CSIRO with permission from NSW OEH. These files distributed emissions in either a gridded format or as point sources. The gridded emissions were defined for a fine-scale grid (1 km x 1 km). Separate emission inputs were used for the different sectors, including petrol and diesel road vehicles, wood heaters, area sources and point sources.

4.2.2 Victoria approach

The modelling for Victoria covered the Port Phillip and Latrobe Valley airsheds, with the TAPM-CTM modelling suite being used.

4.2.2.1 Meteorological modelling

TAPM (The Air Pollution Model) is a three-dimensional meteorological and air pollution model developed by the CSIRO (Hurley, 2008a, 2008b; Hurley et al., 2002a, 2002b; Hibberd et al., 2003; Luhar and Hurley, 2003). TAPM solves the fundamental fluid dynamics and scalar transport equations to predict meteorology and (optionally) pollutant concentrations. It consists of coupled prognostic meteorological and air pollution concentration components. The model predicts airflows that are important to local-scale air pollution, such as sea breezes and terrain-induced flows, against a background of larger scale meteorology provided by synoptic analyses. TAPM incorporates a number of databases, including terrain, vegetation and soil types, and sea-surface temperature.

TAPM was run for the year 2006, a representative meteorological year for modelling studies (EPA Victoria, 2013). The outer domain was a grid of 70 x 60 cells with 18 km spacing and a centre point of latitude 14.966705 and longitude -37.81666. There were two nested grids of 9 x 9 km and 3 x 3 km.

4.2.2.2 Chemical transport modelling

The chemical transport and gas phase air pollution modelling was undertaken using the CSIRO's CTM component of TAPM (Cope et al., 2004). TAPM-CTM has been validated in Victoria (EPA Victoria, 2013), and has been adopted in a number of studies related to public health (Physick et al., 2014; Broome et al., 2016).

The CTM is a three-dimensional Eulerian chemical transport model which includes emissions, transport, chemical transformation, and wet and dry deposition. CTM also includes algorithms for calculating biogenic emissions from vegetation, soils and water. It allows the modelling of photochemical transformations, where subtle changes in emissions, such as the speciation of VOCs, are considered. TAPM-CTM is equipped with several chemical reaction schemes that can be used depending on the complexity of the application. The Victorian model used the chemical scheme Carbon Bond 2005 with aerosol chemistry (cbond05_aero) (Sarwar et al., 2011). Cope et al. (2009) described the TAPM-CTM model, including the base equation for the chemical transformations.

The emission files for the 2006 inventory were provided by CSIRO with permission from EPA Victoria. These files distributed emissions in either a gridded format or as point sources. The gridded emissions were defined for both a large-scale grid (5 km x 5 km) and a small-scale grid (1 km x 1 km). As in NSW, the emission inputs were defined for various different sectors.

4.2.3 Presentation of model outputs

The model results for each pollutant have been summarised as airshed compliance tables. The tables summarise the number of unique days on which each airshed was predicted to be in exceedance of short-term standards, again based on the results for the monitoring stations in Annexure A. For annual mean concentrations, the total number of monitoring stations exceeding a standard was determined. The data for short-term averaging periods were based on maximum predicted concentrations. Although not reported here, consideration was also given to a range of high percentile values (99^{th}, 98^{th}, 95^{th}). The percentile approach has been used to illustrate whether any exceedances are a result of relatively infrequent 'extreme' events, or are more prevalent during the year.

In addition, contour plots, showing the spatial distribution of ground-level concentrations for each pollutant and averaging period in the BAU and Abatement Package Scenarios, are shown in Annexure F. These contours illustrated the areas that were more at risk of exceeding the proposed standards (Annexure F). SO_2 concentration contours could not be developed due to the method used for scaling the industrial emission sources in the model (described in Section 4.1.3).

4.3 Air quality modelling results

4.3.1 Sulfur dioxide

4.3.1.1 Predicted concentrations

The results of the air dispersion modelling for maximum 1-hour SO_2 concentrations in the BAU and abatement Package scenarios are summarised in Figure 4-8 and Figure 4-9 respectively. The corresponding results for maximum 24-hour SO_2 concentrations are shown in Figure 4-10 and Figure 4-11. These figures relate to the monitoring stations listed in Annexure A, and show the maximum SO_2 concentrations predicted at any monitoring location. Generally, the figures show that the maximum SO_2 concentrations is predicted to increase with time (or remain stable) in the BAU scenario, and decrease with time (or remain stable) in the Abatement Package scenario.

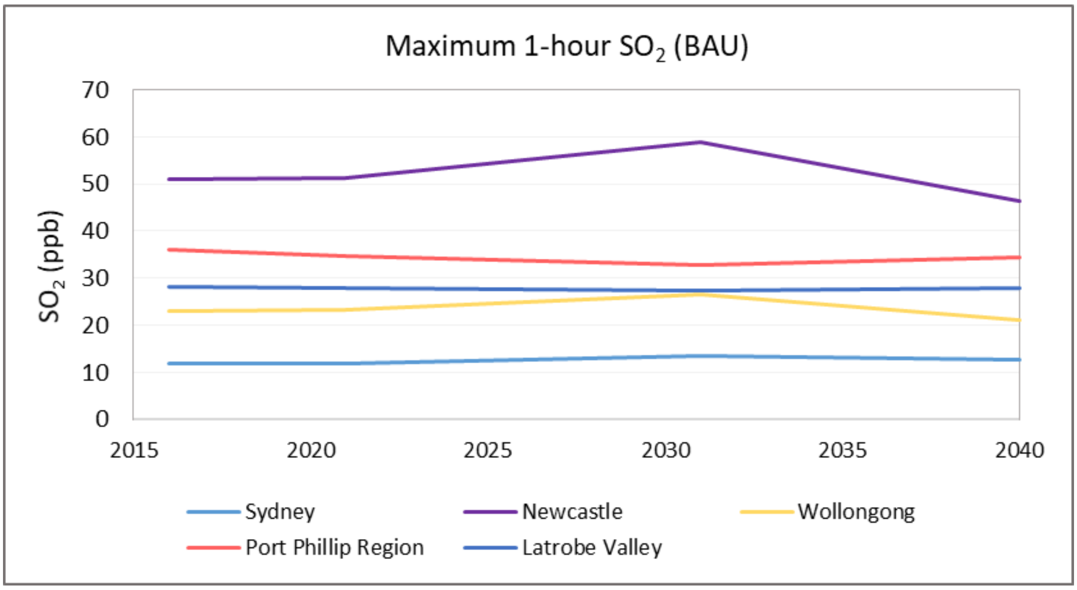

Figure 4-8: Modelled 1-hour maximum SO_2 concentrations at monitoring locations (BAU scenario)

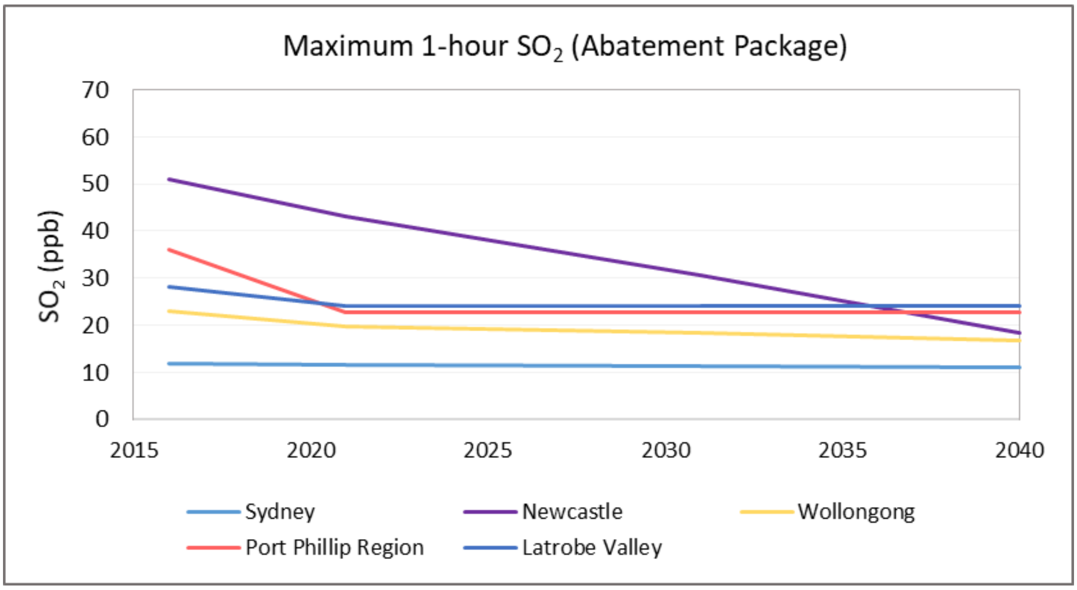

Figure 4-9: Modelled 1-hour maximum SO_2 concentrations at monitoring locations (Abatement Package scenario)

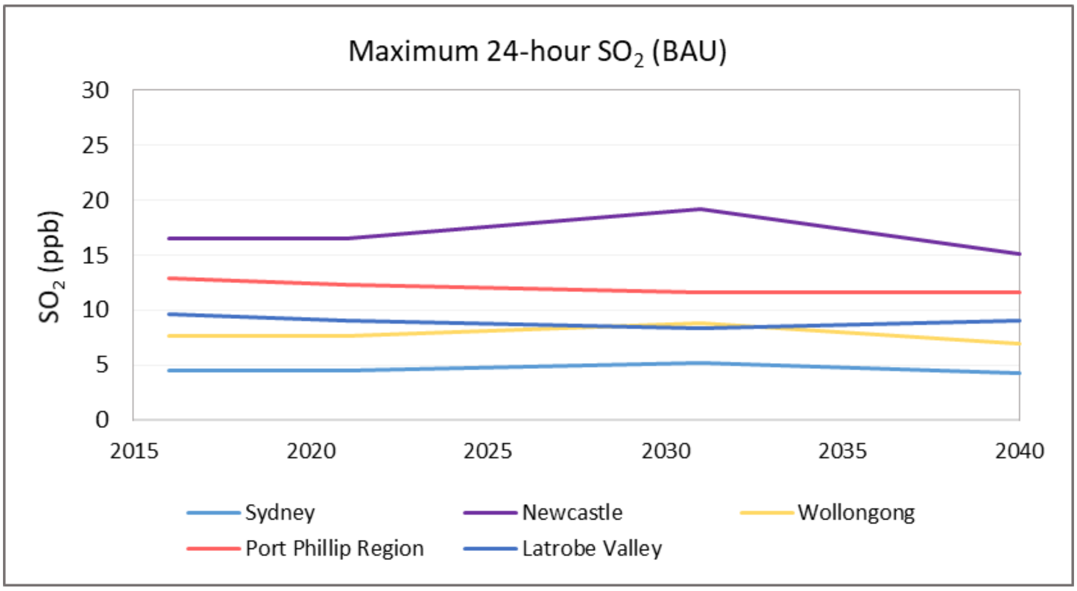

Figure 4-10: Modelled 24-hour maximum SO_2 concentrations at monitoring locations (BAU scenario)

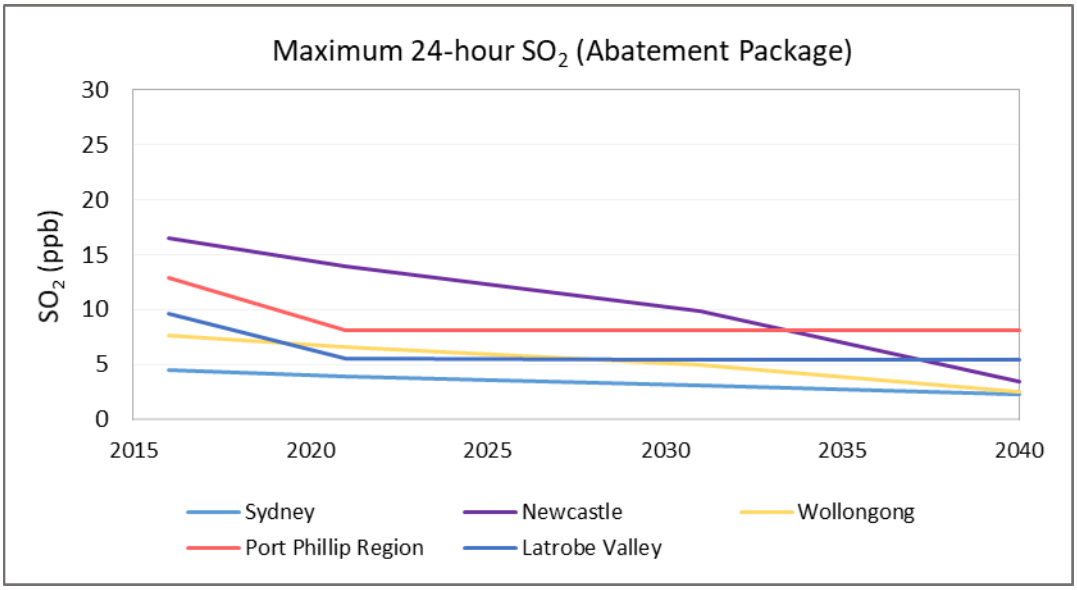

Figure 4-11: Modelled 24-hour maximum SO_2 concentrations at monitoring locations (Abatement Package scenario)

4.3.1.2 Exceedances of standards

For 1-hour and 24-hour SO_2 in NSW the projected unique exceedance days in the BAU and Abatement Package scenarios are shown in Table 4-3 and Table 4-4 respectively. The corresponding results for Victoria are shown in Table 4-5 and Table 4-6. For annual mean SO_2, these tables shown the number of monitoring stations in each airshed with exceedances. The BAU tables also include annual average numbers of exceedances from the monitoring data over the period 2010-2014, the purpose being to show any consistency (or otherwise) between the monitoring and modelling outcomes.

All airsheds covered by the modelling complied with all the 1-hour standards prior to the abatements being applied. Compliance continues into the future with the Abatement Package in place.

In Sydney, there was also compliance with all the 24-hour standards in the BAU scenario, whereas in the other airsheds there were exceedances of the 7 ppb standard. The Abatement Package resulted in a substantial reduction in the number of exceedances. In the Abatement Package scenario, Newcastle would comply with the standard in 2040, and Wollongong in 2021. The Port Phillip Region and the Latrobe Valley were predicted to meet the standard in 2040 and 2021 respectively.

The results for the different percentiles indicated that changes in the patterns of exceedances were not due to the reduction of a small number of high concentrations, but a more general reduction across the concentration range.

For all airsheds covered by the modelling, there was compliance with both the proposed annual mean standards (10 ppb and 20 ppb) prior to the abatements being applied. Compliance continued into the future with the Abatement Package in place.

The comparison between the historical years and the future years in the BAU scenario indicates that the models were overestimating the numbers of exceedances of the 24-hour standard for SO_2.

Table 4-3: Projected exceedances of current and proposed SO_2 standards (BAU scenario, NSW)

Period	Standard (ppb)	NSW: Sydney Measured 2010-2014 annual average[(a)]	NSW: Sydney Predicted 2016	2021	2031	2040	NSW: Newcastle Measured 2010-2014 annual average[(a)]	NSW: Newcastle Predicted 2016	2021	2031	2040	NSW: Wollongong Measured 2010-2014 annual average[(a)]	NSW: Wollongong Predicted 2016	2021	2031	2040
Total number of unique exceedance days																
1-hour	75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total number of unique exceedance days																
24-hour	7	-	-	-	-	-	2	94	94	115	57	4	12	12	24	3
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total number of monitoring stations exceeding standard																
Annual	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(a) Rounded to nearest integer.

Table 4-4: Projected exceedances of current and proposed SO_2 standards (Abatement Package scenario, NSW)

Period	Standard (ppb)	NSW: Sydney 2016	2021	2031	2040	NSW: Newcastle 2016	2021	2031	2040	NSW: Wollongong 2016	2021	2031	2040
Total number of unique exceedance days													
1-hour	75	-	-	-	-	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-	-	-	-	-
	150	-	-	-	-	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-	-	-	-	-
Total number of unique exceedance days													
24-hour	7	-	-	-	-	94	45	3	-	12	-	-	-
	20	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-
Total number of monitoring stations exceeding standard													
Annual	10	-	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	-	-	-

Table 4-5: Projected exceedances of current and proposed SO_2 standards (BAU scenario, VIC)

Averaging period	Standard (ppb)	VIC: Port Phillip Region Measured 2010-2014 annual average[(a)]	VIC: Port Phillip Region Predicted 2016	Predicted 2021	Predicted 2031	Predicted 2040	VIC: Latrobe Valley Measured 2010-2014 Annual average[(a)]	VIC: Latrobe Valley Predicted 2016	Predicted 2021	Predicted 2031	Predicted 2040
Total number of unique exceedance days											
1-hour	75	-	-	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-	-	-
	150	-	-	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-	-	-
Total number of unique exceedance days											
24-hour	7	9	81	78	51	48	1	6	6	6	6
	20	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-
Total number of monitoring stations exceeding standard											
Annual	10	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	-

(a) Rounded to nearest integer.

Table 4-6: Projected exceedances of current and proposed SO_2 standards (Abatement Package scenario, VIC)

Period	Standard (ppb)	VIC: Port Phillip Region 2016	2021	2031	2040	VIC: Latrobe Valley 2016	2021	2031	2040
Total number of unique exceedance days									
1-hour	75	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-
	150	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-
Total number of unique exceedance days									
24-hour	7	81	6	6	-	6	-	-	-
	20	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-
Total number of monitoring stations exceeding standard									
Annual	10	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-

4.3.2 Nitrogen dioxide

4.3.2.1 Predicted concentrations

The results of the air dispersion modelling for maximum 1-hour concentrations in the BAU and abatement Package scenarios are summarised in Figure 4-12 and Figure 4-13. The corresponding results for maximum annual mean NO_2 concentrations are shown in Figure 4-14 and Figure 4-15. As explained earlier, the figures relate to the predictions at the monitoring sites in Annexure A.

In the BAU scenario, maximum 1-hour NO_2 concentrations are predicted to remain relatively stable in the future in the all modelled airsheds except the Port Phillip Region. The Port Phillip Region is predicted to have a reduction in peak concentrations until 2031, when they begin to increase again. In general, the Abatement Package resulted in relatively small reductions in maximum NO_2 concentrations by 2040. For Newcastle the Abatement Package had a more noticeable impact on reducing maximum NO_2 concentrations.

The maximum annual mean concentrations in Sydney were reduced noticeably in the Abatement Package scenario. In the other airsheds the reductions were quite small.

It is worth noting that several of the measures in the Abatement Package were industry-based. These measures, in particular those relating to power stations and cement and metal industries, lead to large reductions in emissions, but they are located outside major urban areas. Whilst they are likely to lead to improvements in peak concentrations in the local area, they are unlikely to significantly affect larger populations further away (i.e. in cities).

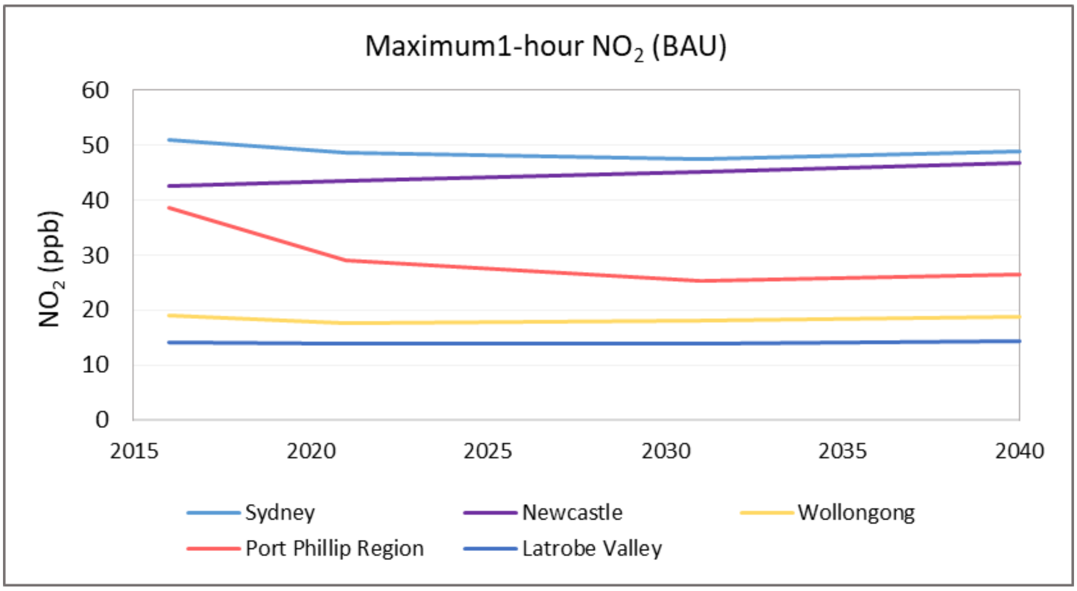

Figure 4-12: Modelled 1-hour maximum NO_2 concentrations at monitoring locations (BAU scenario)

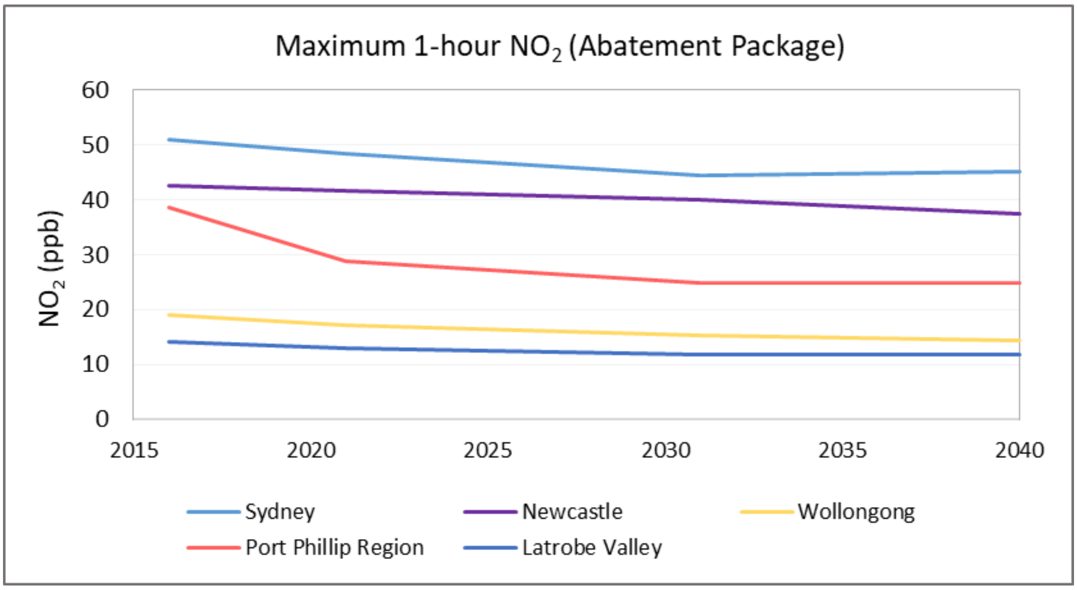

Figure 4-13: Modelled 1-hour maximum NO_2 concentrations at monitoring locations (Abatement Package scenario)

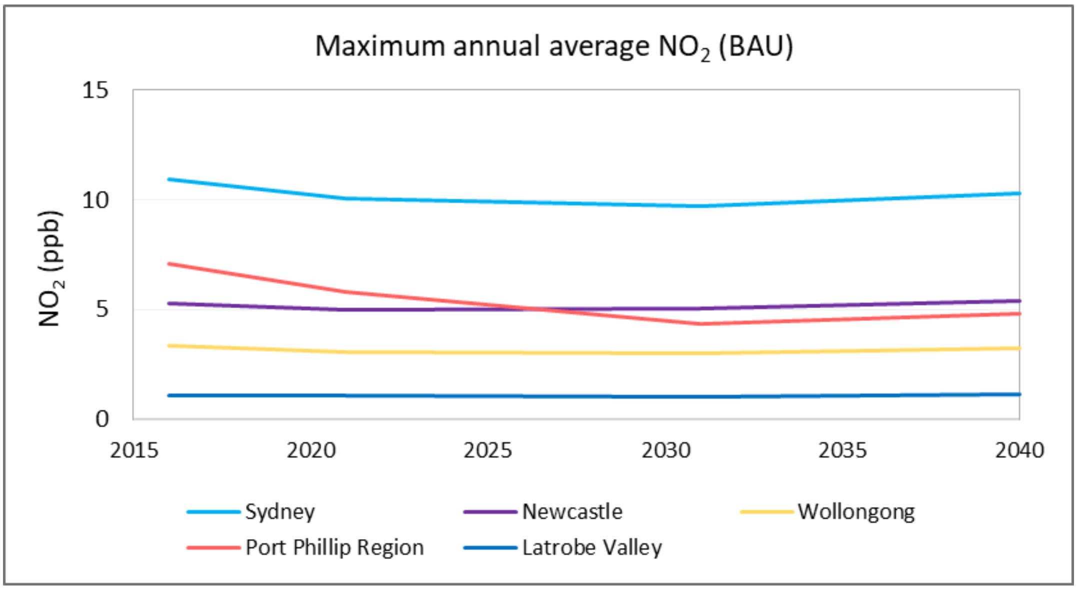

Figure 4-14: Modelled annual average NO_2 concentrations at monitoring locations (BAU scenario)

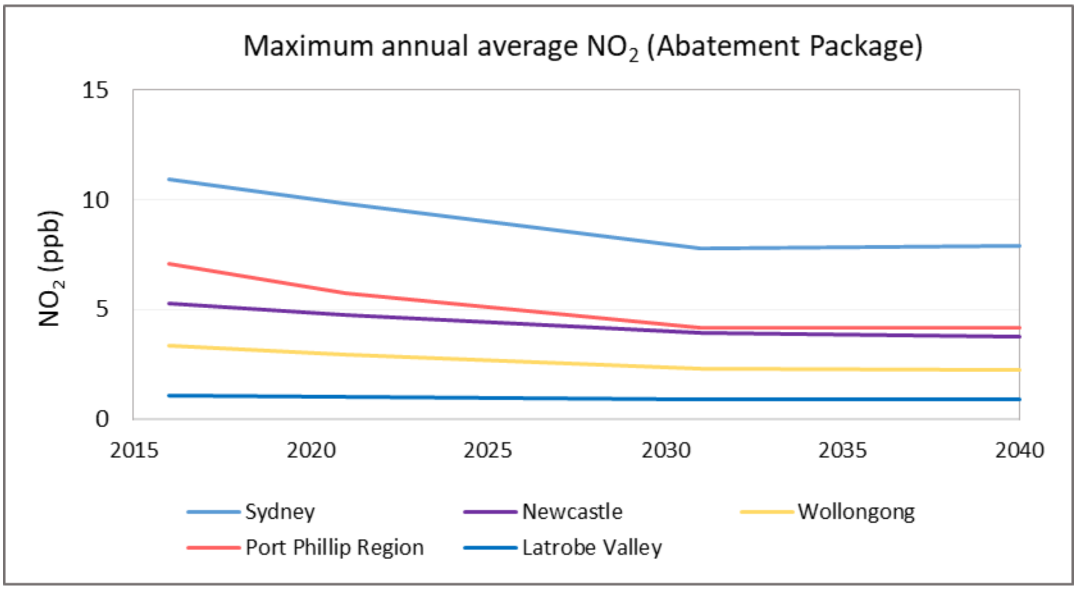

Figure 4-15: Modelled annual average NO_2 concentrations at monitoring locations (Abatement Package scenario)

4.3.2.2 Exceedances of standards

For NO_2 in NSW the projected unique exceedance days/stations in the BAU and Abatement Package scenarios are shown in Table 4-7 and Table 4-8 respectively. The corresponding results for Victoria are shown in Table 4-9 and Table 4-10. As with SO_2, the predictions are for the monitoring stations in Annexure A.

In the BAU scenario all airsheds covered by the modelling complied with all the 1-hour standards of 80, 97 and 120 ppb prior to the abatements being applied. There were exceedances of the 40 ppb standard, but only in Sydney and Newcastle.

The Abatement Package was predicted to slightly reduce the number of exceedances in Newcastle in 2031 and 2040.

The contours for ground-level concentrations (Annexure F) show the area predicted to not meet the standard to be significantly reduced with the Abatement Package. The Abatement Package did have an influence on the airsheds.

For all airsheds covered by the modelling, and in the BAU scenario, there was compliance with the current annual mean standard of 30 ppb and the proposed standard of 19 ppb. Compliance continues into the future with the Abatement Package in place. In Sydney and Wollongong there were some historical exceedances of the proposed standard of 10 ppb, and in Sydney alone some limited exceedances were predicted for the future.

The comparison between the historical measurements and the future predictions indicated that the models were generally underestimating the numbers of exceedances for NO_2 in Sydney and the Port Phillip Region.

As all NO_2 standards were predicted to be met at all monitoring locations in Victoria, contour plots have not been provided for this pollutant.

Table 4-7: Projected exceedances of current and proposed NO_2 standards (BAU scenario, NSW)

Period	Standard (ppb)	NSW: Sydney					NSW: Newcastle					NSW: Wollongong				
		Measured	Projected				*Measured*	Projected				*Measured*	Projected			
		2010-2014 annual average[(a)]	2016	2021	2031	2040	*2010-2014 annual average[(a)]*	2016	2021	2031	2040	*2010-2014 annual average[(a)]*	2016	2021	2031	2040
Total number of unique exceedance days																
1-hour	40	*21*	6	6	6	6	*1*	2	2	2	2	*4*	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total number of monitoring stations exceeding standard																
Annual	10	*4*	1	1	-	1	-	-	-	-	-	*1*	-	-	-	-
	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(a) Rounded to nearest integer.

Table 4-8: Projected exceedances of current and proposed NO_2 standards (Abatement Package scenario, NSW)

Period	Standard (ppb)	NSW: Sydney				NSW: Newcastle				NSW: Wollongong			
		2016	2021	2031	2040	2016	2021	2031	2040	2016	2021	2031	2040
Total number of unique exceedance days													
1-hour	40	6	6	6	6	2	2	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-
Total number of monitoring stations exceeding standard													
Annual	10	1	-	-	-	-	-	-	-	-	-	-	-
	19	-	-	-	-	-	-	-	-	-	-	-	-
	30	-	-	-	-	-	-	-	-	-	-	-	-

Table 4-9: Projected exceedances of current and proposed NO_2 standards (BAU scenario, VIC)

Averaging period	Standard (ppb)	VIC: Port Phillip Region					VIC: Latrobe Valley				
		Measured	Predicted				*Measured*	Predicted			
		2010-2014 annual average(a)	2016	2021	2031	2040	*2010-2014 annual average(a)*	2016	2021	2031	2040
Total number of unique exceedance days											
1-hour	40	9	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-
Total number of monitoring stations exceeding standard											
Annual	10	-	-	-	-	-	-	-	-	-	-
	19	-	-	-	-	-	-	-	-	-	-
	30	-	-	-	-	-	-	-	-	-	-

(a) Rounded to nearest integer.

Table 4-10: Projected exceedances of current and proposed NO_2 standards (Abatement Package scenario, VIC)

Period	Standard (ppb)	VIC: Port Phillip Region				VIC: Latrobe Valley			
		2016	2021	2031	2040	2016	2021	2031	2040
Total number of unique exceedance days									
1-hour	40	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-
Total number of monitoring stations exceeding standard									
Annual	10	-	-	-	-	-	-	-	-
	19	-	-	-	-	-	-	-	-
	30	-	-	-	-	-	-	-	-

4.3.3 Ozone

4.3.3.1 Predicted concentrations

The results of the air dispersion modelling for maximum 1-hour O_3 concentrations in the BAU and Abatement Package scenarios are summarised in Figure 4-16 and Figure 4-17. The corresponding results for maximum 4-hour concentrations are shown in Figure 4-18 and Figure 4-19, and those for maximum 8-hour concentrations are given in Figure 4-20 and Figure 4-21. The predictions are for the monitoring stations in Annexure A.

The formation of O_3 in Australian cities is a result of complex photochemical reactions involving VOCs and NO_X. The formation mechanisms, in particular whether the airsheds are VOC or NO_X limited, may be variable within an airshed, depending on the location, and the duration of an event, and is not well understood for most jurisdictions. This led to challenges with the Abatement Package scenario that has been modelled, with some increases in concentration in some locations. It is unclear whether an entire airshed can be classified as either NO_x or VOC limited, with some jurisdictions noting O_3 events of both types occurring at some stage, or in different locations. Analysis conducted in Sydney and Melbourne has indicated that the Sydney airshed is VOC limited and the Melbourne airshed NO_x limited. Therefore, the impact of abatement measures will vary and may lead to different results in each airshed. It should also be noted that the abatement measures did not cover motor vehicle abatements (with the exception of on-board refuelling vapour recovery). The emission inventories show that motor vehicles are a major source of both NO_x and VOCs in most airsheds. Reduction in VOCs and NO_x from these sources would lead to a reduction in population exposure as the emissions from motor vehicles are widely spread across the population.

For maximum 1-hour, 4-hour and 8-hour O_3 concentrations, the predictions in the BAU scenario show little change in the future for all airsheds. The Abatement Package led to reductions in O_3 concentrations in the Sydney airshed of up to 15% by 2040, and for the Newcastle airshed up to 18% by 2040. The reductions in Wollongong were smaller, being up to around 7% by 2040. In the Port Phillip Region and the Latrobe Valley the reductions were also below 10%.

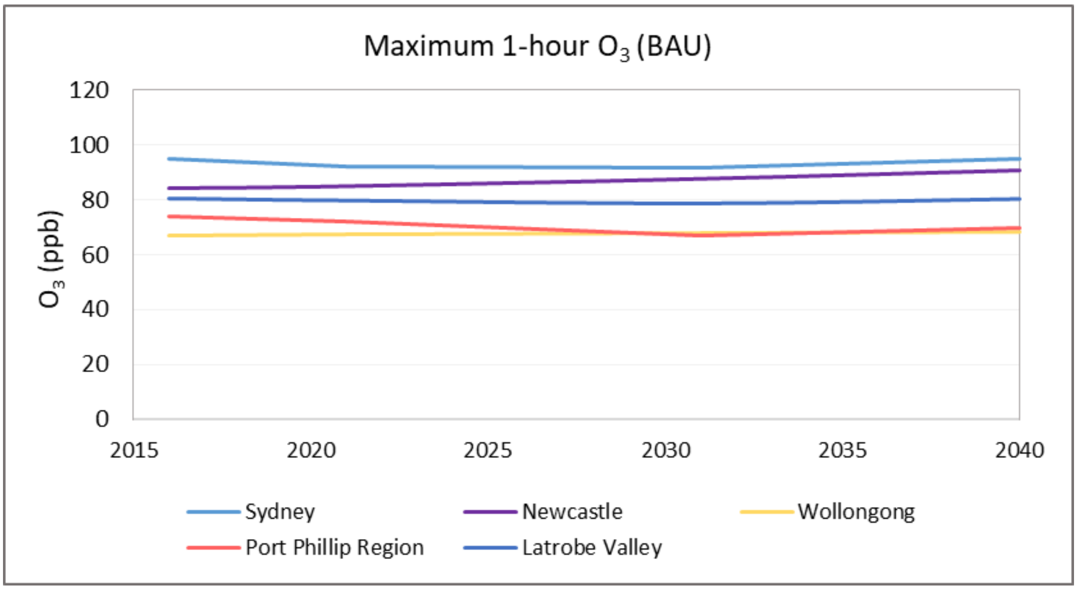

Figure 4-16: Modelled 1-hour maximum O_3 concentrations at monitoring locations (BAU scenario)

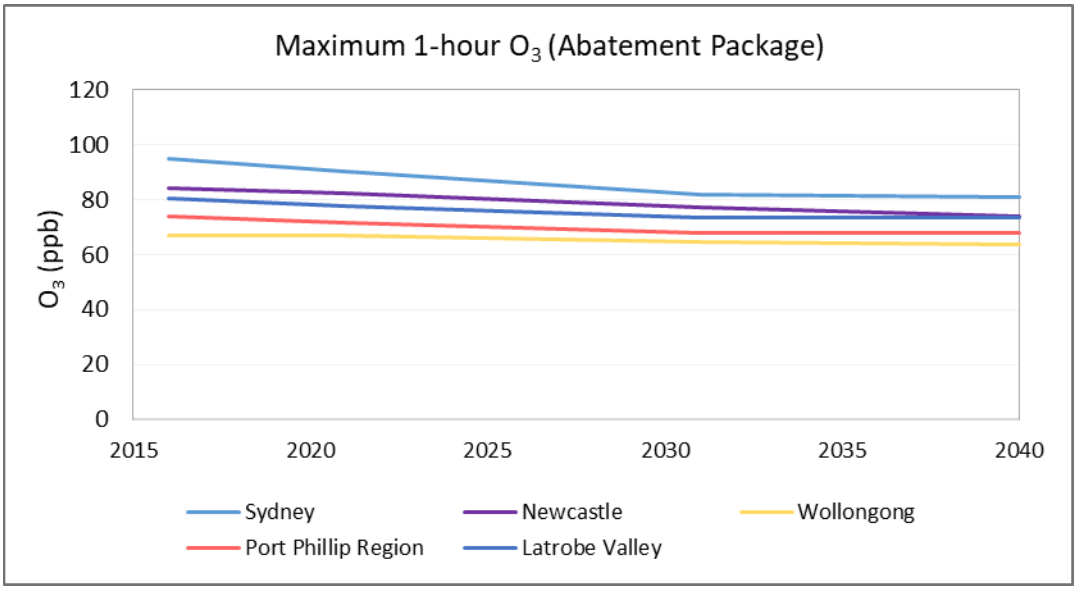

Figure 4-17: Modelled 1-hour maximum O_3 concentrations at monitoring locations (Abatement Package scenario)

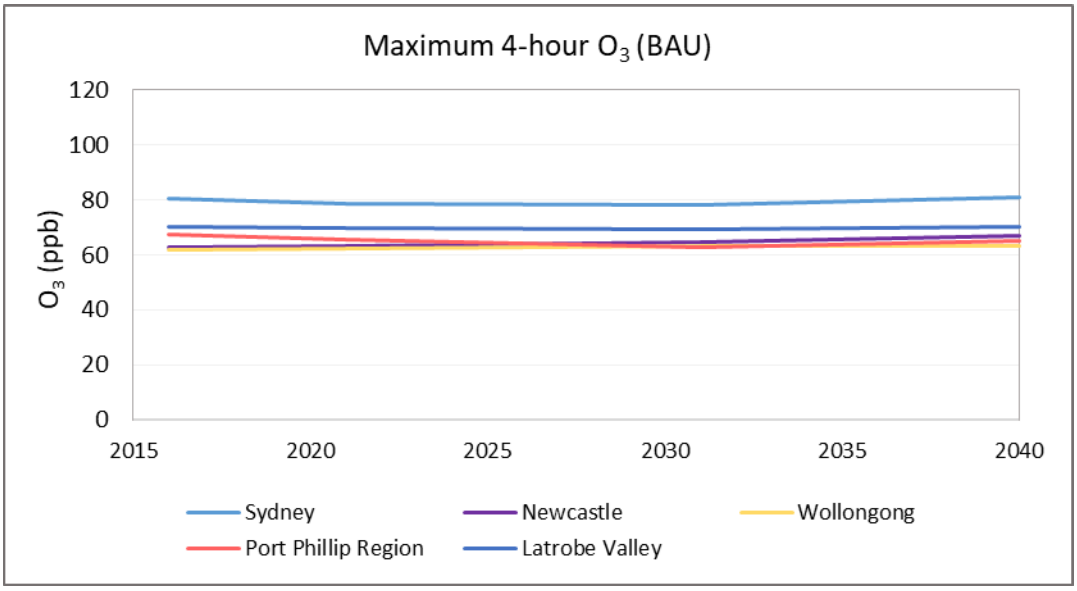

Figure 4-18: Modelled rolling 4-hour maximum O_3 concentrations at monitoring locations (BAU scenario)

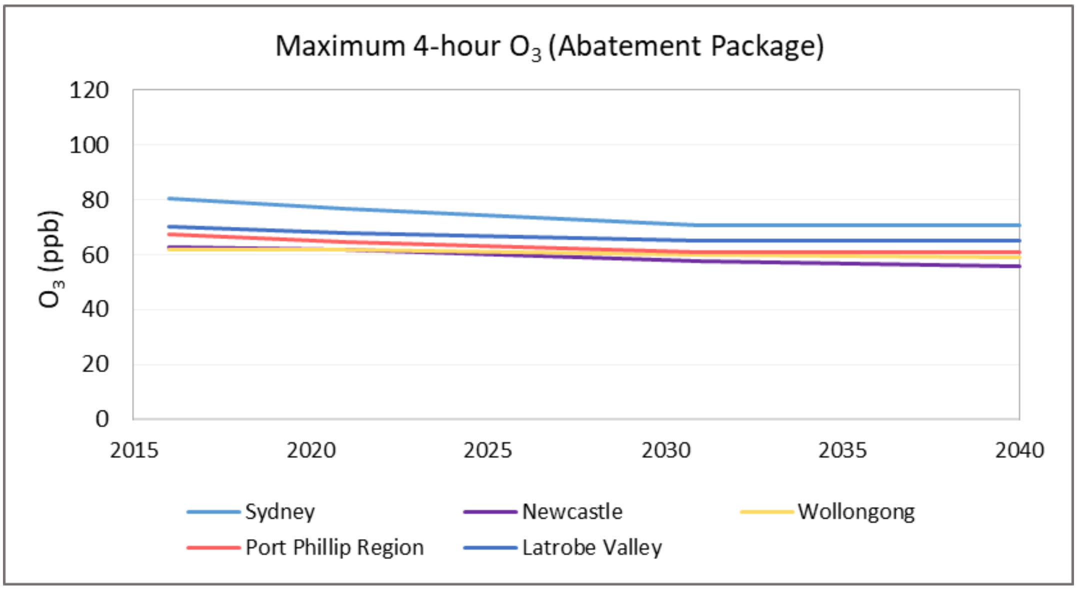

Figure 4-19: Modelled rolling 4-hour maximum O_3 concentrations at monitoring locations (Abatement Package scenario)

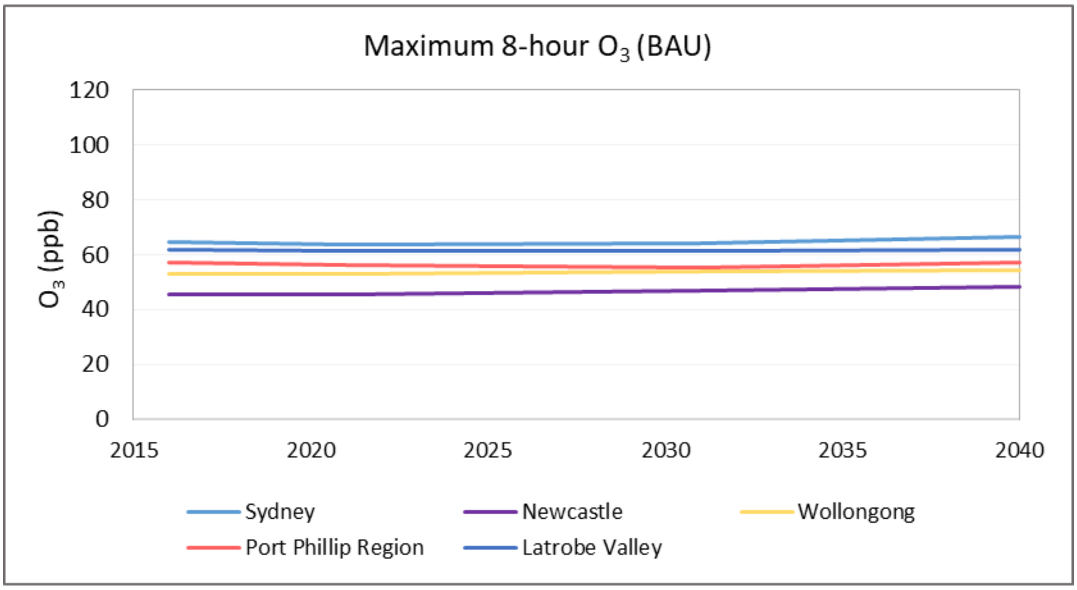

Figure 4-20: Modelled rolling 8-hour maximum O_3 concentrations at monitoring locations (BAU scenario)

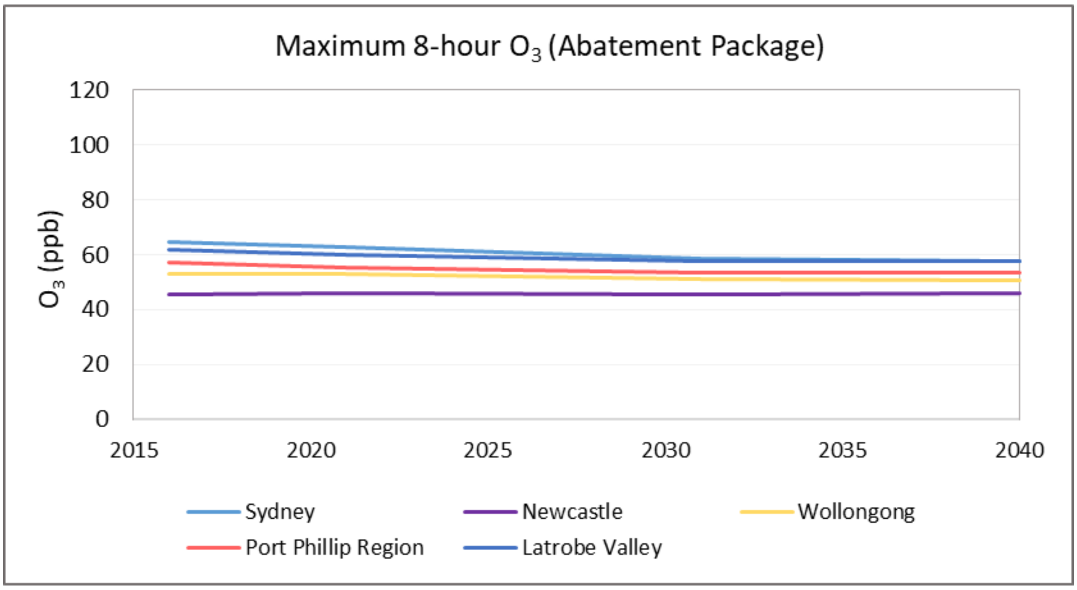

Figure 4-21: Modelled rolling 8-hour maximum O_3 concentrations at monitoring locations (Abatement Package scenario)

4.3.3.2 Exceedances of standards

For O_3 in NSW the projected unique exceedance days in the BAU and Abatement Package scenarios are shown in Table 4-11 and Table 4-12 respectively. The corresponding results for Victoria are shown in Table 4-13 and Table 4-14. The experience with the historical monitoring data showed that the patterns of exceedance for O_3 were more complicated than those for SO_2 and NO_2, and this was also reflected in the projections.

For the 1-hour standards:

- All airsheds except Wollongong were predicted to exceed the 70 ppb standard in the future in the BAU scenario, and the Abatement Package did not result in compliance in the other airsheds.
- In the BAU scenario Sydney and Newcastle exceeded the 85 ppb standard, although the Abatement Package resulted compliance in all years in Newcastle and by 2031 in Sydney. There were predicted to be no exceedances of this standard in the Port Phillip Region or Latrobe Valley.
- Both NSW and Victoria were compliant with the current 100 ppb standard in the BAU scenario.

For the 4-hour standards:

- Both NSW and Victoria exceeded the 60 ppb standard in the BAU scenario, and the Abatement Package did not deliver compliance for either Sydney or the Port Phillip Region. Indeed, the Abatement Package had no substantial effect on the numbers of exceedances predicted to occur in these airsheds.
- Sydney was predicted to exceed the 70 ppb standard, while the Port Phillip Region was predicted to achieve this. The Abatement Package had little effect in Sydney in 2021, but it did reduce exceedances in 2031 and 2040.
- There were small numbers of exceedances of the 80 ppb standard in Sydney in the BAU scenario, and these did not occur in future years in the Abatement Package scenario.

For the 8-hour standards:

- All airsheds were predicted to exceed the 47 ppb standard in at least one year in the BAU scenario. With the exception of Newcastle, this was also the case in the Abatement Package scenario. The Abatement Package has no discernible effect on the number of exceedances in Sydney, with some improvement predicted for the Port Phillip Region in 2040.
- All airsheds except Newcastle and Wollongong were predicted to exceed the 55 ppb standard, even with the Abatement Package. Again, the Abatement Package had no discernible impact in Sydney, with some improvement predicted for the Port Phillip Region in 2031 and 2040.
- Sydney and the Latrobe Valley were predicted to exceed the 60 ppb standard in the BAU scenario in future years. In Sydney and the Latrobe Valley in 2031 and 2040 the Abatement Package resulted in no exceedances. This was most likely due to the overall reductions in VOC and NO_x emissions.
- There were no predicted exceedances of the 70 ppb standard in any airshed in the BAU scenario. With the Abatement Package all airsheds still complied with this standard in future years.

The comparison between the historical measurements and the future predictions in the BAU scenario indicated that the models were generally underestimating the numbers of exceedances for O_3 in NSW, and overestimating exceedances in the Latrobe Valley. It appears that O_3 exceedances in the Port Phillip Region were reasonably well predicted.

Table 4-11: Projected exceedances of current and proposed O_3 standards (BAU scenario, NSW)

Period	Standard (ppb)	NSW: Sydney					NSW: Newcastle					NSW: Wollongong				
		Measured	Predicted				*Measured*	Predicted				*Measured*	Predicted			
		2010-2014 annual average[(a)]	2016	2021	2031	2040	*2010-2014 annual average[(a)]*	2016	2021	2031	2040	*2010-2014 annual average[(a)]*	2016	2021	2031	2040
Total number of unique exceedance days																
1-hour	70	*22*	11	11	11	11	*3*	3	3	3	3	*4*	-	-	-	-
	85	*7*	2	2	2	2	*-*	-	-	3	3	*2*	-	-	-	-
	100	*3*	-	-	-	-	*-*	-	-	-	-	*1*	-	-	-	-
Total number of unique exceedance days																
Rolling 4-hour	60	*23*	14	11	8	14	*4*	3	3	3	3	*5*	2	2	2	2
	70	*11*	5	2	5	8	*1*	-	-	-	-	*2*	-	-	-	-
	80	*5*	2	-	-	2	*-*	-	-	-	-	*1*	-	-	-	-
Total number of unique exceedance days																
Rolling 8-hour	47	*37*	11	11	11	14	*11*	-	-	-	3	*10*	5	5	5	5
	55	*19*	5	5	5	5	*3*	-	-	-	-	*4*	-	-	-	-
	60	*12*	2	2	2	5	*1*	-	-	-	-	*3*	-	-	-	-
	70	*3*	-	-	-	-	*-*	-	-	-	-	*1*	-	-	-	-

(a) Rounded to nearest integer.

Table 4-12: Projected exceedances of current and proposed O_3 standards (Abatement Package scenario, NSW)

Period	Standard (ppb)	NSW: Sydney				NSW: Newcastle				NSW: Wollongong			
		2016	2021	2031	2040	2016	2021	2031	2040	2016	2021	2031	2040
Total number of unique exceedance days													
1-hour	70	11	11	8	8	3	3	3	3	-	-	-	-
	85	2	2	-	-	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-	-	-	-	-
Total number of unique exceedance days													
Rolling 4-hour	60	14	8	8	8	3	3	-	-	2	2	-	-
	70	5	2	2	3	-	-	-	-	-	-	-	-
	80	2	-	-	-	-	-	-	-	-	-	-	-
Total number of unique exceedance days													
Rolling 8-hour	47	11	11	11	11	-	-	-	-	5	5	5	5
	55	5	5	5	5	-	-	-	-	-	-	-	-
	60	2	2	-	-	-	-	-	-	-	-	-	-
	70	-	-	-	-	-	-	-	-	-	-	-	-

Table 4-13: Projected exceedances of current and proposed O_3 standards (BAU scenario, VIC)

Averaging period	Standard (ppb)		VIC: Port Phillip Region					VIC: Latrobe Valley				
			Measured	Predicted				Measured	Predicted			
			2010-2014 annual average[(a)]	2016	2021	2031	2040	*2010-2014 annual average[(a)]*	2016	2021	2031	2040
Total number of unique exceedance days												
1-hour	70		*4*	3	3	-	-	*1*	3	3	3	3
	85		*1*	-	-	-	-	-	-	-	-	-
	100		-	-	-	-	-	-	-	-	-	-
Total number of unique exceedance days												
Rolling 4-hour	60		*6*	6	3	3	3	-	3	3	3	3
	70		*2*	-	-	-	-	-	3	-	-	3
	80		*1*	-	-	-	-	-	-	-	-	-
Total number of unique exceedance days												
Rolling 8-hour	47		*11*	6	9	6	9	*2*	9	9	9	9
	55		*4*	3	3	3	3	-	3	3	3	3
	60		*3*	3	-	-	-	-	3	3	3	3
	70		*1*	-	-	-	-	-	-	-	-	-

(a) Rounded to nearest integer.

Table 4-14: Projected exceedances of current and proposed O_3 standards (Abatement Package scenario, VIC)

Period	Standard (ppb)	VIC: Port Phillip Region				VIC: Latrobe Valley			
		2016	2021	2031	2040	2016	2021	2031	2040
Total number of unique exceedance days									
1-hour	70	3	3	-	-	3	3	3	3
	85	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-
Total number of unique exceedance days									
Rolling 4-hour	60	6	3	3	3	3	3	3	3
	70	-	-	-	-	3	3	3	3
	80	-	-	-	-	-	-	-	-
Total number of unique exceedance days									
Rolling 8-hour	47	6	9	6	6	9	9	3	3
	55	3	3	-	-	3	3	3	3
	60	-	3	-	-	3	3	-	-
	70	-	-	-	-	-	-	-	-

4.4 Assumptions for non-modelled airsheds

For the purposes of the HRA and CBA, it was important to understand how the Abatement Package would affect the other airsheds in Australia. While it was impossible to determine the precise extent of this without airshed-specific modelling, an approach was developed to identify similarities between the other airsheds and the modelled ones. The assumption was that, the greater the similarity between airsheds in terms of emissions and current air quality, the greater the confidence that the airsheds would respond in broadly similar ways to abatement. This allowed an assessment of how the concentrations would change with the Abatement Package in those airsheds that were not modelled.

The current emission inventories were reviewed to understand the contributions of each type of emission source (domestic, industry, motor vehicle, etc.). The percentage contributions of the sources to emissions were compared with the modelled airshed to identify similarities. The similarity was identified for each substance. However, a similarity for O_3 could not be determined due to insufficient information. The most important factor missing from the available data was the biogenic contribution to the VOC and NO_x emission inventory. Without understanding the influence of this significant source, it is impossible to state how the airshed would behave in response to the Abatement Package.

The air quality monitoring data were reviewed for a five-year period to understand the statistical trends for the various pollutants and averaging periods. Seasonal trends were also reviewed.

The results from this analysis used to extrapolate the other airshed concentration trends for the HRA and CBA is shown in Table 4-15.

Table 4-15: Airshed similarity results

Region	NO_2 Similar Airshed	SO_2 Similar Airshed
Adelaide	Melbourne	Melbourne
Darwin	Melbourne	Melbourne
Hobart	Melbourne	Melbourne
South-East Queensland	Melbourne	Melbourne
Perth	Melbourne	Sydney GMR
Canberra	Melbourne	Melbourne

4.5 Constraints, uncertainties and limitations

A study of this type includes a number of inherent assumptions, constraints and subsequently limitations. These cannot all be quantitatively determined.

In addition, the original study design was constrained by the original time frame and budget agreement. This has a direct influence on the final approach and methodology achievable and therefore applied.

The key areas to consider in terms of uncertainties and limitations for this study include:

- Population projection estimates.

- Motor vehicle emission projections.
- Projecting the baseline for future air quality.
- Third-party emission inventories – National Pollutant Inventory (NPI) and others.
- Reliance on other third-party studies.
- Air quality monitoring data (validation being completed by others).
- Air quality monitoring data were provided in whole ppb values.
- The provided air quality monitoring data may have been incomplete.
- While the air quality statistics were supposed to be provided to the study, when they were not, they were generated from the data in hand which may be different compared to the full set of monitoring data.
- Scaling factor applied in a coarse grid model - ground level concentration may not be precise.
- Generating emission files that contain updated facility/source specific emissions was not achievable without assistance from CSIRO. Involvement of the CSIRO was not provided for in the project scope and could not be achieved in the original timeframe available.
- A 4-month model period was run with interpolation instead of a 12-month model – this being constrained by both time and budget allocation.
- SO_2 scaling model configuration for industrial sources was not available for the version of the CTM model provided.
- Only select airsheds have been assessed using a photochemical transport model. The results from these airsheds have been used to infer the likely future behaviours of the other non-modelled airsheds. The non-modelled airsheds may or may not have similar photochemical behaviour to those that have been modelled.

Other points that should be considered in the context of the study constraints and uncertainties are:

- A preferred high-level methodology was provided.
- Detailed methodology was not-predefined.
- The need to use pre-existing models and data.
- Model validation was not included in the project scope, so accuracy of the models could not be quantified.
- The models and emission inventories were proposed to be used as received from EPA Victoria.
- The CTM chemistry schemes selected are those in current use by the regulatory bodies.
- Evaluation or changing the CTM chemistry schemes were not included in the project scope.

5 Summary and recommendations

This air quality study has evaluated - using state-of-the-art photochemical transport models - future air quality in the NSW and Victoria airsheds. Both BAU and Abatement Package scenarios were modelled for the years 2021, 2031 and 2040, with BAU also being modelled in 2016. The projected emissions were based on official state inventories, NPI emissions data, population growth, GVA, and available motor vehicle and other mobile data from various jurisdictions. The purpose of the study was to investigate the future air quality and the effectiveness of the Abatement Package. The results informed the HRA and CBA components of the overall work. Independent and internal model evaluations demonstrated that the modelled results were representative and fit for purpose. However, due to the complicated nature of photochemical reactions, gas-phase pollutant interactions, and the inherent uncertainty within most air quality models, model results of this type should always be considered as indicative. In addition, model uncertainty is considered to increase for the future years and, therefore, the results should be interpreted with this in mind.

5.1 Sulfur dioxide

The monitored SO_2 concentrations in Australia are generally low except in areas impacted by industrial sources, such as Melbourne and Perth, and were not considered to be representative of the exposure of the whole population.

The analysis of historical (2003-2014) air quality monitoring data showed that:

- There are no strong long-term trends in 1-hour, 24-hour and annual SO_2 concentrations.
- The current 1-hour standard (200 ppb) and 24-hour standard (80 ppb) have been achieved in all jurisdictions.
- For most airsheds there is the potential for a limited number of exceedances of the proposed 1-hour standard for SO_2 of 75 ppb in future years, particularly in regional areas with industrial activity. Compliance with the other proposed standards (100 ppb and 150 ppb) should generally be achievable, possibly with some local intervention.
- For several airsheds it will be a challenge to comply with the proposed 24-hour standard for SO_2 of 7 ppb in future years, whereas compliance with the other proposed standards (20 ppb and 40 ppb) should generally be achievable, possibly with some local intervention.

Abatement measures focussing on specific emission sources in the more constrained airsheds, rather than national measures, should be most appropriate for delivering air quality improvements.

Analysis of the BAU and Abatement Package modelling results for future years in NSW and Victoria revealed the following:

- All airsheds covered by the modelling complied with all the 1-hour standards in the BAU scenario.
- There was also compliance with all the 24-hour standards in the BAU scenario, except the 7 ppb standard.
- The Abatement Package resulted in a significant reduction in the number of exceedances of this 24-hour standard, with Sydney being predicted to meet it in 2031. Newcastle would

comply with the standard in 2040, and Wollongong in 2021. The Port Phillip Region and the Latrobe Valley were predicted to meet the standard in 2040.

- For all airsheds covered by the modelling, there was compliance with both the annual mean standards in the BAU scenario.
- The comparison between the historical years and the future years in the BAU scenario indicates that the models were probably overestimating the numbers of exceedances for SO_2.

5.2 Nitrogen dioxide

The analysis of the historical monitoring data for NO_2 revealed the following:

- In recent years (2010-2016) maximum 1-hour and annual mean NO_2 concentrations in all jurisdictions have been relatively stable.
- Concentrations in Australia are generally below the current AAQ NEPM standards (i.e. 120 ppb (1-hour average) and 30 ppb (annual average) in the major cities. The NO_2 concentrations in regional centres are generally lower than those observed in major cities. This is indicative of the impact from motor vehicle emissions to ambient NO_2 concentrations in the significant urban areas.
- For the most urbanised airsheds it is likely to be a significant challenge to comply with the proposed 1-hour standard for NO_2 of 40 ppb in future years. Compliance with the proposed standards of 80 ppb and 97 ppb should generally be possible in all airsheds. All jurisdictions would be likely to achieve continued compliance with the current 120 ppb standard.
- For annual mean NO_2 there have been no exceedances of the proposed standard of 19 ppb. However, in Sydney and the Port Phillip Region there have been exceedances of the proposed standard of 10 ppb at multiple stations and in multiple years.

The modelling of the BAU and Abatement Package scenarios for NO_2 in NSW and Victoria in future years showed the following:

- All airsheds were predicted to comply with all the 1-hour standards of 80, 97 and 120 ppb in the BAU scenario. There were predicted to be exceedances of the 40 ppb standard, but only in Sydney. The Abatement Package was predicted to slightly reduce the numbers of exceedances.
- In the BAU scenario, there was compliance with the current annual mean standard of 30 ppb and the proposed standard of 19 ppb. Compliance continues into the future with the Abatement Package in place. In Sydney and Wollongong there were some historical exceedances of the proposed standard of 10 ppb, and in Sydney some limited exceedances were predicted for the future.
- The comparison between the historical measurements and the future predictions indicated that the models were generally underestimating the numbers of exceedances for NO_2 in Sydney and the Port Phillip Region.

5.3 Ozone

The analysis of the historical monitoring data for O_3 showed the following:

- In summary, with the exception of Sydney where there is a slight downward trend, between 2003 and 2014, there is no clear trend in O_3 concentrations (1-hour, 4-hour and 8-hour maximum) for the jurisdictions assessed where monitoring data is available.
- In years where there were significant bushfires, the influence on peak O_3 concentrations is noted.
- Between 2003 and 2016 most jurisdictions experienced exceedances of both the current 1-hour and 4-hour NEPM standards, most notably in Sydney, Wollongong, the Port Phillip Region and Perth. From 2010 to 2014 there were few exceedances outside these airsheds.
- For a proposed 1-hour standard of 85 ppb, the situation was similar to that for the current standard.
- Two alternative proposed 4-hour standards have been considered as part of this study (70 ppb and 60 ppb). The monitoring data show that the 70 ppb standard was only achieved across all years in Canberra, Townsville and Gladstone. The 60 ppb standard was only achieved across all years in Canberra and Gladstone.
- Four proposed 8-hour standards were considered in this review (70 ppb, 60 ppb, 55 ppb and 47 ppb). Based on the monitoring data for recent years the 70 ppb standard was met in Canberra and Adelaide, as well as in the regional centres of Newcastle, Townsville and Gladstone. In Sydney, Wollongong, the Port Phillip Region and Perth, the lower standards were exceeded in most years.
- In summary, the proposed O_3 standards have generally not been achieved historically, indicating that abatement measures would be required in the future.

The modelling of the BAU and Abatement Package scenarios for O_3 in NSW and Victoria in future years showed the following:

For the 1-hour standards:

- All airsheds except Wollongong will continue to be challenged to achieve the 70 ppb standard in the future, and the Abatement Package does not result in compliance.
- In the BAU scenario Sydney and Newcastle will be challenged to achieve the 85 ppb standard, although the Abatement Package scenario is predicted to achieve compliance in all years in Newcastle, and by 2031 in Sydney. There are predicted to be no exceedances of this standard in Victoria.
- Both jurisdictions are compliant with the current 100 ppb standard in the BAU scenario.

For the 4-hour standards:

- Both NSW and Victoria will be challenged to achieve the 60 ppb standard in the BAU scenario, and the Abatement Package does not deliver compliance for either Sydney or the Port Phillip Region. There is no discernible difference in the number of exceedances predicted to occur from year to year (with Abatement Package) for either Sydney or the Port Phillip Region.
- Sydney will be challenged to achieve the 70 ppb standard, while the Port Phillip Region is predicted to achieve this. There are few differences in the number of exceedances predicted

to occur from year to year (with Abatement Package) for either Sydney or the Port Phillip Region.

- Both Sydney (from 2021) and the Port Phillip Region will comply with the 80 ppb standard in the Abatement Package scenario.

For the 8-hour standards:

- All airsheds except Newcastle are predicted to exceed the 47 ppb standard, even with the Abatement Package. The Abatement Package has no discernible effect on the number of exceedances in Sydney, with some improvement predicted for the Port Phillip Region in 2031 and 2040.
- All airsheds except Newcastle and Wollongong are predicted to exceed the 55 ppb standard, even with the Abatement Package. Again, the Abatement Package has no discernible impact in Sydney, with some improvement predicted for the Port Phillip Region in 2040.
- Sydney, the Port Phillip Region and the Latrobe Valley are predicted to exceed the 60 ppb standard in the BAU scenario. In Sydney in 2031 and 2040 the Abatement Package results in no exceedances. This is most likely due to the overall reduction of VOC and NO_x emissions. For the Port Phillip Region the Abatement Package only delivers a significant reduction in the number of exceedances in 2040.
- There are no predicted exceedances of the 70 ppb standard in any airshed in the BAU scenario. With the Abatement Package all airsheds still comply with this standard in future years.

In summary, the most stringent of the O_3 standard options for each averaging period are not anticipated to be achieved in future years through adoption of the Abatement Package, indicating that abatement measures do not deliver sufficient improvement or emission reductions.

For Melbourne, the analysis across years suggests that current (BAU) strategies in place will deliver an achievement of the current 4-hour and 8-hours standard in future, but attention will need to be given to abatements to ensure these standards are achieved in 2040. The Abatement Package is predicted to deliver an adequate improvement for Melbourne in 2040 for the less stringent 4-hour standard (i.e. 80 ppb and 70 ppb), but is not predicted to be adequate to deliver the improvement required to meet the 8-hour standard.

Sydney is presented with a greater challenge in terms of achieving compliance with the standard in future. The Abatement Package is not predicted to deliver improvement for Sydney in 2040 when the less stringent standard options are evaluated, i.e. 85 ppb 1-hour standard and 60 ppb 8-hour standard. Essentially, the Abatement Package is predicted to deliver insufficient improvement for Sydney to achieve compliance with the more stringent standard considered.

5.4 Concluding remarks

In summary, achieving compliance with the proposed air quality standard for SO_2, NO_2 and O_3 will typically require the introduction of new abatement measures. The Abatement Package determined and agreed through the MCA is found to be generally inadequate to bring about universal compliance with the reviewed alternative standard options. Factors contributing to this include projected growth in population, emission growth projected after 2030, and the distribution of the emission sources impacted by the Abatement Package.

Further analysis of potential abatements options will therefore be necessary if a pathway to compliance with alternative standard options is to be determined. Due to the inherent limitations in extrapolating modelled results to non-modelled airsheds and the limited information available in biogenic VOCs emissions from each jurisdictions (except NSW), it is recommended that any future analysis is based on tailored airshed modelling within each jurisdiction.

5.5 Recommendations for future work

Similar to other regional photochemical models in the rest of the world, there are uncertainties in the input data as well as inherent in the model. The two most significant sources of uncertainty identified in this project relate to estimates of future emissions as well as the representativeness of the full year of modelled meteorological data.

Recommendations are made for future work to quantify the uncertainty, including:

- Investigating the uncertainties in the input data including both emission and meteorological data.
- Conducting a comprehensive uncertainty analysis study to estimate the uncertainty of specific inputs to the model e.g. boundary conditions, chemical mechanism and photolysis, for the selected regional photochemical transport model.
- Conducting model runs with high, average and low emission scenarios.
- Optimising the model performance by adopting the most up-to-date emission and meteorological files and latest developments in the modelling schemes.

6 References

Boylan J and Russell A (2006). PM and light extinction model performance metrics, goals, and criteria for three-dimensional air quality models. *Atmospheric Environment*, Vol. 40, pp. 4946-4959.

Broome R A, Cope M E, Goldsworthy B, Goldsworthy L, Emmerson K, Jegasothy E and Morgan G G (2016). The mortality effect of ship-related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia. *Environment International*, Vol. 87, pp. 85–93.

Cope M E, Hess G D, Lee S, Tory K, Azzi M, Carras J, Lilley W, Manins P C, Nelson P, Ng L, Puri K, Wong N, Walsh S and Young M (2004). The Australian Air Quality Forecasting System. Part I: Project Description and Early Outcomes. *Journal of Applied Meteorology*, Vol. 43, pp. 649-662.

Cope M, Lee S, Noonan J, Lilley B, Hess D and Azzi M (2009). Chemical Transport Model Technical Description. CSIRO Marine and Atmospheric Research Internal Report.

Cope M and Emmerson K (2016). Operational evaluation of CCAM-CTM_cb05_aer2 - O_3, NO_2, CO and SO_2 for July 2010 - June 2011 (Draft). Research Note, September 2016. CSIRO Climate Research Centre.

Cope M, Keywood M, Emmerson K, Galbally I, Boast K, Chambers S, Cheng M, Crumeyrolle S, Dunne E, Fedele R, Gillett R, Griffiths A, Harnwell J, Katzfey J, Hess D, Lawson S, Miljevic B, Molloy S, Powell J, Reisen F, Ristovski Z, Selleck P, Ward J, Zhang C and Zeng J (2014). Sydney Particle Study - Stage-II. The Centre for Australian Weather and Climate Research, CSIRO, Aspendale, Victoria.

DECCW (2010). State of Knowledge: Ozone. NSW Department of Environment, Climate Change and Water NSW, Sydney.

Delaney W and Marshall A (2011). Victorian Air Emissions Inventory for 2006. Proceedings of the 20th International Clean Air and Environment Conference, Auckland, 31 July – 2 August 2011. Clean Air Society of Australia & New Zealand, Eastwood, NSW.

Delaney W, Cope M and Azzi M (2009). Passenger Vehicle Emission Factors for Victoria Derived from CUEDEC Drive Cycle Data. Proceedings 19th International Clean Air and Environment Conference, Perth, Australia.

Digar A, Cohan D S and Bell M L (2011). Uncertainties influencing health-based prioritization of ozone abatement options. *Environmental Science and Technology*. Vol. 45(18), pp. 7761-7.

Duc H N, Trieu T, Scorgie Y, Cope M and Thatcher M (2016). Air Quality Modelling of the Sydney Region using CCAM-CTM. *Air Quality and Climate Change*, Vol. 51(1), pp. 29-33.

ENVIRON (2010). Cleaner non-road diesel engine project – Identification and recommendation of measures to support the uptake of cleaner non-road diesel engines in Australia. Final report to NSW Department of Environment, Climate Change and Water. ENVIRON Australia, April 2010.

EPA Victoria (2013). Future air quality in Victoria - Final report. Publication 1535, July 2013, EPA Victoria, Carlton.

Hanna S R, Lu Z G, Frey H C, Wheeler N, Vukovich J, Arunachalam S, Fernau M and Hansen D A (2001). Uncertainties in predicted ozone concentrations due to input uncertainties for the UAM-V photochemical grid model applied to the July 1995 OTAG domain. *Atmospheric Environment*, Vol. 35, pp. 891–903.

Hibberd M F, Physick W L and Park G (2003). Verification of several aspects of TAPM against multiyear monitoring data at Collie. In *National Clean Air Conference: linking air pollution science, policy and management: CASNO3*, Newcastle NSW. Clean Air Society of Australia and New Zealand.

Hurley P J (2008a). TAPM V4 User Manual. CSIRO Marine and Atmospheric Research, Internal Report No 5, October 2008.

Hurley P J (2008b). The Air Pollution Model (TAPM) Version 4: User Manual. CSIRO Atmospheric Research, Internal Paper 25. 38 p.

Hurley P J, Manins P C, Lee S H, Boyle R, Ng Y L and Dewundege P (2002a). Year-long urban airshed modelling in Melbourne: verification of TAPM for photochemical smog and particles. In *Conference proceedings: 16th International Clean Air & Environment Conference, Christchurch, N.Z*. Clean Air Society of Australia and New Zealand.

Hurley P J, Physick W L and Luhar A K (2002b). The Air Pollution Model (TAPM) Version 2. Part 2: summary of some verification studies. Atmospheric Research technical paper; no.57. CSIRO Atmospheric Research.

Kinrade P, Arold N, Carr R, Denison L, Lam S, Tuxford D and Warren B (2016). Review of the Fuel Quality Standards Act 2000. Report prepared for the Department of the Environment. April 2016. Marsden Jacob Associates, Melbourne.

Luhar A and Hurley P (2003). Evaluation of TAPM, a prognostic meteorological and air pollution model, using urban and rural point-source data. *Atmospheric Environment*, Vol. 37, pp. 2795-2810.

Mallet V and Sportisse B (2006). Uncertainty in a chemistry-transport model due to physical parameterizations and numerical approximations: An ensemble approach applied to ozone modeling. *Journal of Geophysical Research*, Vol. 111, D01302.

McGregor J L and Dix M R (2008). An updated description of the Conformal-Cubic Atmospheric Model. In *High Resolution Simulation of the Atmosphere and Ocean*, (eds. K Hamilton and W Ochfuchi), Springer, pp. 51-76.

Morris R, McNally D, Tesche T, Tonnesen G, Boylan J and Brewer P (2005). Preliminary evaluation of the community multiscale air, quality model for 2002 over the South-Eastern United States. *Journal of the Air and Waste Management Association*, Vol. 55, pp. 1694-1708.

Morris R, Koo B, Guenther A, Yarwood G, McNally D, Tesche T W, Tonnesen G, Boylen J and Brewer P (2006). Model sensitivity evaluation for organic carbon using two multi-pollutant air quality models that simulate regional haze in the southeastern United States. *Atmospheric Environment*, Vol. 40(26), pp. 4960-4972.

NSW EPA (2008). Air Emissions Inventory for the Greater Metropolitan Region in New South Wales. Technical Report No. 8: On-Road Mobile Emissions Module: Results.

NSW EPA (2012). Air Emissions Inventory for the Greater Metropolitan Region in New South Wales. 2008 Calendar Year.

Physick W, Cope M and Sunhee L (2014). The Impact of Climate Change on Ozone-Related Mortality in Sydney. *Int. J. Environ. Res. Public Health*, Vol. 11(1), pp. 1034-1048.

Queensland EPA (2004). Air Emissions Inventory – South-East Queensland Region, Queensland Environmental Protection Agency and Brisbane City Council, Brisbane Qld. http://www.ehp.qld.gov.au/air/pdf/reports/air-emissions-inventory-seq.pdf

Russell A (1997). Regional photochemical air quality modeling: Model formulations, history, and state of the science. Annu. Rev. Energy Environ., Vol. 22, pp. 537-588.

Sarwar G, Appel K W, Carlton A G, Mathur R, Schere K, Zhang R and Majeed M A (2011). Impact of a new condensed toluene mechanism on air quality model predictions in the US. Geoscientific Model Development (GMD), Vol. 4(1), pp. 183-193.

Simon H, Baker K and Phillips S (2012). Compilation and interpretation of photochemical model performance statistics published between 2006 and 2012. *Atmospheric Environment*, Vol. 61, pp. 124-139.

USEPA (2003). Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze. EPA -454/B-07-002. April 2007. U.S. Environmental Protection Agency, North Carolina.

USEPA (2005). Appendix W to Part 51 Guideline on Air Quality Models, 40 CFR Part 51 Volume 70. US Environmental Protection Agency.

WA DEP (2003) National Pollutant Inventory – Perth Airshed Emissions Study 1998/1999 – Revised 2003, Department of Environment Protection, Western Australia, Australia. http://www.npi.gov.au/publications/pubs/perth-aedreport.pdf

Annexure A: Ambient air quality monitoring data used in analysis

A.1 Datasets analysed

The ambient air quality monitoring data included in the analysis were provided by EPA Victoria. Data verification and validation was undertaken or overseen by EPA Victoria prior to the datasets being supplied, and therefore no further data checks were applied.

The following files were received:

- *20160108 Australian Air Network Database.VER2.accdb* (4 February 2015).
- *20160119 Australian Air Network Database.accdb* (23 February 2015).
- *EMADMS 2011 Update - V126 - 11Jul2014 (v125 with some area source updates).mdb* (18 February 2016).
- *EMADMS 2030 Update - 19Oct12 - MLF v111I (v111H w new emission factors for gen aviation).mdb* (18 February 2016).
- *Backup of EMADMS 2030 Update - 19Oct12 - MLF v111I (v111H w new emission factors for gen aviation).mdb* (18 February 2016).
- *EMADMS 2030 Update - 19Oct12 - MLF v111I (v111H w new emission factors for gen aviation).mdb* (19 February 2016).
- *20160119 Australian Air Network Database.accdb* (23 February 2015).
- *EMADMS 2006 Update - 04Apr12 - V118.mdb* (23 February 2015).
- *EMADMS 2030 Update - 19Oct12 - MLF v111I (v111H w new emission factors for gen aviation).mdb* (18 April 2015).

A.2 Monitoring stations included

The air quality monitoring stations included in the study are listed in Table A-1.

Table A-1: AAQ NEPM monitoring stations included in the analysis

Jurisdiction - airshed	SO_2 NEPM stations	NO_2 NEPM stations	O_3 NEPM stations
NSW - Sydney GMR	Blacktown Bringelly Campbelltown W Chullora Macarthur Prospect Richmond (NSW) Woolooware	Blacktown Bringelly Camden Campbelltown W Chullora Liverpool Macarthur Prospect Richmond (NSW) Rozelle Woolooware	Blacktown Bringelly Camden Campbelltown W Liverpool Macarthur Oakdale Prospect Richmond (NSW) Rozelle St Marys Woolooware
NSW - Lower Hunter	Newcastle Wallsend Wyong	Newcastle Wallsend Wyong	Newcastle Wallsend Wyong
NSW - Illawarra	Albion Park Albion Park South Warrawong Wollongong	Albion Park South Wollongong	Albion Park Albion Park South Kembla Grange Wollongong
VIC - PPR	Alphington Altona North Geelong South RMIT	Alphington Brighton Footscray Geelong South Pt Cook RMIT	Alphington Brighton Dandenong Footscray Geelong South Mooroolbark Pt Cook
Latrobe Valley	Traralgon	Traralgon	Traralgon
QLD - SE QLD	Flinders View Springwood	Deception Bay Flinders View Mountain Creek Rocklea Springwood	Deception Bay Flinders View Mountain Creek Rocklea Springwood
QLD - Townsville	Pimlico Stuart	Pimlico	Pimlico
QLD - Gladstone	South Gladstone	South Gladstone	-
SA - Adelaide	Northfield	Christies Elizabeth Kensington Netley Northfield	Christies Elizabeth Kensington Netley Northfield
WA - Perth	Rockingham South Lake Wattleup	Caversham Duncraig Quinns Rock Rockingham Rolling Green South Lake Swanbourne	Caversham Quinns Rock Rockingham Rolling Green South Lake Swanbourne
NT	Palmerston Winnellie	Palmerston Winnellie	Palmerston Winnellie
ACT - Canberra	-	Civic Monash	Civic Monash

Annexure B: Historical exceedances of short-term air quality standards

B.1 Overview

The air quality monitoring data from the period 2003-2016 were compared against the current and proposed standards for SO_2, NO_2 and O_3 to assess historical exceedances (**NB**: in this context the proposed standards are treated as actual standards). It should be noted that not all monitoring stations were included in the analysis, with roadside and some industrial locations being excluded, and only the numerical values of the standards have been considered.

In this section, the exceedance statistics are based on the daily maximum short-term (e.g. 1-hour, rolling 4-hour) concentrations at the monitoring stations. The results are presented in a series of tables, and for each combination of airshed, standard and year, the tables give the following:

- The **total number of exceedance days** across all relevant stations
- The **number of unique exceedance days** across all relevant stations (shown in brackets)

The absolute total number of exceedances was not considered. For example, if the 1-hour NO_2 standard was exceeded five times on given day, this only counted as one exceedance day. However, where exceedances occurred across multiple monitoring stations on the same day, this was counted as a unique exceedance day.

Only airsheds with exceedances are presented.

B.2 SO_2 standards

For SO_2, the exceedances of the 1-hour and 24-hour standards are shown in Table B-1 and Table B-2 respectively, and the results are summarised below.

1-hour SO_2 standards

- *75 ppb (proposed)*
  - Apart from some isolated cases, there was historical compliance with this standard in the NSW GMR and Port Phillip Region of Victoria.
  - The standard was exceeded in some regional areas associated with industrial activity (Latrobe Valley, Gladstone) and in Perth. However, there have been very few exceedances in recent years.
- *100 ppb (proposed)*
  - There were only a few exceedances of this standard, again mainly in the regional areas identified above. The last exceedance was in 2012
- *150 ppb (proposed)*
  - This standard was achieved in all airsheds, with the exception of a single event in 2008 in the Latrobe Valley.
- *200 ppb (current)*
  - This standard was achieved in all airsheds and years.

Table B-1: Historical exceedance days for 1-hour SO_2 standards

Jurisdiction-airshed	Standard (ppb)	Number of exceedance days (unique exceedance days are given in brackets)													
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NSW: Wollongong (4 stations)	75	-	(1)	-	-	-	-	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VIC: Port Phillip Region (4 stations)	75	-	-	-	-	(1)	-	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VIC: Latrobe Valley (1 station)	75	1(1)	1(1)	-	1(1)	2(2)	1(1)	1(1)	-	-	2(2)	-	-	-	-
	100	-	-	-	-	-	1(1)	1(1)	-	-	1(1)	-	-	-	-
	150	-	-	-	-	-	1(1)	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QLD: Gladstone (1 station)	75	-	-	1(1)	3(3)	-	3(3)	-	-	1(1)	-	-	-	1(1)	-
	100	-	-	-	-	-	1(1)	-	-	-	-	-	-	-	-
	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WA: Perth (3 stations)	75	-	1(1)	1(1)	3(3)	-	2(2)	-	-	-	-	1(1)	-	-	-
	100	-	-	1(1)	-	-	-	-	-	-	-	-	-	-	-
	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table B-2: Historical exceedance days for 24-hour SO_2 standards

Jurisdiction-airshed	Standard (ppb)	Number of exceedance days (unique exceedance days are given in brackets)													
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NSW: Newcastle (3 stations)	7	4(4)	5(5)	1(1)	4(4)	4(4)	3(3)	3(3)	1(1)	6(5)	-	-	3(3)	3(3)	1(1)
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NSW: Wollongong (3 stations)	7	11(11)	8(8)	5(5)	6(6)	8(8)	3(3)	10(10)	11(11)	3(3)	1(1)	3(3)	-	-	1(1)
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VIC: Port Phillip Region (4 stations)	7	4(4)	5(5)	4(4)	7(7)	6(6)	8(8)	13(13)	13(13)	8(8)	12(12)	5(5)	10(9)	11(11)	7(7)
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VIC: Latrobe Valley (1 station)	7	1(1)	4(4)	4(4)	6(6)	11(11)	6(6)	6(6)	1(1)	-	2(2)	1(1)	1(1)	-	-
	20	-	-	-	1(1)	-	1(1)	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QLD: South-East Queensland (2 stations)	7	-	-	-	1(1)	-	-	-	1(1)	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QLD: Townsville (2 stations)	7	-	-	1(1)	-	-	-	-	-	-	-	-	-	-	-
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QLD: Gladstone (1 station)	7	6(6)	-	6(6)	31(31)	21(21)	13(13)	7(7)	7(7)	20(20)	9(9)	9(9)	22(22)	18(18)	15(15)
	20	-	-	-	-	1(1)	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WA: Perth (3 stations)	7	3(3)	13(13)	7(7)	4(4)	1(1)	3(3)	4(3)	3(3)	3(3)	4(4)	2(2)	2(2)	7(7)	16(16)
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-

24-hour SO_2 standard

- *7 ppb (proposed)*
  - There were no exceedances of this standard in Darwin and Adelaide.
  - The standard was exceeded on multiple occasions each year in several airsheds, most notably Gladstone, Perth, Port Phillip Region, Latrobe Valley and Wollongong.
- *20 ppb (proposed)*
  - This standard was achieved in the majority of airsheds and years. There were just a few isolated exceedances of this standard in the Latrobe Valley and Gladstone, and the last exceedance was in 2008
- *40 ppb (proposed)*
  - This standard was achieved in all airsheds and years.
- *80 ppb (current)*
  - This standard was achieved in all airsheds and years.

Under current conditions, the results indicate that for most airsheds it will be a challenge to comply with a 24-hour standard for SO_2 of 7 ppb in future years, whereas compliance with the other proposed standards should generally be possible.

B.3 NO_2 standards

For NO_2, the exceedances of the 1-hour standards are shown in Table B-3, and the results are summarised below.

1-hour NO_2 standard

- *40 ppb (proposed)*
  - For this standard there were exceedances in most airsheds, with a link to the level of urbanisation. Multiple exceedance days in the large urban areas of Sydney and the Port Phillip Region. Whilst the numbers of exceedance days have generally decreased in recent years, in 2016 there were still 29 unique days in Sydney and 14 in the Port Phillip region. There were fewer exceedance days in the other state capitals and regional centres.
- *80 ppb (proposed)*
  - This standard was achieved in all airsheds and years, with the exception of single exceedance days in Sydney in 2005, Adelaide in 2004, and Canberra in 2003, and two exceedance days in Canberra in 2008.
- *97 ppb (proposed)*
  - This standard was achieved in all airsheds and years, with the exception of single exceedance days in Adelaide in 2004 and Canberra in 2008.
- *120 ppb (current)*
  - This standard was achieved in all airsheds and years.

Table B-3: Historical exceedance days for 1-hour NO_2 standards

Jurisdiction-airshed	Standard (ppb)	Number of exceedance days (unique exceedance days are given in brackets)													
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NSW: Sydney (10 stations)	40	86(42)	100(56)	71(35)	81(41)	40(23)	15(12)	27(14)	20(14)	23(18)	44(28)	51(27)	30(19)	35(18)	58(29)
	80	-	-	1(1)	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NSW: Newcastle (3 stations)	40	2(2)	2(2)	1(1)	2(2)	-	-	1(1)	-	-	-	4(4)	2(2)	2(1)	2(2)
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NSW: Wollongong (2 stations)	40	4(4)	4(4)	7(6)	12(11)	4(4)	2(2)	8(7)	5(5)	2(2)	3(3)	8(8)	-	3(2)	5(5)
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VIC: Port Phillip Region (6 stations)	40	92(40)	52(27)	48(25)	71(43)	28(20)	37(20)	40(25)	13(12)	9(6)	9(9)	13(11)	14(8)	9(7)	21(14)
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VIC: Latrobe Valley (1 station)	40	1(1)	-	-	1(1)	-	-	1(1)	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QLD: South-East Queensland (5 stations)	40	9(7)	17(13)	14(10)	13(8)	8(7)	3(3)	1(1)	-	-	-	3(3)	16(13)	3(3)	5(5)
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QLD: Townsville (1 station)	40	-	-	-	-	-	-	-	-	1(1)	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Jurisdiction-airshed	Standard (ppb)	Number of exceedance days (unique exceedance days are given in brackets)													
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
QLD: Gladstone (1 station)	40	-	-	-	-	-	-	-	-	-	2(2)	1(1)	1(1)	1(1)	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SA: Adelaide (5 stations)	40	1(1)	5(5)	5(5)	3(3)	-	4(4)	7(5)	5(5)	5(4)	1(1)	2(2)	2(2)	3(3)	-
	80	-	1(1)	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	1(1)	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WA: Perth (7 stations)	40	17(8)	17(13)	15(12)	14(8)	8(7)	3(3)	3(3)	11(10)	1(1)	6(5)	2(2)	1(1)	5(5)	0(0)
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NT: Darwin (1 station)	40	-	-	-	-	-	-	-	-	1(1)	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACT: Canberra (2 stations)	40	13(10)	1(1)	-	3(2)	6(6)	5(5)	3(3)	-	2(1)	1(1)	1(1)	-	-	-
	80	1(1)	-	-	-	-	2(2)	-	-	-	-	-	-	-	-
	97	-	-	-	-	-	1(1)	-	-	-	-	-	-	-	-
	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Under current conditions, the results indicate that for the highly urbanised airsheds it will be a significant challenge to comply with 1-hour standard for NO_2 of 40 ppb in future years. Compliance with the proposed standards of 80 ppb and 97 ppb should generally be possible in all airsheds. All jurisdictions would be likely to achieve continued compliance with the 120 ppb standard.

B.4 O_3 standards

For O_3, the exceedances of the 1-hour, rolling 4-hour, and rolling 8-hour standards are shown in Tables B-4, B-5 and B-6 respectively, and the results are summarised below. Exceedances of the O_3 standards were more prevalent than exceedances of the SO_2 and NO_2 standards.

1-hour O_3 standard

- *70 ppb (proposed)*
  - This standard was exceeded on multiple occasions per year in several of the more urbanised airsheds, especially Sydney, the Port Phillip Region and Perth.
  - This analysis was based on the maximum concentrations.
- *85 ppb (proposed)*
  - This standard was also exceeded on multiple occasions per year in several of the more urbanised airsheds, especially Sydney and the Port Phillip Region.
  - This analysis was based on the maximum concentrations.
- *100 ppb (current)*
  - The current standard was usually exceeded on multiple days in most years in Sydney. Although there were exceedances in the other airsheds, these were less frequent.
  - There have been relatively few exceedances in recent years (e.g. 2012-2016).

4-hour O_3 standard

- *60 ppb (proposed)*
  - Most airsheds will be challenged to achieve the standard, especially in Sydney and the Port Phillip Region, where there were large numbers of exceedances.
  - This analysis was based on the maximum data.
- 70 ppb (proposed)
  - Again, most airsheds will be challenged to achieve this standard. Possible exceptions are Canberra and Adelaide.
  - This analysis is based on the maximum data.
- *80 ppb (current)*
  - In Sydney, the current standard was exceeded on multiple occasions in most years, although there have been relatively few exceedances in recent years.

8-hour O_3 standard

- *47 ppb (proposed)*
  - In all jurisdictions it will be challenging to achieve this standard.

- *55 ppb (proposed)*
    - Most jurisdictions will be challenged to achieve the standard. Possible exceptions are Canberra and South-East Queensland.
- *60 ppb (proposed)*
    - Several jurisdictions will be challenged to achieve this standard.
- *70 ppb (proposed)*
    - Some jurisdictions may be challenged to achieve the standard.

Table B-4: Historical exceedance days for 1-hour O_3 standards

Jurisdiction-airshed	Standard (ppb)	Number of exceedance days (unique exceedance days are given in brackets)													
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NSW: Sydney (11 stations)	70	44(22)	94(30)	71(27)	87(27)	78(29)	30(8)	119(35)	64(23)	62(23)	44(15)	73(24)	94(23)	75(21)	92(28)
	85	14(6)	41(17)	27(13)	45(15)	36(15)	9(5)	55(23)	18(10)	24(8)	6(3)	17(6)	36(9)	13(7)	18(8)
	100	9(5)	21(12)	15(7)	22(11)	16(5)	1(1)	25(11)	5(2)	11(4)	3(3)	4(2)	8(2)	-	2(2)
NSW: Newcastle (3 stations)	70	3(3)	7(4)	4(3)	2(2)	-	-	6(5)	3(3)	1(1)	3(2)	8(6)	3(3)	4(2)	12(8)
	85	-	2(1)	1(1)	1(1)	-	-	1(1)	1(1)	-	-	-	1(1)	1(1)	2(2)
	100	-	1(1)	-	-	-	-	-	-	-	-	-	-	-	-
NSW: Wollongong (4 stations)	70	22(9)	19(7)	10(5)	17(10)	9(4)	2(2)	18(10)	7(4)	12(7)	-	17(8)	4(3)	15(8)	16(10)
	85	12(5)	9(4)	2(1)	6(3)	2(2)	-	4(3)	1(1)	5(3)	-	10(4)	1(1)	2(2)	5(3)
	100	6(4)	5(3)	1(1)	-	-	-	2(2)	-	2(1)	-	7(3)	-	1(1)	2(1)
VIC: Port Phillip Region (6 stations)	70	24(11)	7(4)	10(8)	35(14)	27(15)	18(10)	23(12)	2(2)	-	-	9(6)	34(14)	4(4)	-
	85	10(3)	3(2)	1(1)	17(7)	5(2)	1(1)	1(1)	-	-	-	3(2)	9(5)	-	-
	100	7(2)	2(1)	-	12(4)	4(1)	-	-	-	-	-	-	2(1)	-	-
VIC: Latrobe Valley (1 station)	70	2(2)	-	-	9(9)	3(3)	-	1(1)	-	-	-	1(1)	3(3)	3(3)	-
	85	-	-	-	3(3)	1(1)	-	1(1)	-	-	-	1(1)	-	-	-
	100	-	-	-	3(3)	-	-	1(1)	-	-	-	-	-	-	-
QLD: South-East Queensland (5 stations)	70	7(7)	23(17)	15(12)	6(5)	3(3)	4(4)	7(6)	7(5)	10(6)	8(7)	3(3)	4(4)	10(7)	4(3)
	85	2(2)	4(4)	-	-	1(1)	-	-	2(2)	4(2)	3(3)	-	-	3(2)	-
	100	-	2(2)	-	-	-	-	-	-	1(1)	-	-	-	1(1)	-
QLD: Townsville (1 station)	70	-	-	-	-	-	-	-	-	1(1)	-	-	-	-	-
	85	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SA: Adelaide (5 stations)	70	3(3)	8(4)	1(1)	4(2)	7(6)	4(2)	5(3)	1(1)	2(1)	-	1(1)	3(3)	4(4)	4(3)
	85	-	1(1)	-	2(1)	-	1(1)	-	-	-	-	-	-	-	-
	100	-	-	-	1(1)	-	-	-	-	-	-	-	-	-	-
WA: Perth (6 stations)	70	15(11)	24(17)	20(11)	19(15)	23(17)	19(12)	14(12)	12(10)	14(10)	30(15)	35(18)	8(6)	26(15)	18(10)
	85	2(2)	2(2)	4(2)	2(2)	3(3)	2(2)	3(2)	2(2)	-	8(6)	4(3)	1(1)	5(4)	5(2)
	100	-	2(2)	-	-	-	-	2(2)	-	-	3(2)	1(1)	-	2(1)	1(1)
NT: Darwin (2 station2)	70	-	-	-	-	-	-	-	-	5(5)	13(12)	1(1)	-	2(1)	-
	85	-	-	-	-	-	-	-	-	-	2(2)	-	-	-	-
	100	-	-	-	-	-	-	-	-	-	1(1)	-	-	-	-
ACT: Canberra (2 stations)	70	5(4)	1(1)	-	5(5)	3(3)	-	1(1)	-	-	-	-	-	-	-
	85	3(3)	-	-	4(4)	2(2)	-	-	-	-	-	-	-	-	-
	100	1(1)	-	-	3(3)	1(1)	-	-	-	-	-	-	-	-	-

Table B-5: Historical exceedance days for rolling 4-hour O_3 standards

Jurisdiction-airshed	Standard (ppb)	Number of exceedance days (unique exceedance days are given in brackets)													
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NSW: Sydney (11 stations)	60	55(20)	114(37)	88(29)	118(49)	95(34)	31(10)	119(36)	67(26)	67(22)	50(16)	85(24)	102(5)	88(30)	103(28)
	70	28(11)	51(19)	40(16)	66(29)	44(16)	13(6)	59(23)	30(13)	33(12)	13(7)	32(13)	42(9)	16(10)	26(13)
	80	16(6)	28(14)	19(8)	32(19)	24(9)	2(2)	31(12)	9(8)	13(5)	2(1)	10(5)	13(4)	-	4(2)
NSW: Newcastle (3 stations)	60	2(2)	23(21)	2(2)	2(2)	-	-	4(4)	5(5)	1(1)	3(3)	7(7)	3(3)	8(6)	14(7)
	70	-	13(11)	1(1)	-	-	-	-	1(1)	-	-	2(2)	-	1(1)	4(3)
	80	-	-	-	-	-	-	-	-	-	-	-	-	1(1)	-
NSW: Wollongong (4 stations)	60	21(9)	20(8)	14(9)	19(11)	14(9)	3(2)	21(9)	10(5)	12(5)	4(2)	17(8)	6(4)	20(13)	21(12)
	70	14(5)	12(5)	4(2)	8(5)	5(2)	-	10(6)	3(3)	8(4)	-	12(4)	1(1)	7(4)	8(4)
	80	8(4)	6(3)	2(1)	2(1)	2(2)	-	3(3)	-	5(3)	-	7(3)	-	1(1)	4(2)
VIC: Port Phillip Region (6 stations)	60	31(14)	9(4)	16(9)	55(18)	50(21)	30(14)	32(15)	4(4)	-	-	18(12)	39(13)	7(6)	4(4)
	70	13(4)	3(2)	3(3)	23(8)	19(8)	8(5)	8(7)	1(1)	-	-	3(2)	23(8)	-	-
	80	10(3)	3(2)	-	14(5)	4(1)	-	1(1)	-	-	-	3(2)	4(4)	-	-
VIC: Latrobe Valley (1 station)	60	3(3)	-	-	9(9)	2(2)	-	1(1)	-	-	-	1(1)	1(1)	-	-
	70	-	-	-	6(6)	2(2)	-	1(1)	-	-	-	1(1)	-	-	-
	80	-	-	-	2(2)	1(1)	-	-	-	-	-	1(1)	-	-	-
QLD: South-East Queensland (5 stations)	60	9(9)	28(19)	21(16)	3(2)	6(5)	6(5)	10(8)	7(5)	14(8)	9(8)	4(3)	6(6)	10(7)	4(3)
	70	3(3)	7(7)	-	-	1(1)	1(1)	-	3(2)	5(3)	4(4)	-	-	4(3)	-
	80	1(1)	1(1)	-	-	-	-	-	-	4(2)	1(1)	-	-	2(1)	-
QLD: Townsville (1 station)	60	-	-	-	-	-	-	-	-	3(3)	-	-	-	-	-
	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SA: Adelaide (5 stations)	60	3(3)	10(6)	1(1)	4(3)	10(8)	5(2)	7(3)	-	2(1)	-	6(4)	3(3)	6(5)	2(2)
	70	1(1)	2(2)	1(1)	2(1)	2(2)	1(1)	-	-	1(1)	-	-	-	-	-
	80	-	-	-	1(1)	-	1(1)	-	-	-	-	-	-	-	-
WA: Perth (6 stations)	60	13(10)	24(18)	19(10)	21(15)	20(14)	27(13)	17(11)	14(10)	19(13)	38(17)	40(22)	8(7)	35(23)	22(11)
	70	3(3)	3(3)	4(4)	4(4)	8(6)	6(5)	4(3)	3(3)	2(1)	16(8)	7(6)	1(1)	7(5)	9(5)
	80	-	-	-	-	-	-	3(2)	-	-	6(5)	1(1)	-	2(1)	2(2)
NT: Darwin (2 station2)	60	-	-	-	-	-	-	-	-	9(9)	26(25)	2(2)	2(2)	2(1)	-
	70	-	-	-	-	-	-	-	-	3(3)	6(6)	-	1(1)	1(1)	-
	80	-	-	-	-	-	-	-	-	1(1)	-	-	-	-	-
ACT: Canberra (2 stations)	60	6(4)	1(1)	3(2)	5(5)	5(5)	-	3(3)	-	-	-	-	-	-	-
	70	3(2)	-	-	3(3)	2(2)	-	-	-	-	-	-	-	-	-
	80	1(1)	-	-	1(1)	1(1)	-	-	-	-	-	-	-	-	-

Table B-6: Historical exceedance days for rolling 8-hour O_3 standards

Jurisdiction-airshed	Standard (ppb)	Number of exceedance days (unique exceedance days are given in brackets)													
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NSW: Sydney (11 stations)	47	104(41)	168(55)	136(47)	182(55)	163(47)	56(23)	185(64)	118(39)	125(36)	93(28)	153(43)	184(38)	176(41)	192(43)
	55	43(16)	85(30)	61(20)	102(28)	67(25)	16(8)	101(36)	60(21)	60(20)	27(10)	75(24)	72(18)	51(21)	76(23)
	60	31(11)	52(19)	39(15)	61(20)	45(17)	7(5)	63(23)	36(15)	35(14)	7(4)	35(16)	37(9)	16(8)	36(14)
	70	13(6)	21(8)	18(7)	25(7)	19(6)	-	26(12)	12(6)	11(3)	1(1)	9(3)	9(3)	-	-
NSW: Newcastle (3 stations)	47	11(9)	39(35)	5(5)	5(5)	-	2(2)	12(12)	11(11)	3(3)	9(8)	20(16)	22(15)	21(12)	33(18)
	55	1(1)	16(15)	1(1)	2(2)	-	-	5(5)	5(5)	1(1)	1(1)	5(5)	3(2)	4(4)	12(7)
	60	-	14(13)	-	-	-	-	1(1)	2(2)	-	-	2(2)	-	1(1)	4(3)
	70	-	3(3)	-	-	-	-	-	-	-	-	-	-	1(1)	1(1)
NSW: Wollongong (4 stations)	47	26(10)	36(15)	25(15)	30(16)	27(13)	11(7)	31(15)	21(10)	25(11)	10(5)	26(12)	14(11)	35(18)	38(19)
	55	20(9)	16(6)	9(5)	11(7)	10(6)	3(2)	15(9)	10(5)	11(5)	4(2)	16(7)	4(2)	18(11)	17(10)
	60	14(6)	12(5)	4(2)	6(5)	7(3)	-	8(6)	4(3)	7(4)	-	12(5)	2(1)	5(3)	10(6)
	70	5(4)	6(3)	2(2)	1(1)	-	-	1(1)	1(1)	5(3)	-	7(3)	-	2(2)	4(3)
VIC: Port Phillip Region (6 stations)	47	73(25)	20(8)	27(14)	101(30)	124(44)	64(23)	57(22)	19(8)	-	-	67(24)	76(23)	45(41)	18(16)
	55	29(13)	8(3)	8(6)	49(17)	44(19)	35(17)	24(12)	-	-	-	14(8)	42(13)	4(4)	1(1)
	60	16(6)	3(2)	2(2)	33(13)	26(12)	16(10)	10(8)	-	-	-	4(3)	27(11)	-	-
	70	11(3)	2(2)	-	15(5)	6(3)	1(1)	1(1)	-	-	-	2(2)	6(3)	-	-
VIC: Latrobe Valley (1 station)	47	8(8)	-	2(2)	13(13)	11(11)	4(4)	2(2)	-	-	-	6(6)	6(6)	6(6)	11(11)
	55	4(4)	-	-	8(8)	2(2)	-	-	-	-	-	1(1)	1(1)	2(2)	3(3)
	60	-	-	-	7(7)	2(2)	-	-	-	-	-	1(1)	-	-	-
	70	-	-	-	1(1)	-	-	-	-	-	-	1(1)	-	-	-
QLD: South-East Queensland (5 stations)	47	-	-	-	-	-	3(3)	1(1)	-	5(5)	-	-	-	-	-
	55	-	-	-	-	-	-	-	-	4(4)	-	-	-	-	-
	60	-	-	-	-	-	-	-	-	1(1)	-	-	-	-	-
	70	-	-	-	-	-	-	-	-	-	-	-	-	-	-
QLD: Townsville (1 station)	47	19(16)	55(39)	38(28)	12(10)	21(15)	18(11)	21(18)	9(7)	24(15)	25(16)	21(16)	12(12)	25(16)	13(11)
	55	3(3)	15(13)	7(5)	2(2)	3(2)	2(2)	-	3(2)	11(5)	8(8)	1(1)	3(3)	6(4)	-
	60	2(2)	4(4)	-	1(1)	-	1(1)	-	1(1)	5(3)	3(3)	-	-	4(3)	-
	70	1(1)	1(1)	-	-	-	-	-	-	3(2)	1(1)	-	-	-	-
SA: Adelaide (5 stations)	47	17(10)	20(12)	4(2)	15(9)	46(15)	17(7)	29(12)	12(6)	13(6)	14(8)	20(9)	13(7)	15(7)	16(9)
	55	4(2)	4(3)	1(1)	3(2)	9(6)	3(1)	2(1)	1(1)	2(1)	1(1)	5(2)	1(1)	2(2)	-
	60	1(1)	1(1)	1(1)	2(1)	3(3)	1(1)	1(1)	-	1(1)	-	1(1)	-	-	-
	70	-	-	-	1(1)	-	1(1)	-	-	-	-	-	-	-	-
WA: Perth (6 stations)	47	33(22)	50(26)	47(22)	55(25)	57(33)	53(19)	48(25)	37(20)	48(21)	82(28)	79(36)	23(14)	96(37)	69(29)
	55	6(4)	10(7)	12(7)	17(10)	12(9)	12(7)	12(9)	7(6)	13(8)	33(14)	24(13)	4(3)	26(19)	23(11)
	60	3(3)	2(2)	7(4)	9(8)	8(5)	5(5)	7(5)	3(3)	4(2)	14(8)	6(5)	2(2)	8(7)	11(6)
	70	-	-	1(1)	-	1(1)	-	1(1)	-	-	4(3)	-	-	1(1)	3(1)

Jurisdiction-airshed	Standard (ppb)	Number of exceedance days (unique exceedance days are given in brackets)													
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NT: Darwin (2 station2)	47	-	-	-	-	-	-	-	-	46(46)	91(83)	17(17)	9(7)	7(6)	4(4)
	55	-	-	-	-	-	-	-	-	11(11)	29(28)	1(1)	1(1)	2(1)	-
	60	-	-	-	-	-	-	-	-	8(8)	12(11)	-	1(1)	-	-
	70	-	-	-	-	-	-	-	-	1(1)	2(2)	-	-	-	-
ACT: Canberra (2 stations)	47	9(7)	1(1)	4(3)	5(5)	12(12)	1(1)	9(7)	-	-	-	1(1)	-	1(1)	1(1)
	55	3(2)	-	-	3(3)	1(1)	-	3(3)	-	-	-	-	-	-	-
	60	2(2)	-	-	1(1)	1(1)	-	-	-	-	-	-	-	-	-
	70	-	-	-	1(1)	1(1)	-	-	-	-	-	-	-	-	-

Annexure C: Abatement measures

A Literature review of abatement measure options (air quality emission reduction focus) was undertaken targeting emissions of SO_2, NO_x and VOCs as a precursor/trigger for O_3.

The abatements considered were referenced from:

- Abatement list and references provided by EPA Victoria.
- Other references, the emphasis being a review of material published in past five years. The literature review was completed prior to 31 March 2016.

C.1 Literature reviewed for sulfur dioxide

Industry

- Generation of electrical power - Flue gas desulfurisation; gas capture and treatment.
- Petroleum Refining - Flue gas desulfurisation.
- Iron and Steel production (iron ore) - Flue gas desulfurisation.

Shipping

- Ship to shore power.
- Low sulfur fuel standards for the shipping industry.

Literature reviewed

- De-SO_x and gas capture storage standards at power stations

Cichanowicz J E (2010). Current capital cost and cost-effectiveness of power plant emissions control technologies, Jan 2010. Prepared by J Edward Cichanowicz for the Utility Air Regulatory Group. Available at: *http://www.publicpower.org/files/PDFs/UARGSCR_FGDFinal.pdf* (Accessed: March 2016).

CRS (2013). Increasing the Efficiency of Existing CoalFired Power Plants. Prepared by Richard J. Campbell Specialist in Energy Policy. Congressional Research Service. December 20, 2013. Available at: https://www.fas.org/sgp/crs/misc/R43343.pdf (Accessed: March 2016).

Ecofys (2014). International comparison of fossil power efficiency and CO2 intensity - Update 2014 FINAL REPORT. Prepared by Charlotte Hussy, Erik Klaassen, Joris Koornneef and Fabian Wigand Date: 5 September 2014 Project number: CESNL15173 Ecofys 2014 by order of: Mitsubishi Research Institute, Japan. Available at: *http://www.ecofys.com/files/files/ecofys-2014-international-comparison-fossil-power-efficiency.pdf* (Accessed: March 2016).

EGTEI (2012). Convention on Long-Range Transboundary Air Pollution 50th Working Group on Strategies and Review – 10 to 14 September 2012. Guidance document on control techniques for emissions of sulphur, NOx, VOCs, dust (including PM_{10}, $PM_{2.5}$ and black carbon) from stationary sources. Available at: https://www.unece.org/fileadmin/DAM/env/documents/2012/EB/Informal_document_7_EGTEI_guidance-document_on_stationary_sources_tracked_changes_compared_with_WGSR_version.pdf (Accessed: March 2016).

Hunwick Consultants Pty Ltd (undated). Power station stack gas emissions, a review of control techniques: current and projected. Available at: *http://www.hunwickconsultants.com.au/papers/download/stack_gas_emissions_paper.pdf* (Accessed: March 2016).

USEPA (2002). EPA Air Pollution Control Cost Manual 6th Ed, Jan 2002. Available at: *http://www3.epa.gov/ttncatc1/dir1/c_allchs.pdf* (Accessed: March 2016).

- Low sulfur fuel standards for the shipping industry

Andreoni V et al. (2008). Cost Effectiveness Analysis of the Emission Abatement in the Shipping Sector Emissions EUR 23715 EN – 2008JRC Scientific and Technical Reports prepared by Andreoni, A. Miola, A. Perujo EU 2008. Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC49334/reqno_jrc49334_eur_report_cost_effectiviness.pdf%5B1%5D.pdf (Accessed: March 2016).

BMT (undated). EU Ship Emissions to Air Study (Appendix 2 Atmospheric Emissions & Air Quality). Available at: http://ec.europa.eu/environment/enveco/taxation/ship_emissions/pdf/app2final.pdf

Carr E (2013). Economic Incentives to Reduce Shipping Emissions in Panama. Prepared by Edward Willson Carr, Monday, September 30th, 2013 http://www.udel.edu/MAST/873/AP%20Proposals/Ed%20Carr%20AP%20Proposal.pdf (Accessed: March 2016).

Entec UK Ltd (2005). European Commission Directorate General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments Task 2c – SO2 Abatement Final Report August 2005 Entec UK Limited Task 2 Available at: http://www/SO2 Final_final Report 16_09_05v2.doc (Accessed: March 2016).

Johansson L et al. (2013). The evolution of shipping emissions and the costs of regulation changes in the northern EU area. Atmos. Chem. Phys., 13, 11375–11389, 2013 Available at: http://www.atmos-chem-phys.net/13/11375/2013/acp-13-11375-2013.pdf (Accessed: March 2016).

Litehauz (2012). Investigation of appropriate control measures (abatement technologies) to reduce Black Carbon emissions from international shipping - Study Report 2012. Prepared by Litehauz, Daniel A Lack, Jorgen Thuesen and Robert Elliot Available at: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/Report%20IMO%20Black%20Carbon%20Final%20Report%2020%20November%202012.pdf (Accessed: March 2016).

Wang Kun et al. (2014). WORKING PAPER ITLS-WP-14-06 Modeling the Impacts of Alternative Emission Trading Schemes on International Shipping. Prepared by Kun Wang, Xiaowen Fu and Meifeng Luo April 2014 for the Institute of Transport and Logistics Studies, University of Sydney. Available at: http://sydney.edu.au/business/__data/assets/pdf_file/0017/200564/ITLS-WP-14-06.pdf (Accessed: March 2016).

- Shore-side power

Broome et al. (2016). The mortality effect of ship-related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia. Richard A. Broome, Martin E. Cope, Brett Goldsworthy, Laurie Goldsworthy, Kathryn Emmerson, Edward Jegasothy, Geoffrey G.

Morgan. Environment International 87 (2016) 85–93. Available at: http://lungfoundation.com.au/wp-content/uploads/2016/02/The-Mortality-effect-of-ship-related-fine-particulate-matter.pdf (Accessed: March 2016).

Department of Environment, Climate Change and Water (DECCW) – Cost Abatement Curves for Air Emission Reduction Actions SKM 2010 http://www.epa.nsw.gov.au/resources/air/costcurveairemissionredn.pdf (Accessed: March 2016).

Det Norske Veritas (2015). NSW Ship emissions Study - Emissions from ships operating in the Greater Metropolitan Area. Prepared by Det Norske Veritas (Australia) Pty Ltd for NSW Environment Protection Authority. Available at http://www/Emissions from ships operating in the Greater Metropolitan Area.pdf (Accessed: March 2016).

Entec UK Ltd (2005). European Commission Directorate General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments Task 2c – SO_2 Abatement Final Report August 2005 Entec UK Limited Task 2 Available at: http://www/SO2 Final_final Report 16_09_05v2.doc (Accessed: March 2016).

Hamberg Port Authority (2014). Available at: http://cnss.no/wp-content/uploads/2014/03/Lutz_140306_OPS-Bergen.pdf (Accessed: March 2016).

C.2 Literature reviewed for nitrogen dioxide

Industry

- Iron or steel production (iron ore) - Selective Catalytic Reduction.
- Cement or lime production - Selective Catalytic Reduction.
- Generation of electrical power from coal/Fossil Fuel Electricity Generation - Selective Non-Catalytic Reduction.
- Alumina Production -installation of low NOx burners.
- Water Transport Support Services -Shipping - On-board exhaust gas after treatment to reduce NOx.

Shipping

- Ship to shore power.
- Low sulfur fuel standards for the shipping industry.

Non road diesel engines

On road mobile emissions

- Encouraging active and public transport.
- Incentives to purchase electric/hybrid cars.
- Congestion pricing.

Note: Non road spark ignition engines and wood heaters are excluded from abatements but incorporated as part of the BAU scenario based on the government decision of December 2015.

Literature reviewed

- Encouraging active and public transport, e.g. cycling and buses

Department of Transport - TravelSmart (2011). Evaluation summary - TravelSmart workplace program. Available at: http://www.transport.wa.gov.au/mediaFiles/active-transport/AT_TS_P_Evaluation_Summary_Workplace.pdf (Accessed: March 2016).

Hensher D A and Li Z (2010). Accounting for differences in modelled estimates of RP, SP and RP/SP direct petrol price elasticities for car mode choice: A warning, Transport Policy, 17(3), pp. 191–195. doi: 10.1016/j.tranpol.2010.01.006.

Ker I (2003). Preliminary evaluation of the financial impacts and outcomes of the TravelSmart Individualised marketing program -update. Available at: http://www.transport.wa.gov.au/mediaFiles/active-transport/AT_TS_P_financereport.pdf (Accessed: March 2016).

Stopher P R, Moutou C J and Liu W (2013). Institute of Transport and Logistic Studies Sustainability of voluntary travel behaviour change initiatives: A 5-year study. Available at: http://sydney.edu.au/business/__data/assets/pdf_file/0017/172511/ITLS-WP-13-12.pdf (Accessed: March 2016).

Stopher P, Zhang Y, Zhang J and Halling B (2010). Institute of Transport and Logistic Studies results of an evaluation of TravelSmart in south Australia. Available at: http://sydney.edu.au/business/__data/assets/pdf_file/0013/70501/itls-wp-10-11.doc.pdf (Accessed: March 2016).

Wake D (2012). Engaging Perth workplaces for sustainable transport: An evaluation of the TravelSmart workplace program. Available at: http://atrf.info/papers/2012/2012_Wake.pdf (Accessed: March 2016).

Xia et al. (2014). Traffic-related air pollution and health co-benefits of alternative transport in Adelaide, South Australia. Ting Xia, Monika Nitschke, Ying Zhang, Pushan Shah, Shona Crabb, Alana Hansen. Environment International 74 (2015) 281–290 Available at: http://saferoutespartnership.org/resources/academic-research/travel-impacts-on-air-quality-and-greenhouse-gases (Accessed: March 2016).

- Incentives to purchase electric / hybrid cars

AECOM (2011). Australian Energy Marcket Commission (AEMC). Impact of electric vehicles and natural gas vehicles on the energy markets (2011) Available at: http://www.aemc.gov.au/Media/docs/AECOM%20Initial%20Advice-8fff41dd-f3ea-469d-9966-e50ba2a8d17b-0.pdf (Accessed: March 2016).

Cope M and Lee S (2011). The Centre for Australian Weather and Climate Research Exploring the co-benefit of electric vehicle uptake and ozone pollution reduction in Sydney - final report. Available at: http://www.cawcr.gov.au/technical-reports/CTR_043.pdf (Accessed: March 2016).

Duke M, Andrews D, Anderson and Nicholas T (2009). The feasibility of long range battery electric cars in New Zealand, 37(9), pp. 3455–3462. doi: 10.1016/j.enpol.2008.10.047.

Greaves, S., Backman, H. and Ellison, A.B. (2014) 'An empirical assessment of the feasibility of battery electric vehicles for day-to-day driving', Transportation Research Part A: Policy and Practice, 66, pp. 226–237. doi: 10.1016/j.tra.2014.05.011.

Hensher, D.A. and Mulley, C. (2012) Institute of Transport and Logistic Studies. Cost impacts to motorists of discounted registration fees in the presence of distance-based charges and implications for government revenue. Available at: http://sydney.edu.au/business/__data/assets/pdf_file/0005/149621/ITLS-WP-12-20.docx.pdf (Accessed: March 2016).

Lucchese, P. (no date) Rechargeable vehicles infrastructure deployment policy: French Case. Available at: http://www.oecd.org/futures/Rechargeable%20Vehicles%20Infrastructure%20Deployment%20Policy%20French%20Case.pdf (Accessed: March 2016).

Lutsey N et al (2015) Assessment of leading electric vehicle promotion activities in United States cities (2015). Nic Lutsey, Stephanie Searle, Sarah Chambliss, Anup Bandivadekar. Availlable at: http://www.theicct.org/leading-us-city-electric-vehicle-activities (Accessed: March 2016).

Mader, T. (2013) WA Electric Vehicle Trial - Western Australian electric vehicle trial 2010 – 2012 final report. Available at: http://therevproject.com/trialreport.pdf (Accessed: March 2016).

Softeryx Limited (2009) Economic viability of electric vehicles. Department of Environment and Climate Change. Available at: http://www.environment.nsw.gov.au/resources/climatechange/ElectricVehiclesReportpdf (Accessed: March 2016).

Stevens, B. and Schieb, P.-A. (2013) OECD workshop on: Developing infrastructure for alternative transport fuels and power-trains to 2020/2030/2050 A synthesis report. OECD International Futures Programme, Directorate for Science, Technology and Industry Available at: http://www.oecd.org/futures/synthesisreport.pdf (Accessed: March 2016).

Taylor, M.A.P., Pudney, P., Zito, R., Holyoak, N., Albrecht, A. and Raicu, R. (2009) Planning for electric vehicles in Australia – Can we match environmental requirements, technology and travel demand? Available at: http://atrf.info/papers/2009/2009_Taylor_Pudney_Zito_Holyoak_Albrecht_Raicu.pdf (Accessed: March 2016).

- More stringent new vehicle emission standards

Albrecht, A., Holyoak, N., Pudney, P., Raicu, R., Taylor, M. Zito, R., and Groves, J. (2009) Uptake and use of electric vehicles in Australia. Project code/milestone no. C2-16 M003 Available at: http://scg.ml.unisa.edu.au/autocrc/ev_planning/final_reports/uptake.pdf (Accessed: April 2016).

EPA NSW (2014) TP01: Trends in motor vehicles and their emissions. Advisory Committee on Tunnel Air Quality, Environment Protection Authority, New South Wales Government. Available at: http://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0007/54790/Road-Tunnels_TP01_Trends_inMotor_Vehicles_and_Their_Emissions.pdf (Accessed: March 2016).

OECD (2014) The cost of air pollution. Available at: http://www.oecd.org/env/the-cost-of-air-pollution-9789264210448-en.htm (Accessed: March 2016).

USEPA (2016) Transportation, air pollution, and climate change. Available at: http://www3.epa.gov/otaq/documents/tier3/420r14005.pdf (Accessed: March 2016).

Williamson, M. (2007) An economic analysis to inform the air quality strategy. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/221088/pb12637-icgb.pdf (Accessed: March 2017).

- Changes to fuel standards for motor vehicles

Europa (2001) The costs and benefits of lowering the sulphur content of petrol & diesel to less than 10ppm, prepared by Directorate-General Environment, Sustainable Development Unit and Air and Noise Unit (2001) Available at: http://ec.europa.eu/environment/archives/sulphur/cbloweringsulphurcontent.pdf (Accessed: March 2016).

Kinrade et al. (2016) 2015 review of the fuel quality standards act 2000: Final report (2016). Department of the Environment and Energy, Australian Government. Available at: https://www.environment.gov.au/protection/publications/2015-review-fuel-quality-standards-act-2000-final-report (Accessed: April 2016).

Smit, R. (2014) Department of the environment subject Australian motor vehicle emission inventory for the national pollutant inventory (NPI). Available at: http://www.npi.gov.au/system/files/resources/e8311456-8a41-4473-9fa1-d2f9994ff8da/files/australian-motor-vehicle-emissions-inventory-2014_0.pdf (Accessed: March 2016).

- Non-road diesel engine standards

DEH (2007) Management options for non-road engine emissions in urban areas. Australian Government Department of the Environment and Heritage. Available at: http://www.environment.gov.au/system/files/resources/d78b1ca2-1298-4799-b718-d87fcadf70eb/files/non-road-engine-emissions-options.pdf (Accessed: 17 January 2017).

Environ (2014) Reducing emissions from non-road diesel engines. An information report prepared for the NSW EPA. Available at: http://www.epa.nsw.gov.au/resources/air/140586NonrdDiesInfoRpt.pdf (Accessed: March 2016).

- Reducing emissions from wood heaters

Australia, C. of (1994a) National environment protection council. Available at: http://www.scew.gov.au/system/files/resources/8fcee61a-e161-4745-b009-259f4c878865/files/woodheaters-cris-april2013.pdf (Accessed: March 2016).

Australia, C. of (1994b) National environment protection council. Available at: http://www.scew.gov.au/system/files/consultations/b8edfe53-fd79-4df4-09a5-6425958457f4/files/aq-ris-non-road-spark-ignition-engines-consultation-250510.pdf (Accessed: March 2016).

See NEPC December Decision documents (not yet published). Received from EPA Victoria CONFIDENTIAL\MEM - 2b - DRIS for wood heaters Agenda Paper Attachment B.

- Other

Allemand (2012) Guidance document on control techniques for emissions of sulphur, NOx, VOCs, dust (including PM10, PM 2.5 and black carbon) from stationary sources. Available at: https://www.unece.org/fileadmin/DAM/env/documents/2012/EB/Informal_document_7_EGTEI_guidance-document_on_stationary_sources_tracked_changes_compared_with_WGSR_version.pdf (Accessed: March 2016).

Department of Environment, Climate Change and Water (DECCW) (2011), Cost Abatement Curves for Air Emission Reduction Actions, prepared by SKM 2010 Available at: https://www.epa.nsw.gov.au/resources/air/CostCurveAirEmissionRedn.pdf (Accessed: March 2016).

Lee, S. (2002), Evaluation Policy Alternatives to Alleviate Transportation-Related Pollution. Ph.D. Dissertation, School of Policy, Planning and Development, University of Southern California, Los Angeles. Available at: http://digitallibrary.usc.edu/cdm/ref/collection/p15799coll16/id/552055 (Accessed: March 2016).

OECD (2012) Fuel economy of road vehicles. Available at: http://www.oecd.org/publications/fuel-economy-of-road-vehicles-9789264185029-en.htm (Accessed: March 2016).

OECD (2013) 'The Swedish tax on nitrogen oxide emissions'. Available at: http://www.oecd-ilibrary.org/environment-and-sustainable-development/the-swedish-tax-on-nitrogen-oxide-emissions_5k3tpspfqgzt-en (Accessed: March 2016).

Sterner, T. and Turnheim, B. (2008) Innovation and diffusion of environmental technology industrial NOx abatement in Sweden under refunded emission payments. Available at: http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-DP-08-02.pdf (Accessed: March 2016).

C.3 Literature reviewed for ozone (reduction of volatile organic compounds)

Industry

- Surface Coating Reformulation
- Solvent/Aerosol Use (domestic/commercial) – Reformulation

Domestic

- Solid Fuel Burning - Installation of retro-fit device

On-road mobile emissions

- Encouraging active and public transport.
- Incentives to purchase electric/hybrid cars.
- Congestion pricing.

- On board vapour recovery
- Service Stations - Stage 2 Vapour Recovery

Note: Non road spark ignition engines and wood heaters are excluded from abatements but incorporated as part of the BAU scenario based on the government decision of December 2015.

Literature reviewed

- On-board refuelling vapour recovery

Bluett, R. (2006) Vehicle refuelling: A neglected emission source. Available at: http://atrf.info/papers/2006/2006_Bluett.pdf (Accessed: March 2016).

Commission of the European Communities (2008) Proposal from the Commission to the European Parliament and Council for a directive proposal for stage II petrol vapour recovery during the refuelling of petrol cars at service stations. Executive Summary – Impact Assessment. Available at: http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2008/sec_2008_2938_en.pdf (Accessed: March 2016).

Department of Environment and Climate Change NSW (2007) Discussion paper: Improving air quality through vapour recovery at service stations. Available at: http://www.environment.nsw.gov.au/resources/air/vapourrecovery_07375.pdf (Accessed: March 2016).

Fung, F. and Maxwell, B. (2011) International council on clean transportation on-board refueling vapor recovery: Evaluation of the ORVR program in the United States. Available at: http://www.theicct.org/sites/default/files/publications/ORVR_v4.pdf (Accessed: March 2016).

- Introducing regulated low volatility fuel

Victoria State Government (2014) Environment protection (vehicle emissions) regulations – regulatory impact statement. Available at: http://www.epa.vic.gov.au/our-work/publications/publication/2013/august/1543 (Accessed: March 2016).

Victoria State Government (2014) Environment protection (vehicle emissions) regulations – regulatory impact statement – response to comments. Available at: http://www.epa.vic.gov.au/our-work/publications/publication/2013/august/1543 (Accessed: March 2016).

- Stage II vapour recovery at petrol stations

DECC NSW (2009), Better Regulation Statement Expansion of Vapour Recovery at Petrol Service Stations in the NSW Greater Metropolitan Region. Available at: http://www.epa.nsw.gov.au/resources/air/brostatement.pdf (Accessed: March 2016).

Defra (2005) Stage II Petrol Vapour recovery during Refuelling of motor vehicles at service stations. Defra - citizen space 2015 - Available at: https://consult.defra.gov.uk/industrial-pollution-control/transposition-of-directive-2014-99-eu-on-stage-ii (Accessed: March 2016).

EC (2002), Estimates of Marginal External Costs of Air Pollution in Europe, European Commission: Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme Damages per tonne emission of $PM_{2.5}$, NH_3, SO_2, NO_X and VOCs from each EU25 Member State (excluding

Cyprus) and surrounding sea (March 2005). Available at: http://ec.europa.eu/environment/archives/cafe/activities/pdf/cafe_cba_externalities.pdf (Accessed: March 2016).

- Surface coating standards

CEPA (Canadian Environmental Protection Act), Amendment 2009a Volatile Organic Compound (VOC) Concentration Limits for Architectural Coatings Regulations, (SOR/2009-264). Available at: http://canadagazette.gc.ca/rp-pr/p2/2009/2009-09-30/html/sor-dors264-eng.html (Accessed: March 2016).

CEPA (Canadian Environmental Protection Act) Amendment (2009b) Volatile Organic Compound (VOC) Concentration Limits for Automotive Refinishing Products Regulations P.C. 2009-1036, 2009 Available at: http://canadagazette.gc.ca/rp-pr/p2/2009/2009-07-08/html/sor-dors197-eng.html (Accessed: March 2016).

CSIRO (2015) AP-D181 APAS (Australian Paint Approvals Scheme) 2006 Volatile Organic Compounds (VOC) Limits. Available at: http://www.apas.gov.au/pdfs/D181.pdf (Accessed: March 2016).

EU (European Parliament) 2004 Directive 2004/42/CE of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC Available at: http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32004L0042:EN:HTML (Accessed: March 2016).

NEPC (2009) VOCs from Surface Coatings – Assessment of the Categorisation, VOC Content and Sales Volumes of Coating Products Sold in Australia. Available at: http://www.scew.gov.au/system/files/resources/220add0d-0265-9004-1d22-0c312998402c/files/aaq-rpt-vocs-surface-coatings-final-20090930.pdf (Accessed: March 2016).

USEPA (1998) Economic impact and regulatory flexibility analyses of the final architectural coatings VOC rule. United States Environmental Protection Agency. Available at: https://www3.epa.gov/ttn/ecas/regdata/EIAs/eiaaim.pdf (Accessed: March 2016).

USEPA (1999). New federal regulation for Automobile Refinish Coatings. United States Environmental Protection Agency. Available at: http://www.newmoa.org/publications/auto/autocoat.pdf (Accessed: March 2016).

USEPA (2003) Economic impact analysis of the miscellaneous metal parts and products surface coating NESHAP: Final report (2003). Available at: https://www3.epa.gov/ttnecas1/regdata/EIAs/miscmetalppeia.pdf (Accessed: March 2016).

USEPA (2005) Chapter 153: Mobile Equipment Repair and Refinishing Air quality implementation plans. Available at: http://www.epa.gov/region1/topics/air/sips/me/2005_ME_Ch153.pdf (Accessed: March 2016).

C.4 Abatements – key Information for multi-criteria analysis – development of Abatement Package scenario

Abatement	1. On-board refuelling vapour recovery		
Description	Requirement for onboard emission control systems to capture fuel vapour from the fuel tank during refuelling.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
			Yes
Assumptions	Average vehicle life approximately 10 years; Regulation required taking approximately 1-2 years (2017-2019); Penetration of vehicles into Australian market commences immediately following regulation (vehicle imports from USA already at specification) (2019-2020), however majority of imports to Australia are no this specification. In 2020 minimal uptake equivalent to 20% of the new vehicle fleet have OBVR; for 2030 50% uptake, and 2040 100% uptake in motor vehicle fleet (assumption that all imported vehicles regardless of origin are required to have OBVR). Efficiency of 80% reduction mainly in summer months. Based on 2020 Victoria projected fuel use and calculated diesel vapour emissions, approximately 90% of the VOC at service stations are from petrol. Based on emission factors, approximately 62% emissions from petrol are from filling vehicles. From this assumed 56% of all VOC emissions at service stations are from filling petrol vehicles. Assumptions apply to all states.		
Included in final Abatement Package	No		

Abatement	2. Introducing low-volatility fuel		
Description	Introduce tighter petrol volatility limits over summer. ie decreasing petrol volatility leading to lower evaporation of petrol and therefore reduced emissions		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
			Yes
Assumptions	Assumes Victoria emissions split. Assumes 45% of vapour emissions are released during summer months (based in long term Melbourne temperature differences). Assumes 5% reduction in RVP for summer months.		
Included in final Abatement Package	No		

Abatement	3. Encouraging public transport		
Description	To promote the use of public transport and change travel behaviour by providing subsidies for using public transport.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
	Yes	Yes	Yes
Assumptions	Control efficiency applied 1% encouraging active and public transport 2040.		
Included in final Abatement Package	No		

Abatement	4. Incentives to purchase electric vehicles		
Description	Promote the purchase of electric cars by providing a subsides that eliminates the price differential between electric and petrol powered cars		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
	Yes	Yes	Yes
Assumptions	Control efficiency applied <1% incentives for electric/hybrid vehicles 2040. Uptake 20% (2020); 50% (2030); 100% (2040)		
Included in final Abatement Package	No		

Abatement	5. More stringent new vehicle emission standards		
Description	Bring forward the implementation of the more stringent emissions standards from the Euro 6 requirement.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
	Yes	Yes	Yes
Assumptions	The abatement would only bring forward the current start date of Euro 6 standards by 1-2 years.		
Included in final Abatement Package	No		

Abatement	6. Non-road diesel engines		
Description	Assess potential actions that could be adopted to reduce non-road diesel engine emissions		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
		Yes	
Assumptions	Percentages of non-road diesel contributions were calculated from ENVIRON (2010) report and the total NPI inventory for the state. The percentages were then used for the state to calculate the industry and commercial contributions. The controls applicable were also from the ENVIRON report.		
Included in final Abatement Package	Yes		

Abatement	7. Ship to shore power		
Description	Provision of shore side electrical power to ocean-going vessels, allowing them to shut down auxiliary diesel generators while they are docked.		
Applicable to Regions	Those with working ports		
Emission Reduction Potential	SO_2	NO_x	VOCs
	Yes	Yes	
Assumptions	Inventory specific.		
Included in final Abatement Package	No		

Abatement	8. Low sulfur fuel standards for the shipping industry		
Description	Switching to marine fuels with lower sulfur content		
Applicable to Regions	Those with working ports		
Emission Reduction Potential	SO_2	NO_x	VOCs
	Yes		
Assumptions	Assumed fuel sulfur content reduction from 2.7% to 0.5% by 2020. Emission reduction factor/efficiency 81%. 100% of ships in ports with low sulfur content fuel.		
Included in final Abatement Package	No		

Abatement	9. Industry - De-SOx and gas capture storage standards for power stations		
Description	Retrofit flue gas emission controls to existing power plants.		
Applicable to Regions	Those with operating power stations (non-gas fired)		
Emission Reduction Potential	SO_2	NO_x	VOCs
	Yes	Yes	
Assumptions	Inventory/airshed specific. Where applicable - Control efficiency applied 90% (flue gas desulfurisation) from combustion 2040 (100%); 20% (2020) and 50% (2030); Control efficiency applied 50% (generation of electrical power from coal/fossil fuel electricity - with selective non-catalytic reduction).		
Included in final Abatement Package	Yes		

Abatement	10. Surface coating standards		
Description	Introduction of surface coating standards to reduce VOC emissions from coating products. Standards will align with international improvements in reformulation.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
			Yes
Assumptions	A conservative assumption for the reduction efficiency percentage was based on an average for reformulation or process modification for architectural, industrial maintenance and traffic coatings and surface coating operations from the US EPA CoST database. A reduction efficiency of 63% was assumed with uptake of 10% (2016-2020); 50% (2021-2035) and 90% (2036-2040).		
Included in final Abatement Package	Yes		

Abatement	11. Congestion Pricing		
Description	Application of road congestion pricing as a way to encourage more efficient use of the transport system and address congestion and pollution problems.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
		Yes	Yes
Assumptions	Control efficiency applied ranges from <1% to 2% congestion pricing 2040; Uptake 20% (2020); 50% (2030); 100% (2040)		
Included in final Abatement Package	No		

Abatement	12. Fuel efficiency standards for on-road vehicles		
Description	Introduce fuel economy standards for on-road vehicles to reduce fuel use and emissions.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
		Yes	Yes
Assumptions	The potential benefits realised from the introduction of Euro 6 vehicles and associated design and technology improvements for fuel efficiency were accommodated in the BAU scenario.		
Included in final Abatement Package	No – benefits accommodated within the BAU scenario		

Abatement	13. Industry NOx control technology (cement industry)		
Description	This measure targets the cement industry to introduce abatement technology for NOx emission reduction		
Applicable to Regions	Targets two sources in two locations		
Emission Reduction Potential	SO_2	NO_x	VOCs
		Yes	
Assumptions	Inventory/airshed specific. 2040 Control efficiency applied ranges 50% to 90% Cement or lime production (SCR); Control efficiency applied 90% Iron or Steel Production (SCR). 2030 Control efficiency applied to iron and steel and cement or lime. 2020 Control efficiency applied to cement or lime only.		
Included in final Abatement Package	Yes		

Abatement	14. Industry De-SOx technology - petroleum refineries		
Description	This measure targets petrol refineries to introduce abatement technology for SOx emission reduction		
Applicable to Regions	Targets a single petrol refinery		
Emission Reduction Potential	SO_2	NO_x	VOCs
	Yes		
Assumptions	Installation of SOx capture at petrol refineries. Control efficiency applied 90% (flue gas desulfurisation) on 1 x refinery 2040; NOTE: abatement on refinery alone is theoretical estimate.		
Included in final Abatement Package	Yes		

Abatement	15. Industry De-SOx technology - copper, iron and steel production		
Description	This measure targets the copper smelter, iron and steel industry to introduce abatement technology for SOx emission reduction		
Applicable to Regions	Targets a single steel manufacturer based in one location		
Emission Reduction Potential	SO_2	NO_x	VOCs
	Yes		
Assumptions	Control efficiency applied 90% (flue gas desulfurisation) on iron and steel production 2040; 20% uptake (2020), 50% (2030) and 100% (2040)		
Included in final Abatement Package	Yes		

Abatement	16. VOC control for solvent aerosol use		
Description	Reduce VOC content in aerosol products that are used in the domestic and commercial markets, via either product replacement or reformation.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
			Yes
Assumptions	A conservative reduction efficiency percentage was based on the reformulation or solvent substitution for commercial and domestic solvent or aerosol use from the US EPA CoST database. A reduction efficiency of 63% assumed with uptake of 20% by 2020, 50% by 2030 and 100% by 2040.		
Included in Abatement Package	Yes		

Abatement	17. Stage 1 vapour recovery at petrol stations		
Description	Stage 1 vapour recovery (VR1) at petrol service stations limits the emissions of volatile organic compounds (VOCs) that result from unloading petrol from a road tanker into petrol service station storage tanks. VR1 systems return displaced vapour back to the delivery tanker by means of a vapour-tight connection line.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
			Yes
Assumptions			
Included in final Abatement Package	No		

Abatement	18. Stage 2 vapour recovery at petrol stations		
Description	Stage 2 vapour recovery (VR2) systems at petrol stations limit the emissions of volatile organic compounds (VOCs) that result from fuel vapour when vehicles are refuelled. VR2 systems capture the displaced vapour (from vehicle fuel tank being filled) and return it to the underground fuel storage tank or other appropriate vessel.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
			Yes
Assumptions			
Included in final Abatement Package	No		

Abatement	19. Promoting Switch to Active Transport		
Description	This measure is to encourage travel behaviour change (i.e. the switch to public transport, cycling or walking (or combination) instead of single commuter trip by motor vehicle) – No subsidy offered.		
Applicable to Regions	All		
Emission Reduction Potential	SO_2	NO_x	VOCs
		Yes	Yes
Assumptions			
Included in final Abatement Package	No		

C.5 Abatement package determined from the MCA

The relevance of the abatement measure within the various airsheds and the emission reduction potential were two of the inputs provided for inclusion in the multi-criteria analysis (MCA). The MCA is described in a separate Technical Appendix to this report. The Abatement Package determined and agreed for inclusion in the modelling, includes eight prioritised measures:

- SO_2
  - De-SOx and gas capture storage standards for power stations
  - De-SOx at petrol refineries
  - De-SOx at iron and steel production facilities.
- NO_2
  - De-SO_x and gas capture storage standards for power stations (noting this action also delivered NO_x reductions)
  - Non-road diesel engines improved emission controls
  - Industry NO_x control technology – cement, iron and steel and aluminium industry
- VOCs
  - Improved surface coating standards
  - VOC control for solvent aerosol use
  - On-board refuelling vapour recovery

Annexure D: Emission projections

D.1 Sulfur dioxide emission projections

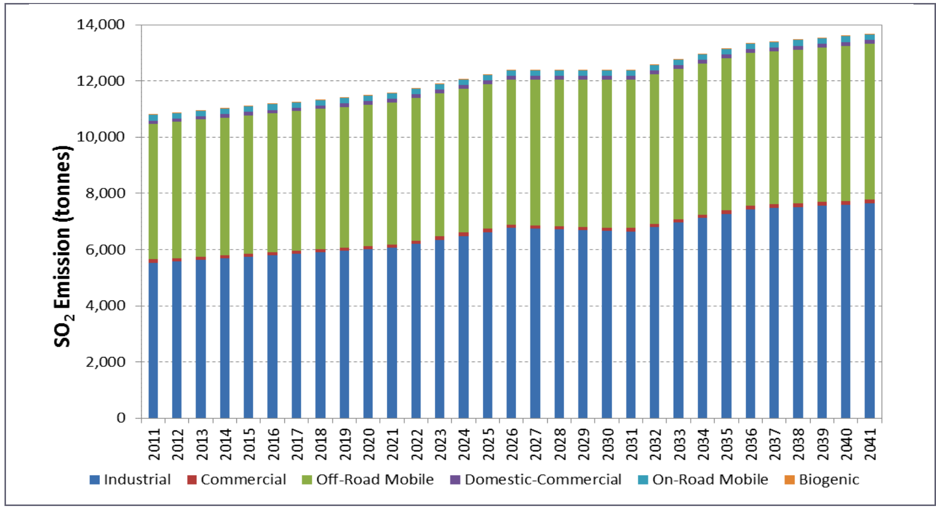

Figure D-1: Sydney BAU scenario SO_2 emission projections

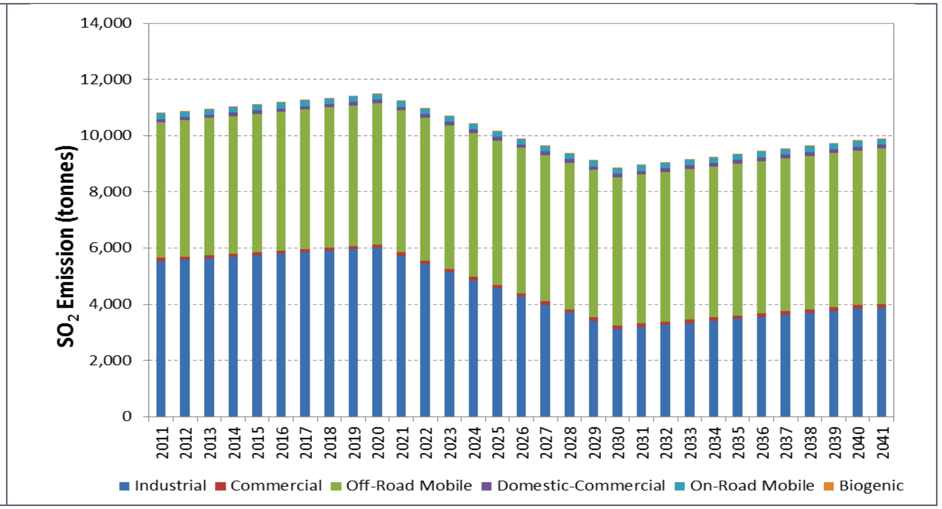

Figure D-2: Sydney Abatement Package scenario SO_2 emission projections

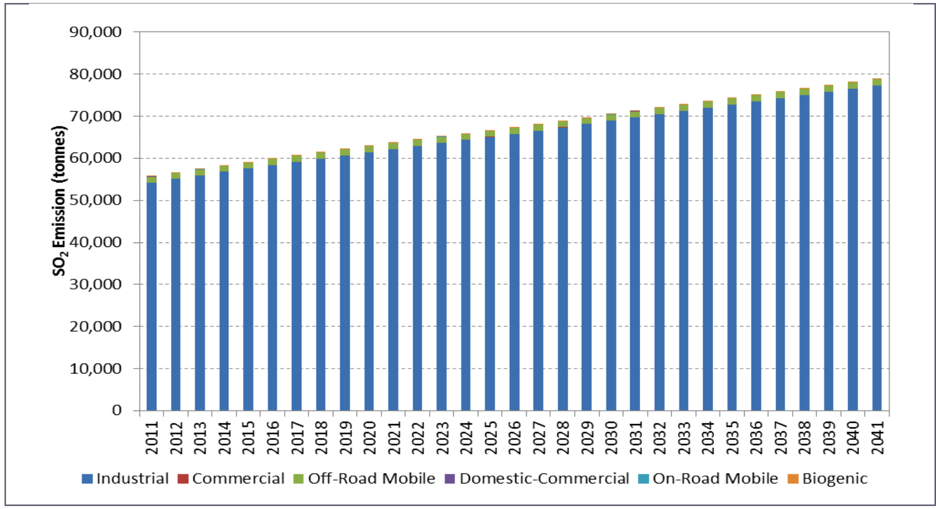

Figure D-3: Lower Hunter BAU scenario SO_2 emission projections

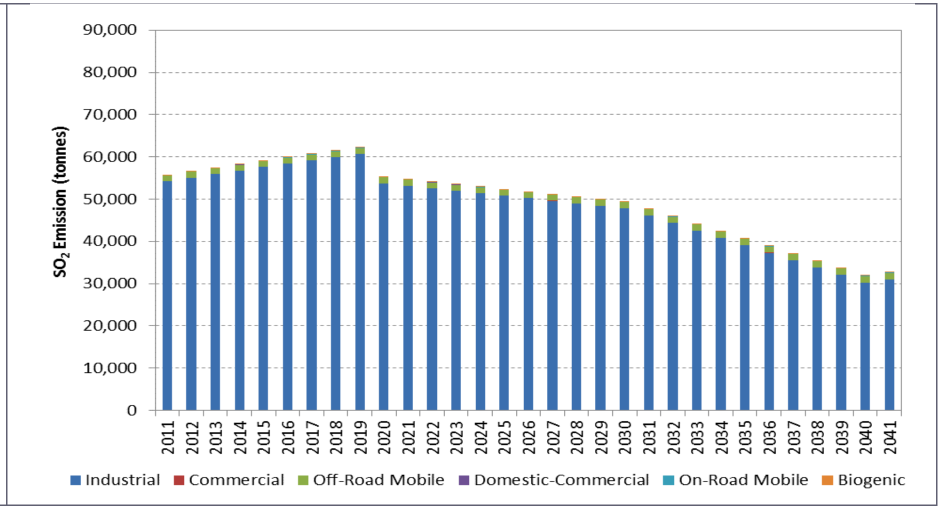

Figure D-4: Lower Hunter Abatement Package scenario SO_2 emission projections

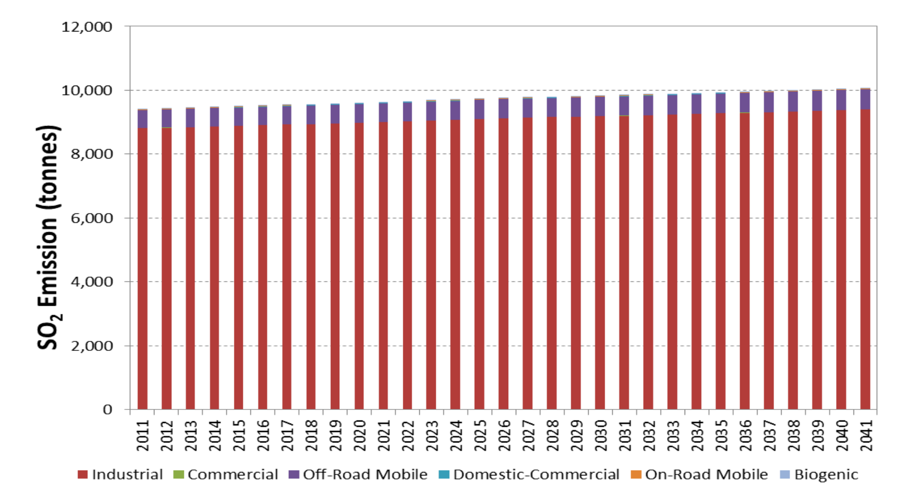

Figure D-5: Illawarra BAU scenario SO_2 emission projections

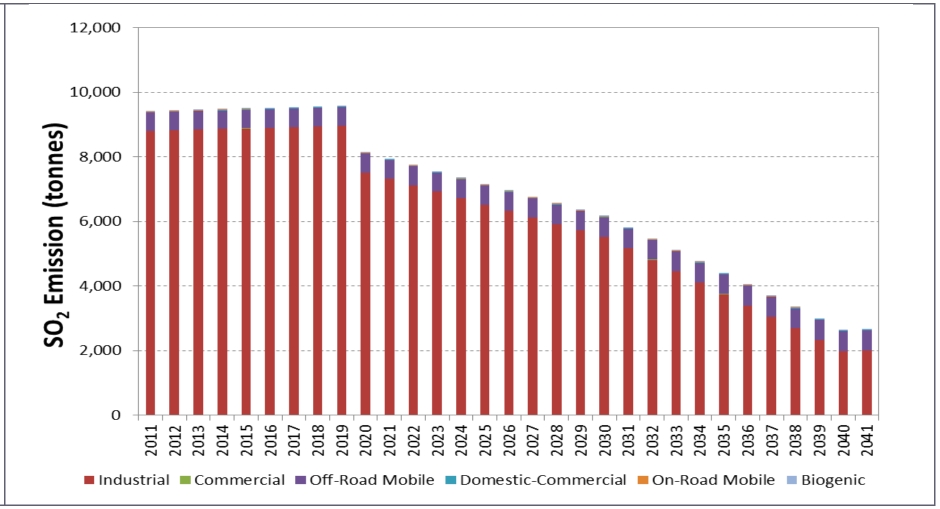

Figure D-6: Illawarra Abatement Package scenario SO_2 emission projections

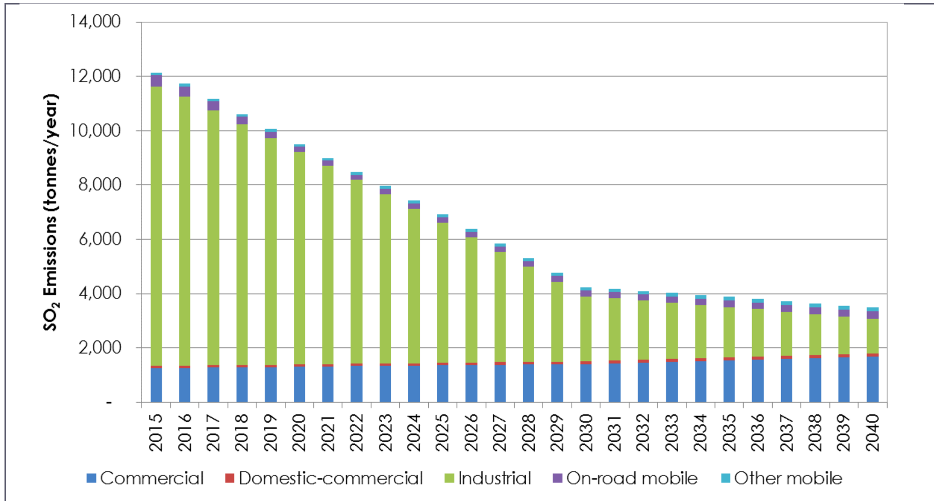

Figure D-7: Port Phillip Region BAU scenario SO_2 emission projections

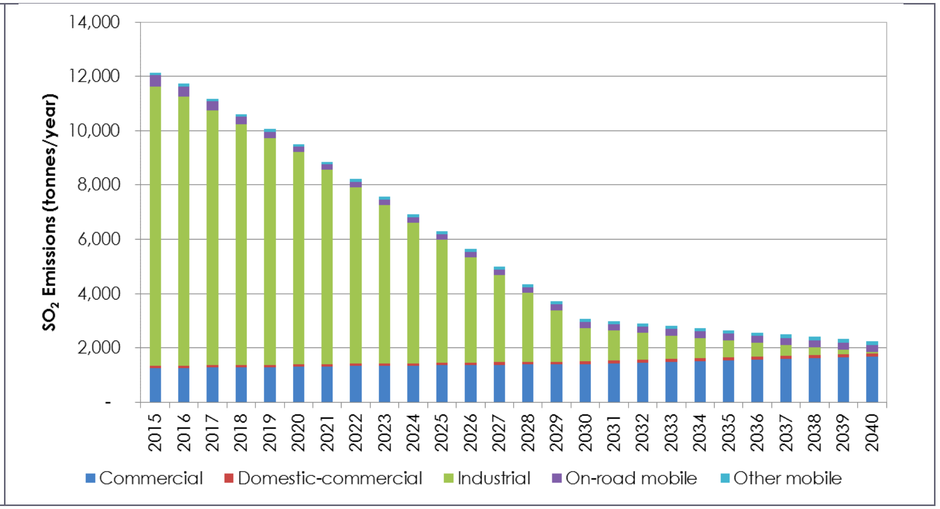

Figure D-8: Port Phillip Region Abatement Package scenario SO_2 emission projections

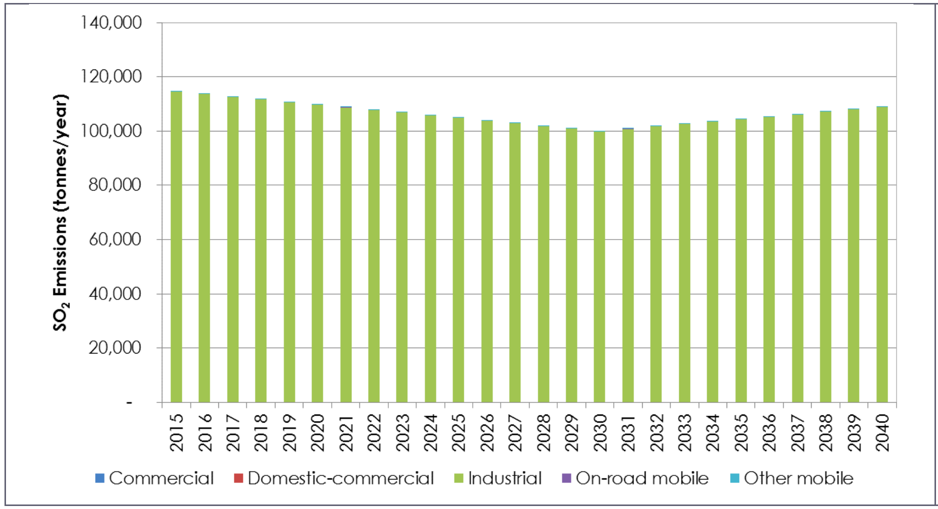

Figure D-9: Latrobe Valley BAU scenario SO_2 emission projections

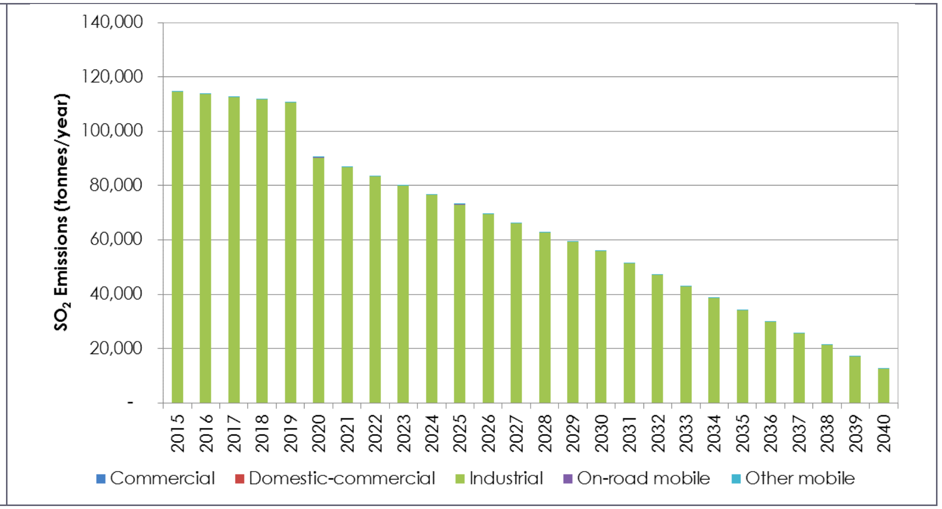

Figure D-10: Latrobe Valley Abatement Package scenario SO_2 emission projections

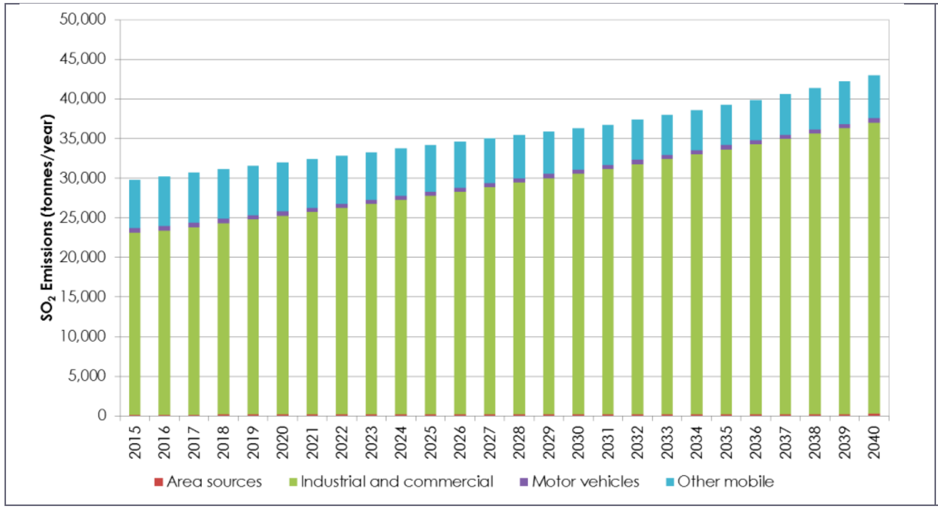

Figure D-11: South-East Queensland BAU scenario SO_2 emission projections

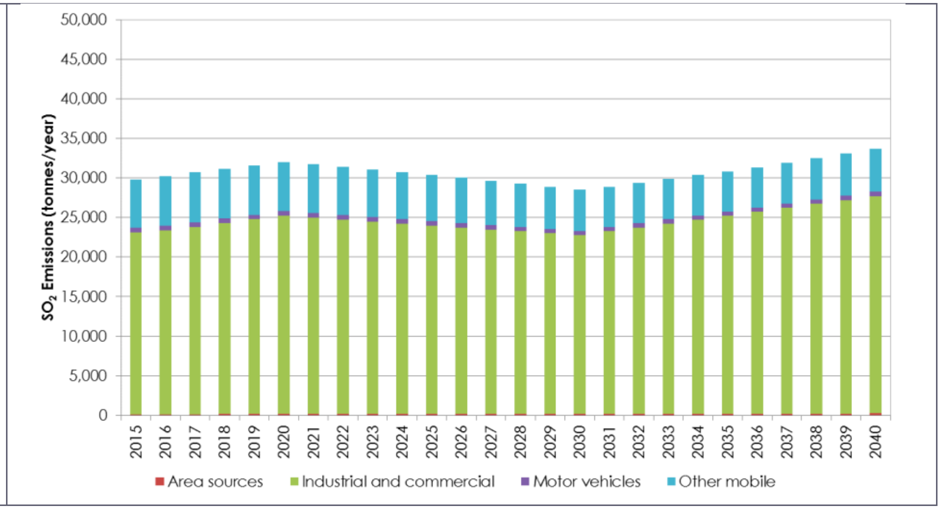

Figure D-12: South-East Queensland Abatement Package scenario SO_2 emission projections

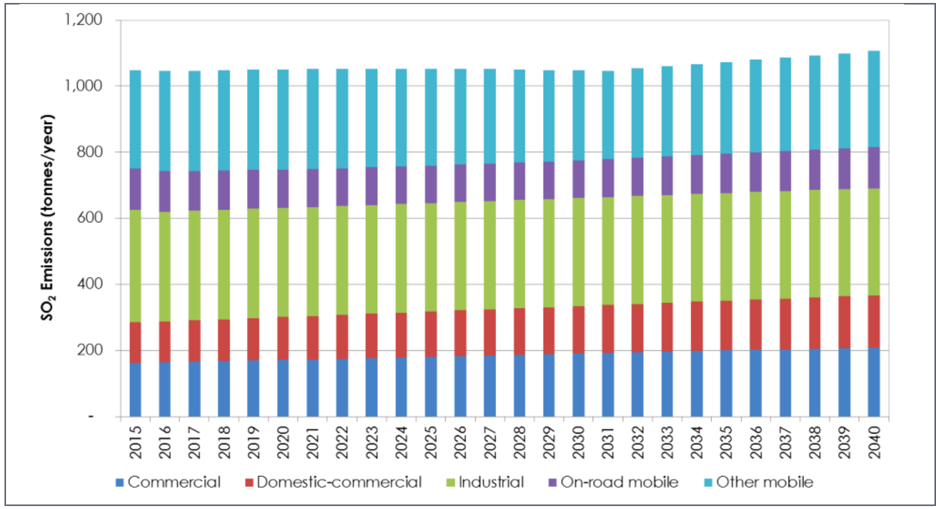

Figure D-13: Adelaide BAU scenario SO_2 emission projections

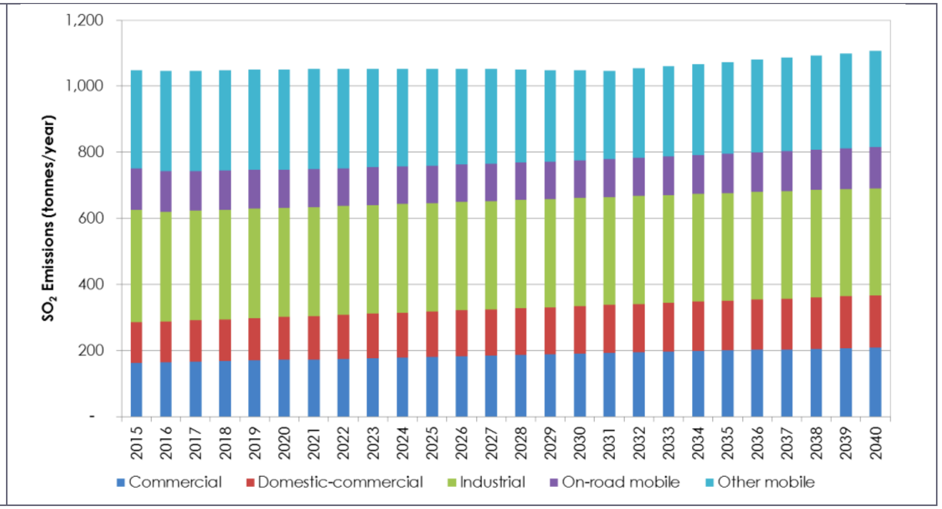

Figure D-14: Adelaide Abatement Package scenario SO_2 emission projections

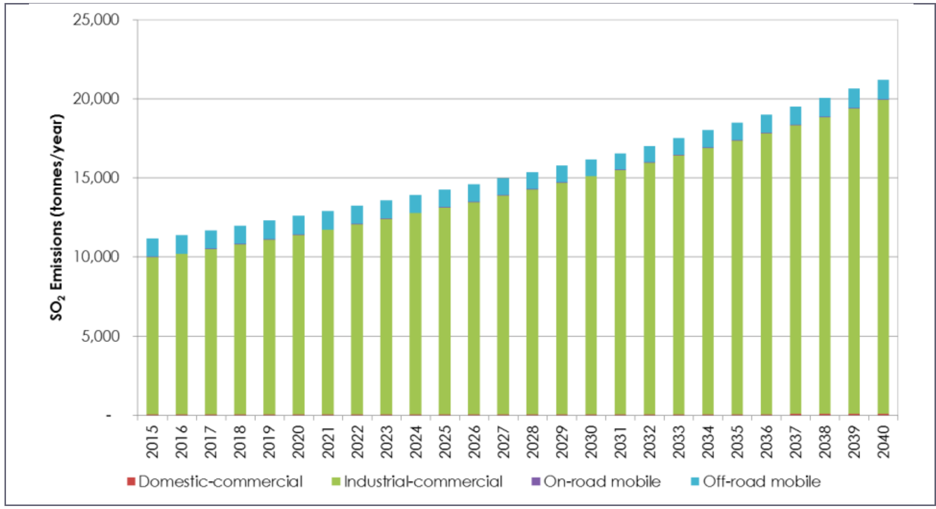

Figure D-15: Perth BAU scenario SO_2 emission projections

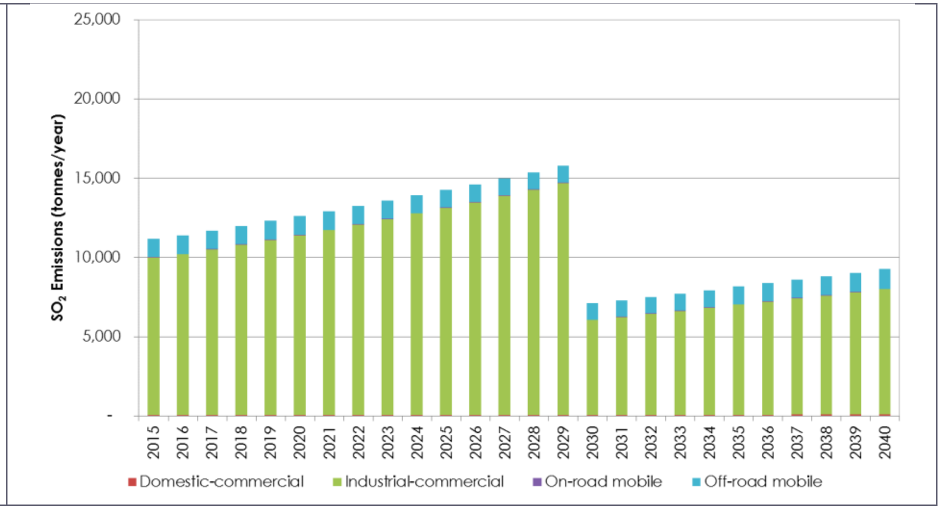

Figure D-16: Perth Abatement Package scenario SO_2 emission projections

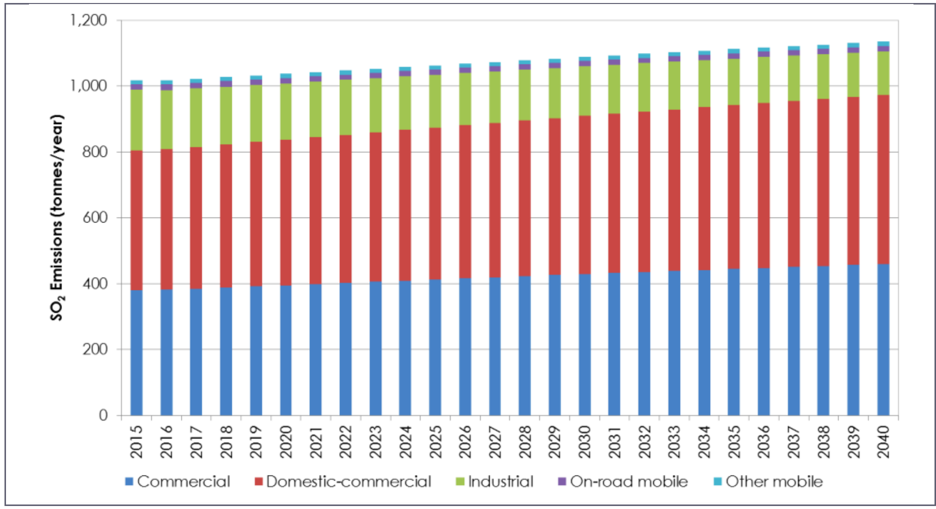

Figure D-17: Hobart BAU scenario SO_2 emission projections

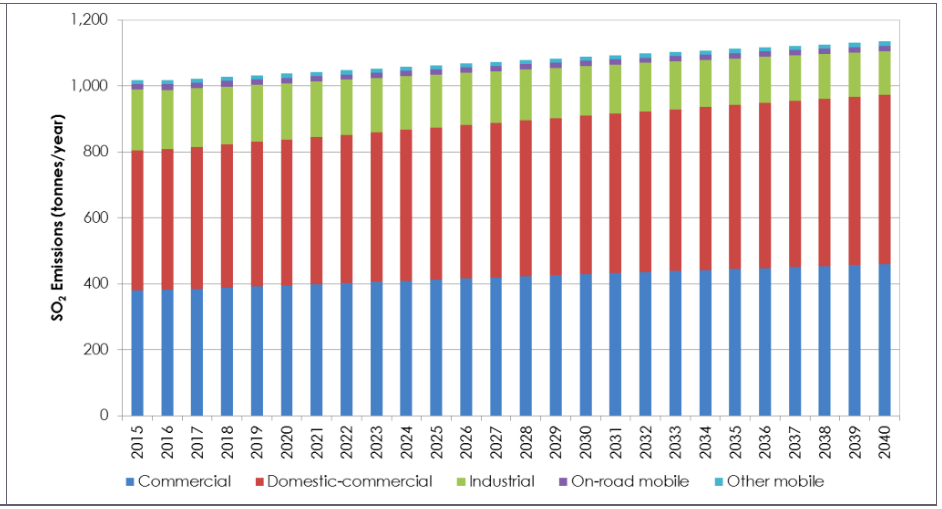

Figure D-18: Hobart Abatement Package scenario SO_2 emission projections

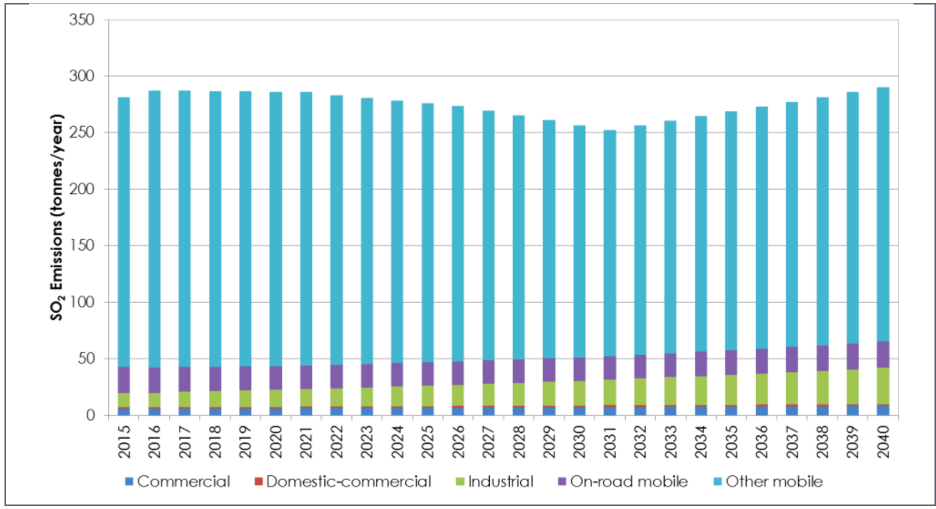

Figure D-19: Darwin BAU scenario SO_2 emission projections

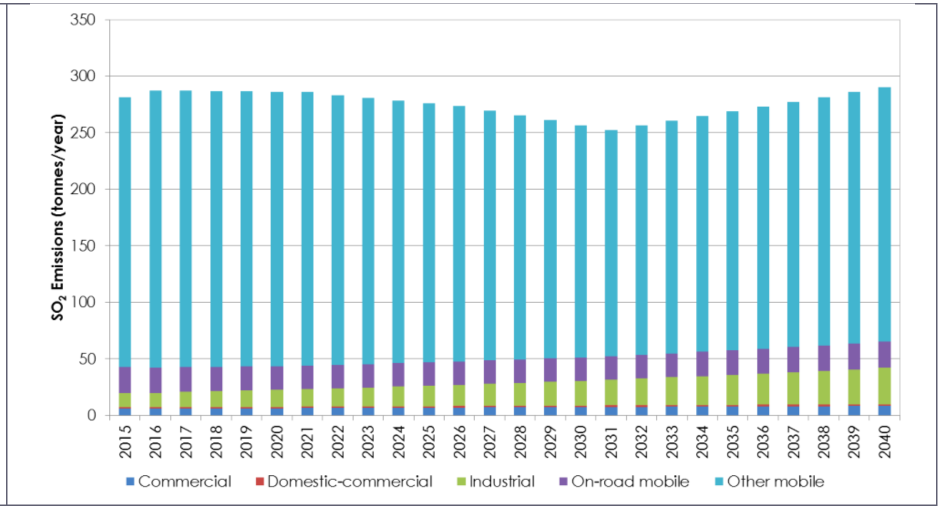

Figure D-20: Darwin Abatement Package scenario SO_2 emission projections

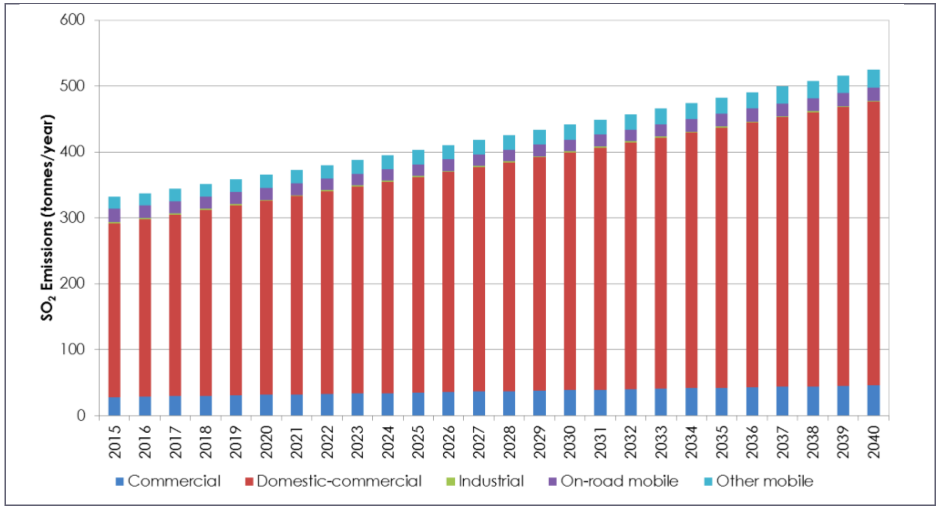

Figure D-21: Canberra BAU scenario SO_2 emission projections

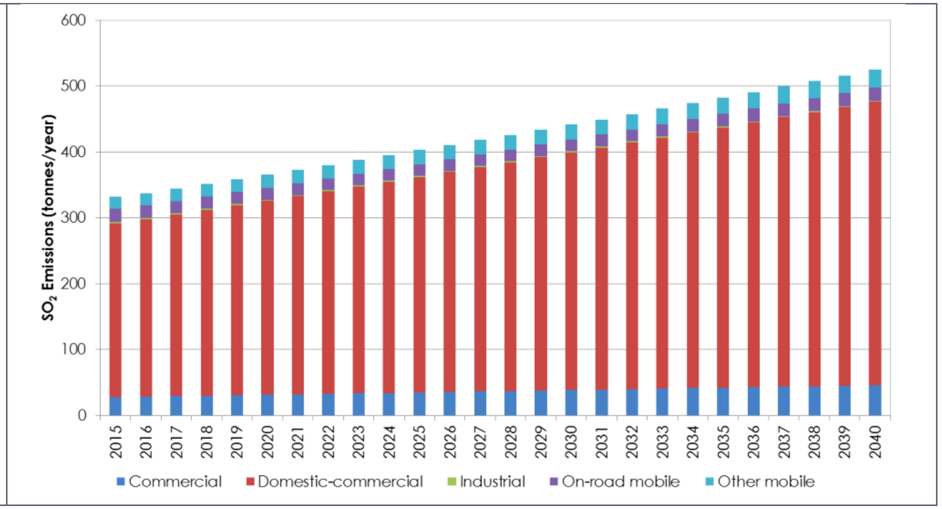

Figure D-22: Canberra Abatement Package scenario SO_2 emission projections

D.2 Nitrogen dioxide emission projections

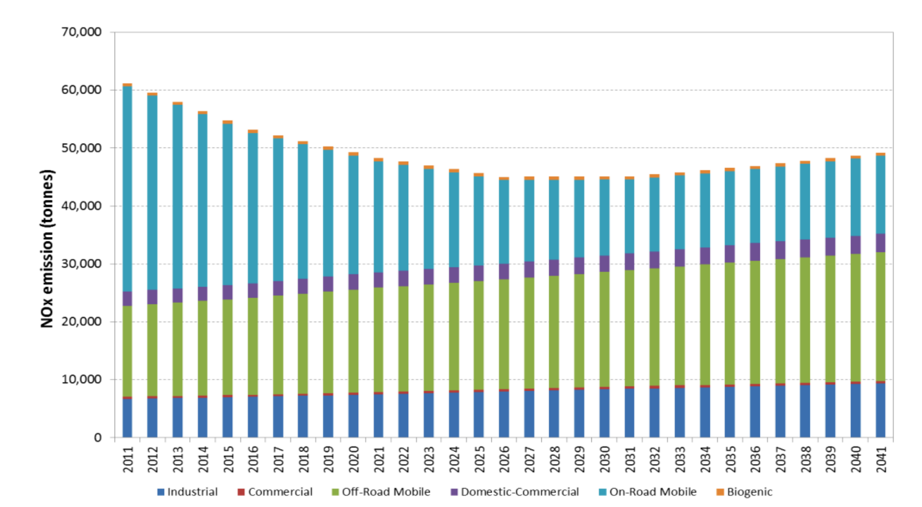

Figure D-23: Sydney BAU scenario NO_X emission projections

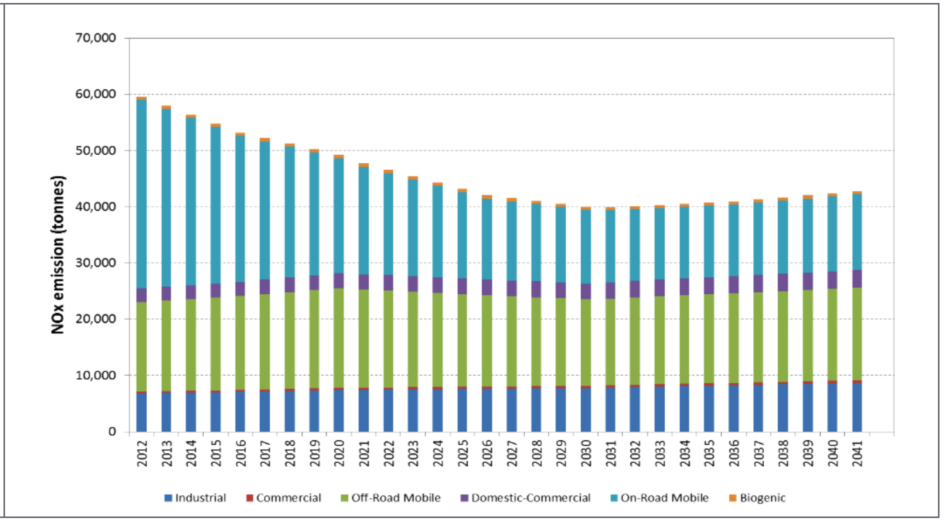

Figure D-24: Sydney Abatement Package scenario NO_X emission projections

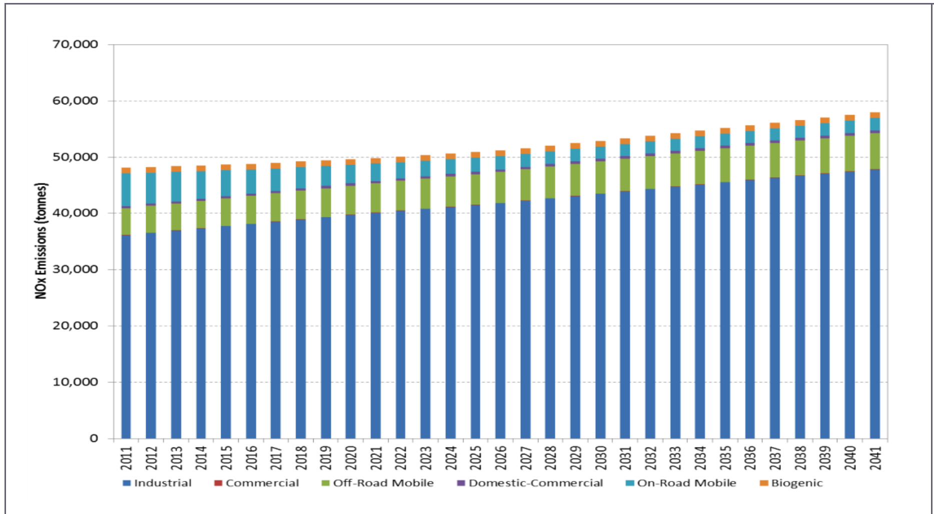

Figure D-25: Lower Hunter BAU scenario NO_X emission projections

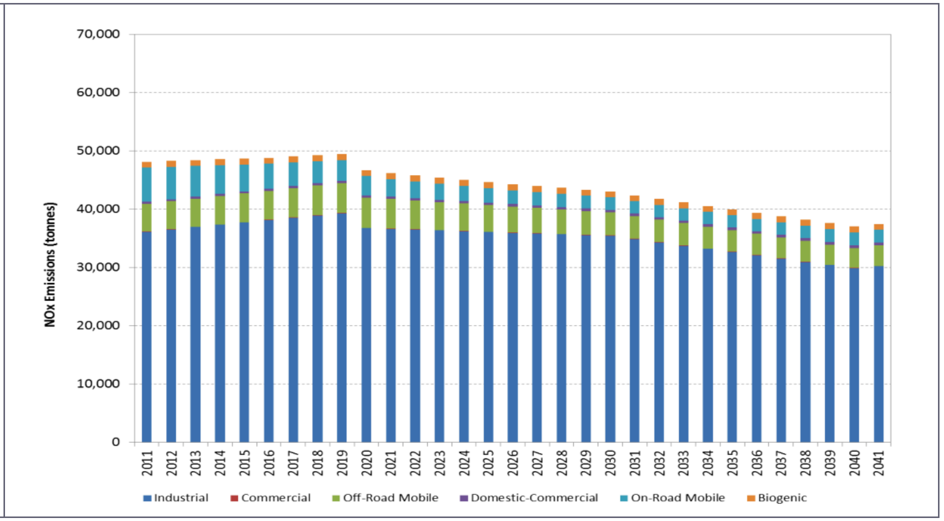

Figure D-26: Lower Hunter Abatement Package scenario NO_X emission projections

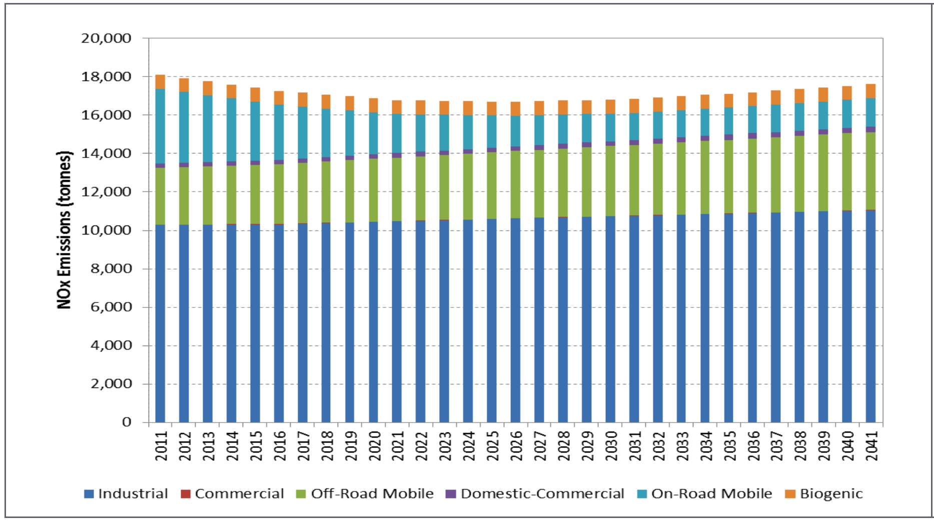

Figure D-27: Illawarra BAU scenario NO_X emission projections

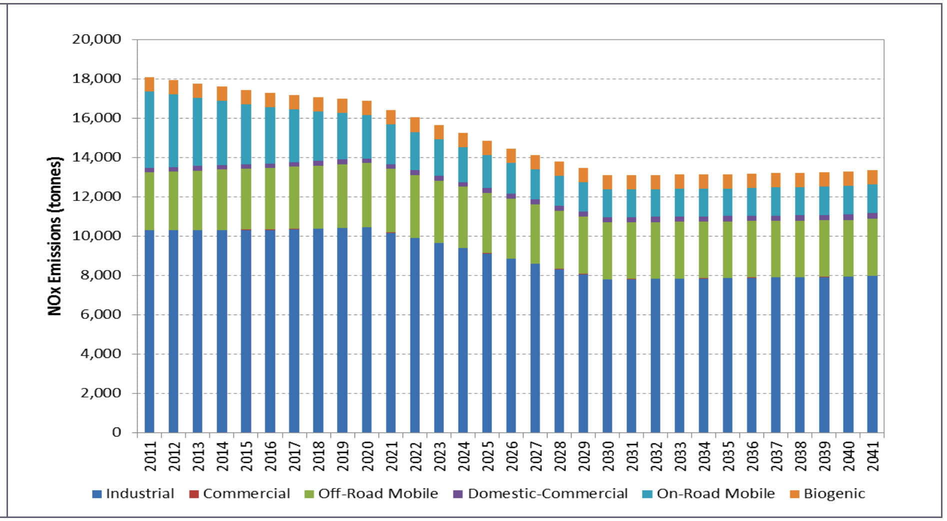

Figure D-28: Illawarra Abatement Package scenario NO_X emission projections

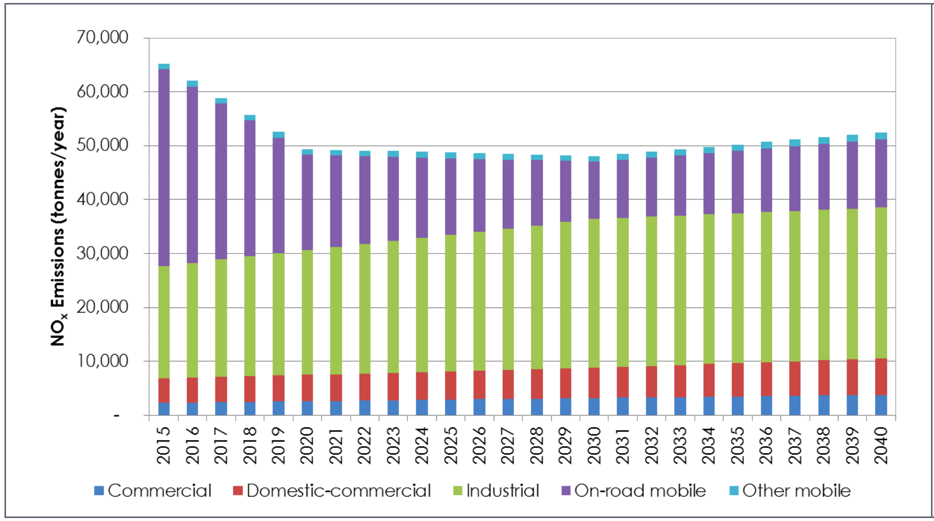

Figure D-29: Port Phillip Region BAU scenario NO_X emission projections

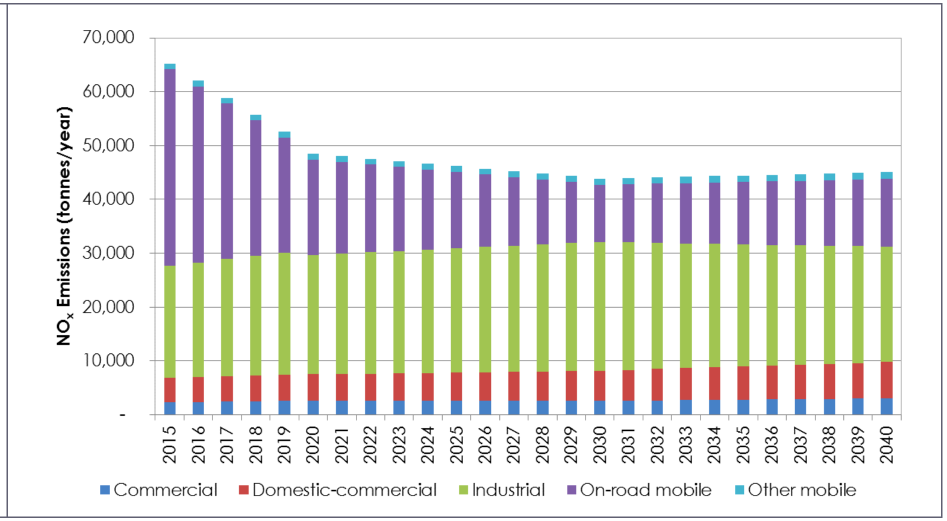

Figure D-30: Port Phillip Region Abatement Package scenario NO_X emission projections

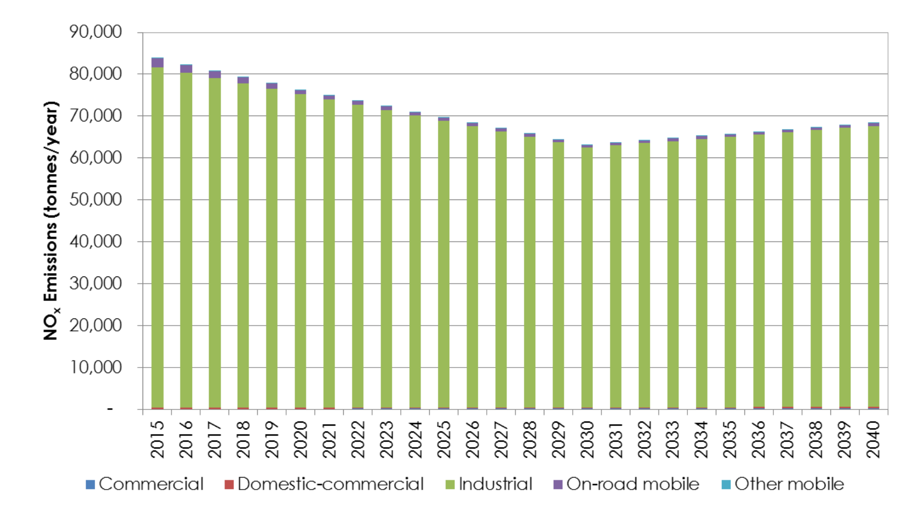

Figure D-31: Latrobe Valley BAU scenario NO_X emission projections

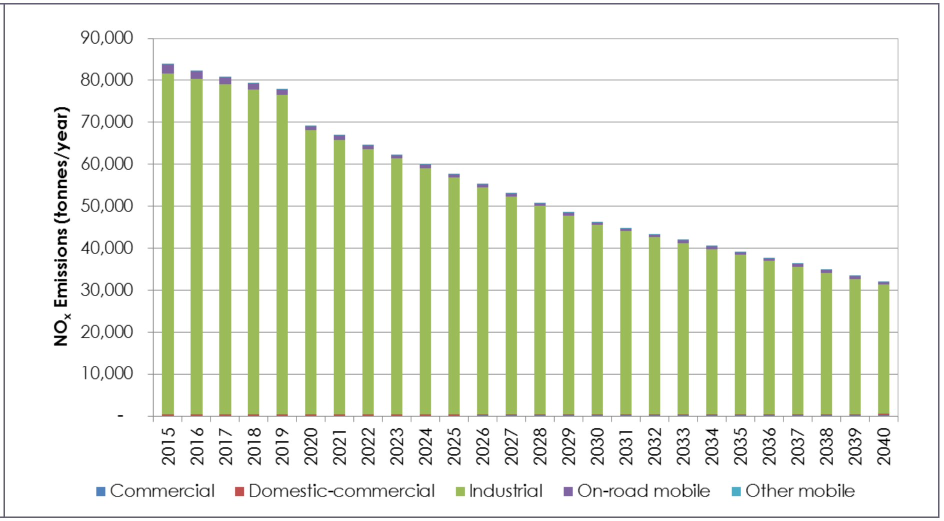

Figure D-32: Latrobe Valley Abatement Package scenario NO_X emission projections

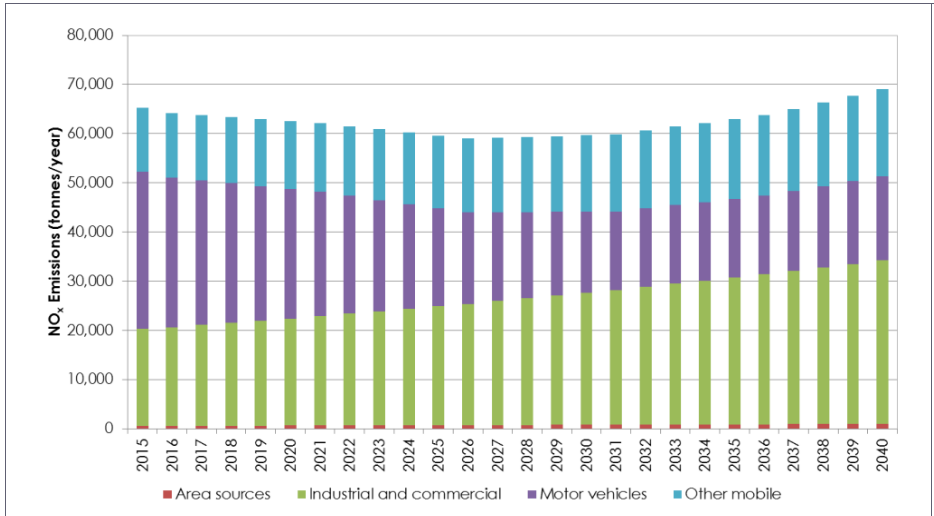

Figure D-33: South-East Queensland BAU scenario NO_X emission projections

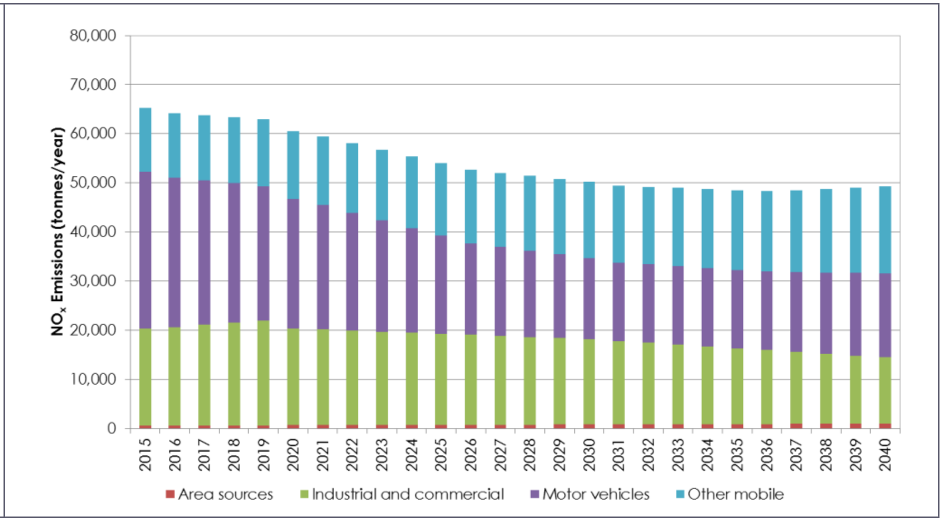

Figure D-34: South-East Queensland Abatement Package scenario NO_X emission projections

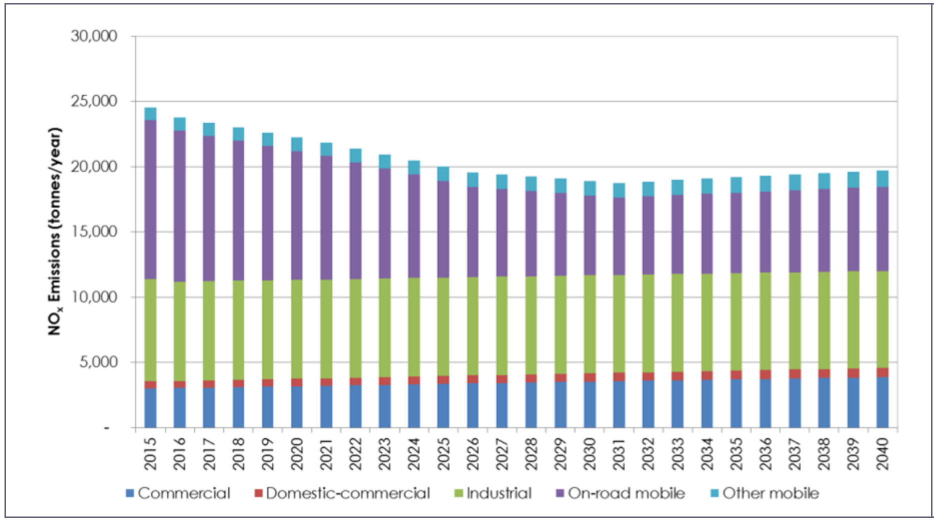

Figure D-35: Adelaide BAU scenario NO_X emission projections

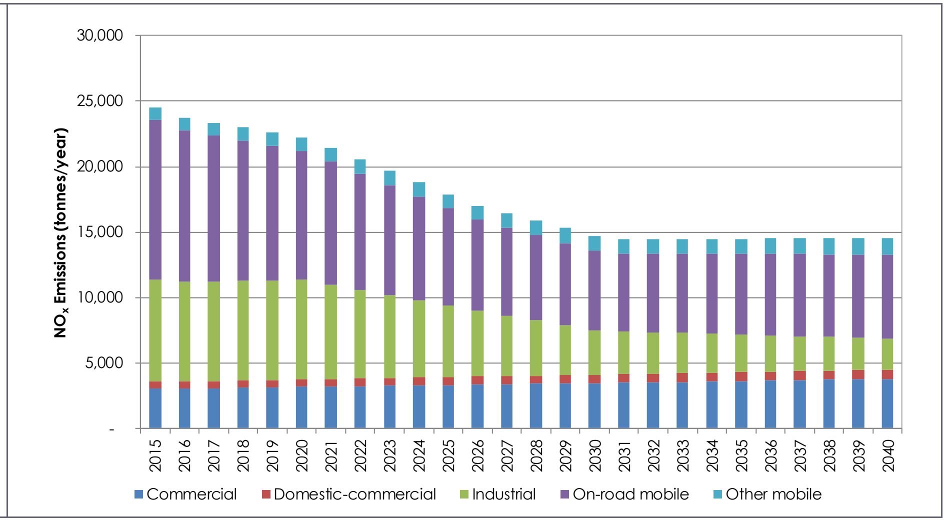

Figure D-36: Adelaide Abatement Package scenario NO_X emission projections

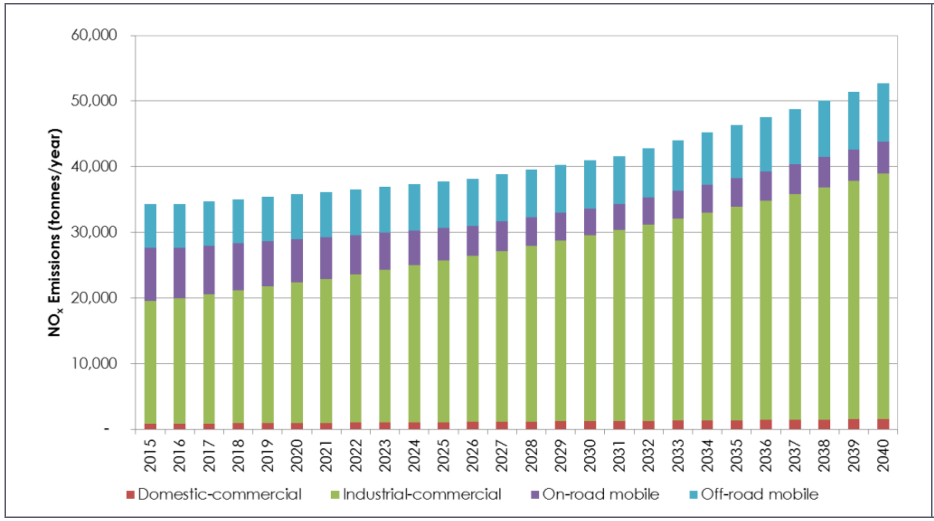

Figure D-37: Perth BAU scenario NO_X emission projections

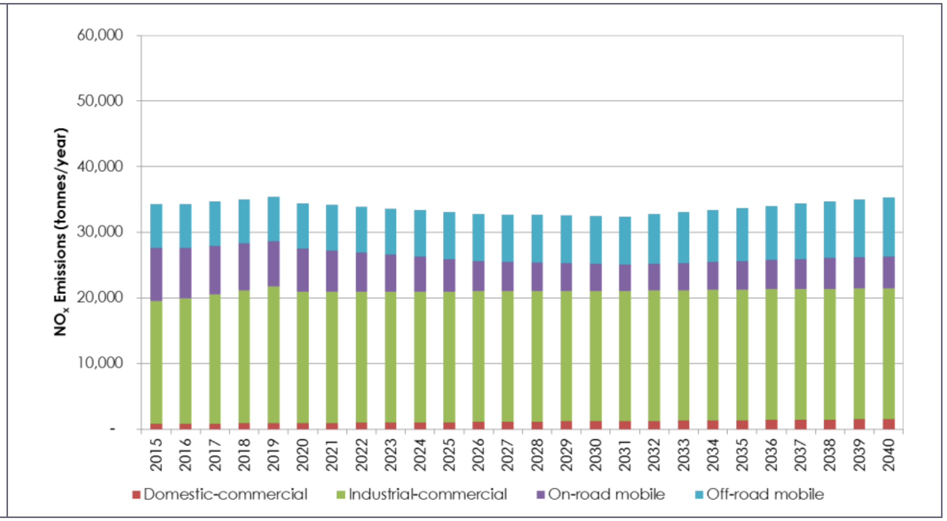

Figure D-38: Perth Abatement Package scenario NO_X emission projections

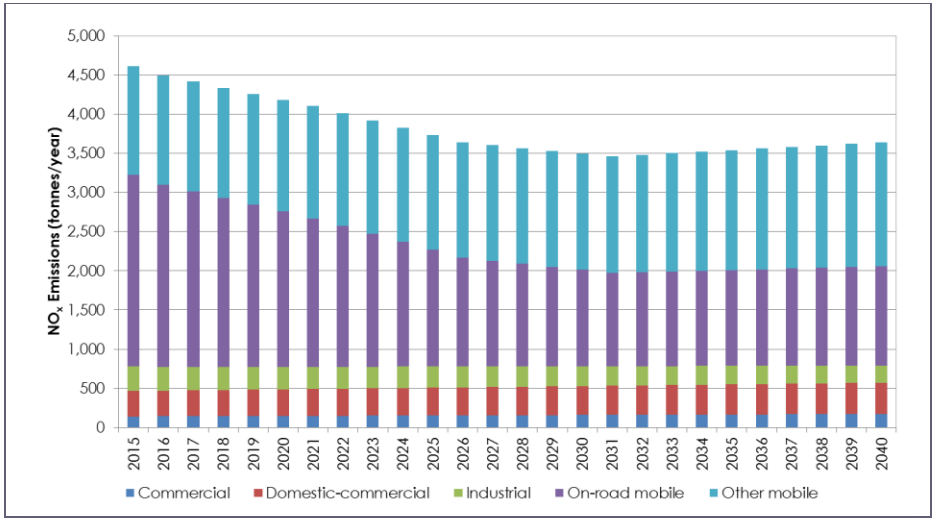

Figure D-39: Hobart BAU scenario NO_X emission projections

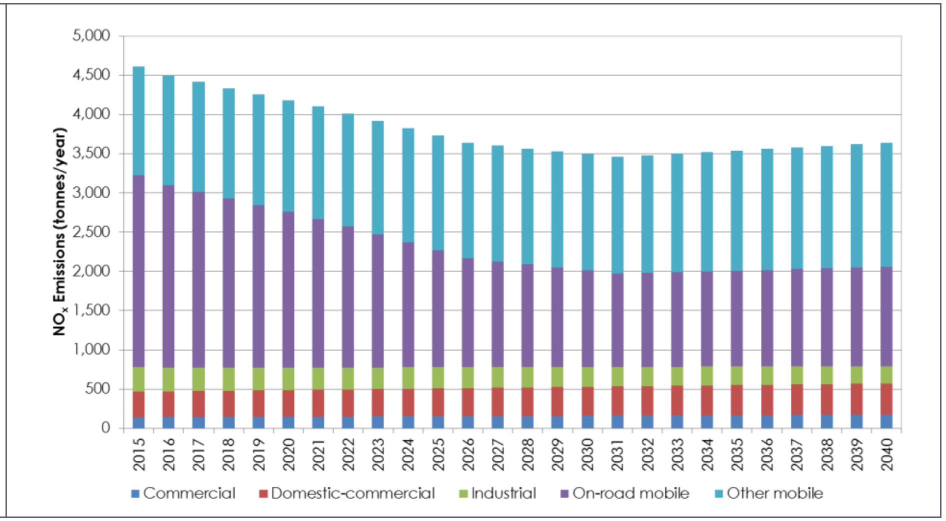

Figure D-40: Hobart Abatement Package scenario NO_X emission projections

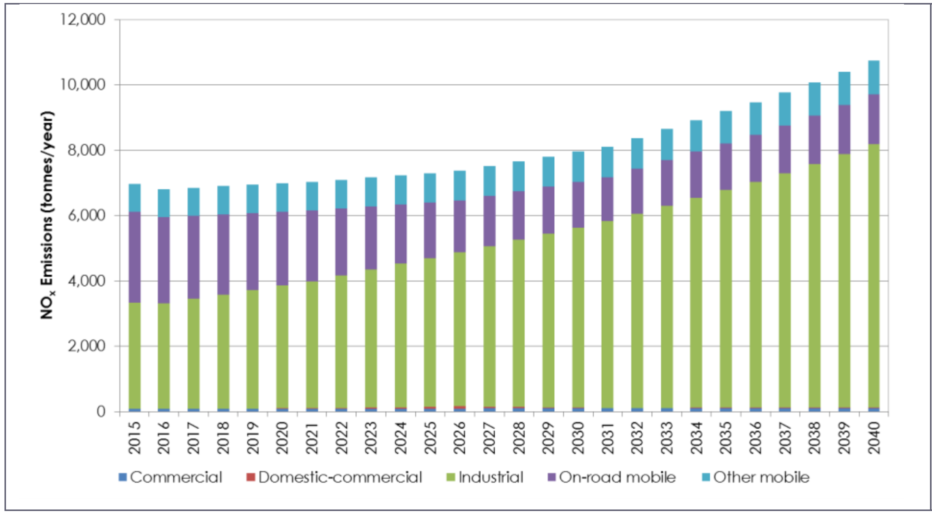

Figure D-41: Darwin BAU scenario NO_X emission projections

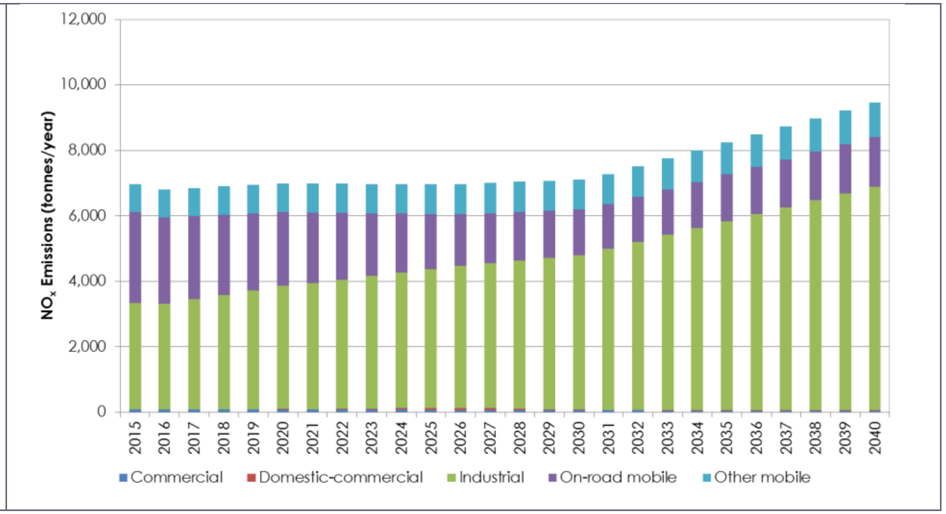

Figure D-42: Darwin Abatement Package scenario NO_X emission projections

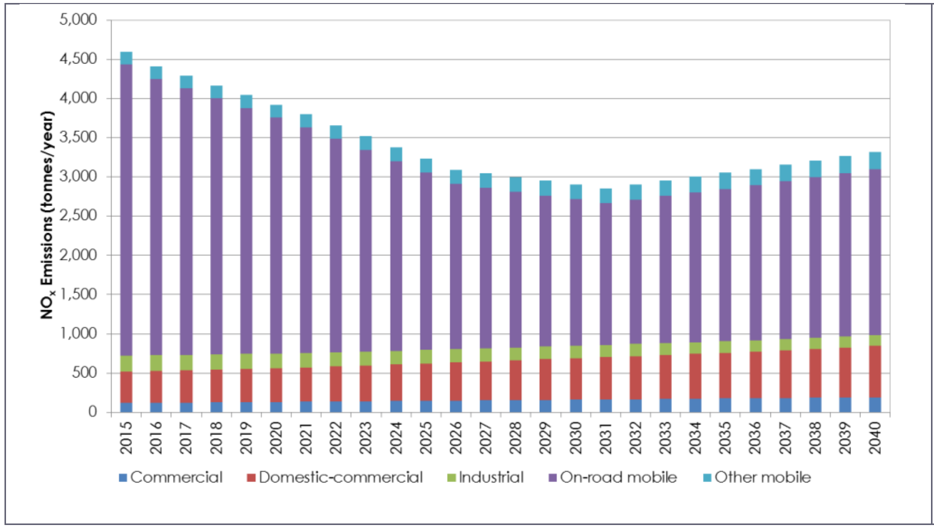

Figure D-43: Canberra BAU scenario NO_X emission projections

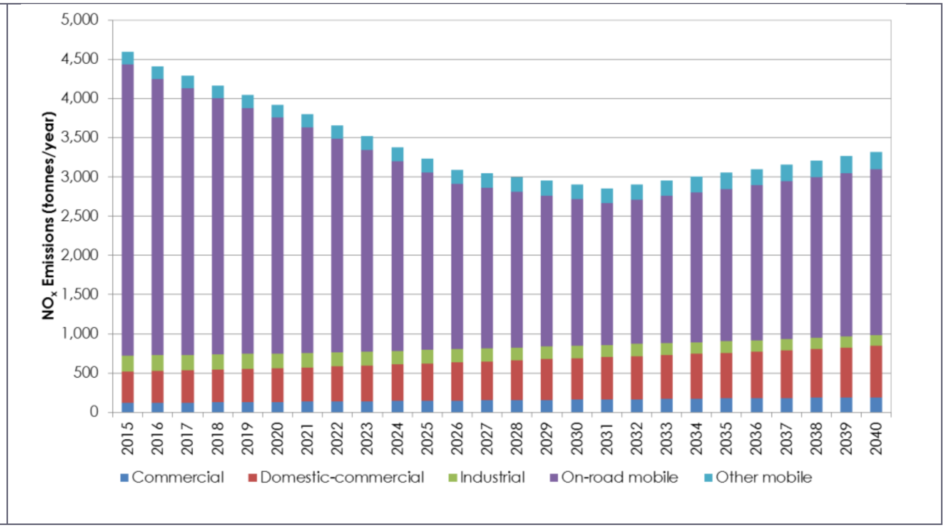

Figure D-44: Canberra Abatement Package scenario NO_X emission projections

D.3 Volatile organic compound emission projections

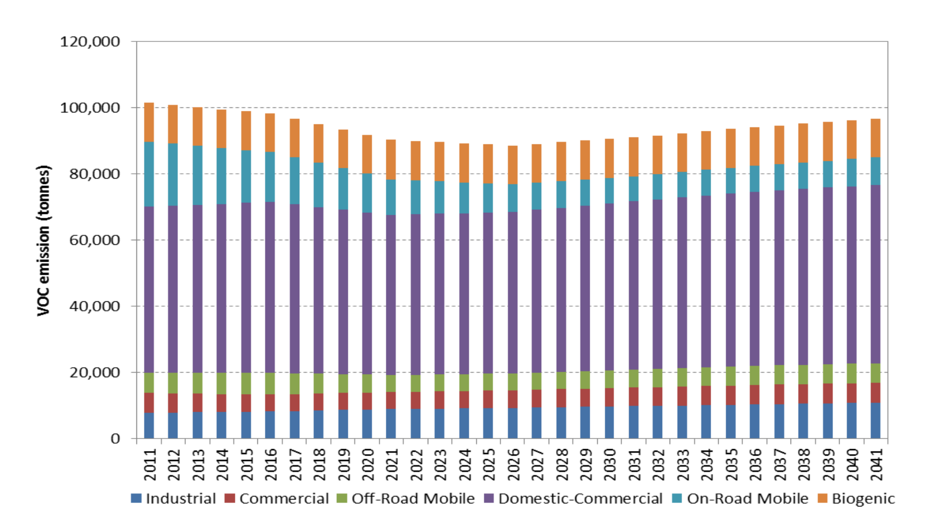

Figure D-45: Sydney BAU scenario VOCs emission projections

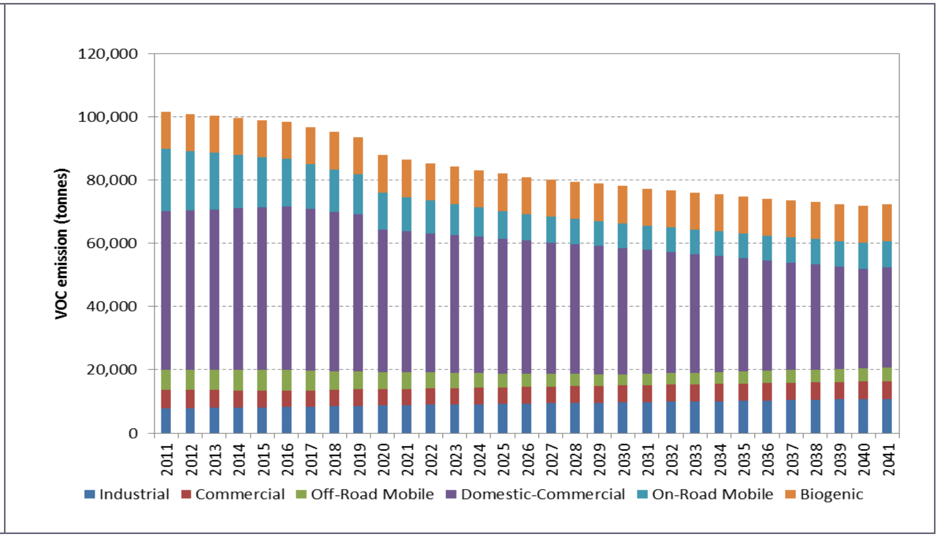

Figure D-46: Sydney Abatement Package scenario VOCs emission projections

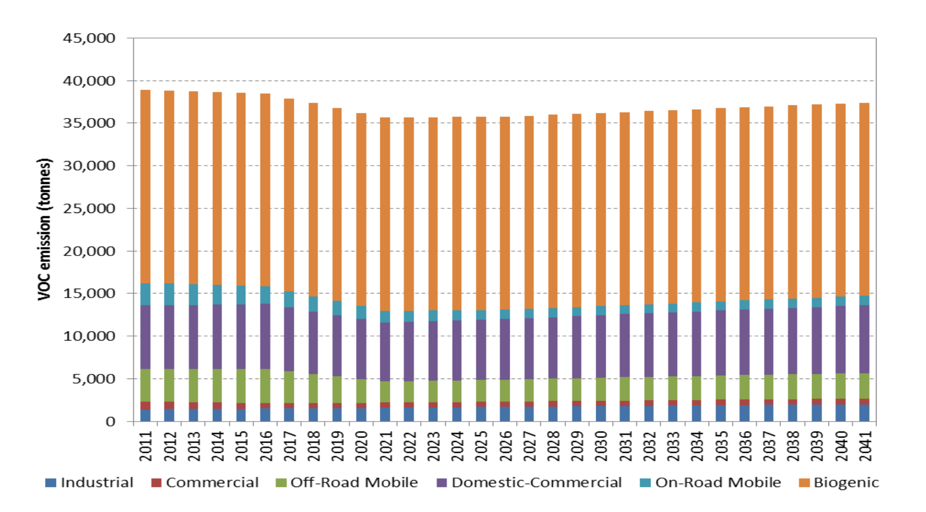

Figure D-47: Lower Hunter BAU scenario VOCs emission projections

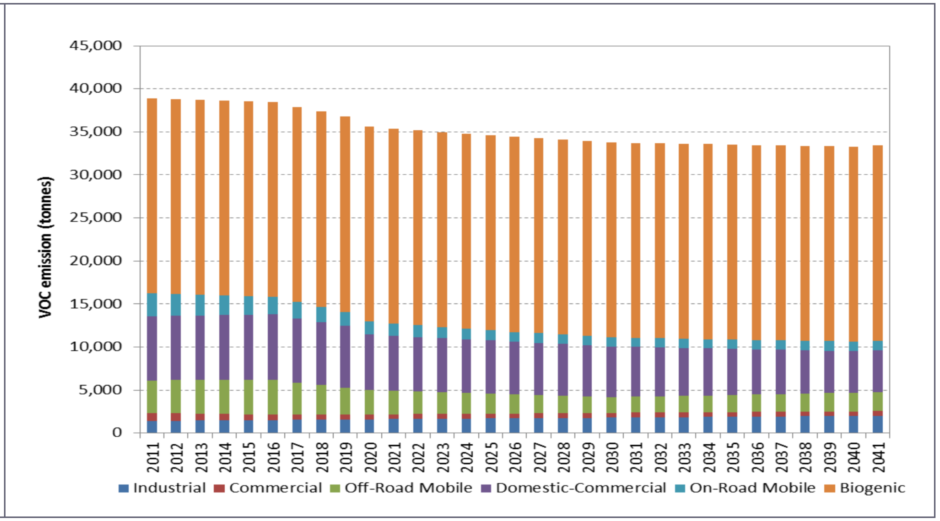

Figure D-48: Lower Hunter Abatement Package scenario VOCs emission projections

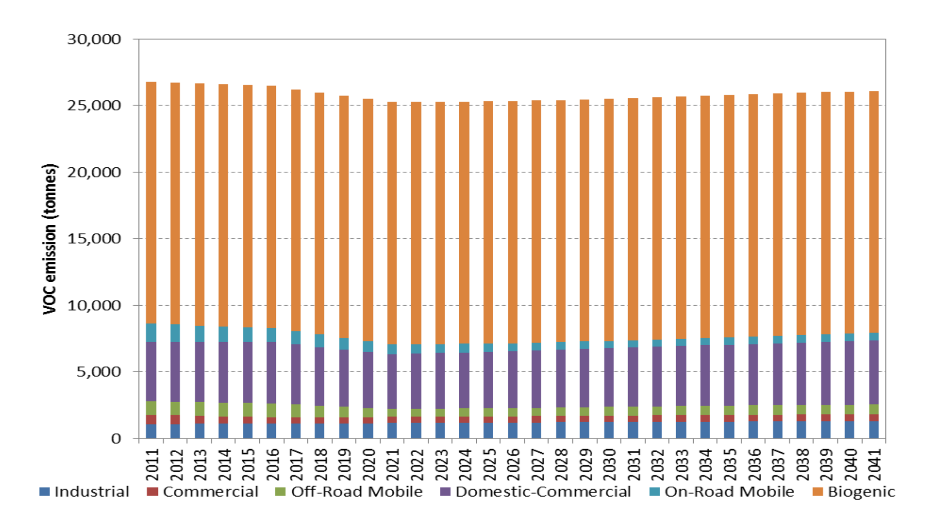

Figure D-49: Illawarra BAU scenario VOCs emission projections

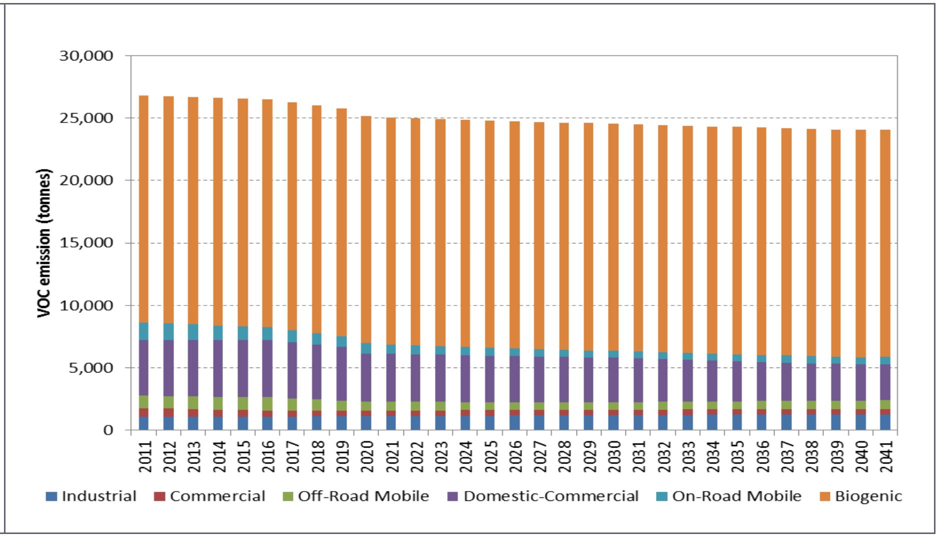

Figure D-50: Illawarra Abatement Package scenario VOCs emission projections

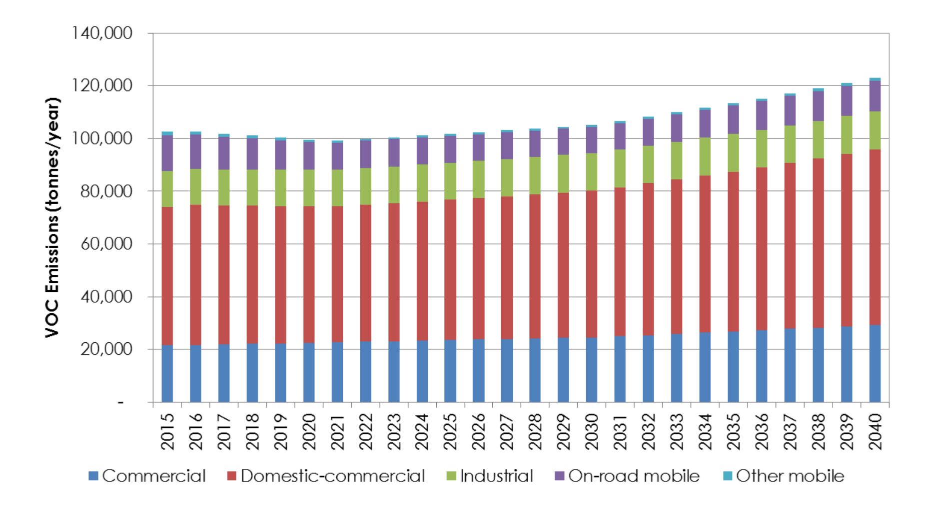

Figure D-51: Port Phillip Region BAU scenario VOCs emission projections

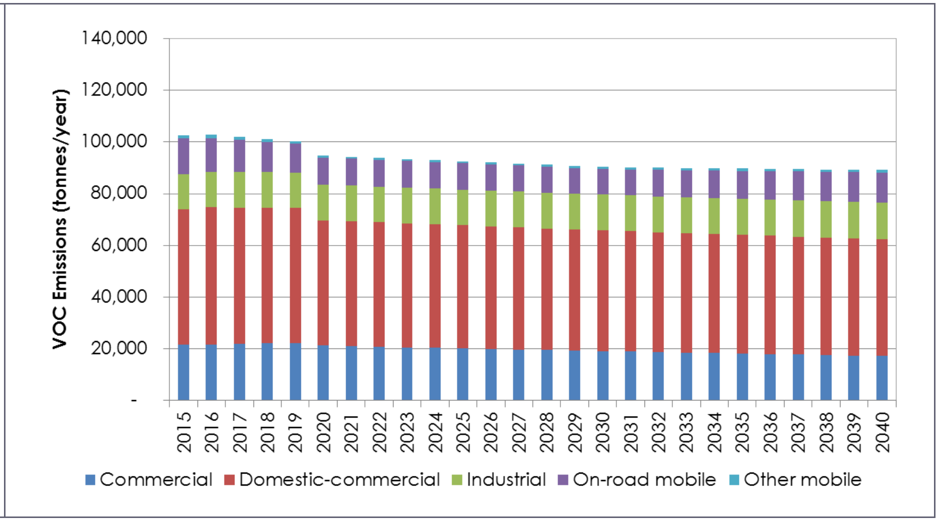

Figure D-52: Port Phillip Region Abatement Package scenario VOCs emission projections

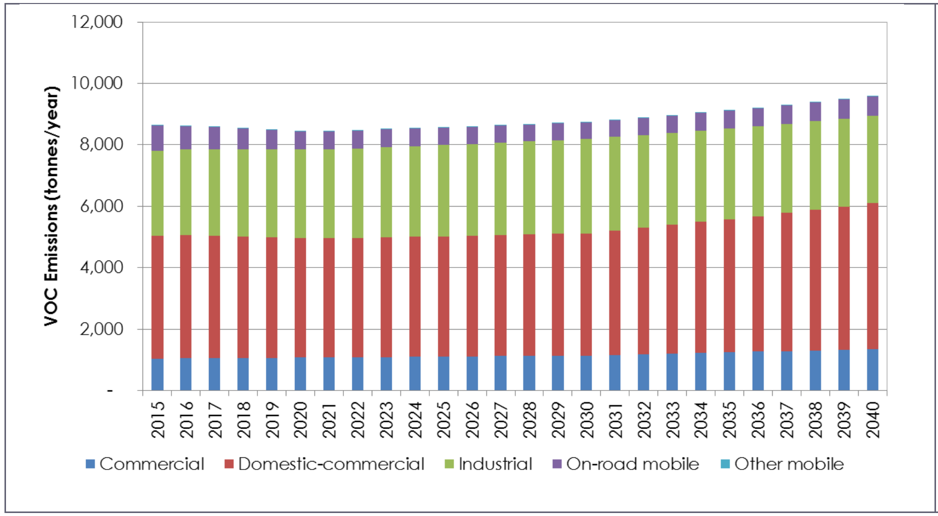

Figure D-53: Latrobe Valley BAU scenario VOCs emission projections

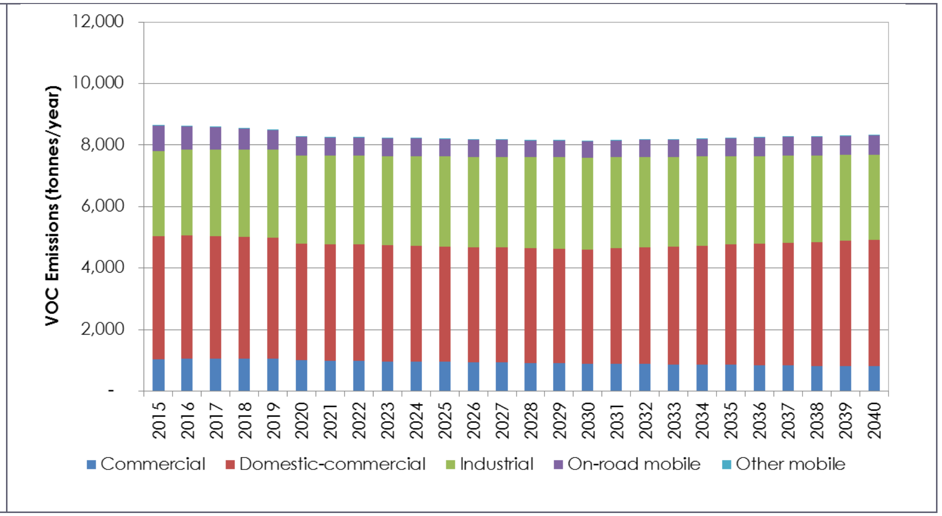

Figure D-54: Latrobe Valley Abatement Package scenario VOCs emission projections

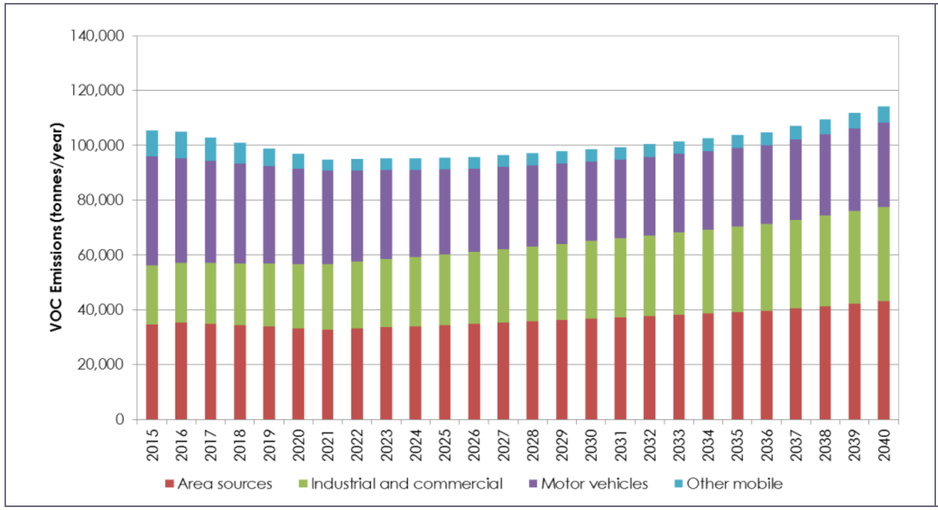

Figure D-55: South-East Queensland BAU scenario VOCs emission projections

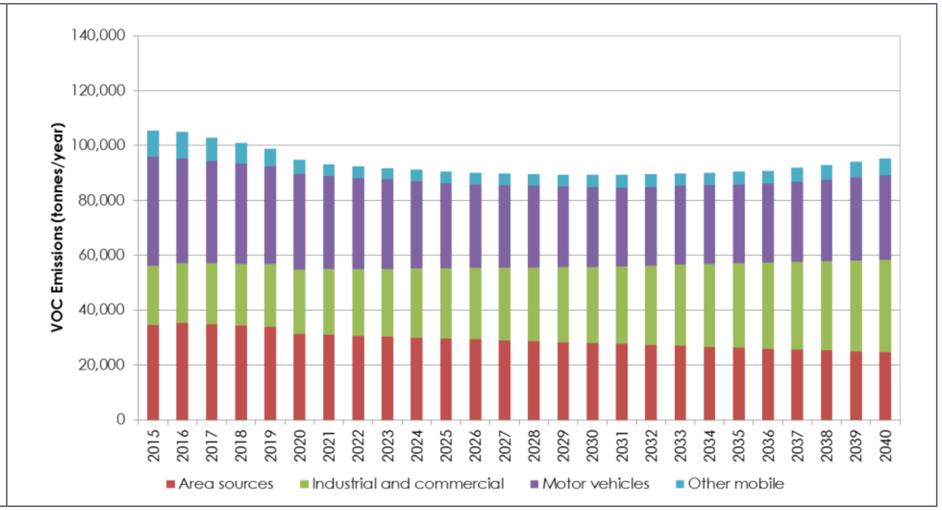

Figure D-56: South-East Queensland Abatement Package scenario VOCs emission projections

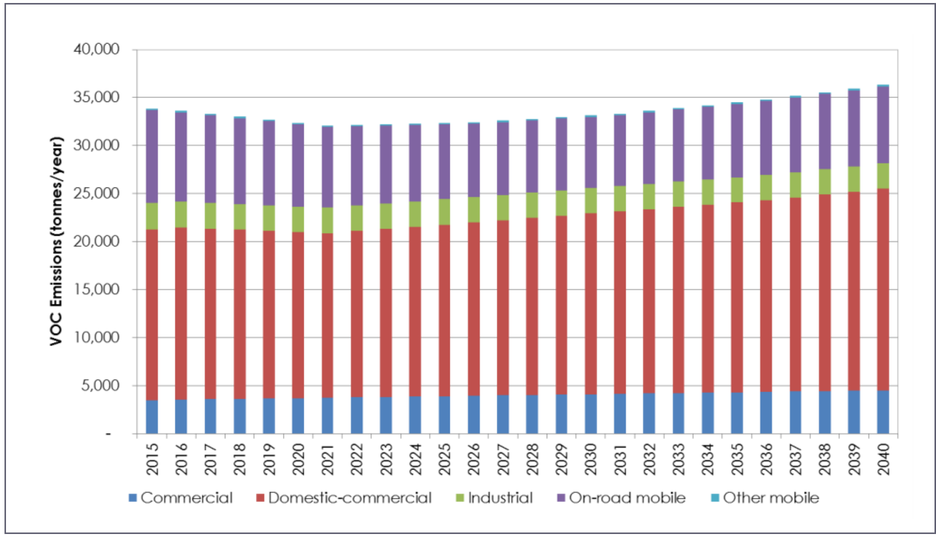

Figure D-57: Adelaide BAU scenario VOCs emission projections

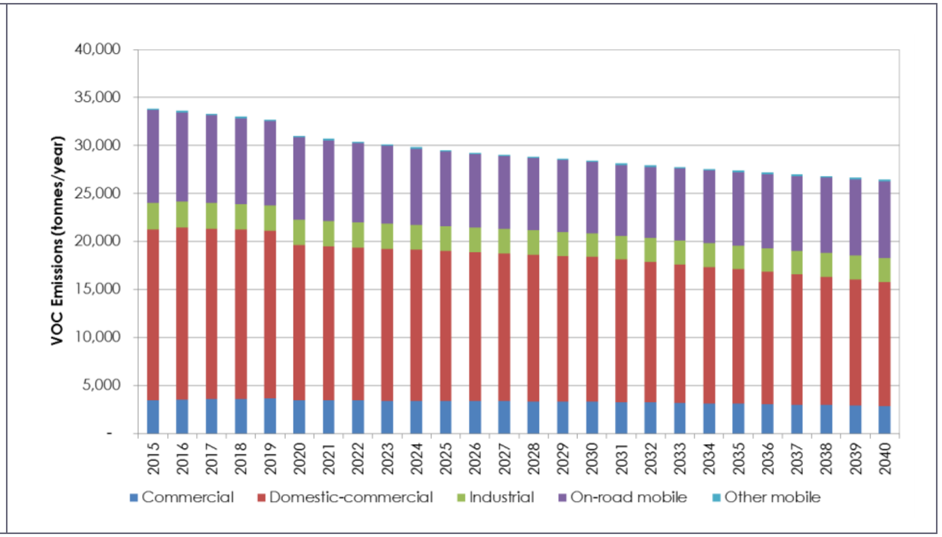

Figure D-58: Adelaide Abatement Package scenario VOCs emission projections

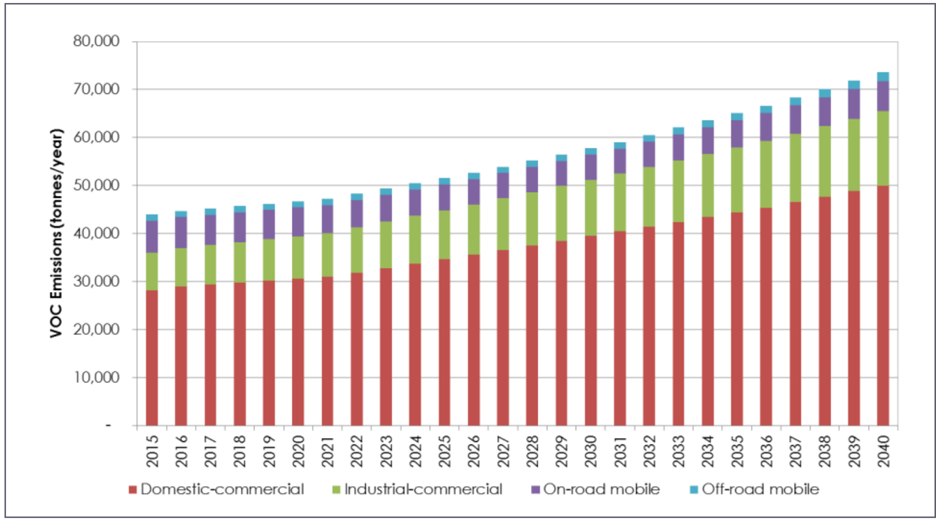

Figure D-59: Perth BAU scenario VOCs emission projections

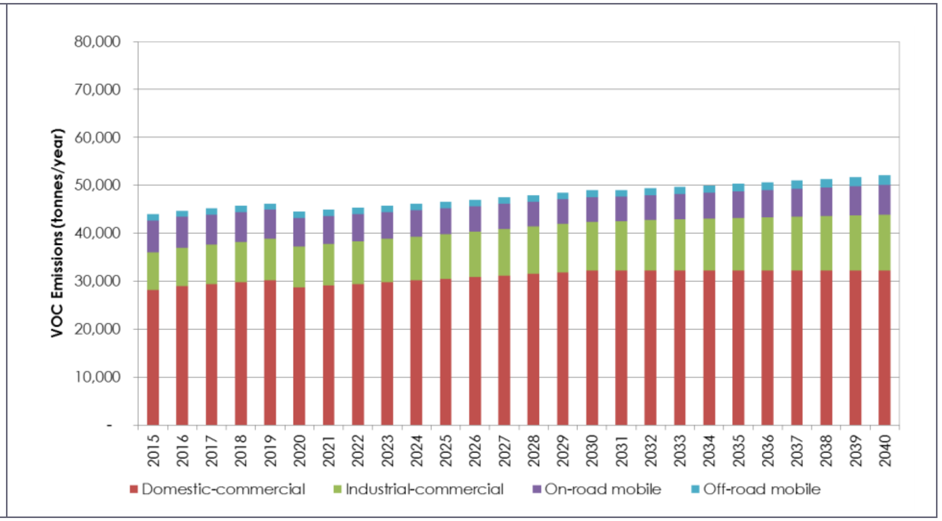

Figure D-60: Perth Abatement Package scenario VOCs emission projections

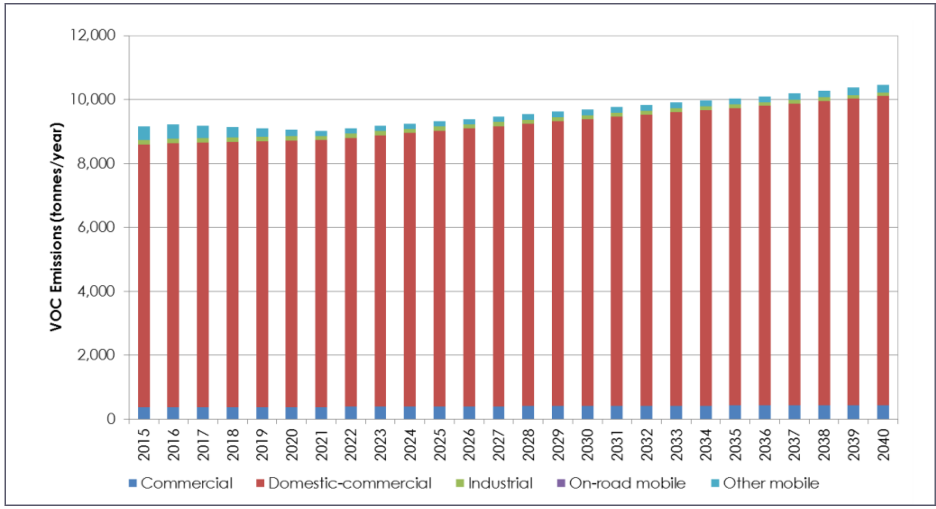

Figure D-61: Hobart BAU scenario VOCs emission projections

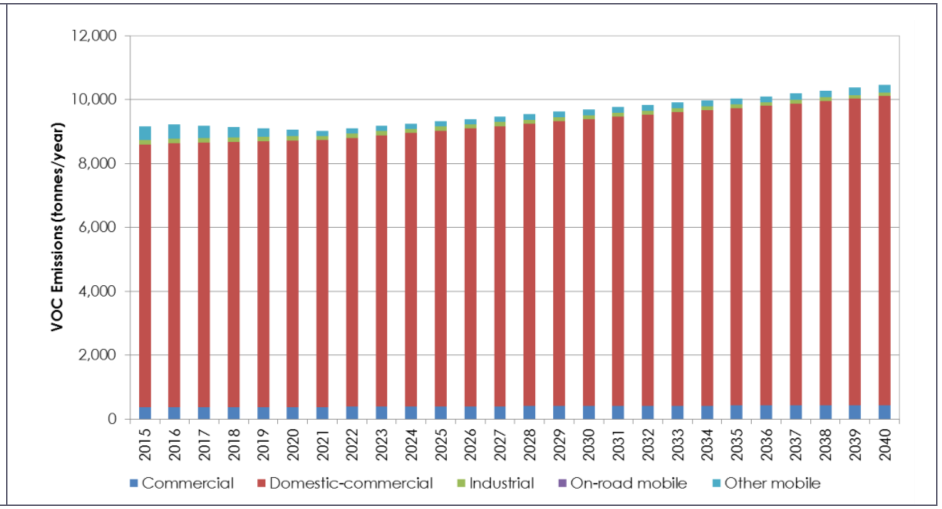

Figure D-62: Hobart Abatement Package scenario VOCs emission projections

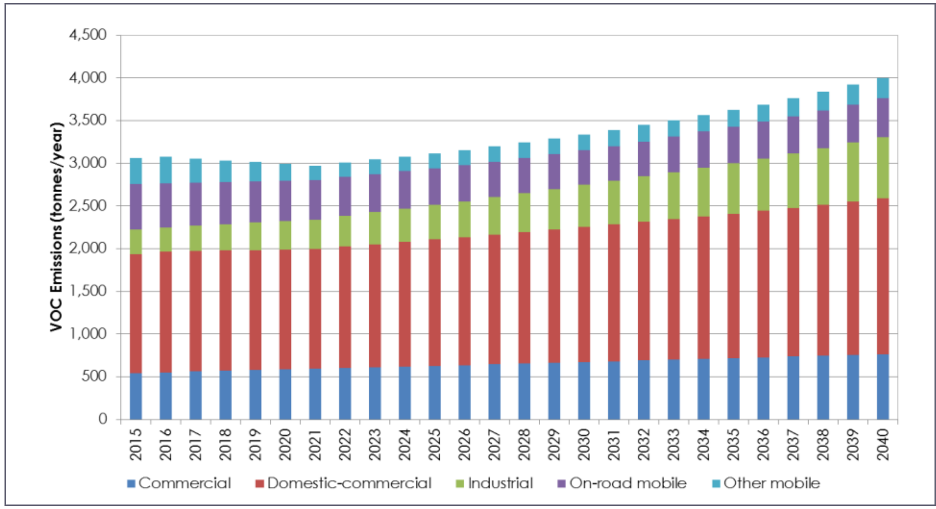

Figure D-63: Darwin BAU scenario VOCs emission projections

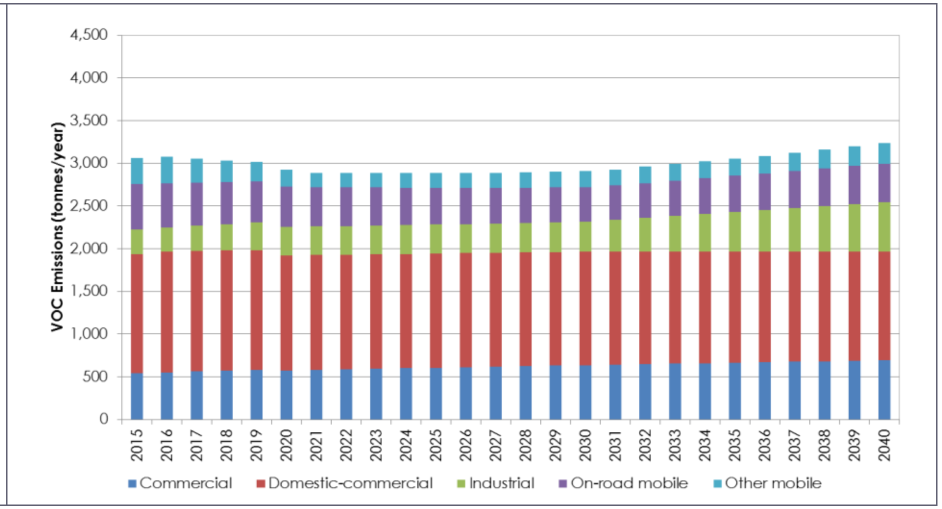

Figure D-64: Darwin Abatement Package scenario VOCs emission projections

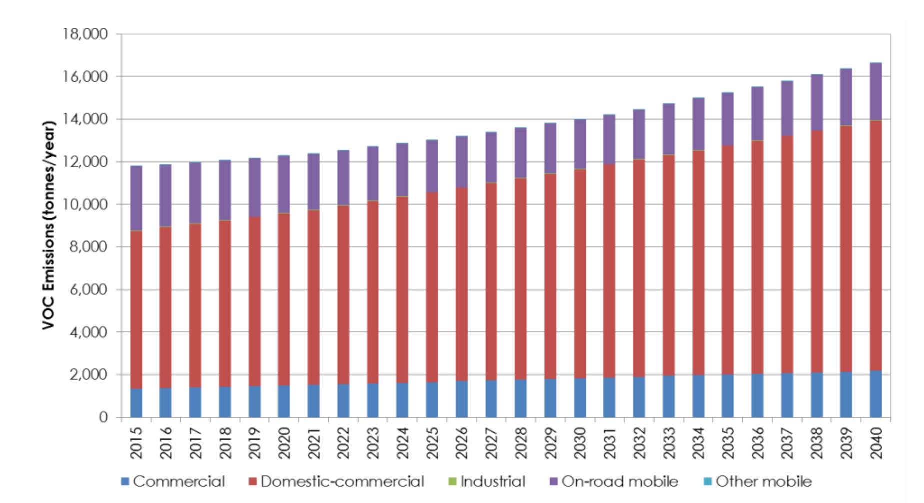

Figure D-65: Canberra BAU scenario VOCs emission projections

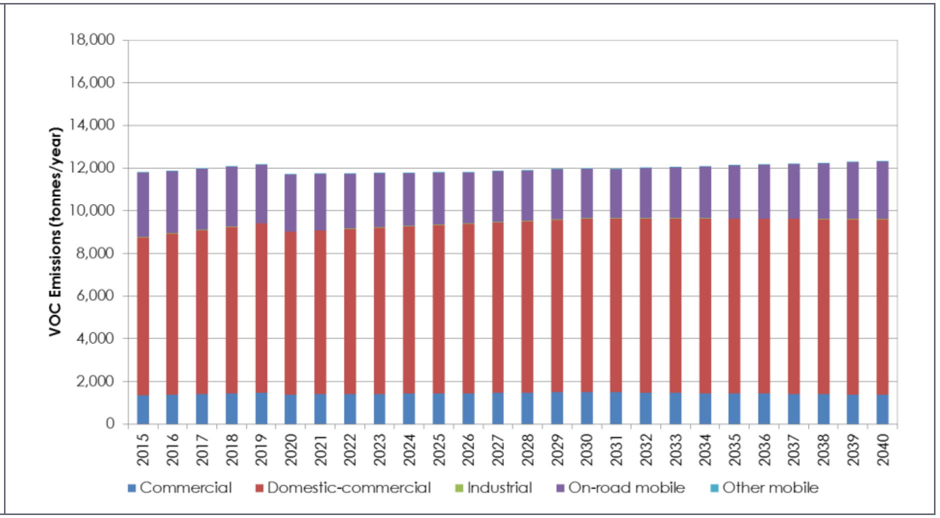

Figure D-66: Canberra Abatement Package scenario VOCs emission projections

Annexure E: Air quality model uncertainty and performance

E.1 Model uncertainty

E.1.1 Overview

Model performance can be evaluated by comparing the measurements and model predictions in a variety of ways. According to USEPA (2003), the model performance can be considered as follows:

- Models are more reliable for estimating longer time averaged concentrations than for estimating short-term concentrations at specific locations
- Estimates of concentrations that occur at a specific time and site are poorly correlated with actual observed concentrations (paired in space and time) and are less reliable (mostly due to reducible uncertainty such as error in plume location due to a wind direction error).
- Models are reasonably reliable in estimating the highest concentrations occurring sometime, somewhere in an area. Model certainty is expected to be in the range of a factor of two.

The Chemical Transport Model (model adopted for this study) uncertainty is threefold:

- The underlying physical parameterisations (biogenic emissions, deposition velocities, turbulent closure, chemical mechanism, etc.),
- The input data (land use data, emission inventories, raw meteorological fields, chemical data, etc.); and
- The numerical approximations (grid sizes, time steps and detailed chemical mechanism) (Mallet and Sportisse, 2006).

Uncertainties related to dispersion models are composed of model formulation uncertainties, and data uncertainties associated with meteorological and emission data. In addition, there is inherent uncertainty in the behaviour of the atmosphere, especially over shorter time scales due to the effects of random turbulence. Refer to USEPA (2005) for an overview of typical model uncertainties General dispersion model limitations are summarised in Table E-1.

Table E-1: Summary of Main Sources of Modelling Uncertainty

Source of Uncertainty	Potential Effects
1. Uncertainties in inputs	Uncertainties include emissions, observational data, meteorology, chemistry and resolution.
Emissions	Estimates of emissions are among the most uncertain inputs of photochemical transport model. Emissions from major industrial sources are reasonably well known as regulatory requirement. Traditionally, biogenic VOC emissions have not been well defined. The temporal and spatial specifications also contribute to the uncertainty. In addition, emission scenario is largely based on assumptions about perceived future policy and technology development. Therefore, a high level of uncertainty has embedded in the existing projected emission scenario (NSW EPA, 2008).
Observational data	Observational data collected to initialise the model system and provide boundary conditions as well as to evaluate model performance have uncertainties due to limited characterisation of their spatial and temporal variability.
Meteorology	Solar radiation influences temperature, photochemical reactions and vertical mixing. Radiative transfer depends on incoming solar radiation and absorption by gases, aerosols and ground level surfaces. The effect of aerosols on radiative transfer (both direct and indirect) is major sources of uncertainty.

Source of Uncertainty	Potential Effects
	In addition, wind direction affects direction of plume travel. Wind speed affects plume rise and dilution of plume, resulting in potential errors in distance of plume impact from source, and magnitude of impact. Usually the effects of temperature errors are small, but temperature affects plume buoyancy, with potential errors in distance of plume impact from source, and magnitude of impact.
Chemistry	Atmospheric chemistry is understood incompletely because it involves thousands of pollutants and tens of thousands of reactions. Reaction rates and pathways are understood adequately for less than one quarter of the chemical species observed in the atmosphere. Inevitably, the photochemical reactions need to be simplified due to excessive computational demand. There are also uncertainties in determining the chemical kinetic parameters for these species by experiment.
Resolution	Representing the range of scales relevant to the physical system places great demand on regional photochemical transport model. Models must span orders of magnitude in time and space. A compromise must be met between the resolution and scales imposed to manage the limitation of available information as well as computational intensity.
Source of Uncertainty	Potential Effects
2. Uncertainties in model formation	Uncertainties associated with model formation maybe due to erroneous or incomplete representations, incommensurability, numerical solution techniques, choice of model domain as well as grid structure.
Oversimplification of physics in model code	Atmospheric dispersion models represent a simplification of the many complex processes involved in determining ground level concentrations of pollutants that can lead to both under prediction and over prediction.
Turbulence	Uncertainties arise from the deterministic representation of turbulent diffusion transport using the gradient transport hypothesis in conjunction with the diffusivity coefficient, Kj. Errors in turbulence can cause either under prediction or over prediction of ground level concentrations.
Removal processes	Uncertainties in estimating pollutant removal are associated with the treatment of pollutant transport near surfaces and the net flux of pollutants from various types of vegetation and soils, i.e. deposition. The nature of these interactions for various species and surface types is a source of uncertainty.
Aerosols	Historically, modelling the physical and chemical processing of aerosol involves great uncertainty. Simulating regional spatial scales and entire ozone seasons involve detailed chemical reactions with aerosol and water droplet surfaces. Knowledge of these multiphase reactions is severely deficient. Treatment of cloud process is computationally intensive and the input data are rarely available.
3. Variability	Variability refers to stochastic atmospheric and anthropogenic processes
Inherent uncertainty	Nature consists of large degree of variability. It contributes to uncertainties associated with emissions estimates and representations of chemistry and meteorology. Models predict 'ensemble mean' concentrations for any specific set of input data (say on a one hour basis), i.e. they predict the mean concentrations that would result from a large set of observations under the specific conditions being modelled. However, for any specific hour with those exact mean hourly conditions, the predicted ground level concentrations will never exactly match the actual pattern of ground level concentrations, due to the effects of random turbulent motions and random fluctuations in other factors such as wind. The inherent uncertainty in concentrations downwind of an emission source has been estimated as 50-75% for a 1-hour average simulation.

E.1.2 Quantifying uncertainty

To quantify the uncertainty, it is necessary to conduct a comprehensive uncertainty analysis to:

- Quantify model sensitivities, i.e. the dependence of outputs on local change in inputs, formulations and design features.
- Provide information to make probabilistic statements about the indications of model output, i.e. likelihood that future air quality estimated by the model will be realised.
- Increase confidence that the model is sufficiently valid for the decision making need by identifying and correcting bias.
- Identify and assess the significance of compensating errors.

By way of example, in the USA, a model uncertainty analysis was conducted by Hanna et al. (2001) to estimate the uncertainty of 128 key input variables of a modelling system to evaluate emissions reductions needed to reduce the O_3 concentrations in northern United States below the national standard. The findings are summarised in Table E-2. It is worth noting that these values are representative at a specific region only. In a more recent study funded by the USEPA, which ran for 2.5 years with a cost of USD 230k, an uncertainty analysis for the regional photochemical model incorporating into integrated air quality planning was conducted (Digar et al., 2011). Key photochemical model inputs, epidemiological parameters, and other assumptions that induce most uncertainty in strategy assessments were investigated (Digar et al., 2011). The uncertainty analysis involved Monte Carlo sampling of input data, Brute Force sensitivity analysis and reduced form model as well as multiple runs of the photochemical model to identify the O_3 response. This approach enables probablistic prediction of the likelihood that an Abatement Package will be sufficient to achieve the air quality improvement target in the presence of parametric uncertainties in the photochemical model.

The best characterisation of the uncertainty would involve iteration of these parameters to derive a function of the simulation errors. However, computing a series of model outputs is in practice very difficult because of the computational costs, i.e. both monetary and time expensive.

The uncertainties in emission inventories mainly result from emission factor assumptions and can be highly variable between different emission source sectors. In air quality modelling applications, considerable additional uncertainty may arise from the spatial distribution of the emissions, i.e. how well the location or distribution of emission sources is known and how well it can be incorporated in the models at an appropriate resolution.

To date, in the international arena, it is noted that formal model evaluation efforts have been inadequate (e.g. Russell, 1997). The acceptability criteria of a regional model's performance for Australian conditions has not been prescribed to date.

Table E-2: Expert estimates of model input uncertainties (e.g. Hanna et al., 2001)

Input category	Variable	Uncertainty range
Initial conditions	O_3 concentrations	Factor of 3
	NO_x and VOC concentrations	Factor of 5
Boundary conditions	O_3 concentration aloft or at side	Factor of 1.5
	NO_x or VOC concentration aloft or at side	Factor of 3

Input category	Variable	Uncertainty range
Meteorology	Wind speed	Factor of 1.5
	Wind direction	+/- 40 degrees
	Air Temperature	+/- 3 K
	Relative humidity	30%
	Daytime vertical diffusivity below 1000 meters	Factor of 1.3
	Night time vertical diffusivity at all other times and heights	Factor of 3
	Rainfall amount	Factor of 2
	Cloud cover	30%
	Cloud liquid water content	Factor of 2
Emissions	Major point source NO_x and VOC	Factor of 1.5
	All other emissions estimates	Factor of 2
Photolysis rates	Six reactions	Factor of 2
Chemical mechanism	Reactions 1 to 83	Factors ranging from 1.17 to 2.5

A comprehensive uncertainty analysis for model sensitivity is outside the scope of this project. In addition, it is extremely difficult to quantify model uncertainties without the documented uncertainties in the input data provided by the jurisdictions. There is limited documentation and information about the sensitivity of the selected regional photochemical models (EPA Victoria, 2013; DECCW, 2010) or the inputs to these models (e.g. the emission inventories). In addition, the provided monitoring data was in whole ppb values, which limits the precision of the monitoring data. This limit in precision results in a higher error when comparing the model versus monitoring data.

Nevertheless, a statistical model performance summary based on the daily maximum 1-hour average and the daily 24-hour ranked data has been adopted to investigate the uncertainty within this study. This approach is in line with the method used by CSIRO to evaluate model performance in Sydney GMR (Simon et al., 2012; Cope and Emmerson, 2016). Mean Fractional Bias (MFB) and Mean Fractional Error (MFE) were calculated in each modelling airshed. The equations are as below:

$$MFB = 100\% \times \frac{2}{N}\sum\frac{(M_i - O_i)}{(M_i + O_i)}$$ (Equation E-1)

$$MFE = 100\% \times \frac{2}{N}\sum\frac{|M_i - O_i|}{(M_i + O_i)}$$ (Equation E-2)

Where:

M_i = modelled concentration

O_i = observation concentration; and

N = number of concentration pairs

The goals and criteria zones of MFE and MFB are shown in E-1 (Boylan and Russell, 2006). The shape of the zones in the limit of small concentrations takes account of the fact that small (and relatively unimportant) differences between very small observed and modelled concentration pairs can lead to large errors and this should be taken into account when considering model performance with respect to the criteria. The criteria used to assess model performance are shown in Table E-3 (Boylan and Russell, 2006; Morris, et al., 2005 and 2006). The model performance analysis for Victoria and Sydney GMR are detailed in see Section E.2.

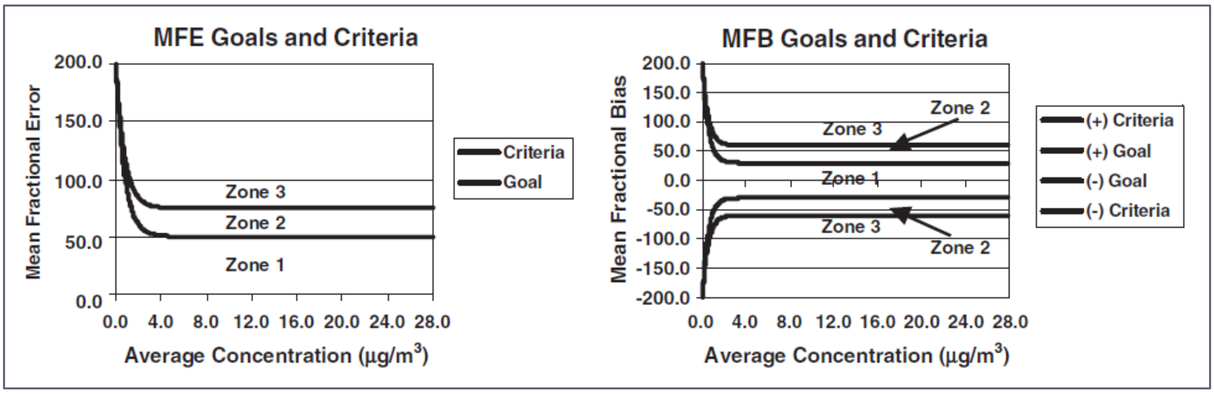

Figure E-1: Goal and criteria for MFE and MFB

Table E-3: Criteria used to assess model performance

Criteria	Bias	Error
B15, E35	within ± 15%	< 35%
B30, E50	within ± 30%	< 50%
B60, E75	within ± 60%	< 75%
B60+, E75+	outside this range	≥ 75%

In summary, the project uncertainty is managed by carefully selecting two state-of-the-art photochemical transport models (TAPM-CTM and CCAM-CTM) that best handle the challenges in their respective regions (Victoria and NSW) as well as using the best available data (meteorological data and updated emission inventory) at the commencement of this project. In this project, estimates of emissions, dispersion modelling, photochemistry modelling and monitoring data contain inherent uncertainties. The overall uncertainties could be much smaller than the sum of all the individual uncertainties from a statistical point of view.

In addition, the USEPA states that dispersion modelling introduces errors of +-10 - 40% in the calculations (USEPA, 2005) and often the factor-of-two accuracy has been quoted as the general rule of thumb for accepted dispersion modelling performance (USEPA, 2003). Model performance analysis shows both models selected and used in this study are within the range of acceptable accuracy. Nonetheless, it is the decision makers' responsibility to weigh the modelled results against other currently available options (i.e. tools and data).

E.2 Model performance

E.2.1 New South Wales

CSIRO has conducted a model evaluation for the same version of CCAM-CTM used in this study for NSW GMR (Cope and Emmerson, 2016). It is concluded that:

- The meteorological modelling is state of the art.
- The NSW GMR emission inventory is extremely detailed and it has captured a high majority of the significant source groups.
- For SO_2, CCAM-CTM is able to successfully reproduce the peak concentrations.

- For NO_2, the model results agree reasonably well in the summer season. However, NO_2 can be over predicted.
- For O_3, the model is able to predict the highest 1–hour O_3 concentrations with acceptable accuracy. However, there is a trend to under predict concentrations at about the 90th percentile and above. It is worth noting that the highest concentrations of O_3 can be under predicted at certain receptor locations.

To confirm the model performance, modelled base case results (BAU 2016) were compared to the most recent and available monitoring data at the AAQ NEPM monitors in Sydney GMR. A statistical approach has been adopted to quantify the modelling system uncertainty.

Q-Q plots were generated based on the BAU 2016 modelled results and monitoring data in 2013 (O_3) and 2014 (SO_2 and NO_2) extracted from the database provided by EPA Victoria. The 1-hour average Q-Q plots for SO_2, NO_2 and O_3 are shown in Figures E-2, E3 and E-4. The 24-hour average Q-Q plots for SO_2, NO_2 and O_3 are shown in Figures E-5, E-6 and E-7 respectively.

For 1-hour and 24-hour SO_2, the model shows reasonable validation for all monitoring locations. In general, it appears that the model slightly over predicts the maximum SO_2 ground level concentration in Wollongong, while slightly under-predicts the maximum SO_2 ground level concentration in Chullora. The SO_2 pattern is likely due to the constraint in SO_2 input of the model explained in Section 4.1.3. Nevertheless, the maximum model predicted ground level SO_2 concentrations at most monitoring stations are within the 1:2 and 2:1 ratios.

For 1-hour and 24-hour NO_2, the model shows relatively good validation for all monitoring locations except in Wollongong. It appears that the model slightly under predicts the ground level NO_2 concentrations at the Wollongong monitor. It is suggested that the data maybe skewed by a significant combustion point source in the region which cannot be characterised by this version of the emission inventory or model. Considering the number of monitoring stations reviewed, one outlying station does not disqualify the model validation.

For 1-hour and 24-hour O_3, the model shows reasonable validation for all monitoring. In general, the maximum predicted O_3 ground level concentrations at most monitoring stations are just below the 1:1 line; and the model slightly under predicts the O_3 ground level concentrations between 20 to 60 ppb. However, the maximum model predicted ground level O_3 concentrations at all monitoring locations are within the 1:2 and 2:1 ratios.

The 1-hour and 24-hour average SO_2 MFBs and MFEs for Sydney, Newcastle and Illawarra airsheds are shown in Table E-4. The maximum 1-hour SO_2 on spatial average in the Sydney airshed and Illawarra airshed were determined to under predict by 44% and 93% respectively; while the Newcastle airshed was over predicted by 20%. For, the 24-hour average statistics, most MFB and MFE fell inside the criteria to assess model performance, i.e. B30+ and E35+. These have proven the modelled SO_2 concentrations are within satisfactory standard.

For 1-hour and 24-hour NO_2, the model shows relatively good correlation for all monitoring locations except in Wollongong (Figures E-3 and E-6). It appears that the model under predicts the ground level NO_2 concentrations at the Wollongong monitor. Considering the number of monitoring stations reviewed, one outlying station does not disqualify the model validation.

The 1-hour and 24-hour average NO_2 MFBs and MFEs for Sydney, Newcastle and Illawarra airsheds are shown in Table E-5.

The maximum 1-hour NO_2 on spatial average in the Sydney, Newcastle and Illawarra airsheds were determined to under predict by 10%, 8% and 69% respectively. For, the 24-hour average statistics, most MFB and MFE for Sydney and Newcastle airsheds fell inside B15, E35 model assessment criterial, with an exception of MFB at 90 percentile in Newcastle airshed which just fell outside B15, i.e. MFB = 21%. For Illawarra airshed, on 24-hour average, most MFB and MFE fell within B60 and E75 model performance criteria with the exception of MFB at maximum fell outside B60+.

These have proven the modelled NO_2 concentrations are within satisfactory standard in Sydney and Newcastle airsheds; while the modelled NO_2 concentration are within acceptable standard in Illawarra airshed.

For 1-hour and 24-hour O_3, the model shows reasonable validation for all monitoring locations (Figures E-4 and E-7). In general, the maximum predicted O_3 ground level concentrations at most monitoring stations are just below the 1:1 line; and the model slightly under predicts the O_3 ground level concentrations between 15 ppb to 30 ppb. However, the maximum model predicted ground level O_3 concentrations at all monitoring locations are within the 1:2 and 2:1 ratios.

The 1-hour and 24-hour average O_3 MFBs and MFEs for Sydney, Newcastle and Illawarra airsheds are shown in Table E-6.

The maximum 1-hour O_3 on spatial average in the Sydney, Newcastle and Illawarra airsheds were determined to under predict by 24%, 18% and 59% respectively. For, the 24-hour average statistics, all MFB in all airsheds fell inside B30 & E50 model performance criteria. This suggests the modelling system matches the upper deciles of the observed distribution very well in the three Sydney GMR airsheds with the exception of under predicting some rare set of conditions.

Under-prediction of peak concentration is common to many photochemical modelling studies (Simon et al., 2012; Cope and Emmerson, 2016). This is likely related to the modelling system's ability to reproduce the relatively rare set of conditions of meteorology, emissions and chemical transport/transformation which led to the formation of such events.

In general, the model is predicting the highest ambient concentrations for O_3, NO_2 and SO_2 within satisfactory performance criteria. The modelled results are also considered acceptable by the independent reviewer and CSIRO. Therefore, it is considered acceptable to calculate the health impacts based on maximum and 99th percentile modelled concentrations derived from this study.

Table E-4: Mean Fractional Bias and Mean Fractional Error for 1-hour and 24-hour SO_2 distribution in modelled NSW airsheds

Statistic	MFB			MFE		
	Sydney	Newcastle	Illawarra	Sydney	Newcastle	Illawarra
1-hour average						
100%	-44%	20%	-93%	-44%	-71%	-93%
99%	2%	55%	-46%	-11%	-55%	-46%
90%	28%	70%	16%	-28%	-70%	-16%
24-hour average						
100%	-25%	-30%	-26%	-25%	-30%	-26%
99%	-26%	-26%	-31%	-26%	-26%	-31%
90%	-31%-	-27%	-22%	-31%	-27%	-22%

Table E-5: Mean Fractional Bias and Mean Fractional Error for 1-hour and 24-hour NO_2 distribution in modelled NSW airsheds

Statistic	MFB			MFE		
	Sydney	Newcastle	Illawarra	Sydney	Newcastle	Illawarra
1-hour average						
100%	-10%	-8%	-69%	-21%	-23%	-69%
99%	-9%	-16%	-58%	-13%	-16%	-58%
90%	-16%	-22%	-60%	-18%	-22%	-60%
24-hour average						
100%	--6%	-2%	-73%	-21%	-15%	-73%
99%	-7%	-10%	-54%	-23%	-13%	-54%
90%	-13%	-21%	-51%	-19%	-24%	-51%

Table E-6: Mean Fractional Bias and Mean Fractional Error for 1-hour and 24-hour O_3 distribution in modelled NSW airsheds

Statistic	MFB			MFE		
	Sydney	Newcastle	Illawarra	Sydney	Newcastle	Illawarra
1-hour average						
100%	-24%	-18%	-59%	-24%	-18%	-59%
99%	-28%	-37%	-43%	-28%	-37%	-43%
90%	-36%	-39%	-34%	-36%	-39%	-34%
24-hour average						
100%	-25%	-30%	-26%	-25%	-30%	-26%
99%	-26%	-26%	-31%	-26%	-26%	-31%
90%	-31%	-27%	-22%	-31%	-27%	-22%

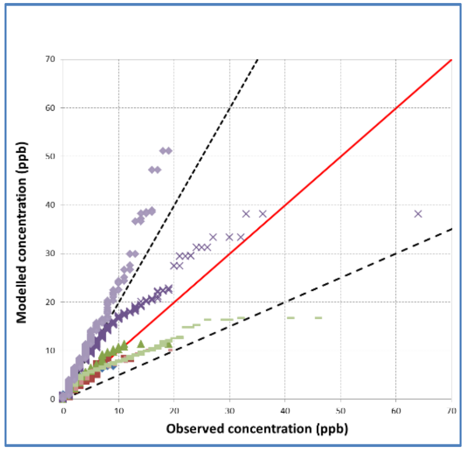

Figure E-2: Q-Q plot for 1-hour average SO_2 concentrations

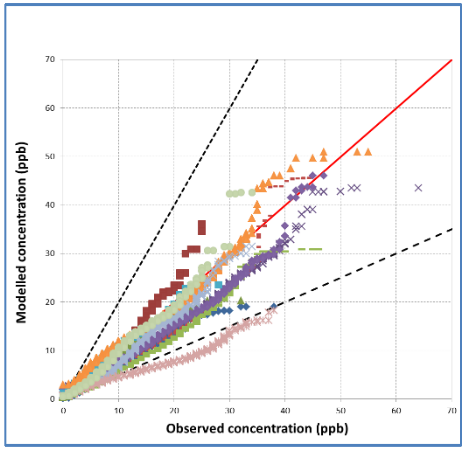

Figure E-3: Q-Q plot for 1-hour average NO_2 concentrations

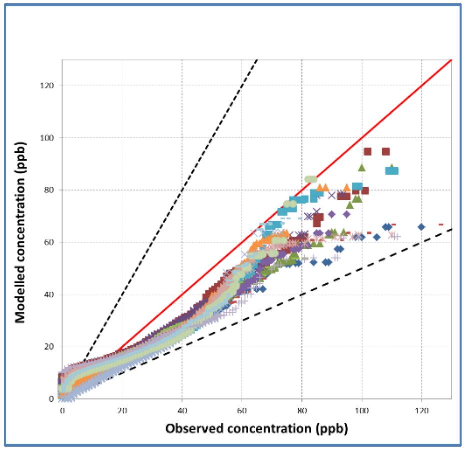

Figure E-4: Q-Q plot for 1-hour average O_3 concentrations

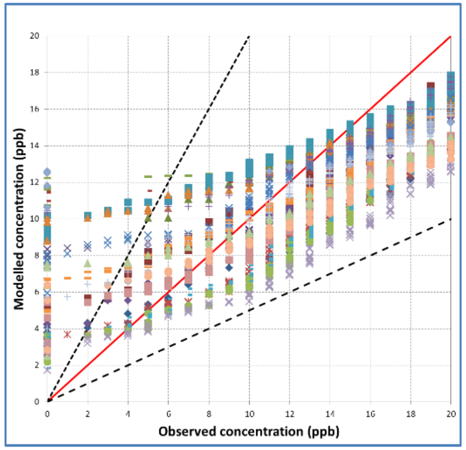

Figure E-5: Q-Q plot for 24-hour average SO_2 concentrations

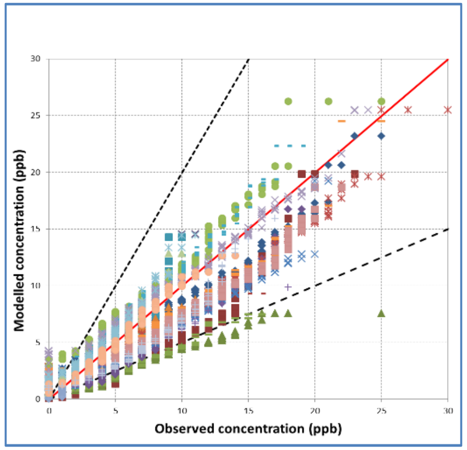

Figure E-6: Q-Q plot for 24-hour average NO_2 concentrations

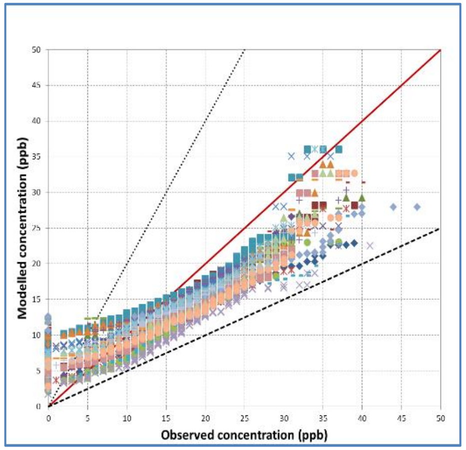

Figure E-7: Q-Q plot for 24-hour average O_3 concentrations

E.2.2 Victoria

TAPM-CTM, as a dispersion model, is a simulation of the defined airshed. Any dispersion model is an estimate of concentrations at specific sites that are actually an ensemble average of numerous repetitions of the same event. Therefore, it is realistic to expect deviations from the observed measurements, and those estimated by the model.

As a confirmation of model performance, the annual emission trends at select monitoring locations were reviewed to establish whether model outputs reasonably reflect reality.

The 2016 estimated emissions were modelled and compared to the most recent, available monitoring data, year 2014, at the Alphington, Footscray, Geelong and Traralgon monitoring stations. This was performed to understand if the modified model predicted current air quality conditions within expectations.

The Victorian air emission inventory has been updated regularly by the EPA Victoria since the inventory was developed (Delaney and Marshall, 2011), which includes the improvement of shipping emissions estimates (Marshall. et. al., 2011). The inventory files provided to this study were date stamped September 2015. The comparison of modelled versus measured SO_2 shows that the SO_2 concentrations were significantly under predicted with the inputs as received from EPA Victoria. This is likely due to the age of the inventory and the updates of the motor vehicle emission in the 2006 emission inventory (Delaney et al., 2009). The 2006 inventory was modified so that model results validated with the monitoring data. The only source that was modified was the motor vehicle SO_2 emission. The modification to the inventory resulted in an increase of SO_2 emissions from vehicles. As motor vehicle emissions are now better understood, it appears that the previous modification is not appropriate for 2016. It is considered more likely that the modelled ground level impacts from industrial emissions, the major SO_2 source, are under predicted, rather than there being an error in the motor vehicle emissions inputs. To compensate for the under prediction, the industrial emissions were scaled by a single factor across the grid. A grid wide scaling factor was the only method that could be applied to correct for the under-prediction. It was not possible to change the base inventory emission files due to not having access to the emissions files and the study timeframe. The factor selected was the one that resulted is the smallest least squared values between the model and monitoring data for the ranked 1-hour SO_2 concentrations. The results presented here use this additional scaling factor.

To further evaluate the model performance compared to monitoring data Quantile-Quantile (Q-Q) plots have been prepared for the current monitoring network. Q-Q plots are a graphical method for comparing two distributions. The two distributions are sorted from highest to lowest and then plotted against each other. If the two distributions being compared are similar, the plotted points will fall on the 1:1 ratio line. The distributions can still be linearly related but not fall on the 1:1 ratio line. Discrepancies from the 1:1 ratio line can indicate where the model results are unable to match the monitoring data. It is common to consider that 1:2 and 2:1 ratios are acceptable model performance (USEPA, 2005), and therefore these ratios are also included in the figures. These figures present a straightforward method to understand if the model is predicting reasonably (i.e. within the factor of two accuracy).

The daily 1-hour maximum Q-Q plots for SO_2, NO_2 and O_3 are displayed in Figures E-8, E-9 and E-10 respectively. The 24-hour average Q-Q plots for SO_2, NO_2 and O_3 are displayed in Figures E11, E-12 and E-13 respectively.

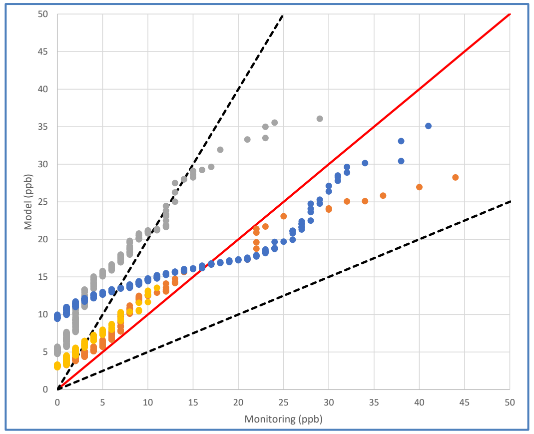

Figure E-8: Q-Q plot for daily 1-hour maximum SO_2 concentrations

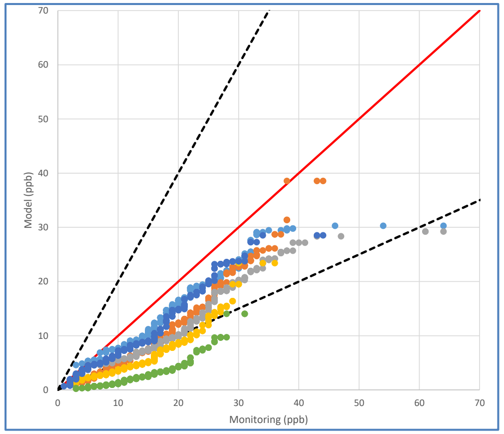

Figure E-9: Q-Q plot for daily 1-hour maximum NO_2 concentrations

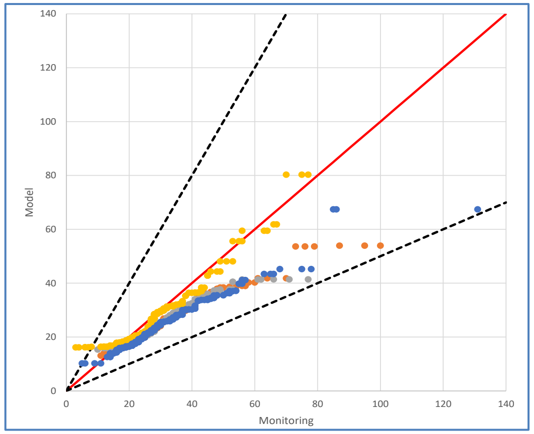

Figure E-10: Q-Q plot for daily 1-hour maximum O_3 concentrations

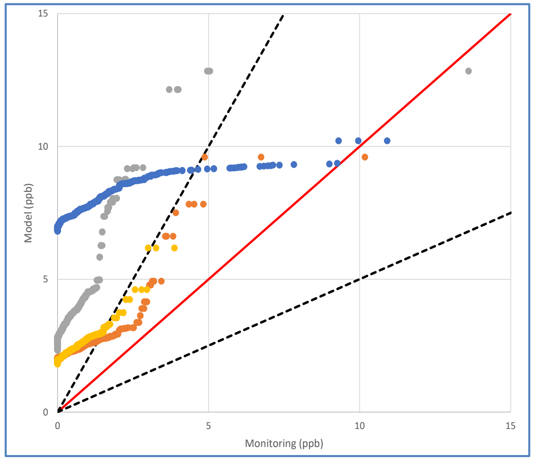

Figure E-11: Q-Q plot for 24-hour average SO_2 concentrations

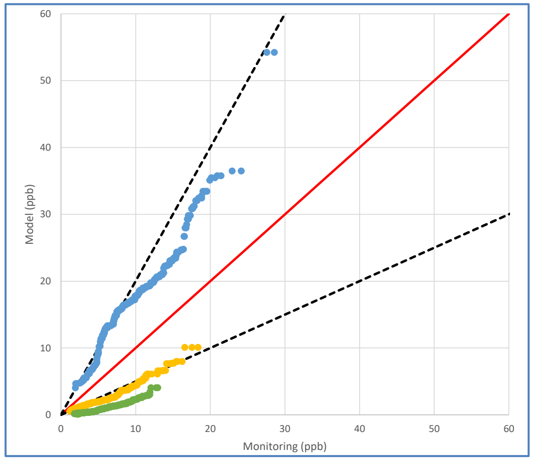

Figure E-12: Q-Q plot for 24-hour average NO_2 concentrations

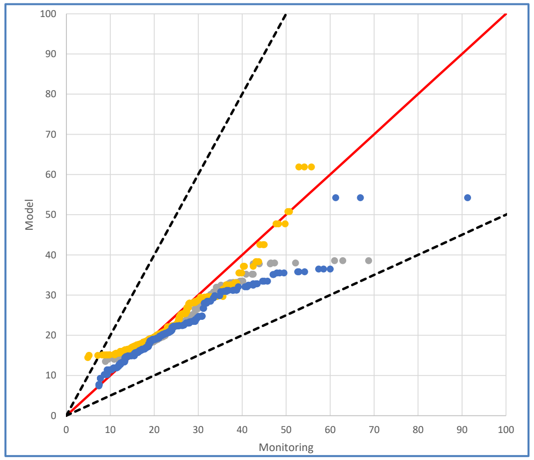

Figure E-13: Q-Q plot for 24-hour average O_3 concentrations

In general, the model is predicting the highest ambient concentrations within a factor of two. The model 24-hour SO_2 correlates to the monitoring data the least for the lower concentrations, which is likely due to the method of modelling the SO_2 industry emissions.

The daily 1-hour maximums and the daily 24-hour average SO_2 MFBs and MFEs for Port Phillip region and Latrobe Valley airsheds are shown in Table E-7. The daily 1-hour SO_2 maximum in the Port Phillip airshed was determined to over predict by 9%, while the Latrobe Valley under predicted by 44%. The daily 24-hour average statistics MFB and MFE fell outside the criteria to assess model performance, i.e. B60+ and E75+. As discussed with the 24-hour SO_2 average quantile-quantile plots, this is likely due to the method of modelling the SO_2 industry emissions.

The daily 1-hour maxima and the daily 24-hour average NO_2 MFBs and MFEs for Port Phillip region and Latrobe Valley airsheds are shown in Table E-8. The maximum daily 1-hour NO_2 maximum determined MFBs and MFEs fell outside the criteria to assess model performance, i.e. B60+ and E75+. The Port Phillip airshed generally under predicted the daily 1-hour maximum by about 50%. The daily 24-hour NO_2 maximum for Port Phillip airshed was on average over predicted by 2% and was within the B15 for the 99th and 90th percentiles. The Latrobe Valley NO_2 daily maximum 1-hour average and 24-hour average determined MFEs and MFBs fell outside the criteria to assess model performance, i.e. B60+ and E75+.

The daily 1-hour maxima and the daily 24-hour average O_3 MFBs and MFEs for Port Phillip region and Latrobe Valley airsheds are shown in Table E-9. The maximum daily 1-hour average O_3 concentration was over predicted by 4% for the Latrobe Valley and by 10% for the maximum 24-hour average. The O_3 concentrations was under predicted for the Port Phillip airshed by 61% for the maximum daily 1-hour maximum and 54% for the maximum 24-hour average. The over predictions are less at the lower statistics indicating the model cannot account for extreme high O_3 days likely due to sources not included in the general inventory, such as bushfires.

Table E-7: Model Mean Fractional Bias and Mean Fractional Error for SO_2 distributions for the Victorian airsheds

Statistic	MFB		MFE	
	Port Phillip Region	Latrobe Valley	Port Phillip Region	Latrobe Valley
Daily 1-hour maximum				
Maximum	9%	-44%	19%	44%
99th Percentile	24%	-20%	25%	20%
90th Percentile	42%	-28%	45%	28%
Daily 24 hour average				
Maximum	102%	94%	102%	94%
99th Percentile	134%	141%	134%	141%
90th Percentile	154%	107%	154%	107%

Table E-8: Model Mean Fractional Bias and Mean Fractional Error for NO_2 distributions for the Victorian airsheds

	MFB		MFE	
Statistic	Port Phillip Region	Latrobe Valley	Port Phillip Region	Latrobe Valley
Daily 1-hour maximum				
Maximum	-61%	-75%	61%	75%
99^{th} Percentile	-38%	-95%	38%	95%
90^{th} Percentile	-43%	-123%	43%	123%
Daily 24 hour average				
Maximum	2%	104%	60%	104%
99^{th} Percentile	-9%	115%	57%	115%
90^{th} Percentile	-14%	124%	58%	124%

Table E-9: Model Mean Fractional Bias and Mean Fractional Error for O_3 distributions for the Victorian airsheds

	MFB		MFE	
Statistic	Port Phillip Region	Latrobe Valley	Port Phillip Region	Latrobe Valley
Daily 1-hour maximum				
Maximum	-61%	4%	61%	4%
99^{th} Percentile	-42%	-7%	42%	7%
90^{th} Percentile	-22%	-11%	22%	11%
Daily 24 hour average				
Maximum	-54%	10%	54%	10%
99^{th} Percentile	-37%	0%	37%	0%
90^{th} Percentile	-11%	-6%	11%	6%

Annexure F: Contour plots

F.1 NSW GMR

F.1.1 Nitrogen dioxide

The maximum predicted contour plots for the 1-hour NO_2 concentrations are shown in the following Figures:

- Figure F-1: Maximum 1-hour NO_2 concentration – 2021 – BAU
- Figure F-2: Maximum 1-hour NO_2 concentration – 2021 – Abatement Package
- Figure F-3: Maximum 1-hour NO_2 concentration – 2031 – BAU
- Figure F-4: Maximum 1-hour NO_2 concentration – 2031 – Abatement Package
- Figure F-5: Maximum 1-hour NO_2 concentration – 2040 – BAU
- Figure F-6: Maximum 1-hour NO_2 concentration – 2040 – Abatement Package

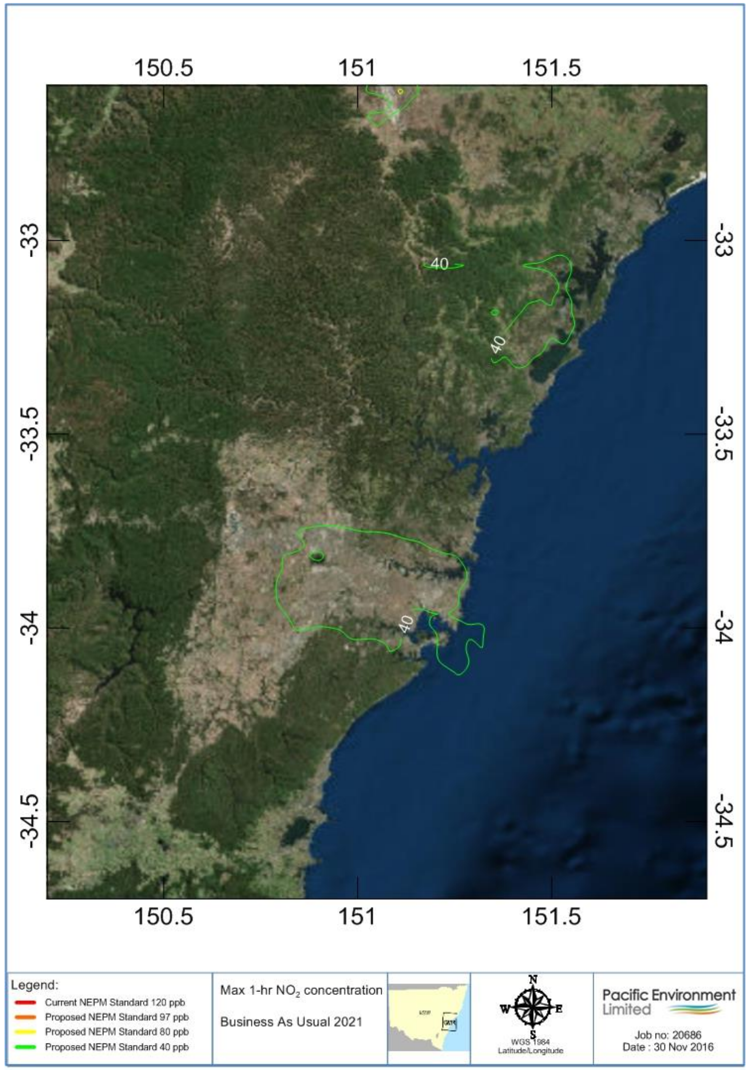

Figure F-1: Maximum 1-hour NO_2 concentration - BAU 2021

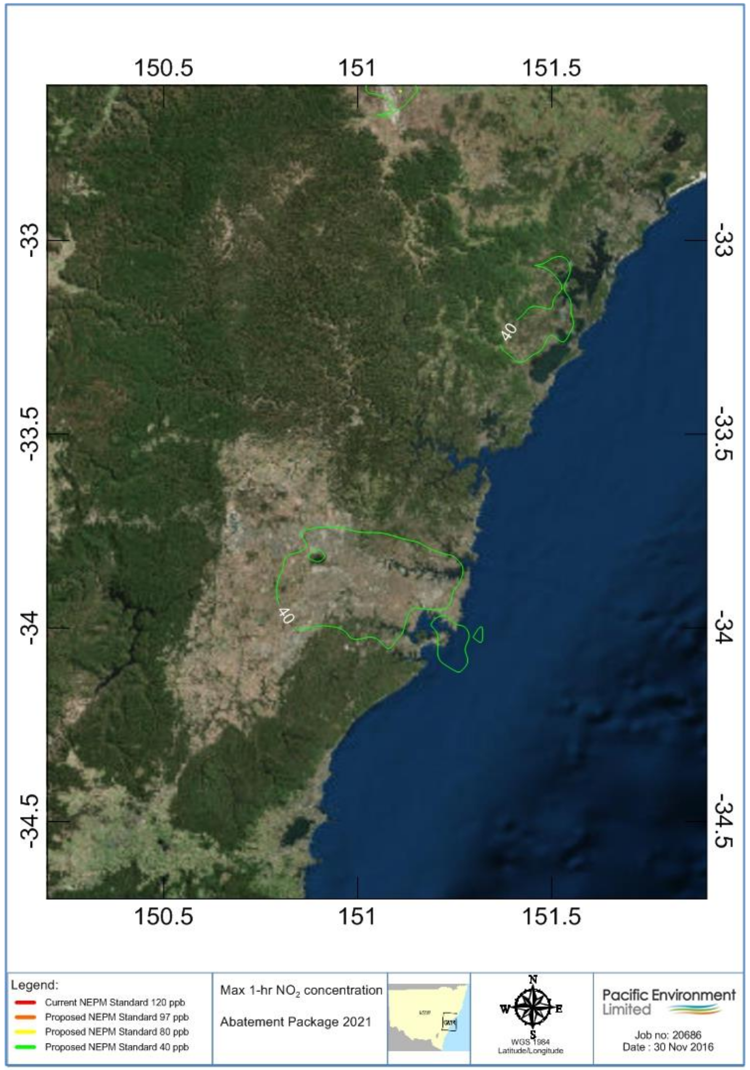

Figure F-2: Maximum 1-hour NO_2 concentration - Abatement Package 2021

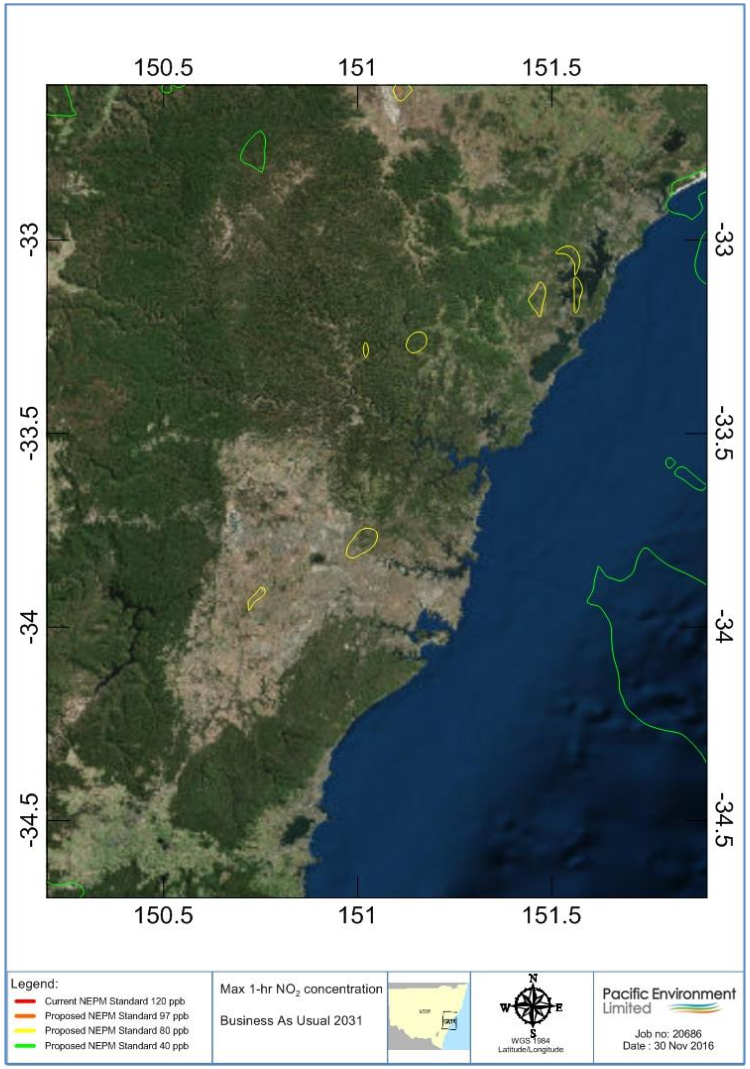

Figure F-3: Maximum 1-hour NO_2 concentration- BAU 2031

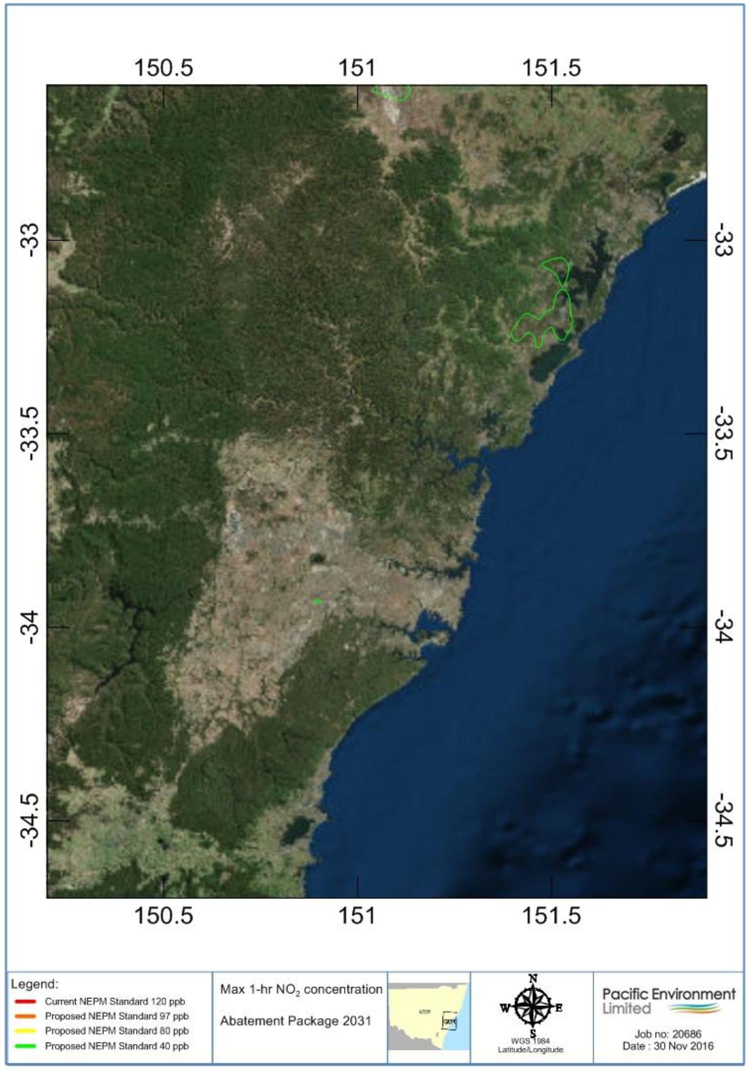

Figure F-4: Maximum 1-hour NO_2 concentration- Abatement Package 2031

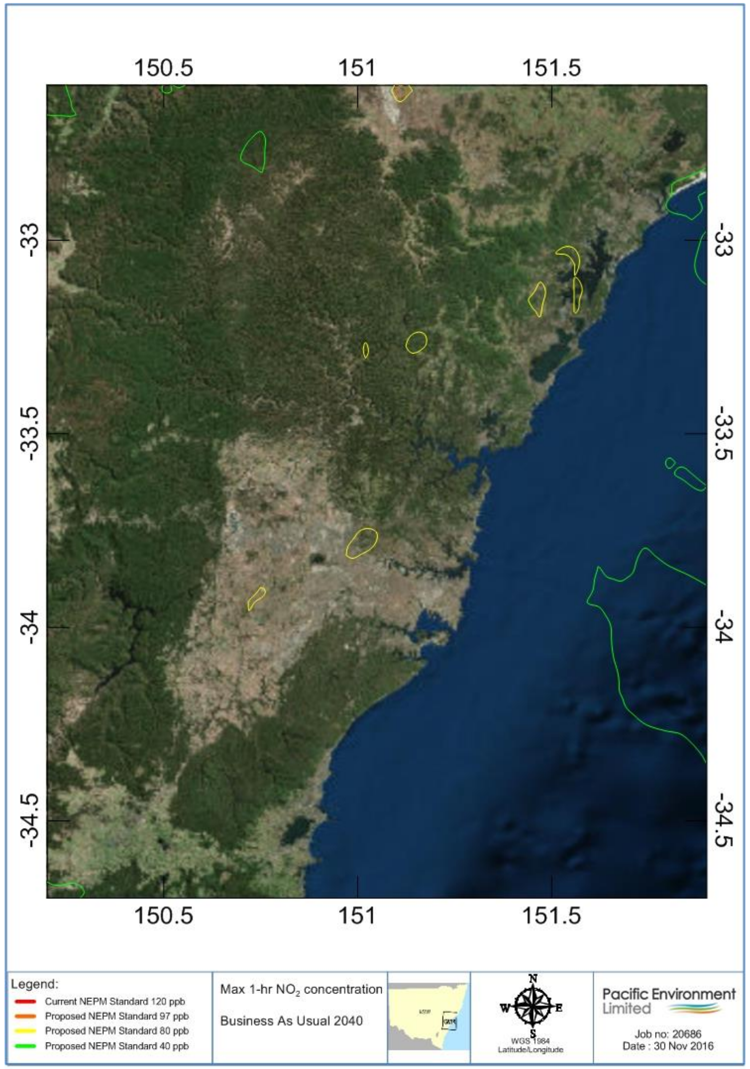

Figure F-5: Maximum 1-hour NO_2 concentration- BAU 2040

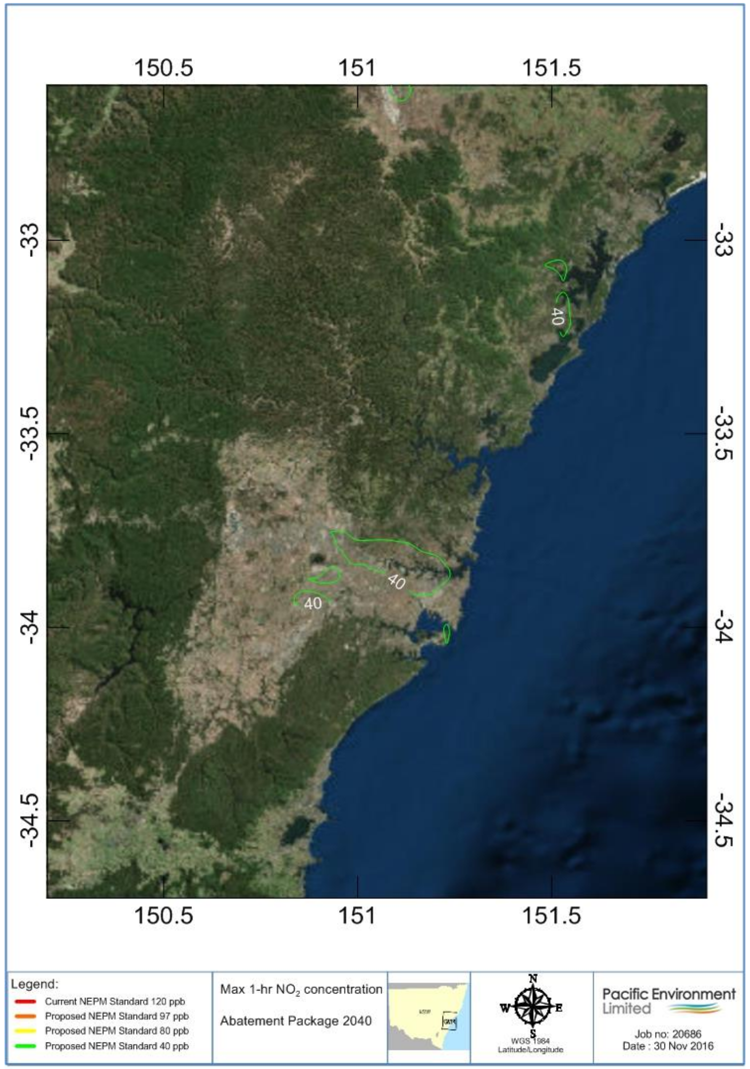

Figure F-6: Maximum 1-hour NO_2 concentration- Abatement Package 2040

F.1.2 Ozone

The maximum predicted contour plots for the 1-hour, 4-hour and 8-hour average O_3 concentrations are shown in the following Figures:

- Figure F-7: Maximum 1-hour O_3 concentration – 2021 - BAU
- Figure F-8: Maximum 1-hour O_3 concentration – 2021 - Abatement Package
- Figure F-9: Maximum 1-hour O_3 concentration – 2031 - BAU
- Figure F-10: Maximum 1-hour O_3 concentration – 2031 - Abatement Package
- Figure F-11: Maximum 1-hour O_3 concentration – 2040 - BAU
- Figure F-12: Maximum 1-hour O_3 concentration – 2040 - Abatement Package

- Figure F-13: Maximum 4-hour O_3 concentration – 2021 - BAU
- Figure F-14: Maximum 4-hour O_3 concentration – 2021 - Abatement Package
- Figure F-15: Maximum 4-hour O_3 concentration – 2031 - BAU
- Figure F-16: Maximum 4-hour O_3 concentration – 2031 - Abatement Package
- Figure F-17: Maximum 4-hour O_3 concentration – 2040 - BAU
- Figure F-18: Maximum 4-hour O_3 concentration – 2040 - Abatement Package

- Figure F-19: Maximum 8-hour O_3 concentration - 2021 BAU
- Figure F-20: Maximum 8-hour O_3 concentration – 2021 - Abatement Package
- Figure E 21: Maximum 8-hour O_3 concentration – 2031 - BAU
- Figure F-22: Maximum 8-hour O_3 concentration – 2031 - Abatement Package
- Figure F-23: Maximum 8-hour O_3 concentration – 2040 - BAU
- Figure F-24: Maximum 8-hour O_3 concentration – 2040 - Abatement Package

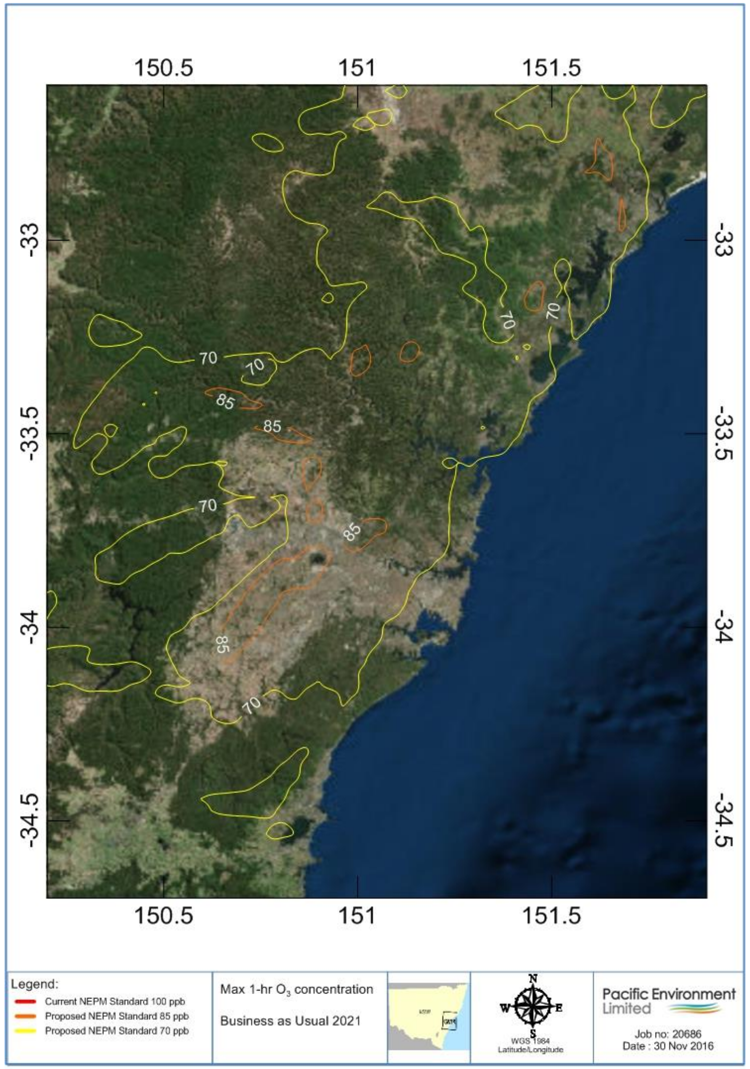

Figure F-7: Maximum 1-hour O_3 concentration - BAU 2021

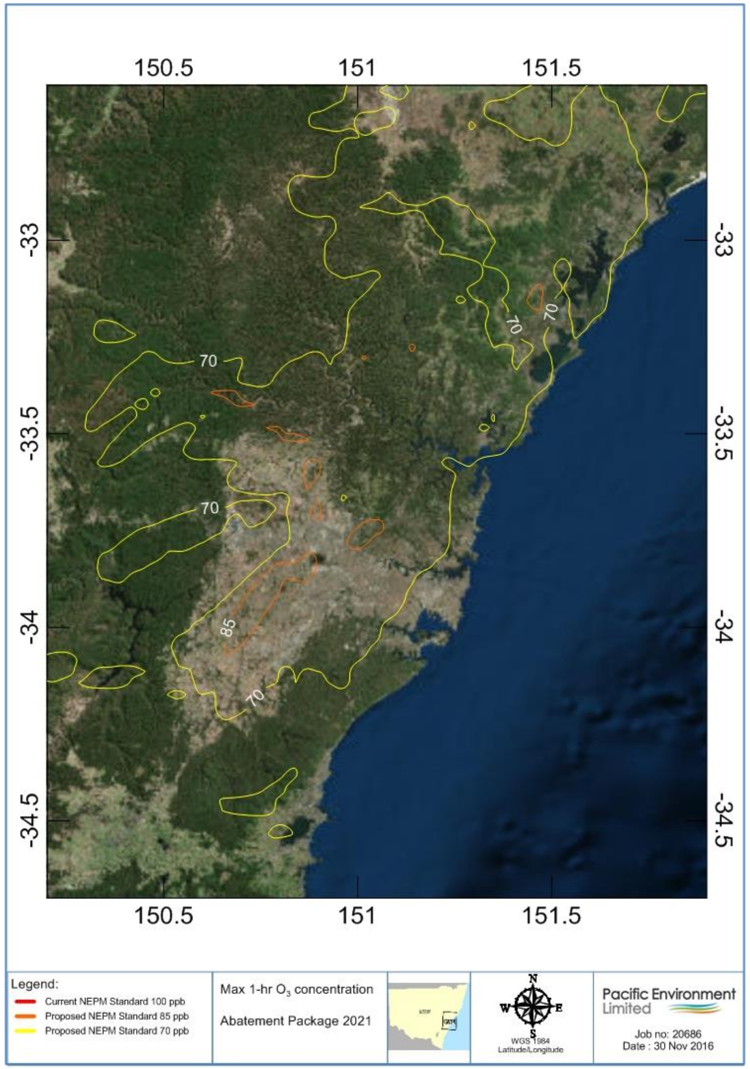

Figure F-8: Maximum 1-hour O_3 concentration - Abatement Package 2021

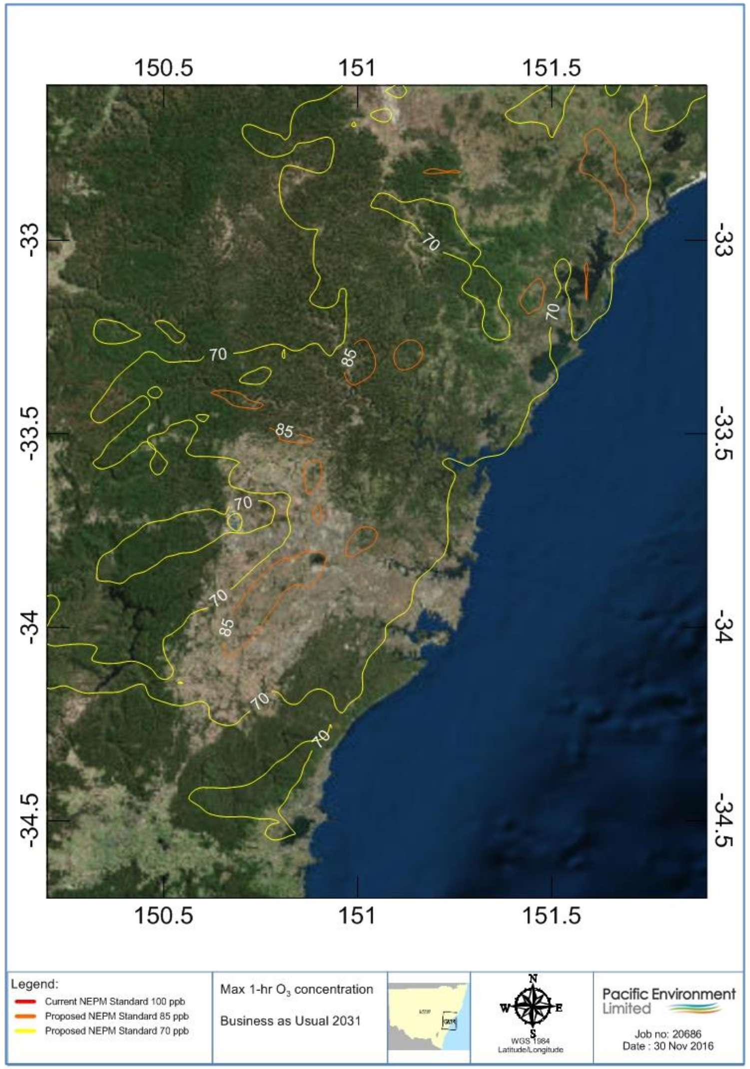

Figure F-9: Maximum 1-hour O_3 concentration - BAU 2031

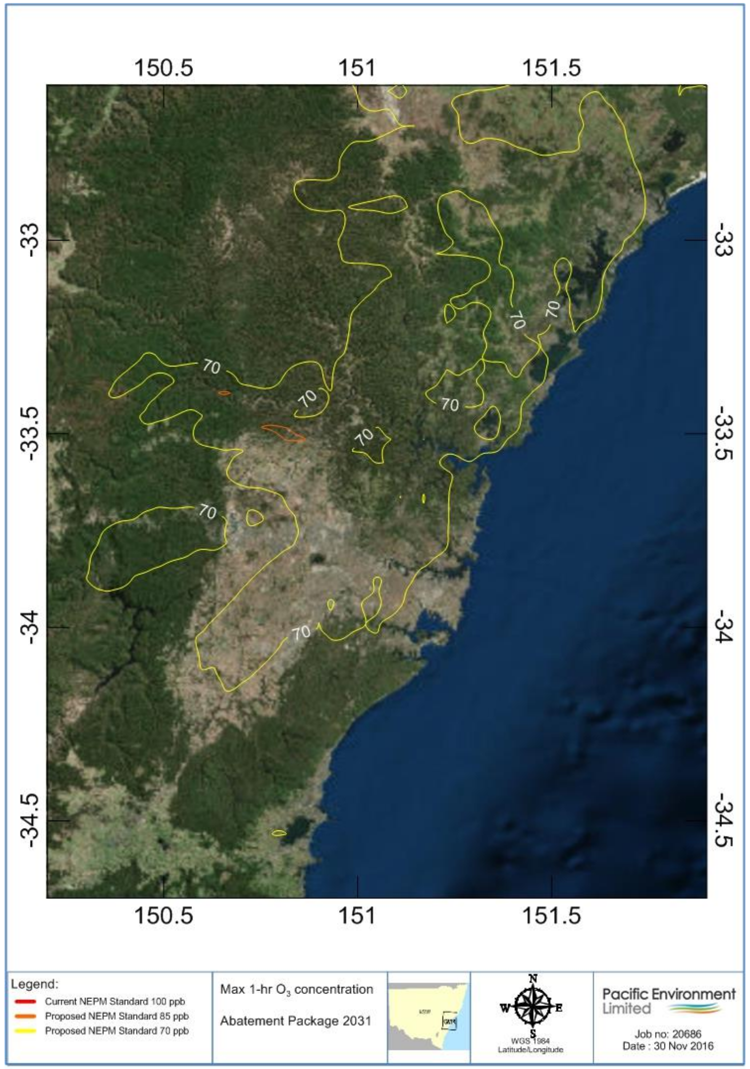

Figure F-10: Maximum 1-hour O_3 concentration - Abatement Package 2031

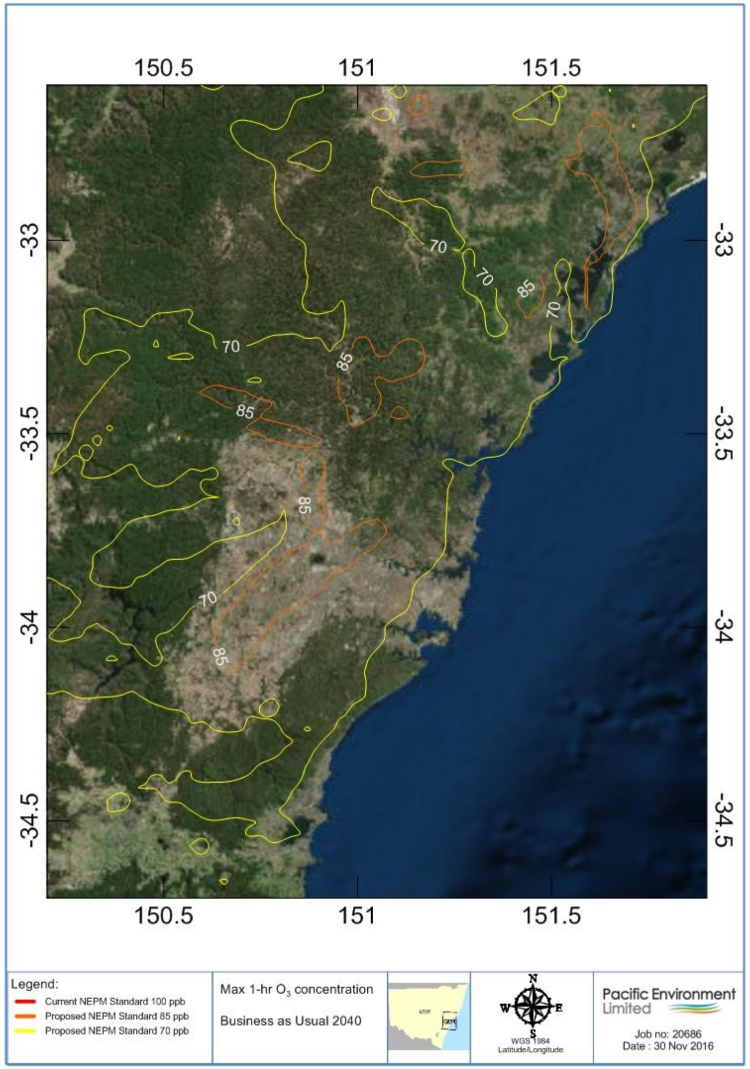

Figure F-11: Maximum 1-hour O_3 concentration - BAU 2040

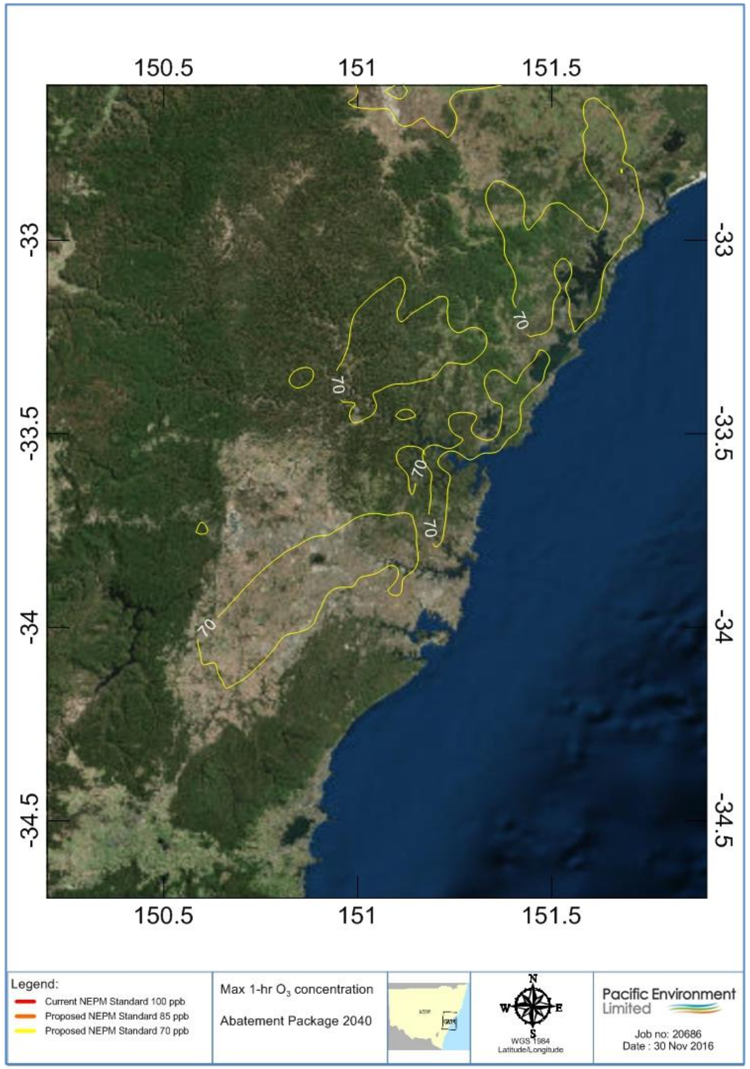

Figure F-12: Maximum 1-hour O_3 concentration - Abatement Package 2040

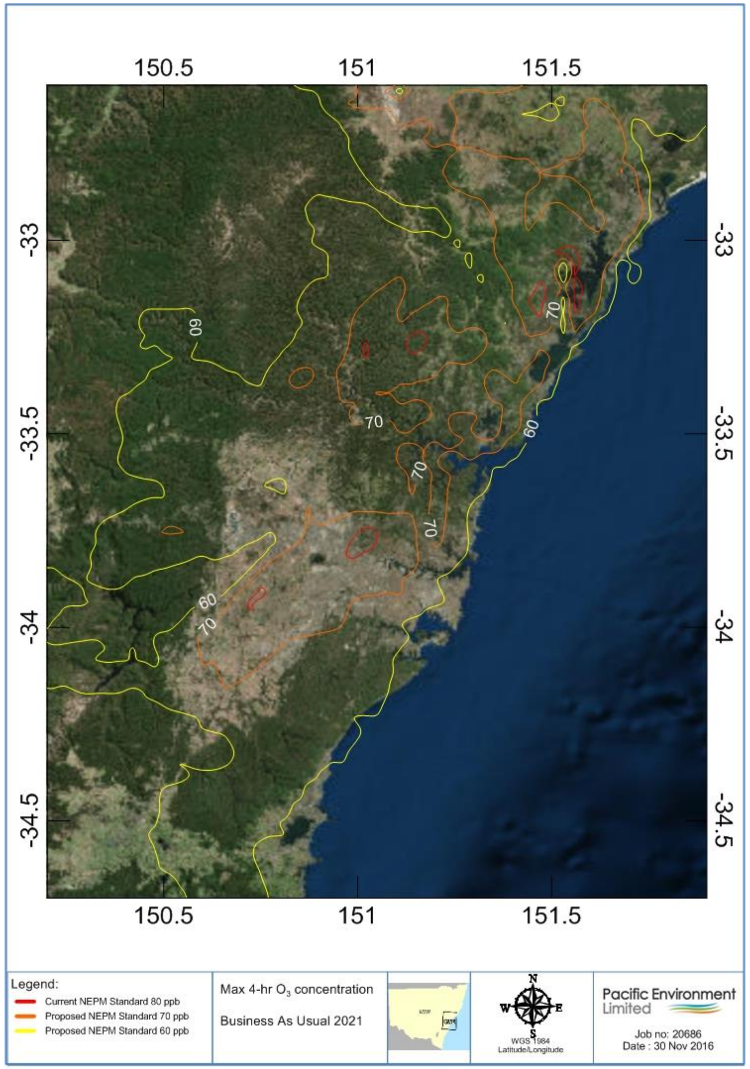

Figure F-13: Maximum 4-hour O_3 concentration - BAU 2021

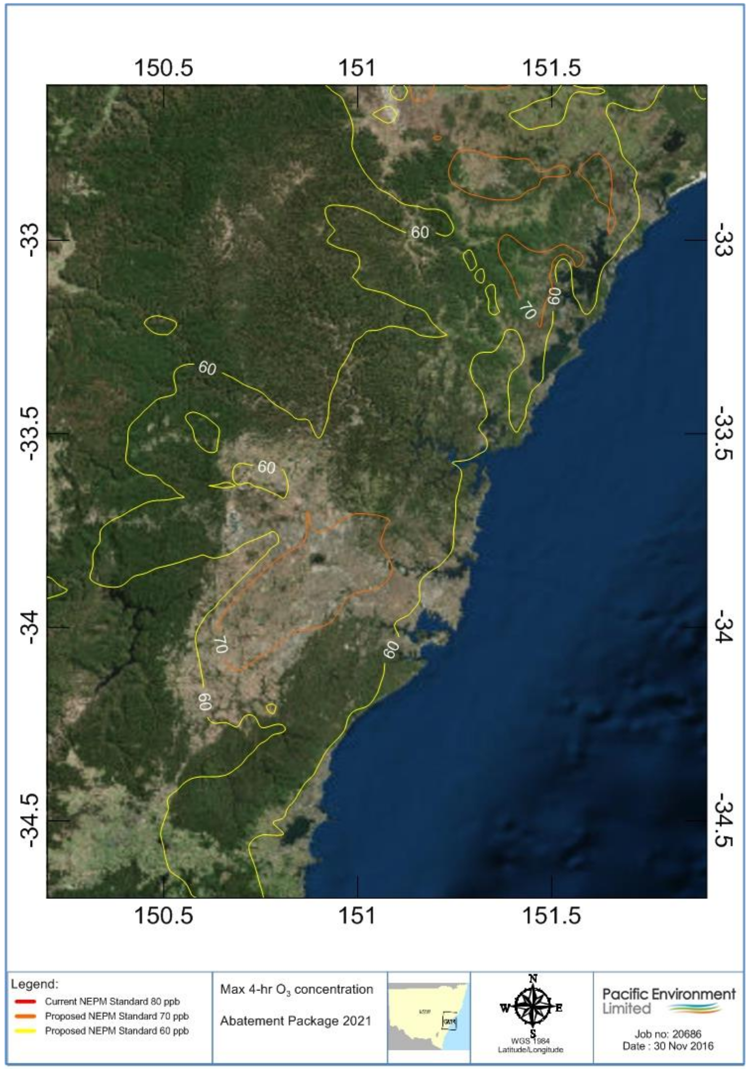

Figure F-14: Maximum 4-hour O_3 concentration - Abatement Package 2021

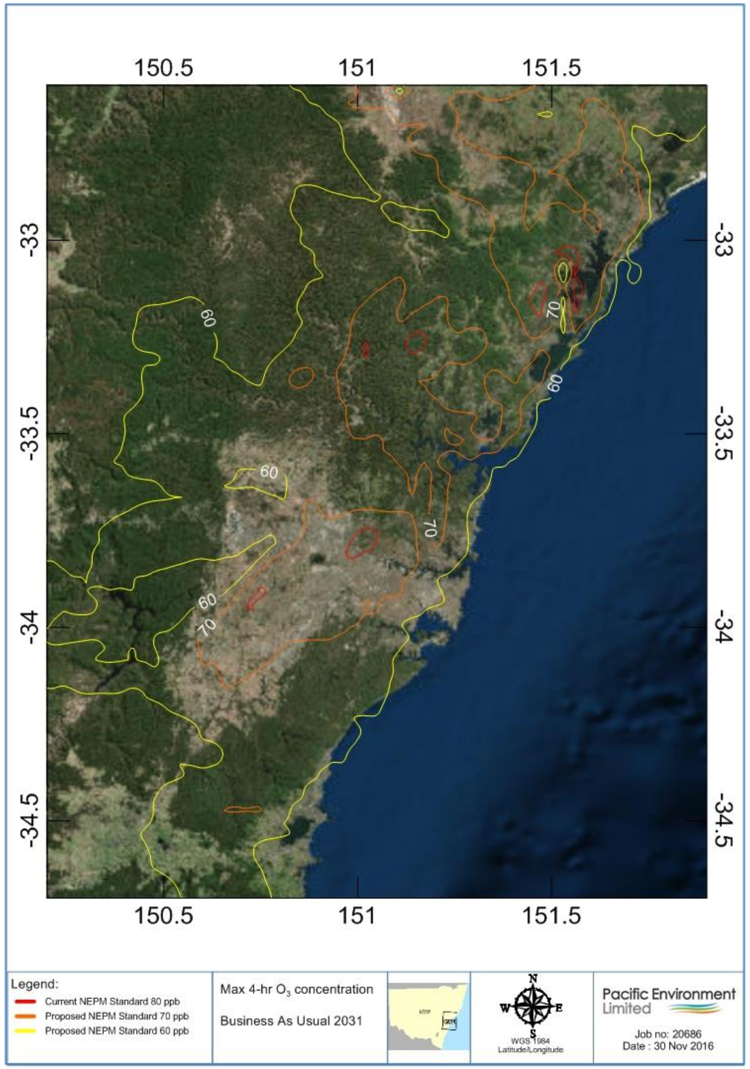

Figure F-15: Maximum 4-hour O_3 concentration - BAU 2031

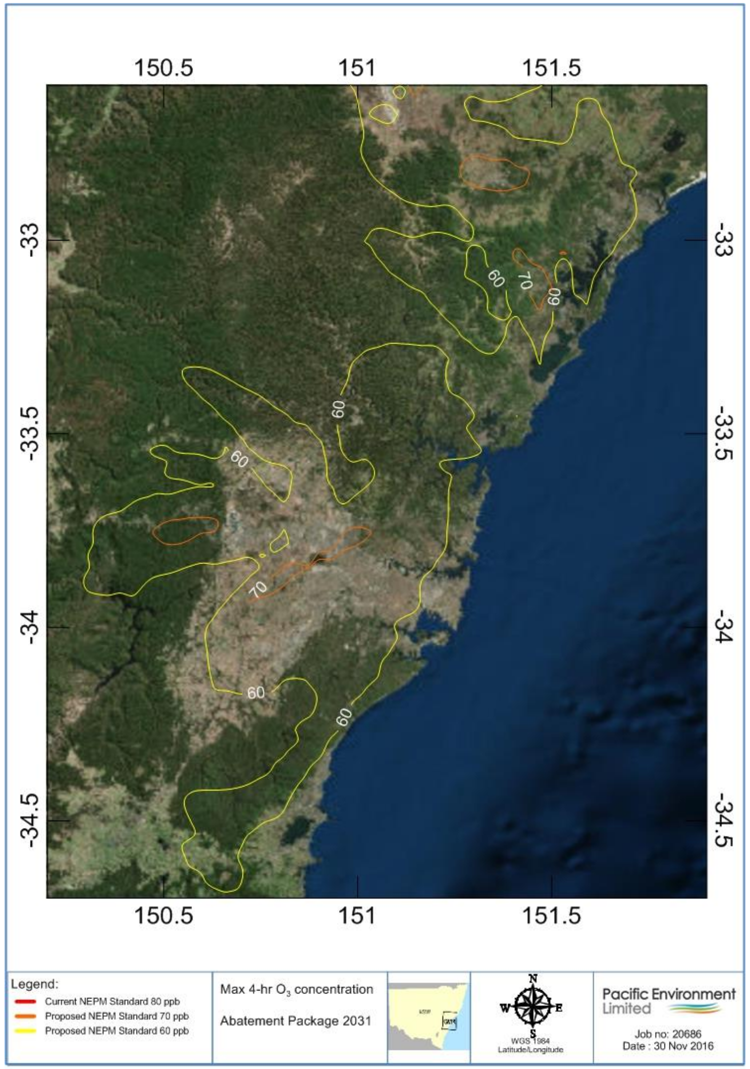

Figure F-16: Maximum 4-hour O_3 concentration - Abatement Package 2031

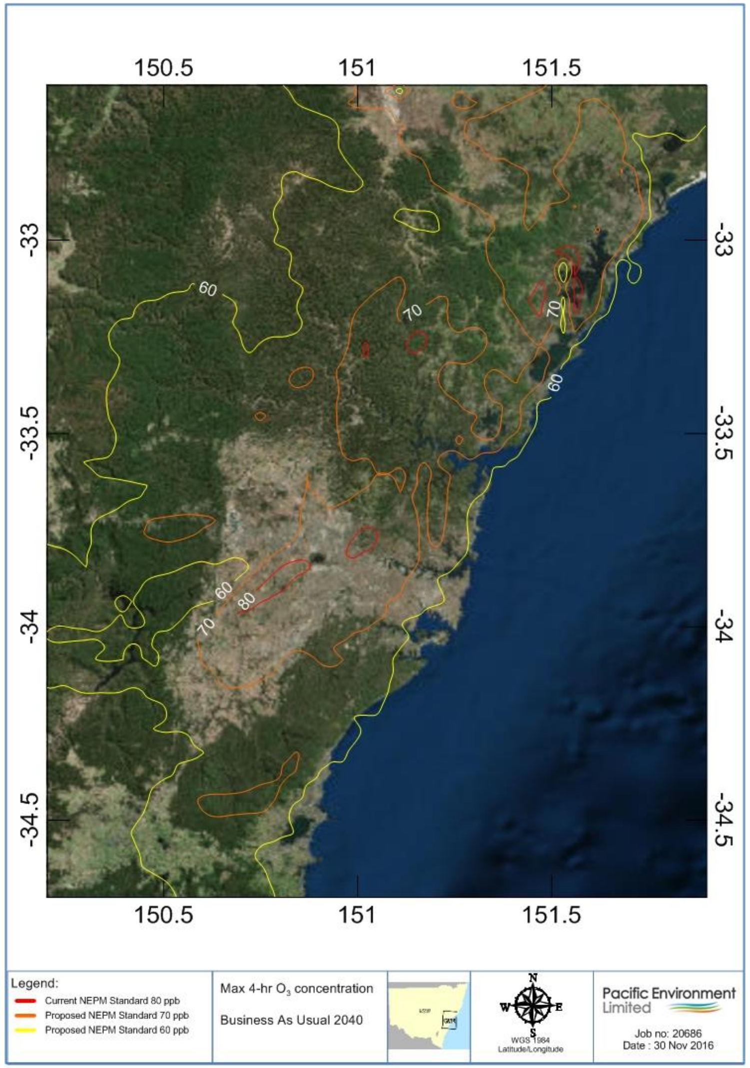

Figure F-17: Maximum 4-hour O_3 concentration - BAU 2040

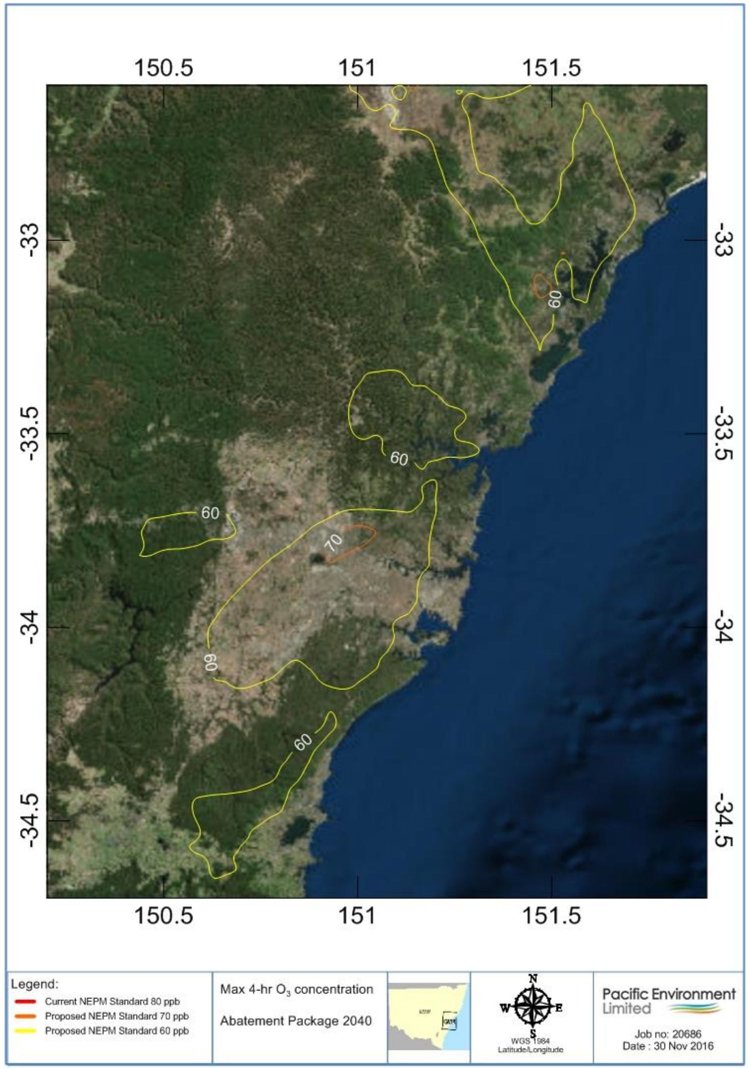

Figure F-18: Maximum 4-hour O_3 concentration - Abatement Package 2040

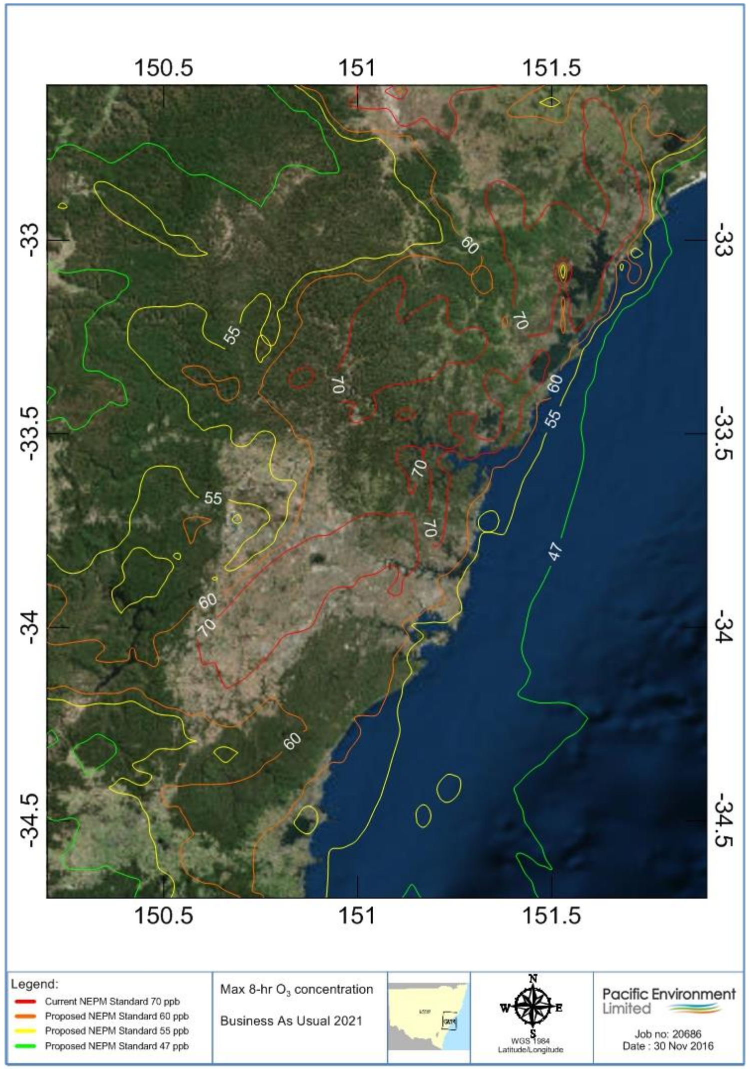

Figure F-19: Maximum 8-hour O_3 concentration - BAU 2021

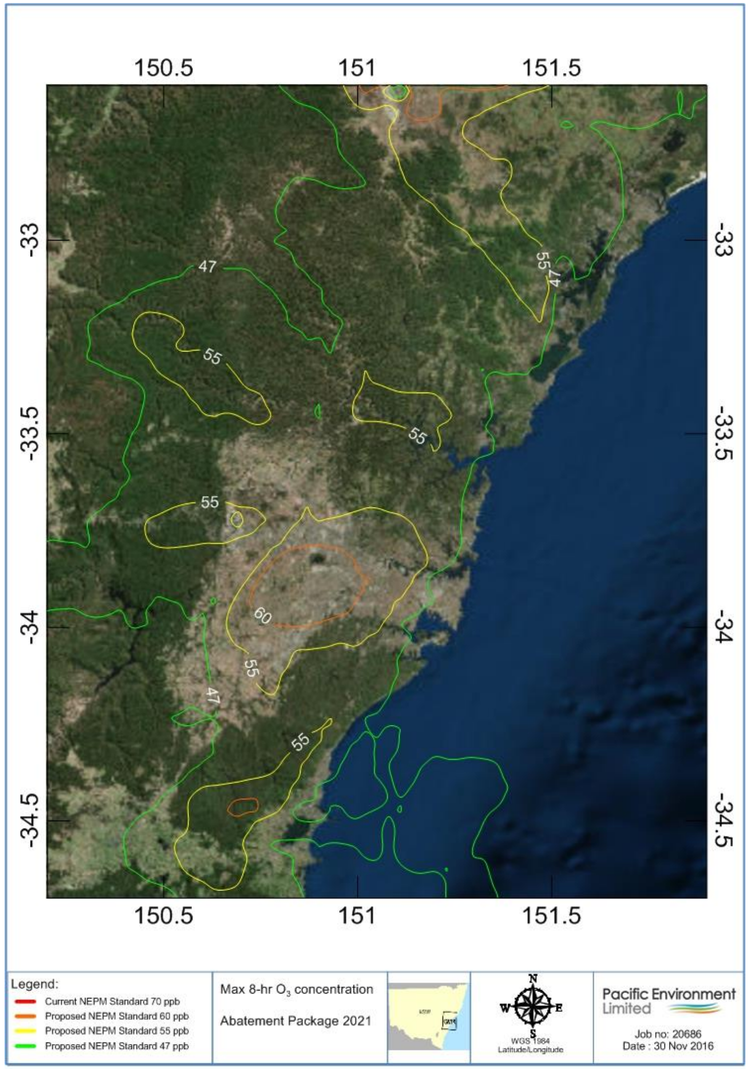

Figure F-20: Maximum 8-hour O_3 concentration - Abatement Package 2021

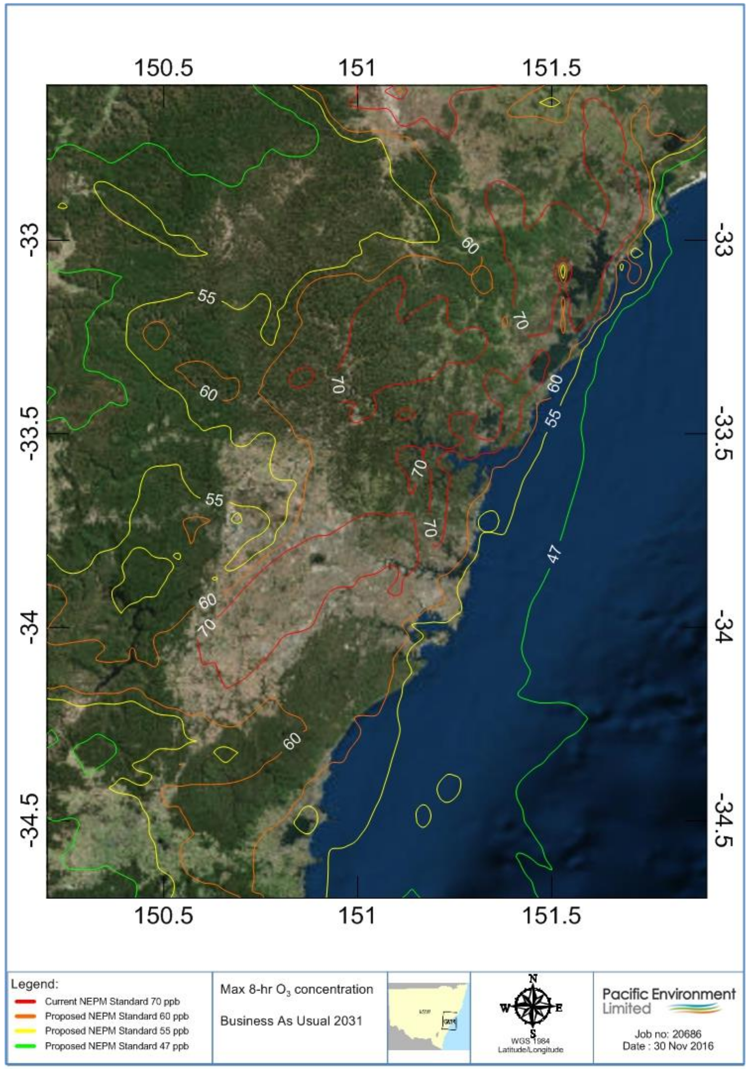

Figure F-21: Maximum 8-hour O_3 concentration - BAU 2031

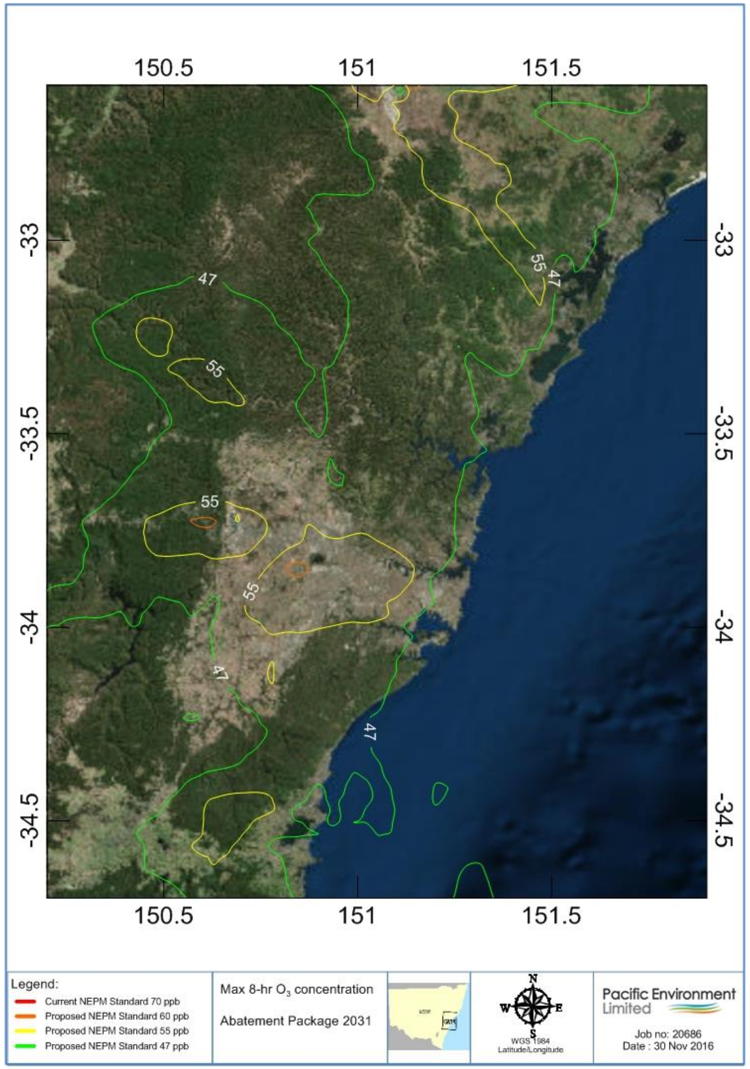

Figure F-22: Maximum 8-hour O_3 concentration - Abatement Package 2031

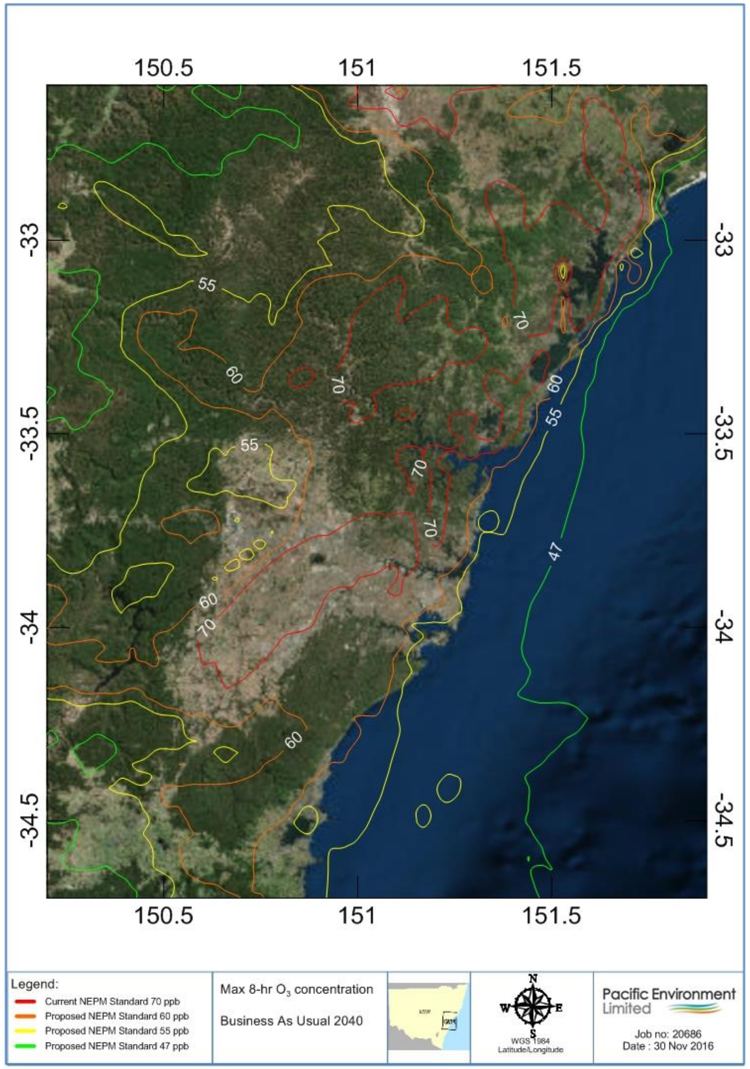

Figure F-23: Maximum 8-hour O_3 concentration - BAU 2040

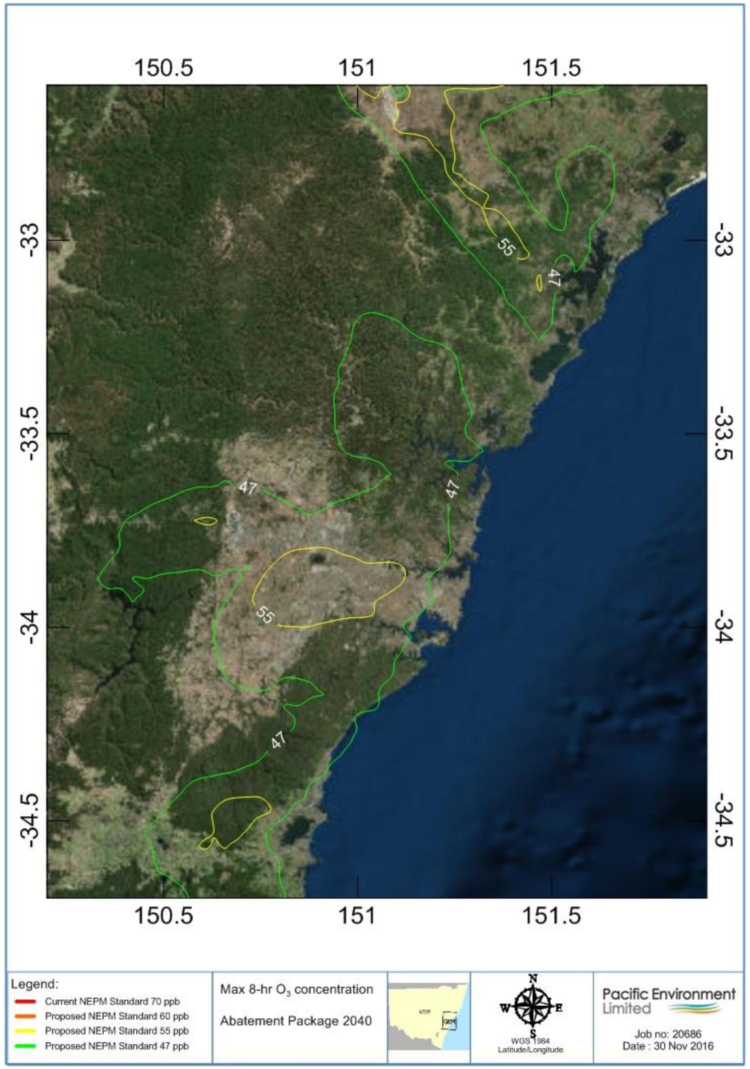

Figure F-24: Maximum 8-hour O_3 concentration - Abatement Package 2040

F.2 Port Phillip Region

The maximum predicted contour plots for the 1-hour, 4-hour and 8-hour average O_3 concentrations are shown in the following Figures:

- Figure F-25: Maximum 1-hour average O_3 concentration – 2021 - BAU
- Figure F-26: Maximum 1-hour average O_3 concentration – 2021 - Abatement Package
- Figure F-27: Maximum 1-hour average O_3 concentration – 2031 - BAU
- Figure F-27: Maximum 1-hour average O_3 concentration – 2031 - Abatement Package
- Figure F-29: Maximum 1-hour average O_3 concentration – 2040 - BAU
- Figure F-30: Maximum 1-hour average O_3 concentration – 2040 - Abatement Package

- Figure F-31: Maximum 4-hour average O_3 concentration – 2021 - BAU
- Figure F-32: Maximum 4-hour average O_3 concentration – 2021 - Abatement Package
- Figure F-33: Maximum 4-hour average O_3 concentration – 2031 - BAU
- Figure F-34: Maximum 4-hour average O_3 concentration – 2031 - Abatement Package
- Figure F-35: Maximum 4-hour average O_3 concentration – 2040 - BAU
- Figure F-36: Maximum 4-hour average O_3 concentration – 2040 - Abatement

- Figure F-37: Maximum 8-hour average O_3 concentration – 2021 - BAU
- Figure F-38: Maximum 8-hour average O_3 concentration – 2021 - Abatement Package
- Figure F-39: Maximum 8-hour average O_3 concentration – 2031 - BAU
- Figure F-40: Maximum 8-hour average O_3 concentration – 2031 - Abatement Package
- Figure F-41: Maximum 8-hour average O_3 concentration – 2040 - BAU
- Figure F-42: Maximum 8-hour average O_3 concentration – 2040 - Abatement Package

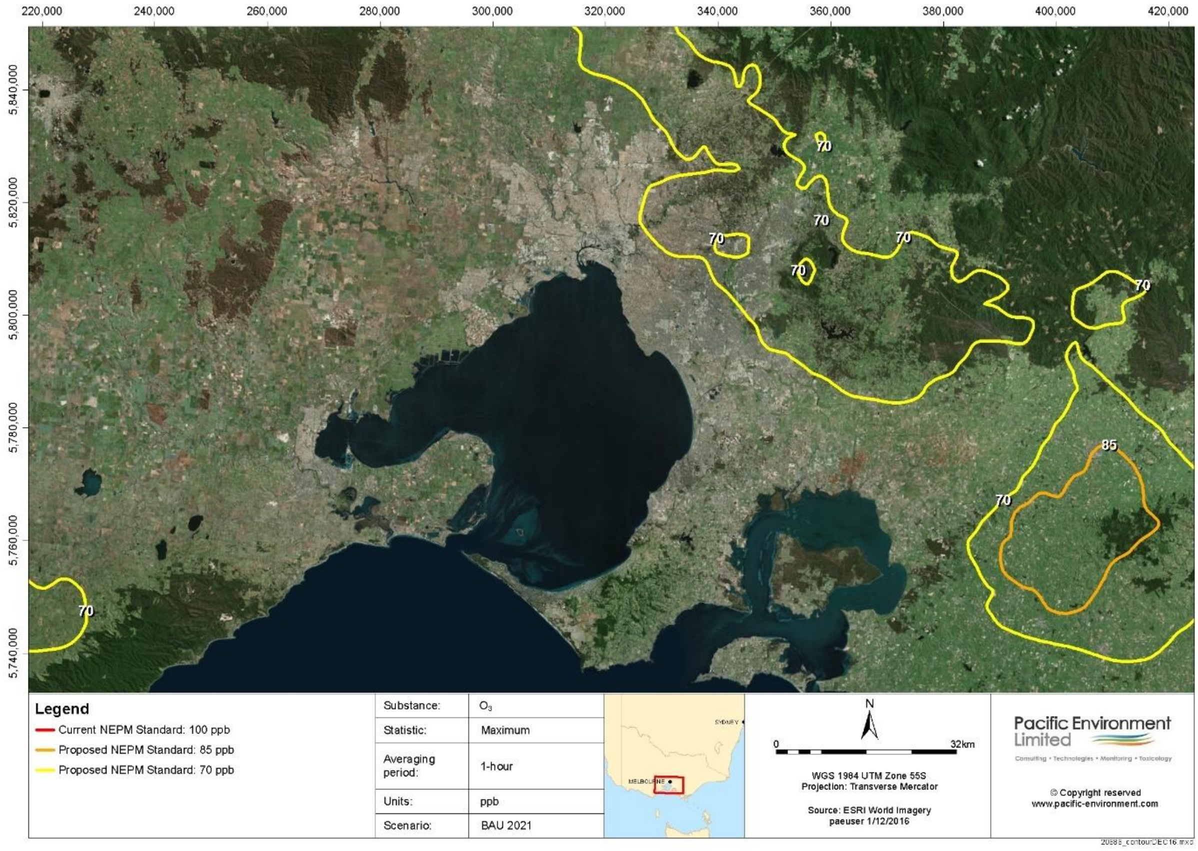

Figure F-25: Maximum 1-hour average O_3 concentration – 2021 - BAU

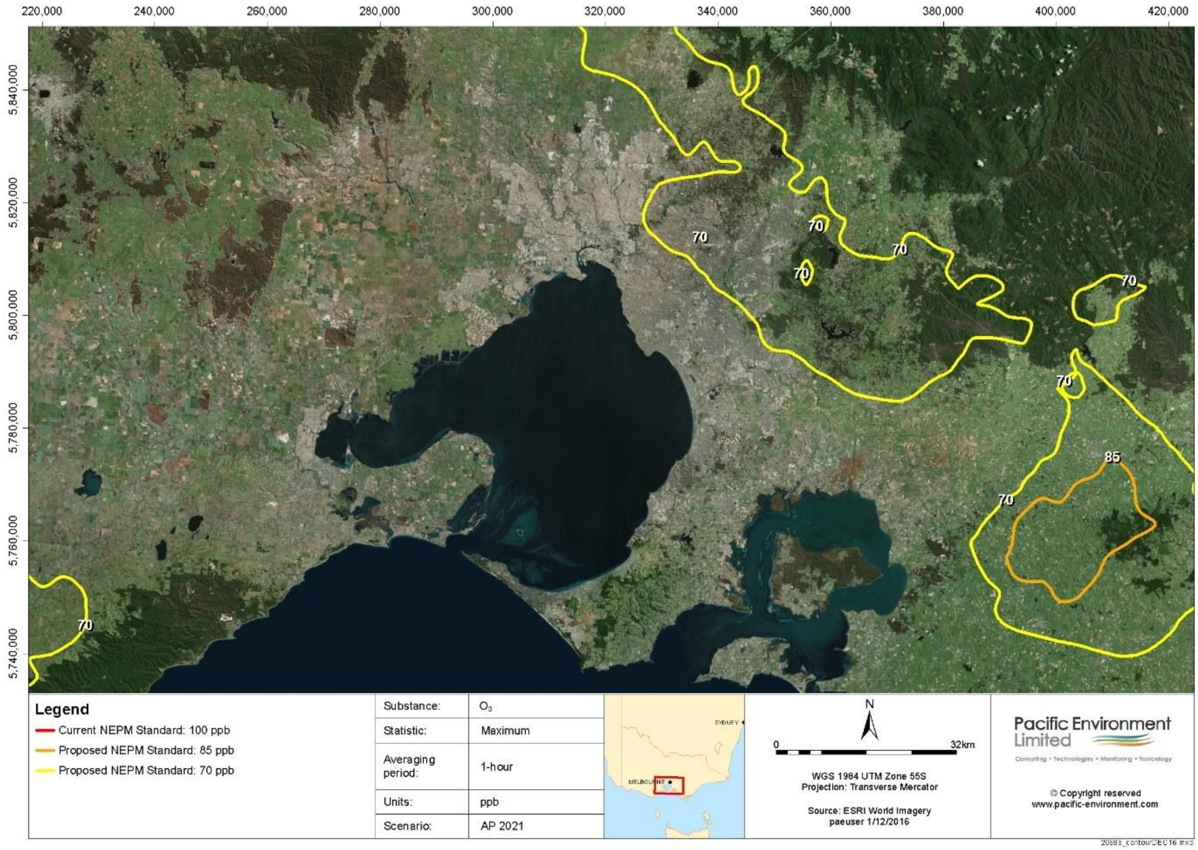

Figure F-26: Maximum 1-hour average O_3 concentration – 2021 - Abatement Package

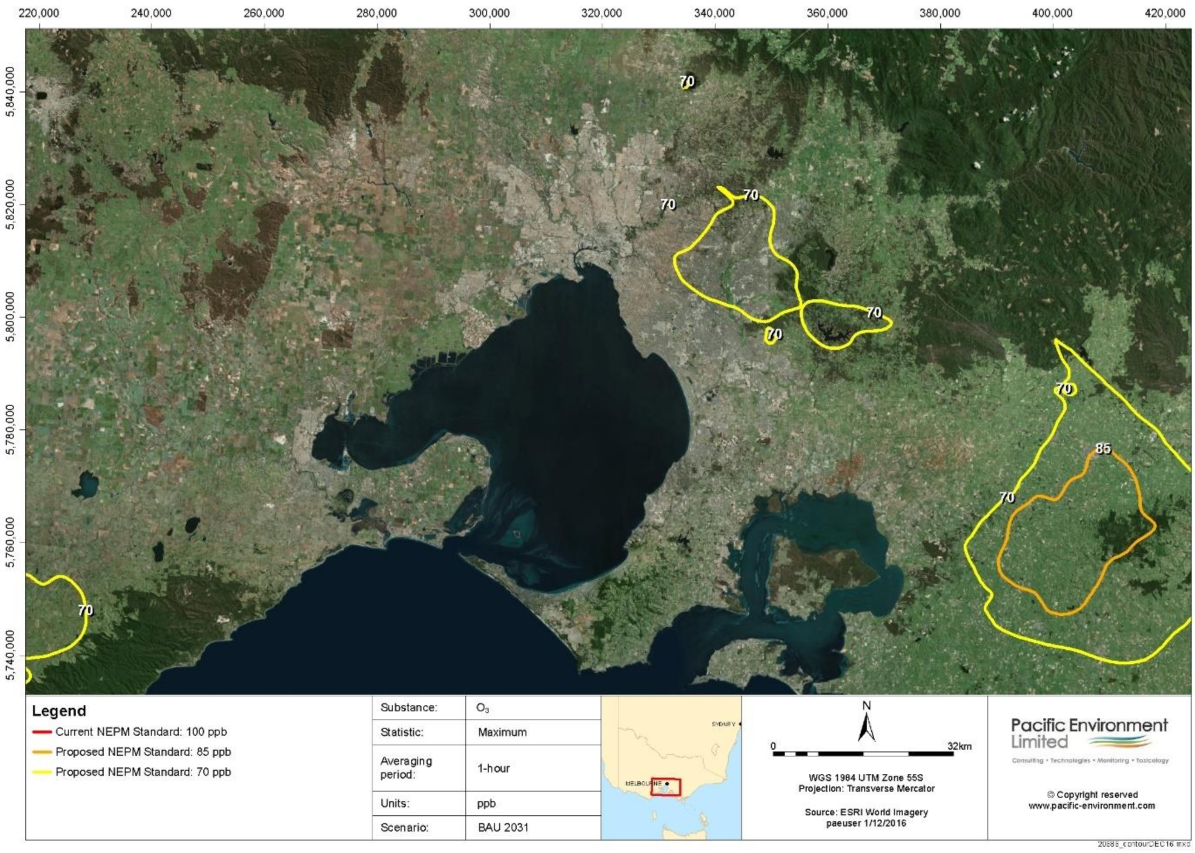

Figure F-27: Maximum 1-hour average O_3 concentration – 2031 - BAU

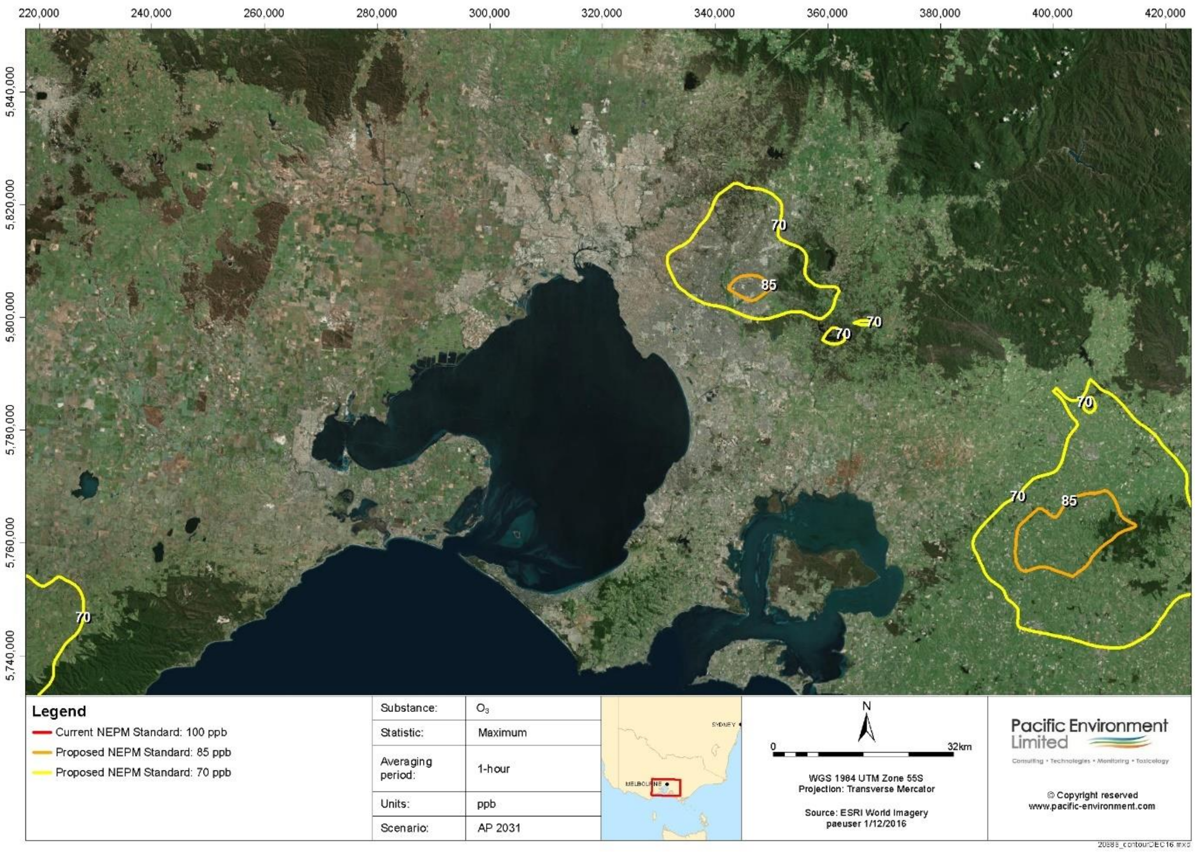

Figure F-28: Maximum 1-hour average O_3 concentration – 2031 - Abatement Package

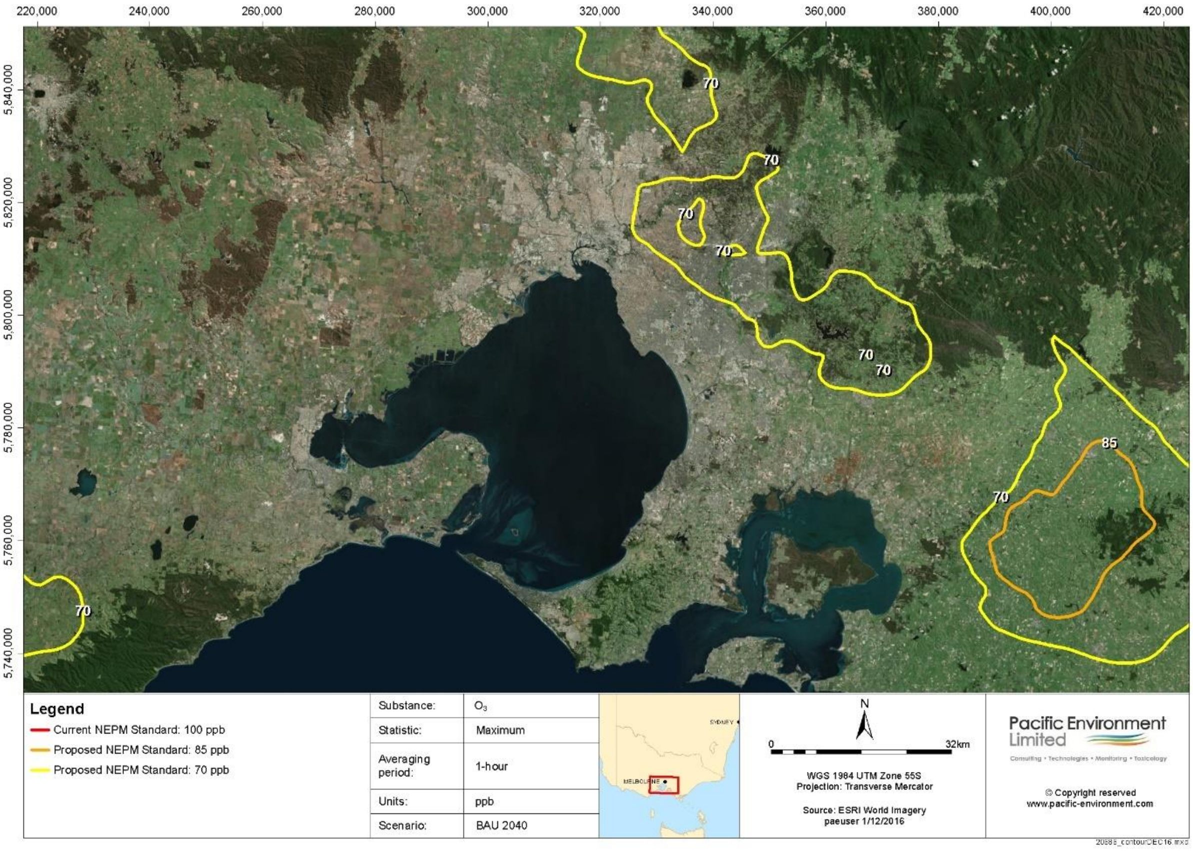

Figure F-29: Maximum 1-hour average O_3 concentration – 2040 - BAU

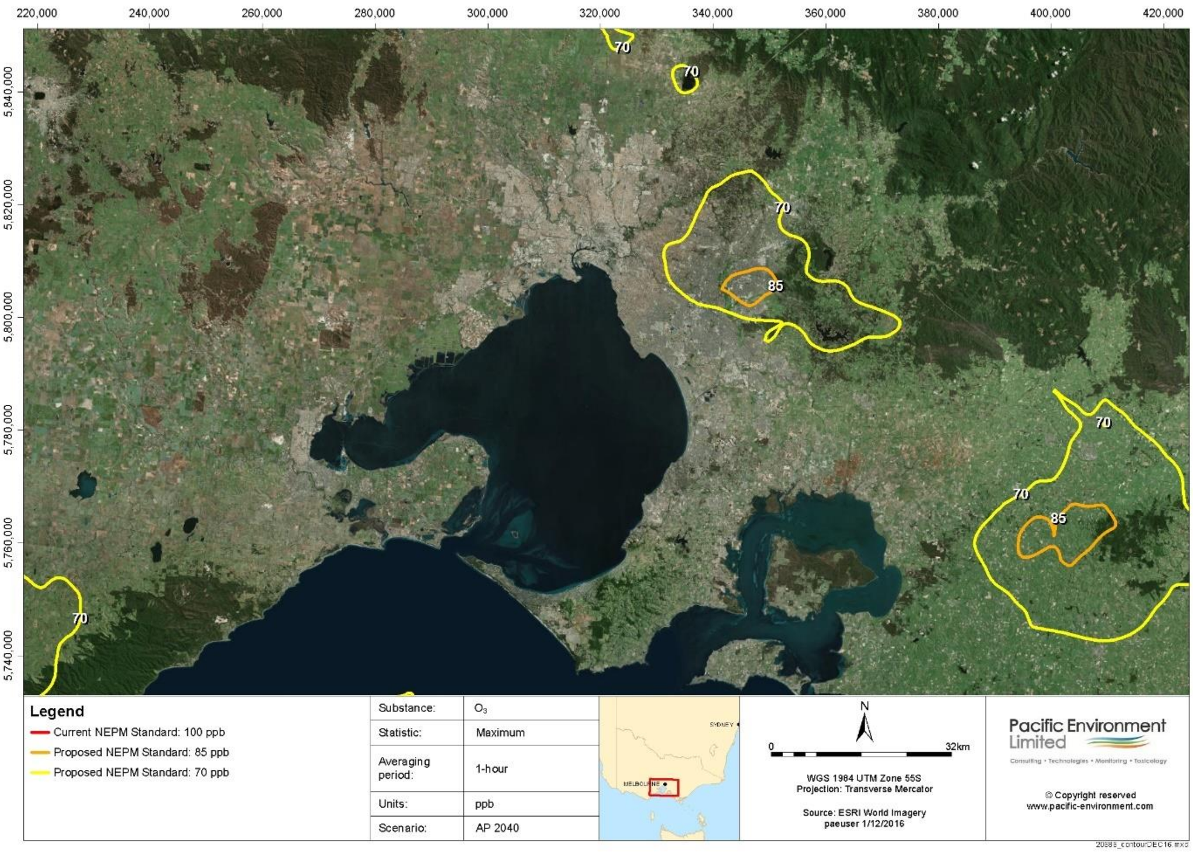

Figure F-30: Maximum 1-hour average O_3 concentration – 2040 - Abatement Package

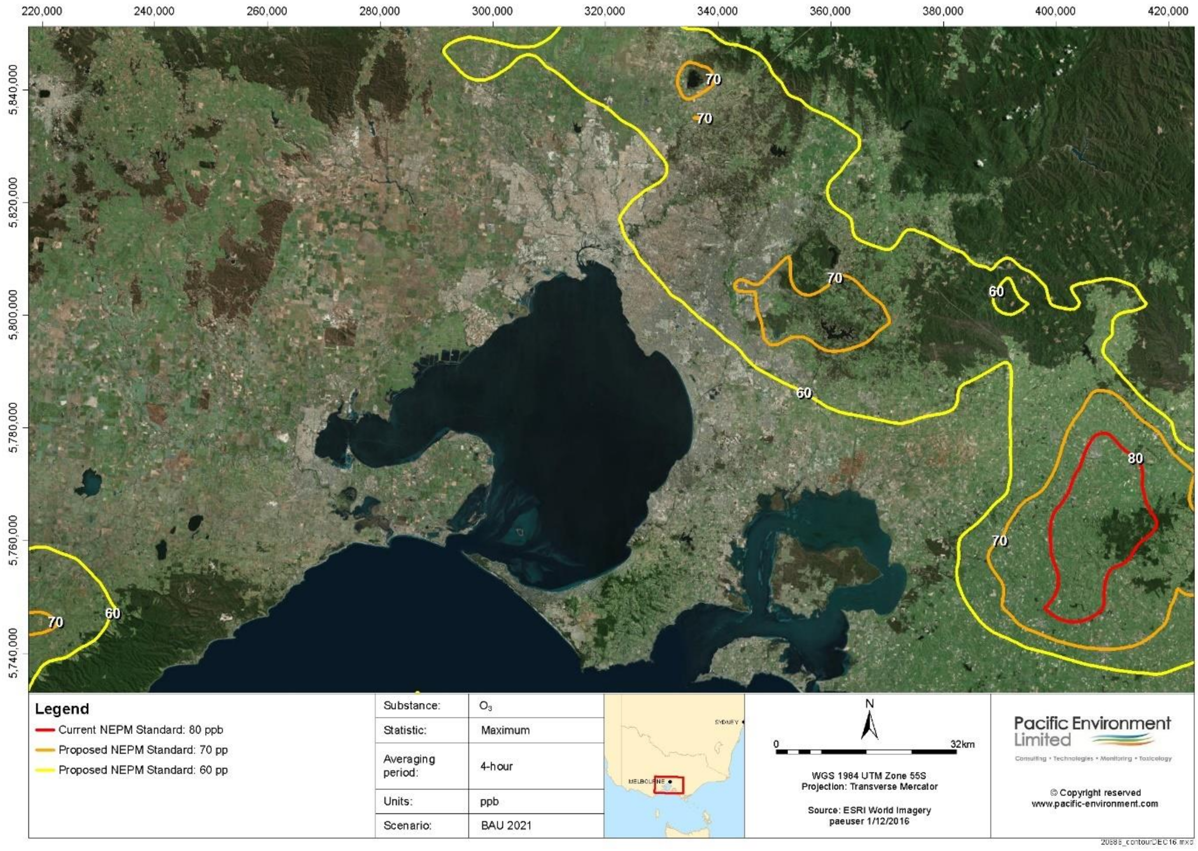

Figure F-31: Maximum 4-hour average O_3 concentration – 2021 - BAU

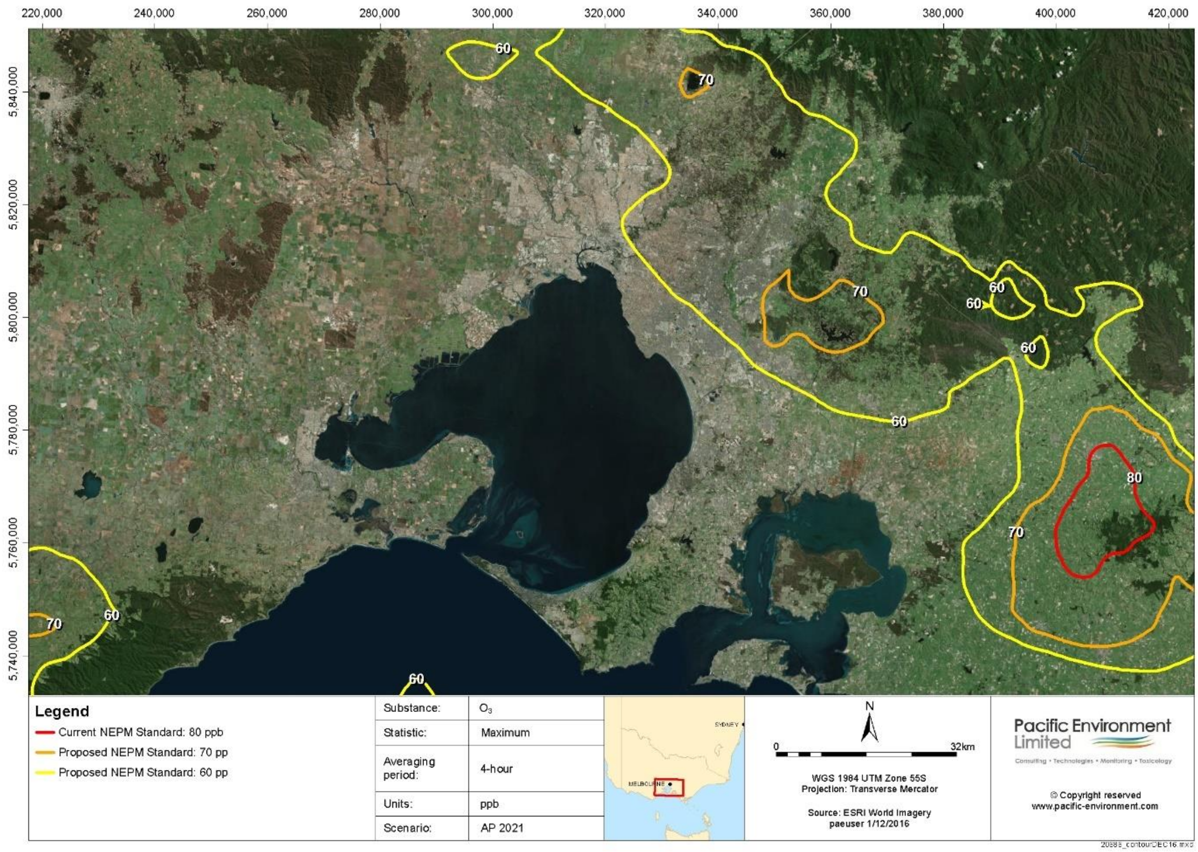

Figure F-32: Maximum 4-hour average O_3 concentration – 2021 - Abatement Package

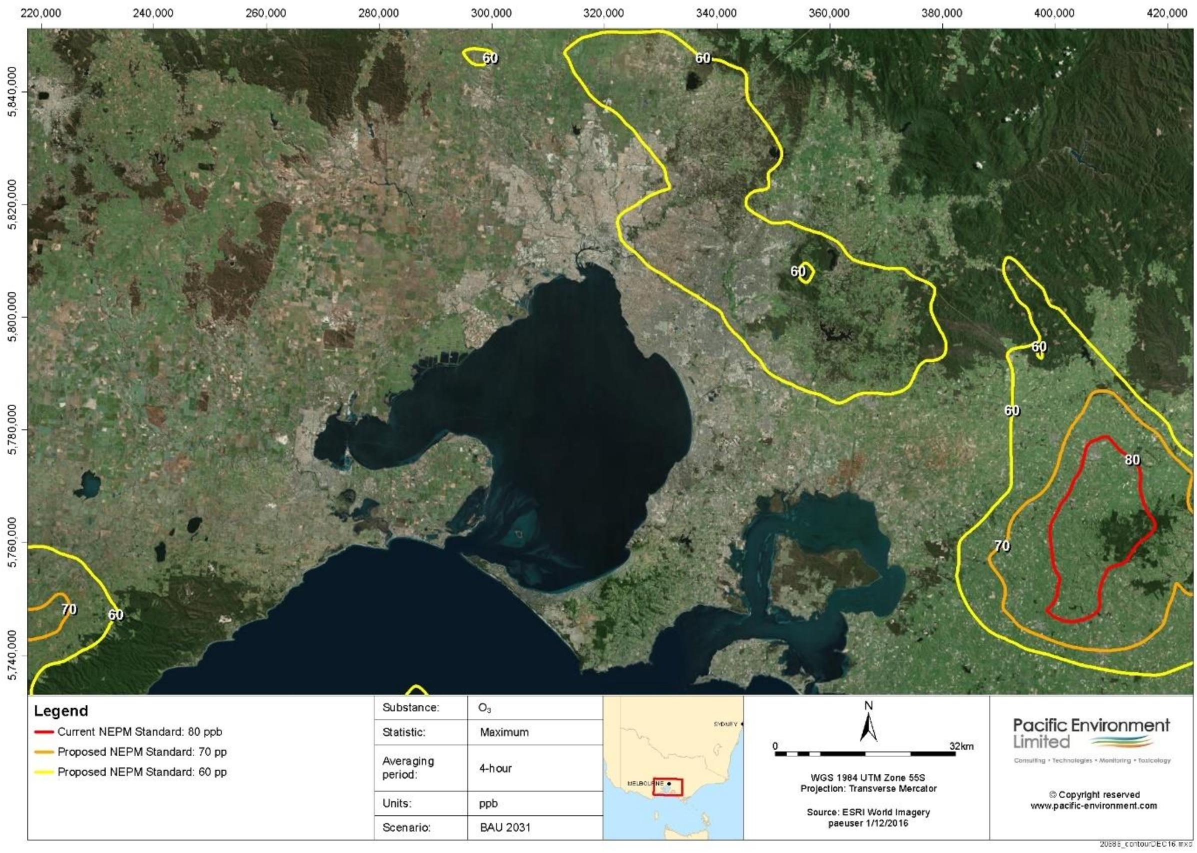

Figure F-33: Maximum 4-hour average O_3 concentration – 2031 - BAU

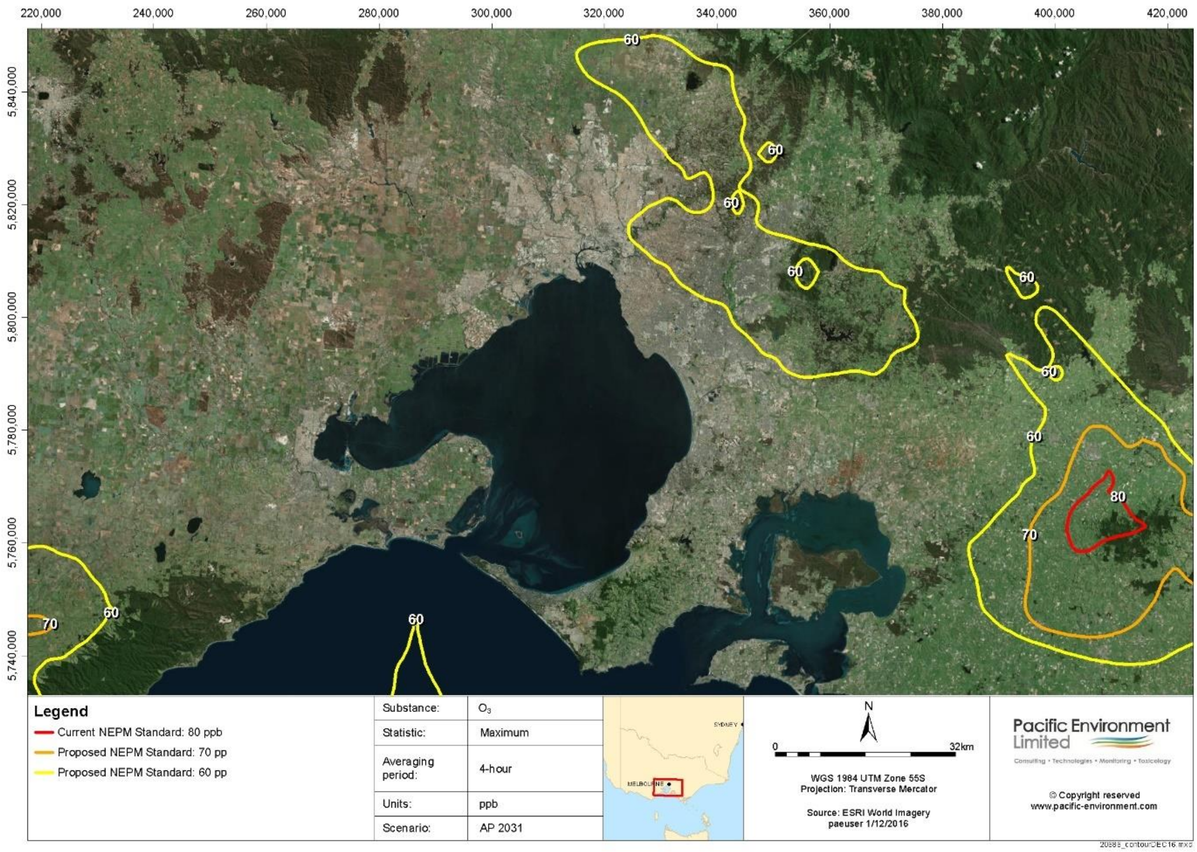

Figure F-34: Maximum 4-hour average O_3 concentration – 2031 - Abatement Package

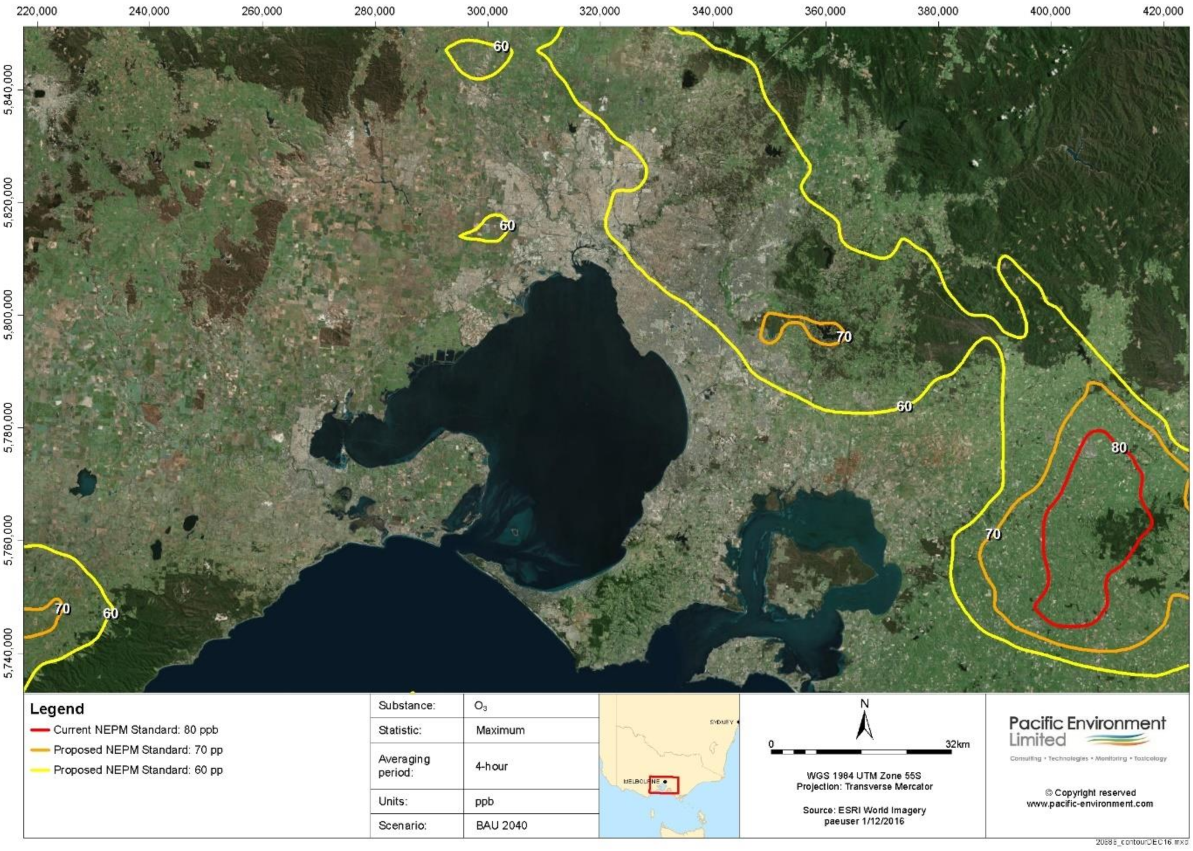

Figure F-35: Maximum 4-hour average O_3 concentration – 2040 - BAU

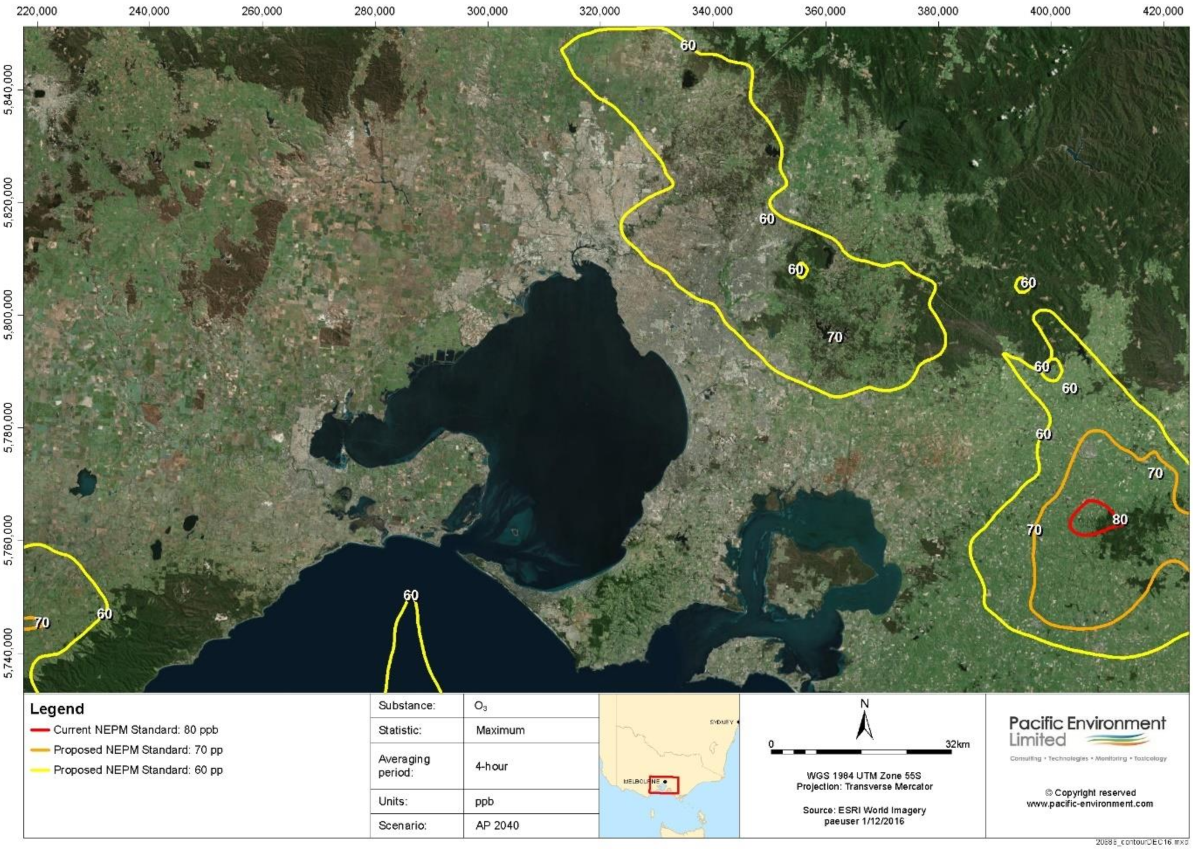

Figure F-36: Maximum 4-hour average O_3 concentration – 2040 - Abatement

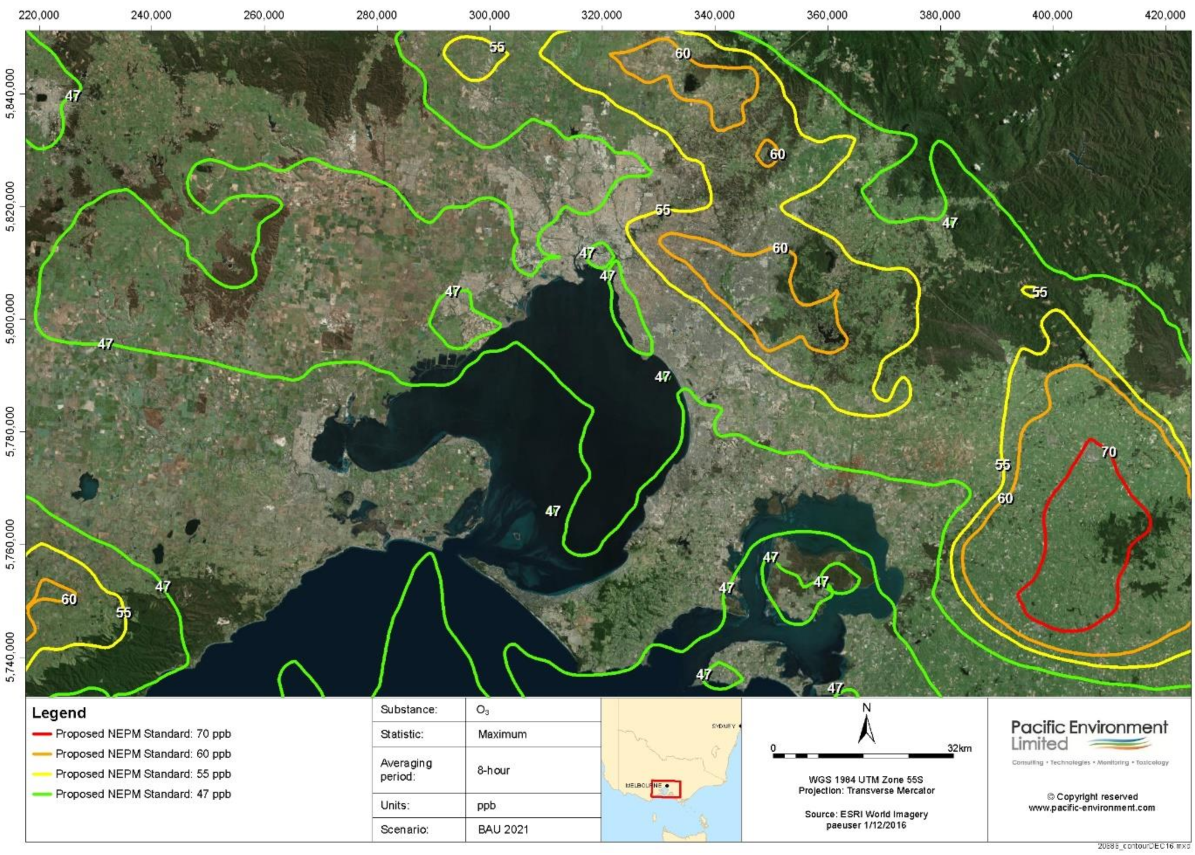

Figure F-37: Maximum 8-hour average O_3 concentration – 2021 - BAU

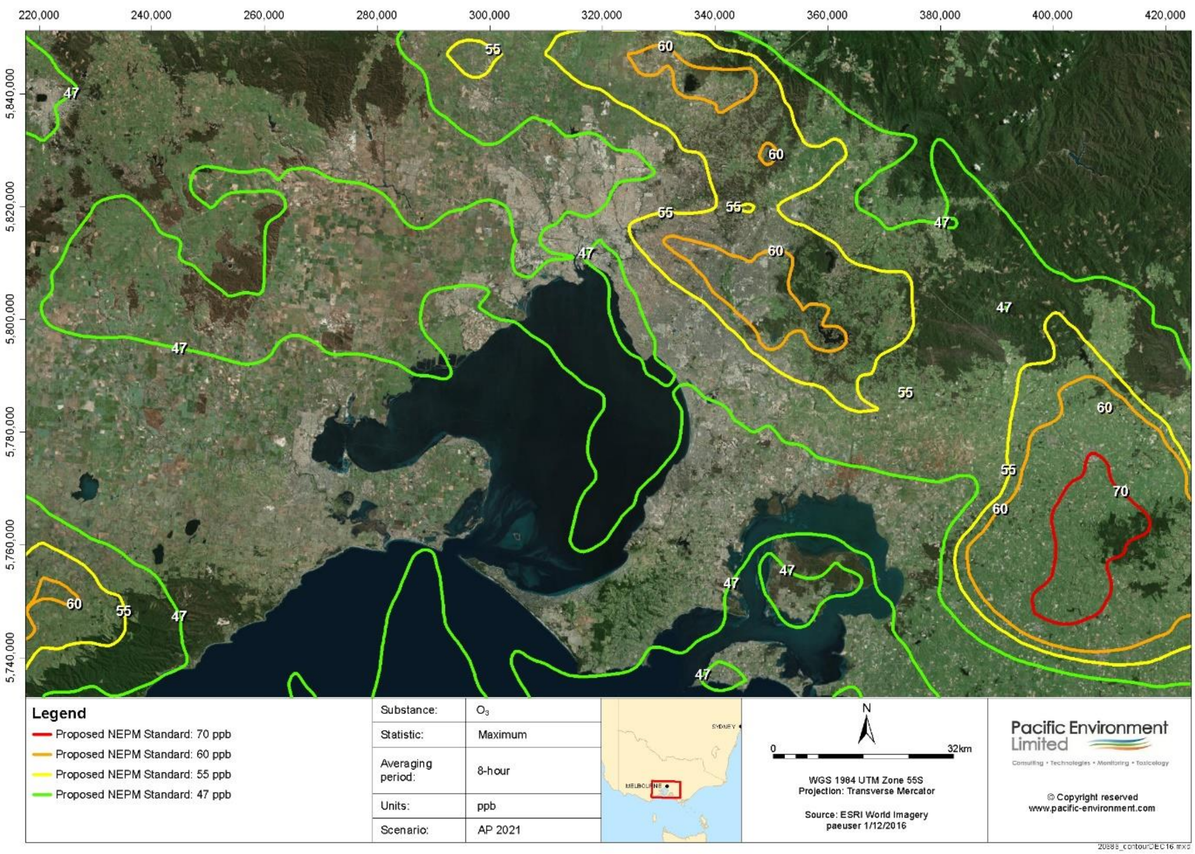

Figure F-38: Maximum 8-hour average O_3 concentration – 2021 - Abatement Package

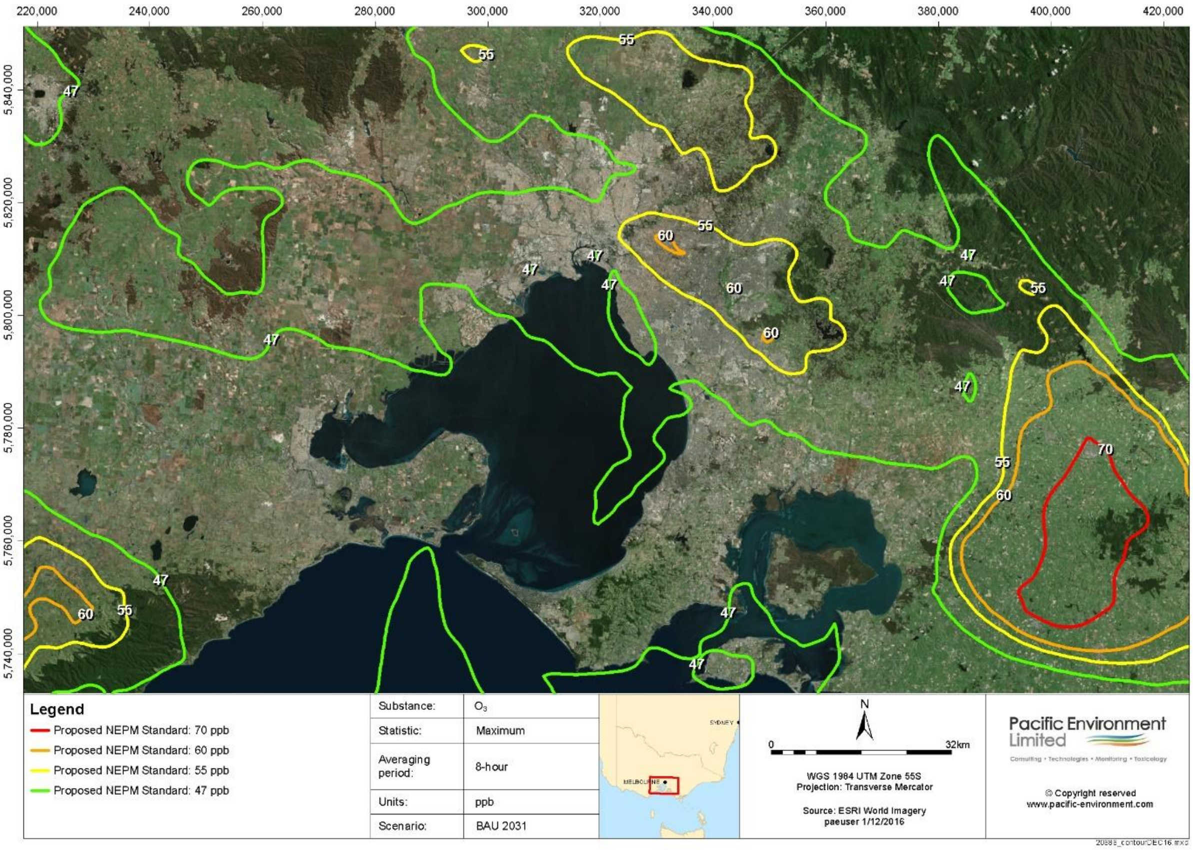

Figure F-39: Maximum 8-hour average O_3 concentration – 2031 - BAU

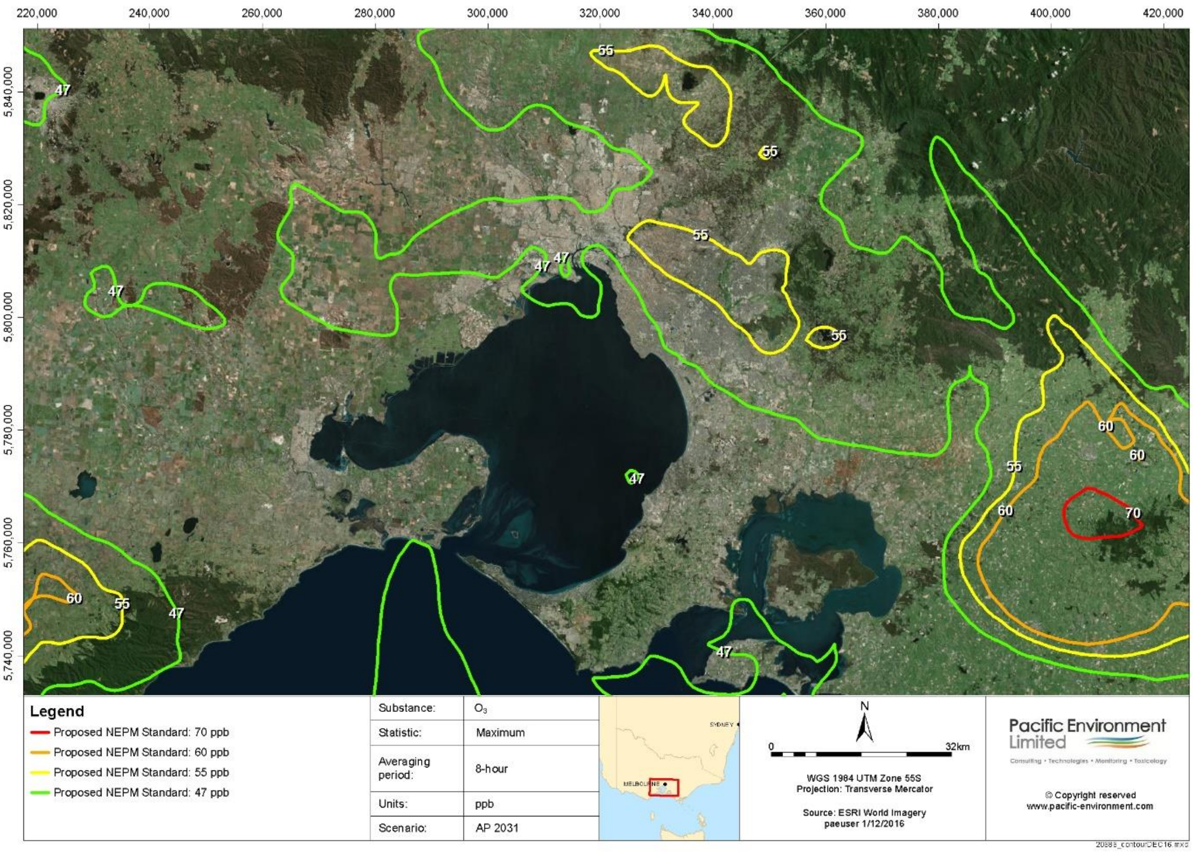

Figure F-40: Maximum 8-hour average O_3 concentration – 2031 - Abatement Package

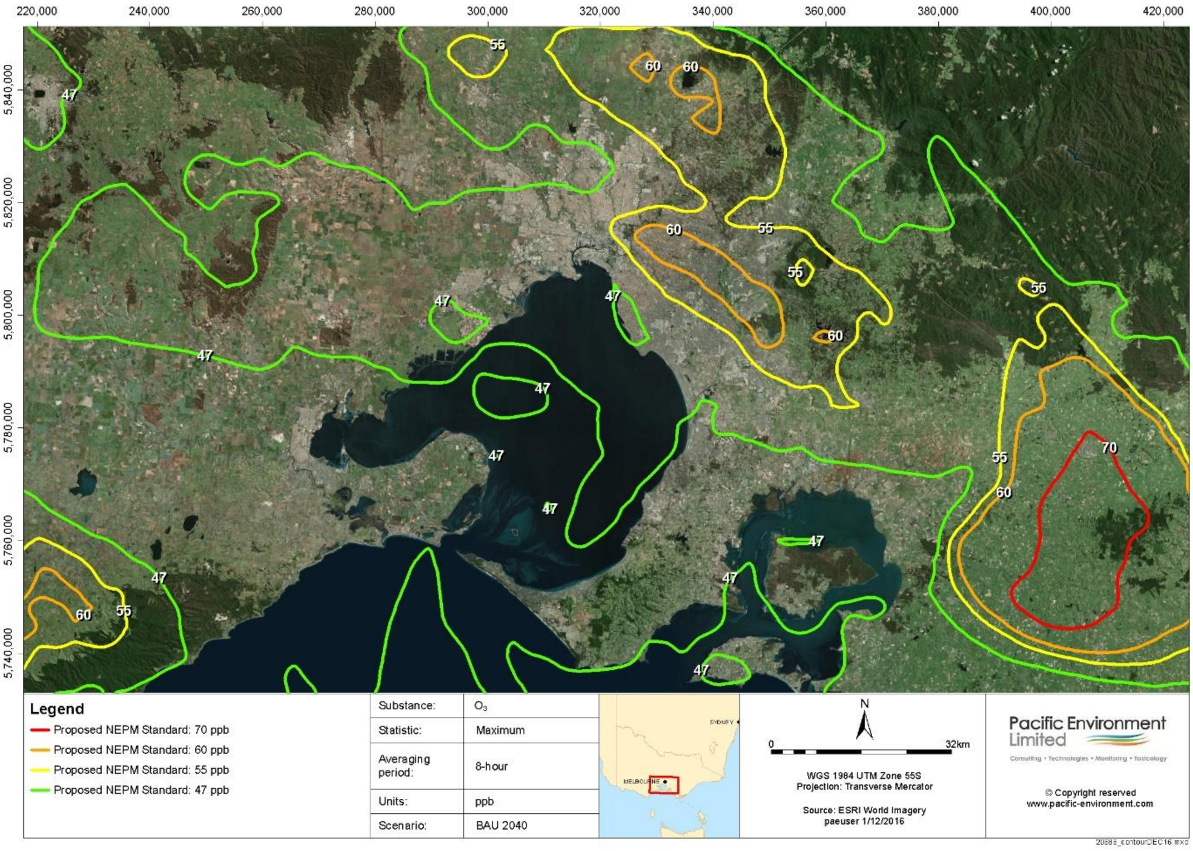

Figure F-41: Maximum 8-hour average O_3 concentration – 2040 - BAU

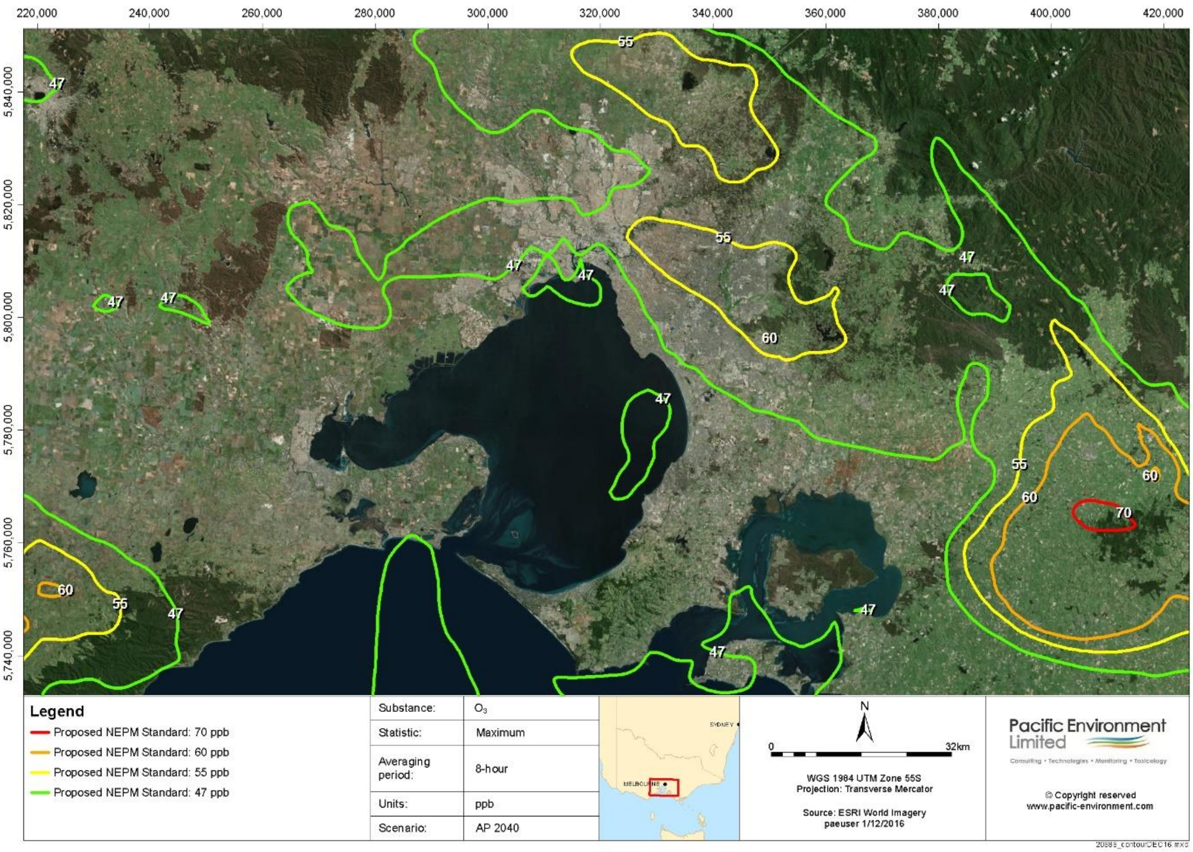

Figure F-42: Maximum 8-hour average O_3 concentration – 2040 – Abatement Package