

**Draft Variation to the National Environment
Protection (Ambient Air Quality) Measure for
sulfur dioxide, nitrogen dioxide and ozone**

Impact Statement

**Prepared for:
National Environment Protection Council**

May 2019

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Executive summary

E.1 Introduction

This Impact Statement has been prepared for the National Environment Protection Council (NEPC) with reference to the requirements of the *National Environment Protection Act 1994* (NEPC Act). It provides information on the sulfur dioxide (SO₂), nitrogen dioxide (NO₂) and ozone (O₃) standards in the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) and options to vary standards. The scope of the Impact Statement was defined largely in terms of the recommendations of the AAQ NEPM review (NEPC 2011a).

The standards in the AAQ NEPM were based on the understanding of the health effects at the time it was introduced (1998). There is now a large body of information that identifies health effects associated with exposure to air pollution at levels below the current AAQ NEPM standards. Even at levels currently experienced in Australian cities, there are strong associations between exposure to NO₂, O₃, and SO₂ and increases in daily mortality and hospital admissions for respiratory and cardiovascular causes. The 2011 AAQ NEPM review concluded there was sufficient evidence to support the review of the standards in the AAQ NEPM.

The Impact Statement collates and analyses the available air quality and health information for these three pollutants in Australia, and considers the feasibility of updating the standards, and the costs and benefits of a range of potential abatement measures that could be introduced to lower concentrations for these pollutants. For each pollutant a number of alternative standards have been considered (NB: for the purpose of this Impact Statement these have been referred to collectively as 'proposed standards'). The preferred options for the standards in this Impact Statement are referred to as 'recommendations' for the standards.

The Impact Statement includes a review of the environmental outcome and goal of the AAQ NEPM, the Australian and international standards, the form of the standards, the treatment of exceptional events, and the need for an exposure-reduction framework.

E.2 General approach

When developing air quality standards a 'weight-of-evidence' approach is typically used. A 'weight-of-evidence' approach comprises decision-making based on a range of available information, logical reasoning and expert judgement. Several broad decision criteria / factors have been considered in the recommendation of the standards for SO₂, NO₂ and O₃. The decision criteria / factors included:

- the averaging periods for SO₂, NO₂ and O₃ in the AAQ NEPM
- the numerical values of the SO₂, NO₂ and O₃ standards
- the form of the SO₂, NO₂ and O₃ standards (e.g. allowed exceedances)
- the adequacy of the health protection afforded by the standards
- the weight of evidence that supports any proposed standards including, for instance, the advice of the World Health Organization (WHO)
- the relevance and achievability of the proposed standards including, for instance, the form of the standards with regards to exceptional events such as bushfires
- any regional environmental differences
- societal costs and benefits of meeting proposed standards
- the options for an exposure-reduction framework for SO₂, NO₂ and O₃.

E.3 Methodology

Overview

In 2011, the NEPC released the *Methodology for Setting Air Quality Standards in Australia* (NEPC 2011b). The approach taken in this Impact Statement was consistent with the standard-setting methodology. Each pollutant was addressed separately, and the main steps were:

- Step 1: Health effects update
- Step 2: Review of international air quality standards
- Step 3: Proposed air quality standards
- Step 4: Analysis of historical air quality
- Step 5: Projections of future air quality
- Step 6: Health risk assessment (HRA).

An overall cost–benefit analysis (CBA) was also conducted. In this, the three pollutants were considered together rather than individually to account for the interactions between pollutants in the Abatement Package scenario.

Step 1: Health effects update

A detailed literature review was conducted to identify any international work that had been undertaken since the AAQ NEPM review report was released, as well as any new epidemiological or toxicological studies that would provide any new evidence to inform the review of the standards for SO₂, NO₂ and O₃.

Step 2: Review of international air quality standards

Since 1998 several countries and agencies have updated their air quality standards for SO₂, NO₂ and O₃ to reflect the current understanding of health effects. The standards currently in force or recommended internationally were reviewed in preparing this report. The WHO guidelines were also considered.

Step 3: Proposed air quality standards

For this Impact Statement, various proposed standards were developed for each pollutant and averaging period as (more stringent) alternatives to the current AAQ NEPM standards. The current and proposed AAQ NEPM standards for SO₂, NO₂ and O₃ are shown in Table E-1.

The proposed standards were identified through a review of international literature and regulations, including the WHO guidelines, the United States Environmental Protection Agency (USEPA) National Ambient Air Quality Standards, and the standards that have been adopted in other leading countries¹. Some specific considerations of this review included the ongoing need for a standard for annual mean SO₂ (which is included in the AAQ NEPM but is not widely used internationally), and the need for a rolling-average 8-hour standard for O₃ (which is used internationally but is not in the AAQ NEPM).

¹ The term 'leading countries' has two meanings in the context of this Impact Statement: 1) Countries that are viewed internationally as leaders in managing air quality, and 2) Countries that have the most stringent standards.

Table E-1: Current and proposed AAQ NEPM standards

Pollutant	Averaging period	Standard concentration (ppb) [current standards in bold]
SO ₂	1-hour	75, 100, 150, 200
	24-hour	7, 20, 40, 80
	Annual	10, 20
NO ₂	1-hour	40, 80, 97, 120
	Annual	10, 19, 30
O ₃	1-hour	70, 85, 100
	Rolling 4-hour	60, 70, 80
	Rolling 8-hour	47, 55, 60, 70

Step 4: Analysis of historical air quality

Air quality monitoring data for the period 2002–2016 were analysed to provide historical context with respect to concentrations of SO₂, NO₂ and O₃ in Australian airsheds, and to contribute to the assessment of achievability of the proposed standards. The analysis 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 identified trends in concentrations and established levels of compliance² with the current and proposed standards in each airshed.

Step 5: Projections of future air quality

This step involved the development of emissions projections (based on ambient monitoring trends, inventories, and population projections), and atmospheric dispersion modelling of the BAU and Abatement Package scenarios. Future projections of air quality were determined for specific years (2016, 2021, 2031 and 2040). The future projections included a 'Business-as-Usual' (BAU) scenario and an 'Abatement Package' scenario, involving the implementation of a single package of emission-reduction measures. The approach used for each jurisdiction was tailored according to the available information, with the most detailed modelling being possible for NSW and Victoria. Pollutant concentrations and exceedances of air quality standards were determined for the projection years in the modelled airsheds.

Step 6: Health risk assessment

Step 6 involved conversion of the predicted concentrations into health outcomes, which were used as inputs to the cost–benefit analysis. The HRA calculated the following:

- the health burden attributable to each of the pollutants under consideration arising from historical concentrations
- the future health burden under both the BAU and Abatement Package scenarios
- the number of health outcomes that would be avoided if the potential standards could be met.

² Where reference is made to 'compliance' in this Impact Statement, 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.

Both long-term (chronic) and short-term (acute) effects on health were considered.

An important part of the HRA was the selection of appropriate concentration-response functions (CRFs). Specific CRFs for Australian studies have been developed (e.g. Jalaludin & Cowie 2012); however, two more recent international projects coordinated by the World Health Organization (WHO) Regional Office for Europe have significantly updated the health evidence and the basis for assessment:

- *Health risks of air pollution in Europe* (HRAPIE) (WHO 2013a)
- *Review of evidence on health aspects of air pollution* (REVIHAAP) (WHO 2013b).

For NO₂ and O₃, the HRAPIE CRFs were considered the most robust available in the literature and incorporated more extensive and more up-to-date information than the Australian CRFs. Some of the CRFs for NO₂ and O₃ from HRAPIE were therefore adopted for this Impact Statement in preference to the ones developed previously for Australia. For SO₂, the CRFs were taken from various sources.

Cost–benefit analysis

A CBA was conducted to provide economic evidence to support the assessment of the proposed standards. The CBA provided estimates for the following:

- the cost of the existing health burden for SO₂, NO₂ and O₃ in present value terms, based on the HRA data for 2010–2014
- the costs and benefits of the Abatement Package scenario over the timeframe 2021–2040.

The abatement measures targeted sources of SO_x, NO_x and volatile organic compound (VOC)³ emissions. The assessment of costs and emission reductions was based on publicly available data. The monetary benefits were estimated based on the health outcomes from the HRA.

The CBA considered the incremental costs and benefits of emission reductions associated with the implementation of the Abatement Package. Costs represented the economic resource costs associated with the implementation of the abatement measures, which included:

- the incremental capital costs associated with upgrades to machinery, plant and equipment
- the incremental operating and maintenance costs
- administrative and compliance costs
- any co-benefits or disbenefits associated with the abatement measures (e.g. changes to fuel consumption, etc.), which offset or increase the costs respectively.

The scope of pollutants was limited to the three gases that are the subject of this Impact Statement (SO₂, NO₂ and O₃) plus PM_{2.5}. The latter was included because some of the abatement measures were expected to reduce PM_{2.5} emissions, and this is expected to deliver substantial benefits to human health because of the strong health evidence on the effects of PM_{2.5}.

E.4 Summary of findings and recommendations

This Impact Statement found there are health effects arising from exposure to O₃, NO₂ and SO₂ in Australian cities at their current concentrations. The associated combined health costs due to mortality and hospitalisation over the period 2010–2014 were of the order of \$562 million to \$2,405 million, depending on

³ VOC emissions were considered here because VOCs are precursors for O₃. O₃ is not emitted directly but is a secondary pollutant formed in the atmosphere by the reaction of NO_x and VOCs in the presence of heat and sunlight.

the choice of CRFs. However, when considering the full CBA, the application of the different CRF groups did not change the overall outcome, which was a negative net present value (NPV) to society.

With the predicted population growth in Australian cities and regional areas, the number of people that are exposed to air pollution will also increase, leading to an increased health burden.

The analysis presented in the Impact Statement shows there are material health benefits associated with meeting the standards that have been proposed for this review. Air quality modelling has shown that some of these standards can be met by 2040. There will be challenges to meet some of the strictest proposed standards for O₃ in many jurisdictions; however, consideration of an exposure-reduction framework, which is focused on reducing the exposure of the population, and thereby reducing the risk to their health, provides a mechanism whereby continual improvements in air quality can be demonstrated even if there are exceedances of the standards.

The Abatement Package scenario modelled as part of this review has been shown to not be cost-effective in achieving reductions in pollutant levels. Consideration should be given to alternative abatements that may achieve a larger impact across whole populations such as those associated with motor vehicles and transport options.

The main recommendations of the Impact Statement with respect to the AAQ NEPM are summarised in Table E-4.

Table E-4: Recommendations from the Impact Statement

Number	Recommendation
Desired environmental outcome and goal	
1	The desired environmental outcome of the AAQ NEPM should be revised to 'minimise the risk of adverse health impacts from exposure to air pollution for all people, wherever they may live'.
2	The goal of the AAQ NEPM should be revised to make reference to the air quality standards and incorporation of exposure-reduction targets for priority pollutants.
Sulfur dioxide	
3	The status quo should be maintained of not including a 10-minute SO ₂ standard in the AAQ NEPM.
4	The 1-hour standard for SO ₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 100 ppb.
5	A future 1-hour SO ₂ standard of 75 ppb is recommended for implementation from 2025 (this timeframe is consistent with the goals for PM _{2.5} in the AAQ NEPM).
6	The 24-hour standard for SO ₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 20 ppb.
7	No future target for 24-hour average SO ₂ concentrations is recommended at this stage.
8	The current annual mean standard for SO ₂ should be removed from the AAQ NEPM.
9	The form of both the 1-hour and 24-hour SO ₂ standards should be the maximum value with no allowable exceedances.
Nitrogen dioxide	
10	The 1-hour standard for NO ₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 90 ppb.
11	The annual standard for NO ₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 19 ppb.
12	The form of both the 1-hour and annual NO ₂ standards should be the maximum value with no allowable exceedances.
13	An exposure-reduction framework, in the form of a long-term goal for NO ₂ , should be established to reduce population exposure and associated health risk.
14	A future 1-hour NO ₂ standard of 80 ppb is recommended for implementation from 2025 as part of an exposure-reduction framework (this timeframe is consistent with the goals for PM _{2.5} in the AAQ NEPM).

Number	Recommendation
15	A future annual NO ₂ standard of 15 ppb is recommended for implementation from 2025 as part of an exposure-reduction framework (this timeframe is consistent with the goals for PM _{2.5} in the AAQ NEPM).
16	Jurisdictions should also commence annual reporting on population exposure to NO ₂ from the commencement of a varied AAQ NEPM.
Ozone	
17	The current 1-hour and 4-hour standards for O ₃ should be removed from the AAQ NEPM.
18	Jurisdictions should continue to record and report 1-hour O ₃ concentrations.
19	A rolling 8-hour standard for O ₃ in the AAQ NEPM should be introduced, and the numerical value of the standard should be 65 ppb.
20	The 8-hour standard should be reviewed in 2025, with the option of reducing it once there is a better understanding of O ₃ generation in capital city airsheds.
21	The form of the 8-hour standard for O ₃ should be the maximum value with no allowable exceedances (excluding exceptional events).
22	An exceptional event rule should be implemented for O ₃ , defined in a way that is consistent with the approach for PM ₁₀ and PM _{2.5} in the AAQ NEPM.
23	An exposure-reduction framework, in the form of a long-term goal for O ₃ , should be considered to reduce population exposure and associated health risk once there is a better understanding of O ₃ generation in capital city airsheds.
24	Jurisdictions should commence annual reporting on population exposure to O ₃ from the commencement of a varied AAQ NEPM.

E.5 Consultation

Stakeholder input is being sought on the options outlined in the Impact Statement. Consultation questions are included at the end of each chapter and at the end of Chapter 12, to assist stakeholders to provide input; however, feedback on other aspects of the Impact Statement and its appendices is also welcome.

All submissions are public documents unless clearly marked 'confidential' and may be made available to other interested parties, including by being published on the NEPC website. Stakeholders should indicate if their submission is confidential or clearly indicate sections that may contain confidential or sensitive information that is not for publication.

Feedback received during the public comment period will be used to inform the development of the NEPM variation.

The *National Environment Protection Council Act 1994* requires that both the draft AAQ NEPM variation and the Impact Statement be made available for public consultation for a period of at least two months. The consultation period will occur over an 11-week period from May to August 2019. The views of stakeholders on these documents are being sought through written and online submissions.

Online submissions are preferred and can be made via: nepc@environment.gov.au

Written submissions may also be made and sent to:

Adam Carlon, NEPC Executive Officer
National Environment Protection Council
Department of the Environment and Energy
GPO Box 787
CANBERRA ACT 2601

Email: nepc@environment.gov.au

The closing date for submissions is Wednesday 7 August 2019.

Following the public consultation period, the NEPC is required to prepare a summary of the issues raised in the stakeholder submissions and responses. In deciding whether or not to make the NEPM variation, the NEPC must take both the Impact Statement and the summary of submissions and responses into account.

Abbreviations and acronyms

Abbreviation/acronym	Definition
AAQ	ambient air quality
ACT	Australian Capital Territory
Air TOG	Air Thematic Oversight Group
APMG	Air Project Management Group
BAU	Business-as-Usual (scenario)
BCR	benefit:cost ratio
CBA	cost–benefit analysis
CCAM	Conformal-Cubic Atmospheric Model
CCAM-CTM	Conformal-Cubic Atmospheric Model - Chemistry Transport Model
CO	carbon monoxide
COPD	chronic obstructive pulmonary disease
CTM	Chemistry Transport Model
EPA Victoria	Environment Protection Authority Victoria
EU	European Union
GMR	Greater Metropolitan Region
HRA	health risk assessment
MCA	multi-criteria analysis
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
NO ₂	nitrogen dioxide
NO _x	nitrogen oxides
NPI	National Pollutant Inventory
NPV	Net present value
NSW	New South Wales
NSW EPA	New South Wales Environment Protection Authority
NT	Northern Territory
O ₃	ozone
OBVR	on-board vapour recovery
Pb	lead
PM	particulate matter
ppb	parts per billion
ppm	parts per million
Qld	Queensland
SA	South Australia
SO ₂	sulfur dioxide
SO _x	sulfur oxides

Abbreviation/acronym	Definition
TAPM	The Air Pollution Model
TAPM-CTM	The Air Pollution Model - Chemical Transport Model
TAS	Tasmania
USEPA	United States Environmental Protection Agency
VIC	Victoria
VOC	volatile organic compound
WA	Western Australia
WHO	World Health Organization
µg	microgram
µm	micrometre

Glossary

Term	Definition
Air quality standard	An air quality standard relates to the concentration of an air pollutant in ambient air. A standard is usually designed to protect human health, but may relate to other adverse effects such as damage to buildings and vegetation. A standard is typically defined as a concentration limit (a numerical value) for a given averaging period (e.g. annual mean, 24-hour mean), and a 'form', which defines how it is implemented (e.g. some exceedances may be permitted). Several different averaging periods may be used for the same pollutant to address long-term and short-term exposure. A standard may also be combined with a goal, such as a requirement for the limit to be achieved by a specified date
Airshed	An airshed is a part of the atmosphere that behaves in a coherent way with respect to the dispersion of emissions.
Ambient air	The external air environment. Does not include the air environment inside buildings or structures.
Ambient air quality	The state of quality and chemical characteristics of air as it exists in the environment.
Anthropogenic sources	Sources derived from human activities, as opposed to those occurring in biophysical environments without human influence.
Area source	Area sources are two-dimensional. They are typically used to express: 1) clusters of point or line sources; 2) ground-level emissions from industrial processes having numerous vents; 3) ground-level emissions from stockpiles or ponds; 4) individual facilities or activities of area sources grouped with like facilities or activities into broad source categories so that releases can be collectively estimated using one methodology.
Background concentration	The existing concentration of a pollutant in the ambient air. Different background concentrations can be defined, such as a 'natural' background (at locations that are far from population centres) and an 'urban' background (at locations in population centres that are not near any specific emission sources but are affected by general pollution from the urban area).
Biogenic	Produced by living organisms or biological processes.
Concentration	The amount of a gaseous pollutant in ambient air, which can be stated in terms of either volume (e.g. parts per billion – ppb) or mass (e.g. micrograms per cubic metre – µg/m ³).
Dispersion modelling	Modelling by computer to mathematically simulate the effect on plume dispersion under varying atmospheric conditions; used to calculate spatial and temporal fields of concentrations and particle deposition due to emissions from various source types.

Term	Definition
Emissions	Release of pollutants to air.
Emission factor	A ratio that relates the release of a pollutant to a measure of activity that can be readily measured (such as the amount of raw material processed or the amount of fuel used).
Exceptional events	The setting of air quality standards recognises that certain events can lead to high concentrations, but these are unpredictable and uncontrollable. Examples include extreme meteorological conditions and bushfires. Control programs that are designed to meet the standards during extreme conditions can be prohibitively expensive or technically unfeasible.
Exposure-reduction framework	An exposure-reduction framework is designed for use, in addition to standards, to reduce population exposure to a pollutant. Exposure-reduction frameworks are used in some jurisdictions to account for the fact that some pollutants have no threshold for health effects, and any reduction in concentrations will lead to a health benefit.
National Environment Protection Measure (NEPM)	Legislation designed to protect and manage particular aspects of the environment, established under the <i>National Environment Protection Act 1994</i> ('NEPC Act').
Percentile	A value on a scale that indicates the percent of a distribution that is equal to it or below it. For example, a score at the 95th percentile is equal to or better than 95 per cent of the scores.
Photochemical model	A model which simulates the changes of pollutant concentrations in the atmosphere using both chemical and physical processes in the atmosphere.
Point source	Point sources are stacks, vents, or other discrete points of pollution release. Typically, these emissions are associated with combustion or process release points from the operating facility. It is usually possible to measure the releases from point sources and records of emissions are often available for these sources.

Conversion of concentration units

Concentrations of gaseous pollutants in air, and similarly air quality standards, can be stated in terms of either volume (e.g. parts per billion – ppb) or mass (e.g. micrograms per cubic metre – $\mu\text{g}/\text{m}^3$), and different units are used in different documents.

The conversion of ppb to $\mu\text{g}/\text{m}^3$ (and vice versa) is dependent on temperature and pressure. For the purpose of this Impact Statement a standardised approach to the conversion of units has been adopted, whereby:

- The primary unit has been taken from the source document.
- Where any conversion was required, the reference conditions of the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) have been used (0°C and an absolute pressure of 101.325 kilopascals (kPa)).

For each pollutant, the following conversion factors have been used:

- SO_2 1 ppb = 2.858 $\mu\text{g}/\text{m}^3$
- NO_2 1 ppb = 2.053 $\mu\text{g}/\text{m}^3$
- O_3 1 ppb = 2.141 $\mu\text{g}/\text{m}^3$.

Some source documents have provided concentrations in both volume- and mass-based units, and the assumed temperature may not have been 0°C. Where this was the case, both the volume and mass units from the source document have been retained.

1 Introduction

1.1 Overview

This Impact Statement has been prepared for the National Environment Protection Council (NEPC) with reference to the requirements of the *National Environment Protection Act 1994* (NEPC Act). It provides information on the sulfur dioxide (SO₂), nitrogen dioxide (NO₂) and ozone (O₃) standards in the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) and options to vary the standards⁴.

The Impact Statement collates and analyses the available information on these pollutants in Australia, and considers the feasibility of updating the standards, and the costs and benefits of a range of potential abatement measures that could be introduced to lower concentrations for these pollutants. For each pollutant a number of alternative standards have been considered (NB: for the purpose of this Impact Statement these have been referred to collectively as 'proposed standards'). The preferred options for the standards in this Impact Statement are referred to as 'recommendations' for the standards.

1.2 The National Environment Protection (Ambient Air Quality) Measure

The AAQ NEPM was originally established by the NEPC in 1998 under the NEPC Act. The objectives of the NEPC Act are to ensure that:

- people enjoy the benefit of equivalent protection from air, water and soil pollution, wherever they live
- decisions by businesses are not distorted and markets not fragmented by variations between jurisdictions in relation to the adoption or implementation of an NEPM.

The AAQ NEPM aims to guide the making of policies that adequately protect human health and wellbeing. The desired environmental outcome of the AAQ NEPM is 'ambient air quality that allows for the adequate protection of human health and wellbeing'. The goals of the AAQ NEPM are to achieve the specified air quality standards and, in the case of particulate matter (PM), to achieve further reductions in maximum concentrations by 2025.

The AAQ NEPM defines national standards, and a nationally consistent framework for the monitoring and reporting of seven common ambient air pollutants. These pollutants are:

- carbon monoxide (CO)
- nitrogen dioxide (NO₂)
- sulfur dioxide (SO₂)
- lead (Pb)
- photochemical oxidants (as O₃)
- particulate matter with an aerodynamic diameter of less than or equal to 10 micrometres (µm) (known as PM₁₀)

⁴ This report deals with 'ground-level' ozone. It does not address ozone in the stratosphere.

- particulate matter with an aerodynamic diameter of less than or equal to 2.5 micrometres (μm) (known as $\text{PM}_{2.5}$)⁵.

The NEPM is implemented by the Commonwealth administratively, and by the states and territories, who tailor air quality management strategies specifically suited to their jurisdiction.

1.3 The 2011 review of the National Environment Protection (Ambient Air Quality) Measure

In 2011, the National Environment Protection Council released the findings of a review of the AAQ NEPM (NEPC 2011a).

The review noted the ambiguity of the term ‘adequate protection’ in the desired environmental outcome of the AAQ NEPM. In addition, the health evidence relating to the effects of air pollution had advanced since the AAQ NEPM was introduced, and epidemiological studies had shown there was no evidence of clear thresholds for health effects for important air pollutants. The review found the setting of standards alone may not be compatible with the concept of adequate protection.

The review provided recommendations in relation to the standards for PM, including revising them to take into account new evidence concerning their health effects. The review also identified evidence that, for the gaseous pollutants, there were health effects at concentrations below the current AAQ NEPM standards.

The recommendations of the 2011 review are being implemented in two main stages:

- Stage 1 – a review of the standards for particulate matter (PM_{10} and $\text{PM}_{2.5}$). This stage has been completed (see Section 1.4)
- Stage 2 – a review of the standards for gaseous pollutants (SO_2 , NO_2 and O_3).

In conjunction with the release of the review in 2011, the NEPC also released the *Methodology for Setting Air Quality Standards in Australia* (NEPC 2011b). The standard-setting methodology establishes the framework to guide the development of air quality standards in Australia and provides detailed guidance on the approach to be used for exposure assessment and risk characterisation.

1.4 Review of standards for particulate matter

In the first stage of implementing the recommendations of the 2011 review, several steps were undertaken to improve the understanding of PM in Australia. These included a health risk assessment⁶ (Frangos & DiMarco 2013; Morgan et al. 2013), an economic analysis (Boulter & Kulkarni 2013), an investigation of exposure-reduction frameworks (Bawden et al. 2012), and a methodology for valuing the health impacts of changes in particle emissions (Aust et al. 2013). This work led to the publication of an impact statement for a proposed variation to the PM standards in the AAQ NEPM (NEPC 2014). A subsequent variation to the AAQ NEPM, which took effect in February 2016⁷, included the formal adoption of the $\text{PM}_{2.5}$ standards, the introduction of an annual average standard for PM_{10} , and an ‘exceptional events’ clause to enable an assessment of the impacts of major incidents such as bushfires and dust storms on PM concentrations. The variation to the

⁵ The NEPM was varied in 2003 to incorporate advisory reporting standards for fine particles ($\text{PM}_{2.5}$) (NEPC 2010).

⁶ This also considered SO_2 , NO_2 and O_3 .

⁷ National Environment Protection (Ambient Air Quality) Measure variation 2015.

AAQ NEPM for particles was endorsed by the National Environment Protection Council under the National Clean Air Agreement in December 2015 (see Section 2).

1.5 Review of standards for gaseous pollutants

The second stage of implementing the recommendations of the 2011 review is currently underway. The National Clean Air Agreement includes a commitment to review the standards for SO₂, NO₂ and O₃, due to the known health effects associated with exposure to these pollutants.

1.5.1 Current standards in the National Environment Protection (Ambient Air Quality) Measure

The current AAQ NEPM standards for SO₂, NO₂ and O₃ are shown in Table 1-1. These standards were adopted in 1998 and are based on the understanding at the time of the health effects of the pollutants. It was acknowledged at the time of making the AAQ NEPM that the standards may not be protective of the health of people with asthma (NEPC 1998).

In common with international practice, each AAQ NEPM standard has a 'numerical value', which is defined as a maximum concentration, and a 'form', which defines how it is implemented. For short-term standards, in most international jurisdictions the form of the standard allows a limited number of exceedances per year, either explicitly or through the use of percentile concentrations. This recognises that certain events can lead to high concentrations, but these are unpredictable and uncontrollable. Examples include extreme meteorological conditions and bushfires. This does not mean there are no potential health effects from exposure to high concentrations during these events, but control programs that are designed to meet the standards during extreme conditions can be prohibitively expensive or technically unfeasible.

Table 1-1: Current AAQ NEPM standards for SO₂, NO₂ and O₃

Pollutant	Averaging period	Maximum concentration ^(a)		Allowed exceedances
		ppb	µg/m ³	
Sulfur dioxide	1-hour	200	570	1 day per year
	24-hour	80	228	1 day per year
	Annual	20	57	None
Nitrogen dioxide	1-hour	120	246	1 day ^(b) per year
	Annual	30	62	None
Photochemical oxidants (as O ₃)	1-hour	100	214	1 day per year
	Rolling 4-hour	80	171	1 day per year

(a) ppb = parts per billion; µg/m³ = micrograms per cubic metre, based on conversion at 0°C.

(b) 'day' = calendar day during which the associated standard is exceeded; 'year' = calendar year.

1.5.2 The Impact Statement

This Impact Statement collates and analyses available information on SO₂, NO₂ and O₃ in Australia, and considers the feasibility of updating the standards, and the costs and benefits of a range of potential abatement measures that could be introduced to lower concentrations for these pollutants. The Impact Statement includes a review of the environmental outcome and goal of the AAQ NEPM, the Australian and

international standards, the form of the standards, the treatment of exceptional events, and an exposure-reduction framework⁸. The objectives of the work are presented in more detail in Section 1.6.

1.5.3 Projects to address other recommendations in the 2011 NEPM Review

The 2011 AAQ NEPM review made a total of 23 recommendations. While this Impact Statement and the AAQ NEPM review for the PM standards address some of these recommendations, other recommendations (relating to monitoring, assessment and reporting) have been addressed by projects led by an AAQ NEPM Expert Working Group (EWG)⁹.

The AAQ NEPM EWG designed and led seven projects:

- Project 1 – Review of Monitoring Methods
- Project 2 – Redesign Monitoring Networks and Risk-based Monitoring
- Project 3 – Population Exposure Assessment Method
- Project 4 – Assessment and Reporting
- Project 5 – Precursors and Emerging Pollutants
- Project 6 – Particles and Health Research
- Project 7 – Establish Specialist Working Group(s).

The AAQ NEPM EWG completed Projects 1, 2 and 4 in early 2017. The findings and outcomes of these projects are summarised below, and changes to the AAQ NEPM are being proposed based on them. Projects 3, 5, 6 and 7 are ongoing and their outcomes will not immediately lead to changes to the AAQ NEPM. Thus, they have not been included in this Impact Statement.

1.5.3.1 Project 1 summary

Project 1 – Review of Monitoring Methods was developed to address Recommendation 12 in the 2011 NEPM Review Report:

- Recommendation 12 – Amend requirements of monitoring methods (clause 16 and Schedule 3) to allow appropriate Australian Standards methods; or methods determined by the European Union (EU) and/or USEPA as Reference or Equivalence Methods.

Rapid advancements are being made in measurement technologies. Consequently, the EWG agreed to explore options that enable more frequent review and updating of monitoring methods, consistent with the rate at which advancements occur.

⁸ An exposure-reduction framework is designed for use, in addition to standards, to reduce population exposure to a pollutant. Exposure-reduction frameworks are used in some jurisdictions to account for the fact that some pollutants have no threshold for health effects, and any reduction in concentrations will lead to a health benefit. These frameworks enable continuous improvement in air quality, and lead to reductions in population exposure irrespective of whether the standards are met or not. The concept of an exposure-reduction framework is consistent with the requirements of the NEPC Act to provide equivalent protection to all Australians wherever they live.

⁹ The EWG was established in 2015 to (i) provide advice to the Air Thematic Oversight Group (replaced with the Air Project Management Group) and the project team for the review of SO₂, NO₂ and O₃, and (ii) lead projects that respond to the remaining monitoring, assessment and reporting recommendations of the AAQ NEPM review. The EWG consisted of state and territory representatives, additional non-government members with expertise in air quality modelling (personnel from CSIRO) and human health risk (personnel from the University of Tasmania), and representatives of the Commonwealth Department of Environment and Energy as observers.

Future monitoring methods could include those for which there are applicable Australian Standards or other recognised methods (for example, USEPA or EU reference or equivalence methods) or the use of alternative, more cost-effective sensors as part of jurisdictional networks to enhance population exposure assessment.

No changes to the draft variation are proposed. The NEPC needs to decide (on a case-by-case basis) how the NEPM could be varied to incorporate a change to a monitoring method. The NEPC would need to unanimously resolve that the variation to a monitoring method does not result in a significant change in the effect of the NEPM for it to be made as a minor variation under section 22A of the NEPC Act.

Key to any future changes is that participating jurisdictions should agree on the monitoring methods to be used, to ensure national consistency.

Updates to Schedule 3 to reflect current Australian Standards have also occurred as part of this work.

1.5.3.2 Project 2 summary

Project 2 – Monitoring Network Design was developed to address Recommendations 10 and 11 in the 2011 NEPM Review Report:

- Recommendation 10 – Redesign monitoring networks to represent population exposure on a pollutant-by-pollutant basis without compromising data collection for long-term trend analysis. A procedure to determine the location and number of sites similar to EU and/or USEPA is recommended.
- Recommendation 11 – Remove the population threshold and formula to enable monitoring on potential population risk rather than on population size.

The NSW members of the EWG were assigned as project lead with support from VIC, QLD, SA and CSIRO.

NSW commissioned two studies to address these recommendations:

- a review of the current NEPM monitoring network in Australia
- a review of current international practice in air monitoring network design.

Based on the studies' findings, the EWG agreed that the final changes proposed for the NEPM were preservation of the population threshold and formula but with a primary focus on risk; achieved through the inclusion of risk-based text in the NEPM to enable jurisdictions to apply risk-based principles in the selection of monitoring locations – in addition to the 25,000-population threshold. Population thresholds represent current international practice in determining minimum monitoring requirements and do not inhibit risk-based monitoring. The review of international best practice for the design of monitoring networks found that all major networks comparable to the NEPM use population as the primary basis for establishing minimum monitoring (or assessment) criteria. Further, the NEPM population threshold of 25,000 is stricter than all other population-based approaches. Typically, in the USA, Canada and the EU population thresholds start at 100,000 people and range from 100,000 – 1,000,000.

Consequently, the following changes to clause 14 of the NEPM are proposed:

- introduction of subclause (1) that highlights that the number of performance monitoring stations must be based on determining the potential population at risk
- changes to subclause (2) to allow additional performance monitoring stations in areas determined as high-risk areas by participating jurisdictions

- retention of the population formula (however, with a lower emphasis on this criteria), i.e. moved to subclause (4)
- definitions for *populations at risk* and *high risk areas*. The proposed definition of *populations at risk* has been developed to align with enHealth's meaning of population risk (enHealth 2012).

1.5.3.3 Project 4 summary

Project 4 – Assessment and Reporting was developed to address Recommendations 15, 16 and 18 in the 2011 NEPM Review Report:

- Recommendation 15 – Revise the assessment (clause 17) and reporting (clause 18) protocol to include additional performance assessment indicators and expanded reporting requirements to enable inclusion of population exposure determinations, severity of exceedance and effectiveness of management actions undertaken.
- Recommendation 16 – Revise guidance documents and templates associated with assessment and reporting to accommodate presentation of clear messages, to allow for better communication and more accessible air quality reports.
- Recommendation 18 – Require timely reporting of all exceedances, with jurisdictions publicly releasing the analysis of these events on their respective websites within 3 months of the event.

The NSW members of the EWG were assigned as project lead with support from QLD, NT, WA and members from the University of Tasmania.

The first steps taken by the group to determine the most appropriate revised template were to review submissions to the 2011 AAQ NEPM review report and survey stakeholders (questionnaires were sent to 80 to 90 stakeholders – responses were received from nine).

Subsequent steps taken were:

- review of the existing AAQ NEPM
- collation of comments on reporting protocols
- liaison with the Clean Air Society of Australia and New Zealand (CASANZ) in relation to the survey
- development of a new NEPM reporting template and amendments to Technical Note 8 (guidance document).

The new template has been updated to optimally present information by converting data tables in Sections C and D into charts either by region or station (whichever jurisdictions deem appropriate). Statistical information on trends and data analysis will also be available as a CSV file. In terms of guidance documents, Technical Note 8 has been updated to reflect these changes and to address how jurisdictions report on measurement uncertainty.

The final template and Technical Note 8 can be made available on request. These documents will need to be revised to include the reporting of population exposure to particles as PM_{2.5} once the population exposure method is finalised.

1.5.3.4 Changes to carbon monoxide

The findings in this report for O₃, NO₂ and SO₂ include recommendations for the removal of maximum allowable exceedances to enhance the health protection provided by the standards. Although not assessed as part of this review, it is proposed that the allowable exceedances for carbon monoxide (CO) also be removed for the following reasons:

- A consistent approach across all pollutants is desired. If the allowable exceedances for O₃, NO₂ and SO₂ are removed, they will only remain for CO.
- The levels of CO across Australia have been continuously low over the past decade and allowable exceedances have not been needed. Refer to AAQ NEPM Compliance Reports from jurisdictions for information about CO levels.
- CO is likely to remain low for the foreseeable future.

1.6 Report objectives

1.6.1 Overview

This Impact Statement investigates the options for reducing exposure to SO₂, NO₂ and O₃ in Australia. Several types of framework have the potential in theory to reduce exposure, the main options being:

- no change to the current framework
- Commonwealth legislation
- voluntary guidelines
- inter-governmental agreement or memorandum of understanding
- variation of the AAQ NEPM.

A variation of the existing AAQ NEPM is highly likely to be the most appropriate step. Specifically, the Impact Statement deals with the possibility of amending the standards and goals for SO₂, NO₂ and O₃ (including the form of the standards) in the AAQ NEPM and considers the prospect of introducing a framework for reducing population exposure for each pollutant. However, for completeness, all of the options listed above have been considered.

The Impact Statement has been prepared with reference to the requirements of the NEPC Act, which are summarised in Section 1.6.2. The Impact Statement also builds on the recommendations of the 2011 review of the AAQ NEPM, as summarised in Section 1.6.3.

1.6.2 Requirements of the National Environment Protection Council Act

The *National Environment Protection Council Act 1994* (section 15) allows the National Environment Protection Council to introduce, vary or revoke NEPMs.

In making or varying any national environment protection measure, the Council must have regard to:

- (a) whether the measure is consistent with section 3 of the Intergovernmental Agreement on the Environment; and
- (b) the environmental, economic and social impact of the measure; and

- (c) the simplicity, efficiency and effectiveness of the administration of the measure; and
- (d) whether the most effective means of achieving the desired environmental outcomes of the measure is by means of a national environment protection standard, goal or guideline or any particular combination thereof; and
- (e) the relationship of the measure to existing inter-governmental mechanisms; and
- (f) relevant international agreements to which Australia is a party; and
- (g) any regional environmental differences in Australia.

These issues were considered through the review of the AAQ NEPM in 2011 (NEPC 2011a). This Impact Statement focuses only on whether the standards for SO₂, NO₂ and O₃ still meet the requirements to achieve the desired environmental outcome of the AAQ NEPM, which is 'adequate protection of human health and wellbeing', and the need for change.

As noted above, section 15(a) of the NEPC Act requires that the Council consider whether an NEPM is consistent with section 3 of the Intergovernmental Agreement on the Environment. Section 3 outlines several principles which have been set out to guide the development and implementation of environmental policy and programs. Two principles in particular have been taken into account in this report:

1. Precautionary principle

Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, public and private decisions should be guided by:

- (a) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment; and
- (b) an assessment of the risk weighted consequences of various options.

2. Intergenerational equity

- (a) The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.

These are important considerations when assessing whether the requirement of the NEPC Act and the desired environmental outcome of the AAQ NEPM are being met and, if not, what changes are required to ensure that they are.

1.6.3 Recommendations of the review of the National Environment Protection (Ambient Air Quality) Measure

This Impact Statement considers some, but not all, of the recommendations of the 2011 review. Certain recommendations relating to SO₂, NO₂ and O₃ are addressed in depth, including:

- Revise the desired environmental outcome and goal of the AAQ NEPM.
- Review the standards for SO₂, NO₂ and O₃ to take into account recent health evidence.
- Introduce an 8-hour standard for O₃.
- Introduce an exposure-reduction framework and targets for priority pollutants.
- Remove allowable exceedances from Schedule 2 and introduce an exceptional events rule.

- Amend the AAQ NEPM protocol (part 4) to incorporate an exceptional events rule, including definition of these events and criteria for assessment and reporting.

Other recommendations concerning specific technical matters (e.g. monitoring methods and protocols, site locations) are being considered through external projects outside the scope of the Impact Statement. The findings of these external projects have been included in this Impact Statement (refer to Section 1.5.3).

1.6.4 General considerations

When developing air quality standards a 'weight-of-evidence' approach is typically used. Health studies play a central role, but the NEPC Act also requires an analysis of environmental, economic and social factors (NEPC 2011b). This Impact Statement collates and analyses available information on SO₂, NO₂ and O₃ in Australia. It considers the feasibility of updating the standards and goals for these pollutants (as currently defined in the AAQ NEPM) and the costs and benefits of a range of potential abatement measures that could be introduced to lower concentrations for these pollutants. It also considers a framework for reducing population exposure to these pollutants. The Impact Statement therefore presents the available information on each of these aspects in relation to specific options for varying the AAQ NEPM standards for SO₂, NO₂ and O₃.

Several broad decision criteria /factors have been considered in the recommendation of the standards for SO₂, NO₂ and O₃. The decision criteria / factors included:

- averaging periods for SO₂, NO₂ and O₃ in the AAQ NEPM
- numerical values of the SO₂, NO₂ and O₃ standards
- form of the SO₂, NO₂ and O₃ standards (e.g. allowed exceedances)
- adequacy of the health protection afforded by standards
- weight of evidence that supports any proposed standards including, for instance, the advice of the World Health Organization (WHO)
- relevance and achievability of the proposed standards including, for instance, the form of the standards with regards to exceptional events such as bushfires
- any regional environmental differences
- societal costs and benefits of meeting proposed standards
- options for an exposure-reduction framework for SO₂, NO₂ and O₃.

These decision criteria / factors are derived from the NEPC's 2011 *Methodology for Setting Air Quality Standards* (NEPC 2011a) and good practice air quality standard setting.

1.7 Scope and structure of the Impact Statement

The scope of the Impact Statement was defined largely in terms of the recommendations of the AAQ NEPM review. These recommendations are provided in Table 1-2, which also summarises how each recommendation has been considered.

The Impact Statement takes into account some, but not all, of the recommendations of the AAQ NEPM review. It is worth noting that some of the recommendations have been addressed by other projects and are also summarised in this Impact Statement.

Table 1-2: Recommendations from the 2011 NEPM review and the projects to address them

Number in NEPM review	Aspect of AAQ NEPM	Recommendation	Included in this Impact Statement?
1	AAQ NEPM goal	Revise the desired environmental outcome of the NEPM to 'minimise the risk from adverse health impacts from exposure to air pollution for all people wherever they may live'.	Yes. Discussion to support the change to the AAQ NEPM outcome and implications is provided in Chapter 5.
2		Revise the desired environmental goal to make reference to the air quality standards and incorporation of exposure-reduction targets for priority pollutants.	Yes. Discussion to support the change to the AAQ NEPM goal and implications is provided in Chapter 5.
3	Air quality standards	Remove lead (Pb) from the AAQ NEPM and include in the Air Toxics NEPM during the scheduled Air Toxics NEPM review of 2012.	No. This will occur as part of an Air Toxics NEPM review.
4		Revise the standards for all air pollutants in Schedule 1 of the NEPM to take into account new evidence around the health effects of air pollution.	Yes. This review considered revised standards for SO ₂ , NO ₂ and O ₃ . Variation to the particle standards occurred as part of the 2015 AAQ NEPM review of particle standards.
5		Introduce compliance standards for PM _{2.5} .	No. Consideration of a compliance standard for PM _{2.5} occurred as part of the 2015 AAQ NEPM review of particle standards.
7		Introduce an annual average standard for PM ₁₀ .	No. Consideration of an annual average standard for PM ₁₀ occurred as part of the 2015 AAQ NEPM review of particle standards.
6		Introduce an 8-hour standard for ozone.	Yes. Discussion and a recommendation regarding the introduction of an 8-hour O ₃ standard is included in this Impact Statement.
8	Exposure reduction	Introduce an exposure-reduction framework and targets for priority pollutants.	Yes. Consideration of an exposure-reduction framework (ERF) has been included for SO ₂ , NO ₂ and O ₃ in Sections 6.10, 7.10 and 8.10 respectively. The 2015 AAQ NEPM particles review considered an ERF for PM.
14		Develop nationally consistent approaches to assess population exposure, including appropriate modelling and emissions inventories.	No. This recommendation will be addressed by a National Air Quality Technical Advisory Group.
9	Allowable exceedances	Remove allowable exceedances from Schedule 2 and introduce a natural events rule.	Yes. Consideration of the removal of the allowable exceedance rule and the introduction of an exceptional events rule for SO ₂ , NO ₂ and O ₃ is provided in Sections 6.12, 7.12 and 8.12 respectively. Consideration of removal of allowable exceedances and introduction of an exceptional events rule for PM were included in the 2015 AAQ NEPM review of particle standards.
10	Monitoring network	Redesign monitoring networks to represent population exposure on a pollutant-by-pollutant basis without compromising data collection for long-term trend analysis. A procedure to determine the location and number of sites similar to EU and/or USEPA is recommended.	No. These recommendations were addressed through a project led by an Expert Working Group. The outcomes of the project will give greater flexibility to jurisdictions in the location and number of monitoring stations. A summary of this work is provided in Section 1.5.3 of this Impact Statement.
11		Remove the population threshold and formula to enable monitoring on potential population risk rather than on population size.	

Number in NEPM review	Aspect of AAQ NEPM	Recommendation	Included in this Impact Statement?
12	Monitoring methods	Amend requirements of monitoring methods (clause 16 and Schedule 3) to allow appropriate Australian Standards methods; or methods determined by the EU and/or USEPA as Reference or Equivalence Methods.	No. This recommendation was addressed through a project led by an Expert Working Group. A summary of this work is provided in Section 1.5.3 of this Impact Statement.
13		Remove Schedule 5 of the AAQ NEPM.	
15	Severity of exceedances	Revise the assessment (clause 17) and reporting (clause 18) protocol to include additional performance assessment indicators and expanded reporting requirements to enable inclusion of population exposure determinations, severity of exceedance and effectiveness of management actions undertaken.	No. These recommendations were addressed through a project led by an Expert Working Group. A summary of this work is provided in Section 1.5.3 of this Impact Statement.
16	Reporting	Revise guidance documents and templates associated with assessment and reporting to accommodate presentation of clear messages, to allow for better communication and more accessible air quality reports.	
18		Require timely reporting of all exceedances, with jurisdictions publicly releasing the analysis of these events on their respective websites within three months of the event.	
17	Form of the standards	Amend the AAQ NEPM protocol (part 4) to incorporate natural event rule including definition of these events and criteria for assessment and reporting.	Yes. Consideration of this recommendation in relation to SO ₂ , NO ₂ and O ₃ has been included in Sections 6.12, 7.12 and 8.12 respectively. Consideration of the form of the standards for PM was included in the 2015 AAQ NEPM review of particle standards.
19	Technical Working Group	Disband the existing PRC and replace with a specialist working group or groups with a broader range of expertise to assist with scientific and technical matters. This working group would report to the Air Quality Working Group.	No. A National Air Quality Technical Advisory Group has formed under the National Clean Air Agreement.
20	Secondary pollutant precursors	Evaluate the options to assess ozone and secondary particle precursors.	No. Consideration of this recommendation will occur under projects led by the National Air Quality Technical Advisory Group.
21	Future work	Initiate research into the composition of particles in Australia and associated health impacts.	No. Consideration of these recommendations will occur under projects led by the National Air Quality Technical Advisory Group.
22		Initiate health research on the impact of air pollution (in particular, particles) in regional areas.	
23		Monitor and report coarse particle fraction.	

The remaining chapters of the Impact Statement address the following aspects:

- air quality management in Australia (Chapter 2)
- statement of the problem and the case for government intervention (Chapter 3)
- review methodology (Chapter 4)
- discussion of the desired environmental outcome and goal of the AAQ NEPM (Chapter 5)
- impact assessments for SO₂, NO₂ and O₃, which are presented in Chapter 6, Chapter 7 and Chapter 8 respectively. Each of these chapters considers:
 - characteristics and sources of the pollutant
 - a review of the recent health evidence
 - the WHO guidelines, the air quality standards in other leading countries, and the proposed air quality standards for review
 - concentrations of the pollutant in Australian airsheds, and exceedances of air quality criteria. These are described in terms of historical trends and future projections
 - a health risk assessment, in which health outcomes are presented for 'Business-as-Usual' (BAU) and 'Abatement Package' scenarios, and for compliance¹⁰ with the proposed standards
 - a cost–benefit analysis
 - a discussion of non-quantifiable benefits and disbenefits
 - the relevance of an exposure-reduction framework
 - a summary of the assessment, and recommendations for the AAQ NEPM variation
- overall results of the cost–benefit analysis (Chapter 9)
- summary of the Impact Statement and the main recommendations for further consultation (Chapter 10)
- discussion of the limitations of the review, and uncertainty in the results (Chapter 11)
- how to make a submission, next steps and consolidated list of consultation questions that are also at the end of relevant chapters (Chapter 12).

¹⁰ Where reference is made to 'compliance' in this Impact Statement, 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.

2 Air quality management in Australia

2.1 National Environment Protection Council

The National Environment Protection Council (NEPC) is established under the *National Environment Protection Council Act 1994* (Cth) (the NEPC Act), and corresponding legislation in other Australian jurisdictions. The members of the NEPC consist of environment ministers from each jurisdiction. The NEPC's primary functions are to make National Environment Protection Measures (NEPMs), and to assess and report on the implementation and effectiveness of NEPMs in each jurisdiction. The purpose of the NEPMs is to ensure that people enjoy the benefit of equivalent protection from air, water or soil pollution and from noise, wherever they live in Australia. The implementation of NEPMs is outside the NEPC's jurisdiction and is achieved through state and territory legislation and associated regulations. Each jurisdiction is required to allocate sufficient resources to enforce the NEPM and report annually on its implementation.

2.2 The National Environment Protection (Ambient Air Quality) Measure

2.2.1 Overview

As noted in Chapter 1, in 1998 the AAQ NEPM established national standards for six criteria pollutants¹¹ and provided a consistent framework for the monitoring and reporting of ambient air quality. A thorough strategic and technical review of the AAQ NEPM was published in 2011 (NEPC 2011a). The review assessed whether the AAQ NEPM was achieving its desired environmental outcome and provided an opportunity for feedback from interested parties regarding the efficacy of the current framework. The NEPC agreed that the review's recommendations would be prioritised and addressed through the development of a then National Plan for Clean Air (NPCA). This was superseded in 2015 by the National Clean Air Agreement.

2.2.2 Desired environmental outcome, goal and standards

The desired outcome of the AAQ NEPM is 'ambient air quality that allows for the adequate protection of human health and wellbeing', and the goal is compliance with air quality standards. The standards for SO₂, NO₂ and O₃ were stated in Chapter 1. There are no sanctions for not meeting the standards and goals of the AAQ NEPM. They aim to guide policy formulation that allows for the adequate protection of health and wellbeing. Under the current AAQ NEPM, participating jurisdictions (Commonwealth, states and territories) are required to undertake reporting and monitoring activities to provide data that assist jurisdictions in formulating air quality policies. The AAQ NEPM itself does not compel or direct pollution control measures.

2.2.3 Exposure-reduction framework

In Australia, most monitoring and assessment to date has largely been directed towards evaluating air quality against standards at specific locations; however, for non-threshold¹² air pollutants it has become clear that the overall health outcomes in a population are driven by large-scale exposure to the prevailing

¹¹ Advisory reporting standards for fine particles (PM_{2.5}) were added to the NEPM in 2003 (NEPC 2010).

¹² Pollutants for which the relationship between the concentration and the health response is, broadly speaking, linear over the full range of ambient concentrations.

background concentration, rather than by relatively small-scale exposure to higher concentrations at localised 'hot spots'. This has compelled a shift in the approach to air quality management, and in some countries and regions (notably the EU) this has taken the form of an 'exposure-reduction framework'. There are currently no targets for exposure-reduction for SO₂, NO₂ and O₃ in the AAQ NEPM.

The development of an exposure-reduction framework for particulate matter in Australia was a recommendation of the AAQ NEPM review, and the options for developing such a framework were investigated by Bawden et al. (2012). The authors identified several approaches to an exposure-reduction framework, including emission-reduction approaches, exposure-reduction approaches, air pollution indices, and economic ('damage cost') approaches. They recommended the establishment of an exposure-reduction framework within the AAQ NEPM, and three main elements:

- *Development of emission-reduction programs.* This would introduce a requirement for jurisdictions to develop programs to reduce emissions so as to reduce exposure to PM.
- *Development of PM_{2.5} monitoring networks and regional emission inventories.* This would involve a requirement to focus monitoring on PM_{2.5} and to carry out a minimum level of monitoring following appropriate national guidance.
- *Development of exposure-reduction targets.* Work would be required at a national level using available information to identify sources and suitable cost-effective control programs, and thus to define realistic targets.

The costs and benefits of an exposure-reduction framework for particulate matter in Australia were also summarised in the Impact Statement for a draft variation to the AAQ NEPM (NEPC 2014). It was noted that meeting a target of a 10 per cent reduction in the annual mean PM_{2.5} concentration between 2015 and 2025 would require extensive additional abatement measures in most jurisdictions and is unlikely to be feasible in practice. Nevertheless, it is important to emphasise the likely health benefits of an exposure-reduction framework.

In 2015 the NEPC agreed to include long-term PM_{2.5} targets to be achieved by 2025 (an annual average target of 7 µg/m³ and a 24-hour target of 20 µg/m³) as a simplified approach for an exposure-reduction framework. These changes took effect in the AAQ NEPM in February 2016.

2.2.4 Monitoring requirements

2.2.4.1 Performance monitoring stations

The states and territories are currently required to monitor and report on air quality to determine whether the AAQ NEPM standards are being met within populated areas. Two approaches are available for evaluating performance against the standards:

- Pollutant concentrations can be measured at 'performance monitoring stations'.
- Pollutant concentrations can be assessed by other means that provide information that is equivalent to measurements. These methods could include, for example, the use of emission inventories, dispersion modelling, and comparisons with other regions.

The AAQ NEPM provides guidance on the location of performance monitoring stations¹³. The air quality standards are designed for locations that are generally representative of the level of exposure of the broad population, rather than for 'hot spots' near major point sources or roads. The AAQ NEPM monitoring protocol (PRC 2001a) states that some monitoring stations should be located in populated areas which are expected to experience relatively high concentrations, providing a basis for reliable statements about air pollution within the region or sub-region as a whole. These stations are called 'generally representative upper bound (GRUB) for community exposure' sites. A performance monitoring station should be operated in the same location for at least five years.

The number of performance monitoring stations for a region with a population of 25,000 people or more is the next whole number above the value calculated in accordance with the formula $(1.5 \times P) + 0.5$, where P is the population of the region (in millions). Additional (or fewer) performance monitoring stations can be implemented depending on local and regional conditions, or existing pollutant levels.

Under the current monitoring protocol in the AAQ NEPM, the exposure of people who live near major sources of pollution – such as busy roads – is not assessed through air quality monitoring. Such people are likely to be exposed to higher levels of air pollution than those measured at performance monitoring stations (NEPC 2011a).

The Commonwealth implements the NEPM administratively; however, it is not required by the NEPM to undertake monitoring as there are currently no non self-governing Commonwealth territories or Commonwealth regions with a population above the 25,000 NEPM protocol threshold.

2.2.4.2 *Trend monitoring stations*

Some performance monitoring stations in each state or territory must be nominated as 'trend' stations. The number of trend stations must be sufficient to enable the assessment of long-term changes in ambient air quality in different parts of the jurisdiction. A trend station must be operated in the same location for at least 10 years.

2.2.4.3 *Evaluation of performance against standards and goals*

The AAQ NEPM sets out the criteria for evaluating performance against the standards and goals. Jurisdictions are required to assess their annual performance against the AAQ NEPM standards and goals at each monitoring station. Performance is assessed as 'met', 'not met', or 'not demonstrated'¹⁴.

2.2.4.4 *Reporting*

Each year, jurisdictions must submit an annual report to the NEPC on the implementation and effectiveness of the AAQ NEPM. The AAQ NEPM establishes the reporting requirements for annual performance reports, including the performance assessment described above, an analysis of the extent to which the standards are met, a statement of the progress made towards achieving the goal, and a description of the circumstances that led to any exceedances of the standards, including the influence of natural events and fire management.

¹³ Performance monitoring stations should be sited, to the extent practicable, in accordance with the requirements of Australian Standard AS2922-1987 (Ambient Air – Guide for Siting of Sampling Units).

¹⁴ 'Not demonstrated' relates to whether there were sufficient data available for a pollutant at the monitoring station to enable an assessment.

2.2.4.5 Accountability

Under the NEPC Act, accountability for meeting the standards lies in the public reporting; that is, there are no penalties associated with non-compliance. Jurisdictions are only required to evaluate their performance at each monitoring station against the AAQ NEPM standards and goals, and to report the results to the NEPC each year.

2.3 Use of the standards and goals in the National Environment Protection (Ambient Air Quality) Measure by jurisdictions

2.3.1 Overview

The AAQ NEPM standards were established in relation to broad air quality within airsheds, and are applicable at urban locations away from hot spots. The original intent of the AAQ NEPM was to avoid monitoring near localised point sources of pollution and at peak sites, as these would not represent general population exposure¹⁵ (NEPC 2011a). Generally speaking, the Australian states and territories manage emissions and air quality in relation to certain types of source (e.g. landfills, quarries, crematoria, and coal mines). The jurisdictions have legislation or guidance which includes design goals, licence conditions or other instruments for protecting local communities from ground-level impacts of pollutants in residential areas outside site boundaries. Where this is the case, the AAQ NEPM standards are often used as the criteria for air quality assessments. For example, environmental licences or planning consent may contain conditions requiring compliance with the AAQ NEPM standards at a site boundary or at the nearest sensitive receptor. Environmental licences often also contain requirements to implement monitoring of ambient air quality. If a company is shown not to comply with licence conditions, in many cases legal action can be taken.

The following paragraphs summarise how the AAQ NEPM standards are implemented in this context by the separate jurisdictions.

2.3.2 New South Wales

In NSW the statutory methods that are used for assessing air pollution from stationary sources are listed in the document *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (NSW EPA 2016). The Approved Methods do not contain specific information on the assessment of, for example, transport schemes and land-use changes. Air quality must be assessed in relation to criteria and averaging periods for specific pollutants that are taken from several sources, including the AAQ NEPM.

2.3.3 Victoria

The Victorian *State Environment Protection Policy (SEPP) for Ambient Air Quality* (SEPP (AAQ)) sets air quality objectives and goals for the state. The SEPP (AAQ) adopts the specifications of the AAQ NEPM, and also includes a separate objective for visibility-reducing particles and a more stringent annual PM₁₀ standard than the AAQ NEPM.

¹⁵ The NEPM review did note that areas impacted by industrial emissions could be included as part of a population exposure monitoring regime, as the general population also includes these sub-populations.

Victoria's *State Environment Protection Policy for Air Quality Management* (SEPP (AQM)) establishes the framework for managing emissions into the air environment in Victoria from all sources. The aims of SEPP (AQM) are to:

- meet the air quality objectives outlined in the SEPP (AAQ)
- drive continuous improvement
- achieve the cleanest air possible.

The management framework and attainment program for the protection of air quality contained in the SEPP (AQM) address not only ambient (or regional) air quality, but also the management of particular sources (for example, industry, motor vehicles and open burning) and local air quality impacts, including air toxics, odorous pollutants, greenhouse gases and ozone-depleting substances.

For high-risk industrial activities ('scheduled premises'), EPA Victoria regulates compliance against the SEPP (AQM) through works approvals and licensing. The key requirements include meeting ground-level concentration criteria for many air quality indicators (in addition to the ambient criteria pollutants), best practice management, and continuous improvement.

The Victorian Government has made new environment protection laws to replace the *Environment Protection Act 1970*. The Government intends the laws to take effect from 1 July 2020. State Environment Protection Policies (SEPPs) will no longer exist under the new laws. Environment reference standards are intended to set out the environmental values and environmental quality objectives necessary to protect those environmental values and may house some elements of current SEPPs. Regulations and other subordinate legislation are under development and will propose to support the operation of the new laws. It is anticipated that separate Victorian public consultation on any proposed subordinate legislation is likely to occur in mid-2019.

2.3.4 Queensland

In Queensland the potential environmental impacts of developments and activities, especially those defined as environmentally relevant activities, are currently managed on a site-specific basis through assessment and conditioning under the *Environmental Protection Act 1994*.

As part of the assessment process, potential air quality impacts are evaluated against the *Environmental Protection (Air) Policy 2008* (Air EPP) made under the Environmental Protection Act. The Air EPP is the principal policy guidance for managing air quality. The Air EPP identifies environmental values to be enhanced or protected, states indicators and air quality objectives for enhancing or protecting the environmental values, and provides a framework for making consistent, equitable and informed decisions about the air environment. The Air EPP presents air quality objectives for 31 indicators (air pollutants). The detailed regulatory requirements for assessing and managing environmental issues are contained in the Environmental Protection Regulation 2008, also made under the Environmental Protection Act.

The *Integrated Development Assessment System* is the process for assessing and deciding development applications at the property level. Development applications are assessed under the *Sustainable Planning Act 2009*. This process includes assessment against local planning instruments and for any impacts the proposed development may have on the surrounding environment.

The *State Planning Policy 5/10 Air, Noise and Hazardous Materials* (2010) complements the existing assessment and management framework by providing a more strategic focus on the location of industrial

land uses (particularly in relation to sensitive land uses such as housing) that can impact on community and human health, wellbeing, amenity and safety from issues such as air pollutants.

2.3.5 South Australia

South Australia references the AAQ NEPM standards for a range of purposes, which include requirements relating to ground-level concentrations for development applications and licence conditions. For example, there is an expectation that submissions for new developments include high quality modelling reports from experienced practitioners, which provide conservative estimates for ground-level impacts of emissions from industrial activities meeting AAQ NEPM standards.

Conditions to meet the standard(s) may be applied within licences under the *Environment Protection Act 1993* and/or within development approvals under the *Development Act 1993*. Other orders or authorisations, or Environment Improvement Plans under the Environment Protection Act may also potentially embody the standards.

Where appropriate, licensees can be required to undertake stack emission testing or monitoring to maintain emission levels to meet design ground-level concentrations. In some instances licensees are also required to undertake ambient monitoring to confirm they are meeting the long-term and short-term standards. Non-licensed activities can also be required to control emissions to meet these standards.

2.3.6 Western Australia

In Western Australia proponents are required to conduct assessments of the air quality impacts of existing or proposed sources of air pollutants under Part IV, or in relation to Works Approvals and Licences under Part V, of the *Environmental Protection Act 1986*. There is an expectation that the risk of impact, as measured against the ambient air quality criteria (e.g. AAQ NEPM) will be minimised at all existing or likely future off-site sensitive receptors. For the purposes of air quality assessment, a 'sensitive receptor' means a location where people are likely to reside or congregate; this may include a dwelling, school, hospital, nursing home, child care facility or public recreation area or land zoned residential that is either developed or undeveloped. Locations of cultural or environmental significance, including 'environmentally sensitive areas' declared under the Act, may also be recognised as sensitive receptors and determined on a case-by-case basis. In some circumstances, the Department of Water and Environmental Regulation or the Department of Health may recommend an alternative ambient air quality guideline be applied in ambient air quality assessments to minimise the risk to a specific population.

2.3.7 Other jurisdictions (Tasmania, Northern Territory and Australian Capital Territory)

In Tasmania, the state and local governments control emissions of industrial activities through permits and environment protection notices. Currently, emissions from industries are regulated under the general provisions of the *Environmental Management and Pollution Control Act 1994* and the *Land Use Planning and Approvals Act 1993*. Conditions are applied during the development assessment process, and then compliance is regulated by either the local council for smaller activities, or by the Tasmanian EPA for larger activities. The *Environment Protection Policy (Air Quality) 2004* (EPP) also provides a framework for the management and regulation of both point and diffuse sources. The EPP sets particle limits to apply at the boundary of an activity, which can be incorporated into the premise's conditions. These limits are not necessarily those specified in the AAQ NEPM; however, the AAQ NEPM standards are applied during the

setting of permit conditions by reference to the standards being met at the nearest sensitive receptor, which may or may not be at the boundary.

In the Northern Territory the AAQ NEPM criteria are typically applied, although there is no formal recognition of the AAQ NEPM standards in Northern Territory regulatory instruments.

The ACT does not formally reference the AAQ NEPM standards; however, it does use them in the planning approval and formal Environmental Impact Assessment processes to ensure they will be achieved. In the absence of specific guidelines for the ACT, either the NSW *Approved Methods* are employed or the emission limits in the NSW Protection of the Environment Operations (Clean Air) Regulation 2010 are applied.

2.3.8 Summary

The AAQ NEPM standards are often used in a variety of locations and contexts, some of which are inconsistent with the intention of the AAQ NEPM. The AAQ NEPM standards are designed for use at locations away from hot spots but are sometimes applied at other locations as part of environmental assessment (for example, at the boundary of an industrial facility).

2.4 Sectoral approaches

2.4.1 Industry

The relevant state and territory environmental agencies administer legislation that allows for the management and control of emissions from large industrial point sources such as power stations, refineries, smelters and cement works. These measures vary in name across the jurisdictions, but are generally works approvals, licences and notices, as well as enforcement programs. In some jurisdictions regulatory measures may be administered specific to a region or centre or source type where focused attention has been required, such as environmental protection policies and regional management plans.

2.4.2 Road vehicles

The management measures for vehicle emissions occur at both a national and state/territory level. The Australian Government has set emission standards for new vehicles through the Australian Design Rules (ADR) via the *Motor Vehicles Standards Act 1989*, and minimum standards for fuel quality via the *Fuel Quality Standards Act 2000*. The National Environment Protection (Diesel Vehicle Emissions) Measure 2001 was made, focusing on PM and NO_x emissions from the in-service fleet.

The reduction in sulfur content of fuel has supported the introduction of exhaust after treatment devices in vehicles, which also provide a co-benefit (reducing particles). At the state and territory level the management strategies vary and include reporting and inspection programs, fines for excessive emissions, lowering the Reid Vapour Pressure of fuel, and vapour recovery at petrol stations. Alternative fuels to petrol and diesel, such as liquefied petroleum gas (LPG) or compressed natural gas (CNG), have been advocated to assist in reducing emissions of volatile organic compounds (VOCs), as well as a transition to hybrid and electric vehicles. Alternative transport modes are advocated to decrease the distance vehicles are used to travel, i.e. replacing vehicle transport mode with public transport (buses, trains and trams) and cycling. This approach is also supported with land-use planning and development strategies supportive of the alternative transport mode.

Education and awareness programs have also been used. Awareness programs are varied and include advocating alternative fuels and transport modes to personal vehicle usage (i.e. cycling and public transport) as well as integrated land-use and transport planning strategies.

2.4.3 Shipping

The Australian Government administers regulations to prevent pollution from ships in Australian waters. The legislative controls reference the International Convention for the Prevention of Pollution from Ships (MARPOL). This sets out provisions for the reduction in emissions of SO₂, NO_x and particulate matter. SO₂ emission reduction is achieved through the setting of limits on the sulfur content of marine fuel oil.

From January 2020 the International Maritime Organization will reduce the global sulfur cap from 3.5 to 0.5 per cent for fuel oil used by ships. This will be the minimum requirement for all ships. Currently, the average sulfur content of marine fuel (usually heavy fuel oil) in the NSW Greater Metropolitan Region is 2.7 per cent. A 0.5 per cent maximum sulfur requirement is estimated to reduce SO₂ (and PM_{2.5}) emissions from all shipping in NSW.

2.5 National Clean Air Agreement

Australia's environment ministers established the National Clean Air Agreement¹⁶ on 15 December 2015, recognising the challenges facing Australia's air quality now and into the future. The agreement sets a framework to help governments identify and prioritise actions that would benefit from national collaboration to address air quality issues, and deliver health, environmental and economic outcomes for Australians. Actions agreed by Australia's environment ministers are listed on the agreement's work plan.

The agreement's initial work plan included the strengthening of the AAQ NEPM's particle standards, which came into effect through a variation to the AAQ NEPM in early 2016¹⁷. It also included the current work to review the AAQ NEPM standards for SO₂, NO₂ and O₃, with a view to strengthening these standards. The updated work plan, agreed by environment ministers in April 2018, continues to recognise this work as a priority.

¹⁶ <http://www.environment.gov.au/protection/air-quality/national-clean-air-agreement>

¹⁷ <http://www.nepc.gov.au/resource/variation-ambient-air-quality-nepm—particles-standards>

Chapters 1 and 2 – Key points

- The AAQ NEPM provides a consistent framework for the monitoring and reporting of ambient air quality in Australia.
- All Australian states and territories report annually against the AAQ NEPM.
- The AAQ NEPM does not compel or direct pollution control measures. It is not directly enforceable on industry.
- The AAQ NEPM standards are designed for locations that are generally representative of the level of exposure of the broad population, rather than for 'hot spots' near major point sources or roads.
- Jurisdictions may employ complementary methods to support their air quality management frameworks. This could include setting design goals and/or licence conditions on industrial premises.
- This review focuses on the review of the O₃, NO₂ and SO₂ standards in the AAQ NEPM.
- A national Expert Working Group worked in parallel with this review on a number of projects to address monitoring, reporting and assessment recommendations from the 2011 AAQ NEPM review. One of these projects has made recommendations for changes to clause 14 of the AAQ NEPM (Number of performance monitoring stations) to consider the potential population at risk (Section 1.5.3).
- The findings in this report for O₃, NO₂ and SO₂ include recommendations for the removal of maximum allowable exceedances to enhance the health protection provided by the standards. Although not assessed as part of this review, it is proposed that the allowable exceedances for carbon monoxide (CO) also be removed.

Chapters 1 and 2 – Consultation questions

- Do you support the recommended changes to clause 14 (incorporating risk into how the number of performance monitoring stations is determined) and the inclusion of relevant definitions?
- Do you support the removal of allowable exceedances for CO?

3 Statement of the problem

3.1 Background

Outdoor air pollution impacts human health. The impacts include premature mortality, hospital admissions, allergic reactions, lung dysfunction, cardiovascular diseases and cancer.

For some pollutants, the non-threshold nature of the health response means that sensitive individuals – such as people with respiratory or cardiovascular disease – may be affected even where concentrations meet or are below the national ambient air quality standards. There is, therefore, still a health benefit (and cost saving) to be gained from any reduction in pollutant concentrations and overall population exposure.

There is a large body of information worldwide that identifies health effects associated with exposure to air pollution at levels below the current AAQ NEPM standards. Even at levels currently experienced in Australian cities, there are strong associations between exposure to NO₂, O₃, and SO₂ and increases in daily mortality and hospital admissions for respiratory and cardiovascular causes. Given that these pollutants are considered as ‘non-threshold’ pollutants, there will always be some level of risk associated with the standard at whatever numerical value is set.

As noted in the 2011 review, the AAQ NEPM has provided a nationally consistent framework for the monitoring and reporting of air quality. The air quality standards contained in the AAQ NEPM have provided nationally consistent benchmarks against which the quality of our air and the risk posed by air pollution to the Australian population can be assessed. The implementation of the AAQ NEPM by jurisdictions has led to greater consistency in air pollution data, and a much stronger database to enable an assessment of the achievability of any new standards that may be developed.

The standards contained in the AAQ NEPM were based on the understanding of the health effects of these air pollutants that existed at the time of making the AAQ NEPM, in 1998. The form of the standards – setting a timeframe for compliance and an allowable number of exceedances (the goal associated with the standards) – was adopted based on the understanding of the achievability of those standards within 10 years of making the AAQ NEPM. There was limited information available to inform that decision at the time of making the AAQ NEPM.

3.2 Why the standards for sulfur dioxide, nitrogen dioxide and ozone are being reviewed

An update of the AAQ NEPM standards for SO₂, NO₂ and O₃ is appropriate and timely for a number of reasons. These are summarised below.

3.2.1 Meeting public expectation

The public expects that environmental legislation will provide a sufficiently high level of protection against the adverse effects of air pollution on health.

3.2.2 Reflecting current scientific understanding

Environmental legislation needs to reflect the current scientific understanding.

The AAQ NEPM review (NEPC 2011a) found that exposure to SO₂, NO₂ and O₃ is associated with health effects at the levels currently experienced in Australian cities. These health effects include increases in mortality, hospital admissions and emergency department attendances, mainly in people with existing respiratory and cardiovascular disease. There is no evidence from epidemiological studies conducted in Australia and overseas that there is a threshold below which adverse health effects are not observed. This means that any increase in population exposure to these pollutants will lead to an increase in risk to the health of the population. The AAQ NEPM review concluded that there was sufficient evidence to support the review of the standards in the AAQ NEPM.

The current AAQ NEPM standards were made in 1998 and were based on the understanding of the health effects of the air pollutants at the time. Subsequent epidemiological studies worldwide, including in Australia, have led to a much better understanding of the health effects of SO₂, NO₂ and O₃ and have led to international agencies strengthening their standards for these pollutants. The current AAQ NEPM standards for these pollutants are therefore inconsistent with international benchmarks.

3.2.3 Growth in population and changing demographics

The Australian Bureau of Statistics (ABS) has developed projections for population growth in Australian cities from 2012 to 2101 (ABS 2013). The ABS population predictions for 2012 and the years modelled for this Impact Statement (2016–2040) are shown in Table 3-1. Over the period of the analysis, substantial population growth is predicted. The projected growth in population will tend to be associated with, for example, increased motor vehicle ownership and vehicle-kilometres travelled (VKT) or increased domestic emissions. In spite of actions to reduce emissions, such as emission standards and new technologies, this growth could make it more difficult to achieve sustained improvements in air quality. This, in turn, can lead to additional overall population exposure and pressure on health services and the economy. Future changes in climate are likely to contribute to the challenge.

Table 3-1: Population growth predictions for state/territory capital cities

City	Total population (million)				
	2012	2016	2021	2031	2040
Sydney	4.7	5	5.3	6.2	6.9
Melbourne	4.2	4.6	5.1	6.2	7.4
Brisbane	2.1	2.4	2.7	3.4	4
Perth	2	2.2	2.6	3.5	4.5
Adelaide	1.3	1.3	1.4	1.6	1.8
Hobart	0.22	0.22	0.24	0.26	0.29
Darwin	0.13	0.14	0.14	0.15	0.16
Canberra	0.38	0.4	0.46	0.56	0.7

3.2.4 Vulnerable groups and changing demographics

The groups within the population that are most vulnerable to the effects of air pollution are children, people over 65 years of age, and people with existing respiratory and cardiovascular disease (including people with asthma). Population statistics show that the Australian population is ageing, with increasing numbers of people in the '65 years and over' age group. Australia also has one of the highest rates of asthma in the

world, especially in children. In the Australian population as a whole, 11 per cent (or 2.5 million people) had doctor-diagnosed asthma in 2014–2015. In children <15 years of age the rate increased to 18 per cent (AIHW 2011). These figures show there is a large group of people within the population who are vulnerable to the effects of the pollutants under consideration in this Impact Statement.

3.3 Rationale and objectives of government intervention

The principal reason for government intervention is to protect the population from the wide-ranging adverse health effects of SO₂, NO₂ and O₃. Air quality standards provide targets to maintain and drive improvements in air quality, and to avoid risk to public health from air pollution. Standards should be defined in a way that reflects the scientific understanding of pollutant sources, air quality, health impacts, and cost to society. The extent to which government needs to intervene is informed by environmental and economic data.

Government intervention should aim to reduce ambient concentrations of O₃, NO₂ and SO₂, especially in populated areas, taking into account the practical limitations on what can be achieved using traditional methods (i.e. reducing primary anthropogenic emissions).

There is a case for government intervention when market failures are present¹⁸. With respect to air quality the primary market failure is a negative externality. Negative externalities exist where the actions of a party result in a cost to a third party not directly involved in that action. In the case of air pollution, the party responsible for causing the pollution does not bear all of the health costs associated with it. While negative externalities are the most prominent of market failures, some secondary market failures could be addressed through the implementation of abatement measures. For example, it has been argued that some households may not be aware that the way in which they operate wood heaters increases air pollution, preventing them from voluntarily adjusting their behaviour (BDA Group 2013). Air quality abatement measures all involve some form of intervention, either through regulation (emissions standards), disincentives to pollute (e.g. financial penalties) or incentives (grants or subsidies) to take actions that reduce emissions. In doing so, the measures are designed to increase societal welfare.

In the AAQ NEPM the primary objective of government is to attain ‘ambient air quality that allows for the adequate protection of human health and wellbeing’. The AAQ NEPM review concluded that this should be modified to ‘minimise the risk from adverse health impacts from exposure to air pollution for all people wherever they may live’. The absence of a threshold for the health effects of air pollutants has prompted support for more stringent air quality standards and for the adoption of an exposure-reduction approach which seeks to gradually reduce general exposures to pollutant concentrations.

This report indicates that current policy interventions are not limiting emissions and concentrations in line with policy objectives. Government intervention is considered necessary to prompt and accelerate policies and measures to reduce population exposure to SO₂, NO₂ and O₃.

3.4 Possible approaches and options

The desired environmental outcome in managing the gaseous pollutants is the achievement of air quality that allows for the adequate protection of human health and wellbeing. Section 17(b) of the NEPC Act

¹⁸ A market failure is where, in the absence of government intervention, the free market does not allocate goods and services in a way that maximises welfare for all of society. Therefore, government intervention to address the market failure can improve the efficiency of resource allocation.

requires that an impact statement include 'a statement of the alternative methods of achieving the desired environmental outcomes and the reasons why those alternatives have not been adopted'.

There are several approaches to delivering the desired environmental outcome that may be considered. These are:

- no change to the current framework
- Commonwealth legislation
- voluntary guidelines
- inter-governmental agreement or memorandum of understanding
- variation of the AAQ NEPM standards.

A variation of the existing AAQ NEPM is highly likely to be the most appropriate step, and was recommended by the AAQ NEPM review (NEPC 2011a); however, for completeness each of these approaches is considered below.

3.4.1 No change to the current framework

The AAQ NEPM represents a harmonised national framework for the management of ambient air quality. The air quality standards and goals in the AAQ NEPM are intended to achieve equity, in that they provide an equivalent minimum level of protection everywhere from the adverse health effects of air pollutants.

The review of the NEPM considered the following:

- the effectiveness of the measure in achieving its desired environmental outcome, which is 'ambient air quality that allows for the adequate protection of human health and wellbeing'
- the effectiveness of the measure in generating comparable, reliable information on the levels of air pollutants
- the environmental, economic and social impact of the measure, including unintended consequences
- the simplicity, efficiency and effectiveness of the administration of the measure, including the adequacy of its support mechanisms
- any regional environmental differences in Australia and the implications for the measure; the links between the AAQ NEPM and other government policies (including other NEPMs) and the potential for integration
- the need, if any, for varying the measure, (in accordance with the Act) including:
 - whether any changes should be made to the Schedules
 - whether any changes should be made to improve the effectiveness of the measure in achieving the desired environmental outcome set out within it
 - the potential costs and benefits of any proposed changes.

The review concluded that the AAQ NEPM has been successful in developing a national approach to the monitoring and assessment of air quality in Australia (NEPC 2011a). The review also found that implementation of the AAQ NEPM has led to a greater understanding of air quality in Australia which has, in turn, led to an improved understanding about the health impacts of air pollution on the community. There has also been a marked reduction in emissions of some pollutants since the AAQ NEPM was made. The review noted that governments now have the opportunity to act more strategically to manage and further improve air

quality in Australia, moving beyond strict compliance with the standards to a focus on reducing population risk and recommended changes to the AAQ NEPM framework that would enable this to occur. Some of these changes were adopted in the 2016 variation to the AAQ NEPM for the particle standards.

Should the AAQ NEPM continue in its current form, this framework will continue. The arguments to maintain the status quo rely on the ability of the current AAQ NEPM standards to achieve the desired environmental outcomes (historically and in the future), and that actions taken by jurisdictions to date are adequate to reduce levels of these pollutants.

The status quo needs to account for the evolution of scientific information around the health and environmental impacts of SO₂, NO₂ and O₃ over time. The NEPC (2011a) concluded that there are health effects currently being experienced in the Australian population at levels below the current standards. This implies that the desired environmental outcome of the AAQ NEPM is not being met. If the AAQ NEPM is not varied to reflect the current scientific knowledge about the health effects of these pollutants, individual jurisdictions may develop vastly different standards leading to potential inconsistencies in the management of air quality across Australia. It would therefore be advisable to consider approaches other than continuing with the AAQ NEPM framework in its current form.

3.4.2 Commonwealth legislation

It is unlikely that the Commonwealth Government, given its powers under the Constitution, could introduce legislation that could deliver the desired environmental outcomes being pursued through the variation to the AAQ NEPM. Furthermore, the Commonwealth is unlikely to pursue unilateral action to set air quality standards given the cooperative national approach being taken at present in relation to environmental issues, particularly through the NEPC and the development of the National Clean Air Agreement, and the fact that the states have responsibility for air quality management. In addition, the Commonwealth is not well placed to play a hands-on role in data collection, analysis and reporting of air quality data, and would have to invest considerable resources to duplicate systems that are already in place at the state and territory level. The AAQ NEPM was developed to overcome the inherent difficulties of the Commonwealth legislation on air quality. This logic still applies, and therefore Commonwealth legislation is not considered to be a feasible approach and has not been included in the impact analysis.

3.4.3 Voluntary guidelines

The National Health and Medical Research Council (NHMRC) has previously determined a set of air quality guidelines for some of the major air pollutants, based on their human health effects. These guidelines have subsequently been revoked with the implementation of the AAQ NEPM. The NEPC was established with the ability to develop standards for ambient air quality. The clear intention at the time of making the AAQ NEPM was that the AAQ NEPM standards would replace NHMRC guidelines for air quality, which has occurred. Therefore, there are no current guidelines in Australia that could be adopted. Indeed, the use of voluntary guidelines would represent a retrograde step in air quality management in Australia. Therefore, voluntary guidelines are not considered a feasible approach and have not been included in the analysis.

3.4.4 Inter-governmental agreement or memorandum of understanding

Inter-governmental agreements were also considered as part of the impact assessment for the variation to include PM_{2.5} in the AAQ NEPM (NEPC 2002); however, it was concluded that this approach would not necessarily provide a sufficient degree of uniformity in the standard-setting process, or in the monitoring and reporting requirements necessary to make the standards meaningful. This approach offers no obvious advantage over the AAQ NEPM variation approach; a similar process would be required, but without the

likelihood of achieving uniformity in practice. Therefore, this approach is not considered feasible and has not been included in the impact analysis.

3.4.5 Variation of the standards in the National Environment Protection (Ambient Air Quality) Measure

A variation to the AAQ NEPM standards will continue to facilitate a harmonised national framework for monitoring and reporting of SO₂, NO₂ and O₃ in conjunction with the framework already established under the AAQ NEPM.

National air quality standards are intended to achieve the NEPC objective of providing equivalent protection, in this case from the adverse health effects associated with air pollution. AAQ NEPM standards provide a well-defined objective for management of air quality, enhancing national certainty in environmental protection.

As indicated above, other means of approaching the issue, apart from varying the AAQ NEPM, would not provide a sufficient degree of uniformity or compatibility in the standards setting process or the monitoring and reporting requirements necessary to make the standards meaningful. The review of the AAQ NEPM found that it has been effective in driving greater understanding of air quality in Australia and in providing a nationally consistent approach to the monitoring and reporting of air quality.

3.5 Consequences of not varying the National Environment Protection (Ambient Air Quality) Measure

If the variation to the AAQ NEPM is not made, the existing standards for SO₂, NO₂ and O₃ may not protect the health of the Australian population to a level that is based on contemporary science and evidence, meaning the desired environmental outcomes of the AAQ NEPM are not met. The risks of not updating the AAQ NEPM standards can be effectively stated in terms of the health impacts and associated costs to society under the BAU scenario.

Without national consistency, some jurisdictions may adopt standards that reflect the most recent health evidence, but these may vary between jurisdictions. This could result in differing environmental performance requirements between jurisdictions, which would fail to deliver the objectives of the Inter-Governmental Agreement on the Environment, in particular the goal of the National Competition Policy, the 'level playing field' and certainty for business decision-making objectives. Voluntary attempts to achieve harmonisation between jurisdictions have had mixed success. The NEPC was specifically established to overcome the problems associated with those voluntary attempts in a manner consistent with the nature of Australian governance.

3.6 Issues to be addressed in the variation

Consideration of the alternatives demonstrates a variation of the AAQ NEPM as the preferred option for SO₂, NO₂ and O₃, as it is considered to be the most effective way to achieve national consistency in the standards adopted for the protection of human health and the environment in Australia.

Given there is no threshold for the effects of the pollutants under consideration in this review, consideration needs to be given to addressing the risks posed to the health of the Australian population by exposure to these pollutants. The issues that affect the level of protection offered by the standards and associated frameworks are:

- the numerical values of the standards

- the form of the standards, and the need for exceptional event rules
- the need and feasibility of exposure-reduction frameworks.

The AAQ NEPM review (NEPC 2011a) recommended that allowable exceedances be removed from the AAQ NEPM and an exceptional events rule be introduced to account for major natural events. Together with the introduction of an exposure-reduction framework, the AAQ NEPM review concluded that this will provide a stronger framework for the protection of population health.

Chapter 3 – Key points

- The most effective way to ensure future consistency in national air quality management and data collection will be a variation to the existing AAQ NEPM, with states and territories using the AAQ NEPM provisions in their own jurisdiction, as is currently done.

Chapter 3 – Consultation questions

- Do you agree with the assessment of options in this report? Have any options been missed?
- Do you agree with the preferred option to vary the AAQ NEPM? In particular, do you agree that continued government involvement is required to address the current and potential future health impacts and costs of SO₂, NO₂ and O₃?

4 Methodology

4.1 Standard-setting methodology

In 2011, the NEPC released the *Methodology for Setting Air Quality Standards in Australia* ('standard-setting methodology') together with the *National Environment Protection (Ambient Air Quality) Measure Review Report* (NEPC 2011a, 2011b). The standard-setting methodology establishes the framework to guide the development of air quality standards in Australia and provides detailed guidance on the approach to be used for exposure assessment and risk characterisation.

The NEPC Act requires consideration of the precautionary principle in the making of a variation of an NEPM. The WHO (2004) notes that, in the application of the precautionary principle, there is no single universal approach. What is considered an 'acceptable risk' or sufficient evidence to act is a function not only of the level of risk and the strength of evidence and uncertainty, but also:

- the magnitude, reversibility and distribution of the risk
- the availability of opportunities to prevent risk
- the public's risk aversion
- society's culture and values.

In setting air quality standards, the level of health protection afforded by a given standard is balanced against the costs and benefits associated with meeting that standard. The final standard is set at the level that encompasses the best overall outcome. The achievability of a standard must also be taken into account. For example, if background pollutant levels (e.g. of O₃ and PM₁₀) from natural sources are high, then in setting a standard for these pollutants, the assessment of risk and associated costs and benefits must include the anthropogenic component. The aim in setting the standard is to minimise the risk while balancing the costs, benefits and achievability of the standard. The costs of not changing the standards also need to be considered as well as an assessment as to whether or not changing the standards is consistent with the requirements of the NEPC Act and the desired environmental outcome of the AAQ NEPM.

In assessing the alternative standards for adoption into the AAQ NEPM and their effectiveness in reducing health impacts if they were met, and therefore the minimising the risk to the population, the following factors have been considered:

- application of the precautionary principle
- current health burden attributable to the pollutants under consideration
- health effects avoided if the alternative standards could be met
- achievability of the standards within a 10-year timeframe
- impact of population growth and the demographics of the population over time – for example, the predicted ageing population which will increase a sensitive population group
- minimising risk to the health of the population, which includes consideration of an exposure-reduction framework and the form of the standard
- feasibility of implementation of actions that could lead to improvements in air quality over time

- whether such actions would lead to improvements in air quality across whole populations or within local areas that are impacted by significant sources
- costs and benefits associated with improvements in air quality and the implementation of the management actions.

The approach taken in this Impact Statement for SO₂, NO₂ and O₃ was consistent with the standard-setting methodology. Each pollutant was addressed separately, and the steps in the assessment are summarised in the following sections. More detailed descriptions of the specific elements can be found in Appendices A (air quality study), B (health risk assessment) and C (cost–benefit analysis). The main steps were:

- Step 1: Health effects update
- Step 2: Review of international air quality standards
- Step 3: Proposed air quality standards
- Step 4: Analysis of historical air quality
- Step 5: Projections of future air quality. This involved the development of emissions projections (based on ambient monitoring trends, inventories, and population projections), and atmospheric dispersion modelling of the BAU and Abatement Package scenarios
- Step 6: Health risk assessment (HRA). This involved conversion of the predicted concentrations into health outcomes which were used as inputs to the cost–benefit analysis.

An overall cost–benefit analysis was also conducted. In this, the three pollutants were considered together rather than individually.

4.2 Step 1: Health effects update

The review of the AAQ NEPM found that, in the time since the AAQ NEPM was adopted in 1998, there was significant new evidence on the health effects of air pollution both in Australia and internationally (NEPC 2011a). This was discussed in detail in the *Discussion Paper: Air Quality Standards* (NEPC 2010). As part of this Impact Statement a detailed literature review was conducted to identify any international work that had been undertaken since the AAQ NEPM review report was released, as well as any new epidemiological or toxicological studies that would provide any new evidence to inform the review of the standards for SO₂, NO₂ and O₃. This approach was consistent with the standard-setting methodology. The full literature review can be found in Appendix B (HRA), and for each pollutant a summary is provided in the relevant chapter.

The literature review found there have been more recent assessments by the WHO and the USEPA since 2011. The information in these reports was summarised, and any new or emerging information on the potential health effects identified. The review of the primary literature found that, even since the international reviews had been completed, new studies had been published that added to the understanding of the health effects under consideration in this Impact Statement. In particular, the evidence for the long-term effects of O₃ and NO₂ has increased. This new information was used in the HRA.

4.3 Step 2: Review of international air quality standards

Since the AAQ NEPM standards for SO₂, NO₂ and O₃ were adopted in 1998 several countries and agencies have conducted reviews of their air quality standards to reflect the current understanding of health effects. The standards in some jurisdictions have been derived to protect vegetation as well as human health. A review of the standards currently in force or recommended internationally for SO₂, NO₂ and O₃ was conducted, and the findings are presented in the corresponding assessment chapters.

4.4 Step 3: Proposed air quality standards

For this Impact Statement, various proposed standards were developed for each pollutant and averaging period as (more stringent) alternatives to the current AAQ NEPM standards. The proposed standards for each pollutant are provided in the corresponding assessment chapters.

The proposed standards were identified through a review of international literature and regulations, including the WHO Air Quality Guidelines, the 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 jurisdictions). The Air TOG has since been reformed as the Air Project Management Group (APMG).

Some specific considerations of this review included the ongoing need for a standard for annual mean SO₂ (which is included in the AAQ NEPM but is not widely used internationally), and the need for a rolling-average 8-hour standard for O₃ (which is used internationally but is not in the AAQ NEPM).

4.5 Step 4: Analysis of historical air quality

An analysis of ambient air quality monitoring data for the period 2002–2016 was conducted to provide historical context with respect to concentrations of SO₂, NO₂ and O₃ in Australian airsheds, and to contribute to the assessment of achievability of the proposed standards. The analysis 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 identified historical trends in concentrations and established the level of compliance with the current and proposed AAQ NEPM standards in each airshed. The full results of the assessment are shown in detail in Appendix A, and summaries for each pollutant are provided in the corresponding assessment chapters of this Impact Statement.

4.6 Step 5: Projections of future air quality

4.6.1 General approach

Future projections of air quality were determined for specific years (2016, 2021, 2031 and 2040). The future projections included a 'Business-as-Usual' (BAU) scenario and an 'Abatement Package' scenario, involving the implementation of a single package of emission-reduction measures.

The approach used for each jurisdiction was tailored according to the available information, with the most detailed treatment being possible for NSW and Victoria.

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 and the Latrobe Valley, which included Melbourne, Geelong and the Latrobe Valley.

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

- They had the most up-to-date, model-ready atmospheric emission inventories.
- They had previously used dispersion and 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 Australian cities and states.

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 NO₂ and SO₂ only). Given the complex photochemistry involved in O₃ formation and removal, this method could not be applied to O₃.

Pollutant concentrations and exceedances of air quality standards were determined for the projection years in the modelled airsheds.

4.6.2 Scenario definition

4.6.2.1 'Business-as-Usual' scenario

To construct the BAU scenario, the underlying future changes in population and activity were built into the jurisdictional emission projections. It was assumed that there would be no changes in legislation; 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 (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)¹⁹.
- *Wood heaters.* It was assumed that the Australian Government's December 2015 decision on the future management of this source would take effect²⁰.
- *Non-road spark-ignition engines and equipment.* For these sources the Australian Government's December 2015 policy decision on future management would take effect²¹.
- *Shipping.* The effects of the reduced sulfur content of marine fuel to a maximum of 0.5 per cent (MARPOL) was implemented; however, this had very little influence on the modelled concentrations.

It is important to note that several industrial sources are scheduled to close prior to 2040, including old, coal-fired power stations in NSW and Victoria. These closures were not all included in the projections. The main effect of this will be that SO₂ emissions and concentrations from industry in the BAU scenario, and the effects of any associated abatement measures, are overestimated in the Impact Statement.

4.6.2.2 'Abatement Package' scenario

In addition to the abatement measures already included in the BAU scenario, achieving a further reduction in the concentrations of SO₂, NO₂ and O₃ would require the implementation of additional measures. For this Impact Statement, a selection of additional measures were modelled as a single 'Abatement Package' scenario, the development of which is described in Appendix A and Appendix C. The 'package' approach is particularly important when considering pollutants that are chemically reactive and influenced by the presence of other pollutants, such as those under consideration in this review.

¹⁹ 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 the sulfur content of petrol in Australia will be reduced in the medium-to-long term.

²⁰ Wood heater emission-reduction strategies have been implemented under the National Clean Air Agreement.

²¹ National emission standards for small petrol engines came into effect from January 2018.

An initial list of 18 additional measures was developed through a literature review and a jurisdictional working group. These 18 measures were then subjected to a multi-criteria analysis (MCA) to identify a preferred combination of measures. The MCA considered, with weightings, aspects such as the quantum of emissions abatement (30 per cent weighting), cost (30 per cent weighting), potential health benefits (10 per cent weighting). Other factors considered included reliability, targeting of costs to the source, timeframe for implementation, technological status, co-benefits, and disbenefits (5 per cent weighting for each). The outcomes of the MCA, and the top three measures for each pollutant – oxides of sulfur (SO_x), oxides of nitrogen (NO_x) and VOCs (as a precursor to O₃) – are summarised in Table 4-1.

Table 4-1: Abatement measures selected for inclusion in the Abatement Package scenario (measure reference number in brackets)

SO _x	NO _x	VOCs (O ₃ precursor)
<ul style="list-style-type: none"> De-SO_x, de-NO_x and gas capture storage standards for power stations (9)^(a) De-SO_x at petrol refineries (14) De-SO_x at iron and steel production (15) 	<ul style="list-style-type: none"> De-SO_x, de-NO_x and gas capture storage standards for power stations (9)^(a) Emission standards for non-road diesel engines (6) Industry NO_x control technology – cement, iron and steel and aluminium industry (13) 	<ul style="list-style-type: none"> VOC control for solvent aerosol use (16) Surface coating standards (10) On-board refuelling vapour recovery (1)

(a) This measure targeted both SO_x and NO_x.

4.6.3 Emission projections

4.6.3.1 Business-as-Usual scenario

Airshed emissions and air quality under the BAU scenario were projected into the future. This enabled the calculation of attributable health risks and the costs and benefits of potential changes to the standards and the effects of the Abatement Package scenario.

The projections also enabled an assessment of the achievability of the potential standards in the future. Emissions were projected over the period 2015 to 2040 for all airsheds, taking into account the likely effects of changes in population and activity on the major emission sources in each airshed. The assumptions used to define the emission projections in the BAU scenario are described in Appendix A.

Detailed emission inventories were available for airsheds in NSW (Sydney, Newcastle and Wollongong) and Victoria (Melbourne and Latrobe Valley). For these airsheds the emission inventories were provided by NSW EPA and EPA Victoria. Where current emission inventory projections were available for the other jurisdictions, these were referenced, otherwise emission data were taken from the National Pollutant Inventory (NPI) – noting that NPI data is based on estimates. The projections took into account the likely changes in major emission sources within each airshed. The detailed, spatially defined emission inventories provided by NSW EPA and EPA Victoria were used to define the emission inputs for all sources in the respective airsheds to allow the calculation of photochemistry and subsequent pollutant concentrations.

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 the NSW Office of Environment and Heritage for this Impact Statement. The inventory contained projections for the years 2011, 2016, 2021, 2026, 2031 and 2036.

Victoria's most recent official emission inventory was completed in 2006 (Delaney & 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 proposed methods to reduce air pollution (EPA Victoria 2013). The inventory contained emission estimates for the year 2006 and 2030. A linear interpolation was assumed for years between 2006 and 2030, and then extrapolated for years after 2030 using population data.

The BAU emission inventories for the other jurisdictions were based on the published data sources outlined in Appendix A.

4.6.3.2 *Abatement Package scenario*

The additional abatement measures identified through the MCA were included in the air dispersion modelling for NSW (Sydney, Newcastle and Wollongong) and Victoria (Melbourne, Latrobe Valley) to predict the future air pollution levels if the abatements were implemented. It was assumed that the measures would be implemented from 2020, with gradual uptake until 2040. This timing allowed for the regulatory or enabling mechanisms, and/or design and approval processes that would be required for any infrastructure changes.

The emission reductions associated with the Abatement Package were estimated using a high-level review approach. The reductions were indicative, and the measures were not verified with specific industries to determine the feasibility of implementation, site-specific cost considerations, and the extent to which industry may have already partially implemented them. Similarly, the emission reductions did not take into account any jurisdiction-specific management or enforcement tools that may be available. Jurisdictions may have suitable mechanisms in place to influence the implementation of the measures, and to expedite the delivery of emission reductions locally.

4.6.4 **Air quality projections**

4.6.4.1 *Model selection*

A detailed discussion of the air dispersion modelling is provided in Appendix A. Different model systems were used to determine the fate and transport of emissions in NSW and Victoria. Each model system comprised a prognostic meteorological model, a chemical transport model, and post-processing suitable for the estimation of both changes in air quality and associated population exposure.

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. Both CCAM and TAPM use complex chemical mechanisms to predict the airshed chemistry under different emission scenarios, which is important when considering SO₂, NO₂ and O₃. 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 work. It was beyond the scope of the work to develop new models.

4.6.4.2 *Non-modelled airsheds*

For other (non-modelled) airsheds, the future air quality projections were based on a similarity analysis, whereby conditions in the airshed were compared with those in the NSW and Victoria airsheds, and a representative projection was allocated.

4.7 Step 6: Health risk assessment

The HRA is described in Appendix B. It was conducted in accordance with both the NEPC standard-setting methodology (NEPC 2011b) and the methodology used by Frangos and DiMarco (2013) in an earlier HRA. The HRA for this Impact Statement calculated the following:

- the health burden attributable to each of the pollutants under consideration arising from historical concentrations
- the future health burden under both the BAU and Abatement Package scenarios
- the number of health outcomes that would be avoided if the potential standards could be met.

Both long-term (chronic) and short-term (acute) effects on health were considered. It is worth noting that long-term effects are a result of exposure to pollutants over a long period of time (months or years), whereas acute effects are associated with short-term exposure to air pollutants (such as following a high pollution day). The acute impacts (e.g. mortality) are many times smaller than chronic impacts.

4.7.1 Concentration-response functions

A concentration-response function (CRF) defines the increase in a health outcome per unit increase in pollutant concentration (see Section 2.3 of Appendix B). Specific CRFs for Australian studies have been developed (e.g. Jalaludin & Cowie 2012); however, two more recent international projects coordinated by the WHO Regional Office for Europe have significantly updated the health evidence and the basis for assessment:

- *Review of evidence on health aspects of air pollution (REVIHAAP)* (WHO 2013a)
- *Health risks of air pollution in Europe (HRAPIE)* (WHO 2013b).

For NO₂ and O₃ the HRAPIE CRFs were considered to be the most robust available in the literature and incorporated more extensive and more up-to-date information than the Australian CRFs. Some of the CRFs for NO₂ and O₃ from HRAPIE were therefore adopted for this Impact Statement in preference to the ones developed previously for Australia. For SO₂ the CRFs were taken from various sources.

Three groups of CRFs were used in the work (further details are provided in the pollutant-specific chapters of Appendix B):

- **Group 1 CRFs.** This group included the recommendations from the HRAPIE project for NO₂ and O₃ and drew upon various studies for SO₂.
 - For NO₂ and O₃ the CRFs from HRAPIE were used in preference to the ones developed previously for Australia. In line with the recommendation by the WHO (2013b), the Group 1 CRFs applied the HRAPIE cut-off²² for annual average NO₂ of 20 µg/m³, and the cut-off for daily maximum 8-hour O₃ of 35 ppb. This is because the shape of the CRF curves below these cut-offs is highly uncertain.
 - For SO₂ the CRFs for 1-hour and 24-hour exposures were taken from various sources, as recommended by Jalaludin and Cowie (2012). No studies investigating the long-term effects of exposure to SO₂ on health were identified.

²² In this report the term 'cut-off' is used where a lower limit is applied to a CRF because there are insufficient data to characterise the CRF at lower concentrations. It should be noted that this is not the same as the threshold for the health effects of air pollution.

- *Group 2 CRFs.* This group used the same CRFs as Group 1; however, the 20 µg/m³ and 35 ppb cut-offs for mortality from long-term NO₂ and short-term O₃ exposure were not applied. The rationale for excluding the cut-offs was that, while the shape of the CRFs below these levels is unclear, this does not necessarily mean no health outcomes can be assumed. The data used to derive the CRFs recommended by WHO (2013b) were from Europe, where concentrations in major airsheds often exceed these levels; however, concentrations of these pollutants in major Australian airsheds are different to those in Europe. In particular, NO₂ concentrations in Sydney and Melbourne are below those in many of the major European cities.
- *Group 3 CRFs.* This group includes only Australia-specific CRFs. The CRFs for NO₂ and O₃ were taken from a review by Australian epidemiologists prepared for EPA Victoria, entitled *Health Risk Assessment – Preliminary Work to Identify Concentration-Response Functions for Selected Ambient Air Pollutants* (Jalaludin & Cowie 2012). The SO₂ CRFs were the same as those in Group 1.

NB: The HRA was based primarily on the Group 1 CRFs, and the health outcomes and CRFs for this group are summarised in Table 4-2. The Group 2 and Group 3 CRFs were included in the work to examine the sensitivity of the HRA (and cost–benefit analysis) results to CRF selection.

The air quality data were combined with these CRFs and baseline health statistics for each location, to calculate the number of attributable health outcomes due to each pollutant. The baseline mortality data (rate/100,000 population) were obtained from the ABS for 2010–2014, and for all airsheds assessed in the HRA. Hospital admissions data and emergency department data for each outcome and age group considered were obtained from the relevant state/territory health departments. The population data used in the risk characterisation were obtained from the most recent ABS estimates for 2010–2014, as well as for the projections out to 2040.

4.7.2 Historical health burden

For current air quality, the air monitoring data from all jurisdictions were used in the exposure assessment. The data were limited to the designated air monitoring stations under the AAQ NEPM. The monitoring data were averaged for the relevant averaging periods across all stations to provide a ‘network average’. This was consistent with the exposure data used in epidemiological studies that have identified adverse health effects in a population, and with the ‘standard-setting methodology’. For NO₂ and O₃ natural background levels were subtracted from the monitored levels, which means the calculated health risks related to anthropogenic sources only. The background levels used were those contained within the report by Frangos and DiMarco (2013) and were 8.7 ppb for O₃ and 2.1 ppb for NO₂. No natural background levels for SO₂ were identified, as there are no significant natural sources in the Australian airsheds.

4.7.3 Future health burden

The results of the air dispersion modelling for the BAU and Abatement Package scenarios were used in the exposure assessment for projected air quality to 2040. As with the monitoring data, the values predicted for the locations where AAQ NEPM monitoring stations are currently located were averaged to give a network average. These values were adjusted for natural background levels. This assumed that background levels would not change during the period 2016–2040.

Table 4-2: Health outcomes and CRFs for SO₂, NO₂ and O₃ (Group 1)

Averaging period/ statistic	Health outcome (age group in years)	SO ₂		NO ₂		O ₃	
		CRF ^(a, b)	Source	CRF ^(a, b)	Source	CRF ^(a, b)	Source
Annual average	Annual all-cause ^(c) mortality (30+)	–	–	0.94 (0.53 – 1.37) [cut-off at 20 µg/m ³]	WHO (2013b)	–	–
	Annual cardiovascular mortality (30+)	–	–	–	–	–	–
	Annual respiratory mortality (30+)	–	–	–	–	–	–
24-hour average	Daily all-cause ^(c) mortality (all)	0.17 (0.13 – 0.20)	Anderson et al. (2007)	–	–	–	–
	Hospital admissions for cardiovascular disease (65+)	–	–	0.30 (0.07 – 0.53)	EPHC (2005)	–	–
	Hospital admissions for respiratory disease (65+)	–	–	0.37 (0.24 – 0.50)	WHO (2013b)	–	–
	Hospital admissions for respiratory disease (15–64)	–	–	0.37 (0.24 – 0.50)	WHO (2013b)	–	–
	Emergency department visits for asthma (<15)	2.00 (0.88 – 3.00)	Jalaludin et al. (2008)	0.12 (0.12 – 0.33)	EPHC (2005)	–	–
Daily maximum 8-hour	Daily all-cause ^(c) mortality (all)	–	–	–	–	0.06 (0.03 – 0.09) [cut-off at 35 ppb]	WHO (2013b)
Daily maximum 1-hour	Daily all-cause ^(c) mortality (all)	–	–	0.06 (0.03 – 0.08)	WHO (2013b)	–	–
	Hospital admissions for respiratory disease (65+ years)	0.52 (0.19 – 0.87)	Simpson et al. (2005a,b)	–	–	–	–
	Emergency department visits for asthma (<15)	–	–	–	–	0.10 (0.08 – 0.18)	EPHC (2005)

(a) Percentage increase in health outcome per 1 ppb increase in concentration.

(b) Central estimate and 95 per cent confidence interval.

(c) 'All-cause mortality' refers to acute mortality events that are estimated to shorten life by six months.

4.7.4 Health outcomes avoided by meeting standards

To assess the health outcomes avoided by meeting the proposed standards, a 'roll-back' procedure was applied. The percentage reduction in concentration required for the maximum value across the network to comply with the potential standard was determined, and then applied to the yearly dataset. These data were then used to calculate the number of health outcomes avoided if the standards could be met. More details of this approach can be found in Appendix B.

To enable assessment of the attributable health effects in each jurisdiction, baseline health data were obtained. The mortality data for 2010–2014 were obtained from the Australian Bureau of Statistics for all cities and regional centres considered in the HRA. Hospital admissions and emergency department data were obtained from the relevant state/territory health departments for the same locations and the same time period. For the projected years, the latest 2014 data were used as the baseline data.

Population data were obtained from the ABS, including projections out to 2040 for all age groups considered in the HRA.

The risk characterisation calculated the number of attributable health outcomes for each pollutant and each scenario assessed. The year 2010 was assessed in both the current HRA and in the report by Frangos and DiMarco (2013). The results from the current HRA are consistent with those of Frangos and DiMarco (2013).

4.8 Cost–benefit analysis

4.8.1 Purpose

A cost–benefit analysis (CBA) was conducted to provide economic evidence to support the assessment of the proposed standards (see Appendix C). The CBA provided estimates for the following:

- the cost of the existing health burden for SO₂, NO₂ and O₃ in present value (PV) terms, based on the HRA data for 2010–2014
- the costs and benefits of the Abatement Package scenario.

The abatement measures targeted sources of SO_x, NO_x and VOC emissions. The assessment of costs and emission reductions was based on publicly available data. The monetary benefits were estimated based on the health outcomes from the HRA.

4.8.2 Overview of approach

The CBA considered the incremental costs and benefits of emission reductions associated with the implementation of the Abatement Package. Costs represented the economic resource costs associated with the implementation of the abatement measures, which included:

- the incremental capital costs associated with upgrades to machinery, plant and equipment
- the incremental operating and maintenance costs
- administrative and compliance costs
- any co-benefits or disbenefits associated with the abatement measures (e.g. changes to fuel consumption, etc.), which offset or increase the costs respectively.

Benefits were valued based on the emission reductions achieved. A reduction in emissions was estimated to result in a change in pollutant concentrations, which in turn resulted in an overall improvement in health outcomes for the exposed population.

The geographical scope of the CBA was limited to the airsheds for which air quality modelling data were available, and those where the abatement measures were estimated to reduce emissions from the airshed. These included Sydney, Newcastle, Wollongong, Melbourne, Latrobe Valley, Brisbane, Perth, Adelaide and Darwin.

The scope of pollutants was limited to the three gases that are the subject of this Impact Statement (SO₂, NO₂ and O₃) plus PM_{2.5}. The latter was included because some of the abatement measures were expected to reduce PM_{2.5} emissions, and this is expected to deliver substantial benefits to human health because of the strong health evidence on the effects of PM_{2.5}.

The CBA was conducted over a 20-year period (2021–2040) using a 7 per cent per annum real discount rate.

4.8.3 Cost of abatement measures

The costs of implementing the additional abatement measures were calculated over the period (2021–2040) and discounted back to the current period in order to obtain a net present value in 2016 dollars. This was compared with the total quantum of abatement estimated to be achievable through the implementation of the abatement measures to calculate the marginal cost of abatement. Further information on the marginal cost of abatement can be found in Appendix C.

The analysis focused on the direct costs incurred by industry and government. These costs were categorised as follows:

- Capital cost – the cost associated with the purchase and installation of new equipment, or upgrades to existing equipment. This type of cost is typically one-off in nature
- Operating/maintenance cost – the ongoing cost associated with the continued operation or maintenance of equipment. This cost also includes other costs that may be incurred on an ongoing basis by industry or consumers
- Administrative or regulatory cost – the costs incurred by either industry or government associated with compliance with the new abatement measures.

The key outcome of the cost–benefit analysis was an estimate of the costs relating to the implementation of each abatement measure in the Abatement Package.

4.8.4 Valuation of benefits

Where the data were available, the CBA estimated the benefits associated with reductions in SO₂, NO₂ and O₃ concentrations by considering the following:

- reduced quantity of emissions (tonnes per annum)
- resulting change in concentrations of SO₂, NO₂ and O₃ in each airshed
- resulting change in population exposure to these pollutants
- projected difference in health outcomes associated with that change in exposure, as provided by the HRA
- value of those health outcomes, expressed in monetary terms.

This approach is referred to as the ‘impact pathway’ approach (Defra 2013).

Data on health outcomes provided by the HRA included:

- premature mortality (deaths brought forward)
- hospital admissions related to cardiovascular and respiratory diseases
- emergency department visits.

The economic costs avoided from reductions in these outcomes were estimated based on the willingness to pay (WTP) of the population to avoid the risk of premature mortality or a reduced quality of life, avoided hospitalisation costs, and the avoided loss in productivity associated with having to take time off work. The avoided risk of premature mortality, which is the most material of the health outcomes in monetary terms, was valued based on a study published by the Australian Safety and Compensation Council (ASCC 2008).

Some abatement measures that targeted NO_x emissions also reduced $\text{PM}_{2.5}$ emissions. Of the abatement measures selected for analysis in this Impact Statement, Measure 6 (non-road diesel engine standards) reduced emissions and therefore concentrations of $\text{PM}_{2.5}$ in the atmosphere. The benefits of the $\text{PM}_{2.5}$ emission reductions were valued using the damage costs provided by PAEHolmes (Aust et al. 2013). The damage cost approach was applied by estimating a cost per tonne of emissions (\$ per tonne) for each airshed, or in this case a benefit per tonne of emission reduction, and applying that figure to the estimated change in emissions. Moreover, measures that reduce NO_x and SO_x emissions also contribute to reduced formation of secondary particulate matter (nitrate and sulfate particles); however, the potential reduction in secondary PM is highly uncertain. Therefore, the CBA does not include the benefits of secondary PM reduction.

The avoided benefit per tonne of NO_x and SO_x reductions was estimated using the results of the impact pathway analysis. This approach is consistent with previous studies, which have calculated damage costs by first collating \$ per tonne estimates based on impact pathway results, and then regressing this data against the population density of the corresponding airsheds. This type of regression is used because the economic cost per tonne of pollutant is known to be related to the population density of the corresponding airshed. The results of the regression are then used to estimate the economic cost per tonne (the ‘unit damage cost’) in any airshed by using the population density of that airshed.

To avoid double counting, the CBA only includes changes to either long-term mortality (chronic effects) or short-term mortality (acute effects) from exposure to pollutant concentrations, but not both, as this can risk double counting health impacts. This adjustment is only relevant for NO_2 , which includes both long-term and short-term health endpoints.

Similarly, only the outcomes associated with exposure to SO_2 concentrations, measured as a daily average concentration, are included. These include mortality and emergency department visits for asthma. While the HRA includes an outcome associated with exposure to SO_2 concentrations measured as the maximum 1-hour concentration for each day, this has been excluded to avoid potential double counting.

The WHO (2013b) also recommends a reduction of up to 33 per cent for estimated mortality due to NO_2 exposure where mortality associated with $\text{PM}_{2.5}$ exposure is also estimated. Consistent with the approach used by Defra (2015), a 16.6 per cent reduction in mortalities associated with NO_2 exposure is applied.

4.8.5 Non-quantified benefits

A number of benefits could not be reliably quantified due to limited data. These include reduced labour productivity, a reduction in the emission of other pollutants, avoidance of some non-health impacts, and a reduction in secondary PM formation. These are considered in Appendix C (CBA).

Chapter 4 – Key points

- The approach taken in this Impact Statement is consistent with the Methodology for Setting Air Quality Standards in Australia (NEPC 2011b) and standard-setting methodologies used internationally.
- Each pollutant was assessed individually using a combination of the impact pathway approach and the damage cost approach, based on data availability. The main steps include reviews of the health evidence for these pollutants and of international air quality standards, analysis of historical air quality and projections of future air quality, and a health risk assessment compared to proposed air quality standards.
- A cost–benefit analysis (CBA) was also conducted to assess the costs and benefits of possible abatement measures to lower concentrations of these pollutants. In this, the three pollutants were considered together rather than individually, to account for the interactions between pollutants in the Abatement Package.

Chapter 4 – Consultation questions

- Have all key assumptions been correctly identified and included in the analysis? If not, please provide details.
- Can you suggest any improvements to the methodology used in this report for future reviews?

5 Assessment of desired environmental outcome and goal

5.1 Background

The desired environmental outcome of the AAQ NEPM is 'ambient air quality that allows for the adequate protection of human health and wellbeing'. The goal of the AAQ NEPM is to achieve the specified air quality standards and, in the case of PM_{2.5}, to achieve (by 2025) further reductions in maximum concentrations. During the review of the AAQ NEPM (NEPC 2011a), various issues with the definition of the desired environmental outcome and the goal were identified, which meant they were not compatible with the concept of adequate protection of human health and wellbeing. These issues are discussed briefly below.

5.2 Discussion

Firstly, during the review of the AAQ NEPM it was apparent that the meaning of 'adequate protection' was ambiguous, and there was no shared understanding of what it meant. Some stakeholders requested absolute protection from the health effects of air pollution. This needs to be clarified.

The desired environmental outcome should be revised to consider principles of environmental justice, acknowledge the health risks associated with air pollutant exposure (see below) wherever people live, and that implementation of the AAQ NEPM would aim to minimise these risks as much as possible by providing better protection.

Air quality standards and long-term goals provide drivers to improve air quality, and to ensure that air pollution levels – and the associated risk to public health – do not increase in the future. Standards should be defined in a way that reflects the scientific understanding of pollutant sources, air quality, health impacts, and cost to society. The proposed change to the outcome and goal (minimising risk) will better drive air quality management strategies.

Secondly, the findings of epidemiology studies have shown there is no evidence of a clear threshold for the health effects of important air pollutants, including those addressed by this Impact Statement. There is also now a large body of information worldwide that identifies health effects associated with exposure to air pollution at levels below the current AAQ NEPM standards. The non-threshold nature of air pollutants means compliance with the standards alone may not achieve the desired environmental outcome of 'adequate protection' for the Australian population against the adverse health effects of air pollution. In addition, the AAQM NEPM standards themselves no longer reflect the current understanding of the health effects of SO₂, NO₂ and O₃, and in particular, the results of studies that have been conducted in Australia.

Through the AAQ NEPM review, it was recommended that the desired environmental outcome be revised to acknowledge the health risks associated with air pollutant exposure, and that implementation of the AAQ NEPM would aim to minimise these risks as much as possible. It was also recommended that, to ensure the requirement of the NEPC Act to provide equivalent protection for all Australians is met, consideration be given to patterns of exposure and reducing risks to the whole population arising from these exposures, and that the desired environmental outcome be amended to focus on minimising risk for all people wherever they may live to all parts of the community (NEPC 2011a).

Given the current understanding of the health effects of the air pollutants under consideration in this Impact Statement, the combination of more stringent standards and a framework to reduce exposure and associated risk to the population, whether the standards are met or not, may be a more effective approach to achieving the desired environmental outcome of the AAQ NEPM. This is consistent with the NEPC standard-setting

methodology, which recommends that an integrated approach for improving air quality that considers the health impacts of air pollution, emission abatement, exposure-reduction and costs, will maximise the net benefit to the Australian community.

The desired environmental outcome should reflect the desire to continuously improve air quality to minimise risk to the health of the Australian population. An exposure-reduction approach in the AAQ NEPM which drives continuous improvement will complement health-based standards that provide equitable protection for all to reduce health impacts from these pollutants now and in the future.

Issues for this Impact Statement included how the desired outcome of the NEPM would be affected by recent health evidence, how to set standards that meet the desired environmental outcome of the AAQ NEPM (i.e. how to achieve adequate protection), and how achievable any alternative standards would be.

5.3 Recommendations

On the basis of this Impact Statement, the recommendations below are made to ensure that the desired environmental outcome and goal of the AAQ NEPM are achieved. These recommendations should be implemented in combination with revised air quality standards for SO₂, NO₂ and O₃, as discussed in Chapters 6, 7 and 8 of the Impact Statement.

Recommendation 1: The desired environmental outcome of the AAQ NEPM should be revised to 'minimise the risk of adverse health impacts from exposure to air pollution for all people, wherever they may live'.

Recommendation 2: The goal of the AAQ NEPM should be revised to make reference to the air quality standards and incorporation of exposure-reduction targets for priority pollutants.

Chapter 5 – Key points

- The AAQ NEPM review (NEPC 2011a) recommended changes to the desired environmental outcome and goal of the AAQ NEPM to acknowledge the health risks associated with air pollutant exposure and consider environmental justice principles.
- The recommended environmental outcome of the AAQ NEPM is consistent with the AAQ NEPM review (2011), which is 'ambient air quality that allows for the adequate protection of human health and wellbeing'.
- The recommended environmental goal of the AAQ NEPM is also consistent with the AAQ NEPM review (2011), which is to achieve the specified air quality standards and, in the case of PM_{2.5}, to achieve (by 2025) further reductions in maximum concentrations.

Chapter 5 – Consultation questions

- Do you support the desired environmental outcome of the AAQ NEPM being revised to 'minimise the risk of adverse health impacts from exposure to air pollution for all people, wherever they may live'?
- Do you support the goal of the AAQ NEPM being revised to make reference to the air quality standards and incorporation of exposure-reduction targets for priority pollutants?

6 Impact assessment for sulfur dioxide

6.1 Characteristics and sources

SO₂ is a colourless gas with a pungent odour. It is known to have adverse effects on human health, and is also a major precursor to acid rain, which is associated with the acidification of lakes and streams, accelerated corrosion of buildings and monuments, and reduced visibility. SO₂ contributes to secondary particle formation by reaction with ammonia to form sulfate salts. This can be a significant contributor to PM_{2.5} concentrations in some airsheds.

Natural sources of SO₂ include geothermal activity (e.g. hot springs and volcanoes) and the decay of vegetation. Anthropogenic SO₂ results primarily from the combustion of fossil fuels containing sulfur (e.g. coal, oil), such as at power stations or smelting facilities. Australian automotive diesel fuels are low in sulfur, but Australian automotive petrol is high in sulfur content compared to 35 OECD member countries. Overall, however, Australian automotive fuel is not a major source of SO₂.

The NPI data for 2014–2015 estimates the following with respect to SO₂ emissions in Australia:

- 94 per cent of emissions were from industrial facilities. The main contributors were electricity generation (50 per cent) and non-ferrous metal manufacturing (43 per cent).
- Six per cent of emissions were from diffuse sources. The main contributors were fuel combustion (55 per cent) and commercial boating/shipping (25 per cent).

The estimates of annual emissions in each Australian airshed (for both facility and diffuse sources) are summarised in Table 6-1. There was considerable variation across the jurisdictions, and this will influence the ambient concentrations and the potential risk to the exposed population.

Table 6-1: Total estimated emissions of SO₂ from industrial facilities and diffuse sources (NPI, 2014–2015)

Jurisdiction/airshed	SO ₂ emissions (tonnes/year)
NSW: Greater Sydney	190,000
VIC: Port Phillip Region	54,000
QLD: South-East Queensland	15,000
SA: Adelaide	1,800
WA: Perth	8,500
TAS: Hobart	1,100
NT: Darwin	540
ACT: Canberra	350

6.2 Health evidence

A detailed, up-to-date review of the health effects of SO₂ can be found in Appendix B, and the main findings are summarised below.

Since the adoption of the AAQ NEPM in 1998, there has been a large amount of research on short-term exposure to SO₂ in ambient air, and this has been extensively reviewed (e.g. USEPA 2008; WHO 2013b). The findings of recent studies have strengthened the evidence that the main health effects associated with SO₂ are short-term effects on the respiratory system. Studies have found that exposure to SO₂ for one hour to 24 hours is associated with increases in daily mortality and hospital admissions, mainly for respiratory causes. Increases in mortality have also been found with cardiovascular disease. Increases in emergency department attendances for children (<15 years) with asthma have also been linked with exposure to SO₂. Children, people over 65 years of age, and people with existing disease (respiratory, cardiovascular and asthma) are the groups that are most susceptible to the effects of SO₂.

Since 1998 there have been a number of Australian studies linking exposure to SO₂ with mortality and morbidity. The results of these studies have shown that the associations found in overseas studies have also been found in Australian cities, even though the SO₂ levels measured in Australia are generally lower than those in North America and Europe.

The evidence for long-term health effects associated with SO₂ is weak, although the data are limited. The lack of consistency across studies, inability to distinguish potential confounding by co-pollutants, and uncertainties regarding the geographic scale of analysis, limit the interpretation of a causal relationship (USEPA 2008). A major consideration in evaluating SO₂-related health effects and long-term exposure is the high correlation, and potential confounding, among the co-pollutant levels observed, particularly between long-term average particle concentrations and SO₂.

6.3 World Health Organization guidelines

The current WHO guidelines for SO₂, as defined in the 2005 global update (WHO 2006), are given in Table 6-2. WHO currently has SO₂ guidelines for 10-minute and 24-hour averaging periods only. Air quality data in Australia and in other leading countries indicate that, in general, SO₂ levels are low, with short-term peaks only experienced at locations close to major sources of SO₂. This has led a number of international agencies to not set a 10-minute SO₂ standard. The global update reduced the 24-hour guideline from 125 to 20 µg/m³ to reflect evidence showing that health effects were associated with much lower levels of SO₂ than previously found. The WHO noted that an annual guideline was not needed, since compliance with the 24-hour level will assure low annual average levels. The REVIHAAP study (WHO 2013b) did not recommend any change to the WHO guidelines for SO₂ but indicated that the evidence should be revisited.

Table 6-2: Current WHO guidelines for SO₂ (WHO 2006)

Agency	Averaging period	Guideline		Form of standard	Allowable exceedances
		ppb	µg/m ³		
WHO	10-minute	175	500	–	None
	24-hour	7	20	–	None

6.4 Air quality standards in other leading countries

The current international standards for SO₂ derived to protect human health are summarised in Table 6-3, with the current Australian (AAQ NEPM) standards shown for comparison. It can be seen that for the 1-hour averaging period in particular, a wide range of values are in use.

The numerical values of the AAQ NEPM standards are higher²³ than those in other leading countries, which is due in part to the change in the understanding of the health effects of SO₂ since the AAQ NEPM was introduced in 1998. The AAQ NEPM standards were based on the understanding at the time. International agencies have since reviewed their standards for SO₂ and have adopted more stringent approaches to reflect the developing understanding of health effects. This means that the Australian standards are not consistent with international benchmarks, which have been set to protect human health in countries that have much higher levels of SO₂, and therefore compliance with the standards would be more difficult than in Australian cities. The focus in setting these standards internationally has been protection of human health and reducing the risk to the health of the population posed by exposure to SO₂.

Table 6-3: International standards for SO₂

Averaging period	Country	Standard ^(a)		Form of standard	Allowable exceedances
		ppb	µg/m ³		
15-minute	United Kingdom	94	266	–	35 times per year
1-hour	Australia	200	572		1 day per year
	US (USEPA)	75	214	99 th percentile of 1-hour daily maximum concentrations averaged over 3 years	None ^(d)
	Canada	70 ^(b) , 65 ^(c)	200, 186	3 year average of annual 99 th percentile of the daily maximum 1-hour values	None ^(d)
	European Union	124	350	–	24 times per year
	United Kingdom	124	350	–	24 times per year
	New Zealand ^(e)	124	350	–	9 times per year
	New Zealand ^(e)	177	570	–	None
24-hour	Australia	80	229		1 day per year
	European Union	44	125	–	3 days per year
	United Kingdom	44	125	–	3 days per year
Annual	Australia	20	57		None
	Canada	5 ^(b) , 4 ^(c)	14.3, 11.4	–	None

(a) Values in italics have been obtained using the conversion factors stated at the start of this Impact Statement.

(b) To be met by 2020

(c) To be met by 2025

(d) A 99th percentile concentration standard effectively allows some exceedances per year.

(e) New Zealand has two standards: one allowing nine exceedances per year and one allowing no exceedances.

6.5 Proposed air quality standards for review

The proposed standards for SO₂ that were investigated in the review, and the existing AAQ NEPM standards, are shown in Table 6-4. The proposed standards were all lower than the existing AAQ NEPM standards, to reflect both the recent health evidence and the more stringent standards in place in other leading countries.

²³ The different forms of the standards mean that a direct comparison is not always possible.

Table 6-4: Current AAQ NEPM standards and proposed standards for SO₂

Pollutant	Averaging period	Concentration (ppb) ^(a)	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

(a) Current AAQ NEPM standards are highlighted with light blue shading.

6.6 Concentrations and exceedances

6.6.1 Historical trends

Appendix A, Section 2.2 presents an analysis of the SO₂ monitoring data from the AAQ NEPM monitoring stations in each jurisdiction over the period 2003–2016.

Overall, there were few clear long-term trends in 1-hour, 24-hour and annual mean SO₂ concentrations. The unique²⁴ exceedance days across all stations for the period between 2003 and 2016 are summarised in Table 6-5 (major cities) and Table 6-6 (regional centres), with exceedances for the more recent period between 2010 and 2014, as used in the HRA, being shown for comparison. Again, the current standards are identified with light blue shading.

For 1-hour SO₂, the analysis showed that the current standard of 200 ppb has been achieved in all airsheds. Exceedances of the proposed standards of 100 ppb and 150 ppb have occurred but have been very infrequent. There have been multiple exceedances of the proposed standard of 75 ppb in some jurisdictions.

For 24-hour SO₂, the current standard of 80 ppb was achieved in all jurisdictions. Compliance with the proposed standards of 20 ppb and 40 ppb has also generally been achieved; however, in several airsheds there has not been compliance with the proposed standard of 7 ppb.

Annual average SO₂ concentrations were low, even though there were peaks in the 1-hour and 24-hour data, indicating that these peaks were infrequent. There has been historical compliance with the most stringent proposed standard of 10 ppb in all airsheds.

Due to the low sulfur content of Australian automotive fuels, and consequently the small contribution of road traffic to SO₂ emissions, SO₂ levels in Australian cities are generally well below the current air quality standards²⁵. Where exceedances of SO₂ standards occurred, these were usually in regional areas affected

²⁴ This is the total across all monitoring stations, excluding any 'duplication' where exceedances occurred at more than one station on the same day.

²⁵ Although the maximum sulfur content of petrol (50 ppm) is higher than in, for example, the EU, this does not appear to have had a major impact on urban SO₂ concentrations.

by emissions from large industrial facilities. In general, the SO₂ levels were higher in these regions than in the major cities. This suggests that abatement measures focusing on specific emission sources in the more constrained airsheds, rather than national measures, will be most appropriate for delivering air quality improvements.

Table 6-5: Historical exceedances of current and proposed SO₂ 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
		Total number of unique exceedance days						
1-hour	75	– (–)	1 (–)	– (–)	– (–)	5 (1)	– (–)	– (–)
	100	– (–)	– (–)	– (–)	– (–)	1 (–)	– (–)	– (–)
	150	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)
	200	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)
		Total number of unique exceedance days						
24-hour	7	– (–)	112 (47)	2 (1)	– (–)	71 (14)	– (–)	– (–)
	20	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)
	40	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)
	80	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)
		Total number of monitoring stations exceeding standard						
Annual	10	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)
	20	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)	– (–)

Table 6-6: Historical exceedances of current and proposed SO₂ 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
		Total number of unique exceedance days				
1-hour	75	– (–)	1 (–)	9 (2)	– (–)	9 (1)
	100	– (–)	– (–)	3 (1)	– (–)	– (–)
	150	– (–)	– (–)	1 (–)	– (–)	– (–)
	200	– (–)	– (–)	– (–)	– (–)	– (–)
		Total number of unique exceedance days				
24-hour	7	19 (9)	32 (18)	17 (5)	– (–)	120 (67)
	20	– (–)	– (–)	1 (–)	– (–)	– (–)
	40	– (–)	– (–)	– (–)	– (–)	– (–)
	80	– (–)	– (–)	– (–)	– (–)	– (–)
		Total number of monitoring stations exceeding standard				
Annual	10	– (–)	– (–)	– (–)	– (–)	– (–)
	20	– (–)	– (–)	– (–)	– (–)	– (–)

6.6.2 Future projections

The results of the air dispersion modelling showed that the maximum predicted SO₂ concentrations will tend to increase with time (or remain stable) in the BAU scenario and decrease with time (or remain stable) in the Abatement Package scenario.

The number of unique exceedance days was calculated for each standard and each airshed. 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 Appendix A, Annexure F.

For 1-hour and 24-hour SO₂ in NSW the projected unique exceedance days in the BAU and Abatement Package scenarios are shown in Table 6-7 and Table 6-8 respectively. The corresponding results for Victoria are shown in Table 6-9 and Table 6-10. For annual mean SO₂, these tables show the number of monitoring stations with exceedances, in each airshed. The BAU tables also include 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 SO₂.

Table 6-7: Projected exceedances of current and proposed SO₂ 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	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 6-8: Projected exceedances of current and proposed SO₂ 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	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 6-9: Projected exceedances of current and proposed SO₂ standards (BAU scenario, VIC)

Averaging period	Standard (ppb)	VIC: Port Phillip Region					VIC: Latrobe Valley				
		Measured	Projected				Measured	Projected			
		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	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 6-10: Projected exceedances of current and proposed SO₂ 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	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	–	–	–	–	–	–	–	–

6.7 Health risk assessment

6.7.1 Health outcomes for Business-as-Usual and Abatement Package scenarios

The aggregated estimates for the number of historical and projected attributable health outcomes due to SO₂ in the modelled airsheds (NSW and Victoria) and other airsheds are shown in Table 6-11. The projected outcomes are presented for both the BAU and Abatement Package scenarios, and the health outcomes avoided in the latter are also stated for NSW and Victoria.

Table 6-11: Historical and projected health burden attributable to SO₂ in Australian airsheds

Airshed	Number of attributable health outcomes			Health outcomes avoided ^(b)				
	Annual average 2010–2014	Scenario	2021	2031	2040	2021	2031	2040
Daily mortality, all-cause ^(a)								
NSW and Victoria	70	BAU	153	180	220			
		Abatement Package	112	120	89	40	60	130
Other airsheds	37	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a
Hospital admissions for respiratory disease (65+ years)								
NSW and Victoria	1076	BAU	2,355	2,803	3,273			
		Abatement Package	1,726	1,809	1,355	629	994	1,918
Other airsheds	470	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a
Emergency department visits for asthma (<15 years)								
NSW and Victoria	249	BAU	554	647	760			
		Abatement Package	393	443	335	161	204	425
Other airsheds	98	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a

(a) 'All-cause mortality' refers to acute mortality events that are estimated to shorten life by six months.

(b) The method for calculating the health outcomes is based on averaging concentrations across an airshed. As some of the SO₂ monitoring stations are in locations that are influenced by emissions from industrial sources, this may lead to an overestimate of the risk to the population in the corresponding airshed. For example, this is particularly the case in the Melbourne airshed where estimated health outcomes are significantly above those of other pollutants and this is not considered to be reflective of current SO₂ levels in this airshed, which are well below AAQ NEPM standards.

The results show that there is a notable health burden associated with exposure to recent historical levels of SO₂. In Sydney and Melbourne, the health burden is projected to increase substantially in the future under the BAU scenario. It was noted in Section 4.6.2.1 that future emissions and concentrations of SO₂ from industry (and hence the attributable and avoided health outcomes) are likely to be overestimated in the BAU scenario.

In the Abatement Package scenario there are marked reductions in the incidence of the health outcomes, such that by 2040 all-cause mortality and respiratory illness due to SO₂ are generally approaching the 2010–2014 average, with the exception of Melbourne (see Appendix B), where they are predicted to still be higher. For Melbourne the results indicate that the Abatement Package would not lead to sufficient reductions in SO₂ levels to offset the predicted increase in emissions in future years.

6.7.2 Health outcomes for compliance with standards

6.7.2.1 1-hour standards

The proposed 1-hour standard of 75 ppb has only been exceeded in Perth, Gladstone and the Latrobe Valley (see Appendix A). These locations are dominated by large industrial sources, and the exceedances have been infrequent. The health outcomes associated with 1-hour SO₂ concentrations are therefore low, and for the majority of the Australian population meeting the proposed standards would not lead to a material health benefit. The health outcomes for compliance with the proposed 1-hour standards have therefore not been presented here.

6.7.2.2 24-hour standards

The numbers of health outcomes associated with meeting the SO₂ 24-hour standards of 7 ppb and 20 ppb are given in Appendix B, Annexure A, Section A.2. Table 3-5 in Appendix B presents the numbers of health outcomes avoided in the NSW and Victoria airsheds by compliance with the proposed 24-hour standards for SO₂ of 7 ppb and 20 ppb (again these are probably overestimated). The overall figures for the NSW and Victoria airsheds and the corresponding results for the other airsheds (2010–2014 average only) are given in Table 6-12. The proposed 24-hour standard of 7 ppb has historically been exceeded in most Australian cities in some years (see Appendix A, air quality study, Section 2.2). It is clear that meeting the proposed 24-hour standard of 7 ppb would have a health benefit, especially in Melbourne. The 20 ppb standard is met in most airsheds, and therefore the health benefits that would be achieved by meeting the proposed standard are smaller.

Table 6-12: Health outcomes avoided if proposed 24-hour SO₂ standards of 7 ppb and 20 ppb are met in Australian airsheds

Airshed	24-hour SO ₂ standard of 7 ppb Health outcomes avoided ^(b)				24-hour SO ₂ standard of 20 ppb Health outcomes avoided ^(b)			
	Annual average 2010–2014	2021	2031	2040	Annual average 2010–2014	2021	2031	2040
Daily mortality, all-cause ^(a)								
NSW and Victoria	23	51	57	70	2	-	-	3
Other airsheds	3	-	-	-	-	-	-	-
Hospital admissions for respiratory disease (65+ years)								
NSW and Victoria	352	596	634	729	238	-	-	-
Other airsheds	1	-	-	-	-	-	-	-
Emergency department visits for asthma (<15 years)								
NSW and Victoria	101	199	215	251	7	-	-	4
Other airsheds	9	-	-	-	-	-	-	-

(a) 'All-cause mortality' refers to acute mortality events that are estimated to shorten life by six months.

(b) The method for calculating the health outcomes is based on averaging concentrations across an airshed. As some of the SO₂ monitoring stations are in locations that are influenced by emissions from industrial sources, this may lead to an overestimate of the risk to the population in the corresponding airshed. For example, this is particularly the case in the Melbourne airshed where estimated health outcomes are significantly above those of other pollutants and this is not considered to be reflective of current SO₂ levels in this airshed, which are well below AAQ NEPM standards.

The under-prediction of SO₂ in Wollongong and the Latrobe Valley in the air dispersion modelling (see Annexure E, Section E.2 of Appendix A) will not greatly impact these results as:

- there is predicted to be compliance with all but the most stringent 24-hour standard of 7 ppb (and the level of error is not expected to change this)
- the attributable health effects in these areas will have been under-predicted.

6.8 Cost–benefit analysis

The full CBA can be found in Appendix C, and the findings for SO₂ are presented in Chapter 9. The aggregated historical health cost due to SO₂ for all jurisdictions over the period 2010–2014 was \$72 million (under all three CRF groups from the sensitivity tests). This is somewhat lower than the corresponding values for NO₂ and O₃.

The abatement measures modelled (over the period 2021–2040) were clearly not economically efficient at the national level for SO₂, with a cost of around \$24.4 billion and a benefit of \$196 million. The measures were only found to be economically efficient in Queensland and Western Australia.

6.9 Non-quantified benefits and disbenefits

SO₂ can cause effects on ecosystems in a number of ways. Acute and chronic exposures to SO₂ have phytotoxic effects on vegetation that include foliar injury, decreased photosynthesis, and decreased growth. Emissions of SO₂ can lead to the deposition of acid rain over large distances and can therefore damage ecosystems on a regional scale. This may include forests experiencing defoliation and dieback, and lakes and watercourses losing the ability to support aquatic life due to the changing acidity and mobilisation of certain minerals. To date, acid rain is not a problem in Australia; however, SO₂ deposition can affect vegetation around large industrial point sources unless appropriate ambient concentrations are achieved through emission source management.

SO₂ can also form secondary particles (sulfates) that cause haze and reduce visibility. This is brought about by their high light-scattering ability. These sulfate particles have a modifying effect on enhanced greenhouse warming as they reflect incoming heat from the sun. Haze can detract from the ‘natural appeal’ of a location, thereby influencing tourism and associated activities. Some authors have estimated the marginal social costs of precursor emissions that lead to the formation of secondary PM. For example, Heo et al. (2016) estimate a range of marginal social costs of US\$14,000–24,000 per tonne of SO_x. Such values would result in very large potential benefits; however, for the reasons noted in Appendix C, it would not be appropriate to include these benefits in the CBA.

6.10 Exposure-reduction framework

SO₂ is considered to be a non-threshold pollutant, for which an exposure-reduction framework would, in theory, be appropriate. However, although communities close to large industrial facilities can be exposed to relatively high ambient concentrations of SO₂, at locations further away from these sources the SO₂ levels are generally low. As noted earlier, the sulfur content of automotive fuels in Australia is relatively low compared with other sectors, which means that the contribution of road traffic to ambient SO₂ concentrations is also low. Consequently, the impacts of SO₂ on health are not widely spread across the population, but are highly localised, and usually where there is a low population.

Given that exposure across whole populations is low for SO₂ it is considered that an exposure-reduction framework is not the most effective mechanism for reducing the potential health risk in the affected communities. The control of industrial sources is outside the AAQ NEPM framework. Actions taken by individual jurisdictions through the management of industrial sources will be more likely to achieve reductions in SO₂ concentrations and the associated health risk in the affected communities.

6.11 Summary of sulfur dioxide assessment

6.11.1 What does the recent health evidence tell us?

Since the adoption of the AAQ NEPM in 1998, there has been a large amount of research on short-term exposure to SO₂ in ambient air, although relatively few studies since the 2011 AAQ NEPM review. The findings of recent studies have strengthened the evidence that the main health effects associated with SO₂ are short-term effects on the respiratory system and have concluded that the associations previously reported remain valid.

Since 1998 there have also been a number of Australian studies of the link between exposure to SO₂ and mortality and morbidity. The results of these studies have shown that the associations found in overseas studies are also found in Australian cities, even though the SO₂ levels monitored in Australia are generally lower than those in North America and Europe.

The evidence for long-term health effects associated with SO₂ is weak, although the data are limited. A major consideration in evaluating SO₂-related health effects and long-term exposure is the high correlation, and potential confounding, among the co-pollutant levels observed, particularly between long-term average particle concentrations and SO₂.

6.11.2 What do the WHO guidelines and international standards tell us?

The AAQ NEPM standards were made in 1998 based on the understanding of the health effects of SO₂ at that time. Since that time the WHO and international agencies have reviewed their guidelines and standards for SO₂ and have adopted more stringent ones to reflect the current understanding of the health effects of this pollutant. The situation for each averaging period is summarised below:

- *10-minute*: Although there is a WHO guideline for 10-minute average SO₂, this period is not currently included in the AAQ NEPM. Air quality data in Australia indicate that, in general, SO₂ levels are low, with short-term peaks only experienced at locations close to major sources of SO₂ that are not covered by the AAQ NEPM. A similar situation exists in other leading countries, and the relevant agencies have therefore not set a 10-minute SO₂ standard.
- *1-hour*: Various 1-hour standards for SO₂ are in force internationally, and some of these values are considerably lower than the current AAQ NEPM standard of 200 ppb.
- *24-hour*: The WHO 2005 global update reduced the 24-hour guideline to 7 ppb to reflect evidence showing that health effects were associated with much lower levels of SO₂ than previously found. This is much lower than the AAQ NEPM standard of 80 ppb. The international standards are also more stringent than the current AAQ NEPM standard.
- *Annual*: The main health effects associated with SO₂ are short-term effects on the respiratory system. The WHO has noted that an annual guideline is not needed, since compliance with the 24-hour level will assure low annual average levels. The review of the recent health evidence (Appendix B) concludes that the lack of strong evidence for long-term health effects from exposure to SO₂ has led international agencies to revoke annual average standards and focus on implementing short-term standards.

6.11.3 What do the air quality measurements and modelling tell us?

The historical air quality assessment and future modelling has shown that most of the proposed SO₂ standards can be met now and into the future without the need for additional abatement measures. This would suggest that the SO₂ standards could be lowered without cost (or indeed, benefit). The exception to this is the most stringent 24-hour standard of 7 ppb, which could nevertheless be met at all locations with the Abatement Package.

It should be noted that there was some uncertainty in the future modelling for SO₂. For example, it appears that the numbers of exceedances of the proposed SO₂ standards were overestimated for NSW and Victoria, and it is possible that fewer exceedances of the 7 ppb standard could occur in practice without the Abatement Package. This overestimation would be exacerbated by the overestimation of future emissions from industrial sources.

6.11.4 What does the HRA tell us?

Exposure to recent historical levels of SO₂ in some Australian airsheds is associated with adverse health outcomes, and the health burden is projected to increase substantially in the future under the BAU scenario. In the Abatement Package scenario there are marked reductions in the incidence of the health outcomes, such that by 2040 all-cause mortality and respiratory illness due to SO₂ are generally approaching the 2010–2014 average, with the exception of Melbourne.

The proposed 1-hour standard of 75 ppb has only been exceeded in locations that are dominated by large industrial sources, and the exceedances have been infrequent. The health outcomes associated with 1-hour SO₂ concentrations are therefore low, and for the majority of the Australian population meeting the proposed standards would not lead to a material health benefit.

The proposed 24-hour standard of 7 ppb has historically been exceeded in most airsheds, and compliance with the proposed 24-hour standard of 7 ppb would have a health benefit. The 20 ppb standard is met in most airsheds, therefore the health benefits that would be achieved by meeting the proposed standard are smaller.

6.11.5 What does the CBA tell us?

The abatement measures modelled were clearly not economically efficient at the national level for SO₂, with a cost of around \$24.4 billion and a benefit of \$196 million. The benefits were relatively low because of the low population where the reductions in concentration would occur. Abatement measures would more suitably be implemented at a jurisdiction level.

6.12 Recommendations

6.12.1 What SO₂ standards should be adopted to protect health?

The following sections provide the recommendations for the variation of the SO₂ standards in the AAQ NEPM, and the supporting rationale. Where long-term future goals have been recommended, these have been considered to be achievable in the Australian jurisdictions, based on the available evidence.

6.12.1.1 10-minute standard

Although the WHO has a guideline for 10-minute average SO₂, short-term peaks are only experienced at locations close to major sources of SO₂ and are not covered by the AAQ NEPM. A similar situation exists in other leading countries, and a number of international agencies have not set a 10-minute standard. Based on the weight-of-evidence approach, it is therefore considered appropriate to retain the status quo, with the 10-minute SO₂ standard being excluded from the AAQ NEPM, and with concentrations being managed through state and territory environmental legislation and frameworks.

Recommendation 3: The status quo should be maintained of not including a 10-minute SO₂ standard in the AAQ NEPM.

6.12.1.2 1-hour standard

Various 1-hour standards for SO₂ are in force internationally, and some of these values are considerably lower than the current AAQ NEPM standard of 200 ppb. This means that the Australian standard is not consistent with international benchmarks, which have been set to protect human health in countries that have much higher levels of SO₂.

In this Impact Statement it has been shown that a tighter Australian standard of 100 ppb would be achievable in future years in NSW and Victoria under the BAU scenario (i.e. without the need for abatement measures), and is considered to be appropriate for the AAQ NEPM. In numerical terms this would be towards the lower end of the range of values in use in other leading countries. There have historically been small numbers of exceedances of the proposed standard of 100 ppb in Perth and the Latrobe Valley, and these would be suitably addressed through local abatement measures.

Compliance with the most stringent proposed standard of 75 ppb was found to be possible with the Abatement Package; however, the health benefit at the national level would be relatively low, and the Abatement Package would be very uneconomic. In fact, most jurisdictions can meet 75 ppb with few exceedances except at industry-affected locations. Setting a goal of 75 ppb for a future standard would allow some time for air quality management practices to be developed. Note that the setting of a future standard for SO₂ is not intended to act as an exposure-reduction approach, as it would not be the most effective mechanism for reducing the population health risk.

Recommendation 4: The 1-hour standard for SO₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 100 ppb.

Recommendation 5: A future 1-hour SO₂ standard of 75 ppb is recommended for implementation from 2025 (this timeframe is consistent with the goals for PM_{2.5} in the AAQ NEPM).

6.12.1.3 24-hour standard

The WHO guideline for 24-hour SO₂ is 7 ppb, and some jurisdictions (the EU and the UK) have a 24-hour standard of 44 ppb. These values are considerably lower than the current AAQ NEPM standard of 80 ppb. As with 1-hour SO₂, this means that the Australian standard is not consistent with international benchmarks, which have been set to protect human health in countries that have much higher levels of SO₂.

This Impact Statement has shown that, apart from a single exceedance in the Latrobe Valley, a considerably tighter Australian standard of 20 ppb has been achieved historically. Compliance with a standard of 20 ppb would also be achievable in the future in NSW and Victoria without the need for abatement measures. A standard of 20 ppb is considered to be appropriate for the AAQ NEPM. Although this is higher than the WHO guideline of 7 ppb, it is significantly lower than the standards in place in other leading countries, and compliance with this standard would have a material health benefit.

Compliance with the WHO guideline of 7 ppb would be possible with the Abatement Package; however, the health benefits at the national level would be relatively low, and the Abatement Package would be very uneconomic. However, the comparison between the historical measurements and the future predictions indicated that the models were generally overestimating the numbers of exceedances of the 7 ppb standard. This indicates that this standard may be more achievable in the future than the modelling suggests.

Recommendation 6: The 24-hour standard for SO₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 20 ppb.

Recommendation 7: No future target for 24-hour average SO₂ concentrations is recommended at this stage.

6.12.1.4 Annual standard

The lack of strong evidence for long-term health effects from exposure to SO₂ has led international agencies to revoke annual average standards and focus on implementing short-term standards for the protection of human health. The WHO has noted that an annual guideline is not needed. Moreover, the analysis in Section 6.6 shows there have been no exceedances of the current and proposed annual mean standards for SO₂, and there are not predicted to be exceedances in the future. This supports the removal of the annual mean SO₂ standard from the AAQ NEPM.

Should a decision be made to retain the annual mean standard, a reduction in the value of the standard from 20 ppb to 10 ppb would be appropriate. There has been historical compliance with the proposed standard of 10 ppb in all airsheds, and compliance is predicted to continue in the future.

Recommendation 8: The current annual mean standard for SO₂ should be removed from the AAQ NEPM.

6.12.2 What form should the standards take?

Allowing exceedances of standards can weaken the health protection inherent in their numerical values. Most international jurisdictions do allow some exceedances of the 1-hour and 24-hour SO₂ standards, either explicitly or through the use of percentile concentrations, but these apply to numerical values of the standards that are lower than in Australia. The WHO does not state any allowed exceedances of its 24-hour guideline for SO₂.

In the air quality study, the analysis of the monitoring data did not reveal any extreme meteorological conditions that led to very high SO₂ concentrations. Furthermore, natural sources of SO₂ include volcanic activity and fires, but Australia does not have any active volcanoes and the analysis of the monitoring data for periods with significant bushfire activity and other types of burning did not reveal any association with elevated SO₂ levels. Therefore, an 'exceptional events' rule is not required for SO₂.

The main sources of SO₂ are industrial facilities which will have localised impacts. The management of industrial sources is not through the implementation of the AAQ NEPM but through individual jurisdictions' management strategies.

Given the above, it is recommended that for both the 1-hour and 24-hour SO₂ standards the form should be the maximum value with no allowable exceedances. This is consistent with the 2016 variation to the AAQ NEPM for the PM standards, in which allowable exceedances were removed and an exceptional events reporting protocol was introduced. A corresponding approach for SO₂ would help jurisdictions better understand the reasons for exceedances.

Setting a 'not-to-be-exceeded' form of the standards is also the most effective way of ensuring the requirements of the NEPC Act for 'equivalent protection for all Australians wherever they live' and the desired environmental outcome of the AAQ NEPM are achieved.

Recommendation 9: The form of both the 1-hour and 24-hour SO₂ standards should be the maximum value with no allowable exceedances.

6.12.3 Are the recommended standards achievable with reasonable measures?

The air quality assessment and future modelling has shown that the recommended standards for 1-hour and 24-hour SO₂, of 100 ppb and 20 ppb respectively, can be met in most of the Australian airsheds. The proposed 1-hour standard of 100 ppb has only been exceeded in locations that are dominated by large industrial sources in Perth and the Latrobe Valley, and the exceedances have been infrequent. State-based abatement measures would be the most suitable action to achieve compliance with the 1-hour standard in these locations.

6.12.4 Should an exposure-reduction framework for SO₂ be considered?

Given that exposure across whole populations is low for SO₂, it is considered that an exposure-reduction framework would not be the most effective mechanism for reducing the population health risk.

Chapter 6 – Key points

- SO₂ is a colourless gas with a pungent odour. Natural sources of SO₂ include geothermal activity (e.g. hot springs and volcanoes) and the decay of vegetation. Anthropogenic SO₂ results primarily from the combustion of fossil fuels containing sulfur (e.g. coal, oil), such as at power stations or smelting facilities. Combustion of diesel fuel used in automotive and shipping is also a source of SO₂.
- The main health effects associated with SO₂ are short-term effects on the respiratory system, especially for children, the elderly and people with pre-existing respiratory conditions such as asthma.
- SO₂ levels in Australian cities are generally well below the current air quality standards. Where exceedances do occur, these are usually in regional areas affected by emissions from large industrial facilities.
- Projections indicate SO₂ concentrations in modelled airsheds are likely to remain stable or increase over time if emissions continue as forecast with no abatement.
- Historical air quality assessment and future modelling has shown that most of the proposed SO₂ standards can be met now and into the future without the need for additional abatement measures.
- There is a notable health burden associated with exposure to recent levels of SO₂ that is likely to increase substantially in the future if emissions continue as forecast with no abatement.
- The impacts of SO₂ on health are not widely spread across the population, but are highly localised, and usually where there is a low population. Introduction of an exposure-reduction framework is not recommended for SO₂ as action by individual jurisdictions through the management of industrial sources will more likely achieve reductions in SO₂ concentrations and associated health risks in the affected communities.

Chapter 6 – Consultation questions

- Do you agree with the recommendations made in this report for the SO₂ standards? Your answer should consider whether you agree:
 - a. with maintaining the status quo of not including a 10-minute SO₂ standard in the AAQ NEPM
 - b. with retaining the averaging periods of 1-hour and 24-hours for SO₂ and removal of the annual SO₂ standard given the weak evidence of health effects from long-term exposures to SO₂
 - c. that there are no other averaging periods for SO₂ that should be considered in the future
 - d. with the preferred numerical value for the 1-hour SO₂ standard (100 ppb) and the future 1-hour standard (75 ppb) for implementation by 2025
 - e. with the preferred numerical value for the 24-hour SO₂ standard (20 ppb) and no future 24-hour standard
 - f. that there should be no allowable exceedances for the SO₂ standards
 - g. that an exposure-reduction framework is not needed for SO₂.

7 Impact assessment for nitrogen dioxide

7.1 Characteristics and sources

NO₂ is a reactive gas which has a reddish-brown colour at typical atmospheric temperatures. It has a strong odour and recognised impacts on human health. NO₂ is also a precursor of photochemical smog and contributes to secondary particle formation by reaction with ammonia to form nitrate salts. This can be a significant contributor to PM_{2.5} concentrations in airsheds with significant ammonia and NO_x emissions.

Natural sources of NO₂ include bacterial respiration, volcanoes and the extreme heating of air during lightning strikes. The main anthropogenic source of NO₂ is fuel combustion, and in urban areas the largest contributor is road vehicle exhaust. Other sources include the burning of coal, oil, or natural gas, and industrial processes. Fuel combustion results in the simultaneous emission of nitric oxide (NO) along with NO₂, and the two compounds are collectively referred to as oxides of nitrogen (NO_x). NO₂ has a greater impact on health than NO.

In the atmosphere, NO is oxidised to NO₂. NO and NO₂ exist in a complex equilibrium that is influenced by the presence of atmospheric oxidants such as O₃, the concentration and speciation of VOCs, sunlight, and other factors. The concentrations of NO₂ in the atmosphere at any given time are determined by the rates of competing chemical reactions (see Section 8.1). The reactions that form NO₂ from NO are reversible, and the net concentration of each substance is determined by competition between the forward and reverse reactions as well as the rate of other reactions that involve NO and NO₂. This complex atmospheric chemistry, and the spatial and temporal distributions of different sources, complicates the evaluation of NO₂.

The main sources of NO_x in Australia are industry and motor vehicles. The NPI data for 2014–2015 estimates the following with respect to NO_x emissions in Australia:

- 29 per cent of emissions were from electricity generation
- 26 per cent of emissions were from motor vehicles
- 10 per cent of emissions were from burning, including bushfires, hazard reduction burning, regeneration and agricultural burning.

The estimates of the annual emissions in each Australian airshed (for both facility and diffuse sources) are summarised in Table 7-1. As with SO₂, there was significant variation across the jurisdictions, and this will influence the ambient concentrations and the potential risk to the exposed population.

Table 7-1: Total estimated emissions of NO_x from industrial facilities and diffuse sources (NPI, 2014–2015)

Airshed	NO _x emissions (tonnes/year)
NSW: Greater Sydney	270,000
VIC: Port Phillip Region	130,000
QLD: South-East Queensland	88,000
SA: Adelaide	36,000
WA: Perth	51,000
TAS: Hobart	6,800
NT: Darwin	12,000
ACT: Canberra	8,100

7.2 Health evidence

A detailed, up-to-date review of the health effects of NO₂ can be found in Appendix B, and the main findings are summarised below.

In recent years there has been a significant increase in the number of studies that have investigated the effects of NO₂ on health. International reviews (e.g. WHO 2013a; USEPA 2016) have found there is considerable new evidence on the health effects of NO₂, and that these effects are independent of other pollutants, including PM. The results of the recent studies have strengthened the evidence base for independent effects of NO₂ on health, and for long-term effects, and have led to the lowering of air quality standards for NO₂ in some countries.

Short-term exposure to NO₂ has been linked to increases in all-cause, cardiovascular and respiratory mortality. The recent studies have provided evidence that has strengthened the association with hospital admissions and emergency department visits for respiratory disease including all respiratory causes, asthma and chronic obstructive pulmonary disease (COPD). Studies of children with asthma show associations between nitrogen dioxide and reductions in lung function, increases in cough, night-time asthma and school absenteeism. An increase in symptoms in asthmatic children and increases in airway inflammation and hyper-responsiveness have also been observed.

Epidemiological studies of long-term effects of NO₂ exposure on mortality (both respiratory and cardiovascular causes) and on children's respiratory symptoms and lung function also support the conclusion that NO₂ has an independent effect on health. Long-term exposure to NO₂ has been linked to deficits in lung function growth. There is also strong evidence of an association between long-term exposure to NO₂ and the incidence of asthma and wheeze. This new evidence suggests that NO₂ exposure may actually cause asthma rather than just exacerbate existing asthma.

However, unlike particulate air pollution, which has been studied in detail, there is much greater uncertainty as to the quantitative health impact on large populations of long-term exposure to NO₂. The evidence is growing, but there is still uncertainty regarding long-term mortality impacts of NO₂ compared to those associated with particulate matter. This is clearly reflected in the recent report released by the UK Committee on the Medical Effects of Air Pollutants (COMEAP), which notes the lack of consensus from within the committee, in particular regarding the causality of NO₂ associations with mortality, interpretation of results from multi-pollutant models in cohort studies, and the estimation of health burden from long-term exposure to NO₂ (COMEAP 2018).

There are only a limited number of large epidemiological studies that have estimated CRFs for mortality associated with long-term exposure to NO₂. Hence, there is much greater uncertainty associated with determining the appropriate CRF for long-term NO₂ exposure and mortality to use in an assessment of population health outcomes from exposure to NO₂. This uncertainty is reflected by the WHO HRAPIE report, which classes the long-term mortality CRF for NO₂ as a Group B CRF '.... for which there is more uncertainty about the precision of the data used for quantification of effects' (WHO 2013b).

In addition, there is likely to be considerable overlap between the health effects of long-term exposure to NO₂ and PM_{2.5}, as they are highly correlated. Any method to quantify the health outcomes associated with NO₂ should include an adjustment to remove the contribution of PM_{2.5}.

Short-term exposure to NO₂ levels currently experienced in Australian cities has been associated with the main health outcomes identified above. No studies investigating the long-term effects of exposure to NO₂ on health have been conducted in Australia.

The review of the current literature strengthens the findings of the AAQ NEPM review (NEPC 2011a).

7.3 World Health Organization guidelines

The current WHO guidelines for NO₂ are given in Table 7-2. These guidelines were defined in the 2005 global update (WHO 2006), although the values for both the 24-hour and annual mean were retained from the previous edition of the guidelines in 2000.

Table 7-2: Current WHO guidelines for NO₂ (WHO 2006)

Agency	Averaging period	Guideline		Form of standard	Allowable exceedances
		ppb	µg/m ³		
WHO	1-hour	97	200	–	None
	Annual	19	40	–	None

7.4 Air quality standards in other leading countries

The current international standards derived to protect human health for NO₂ are summarised in Table 7-3. It is worth noting that 24-hour standards (as recommended by the WHO) are not in common use. As with SO₂, the current AAQ NEPM standards are less stringent than some of the international standards, with the exception of the USEPA annual average. As noted earlier, the SO₂ standards in the AAQ NEPM were adopted in 1998 and were based on the understanding of the health effects at the time.

Table 7-3: International standards for NO₂

Averaging period	Country	Standard ^(a)		Form of standard	Allowable exceedances
		ppb	µg/m ³		
1-hour	Australia	120	246	–	1 day per year
	USEPA	100	205	99 th percentile of 1-hour daily maximum concentrations averaged over 3 years	None
	United Kingdom	97	200	–	18
	European Union	97	200	–	18
	New Zealand	97	200	–	9
Annual	Australia	30	62	–	None
	USEPA	53	109	–	None
	United Kingdom	19	40	–	None
	European Union	19	40	–	None

(a) Values in italics have been obtained using the conversion factors stated at the start of this Impact Statement.

7.5 Proposed air quality standards for review

The proposed standards for NO₂ that were investigated in the review, and the existing AAQ NEPM standards, are shown in Table 7-4. The proposed standards were all lower than the existing AAQ NEPM standards, to reflect both the recent health evidence and the more stringent standards in place in other leading countries.

Table 7-4: Current AAQ NEPM standards and proposed standards for NO₂

Pollutant	Averaging period	Concentration (ppb) ^(a)	Source
NO ₂	1-hour	40	Air TOG
		80	Air TOG
		97	Air TOG
	Annual	120	AAQ NEPM
		10	Air TOG
		19	Air TOG
		30	AAQ NEPM

(a) Current AAQ NEPM standards are highlighted with light blue shading.

7.6 Concentrations and exceedances

7.6.1 Historical trends

Appendix A, Section 2.3 presents an analysis of the NO₂ monitoring data from the AAQ NEPM monitoring stations in each jurisdiction over the period 2003–2016.

As with SO₂, there were no strong trends in the data between 2003 and 2016. In recent years (2010–2016) NO₂ concentrations in all jurisdictions have been relatively stable. The maximum 1-hour NO₂ concentrations in the regional centres were generally lower than those in the major cities. This is probably indicative of the impact of motor vehicle emissions on ambient NO₂ concentrations.

The exceedances of the current and proposed NO₂ standards in the major cities and regional centres are summarised in Table 7-5 and Table 7-6 respectively. All measured NO₂ 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).

Table 7-5: Historical exceedances of current and proposed NO₂ 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
		Total number of unique exceedance days						
1-hour	40	376 (106)	267 (46)	73 (16)	40 (14)	78 (19)	1 (1)	30 (3)
	80	1 (-)	- (-)	- (-)	1 (-)	- (-)	- (-)	3 (-)
	97	- (-)	- (-)	- (-)	1 (-)	- (-)	- (-)	1 (-)
	120	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
		Total number of monitoring stations exceeding standard						
Annual	10	54 (18)	25 (7)	- (-)	- (-)	- (-)	- (-)	- (-)
	19	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)
	30	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)	- (-)

Table 7-6: Historical exceedances of current and proposed NO₂ 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	
	Total number of unique exceedance days					
1-hour	40	17 (6)	63 (18)	3 (–)	1 (1)	6 (4)
	80	– (–)	– (–)	– (–)	– (–)	– (–)
	97	– (–)	– (–)	– (–)	– (–)	– (–)
	120	– (–)	– (–)	– (–)	– (–)	– (–)
	Total number of monitoring stations exceeding standard					
Annual	10	– (–)	2 (–)	– (–)	– (–)	– (–)
	19	– (–)	– (–)	– (–)	– (–)	– (–)
	30	– (–)	– (–)	– (–)	– (–)	– (–)

Under existing conditions, the results indicate that for most urbanised airsheds it will be a challenge to comply in future years with the proposed 1-hour standard for NO₂ of 40 ppb. 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 NO₂ 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.

7.6.2 Future projections

In the BAU scenario, maximum 1-hour NO₂ concentrations are predicted to remain relatively stable in the future in all the 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 NO₂ concentrations by 2040. For Newcastle the Abatement Package had a more noticeable impact on reducing maximum NO₂ 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).

For NO₂ in NSW the projected unique exceedance days in the BAU and Abatement Package scenarios are shown in Table 7-7 and Table 7-8 respectively. The corresponding results for Victoria are shown in Table 7-9 and Table 7-10. 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.

Table 7-7: Projected exceedances of current and proposed NO₂ 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	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 7-8: Projected exceedances of current and proposed NO₂ 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 7-9: Projected exceedances of current and proposed NO₂ standards (BAU scenario, VIC)

Averaging period	Standard (ppb)	VIC: Port Phillip Region				VIC: Latrobe Valley					
		Measured	Projected				Measured	Projected			
		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 7-10: Projected exceedances of current and proposed NO₂ 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	–	–	–	–	–	–	–	–

The contours for ground-level concentrations (Appendix A, 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 NO₂ in Sydney and the Port Phillip Region.

As all NO₂ standards were predicted to be met at all monitoring locations in Victoria, contour plots have not been provided for this pollutant.

7.7 Health risk assessment

7.7.1 Health outcomes for Business-as-Usual and Abatement Package scenarios

The aggregated estimates for the number of historical and projected attributable health outcomes due to NO₂ in the modelled airsheds (NSW and Victoria) and other airsheds are shown in Table 7-11. The projected outcomes are presented for both the BAU and Abatement Package scenarios, and the health outcomes avoided in the latter are also stated for NSW and Victoria. As noted earlier, these outcomes are based on the Group 1 CRFs which included the HRAPIE cut-off of 20 µg/m³ for annual mean NO₂. This meant that the health burden for long-term all-cause mortality was zero, because average airshed NO₂ concentrations were lower than the cut-off, even though concentrations at some monitoring stations (e.g. in Sydney) were above this value.

In recent years (2010–2014) levels of NO₂ in Australian airsheds have had an impact on public health, especially in the more urbanised airsheds of Sydney and Melbourne. In Sydney and Melbourne, the health burden is projected to either increase in the future under the BAU scenario or decrease between 2014 and 2021 but then return to levels similar to those in 2014 by 2040. Although the Abatement Package scenario leads to some reductions in the incidence of the health outcomes, in some cases there is little improvement (and even some increases) relative to the 2010–2014 average.

Table 7-11: Historical and projected health burden attributable to NO₂ in Australian airsheds

Airshed	Number of attributable health outcomes			Health outcomes avoided				
	Annual average 2010–2014	Scenario	2021	2031	2040	2021	2031	2040
Daily mortality, all-cause ^(a)								
NSW and Victoria	133	BAU	65	58	81			
		Abatement Package	65	42	51	0	16	30
Other airsheds	43	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a
Hospital admissions for respiratory disease (65+ years)								
NSW and Victoria	82	BAU	60	61	83			
		Abatement Package	57	51	60	3	10	23
Other airsheds	25	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a
Emergency department visits for asthma (<15 years)								
NSW and Victoria	2344	BAU	2717	2796	3748			
		Abatement Package	2567	2324	2710	150	472	1038
Other airsheds	650	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a
Hospital admissions, respiratory (65+ years)								
NSW and Victoria	1326	BAU	1535	1578	2119			
		Abatement Package	1450	1313	1532	85	265	587
Other airsheds	373	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a
Hospital admissions, respiratory (15–64 years)								
NSW and Victoria	1177	BAU	733	742	1034			
		Abatement Package	689	624	744	43	118	291
Other airsheds	382	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a
Emergency department visits, asthma (<15 years)								
NSW and Victoria	103	BAU	74	73	101			
		Abatement Package	69	63	72	5	10	29
Other airsheds	28	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a

(a) 'All-cause mortality' refers to acute mortality events that are estimated to shorten life by six months.

7.7.2 Health outcomes for compliance with standards

7.7.2.1 1-hour standards

It was shown in the air quality study (Appendix A, Section 2.3) that the current AAQ NEPM standard for 1-hour NO₂ (120 ppb) is met in all airsheds. The proposed 1-hour standards of 80 ppb and 97 ppb are also currently met; however, there have historically been exceedances in most airsheds of the proposed 1-hour standard of 40 ppb. All the proposed standards are predicted to be met in all modelled locations except Sydney. The 1-hour 40 ppb standard is the only standard predicted to be exceeded in Sydney.

The number of health outcomes associated with meeting the NO₂ 1-hour standard of 40 ppb are given in Appendix B. Table 7-12 presents the numbers of health outcomes avoided in the NSW and Victoria airsheds by compliance with the proposed 1-hour standard for NO₂ of 40 ppb. The corresponding results for the other airsheds (2010–2014 average only) are also given. A substantial number of attributable health outcomes would be avoided in Sydney if the proposed 1-hour standard for NO₂ of 40 ppb could be met.

Table 7-12: Health outcomes avoided if proposed 1-hour NO₂ standard of 40 ppb is met in Australian airsheds

Airshed	Average 2010–2014	1-hour NO ₂ standard of 40 ppb Health outcomes avoided		
		2021	2031	2040
Daily mortality, all-cause ^(a)				
NSW and Victoria	17	18	4	10
Other airsheds	31	–	–	–
Hospital admissions, cardiovascular (65+ years)				
NSW and Victoria	543	848	208	490
Other airsheds	811	–	–	–
Hospital admissions, respiratory (65+ years)				
NSW and Victoria	313	480	118	277
Other airsheds	470	–	–	–
Hospital admissions, respiratory (15–64 years)				
NSW and Victoria	252	209	51	122
Other airsheds	472	–	–	–
Emergency department visits, asthma (<15 years)				
NSW and Victoria	22	209	51	122
Other airsheds	37	–	–	–

(a) 'All-cause mortality' refers to acute mortality events that are estimated to shorten life by six months.

7.7.2.2 Annual average standards

It was shown in the air quality study (Appendix A, Section 2.3) that the current NEPM standard for annual average NO₂ of 30 ppb and the proposed standard of 19 ppb are met in all airsheds. There have historically been exceedances of the proposed standard of 10 ppb in Sydney, the Port Phillip Region and Wollongong. In Sydney and the Port Phillip Region the exceedances of the 10 ppb standard have occurred at multiple stations and in multiple years.

Because average airshed concentrations were below the HRAPIE cut-off for long-term NO₂ concentrations of 20 µg/m³ (around 10 ppb, i.e. the lowest proposed standard), no health benefits of meeting the standards could be determined.

It is worth noting that reducing the maximum 1-hour values to meet 40 ppb alone does not lead to the meeting of the 10 ppb annual average standard; however, in all cases assessed, meeting the 10 ppb annual standard leads to the 40 ppb 1-hour standard being met.

7.8 Cost–benefit analysis

The full CBA can be found in Appendix C, and the findings for NO₂ are presented in Chapter 9. The range of the aggregated historical health cost due to NO₂ for all jurisdictions over the period 2010–2014 was \$265 million to \$761 million (based on the different CRF groups from the sensitivity tests)²⁶. This is higher than the corresponding value for SO₂, and slightly higher than that for O₃.

²⁶ Note that the CRF group used did not change the overall outcome of the CBA, i.e. a negative NPV.

The abatement measures modelled (over the period 2021–2040) were clearly not economically efficient at the national level for NO₂, with a cost of around \$24.4 billion and a benefit of \$1.3 billion (when the co-benefit of the reduction in PM_{2.5} emissions was considered). The measures were not economically efficient in any jurisdiction.

7.9 Non-quantified benefits and disbenefits

NO₂ is associated with impacts on crops and vegetation, as well as nitrification of lakes and rivers. Exposures to NO₂, nitric oxide (NO), peroxyacetyl nitrate (PAN), and nitric acid (HNO₃) cause similar forms of plant foliar injury and decreased growth (USEPA 2016). NO₂ also plays an important role in the atmospheric reactions that create particulate matter, ground-level O₃ (photochemical smog) and acid rain. NO₂ can cause adverse effects on respiratory systems of animals. As the AAQ NEPM standards are based on the protection of human health (consistent with the goal of the AAQ NEPM), standards have not been derived for these vegetation and other ecological effects; however, any reduction in NO₂ levels resulting from the adoption of more stringent standards will also lead to reductions in the effects on vegetation. It should be noted that in overseas jurisdictions where standards have been developed to protect vegetation, such as the US and Canada, these standards are equivalent to the health based standards in some cases.

Heo et al. (2016) estimated a range of marginal social costs of US\$3,800–14,000 per tonne NO_x emission. As with SO₂, such values would result in very large potential benefits; however, for the reasons noted in Appendix C, it would not be appropriate to include these benefits in the CBA.

7.10 Exposure-reduction framework

It has been observed in this Impact Statement that there are health effects associated with exposure to NO₂ in Australian cities and regional centres, even though the current AAQ NEPM standards are met in most airsheds. The HRA has shown there would be health benefits associated with the adoption of the 1-hour standard of 40 ppb; however, increased population growth and associated motor vehicle kilometres travelled (VKT) could make it challenging for the larger jurisdictions to meet the standards in the future. The introduction of an exposure-reduction framework for NO₂ would provide a framework for individual jurisdictions to reduce this risk across the population. Given the importance of NO₂ in O₃ formation, a corresponding exposure-reduction framework would be advisable for O₃ (see Section 8.12).

7.11 Summary of nitrogen dioxide assessment

7.11.1 What does the recent health evidence tell us?

In recent years there has been a significant increase in the number of studies that have investigated the effects of NO₂ on health. The results of the recent studies have strengthened the evidence base for independent effects of NO₂ on health, and for long-term effects, and have led to the tightening of air quality standards for NO₂ in some countries.

Short-term exposure to NO₂ levels currently experienced in Australian cities has been associated with the main health outcomes identified above. At the time of conducting the literature review no studies investigating the long-term effects of exposure to NO₂ on health had been conducted in Australia.

7.11.2 What do the WHO guidelines and international standards tell us?

As with SO₂, the current AAQ NEPM standards for 1-hour and annual average NO₂ are less stringent than the international standards and the WHO guidelines, with the exception of the USEPA annual average. The NO₂ standards in the AAQ NEPM were adopted in 1998 and were based on the understanding of the health effects at the time.

7.11.3 What do the air quality measurements and modelling tell us?

The air quality assessment and future modelling has shown that NO₂ concentrations in both the major cities and regional centres have historically been and are likely to continue to be below the current AAQ NEPM standards (120 ppb for the 1-hour average, and 30 ppb for the annual average).

The proposed 1-hour standards of 80 ppb and 97 ppb are also currently met; however, there have historically been exceedances in most airsheds of the proposed 1-hour standard of 40 ppb. All the proposed standards are predicted to be met in all modelled locations except Sydney. The 1-hour 40 ppb standard is the only standard predicted to be exceeded in Sydney.

For annual mean NO₂ 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.

There was some uncertainty in the future modelling for NO₂. For example, it appears that the numbers of exceedances of the proposed NO₂ standards were underestimated in Sydney and the Port Phillip Region, and it is possible that fewer exceedances of the standard could occur in practice without the Abatement Package.

7.11.4 What does the HRA tell us?

In recent years, levels of NO₂ in Australian airsheds have had an impact on public health, especially in the more urbanised airsheds of Sydney and Melbourne. In Sydney and Melbourne, the health burden is projected to increase in the future under the BAU scenario. Although the Abatement Package scenario leads to some reductions in the incidence of the health outcomes, in some cases there is little improvement (and even some increases) relative to the 2010–2014 average.

There would be a health benefit in Sydney if the proposed 1-hour standard for NO₂ of 40 ppb could be met.

7.11.5 What does the CBA tell us?

The abatement measures modelled were clearly not economically efficient at the national level for NO₂, with a cost of around \$24.4 billion and a benefit of \$1.4 billion. The benefits were relatively low because of the low population where the reductions in concentrations would occur. Abatement measures would be more suitably implemented at a jurisdiction level.

7.12 Recommendations

7.12.1 What NO₂ standards should be adopted to protect health?

The following sections provide the recommendations for the variation of the NO₂ standards in the AAQ NEPM, and the supporting rationale. Where long-term future goals have been recommended, these have been considered to be achievable in the Australian jurisdictions, based on the available evidence.

7.12.1.1 1-hour standard

The standard for 1-hour NO₂ in the AAQ NEPM is 120 ppb, whereas the lowest standard in other leading countries and the WHO guidelines is 97 ppb.

Although it has not been investigated in this Impact Statement, a more stringent Australian standard of 90 ppb would generally be achievable in all Australia jurisdictions and would contribute to driving improvement. This is therefore recommended for incorporation into the AAQ NEPM.

In the longer term, a more stringent goal for 1-hour NO₂ than 90 ppb should be considered, as the evidence of health impacts at levels below this is clear. The 1-hour standard of 80 ppb has been met in most jurisdictions, with small numbers of exceedances in Sydney, Adelaide and Canberra. Again, these are not predicted to occur in the future under the BAU scenario. The standard of 80 ppb would therefore be an appropriate longer-term goal as part of an exposure-reduction framework (see Section 7.12.4). Compliance with the standard of 40 ppb has historically not been possible in all jurisdictions and would not be possible in Sydney in the future, even with the Abatement Package. As already noted, the Abatement Package itself would be very uneconomic.

Recommendation 10: The 1-hour standard for NO₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 90 ppb.

7.12.1.2 Annual standard

The AAQ NEPM standard for annual mean NO₂ of 30 ppb is lower than the standard in the US (53 ppb), but still higher than the WHO guidelines and standards in Europe (19 ppb). The historical monitoring data and the model projections indicate that a standard of 19 ppb would be achievable in the Australian airsheds and would align Australia with the tightest international standards.

An annual NO₂ standard of 10 ppb would not appear to be achievable in several jurisdictions based on the historical monitoring data. Although it has not been assessed in this Impact Statement, an intermediate standard of 15 ppb ought to be achievable, and this is recommended as a longer-term goal to drive further improvement.

Recommendation 11: The annual standard for NO₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 19 ppb.

7.12.2 What form should the standards take?

The analysis of the NO₂ monitoring data for the period 2010–2016 showed that there were no exceptional events that led to exceedances of the 1-hour (or annual mean) standards in any of the airsheds. Given the

health burden associated with NO₂, it is recommended that the form of the 1-hour standard should be the maximum value with no allowable exceedances. This is consistent with the WHO guidelines, and more stringent than the form of the standard in other leading countries.

As there is no evidence that bushfires, hazard reduction burns or agricultural burning leads to elevated NO₂ levels, an exceptional event rule is not applicable for NO₂.

Recommendation 12: The form of both the 1-hour and annual NO₂ standards should be the maximum value with no allowable exceedances.

7.12.3 Are the recommended standards achievable with reasonable measures?

Historically, the proposed 1-hour standards of 97 ppb and 80 ppb have been met in most jurisdictions. There have been small numbers of exceedances in Sydney, Adelaide and Canberra, but these are not predicted to occur in the future under the BAU scenario.

There have been no exceedances of the proposed standard of 19 ppb for annual mean NO₂, and this is predicted to continue in the future.

7.12.4 Should an exposure-reduction framework for NO₂ be considered?

An exposure-reduction framework (and target) for NO₂ should be established to reduce population exposure and associated health risk. Given the close relation between NO₂ and O₃, an exposure-reduction framework for NO₂ would need to be consistent with that adopted for O₃, to ensure the reductions required in NO₂ also enable any target for O₃ exposure-reduction to be achieved. Consistent with the approach used in the AAQ NEPM variation for PM_{2.5}, it is recommended that jurisdictions evaluate and report population exposure to NO₂ annually from the commencement of the varied AAQ NEPM. Jurisdictions should agree on any procedures or methods to ensure consistency. To be consistent with the AAQ NEPM, it is also proposed that a simplified response to implementing an exposure-reduction framework for NO₂ is adopted – this is achieved through the setting of a long-term annual average goal for NO₂.

Recommendation 13: An exposure-reduction framework, in the form of a long-term goal for NO₂, should be established to reduce population exposure and associated health risk.

Recommendation 14: A future 1-hour NO₂ standard of 80 ppb is recommended for implementation from 2025 as part of an exposure-reduction framework (this timeframe is consistent with the goals for PM_{2.5} in the AAQ NEPM).

Recommendation 15: A future annual NO₂ standard of 15 ppb is recommended for implementation from 2025 as part of an exposure-reduction framework (this timeframe is consistent with the goals for PM_{2.5} in the AAQ NEPM).

Recommendation 16: Jurisdictions should also commence annual reporting on population exposure to NO₂ from the commencement of a varied AAQ NEPM.

Chapter 7 – Key points

- NO₂ has a strong odour and is a reactive gas that has a reddish-brown colour at typical atmospheric temperatures. NO₂ is also a precursor of photochemical smog and contributes to secondary particle formation by reaction with ammonia to form nitrate salts.
- Natural sources of NO₂ include bacterial respiration, volcanoes and the extreme heating of air during lightning strikes. The main anthropogenic source of NO₂ is fuel combustion, and in urban areas the largest contributor is road vehicle exhaust. Other sources include the burning of coal, oil, or natural gas, and industrial processes.
- NO₂ may be harmful to the lungs, especially for children, the elderly and people with lung disease. It may also exacerbate pre-existing respiratory conditions such as asthma.
- NO₂ levels in Australian cities are below the current air quality standards. In recent years (2010–2016), NO₂ concentrations in all jurisdictions have been relatively stable.
- Projections indicate NO₂ concentrations are likely to remain relatively stable in most airsheds that were modelled if emissions continue as forecast with no abatement.
- Historical air quality assessment and future modelling has shown that most of the proposed NO₂ standards can be met now and into the future without the need for additional abatement measures, except for the most stringent proposed standards. An Abatement Package of possible measures reduced some of these exceedances.
- In recent years (2010–2014), levels of NO₂ in Australian airsheds have had an impact on public health, especially in the more urbanised airsheds of Sydney and Melbourne – the health burden is projected to increase in the future in these cities if emissions continue as forecast with no abatement.
- An exposure-reduction framework for NO₂ could provide a framework to reduce the risk across the population of not meeting future standards for larger jurisdictions, particularly given increased population growth and associated motor vehicle kilometres travelled.

Chapter 7 – Consultation questions

- Do you agree with the recommendations made in this report for the NO₂ standards? Your answer should consider whether you agree:
 - a) with retaining the averaging periods of 1-hour and annual for NO₂
 - b) that there are no other averaging periods that should be considered for NO₂ in the future
 - c) with the preferred numerical value for the 1-hour NO₂ standard (90 ppb) and the future 1-hour standard (80 ppb) for implementation by 2025
 - d) with the preferred numerical value for the annual NO₂ standard (19 ppb) and the future annual standard (15 ppb) for implementation by 2025
 - e) that there should be no allowable exceedances for NO₂ standards
 - f) with the introduction of an exposure-reduction framework for NO₂
 - g) that jurisdictions should commence annual reporting on population exposure to NO₂ from the commencement of a varied AAQ NEPM.

8 Impact assessment for ozone

8.1 Characteristics and sources

O₃ is a highly reactive gas and a major component of photochemical smog. O₃ is known to impact on health largely through effects in the respiratory tract. It can also damage vegetation and materials, and is a potent greenhouse gas.

O₃ is not emitted directly but is a secondary pollutant formed in the atmosphere by the reaction of NO_x and VOCs in the presence of heat and 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 O₃ formation. The rate at which O₃ is formed is limited by the amount of sunlight and the amount of VOCs available, with the quantity of O₃ produced being generally limited by the amount of NO_x available. NO and NO₂ react with O₃ differently. NO can react directly with O₃ to form NO₂ and O₂, while NO₂ plays a very important role in the formation of O₃. Figure 8-1 illustrates these reaction mechanisms. Both reactions are important in understanding O₃ formation in urban and rural regions. In urban areas vehicle emissions provide a large source of fresh NO which can react with O₃, lowering the O₃ concentrations. As the NO is oxidised to NO₂, this NO₂ becomes available to form O₃ in less urbanised regions where there is less fresh NO to directly react with O₃. In Figure 8-1, M* represents a third compound (i.e. VOCs) that is necessary for this reaction to occur.

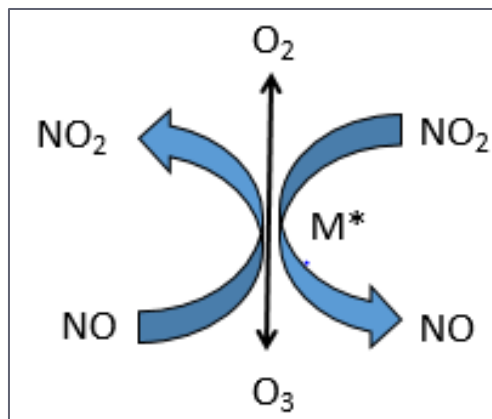


Figure 8-1: Simplified representation of reactions between oxides of nitrogen and ozone

The sources of O₃ are effectively those that relate to NO_x and VOCs. Sources of NO_x in Australia, based on estimated data from the NPI, were discussed in Section 7.1. Emissions of VOCs are also included in the NPI as 41 individual substances. The main sources of VOCs are emissions from natural processes (e.g. biogenic emissions, bushfires and hazard reduction burns), motor vehicle emissions, and the use of domestic and commercial solvents. The estimates of the annual VOC emissions in each Australian airshed (for both facility and diffuse sources) are summarised in Table 8-1. Motor vehicle emissions are a key source of both NO_x and VOCs and are therefore important in the consideration of O₃ formation.

O₃ levels in Australia are influenced by bushfires. An analysis conducted by EPA Victoria to inform this review has shown that O₃ peaks have been linked to bushfires in Victoria, Western Australia and Canberra. A review of the annual reports to the NEPC also indicates that bushfires can have a significant impact on O₃ exceedances in most jurisdictions. This link is also found internationally. For example, the USEPA has

introduced an ‘exceptional events rule’ that permits exceedances of the O₃ standards, where it can be shown that they are caused by major natural events such as bushfires. Strict guidelines have been prepared by the USEPA that need to be followed to determine such exceptional events.

Table 8-1: Total estimated emissions of VOCs from industrial facilities and diffuse sources (NPI, 2014–2015)

Airshed	VOC emissions (tonnes/year)
NSW: Greater Sydney	190,000
VIC: Port Phillip Region	160,000
QLD: South-East Queensland	310,000
SA: Adelaide	43,000
WA: Perth	49,000
TAS: Hobart	8,400
NT: Darwin	6,100
ACT: Canberra	13,000

8.2 Health evidence

A detailed, up-to-date review of the health effects of O₃ can be found in Appendix B. International studies have provided evidence that exposure to O₃ is causally linked to short-term acute mortality and morbidity primarily for respiratory causes, but not long-term chronic mortality. There is some evidence that O₃ exposures are also associated with cardiovascular outcomes, but the evidence is not as strong as for respiratory outcomes.

The most recent reviews conducted by the international agencies including the WHO (2013b), the USEPA (2013) and the UK Committee on the Medical Effects of Air Pollutants (COMEAP 2015) have investigated the evidence on both short-term and long-term effects of O₃ on health. The reviews have found there is new evidence on the association between daily maximum 1-hour and 8-hour O₃ concentrations and all-cause, cardiovascular and respiratory mortality, as well as cardiovascular and respiratory hospital admissions. There is currently no convincing evidence of a threshold for short-term exposure to a daily maximum 1-hour or 8-hour O₃ concentration, or of a non-linear relationship at low concentrations. The evidence base for long-term effects of O₃ has also strengthened; in particular, long-term exposure to O₃ is linked to the incidence of asthma, and not just the exacerbation of existing asthma. O₃ was also found to be associated with a range of reproductive and developmental effects that had not previously been linked with O₃ exposure.

8.3 World Health Organization guidelines

The WHO currently has a guideline for the daily maximum rolling²⁷ 8-hour O₃ concentration of 47 ppb (100 µg/m³), as shown in Table 8-2. This was defined in the 2005 global update (WHO 2006), which lowered the guideline from the previous value of 120 µg/m³ defined in the second edition of *Air Quality Guidelines for Europe* (WHO 2000). The WHO noted that it is possible health effects could occur below 100 µg/m³ in some sensitive individuals.

²⁷ The rolling 8-hour average is based on 1-hour measurements.

Table 8-2: Current WHO guideline for O₃ (WHO 2006)

Agency	Averaging period	Guideline ^(a)		Form of standard	Allowable exceedances
		ppb	µg/m ³		
WHO	8-hour ^(b)	47	100	–	None

(a) Values in italics have been obtained using the conversion factors stated at the start of this Impact Statement.

(b) Maximum daily rolling 8-hour average.

The WHO does not define a 1-hour O₃ guideline. In adopting a rolling 8-hour standard in place of a 1-hour standard the WHO explained that this was based on research indicating prolonged exposure to O₃ is a more significant public health risk. Hence, an 8-hour averaging period was more relevant than a 1-hour averaging period for the protection of human health, due to the increasing health impacts of O₃ with exposure over multiple hours. The 8-hour guideline would also protect against acute 1-hour exposure (WHO 2000; NEPC 2005). Similarly, the WHO does not provide a 4-hour guideline for O₃. The REVIHAAP project concluded that epidemiological evidence supported health estimates based on daily maximum 8-hour O₃ (WHO 2013b). The WHO did not find evidence that a 1-hour standard provided any additional health protection.

8.4 Air quality standards in other leading countries

The current international standards for O₃ to protect human health are summarised in Table 8-3. As O₃ forms in the presence of sunlight, tighter O₃ standards are more likely to be adopted in colder climate countries where O₃ formation potential is lower. O₃ is often higher and more difficult to control in large, hot metropolitan areas. Because different O₃ standards have been adopted by different jurisdictions, a summary for each averaging period is provided below.

Table 8-3: International standards for O₃

Averaging period	Country	Standard ^(a)		Form of standard	Allowable exceedances
		ppb	µg/m ³		
1-hour	Australia	100	214	–	1 day per year
	New Zealand	70	150	–	None
	California EPA	90	193	–	None
Rolling 4-hour	Australia	80	171	–	1 day per year
Rolling 8-hour	California EPA	70	150	–	None
	USEPA ^(b)	70	150	Annual 4 th highest value averaged over 3 years	None (but an exceptional events rule is defined)
	United Kingdom ^(c)	47	100	–	10
	Canada ^(d)	63 ^(e)	135	Annual 4 th highest value averaged over 3 years	None
		62 ^(f)	133		
European Union ^(g)	56	120	–	25 averaged over 3 years	

(a) Values in italics have been obtained using the conversion factors stated at the start of this Impact Statement.

(b) <https://www.epa.gov/criteria-air-pollutants/naaqs-table>

(c) https://uk-air.defra.gov.uk/assets/documents/Air_Quality_Objectives_Update.pdf

(d) <http://airquality-qualitedelair.come.ca/en/>

(e) 2015

(f) 2020

(g) <http://ec.europa.eu/environment/air/quality/standards.htm>

8.4.1 1-hour standards

The 1-hour standard is used in Australia but is not used by the USEPA, EU, UK or Canada, nor is it recommended by the WHO. A 1-hour standard is only applied in Australia, New Zealand and California. The standard in Australia is less stringent than in the other locations.

California EPA adopted a rolling 8-hour O₃ standard in 2005; however, following a thorough review it decided to retain the 1-hour O₃ standard on the basis of the following:

- It would enable the continuation of historical tracking against the 1-hour O₃ averaging period (which commenced in 1959).
- It protects against short, peak exposures, based on the findings from controlled human exposure studies. However, the California EPA report did not consider the potential for the 8-hour standard to also protect against 1-hour exposures.

Management of O₃ pollution in California remains a significant problem. In 2016 California exceeded the USEPA 8-hour national O₃ standard of 70 ppb on 145 days across Los Angeles, Orange, Riverside and San Bernardino counties²⁸.

With regard to the second point (the California EPA's finding that the 1-hour standard protected against short-term peak exposures), the USEPA found that an 8-hour time period to represent O₃ exposure was justified by the combined evidence from epidemiological and clinical studies (USEPA 2014). However, in contrast to the California EPA, they did not find specific evidence to support a 1-hour O₃ standard in addition to an 8-hour standard, despite having clinical evidence of the health impacts of 1-hour O₃ exposure, due to the predictable co-occurrence of both 1 and 8-hour exposures. The USEPA determined that an 8-hour standard would provide substantial protection against 1-hour exposures because exceedances of 8-hour standards were always more numerous than exceedances of the equivalent 1-hour standards. This is also reflected in the Australian monitoring data (see Section 8.6).

8.4.2 4-hour standards

The 4-hour averaging period, which is included in the AAQ NEPM, is not used outside Australia, and it has not been considered as a standard by the WHO.

Epidemiological studies have not focused on a 4-hour averaging period, so evidence is not available to assess the benefits and drawbacks of a 4-hour averaging period. While it is not clear that there is an epidemiological reason for using a 4-hour averaging period, it is clear that the 8-hour averaging period appropriately represents the daily exposure.

Elevated O₃ formation episodes may lead to exceedance levels for a number of hours, but not the full eight hours. The 8-hour metric represents the typical individual exposure, rather than the length of the O₃ event. It captures the elevated O₃ (including lower exposures) that often occurs before and after 4-hour exceedance events.

The USEPA found that an 8-hour time period to represent O₃ exposure was justified by the combined evidence from epidemiological and clinical studies (USEPA 2014). The WHO REVIHAAP concluded that epidemiological evidence supported health estimates based on daily maximum 8-hour O₃ (WHO 2013b).

²⁸ *Los Angeles Times*, 'Southern California smog worsens for second straight year despite reduced emissions', 15 Nov. 2017, <http://www.latimes.com/local/lanow/la-me-ln-bad-air-days-20171115-story.html>

As a controlling standard, an Australian 8-hour standard of 70 ppb would capture longer-term health impacts of most concern and would generally ensure current 1-hour and 4-hour standards would not be exceeded. The adoption of a 65 ppb 8-hour O₃ standard would provide additional protection against prolonged O₃ exposures, as well as against shorter-term peaks of concern.

8.4.3 8-hour standards

The rolling 8-hour averaging period is the one in common use internationally, and it is the only standard for O₃ applied by the USEPA, EU, UK and Canada. The USEPA, in explaining the move from a 1-hour standard to an 8-hour standard, stated that although 1–3 and 6–8-hour O₃ exposures can be addressed through 1-hour or 8-hour standards, the 8-hour standard is more directly associated with the health effects of most concern (USEPA 1996; NEPC 2005). However, an 8-hour standard is not currently included in the AAQ NEPM.

The EU only applies an 8-hour O₃ standard but it also uses a 1-hour community information value on the basis that an 8-hour period is too long for triggering an information release. Information warnings based on 8-hour averages would be delivered too late to avoid adverse health consequences (NEPC 2005).

For this reason, it is recommended that a 1-hour O₃ community health information value or alternative forecast mechanism is used by states and territories to provide quick community health alerts, in conjunction with an 8-hour standard.

8.5 Proposed air quality standards for review

The proposed standards for O₃ that were investigated in the review, and the existing AAQ NEPM standards, are shown in Table 8-4. There is currently no 8-hour standard for O₃ in the AAQ NEPM. The proposed standards were all lower than the existing AAQ NEPM standards, to reflect both the recent health evidence and the more stringent standards in place in other leading countries.

Table 8-4: Current AAQ NEPM standards and proposed standards for O₃

Pollutant	Averaging period	Concentration (ppb) ^(a)	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

(a) Current AAQ NEPM standards are highlighted with light blue shading.

8.6 Concentrations and exceedances

8.6.1 Historical trends

Appendix A, Section 2.4 presents an analysis of the O₃ monitoring data from the AAQ NEPM monitoring stations in each jurisdiction over the period 2003–2016.

For Sydney there was a slight downward trend in maximum 1-hour and 4-hour O₃ concentrations from 2003 to 2016. For all other cities and regional centres no clear trend was apparent. There were also no systematic, long-term patterns in the data for 8-hour O₃ concentrations. A number of the peak O₃ concentrations in various years were associated with large bushfires.

The O₃ exceedances between 2003 and 2016 (and 2010–2014) are summarised for the major cities and regional centres in Table 8-5 and Table 8-6 respectively. The measurements 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 in most airsheds and in most years. This was particularly evident in the data for Sydney.

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 Townsville and Gladstone.

Two alternative proposed 4-hour standards were considered for this Impact Statement (70 ppb and 60 ppb). The monitoring data showed 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 O₃ standards have generally not been achieved historically, indicating that abatement measures would be required in the future.

Table 8-5: Historical exceedances of current and proposed O₃ 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 8-6: Historical exceedances of current and proposed O₃ 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)	– (–)	– (–)

8.6.2 Future projections

For O₃ in NSW the projected unique exceedance days in the BAU and Abatement Package scenarios are shown in Table 8-7 and Table 8-8 respectively. The corresponding results for Victoria are shown in Table 8-9 and Table 8-10.

The experience with the historical monitoring data showed the patterns of exceedance for O₃ were more complicated than those for SO₂ and NO₂, 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 in 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.

Table 8-7: Projected exceedances of current and proposed O₃ 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	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 8-8: Projected exceedances of current and proposed O₃ 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 8-9: Projected exceedances of current and proposed O₃ standards (BAU scenario, VIC)

Averaging period	Standard (ppb)	VIC: Port Phillip Region					VIC: Latrobe Valley					
		Measured	Projected				Measured	Projected				
		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 8-10: Projected exceedances of current and proposed O₃ 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	–	–	–	–	–	–	–	–

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 O₃ in NSW, and overestimating exceedances in the Latrobe Valley. It appears that O₃ exceedances in the Port Phillip Region were reasonably well predicted.

It is worth repeating that the processes of O₃ formation and removal are complex, and require detailed modelling. This was only possible for NSW and Victoria, and therefore for the other jurisdictions there were no projections of O₃ concentrations and associated health outcomes (as well as monetised benefits). The modelling of ozone is also subject to uncertainty and, given it underestimated exceedances of standards in Sydney, on the whole, greater weight should be given to the historical measurements than to the future modelling when providing recommendations on possible new standards.

8.6.3 Ozone and bushfires

Bushfire smoke is a complex mixture of particulate and gaseous pollutants. Smoke composition depends on many factors including the fuel type, moisture content, fire temperature, atmospheric conditions, the season, and age of the smoke. Bushfire smoke contains numerous chemicals, many with known adverse human health effects. Bushfires are a natural source of O₃ precursors (NO_x and VOCs) that can react to form O₃ at concentrations that exceed the current standards. Concentrations of the precursors within smoke plumes are sufficient to generate O₃ and increase the concentration during the fire event.

The O₃ event may be further influenced by the presence of emissions of precursor pollutants from industry, motor vehicles and domestic sources, in conjunction with favourable weather conditions for photochemical smog formation. The intersection of these events is more prevalent during the warmer summer months, and in early autumn and late spring when warm temperature conditions occur.

Data analysis conducted by EPA Victoria for this review shows that 35 O₃ events can be linked to a variety of fire events, during the period 2003–2014. The events are summarised in Figure 8-2. Exceedances of the O₃ standards have occurred in all jurisdictions, including Queensland; however, the data was not provided and is not shown. O₃ related fire events have occurred in all but four of the years for which data were presented. It is reasonable to expect that most years going forward will present conditions suited to these events.

Bushfires can have a significant impact on ozone exceedances in most jurisdictions. In the NSW metropolitan region around 50 per cent of O₃ standard breaches are due to bushfires. The United States has an exceptional events rule that permits exceedances of the O₃ standards where it can be shown they are caused by exceptional events such as fires. Other jurisdictions use an O₃ standard typically averaged over three years and/or have an arbitrary exceedance allowance.

The size, scale, duration, intensity and cause of the fires are variable, with approximately half the fire events lasting more than one day. The event analysis shows that fire events may be major bushfires or smaller bushfires, and are often triggered by lightning strikes and human activities.

Not all fires will lead to O₃ events or an exceedance of the standard. Suitable meteorological conditions (importantly air temperature) need to be present to drive the reactions. The mix ratio of precursor emissions will also influence the reactions, and O₃ formation potential. Emissions of NO_x may reduce O₃ concentrations close to the fire (i.e. source of emission). New NO_x emissions will react with O₃ reducing its concentration. It is also possible, at some distance downwind from the fire (emissions source), that the NO_x emission will produce more O₃.

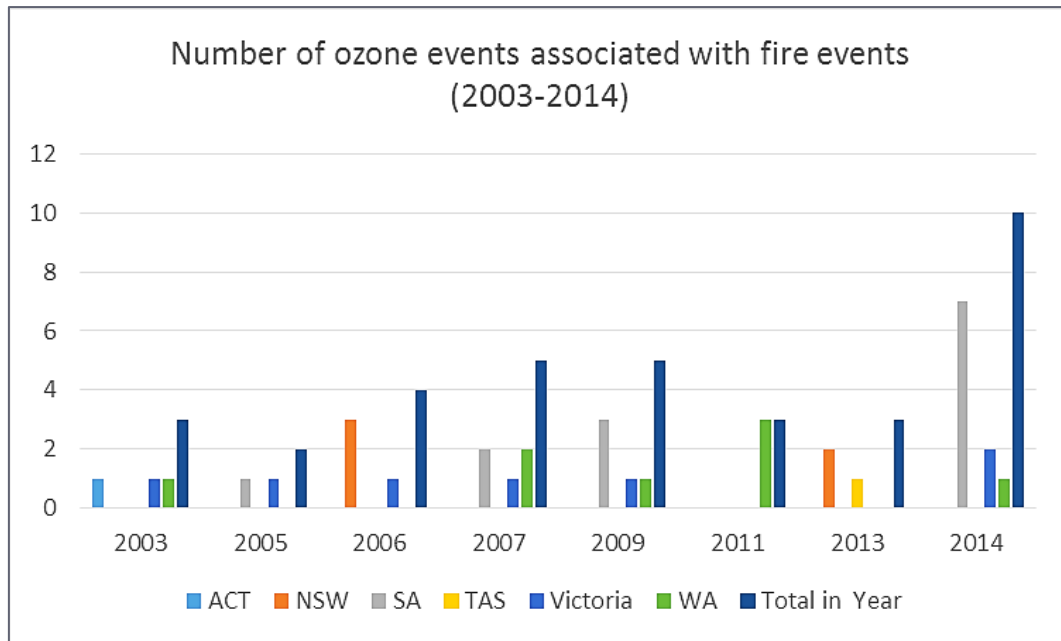


Figure 8-2: Ozone events associated with fire events (2003–2014)

Climate variability and higher temperatures predicted in the future as a result of climate change are likely to increase the potential for O₃ formation. Climate change projections for Australia suggest a likely and significant increase in the frequency of high fire risk weather. A substantial increase in the probability of extreme fire risk across Australia from grasses and forest is also predicted. This has important ramifications for air pollution and its impacts on human health in the future. As O₃ formation is influenced by air temperature and vegetation, the levels of O₃ and increased air temperatures due to global warming are likely to exacerbate the incidence and severity of photochemical smog events in Australia's cities.

8.7 Health risk assessment

To avoid potential double counting of the health effects due to different averaging periods for O₃, the HRA has been undertaken for the 1-hour maximum O₃ concentrations. This is the averaging period for which the most consistent health evidence in Australian studies exists.

8.7.1 Health outcomes for Business-as-Usual and Abatement Package scenarios

The aggregated estimates for the number of historical and projected attributable health outcomes due to O₃ in the modelled airsheds (NSW and Victoria) and other airsheds are shown in Table 8-11. The results show there is a substantial health burden associated with exposure to recent historical levels of O₃, particularly in the major cities. In Sydney and Melbourne, the health burden is projected to increase substantially in the future under the BAU scenario.

Overall, the Abatement Package scenario did not have a large effect on health outcomes. The abatement measures resulted in only small reductions in health outcomes in 2031 and 2040. In Melbourne in 2021, the year in which it was assumed the abatement measures would be implemented, there was a predicted increase in the attributable health effects due to O₃. The reasons for this are unknown, but are likely to be due in part to the complex photochemistry between NO₂ and O₃.

Table 8-11: Historical and projected health burden attributable to O₃ in Australian airsheds

Airshed	Number of attributable health outcomes					Health outcomes avoided		
	Annual average 2010–2014	Scenario	2021	2031	2040	2021	2031	2040
Daily mortality, all-cause ^(a)								
NSW and Victoria	217	BAU	111	134	156			
		Abatement Package	100	122	144	11	12	13
Other airsheds	130	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a
Emergency department visits, asthma (<15 years)								
NSW and Victoria	263	BAU	265	323	358			
		Abatement Package	288	321	353	-23	3	5
Other airsheds	164	BAU	n/a	n/a	n/a	n/a	n/a	n/a
		Abatement Package	n/a	n/a	n/a	n/a	n/a	n/a

(a) 'All-cause mortality' refers to acute mortality events that are estimated to shorten life by six months.

8.7.2 Health outcomes for compliance with standards

The numbers of health outcomes associated with meeting the O₃ standards are given in Appendix B (Annexure C, Section C.2).

The numbers of health outcomes avoided in the Australian airsheds by compliance with the proposed 1-hour²⁹ standards for O₃ of 70, 85 and 100 ppb are presented in Table 8-12, Table 8-13, and Table 8-14 respectively. The results show that, based on the historical monitoring data, there would be health benefits if the proposed 1-hour O₃ standards of 85 ppb or 70 ppb could be achieved. The largest benefit would be in Sydney. Conversely, the modelling suggests that health outcomes would increase in NSW overall for compliance with the 70 ppb and 85 ppb standards (i.e. the health outcomes avoided are negative). However, as observed earlier, greater weight should be given to the historical measurements than to the (more uncertain) future modelling when providing recommendations on possible new standards. It is also worth noting that future patterns in ozone are complicated by growth in population and activity, and how these are distributed in time and space.

Table 8-12: Health outcomes avoided if proposed 1-hour O₃ standard of 70 ppb is met in Australian airsheds

Airshed	Health outcomes avoided			
	Average 2010–2014	2021	2031	2040
Daily mortality, all-cause ^(a)				
NSW and Victoria	132	-195	-47	-41
Other airsheds	-(b)	-(b)	-(b)	-(b)
Emergency department visits, asthma (<15 years)				
NSW and Victoria	55	21	26	35
Other airsheds	8	-(b)	-(b)	-(b)

(a) 'All-cause mortality' refers to acute mortality events that are estimated to shorten life by six months.

²⁹ NB: Although there was no Group 1 CRF for daily, all-cause mortality associated with 1-hour O₃, it is still appropriate to present results for this outcome based on the CRF for 8-hour O₃. In other words, although the health benefits are for compliance with a 1-hour standard, reducing maximum 1-hour concentrations also leads to reductions in other concentration metrics (in this case, 8-hour).

(b) For these conditions, either the standard was already met in the airshed, or data were not available.

Table 8-13: Health outcomes avoided if proposed 1-hour O₃ standard of 85 ppb is met in Australian airsheds

Airshed	Health outcomes avoided			
	Average 2010–2014	2021	2031	2040
Daily mortality, all-cause ^(a)				
NSW and Victoria	52	-71	-82	-87
Other airsheds	-(b)	-(b)	-(b)	-(b)
Emergency department visits, asthma (<15 years)				
NSW and Victoria	19	7	8	11
Other airsheds	-(b)	-(b)	-(b)	-(b)

(a) 'All-cause mortality' refers to acute mortality events that are estimated to shorten life by six months.

(b) For these conditions, either the standard was already met in the airshed, or data were not available.

Table 8-14: Health outcomes avoided if existing 1-hour O₃ standard of 100 ppb is met in Australian airsheds

Airshed	Health outcomes avoided			
	Average 2010–2014	2021	2031	2040
Daily mortality, all-cause ^(a)				
NSW and Victoria	18	-(b)	-(b)	-(b)
Other airsheds	-(b)	-(b)	-(b)	-(b)
Emergency department visits, asthma (<15 years)				
NSW and Victoria	17	-(b)	-(b)	-(b)
Other airsheds	7	-(b)	-(b)	-(b)

(a) 'All-cause mortality' refers to acute mortality events that are estimated to shorten life by six months.

(b) For these conditions, either the standard was already met in the airshed, or data were not available.

8.8 Cost–benefit analysis

The full CBA can be found in Appendix C, and the findings for O₃ are presented in Chapter 9. The range of the aggregated historical health cost due to O₃ for all jurisdictions over the period 2010–2014 was \$225 million to \$1,572 million (based on the different CRF groups)³⁰. This range was higher than the corresponding value for NO₂.

The abatement measures modelled (over the period 2021–2040) were clearly not economically efficient at the national level for O₃, with a cost of around \$430 million and a benefit of \$20 million. The measures were not economically efficient in any jurisdiction.

8.9 Non-quantified benefits and disbenefits

O₃ is associated with impacts on vegetation and materials (e.g. rubber and plastics), as well as the nitrification of lakes and rivers. As the AAQ NEPM standards are based on the protection of human health, standards have not been derived for these other effects; however, any reduction in O₃ levels resulting from the adoption of more stringent standards will also lead to reductions in the effects on vegetation. O₃ is also a potent greenhouse gas. The impacts of climate change are predicted to increase O₃ levels, and in particular, O₃

³⁰ Note that the CRF group used does not change the overall outcome of the CBA, i.e. a negative NPV.

events in the future. Any reductions in O₃ levels due to the implementation of air quality management actions to meet more stringent standards will have additional benefits in terms of reducing these other impacts.

8.10 Exposure-reduction framework

As shown in the analysis, there are significant health effects associated with exposure to O₃ in the Australian airsheds. The introduction of the abatement measures would lead to reductions in O₃ in most jurisdictions, however these measures have been shown to not be economically efficient. One of the key challenges is the population growth predicted between 2016 and 2040. As the health effects attributable to O₃ are based on risks to whole populations, small improvements in air quality are offset if the predicted population growth is large, and this can result in increases in population-based health effects.

Given the health burden posed by O₃ in Australian cities, an exposure-reduction framework would provide a framework where population exposure to O₃ can be reduced, even if the standards can't be met at the present time. It also provides a mechanism whereby jurisdictions can report improvements in O₃ levels rather than just reporting that exceedances of standards have occurred.

8.11 Summary of ozone assessment

8.11.1 What does the recent health evidence tell us?

International studies have provided evidence that exposure to O₃ is causally linked to short-term acute mortality and morbidity primarily for respiratory causes. There is some evidence that O₃ exposures are also associated with cardiovascular outcomes, but the evidence is not as strong as for respiratory outcomes.

Reviews have found there is new evidence on the associations between daily maximum 1-hour and 8-hour O₃ concentrations and all-cause, cardiovascular and respiratory mortality, as well as cardiovascular and respiratory hospital admissions. There is currently no convincing evidence of a threshold for short-term exposure to a daily maximum 1-hour or 8-hour O₃ concentration, or of a non-linear relationship at low concentrations. The evidence base for long-term effects of O₃ has also strengthened; in particular, long-term exposure to O₃ is linked to the incidence of asthma, and not just the exacerbation of existing asthma. O₃ was also found to be associated with a range of reproductive and developmental effects that had not previously been linked with O₃ exposure.

8.11.2 What do the WHO guidelines and international standards tell us?

The only WHO guideline for O₃ is for the daily maximum 8-hour concentration (47 ppb, 100 µg/m³). The 8-hour averaging period is the one in common use internationally, but it is not included in the AAQ NEPM. The 4-hour averaging period, which is included in the AAQ NEPM, is not used outside Australia. The 1-hour averaging period standard used in Australia is not used by the USEPA, EU, UK or Canada, nor is it recommended by the WHO.

8.11.3 What do the air quality measurements and modelling tell us?

The ambient monitoring data showed there is significant year-to-year variability in the O₃ levels observed in the Australian airsheds. O₃ levels are influenced by hot summers (temperature) and bushfires. Patterns of exceedances of the air quality standards (current and proposed) for O₃ have been more complicated than those for SO₂ and NO₂.

In Sydney there was a slight downward trend in maximum 1-hour and 4-hour O₃ concentrations from 2003 to 2016. For all other cities and regional centres no clear trend was apparent. There were also no systematic, long-term patterns in the data for 8-hour O₃ concentrations. A number of the peak O₃ concentrations in various years were associated with large bushfires.

Historically, exceedances of the current AAQ NEPM standards (100 ppb for the 1-hour average, and 80 ppb for the rolling 4-hour average) occurred in most airsheds and in most years. This was particularly evident in the data for Sydney. Clearly there would have been more exceedances of the more stringent proposed standards. The modelling for future years showed that the Abatement Package would not have a substantial effect on the general exceedance patterns in Sydney and the Port Phillip Region, although exceedances would be reduced.

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 the modelling for future years, the Abatement Package had 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.

The comparison between the historical measurements and the future predictions in the BAU scenario indicated the models were generally underestimating the numbers of exceedances for O₃ in NSW, and overestimating exceedances in the Latrobe Valley. It appears that O₃ exceedances in the Port Phillip Region were reasonably well predicted.

The processes of O₃ formation and removal are complex and require detailed modelling. This was only possible for NSW and Victoria, and therefore for the other jurisdictions there were no projections of O₃ concentrations and associated health outcomes (as well as monetised benefits). The modelling of ozone is also subject to uncertainty and, given it underestimated exceedances of standards in Sydney, on the whole greater weight should be given to the historical measurements than to the future modelling when providing recommendations on possible new standards.

8.11.4 What does the HRA tell us?

The aggregated estimates for the number of historical and projected attributable health outcomes due to O₃ in the modelled airsheds (NSW and Victoria) and other airsheds are shown in Table 8-11. The results show that there is a substantial health burden associated with exposure to recent historical levels of O₃, particularly in the major cities. In Sydney and Melbourne, the health burden is projected to increase substantially in the future under the BAU scenario.

Overall, the Abatement Package scenario did not have a large effect on health outcomes. The abatement measures resulted in only small reductions in health outcomes in 2031 and 2040. In Melbourne in 2021, the year in which it was assumed that the abatement measures would be implemented, there was a predicted increase in the attributable health effects due to O₃. The reasons for this are unknown but are likely to be due in part to the complex photochemistry between NO₂ and O₃.

The numbers of health outcomes associated with meeting the O₃ standards are given in Appendix B (Annexure C, Section C.2). The implementation of the Abatement Package did not lead to the meeting of the proposed 1-hour standard for O₃ of 70 ppb. The 85 ppb and 100 ppb proposed standards were met with the Abatement Package. The numbers of health outcomes avoided in the Australian airsheds by compliance with the proposed 1-hour standards for O₃ of 70, 85 and 100 ppb are presented in Table 8-12, Table 8-13, and

Table 8-14 respectively.

8.11.5 What does the CBA tell us?

The abatement measures modelled were clearly not economically efficient at the national level for O₃, with a cost of \$430 million and a benefit of \$20 million under CRF Group 1. In fact, the CBA showed that the package of abatement measures was uneconomic regardless of CRF group adopted. The benefits were relatively low, partly because of the low population where reductions in concentration would occur, and partly because of the complex, non-linear relationships between changes in O₃ concentrations and changes in precursor emissions.

8.12 Recommendations

8.12.1 What O₃ standards should be adopted to protect health?

The following sections provide the recommendations for the variation of the O₃ standards in the AAQ NEPM, and the supporting rationale.

8.12.1.1 1-hour and 4-hour standards

The 1-hour and 4-hour forms of the Australian O₃ standard were established in 1998. Since that time new health science information has become available to better guide the most appropriate form of the O₃ standard. In particular, the REVIHAAP project concluded that epidemiological evidence supported health estimates based on daily maximum 8-hour O₃ (WHO 2013b). The WHO did not find evidence that a 1-hour standard provided any additional health protection. Epidemiological studies have not focused on a 4-hour averaging period, so evidence is not available to assess the benefits and drawbacks of a 4-hour averaging period. While it is not clear there is an epidemiological reason for using a 4-hour averaging period, it is clear that the 8-hour averaging period appropriately represents the daily exposure.

The 1-hour standard is used in Australia but is not used by the USEPA, EU, UK or Canada, nor is it recommended by the WHO. A 1-hour standard is only applied in Australia, New Zealand and California. The standard in Australia is less stringent than in the other locations. The 4-hour averaging period, which is included in the AAQ NEPM, is not used outside Australia, and it has not been considered as a standard by the WHO.

Because O₃ is a secondary pollutant that forms in the atmosphere over a period of hours, peak 1-hour O₃ exposures do not occur in isolation but as part of a photochemical smog event or burn with a duration of many hours. This is apparent in the Australian monitoring data. For example, in the last decade, the 1-hour NEPM standard has not been exceeded in Victoria, and has rarely been exceeded in NSW, in the absence of exceedances of a hypothetical rolling 8-hour standard. A rolling 8-hour standard captures all O₃ events from 1–8 hours and is now commonly applied by the nations with the tightest air pollution standards. This 8-hour standard is a controlling standard that can generally also enable 1-hour and 4-hour O₃ values to be met.

Based on the above, it would be appropriate to remove the 1-hour and 4-hour O₃ standards from the AAQ NEPM and replace them with a (more appropriate) rolling 8-hour standard (see below). Maintaining 1-hour and 4-hour standards when an 8-hour standard is introduced would also unnecessarily duplicate reporting, while not providing additional health protection.

However, in the Australian context, it is recognised there would be some benefit to tracking historical 1-hour O₃ trends. In addition, it is worth noting that the EU only applies an 8-hour O₃ standard, but it also uses a 1-hour community information value on the basis that an 8-hour period is too long for triggering an information release. Information warnings based on 8-hour averages would be delivered too late to avoid adverse health consequences (NEPC 2005). Therefore, it is recommended that jurisdictions continue to record and report 1-hour O₃ concentrations so that data continue to be available for analysis. For this reason, it is recommended that a 1-hour O₃ community health information value or alternative forecast mechanism is used by states and territories to provide quick community health alerts in conjunction with an 8-hour standard.

Recommendation 17: The current 1-hour and 4-hour standards for O₃ should be removed from the AAQ NEPM.

Recommendation 18: Jurisdictions should continue to record and report 1-hour O₃ concentrations.

8.12.1.2 8-hour standard

The only WHO guideline for O₃ is for the daily maximum rolling 8-hour concentration (47 ppb). The 8-hour averaging period is the one in common use internationally, but it is not currently included in the AAQ NEPM. As noted above, a rolling 8-hour standard captures all O₃ events from 1–8 hours and is now commonly applied by the nations with the tightest air pollution standards. This 8-hour standard is a controlling standard that can generally also enable 1-hour and 4-hour O₃ values to be met.

The analysis presented in this Impact Statement has shown that the 8-hour standard of 47 ppb has been significantly exceeded historically in almost all airsheds, and exceedances are predicted in the future in NSW and Victoria. The proposed standards of 55 ppb and 60 ppb are also predicted to be exceeded in the BAU scenario, particularly in large cities. There have been few historical exceedances of the 70 ppb standard, and few exceedances are also predicted for the future. The Impact Statement has shown there have been, and are likely to be in the future, some exceedances of the 60 ppb standard.

The 70 ppb standard is consistent with the status quo, as it is roughly equivalent to the current 1-hour and 4-hour standards, whereas a 60 ppb standard would introduce significant difficulties in terms of compliance issues in large cities, with a requirement for a complex and extensive package of abatement measures. Although it has not been investigated in this Impact Statement, an intermediate standard of 65 ppb is therefore recommended for incorporation into the AAQ NEPM. This is higher than the WHO guideline and EU and UK standards, similar to Canada and stricter than the US. The difference between these standards also reduces once the form of the standard and allowable exceedances are considered (refer to Table 8-3). Whilst it should generally be more achievable in Australian jurisdictions than 60ppb, it would also drive improvements in health.

The comparison between the historical measurements and the future predictions indicated that the models were potentially underestimating the numbers of exceedances for O₃ in Sydney, and overestimating exceedances in the Port Phillip Region. This means that exceedances of the 65 ppb standard in Sydney may be more pronounced than the modelling has suggested.

Recommendation 19: A rolling 8-hour standard for O₃ in the AAQ NEPM should be introduced, and the numerical value of the standard should be 65 ppb.

Recommendation 20: The 8-hour standard should be reviewed in 2025, with the option of reducing it once there is a better understanding of O₃ generation in capital city airsheds.

8.12.2 What form should the standards take?

In line with the recommendations for SO₂ and NO₂, as well as the WHO guideline and the approach adopted for PM in the AAQ NEPM, the form of the 8-hour standard for O₃ should be the maximum value with no allowable exceedances.

However, in several jurisdictions exceedances of the O₃ standards are associated with major fire events. An exceptional event rule is therefore recommended for O₃, with an approach that is consistent with that currently defined in the AAQ NEPM for PM₁₀ and PM_{2.5}. That is to say, for the purpose of reporting compliance against an 8-hour O₃ standard, jurisdictions should include all measured data, including monitoring data directly associated with an exceptional event. The reporting protocols currently in place for PM would help jurisdictions to better understand the reasons for O₃ exceedances.

Recommendation 21: The form of the 8-hour standard for O₃ should be the maximum value with no allowable exceedances (excluding exceptional events).

Recommendation 22: An exceptional event rule should be implemented for O₃, defined in a way that is consistent with the approach for PM₁₀ and PM_{2.5} in the AAQ NEPM.

8.12.3 How will prescribed burns be managed under an exceptional events rule?

Concentrations of the precursors within the smoke plumes of bushfires are sufficient to generate O₃ and increase concentrations during the fire event. Not all fires will lead to O₃ events or an exceedance of the standard. Suitable meteorological conditions (importantly air temperature) and precursor emissions need to be present to drive the reactions. Climate variability and higher temperatures predicted in the future as a result of climate change are likely to increase the potential for O₃ formation.

It is important to manage prescribed burns to minimise the production of O₃ and other air pollutants. To this end all O₃ monitoring data and all exceedances of O₃ standards, with and without exceptional events, should be fully reported and described. This will assist policy analysis of management options.

8.12.4 Are the recommended standards achievable with reasonable measures?

For 8-hour O₃ the proposed standard that appears to be the most generally achievable in the BAU scenario is 70 ppb, and the recommended standard for the AAQ NEPM is a more stringent 65 ppb. However, it should be noted that compliance with the 65 ppb standard in NSW may be challenging in practice given that the modelling under-predicted exceedances.

Any lower standard would require the introduction of abatement measures. This is particularly important for Sydney, which has significant challenges not experienced in other jurisdictions. One of the key challenges is the difference in the actions required to reduce O₃ levels in NO_x limited airsheds compared to VOC limited

airsheds. As shown in the modelling of the abatement measures, one package of measures applied to all airsheds can lead to benefits in one airshed but significant disbenefits in others, depending on whether it is VOC or NO_x limited. This suggests that the actions taken to reduce O₃ need to differ and should be determined on a jurisdictional basis. Alternatively, packages of abatement measures could be developed for NO_x limited airsheds and a separate package for VOC limited airsheds; however, for most jurisdictions there is uncertainty in determining whether their airshed is either VOC or NO_x limited, with the exceptions being Melbourne and Sydney (though information for Sydney and Melbourne should also be reviewed and updated). To enable a national package of measures to be developed, air dispersion modelling should be undertaken for each airshed so the key issues and challenges for each jurisdiction are well understood. To enable this, more detailed and consistent emission inventories for the non-modelled jurisdictions need to be developed.

8.12.5 Should an exposure-reduction framework for O₃ be considered?

An exposure-reduction framework (and target) for O₃ should be established to reduce population exposure and associated health risk. If an exposure-reduction framework is adopted for NO₂, it is recommended that one also be adopted for O₃, as the reduction in O₃ is dependent on reductions in both VOCs and NO₂.

Any exposure-reduction framework for O₃ should set a target for reduction in levels over a specified time period. A national target could be established but the actions taken to meet that target would be specific to the individual jurisdictions.

Consistent with the approach used in the AAQ NEPM variation for PM_{2.5}, it is recommended that jurisdictions evaluate and report population exposure to O₃ from the commencement of the varied AAQ NEPM. Jurisdictions should agree on any procedures or methods to ensure consistency. To be consistent with the AAQ NEPM it is also proposed that a simplified response to implementing an exposure-reduction framework for O₃ would be to adopt a long-term goal to be decided once more detailed and consistent emission inventories for the non-modelled jurisdictions are developed.

Recommendation 23: An exposure-reduction framework, in the form of a long-term goal for O₃, should be considered to reduce population exposure and associated health risk once there is a better understanding of O₃ generation in capital city airsheds.

Recommendation 24: Jurisdictions should commence annual reporting on population exposure to O₃ from the commencement of a varied AAQ NEPM.

Chapter 8 – Key points

- O₃ is a highly reactive gas and a major component of photochemical smog. O₃ is not emitted directly but is a secondary pollutant formed in the atmosphere by the reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of heat and 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 O₃ formation.
- O₃ is known to impact on health largely through effects in the respiratory tract. It may be harmful to the lungs, especially for children, the elderly and people with lung disease. It may also exacerbate pre-existing respiratory conditions such as asthma. It can also damage vegetation and materials and is a potent greenhouse gas.
- There have been no clear trends in O₃ concentrations in Australian cities or regional centres from 2003–2016 except for Sydney, where there has been a slight downward trend.
- O₃ exceedances have occurred in most airsheds in most years between 2003 and 2016, particularly in Sydney.
- There is a substantial health burden associated with exposure to recent historical levels of O₃, particularly in the major cities. In Sydney and Melbourne, the health burden is projected to increase substantially in the future if emissions continue as forecast with no abatement.
- 1-hour or 4-hour averaging periods are not widely used (1-hour), or not used at all (4-hour), outside of Australia and are not recommended by the WHO.
- An 8-hour averaging period is the only one commonly used for ozone internationally and the only averaging period applied in the US, EU, UK and Canada, and recommended by the WHO. The WHO found that it provides sufficient health protection and a 1-hour standard is not required.
- As a controlling standard, an Australian 8-hour standard of 70 ppb would capture longer-term health impacts of most concern and would generally ensure current 1-hour and 4-hour standards would not be exceeded. The adoption of a 65 ppb 8-hour O₃ standard would provide additional protection against prolonged O₃ exposures, as well as against shorter-term peaks of concern.
- O₃ exceedances are influenced by bushfires in most jurisdictions. Given this, an exceptional events rule may be appropriate that permits exceedances of the O₃ standards when they are caused by major natural events such as bushfires.
- Given the health burden posed by O₃ in Australian cities, an exposure-reduction framework would provide a mechanism to reduce population exposure to O₃ and allow jurisdictions to report improvements in O₃ levels as well as any exceedances of the standard.

Chapter 8 – Consultation questions

- Do you agree with the recommendations made in this report for the O₃ standards? Your answer should consider whether you agree:
 - a) with the introduction of a rolling 8-hour O₃ standard and removal of the 1-hour and 4-hour averaging periods
 - b) with jurisdictions continuing to record and report 1-hour concentrations even if there is no 1-hour standard
 - c) that there are no other averaging periods that should be considered for O₃ in the future
 - d) with the preferred numerical value for the 8-hour O₃ standard (65 ppb)
 - e) that there should be no allowable exceedances for the O₃ standards
 - f) with the introduction of an exposure-reduction framework for O₃ (in the form of a long-term goal for O₃) once O₃ generation in capital cities is better understood
 - g) with jurisdictions commencing annual reporting on population exposure to O₃ from the commencement of a varied AAQ NEPM
 - h) with the introduction of an exceptional events rule for O₃ that is consistent with the approach for the PM_{2.5} and PM₁₀ standards in the AAQ NEPM. Note that an exceptional events rule will differ from an allowable exceedances rule as it will only apply to exceptional events (such as bushfires and dust storms) rather than be based on a fixed number of days.

9 Results of cost–benefit analysis

The CBA provided estimates for the following:

- the cost of the existing health burden for SO₂, NO₂ and O₃ in present value (PV) terms and 2016 dollars, based on the HRA data for 2010–2014
- the costs and benefits of the Abatement Package scenario.

The abatement measures targeted emission sources for SO_x, NO_x and VOCs. The assessment of costs and emission reductions was based on publicly available data. The monetary benefits were estimated based on the health outcomes from the HRA.

The CBA is described in detail in Appendix C, and the results are summarised below.

9.1 Cost of existing health burden

For the existing health burden, the aggregated health costs of SO₂, NO₂ and O₃ over the period 2010 to 2014 (based on the central estimate for the Group 1 CRFs) are provided in Table 9-1. Of the three pollutants, exposure to NO₂ is estimated to have had the greatest health burden between 2010 and 2014, and the effects of NO₂ are estimated to be the highest in NSW. This health burden for NSW reflects a combination of high NO₂ concentrations and a large population size. O₃ has the second highest estimated health cost of the three pollutants, and for the same reasons as NO₂, the greatest burden is estimated for NSW. The health costs associated with exposure to SO₂ are estimated to be the lowest, due to fewer mortalities estimated to be associated with exposure to SO₂ concentrations.

Table 9-1: Aggregated cost of health burden for 2010–2014

Jurisdiction	Health cost (\$, 2016 PV)		
	SO ₂	NO ₂	O ₃
New South Wales (NSW)	\$18 m ^(a)	\$122 m	\$111 m
Victoria (VIC)	\$29 m	\$83 m	\$29 m
Queensland (QLD)	\$11 m	\$27 m	\$34 m
Western Australia (WA)	\$12 m	\$15 m	\$32 m
South Australia (SA)	\$2 m	\$19 m	\$16 m
Northern Territory (NT)	\$0 m	\$0 m	\$2 m
Total	\$72 m	\$265 m	\$225 m

(a) 'm' = million

Due to the uncertainty in the health response, the health burden was estimated using the two alternative groups of CRFs (Group 2 and Group 3). The uncertainty of the CRFs on the health burden in the period 2010 to 2014 (expressed as a range) are provided in Table 9-2. The impact of the CRF groups on the cost–benefit analysis is discussed further in Annexure B of Appendix C. Ultimately, the CRF groups chosen for NO₂ and O₃ did not change the overall outcome of the CBA: a negative NPV. The estimated mortality from long-term exposure to NO₂ was substantially higher using the Group 3 CRFs. In both the alternative CRF sensitivities, a much larger estimate of the health burden associated with O₃ exposure was estimated. This was because of higher estimated mortalities from exposure.

Table 9-2 Range of uncertainty on existing health burden using different CRFs (\$, 2016 PV)

SO ₂	NO ₂	O ₃
\$72 m ^(a)	\$265 – \$761 m	\$225 – \$1,572 m

(a) The estimated health burden of SO₂ is the same across the three groups of CRFs because the exposure-response functions used are the same.

9.2 Costs and benefits of the Abatement Package

The results of the high-level desktop CBA in Table 9-3 show that the costs of the Abatement Package are likely to considerably outweigh the health benefits at the national level. The benefit:cost ratio for the Abatement Package corresponding to SO₂, NO₂ and O₃ is estimated at 0.01, 0.06 and 0.05 respectively.

Two important qualifications accompany the CBA results:

- There are a number of benefits that could not be reliability quantified.
- The costs and benefits of the abatement measures do not reflect the likely costs and benefits of meeting various air quality standards.

Unquantified benefits include lost labour productivity, a reduction in the emission of other pollutants, avoidance of some non-health impacts, and a reduction in secondary PM formation.

While the CBA estimated the costs and benefits of the Abatement Package at the national level, it did not necessarily provide an indication of the likely costs and benefits of meeting alternative air quality standards. This is because, although some abatement measures are implemented at the national level (e.g. emission standards for road vehicles), each jurisdiction implements policy and regulations that are designed to meet the standards locally, and this may include jurisdiction-specific CBAs and other analyses to select the most appropriate set of measures.

The results of the CBA suggest that the implementation of abatement measures for selected pollutants can be economically efficient *in selected airsheds*. Therefore, this CBA recommends that abatement measures to meet updated ambient air quality standards should only be implemented if appropriate state-level policy assessment processes support their implementation, or if a national assessment, including a more detailed CBA, supports their implementation at a national level.

Furthermore, the CBA also suggests that policy approaches such as an exposure-reduction framework, which targets reductions in population exposure instead of average concentrations, could provide an effective complement to standards.

Table 9-3: Projected costs and benefits of the Abatement Package, aggregated over the period 2021–2040

Jurisdiction	Pollutant		
	SO ₂	NO ₂ ^(a)	O ₃
Costs (\$, 2016 PV)			
NSW	\$13,887 m	\$9,604 m	\$109 m
NT	\$543 m	\$327 m	\$3 m
QLD	\$19 m	\$3,333 m	\$104 m
SA	\$0 m	\$2,125 m	\$38 m
VIC	\$9,937 m	\$7,032 m	\$102 m
WA	\$23 m	\$1,949 m	\$75 m
Total	\$24,409 m	\$24,369 m	\$430 m
Benefits (\$, 2016 PV)^(b)			
NSW	\$44 m	\$58 m (\$1,183 m)	\$9 m
NT	\$0 m	\$1 m (\$0 m)	\$0 m
QLD	\$36 m	\$18 m (\$0 m)	\$0 m
SA	\$0 m	\$9 m (\$0 m)	\$0 m
VIC	\$64 m	\$26 m (\$457 m)	\$11 m
WA	\$52 m	\$20 m (\$0 m)	\$0 m
Total	\$196 m	\$133 m (\$1,639 m)	\$20 m
Benefit:cost ratio (BCR)			
NSW	0.0	0.1	0.1
NT	0.0	0.0	0.0
QLD	1.9	0.0	0.0
SA	n/a	0.0	0.0
VIC	0.0	0.1	0.1
WA	2.3	0.0	0.0
National	0.01	0.07	0.05
Net present value (\$, 2016)			
National total	–\$24,213 m	–\$22,597 m	–\$410 m

(a) Benefits from reductions in PM_{2.5} emissions are displayed in brackets.

(b) The estimation of monetised health benefits over the period 2021–2040 did not include any 'uplift' factor to account for the expected growth in willingness to pay to avoid health outcomes. This was because of uncertainty in the outlook for real income growth at the time of writing. This assumption resulted in a conservative estimate of future health benefits.

Chapter 9 – Key points

- The cost–benefit analysis (CBA) estimates the:
 - cost of the existing health burden for SO₂, NO₂ and O₃ in present value (PV) terms and 2016 dollars, based on the HRA data for 2010–2014
 - costs and benefits of the Abatement Package scenario.
- This Impact Statement has found there are health effects arising from exposure to SO₂, NO₂ and O₃ in Australian cities at the current levels. The associated combined health costs due to mortality and hospitalisation over the period 2010–2014 were in the order of \$562 million to \$2,405 million, based on the different concentration-response function groups from the sensitivity tests.
- The Abatement Package was developed following a multi-criteria analysis of potential abatement options that gave the highest weighting to quantum of abatement, cost and (to a lesser degree) health benefits.
- The Abatement Package scenario modelled as part of this review has been shown to not be cost-effective in achieving reductions in pollutant levels.
- Consideration should be given to alternative abatements that may achieve a larger impact across whole populations, such as those associated with motor vehicles and transport options.
- In many cases additional abatements are not required to meet the proposed standards and the health benefit gained is substantial.

10 Overall summary and recommendations

10.1 Overview

This Impact Statement has found there are health effects arising from exposure to the pollutants under consideration, O₃, NO₂ and SO₂, in Australian cities at the current levels of these pollutants. The associated combined health costs due to mortality and hospitalisation over the period 2010–2014 were of the order of \$562 million to \$2,405 million, based on the different CRF groups from the sensitivity tests. However, when considering the full CBA, the application of the different CRF groups did not change the overall outcome, which was a negative NPV to society.

Other non-quantified costs include increased medication usage, work loss days and absences from schools. Loss of productivity costs are likely to be significant. With the predicted population growth in Australian cities and regional areas, the number of people who are exposed to air pollution will also increase, leading to an increased health burden.

The analysis presented in this Impact Statement has shown there are material health benefits associated with meeting the standards that have been proposed for this review. Air quality modelling has shown that some of these standards can be met by 2040. There will be challenges to meet some of the strictest proposed standards for O₃ in many jurisdictions; however, consideration of an exposure-reduction framework, which focuses on reducing the exposure of the population and thereby reducing the risk to their health, provides a mechanism whereby continual improvements in air quality can be demonstrated even if there are exceedances of the standards.

The Abatement Package scenario modelled as part of this review has been shown to not be cost-effective in achieving reductions in pollutant levels. Consideration should be given to alternative abatements that may achieve a larger impact across whole populations, such as those associated with motor vehicles and transport options. However, as discussed above, in many cases additional abatements are not required to meet the proposed standards and the health benefit gained is substantial.

10.2 Recommendations for the National Environment Protection (Ambient Air Quality) Measure

10.2.1 Desired environmental outcome and goal

- Recommendation 1: The desired environmental outcome of the AAQ NEPM should be revised to 'minimise the risk of adverse health impacts from exposure to air pollution for all people, wherever they may live'.
- Recommendation 2: The goal of the AAQ NEPM should be revised to make reference to the air quality standards and incorporation of exposure-reduction targets for priority pollutants.

10.2.2 Sulfur dioxide

- Recommendation 3: The status quo should be maintained of not including a 10-minute SO₂ standard in the AAQ NEPM.

- Recommendation 4: The 1-hour standard for SO₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 100 ppb.
- Recommendation 5: A future 1-hour SO₂ standard of 75 ppb is recommended for implementation from 2025 (this timeframe is consistent with the goals for PM_{2.5} in the AAQ NEPM).
- Recommendation 6: The 24-hour standard for SO₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 20 ppb.
- Recommendation 7: No future target for 24-hour average SO₂ concentrations is recommended at this stage.
- Recommendation 8: The current annual mean standard for SO₂ should be removed from the AAQ NEPM.
- Recommendation 9: The form of both the 1-hour and 24-hour SO₂ standards should be the maximum value with no allowable exceedances.

10.2.3 Nitrogen dioxide

- Recommendation 10: The 1-hour standard for NO₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 90 ppb.
- Recommendation 11: The annual standard for NO₂ in the AAQ NEPM should be retained, and the numerical value of the standard should be reduced to 19 ppb.
- Recommendation 12: The form of both the 1-hour and annual NO₂ standards should be the maximum value with no allowable exceedances.
- Recommendation 13: An exposure-reduction framework, in the form of a long-term goal for NO₂, should be established to reduce population exposure and associated health risk.
- Recommendation 14: A future 1-hour NO₂ standard of 80 ppb is recommended for implementation from 2025 as part of an exposure-reduction framework (this timeframe is consistent with the goals for PM_{2.5} in the AAQ NEPM).
- Recommendation 15: A future annual NO₂ standard of 15 ppb is recommended for implementation from 2025 as part of an exposure-reduction framework (this timeframe is consistent with the goals for PM_{2.5} in the AAQ NEPM).
- Recommendation 16: Jurisdictions should also commence annual reporting on population exposure to NO₂ from the commencement of a varied AAQ NEPM.

10.2.4 Ozone

- Recommendation 17: The current 1-hour and 4-hour standards for O₃ should be removed from the AAQ NEPM.
- Recommendation 18: Jurisdictions should continue to record and report 1-hour O₃ concentrations.

- Recommendation 19: A rolling 8-hour standard for O₃ in the AAQ NEPM should be introduced, and the numerical value of the standard should be 65 ppb.
- Recommendation 20: The 8-hour standard should be reviewed in 2025, with the option of reducing it once there is a better understanding of O₃ generation in capital city airsheds.
- Recommendation 21: The form of the 8-hour standard for O₃ should be the maximum value with no allowable exceedances (excluding exceptional events).
- Recommendation 22: An exceptional event rule should be implemented for O₃, defined in a way that is consistent with the approach for PM₁₀ and PM_{2.5} in the AAQ NEPM.
- Recommendation 23: An exposure-reduction framework, in the form of a long-term goal for O₃, should be considered to reduce population exposure and associated health risk once there is a better understanding of O₃ generation in capital city airsheds.
- Recommendation 24: Jurisdictions should commence annual reporting on population exposure to O₃ from the commencement of a varied AAQ NEPM.

10.3 Other recommendations

The following general recommendations have resulted from this work:

- To assist in the assessment of air quality in the future in all Australian cities, detailed and nationally consistent emission inventories need to be developed to enable air dispersion modelling for all jurisdictions. This will enable cost-effective abatement measures to be identified for each jurisdiction based on an understanding of pollutant formation in that jurisdiction.
- A 1-hour O₃ community health information value or alternative forecast mechanism should be used by states and territories to provide quick community health alerts in conjunction with an 8-hour standard.
- Given the growing evidence on the long-term effects of O₃ on health, it is recommended that a watching brief be kept on key research and trends in international standards in this area, with a view to potentially adopting a long-term goal as part of an exposure-reduction framework, in the future.
- A watching brief should be kept on the association between SO₂ and low birth weights.
- Consideration should be given to investigating additional abatement measures that address motor vehicle emissions and broader transport options, given the significant contribution to NO₂ levels in Australian cities from these sources.
- Clause 14 in the AAQ NEPM (Number of performance monitoring stations) should be amended to introduce a primary focus on risk as determined by jurisdictions.
- The allowable exceedances rule should be removed for CO for consistency with the other pollutants in the AAQ NEPM, and based on the recent historical and likely concentrations of CO in the future.

11 Limitations and uncertainties

11.1 Overview

There are a number of limitations and uncertainties arising in respect of the benefits which have been modelled in this analysis that may result in the total quantum of estimated benefits being somewhat underestimated. This largely arises due to a number of benefits not being explicitly quantified. These include:

- other potential health outcomes
- the locations modelled being confined to large cities and a number of major regional centres
- reductions in other pollutants other than those for which new standards are being proposed (and the co-benefits arising from reductions in PM_{2.5})
- other non-health benefits (e.g. reduced productivity)
- environmental benefits.

In addition, there are inherent uncertainties in the use of air dispersion models.

11.2 Dispersion modelling

Studies of this nature involving 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. The USEPA states that dispersion modelling introduces errors of ± 10 – 40 per cent in the calculations (USEPA 2005). A 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 used for this Impact Statement were predicting concentrations within the range of acceptable accuracy.

11.3 Health risk assessment

There were a number of uncertainties in the HRA process. These included:

- the use of current baseline health data for future projections. Changes in age distribution and health status over time may either increase or decrease the predicted risk (which cannot be quantified). The projected ABS population data show an ageing population, with a greater percentage of people over 65 years of age in the future
- uncertainties in air dispersion modelling may over-predict or under-predict the exposure data used in the HRA, which in turn may over-predict or under-predict health outcomes. As discussed in Appendix A, analysis of the predicted O₃ levels in Sydney suggests that the model is under-predicting. This means the predicted health effects and avoided health effects if alternative standards were met may also be underestimated
- the use of overseas concentration-response data to assess long-term NO₂ impacts may result in uncertainty due to differences in population, air pollution levels, and climatic conditions, that may change the risk to the population in Australian cities. Results of short-term studies conducted in Australia on the impact of NO₂ on mortality and hospital admissions have found similar results to those obtained in studies in Europe and Canada. On that basis the uncertainty introduced by using the long-term estimates from European studies is likely to be small.

11.4 Cost–benefit analysis

The following are key limitations with respect to the estimation of costs in the CBA:

- The costing of the abatement measures was derived from high-level desktop research of publicly available information. No consultation with industry was undertaken to determine the feasibility of implementing the abatement measures, to what extent they may have already been partially implemented, or whether there are other mechanisms which could achieve a similar abatement result but at a different cost.
- Whilst some of the abatement measures have previously been the subject of detailed analysis, and so likely accurately reflect the true cost of implementation, other measures have limited cost data availability (either in an Australian context or where implemented overseas) and so should be considered indicative only.

In addition, the costs associated with a number of abatement measures are highly dependent on a range of detailed implementation assumptions and were only considered at a high level in the CBA.

In relation to benefits:

- There are a number of benefits that could not be reliability quantified.
- The costs and benefits of the abatement measures do not reflect the likely costs and benefits of meeting various air quality standards.

Unquantified benefits include lost labour productivity, a reduction in the emission of other pollutants, avoidance of some non-health impacts, and a reduction in secondary PM formation.

12 Consultation

Stakeholder input is being sought on the options outlined in the Impact Statement. Consultation questions are included at the end of each chapter as a guide to assist stakeholders to provide input. A list of all the consultation questions is provided at the end of this chapter; however, feedback is also welcomed on other aspects of the Impact Statement and its appendices.

All submissions are public documents unless clearly marked 'confidential' and may be made available to other interested parties, including by being published on the NEPC website. Stakeholders should indicate if their submission is confidential or clearly indicate sections that may contain confidential or sensitive information that is not for publication.

Feedback received during the public comment period will be used to inform the development of the NEPM variation.

The *National Environment Protection Council Act 1994* requires that both the draft AAQ NEPM variation and the Impact Statement be made available for public consultation for a period of at least two months. The consultation period will occur over an 11-week period from May to August 2019. The views of stakeholders on these documents are being sought through written and online submissions.

Online submissions are preferred and can be made via: nepc@environment.gov.au

Written submissions may also be made and sent to:

Adam Carlon, NEPC Executive Officer
National Environment Protection Council
Department of the Environment and Energy
GPO Box 787
CANBERRA ACT 2601

Email: nepc@environment.gov.au

The closing date for submissions is Wednesday 7 August 2019.

Following the public consultation period, the NEPC is required to prepare a summary of the issues raised in the stakeholder submissions and responses. In deciding whether or not to make the NEPM variation, the NEPC must take both the Impact Statement and the summary of submissions and responses into account.

Consultation questions

Chapter 1 Introduction and Chapter 2 Air quality management in Australia

- Do you support the recommended changes to clause 14 (incorporating risk into how the number of performance monitoring stations is determined) and the inclusion of relevant definitions?
- Do you support the removal of allowable exceedances for CO?

Chapter 3 Statement of the problem

- Do you agree with the assessment of options in this report? Have any options been missed?

- Do you agree with the preferred option to vary the AAQ NEPM? In particular, do you agree that continued government involvement is required to address the current and potential future health impacts and costs of SO₂, NO₂ and O₃?

Chapter 4 Methodology

- Have all key assumptions been correctly identified and included in the analysis? If not, please provide details.
- Can you suggest any improvements to the methodology used in this report for future reviews?

Chapter 5 Assessment of desired environmental outcome and goal

- Do you support the desired environmental outcome of the AAQ NEPM being revised to 'minimise the risk of adverse health impacts from exposure to air pollution for all people, wherever they may live'?
- Do you support the goal of the AAQ NEPM being revised to make reference to the air quality standards and incorporation of exposure-reduction targets for priority pollutants?

Chapter 6 Impact assessment for sulfur dioxide

- Do you agree with the recommendations made in this report for the SO₂ standards? Your answer should consider whether you agree:
 - a) with maintaining the status quo of not including a 10-minute SO₂ standard in the AAQ NEPM
 - b) with retaining the averaging periods of 1-hour and 24-hours for SO₂ and removal of the annual SO₂ standard given the weak evidence of health effects from long-term exposures to SO₂
 - c) that there are no other averaging periods for SO₂ that should be considered in the future
 - d) with the preferred numerical value for the 1-hour SO₂ standard (100 ppb) and the future 1-hour standard (75 ppb) for implementation by 2025
 - e) with the preferred numerical value for the 24-hour SO₂ standard (20 ppb) and no future 24-hour standard
 - f) that there should be no allowable exceedances for the SO₂ standards
 - g) that an exposure-reduction framework is not needed for SO₂.

Chapter 7 Impact assessment for nitrogen dioxide

- Do you agree with the recommendations made in this report for the NO₂ standards? Your answer should consider whether you agree:
 - a) with retaining the averaging periods of 1-hour and annual for NO₂
 - b) that there are no other averaging periods that should be considered for NO₂ in the future
 - c) with the preferred numerical value for the 1-hour NO₂ standard (90 ppb) and the future 1-hour standard (80 ppb) for implementation by 2025
 - d) with the preferred numerical value for the annual NO₂ standard (19 ppb) and the future annual standard (15 ppb) for implementation by 2025
 - e) that there should be no allowable exceedances for NO₂ standards

- f) with the introduction of an exposure-reduction framework for NO₂
- g) that jurisdictions should commence annual reporting on population exposure to NO₂ from the commencement of a varied AAQ NEPM.

Chapter 8 Impact assessment for ozone

- Do you agree with the recommendations made in this report for the O₃ standards? Your answer should consider whether you agree:
 - a) with the introduction of a rolling 8-hour O₃ standard and removal of the 1-hour and 4-hour averaging periods
 - b) with jurisdictions continuing to record and report 1-hour concentrations even if there is no 1-hour standard
 - c) that there are no other averaging periods that should be considered for O₃ in the future
 - d) with the preferred numerical value for the 8-hour O₃ standard (65 ppb)
 - e) that there should be no allowable exceedances for the O₃ standards
 - f) with the introduction of an exposure-reduction framework for O₃ (in the form of a long-term goal for O₃) once O₃ generation in capital cities is better understood
 - g) with jurisdictions commencing annual reporting on population exposure to O₃ from the commencement of a varied AAQ NEPM
 - h) with the introduction of an exceptional events rule for O₃ that is consistent with the approach for the PM_{2.5} and PM₁₀ standards in the AAQ NEPM. Note that an exceptional events rule will differ from an allowable exceedances rule as it will only apply to exceptional events (such as bushfires and dust storms) rather than be based on a fixed number of days.

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