Review of Ambient Air Quality NEPM for SO_2, NO_2 and O_3

Cost Benefit Analysis

EPA Victoria

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1   Executive Summary

This report presents a cost benefit analysis (CBA) of abatement measures that target reductions in sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3) concentrations in Australian airsheds. The CBA provides economic evidence to support the review of Ambient Air Quality (AAQ) standards for SO_2, NO_2 and O_3 by the National Environment Protection Council (NEPC).

The AAQ National Environment Protection Measure (AAQ NEPM) standards specify the maximum allowable ambient concentrations, calculated over selected 'averaging periods', for carbon monoxide (CO), SO_2, NO_2, O_3, lead and particulate matter (PM). The NEPC is reviewing the standards for SO_2, NO_2 and O_3. This review is being led by Environment Protection Authority (EPA) Victoria. The review considers recent developments in the health evidence on the effects of SO_2, NO_2, O_3 and international policy approaches to manage concentrations.

The NEPC standard selection framework considers a range of factors and not just the costs and benefits of meeting standards. These factors include the health protection provided by a standard, and the standards used in other jurisdictions. The decision to vary the standards is supported by analyses commissioned by EPA Victoria – including an Impact Statement, which assesses the impacts of potential changes, a health risk assessment (HRA) and this CBA.

The CBA assessed the potential costs and benefits of a set of potential abatement measures, referred to as the 'Abatement Package scenario', based on publicly available data on costs and detailed modelling of the health benefits. The Abatement Package scenario was selected using multi-criteria analysis (MCA). The potential health benefits were estimated using a combination of the impact pathway approach, which considers the pathway from emissions to monetised health impacts, and the damage cost approach, which establishes a relationship between the quantity of emissions and monetised impacts.

The results of the CBA show that the costs of the Abatement Package scenario are likely to significantly outweigh the health benefits. This partly reflects that the package includes some high cost measures to reduce emissions from industry in low population areas, which provide relatively low health benefits.

The benefit-cost ratio (BCR) for the Abatement Package scenario corresponding to SO_2, NO_2 and O_3 are estimated at 0.01, 0.07 and 0.05 respectively. However:

- there are a number of benefits which could not be reliability quantified including lost labour productivity, a reduction in the emission of other pollutants, avoidance of some non-health impacts, and a reduction in secondary PM formation

- the costs and benefits of the abatement measures do not reflect the likely costs and benefits of meeting various air quality standards

- this does not mean that all potential actions with in the Abatement Package scenario have a BCR of less than one.

While the CBA estimates the costs and benefits of an Abatement Package scenario at a national level, it does not necessarily provide an indication of the likely costs and benefits of meeting alternative AAQ standards. This is because in practice, while some measures to meet standards are implemented at a national level, individual states and territory governments implement much of the regulation and policy designed to meet the standards in that state or territory. Moreover, some tightened standards could be met without the need for abatement and therefore without additional cost.

As such, each jurisdiction assesses and implements abatement measures following their own policy processes, which may include jurisdiction-specific CBAs and other analyses to select the most appropriate set of abatement 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 AAQ standards should only be implemented if appropriate state-level policy assessment processes support their implementation, or if a national assessment, including 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.

2 Introduction

2.1 Background to the project

Environment Protection Authority (EPA) Victoria has commissioned Pacific Environment and Aurecon to prepare a Cost Benefit Analysis (CBA) and Impact Statement for the review of the national air quality standards for sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3).

The Ambient Air Quality National Environment Protection Measure (AAQ NEPM) standards include monitoring and advisory reporting standards for pollutants that affect human health. The standards are expressed as maximum allowable ambient concentrations, calculated over selected 'averaging periods', for carbon monoxide (CO), SO_2, NO_2, O_3, lead and particulate matter (PM).

A review of the AAQ NEPM in 2011 recommended a review of the standards for PM, SO_2, NO_2, O_3 and other pollutants, to take into account the most recent evidence on the effects of these pollutants on human health. The Council of Australian Governments (COAG) agreed that the review of the particle standards would be prioritised.

The AAQ NEPM was varied in 2016 to introduce more stringent standards for PM_{10} and $PM_{2.5}$, which are particles with aerodynamic diameters of less than or equal to 10 and 2.5 micrometres respectively. The variation was based on developments in the health evidence, and an economic analysis and Impact Statement that assessed the impact of potential changes to the standards.

The purpose of this review is to provide evidence to the National Environment Protection Council (NEPC) to inform the review of the standards for SO_2, NO_2 and O_3. The review includes a supporting air quality study, a health risk assessment (HRA), a CBA (described in this report), and an Impact Statement.

The Impact Statement summarises the air quality study, HRA and CBA, and also includes a broader discussion on the standards and policy approaches adopted internationally and the rationale for these policy approaches.

2.2 Purpose and limitations of the cost benefit analysis

This CBA aims to support the Impact Statement by providing economic evidence on the possible costs and benefits of abatement measures to reduce concentrations of SO_2, NO_2 and O_3. The abatement measures target sources of sulfur oxides (SO_X), nitrogen oxides (NO_X) and volatile organic compounds (VOC) emissions[1]. The assessment of costs and emission reductions was based on publicly available data. The benefits were estimated based on data provided by the HRA.

The CBA builds on prior work commissioned by EPA Victoria, including a multi-criteria analysis (MCA) to select abatement measures (the 'Abatement Package scenario'), and the development of a framework to estimate the health benefits associated with the reduction in pollutant concentrations. The Abatement Package scenario was selected by prioritising measures on the quantum of abatement (30 per cent weight), cost (30 per cent weight) and to a lesser degree health benefits (10 per cent weight). Other factors included reliability, targeting of costs to the source, timeframe for implementation, technological status, co-benefits and dis-benefits (5 per cent weight each). This resulted in the highest scores being given to high cost industry specific measures to reduce SO_2 and NO_2 in areas with low populations.

While the CBA estimates the costs and benefits of the 'Abatement Package scenario' at a national level, it does not necessarily provide an indication of the likely costs and benefits of meeting alternative AAQ standards. This is because in practice, while some measures to meet standards are implemented at a national level, individual states and territory governments implement much of the regulation and policy designed to meet the standards in that state or territory. As such, each jurisdiction assesses and implements

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[1] O_3 is not emitted directly but formed through chemical reactions in the atmosphere. Therefore, abatement measures for O_3 target VOC emissions, which are a precursor to the formation of O_3.

abatement measures following their own policy processes, which may include jurisdiction-specific CBAs and other analyses to select the most appropriate set of abatement measures.

2.3   Structure of this report

The remainder of this report is structured as follows:

- Section 3 outlines the methodology used to select abatement measures, and estimate costs and benefits.

- Section 4 provides an estimate of the existing health burden of SO_2, NO_2 and O_3 in monetary terms.

- Section 5 presents the CBA results

- Section 6 presents an analysis of the sensitivity of results to different values of uncertain assumptions.

- Section 7 summarises the main findings of the study.

- Annexure A provides an overview of the HRA process.

- Annexure B provides detail on the damage cost approach, which is a technique used to estimate some of the health benefits.

- Annexure C summarises the abatement measures, and their costs and emission reductions.

3 Cost benefit analysis methodology

3.1 Cost benefit analysis framework

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

- 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 dis-benefits 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 is estimated to result in a change to pollutant concentrations, which in turn results in an overall improvement in health outcomes for the exposed population.

3.2 Scope

The geographical scope of the CBA was limited to the airsheds for which air quality data were available, and those where the abatement measures were estimated to reduce emissions from the airshed. These include Sydney, Newcastle, Wollongong, Melbourne, Latrobe Valley, Brisbane, Perth, Adelaide and Darwin. The airsheds cover a large proportion of the Australian population (approximately 70 per cent) and the airsheds cover the parts of Australia with the highest population density.

Implicitly, the CBA assumes that abatement measures target these airsheds. Therefore, the estimates of costs relate to abatement measures for sources in these airsheds, and the estimate of benefits relates to reduced exposure for the population residing in these airsheds.

The choice of airsheds with the highest population densities reflects that abatement measures are expected to be more economically efficient where the measures target sources located in areas of high population density. This is because the benefits of emission reduction are strongly correlated with population density.

The scope of pollutants is limited to the three gases that are the subject of this study (SO_2, NO_2 and O_3) and primary emissions of $PM_{2.5}$. The latter is included because one of the abatement measures (reducing emissions from non-road diesel equipment) is 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 $PM_{2.5}$.

3.3 Cost benefit analysis parameters

The CBA has been conducted over a 20-year evaluation period (2021-2040), using a central social discount rate of 7 per cent (real), and sensitivity discount rates of 3 and 10 per cent (real) as per Australian Government guidance (OBPR, 2016).

3.4 Methodology to estimates costs

The costs of abatement were estimated by:

- identifying measures that target sources of SO_X, NO_X and VOC emissions
- selecting a preferred set of measures using MCA
- estimating the costs and emission reductions for measures selected through the MCA
- calculating a present value (PV) of costs by pollutant and jurisdiction for use the CBA.

3.4.1   Multi-criteria analysis

A total of 18 candidate abatement measures that target emission sources of the three pollutants were identified (refer to Annexure C). MCA was used to select nine final abatement measures in the CBA. Each measure was assessed in terms of:

- effectiveness (whether the measure targets the pollutant for which the abatement is required, the quantum of possible abatement, and the reliability of the abatement)

- efficiency (the marginal cost of the abatement and the likely health benefits)

- appropriateness (whether the measure targets sources that cause the greatest exposure)

The Abatement Package scenario was selected by prioritising measures on the quantum of abatement (30 per cent weight), cost (30 per cent weight) and to a lesser degree health benefits (10 per cent weight). Other factors included reliability, targeting of costs to the source, timeframe for implementation, technological status, co-benefits and dis-benefits (5 per cent weight each). These criteria were grouped into effectiveness (quantum of abatement and reliability), efficiency (targeting, timeframe for implementation, technological status and cost) and appropriateness (direct health benefits, co-benefits and dis-benefits).

Each of the abatement measures targets sources that contribute to levels of SO_2, NO_2 and/or O_3 in the atmosphere. The abatement measures that target SO_2 and NO_2 reductions result in incrementally lower emissions of SO_X and NO_X respectively. The abatement measures that target sources contributing to O_3 concentrations target sources of VOC emissions, which are a precursor that contribute to O_3 formation. Therefore, abatement measures for O_3 result in incrementally lower emissions of VOC.

The MCA was developed as part of prior work commissioned by the EPA Victoria, with contributions from Ernst & Young, Pacific Environment and EPA Victoria. Each abatement measure was scored against each of the above criteria to calculate a total score.

3.4.2   Selected abatement measures

Preferred abatement measures were identified as those with the highest weighted score based on the criteria weights for effectiveness (35 per cent), efficiency (45 per cent) and appropriateness (20 per cent). The top three abatement measures for each pollutant were endorsed by EPA Victoria for inclusion in the CBA.

The nine measures with the highest score are shown in Table 3-1 below. Two measures target SO_2, two target NO_2, three target O_3, and one measure targets both NO_2 and SO_2.

Table 3-1 Abatement measures selected for Cost-Benefit Analysis

Pollutant	Measure No.	Abatement Description
SO_2	Measure 9	De-SO_X and NO_X, for power stations
SO_2	Measure 14	De-SO_X at petrol refineries
SO_2	Measure 15	De-SO_X at iron and steel production facilities
NO_2	Measure 9	De-SO_X and NO_X, for power stations
NO_2	Measure 6	Non-road diesel engine standards
NO_2	Measure 13	Industry NO_X control technology (cement, iron and steel, and aluminium industries)
O_3	Measure 1	On-board refuelling vapor recovery
O_3	Measure 10	Surface coating standards
O_3	Measure 16	VOC control for solvent aerosol use

3.4.3   Cost components

The CBA includes the following costs associated with the implementation of abatement measures:

- **Capital costs** – The costs associated with the purchase and installation of new plant, machinery or equipment and upgrades to existing plant, machinery or equipment.

- **Operating and maintenance costs** – The ongoing costs associated with continued operation and maintenance of the measure.

- **Administrative and regulatory costs** – The costs incurred by either industry or government for complying with new regulations and administering the regulations respectively.

- **Co-benefits and dis-benefits** – Changes in fuel consumption.

Costs for each selected abatement measure were derived from desktop research of publicly available information. Annexure C outlines the assumptions and approach to estimate costs and emission reductions for each of the selected abatement measures.

Where the literature provided costs and emission reduction estimates for implementing the measure across an entire state or territory, the costs and emission reductions were pro-rated to the airsheds included in the scope of the CBA, using the proportion of population residing in the airsheds included.

3.5 Methodology to estimate benefits

The benefit of emission reductions was estimated based on a combination of the impact pathway approach (refer to section 3.5.1), where the required data were available, and the damage cost approach (refer to section 3.5.5) where they were not.

3.5.1 Impact pathway approach

Where the data were available, the CBA estimated the benefits associated with reductions in SO_2, NO_2 and O_3 concentrations by considering:

- the reduced quantity of SO_X, NO_X and VOC emissions (tonnes p.a.)

- the resulting change in concentrations of SO_2, NO_2 and O_3 in each airshed

- the resulting change in the populations' exposure to the concentrations of these pollutants

- the projected difference in health outcomes associated with that change in exposure

- the value of those health outcomes expressed in monetary terms.

This approach is referred to as the 'impact pathway' (DEFRA, 2013), and is summarised in Figure 1.
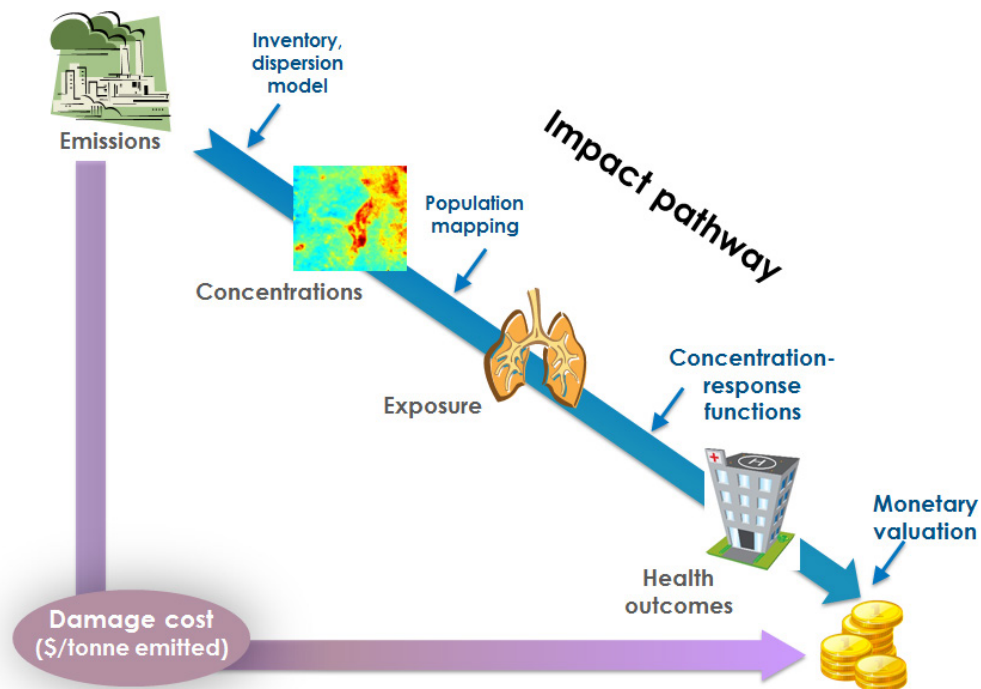

Figure 1 Impact pathway

Most of the above calculations were completed in the air quality study and the HRA (Pacific Environment, 2018a; Pacific Environment 2018b). The air quality study estimates the changes in concentration resulting

from a change in emissions. The HRA provides the projected difference in health outcomes by considering the change in modelled concentrations and the associated change in population exposure.

Annexure A provides an overview of the steps to conduct a HRA, which includes estimating baseline health incidence, the changes in pollutant concentrations, and the changes in health incidence associated with the changes in pollutant concentrations.

Estimating changes in health incidence and uncertainty in health response

The final step (changes in health incidence associated with the changes in pollutant concentrations) is estimated using concentration-response functions (CRF). CRFs used for this CBA are expressed as the percentage change in health incidence due to a unit change in concentration levels.

A range of sources are available to estimate the responsiveness of population health to changes in pollution exposure. The central results in the CBA use CRFs that are based on recommendations by the World Health Organization (WHO) from the recent *Health risks of air pollution in Europe – HRAPIE* project to model mortality outcomes associated with exposure to NO_2 and O_3 (WHO, 2013), a CRF recommended by Anderson et al (2007) to model mortality outcomes associated with exposure to SO_2, and CRFs recommended by Jalaludin and Cowie (2012) for other outcomes. These are referred to as the 'Group 1' CRFs in the HRA.

The HRAPIE study reviews the most up to date literature on the health effects of exposure to air pollution The central results follow the guidance in WHO (2013) on mortality outcomes associated with NO_2 and O_3 exposure, which include recommendations on:

- the expected change in health incidence based on a unit change in pollutant concentrations, measured as an average concentration over various averaging periods
- a 'cut-off' point below which no change to health incidence is estimated because of the uncertainty in health effects below this cut-off.

To reflect uncertainty in the possible health response, the CBA also reports two sensitivities using alternate groups of CRFs. The first (Group 2) applies the HRAPIE recommendations except for the application of a cut-off (referred to as the 'no cut-off' sensitivity), because while uncertain there may be some health effects from population exposure to concentrations below the cut-off levels. The second (Group 3) uses recommendations from an earlier Australian study prepared for EPA Victoria titled *Health Risk Assessment – Preliminary Work to Identify Concentration-Response Functions for Selected Ambient Air Pollutants* (Jalaludin and Cowie, 2012), to quantify the mortality outcomes associated with exposure to NO_2 and O_3.

Data on health outcomes provided by the HRA include:

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

Economic costs of health outcomes

The economic costs avoided from a reduction 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 valuation of premature mortality is based on the concept of the value of a statistical life (VSL) and the value of a statistical life year (VSLY). The VSL represents the WTP of an individual to avoid the statistical risk of premature mortality. The VSL can be estimated through analysis of survey responses or by analysing data on the choices individuals make in the real world (e.g. by analysing the wage premium a worker needs to accept a job which has a risk of causing mortality). The VSLY is a related concept which measures the risk of bringing forward mortality by one year.

Premature mortalities due to chronic (long-term) exposure have been valued based on the VSL. This is consistent with almost all of the relevant air quality CBA studies in Australia (e.g. Boulter and Kulkarni, 2013). Premature mortalities due to acute (short-term) exposure have been valued based on the VSLY. This reflects

that acute premature mortality tends to affect the population with an already comprised health status (e.g. the elderly), and therefore the expected shortening of life expectancy is much lower compared to chronic mortality.

The remaining health outcomes incorporate:

- the concept of 'disability weights' (Access Economic, 2008), which relates to the WTP to avoid the discomfort associated with the health condition over a year, expressed as a fraction of the VSLY
- the resources costs associated with hospitalisation
- the cost of lost productivity from workers not being at work due to hospitalisation.

Assumptions relating to the valuation of health outcomes are summarised in Table 3-2.

Table 3-2 Assumptions for economic value of health outcomes

Assumption	Value (2016 prices)	Based on
Value of a statistical life	$7.4 m ^	Access Economics (2008)
Value of a statistical life year	$320,000	Access Economics (2008)
Life years lost due to acute mortality	0.5	DEFRA (2013)
WTP to avoid illness (respiratory)	$431	Access Economics (2008) disability weights
WTP to avoid illness (cardiovascular)	$584	Access Economics (2008) disability weights
Average weekly earnings (AWE)	$1,161	ABS Cat. No 6302 AWE Australia (May 2016)
Hospital stay (respiratory)	3 days	AIHW (2015)
Hospital stay (cardiovascular)	3.8 days	AIHW (2015)
Lost productivity (respiratory)	$697	Calculated based on above assumptions
Lost productivity (cardiovascular)	$871	Calculated based on above assumptions
Hospitalisation cost (respiratory)	$6,595	AIHW (2015)
Hospitalisation cost (cardiovascular)	$6,316	AIHW (2015)
Emergency department visit (asthma)	$807	AIHW (2015)

Note ^: This VSL has been applied to estimate the health benefits in future years (2021-2040). Some previous studies have applied an 'uplift' factor to account for the expected growth in WTP to avoid health outcomes, in line with expected growth in real incomes (e.g. Boulter and Kulkarni, 2013). An uplift factor has not been applied in this CBA because of uncertainty in the outlook for real income growth at the time of writing. This results in a conservative estimate of future health benefits.

3.5.2 Particulate matter co-benefits

Some abatement measures that target NO_X emissions also reduce $PM_{2.5}$ emissions. Of the abatement measures selected for analysis in this study, Measure 6 (non-road diesel engine standards) reduces emissions and therefore concentrations of $PM_{2.5}$ in the atmosphere. The benefit of the $PM_{2.5}$ emission reductions were valued using the damage costs provided by PAEHolmes (2013).

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.

3.5.3 Adjustments 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. Jalaludin et al (2009) note that including both in a CBA can risk double-counting health impacts.

This adjustment is only relevant for NO_2, which includes both long-term and short-term health endpoints. For the central CBA results, which use the CRFs recommended by HRAPIE, only short-term mortality is included, because:

- no long-term mortalities are predicted by the HRA due to the application of a cut-off

- WHO (2013) notes that the recommended CRF for long-term mortality is less certain than the CRF for short-term mortality, and therefore a lower level of confidence is placed on results using the former[2].

For the sensitivity using Group 2 and Group 3 CRFs, only short-term mortality is included.

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.

3.5.4   Unquantified impacts

The emission reductions are expected to result in other health and non-health benefits that could not be quantified in the CBA due to data limitations. These include:

- restricted activity days and working days lost (i.e. where population exposure results in time off work or lower productivity but not in hospitalisation or an emergency department visit)

- low birth weights associated with SO_2 exposure, for which there is emerging evidence (e.g. Yang and Chou, 2017)

- reduction in the emissions of other pollutants due to the implementation of abatement measures, including CO, benzene, toluene and xylenes

- non-health impacts such as agricultural and timber yields, building soiling, materials damage, impact on coastal estuaries and aquatic ecosystem, and improved visibility.

There is limited data on these impacts, and previous assessments have tended to use qualitative or case study approaches (e.g. US EPA, 2010). The impacts are also expected to be less material in monetary terms compared to the mortality and morbidity impacts included in the CBA. For example, US EPA (2010) estimates that the work days lost associated with exposure to $PM_{2.5}$ represent around 0.2 per cent of the total monetised health benefits.

Secondary PM formation

SO_X and NO_X emissions contribute to the formation of secondary $PM_{2.5}$, which is $PM_{2.5}$ formed through chemical reactions in the atmosphere rather than being directly emitted. Therefore, a reduction in SO_X and NO_X emissions could reduce concentrations of secondary $PM_{2.5}$. This is important because secondary PM dominates the air quality burden in many urban airsheds.

While the mechanisms that lead to secondary PM formation are well understood, limited data and modelling is available to reliably quantify the effect of reducing the precursor pollutants on secondary PM concentrations. Therefore, the benefits of avoided secondary PM were not included in the CBA. Section 5.2.3 provides a discussion on the possible order of magnitude of these benefits based on some recent literature estimates from the United States.

3.5.5   Damage cost approach

The HRA only provides an estimate of avoided health outcomes where the concentration data were available. Therefore, the impact pathway approach could only be applied for some airshed and pollutant

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[2] WHO (2013) classifies the CRFs as either 'Group A' CRFs, which enable a more reliable quantification of effects because there is greater data to estimate pollutant exposure-outcome relationships, and 'Group B' CRFs, which are less reliable. The recommended CRF for long-term mortality is classified as a Group B CRF. The recommended CRF for short-term mortality is classified as a Group A CRF.

combinations, and for the other combinations a damage cost approach was used. The approaches used for different combinations of airshed and pollutant are summarised in Table 3-3.

Table 3-3 Approach used to estimate health benefits

Pollutant	Airsheds
Use of impact pathway approach	
SO_2	Sydney, Newcastle, Wollongong, Melbourne, Latrobe Valley
NO_2	Sydney, Newcastle, Wollongong, Melbourne
O_3	Sydney, Newcastle, Wollongong, Melbourne, Latrobe Valley
Use of damage cost approach	
SO_2	Brisbane, Perth, Adelaide, Darwin
NO_2	Latrobe Valley, Brisbane, Perth, Adelaide, Darwin
$PM_{2.5}$	Sydney, Melbourne, Newcastle, Wollongong, Latrobe Valley, Brisbane, Perth, Adelaide, Darwin
O_3	None

The damage cost approach is 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.

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 was 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.

This CBA used this approach by estimating the following for each combination of pollutant, airshed, scenario (BAU or Abatement) and year (2021, 2031 or 2040) for which impact pathway results were available:

- the $ per tonne, calculated by dividing the avoided health costs by the emission reduction
- the population density of the corresponding airshed.

Regression analysis was used to estimate the relationship between unit damage costs and population density. The results of this regression were used to estimate a unique unit damage cost for each airshed where no impact pathway results were available. The unit damage cost ($ per tonne) is then applied to the estimated emission reduction (tonnes) to arrive at an estimate of the avoided health costs ($).

Details of the regression analysis and resulting damage costs are provided in Annexure B.

4 Estimate of existing health burden

4.1 Central estimate of health burden

The health costs of SO_2, NO_2 and O_3 over the period 2010 to 2014 were estimated using the impact pathway approach outlined in Section 3.5.1. The results are provided in Table 4-1 below.

Table 4-1 Estimate of existing health burden between 2010-2014 (2016 $m PV)

Jurisdiction	SO_2	NO_2^	O_3
New South Wales (NSW)	$18	$122	$111
Victoria (VIC)	$29	$83	$29
Queensland (QLD)	$11	$27	$34
Western Australia (WA)	$12	$15	$32
South Australia (SA)	$2	$19	$16
Northern Territory (NT)	$0	$0	$2
Total	**$72**	**$265**	**$225**

Note ^: To avoid double-counting of health impacts, 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.

Of the three pollutants, exposure to NO_2 is estimated to have had the greatest health burden between 2010 – 2014, and the effects of NO_2 are estimated to be the highest in NSW. This health burden for NSW reflects a combination of NO_2 concentrations that are relatively higher than the other airsheds, and a large population size. O_3 has the second highest estimated health cost of the three pollutants, and for the same reasons as NO_2, the greatest burden is estimated for NSW. However, it should be noted that the numbers of unique exceedances of the O_3 standards are far greater than for NO_2 (refer to Pacific Environment, 2018b), but the higher health burden of NO_2 reflects that there are greater mortality and morbidity outcomes associated with exposure to NO_2.

The health costs associated with exposure to SO_2 are estimated to be the lowest, due to fewer mortalities estimated to be associated with exposure to SO_2 concentrations.

Queensland, Western Australia, South Australia and Northern Territory are estimated to have a lower share of the health burden associated with exposure to SO_2, NO_2 and O_3. This is due to both lower concentrations and lower population size.

4.2 Uncertainty in health burden estimates

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 range of uncertainty in the health burden over the period 2010 to 2014, expressed as the range of estimates calculated using the different CRF groups, is provided in Table 4-2. The impact of the choice of CRFs on the cost-benefit analysis is discussed further in Annexure B.

Table 4-2 Range of uncertainty on existing health burden using different CRFs ($m PV)

SO_2	NO_2	O_3
$72 ^	$265 – $761	$225 – $1,572

Note ^: The estimated health burden of SO_2 is the same across the three groups of CRFs because the exposure-response functions used are the same.

The estimated mortality from long-term exposure to NO_2 is substantially higher using the Group 3 CRFs. In both of the alternative CRFs sensitivities, a much larger estimate of the health burden associated with O_3 exposure is estimated. This is because of higher estimated mortalities from exposure.

5 Results

5.1 Costs and benefits of the Abatement Package scenario

Table 5-1 presents the projected costs and benefits of implementing the abatement measures by pollutant and jurisdiction. Note that the results for NO_2 include the benefit from reductions in $PM_{2.5}$ emissions.

Table 5-1 Projected costs and benefits of implementing abatement package (2021-2040)

Jurisdiction	SO₂	NO₂ ^*	PM₂.₅ ^	O₃
Costs (2016 $m PV)				
NSW	$13,887	$9,604		$109
NT	$543	$327		$3
QLD	$19	$3,333		$104
SA	$0	$2,125		$38
VIC	$9,937	$7,032		$102
WA	$23	$1,949		$75
Total	**$24,409**	**$24,369**		**$430**
Benefits (2016 $m PV)				
NSW	$44	$58	$1,183	$9
NT	$0	$1	$0	$0
QLD	$36	$18	$0	$0
SA	$0	$9	$0	$0
VIC	$64	$26	$457	$11
WA	$52	$20	$0	$0
Total	**$196**	**$133**	**$1,639**	**$20**
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
Total	**0.01**	**0.07**		**0.05**
Net Present Value (NPV 2016 $m)				
Total	**-$24,213**	**-$22,597**		**-$410**

Note ^: Benefits from reductions in $PM_{2.5}$ emissions are included in the NPV and BCR calculations for NO_x.

Note *: To avoid double-counting of health impacts, 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.

Costs exceed benefits for each pollutant, and therefore a negative NPV and a BCR of less than 1 is estimated for each pollutant. Overall, the Abatement Package scenario is estimated to result in a **NPV of -\$47,220 million** and a **BCR of 0.04**. The results of the CBA should be interpreted considering the qualifications outlined in section 5.2.

A higher BCR is estimated for NO_2 than SO_2 and O_3. The main contributor to this result is the contribution of $PM_{2.5}$ reductions to health benefits. A lower BCR is estimated for SO_2 because unlike NO_2 and O_3, no mortality benefits are expected from a reduction in SO_X emissions.

A low BCR is estimated for most pollutant and jurisdiction combinations (0.1 or lower), except for SO_2 in Queensland and Western Australia. The results for SO_2 in these jurisdictions largely reflects the effectiveness of the de-SO_X measure at petrol refineries, which achieves large reductions in SO_X emissions at relatively low cost.

5.2 Qualifications

The following qualifications accompany the CBA results:

- the benefits are more meaningful when considered in total, rather than considering the benefits by an individual pollutant, because while abatement measures target individual pollutants their implementation can affect the levels of other (non-targeted) pollutants

- the costs and benefits of the abatement measures do not reflect the likely costs and benefits of meeting various air quality standards

- there are a number of benefits which could not be reliably quantified.

Each of these qualifications is discussed in turn.

5.2.1 Interaction between pollutants

Some measures which target sources of NO_X emissions can indirectly affect levels of O_3 in the atmosphere because of the complex chemical interactions that lead to the formation of O_3. Therefore, the changes to health outcomes associated with changes in O_3 concentrations reflect not only the effect of abatement measures targeting O_3 concentrations (by reducing VOC), but also those that target NO_2 concentrations (by reducing NO_X).

As such, the benefits associated with changes in O_3 concentrations should not be interpreted as the benefits solely associated with abatement measures that target O_3 concentrations. The benefits estimated in this CBA also include the effect of a reduction in NO_2 on O_3 concentrations. As a result, the estimated benefits associated with changes in O_3 concentrations from the implementation of the *total* Abatement Package scenario should not be interpreted as the expected benefits of implementing only the measures which target VOC sources.

5.2.2 Likely costs and benefits of meeting air quality standards

While the CBA estimates the costs and benefits of the 'Abatement Package scenario' at a national level, it does not necessarily provide an indication of the likely costs and benefits of meeting alternative AAQ standards. This is because in practice, while some measures to meet standards are implemented at a national level, individual states and territory governments implement much of the regulation and policy designed to meet the standards in that state or territory. As such, each jurisdiction assesses and implements abatement measures following their own policy processes, which may include jurisdiction-specific CBAs and other analyses to select the most appropriate set of abatement measures. Moreover, some tightened standards could be met without the need for abatement and therefore without additional cost.

5.2.3   Unquantified benefits

A number of benefits could not be reliably quantified due to limited data (refer to section 3.5.4). 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.

Some authors have estimated the marginal social costs of precursor emissions that lead to the formation of secondary PM (e.g. see Heo, Adams and Gao, 2016). Heo et al (2016) estimate a range of marginal social costs of US\$3,800−14,000 per tonne NO_X, and US\$14,000−24,000 per tonne of SO_X. The authors note that ammonia is often the limiting factor for ammonium nitrate formation.

Using these estimates results in a very large potential benefit from reductions in secondary PM formation, through reductions in SO_X and NO_X emissions associated with the Abatement Package scenario, of approximately AU\$20 and AU \$10 billion respectively. However, these estimates are not appropriate to include in the CBA because:

- population density and demographics in the source study are likely to be different to Australia airsheds

- concentrations of ammonia are likely to play a major role in influencing the formation of secondary PM, and the relative concentrations of ammonia and other precursors to secondary PM formation are likely to be different in Australian airsheds compared to the airsheds of the source study

- including both the effects from direct exposure and from secondary PM formation is likely to lead to double counting.

6 Sensitivity analysis

6.1 Approach to sensitivity analysis

The CBA uses a number of economic and technical assumptions that are inherently uncertain. These include:

- choice of social discount rate
- a low or high VSL
- uncertainty in costs
- choice of CRFs
- uncertainty in the air quality analysis used to model changes in pollutant concentrations
- a low or high health response from changes in pollutant exposure.

6.1.1 Uncertain economic assumptions

Choice of social discount rate

The social discount rate represents the rate at which future costs and benefits are reduced so that they are comparable with costs and benefits incurred today. It can be based on the rate at which society is willing to give up consumption today for greater consumption in the future (the 'time preference' approach), or the rate of return that the funds could have achieved by investing the funds in an alternative policy or project (the 'opportunity cost' approach).

This rate is both highly uncertain, and debated among economists. The CBA uses a central social discount rate of 7 per cent (real), consistent with the guidance provided by OBPR (2016). Following the same guidance, the sensitivity analysis uses discount rates of 3 and 10 per cent (real). In particular, a lower discount rate is justified on the grounds that the opportunity costs of funds are currently very low internationally, by historical standards.

Low or high VSL

To reflect uncertainty in the estimate of the VSL, and the corresponding VSLY, Access Economics provides two sensitivity values for VSL. These have been used in sensitivity analysis, after adjusting for the increase in WTP to avoid the risk of premature mortality over time, and changes in prices. The results in low and high VSL values of $4.6 and $10.0 million (2016 prices), compared to a central value of $7.4 million.

Lower or highest abatement costs

The abatement cost analysis relies on publicly available data on abatement measures adopted internationally. Some of these data may be out of date due to developments in abatement technologies and costs, and some may not reflect the likely costs of implementation in Australia. In many cases the sources acknowledge the uncertainty in cost estimates. To acknowledge this uncertainty, two sensitivity tests are included – a low costs sensitivity (assuming 50 per cent of the central costs) and a high costs sensitivity (assuming 150 per cent of the central costs).

6.1.2   Uncertain technical assumptions

Choice of CRFs

The central results in the CBA use CRFs for NO_2 and O_3 exposure that are based on recommendations by the World Health Organization (WHO) from the recent *Health risks of air pollution in Europe – HRAPIE* project (WHO, 2013).

To reflect uncertainty in the possible health response, the CBA also reports two sensitivities using alternative groups of CRFs. The first (Group 2) applies the HRAPIE recommendations except for the application of a cut-off (referred to as the 'no cut-off' sensitivity), because while uncertain there may be some health effects from population exposure to concentrations below the cut-off levels. The second (Group 3) uses recommendations from an earlier Australian study prepared for EPA Victoria titled *Health Risk Assessment – Preliminary Work to Identify Concentration-Response Functions for Selected Ambient Air Pollutants* (Jalaludin and Cowie, 2012) to quantify the mortality outcomes associated with exposure to NO_2 and O_3.

Uncertainty in the air quality analysis

The estimate of health effects and associated benefits is based on modelling that predicts concentrations of pollutants. The accuracy of the models in predicting historical concentrations was analysed to characterise the uncertainty in air quality modelling and the impact this has on CBA results. This analysis focused on the uncertainty in predicting NO_2 and O_3 concentrations because of their association with premature mortality, which dominates abatement benefits.

The analysis was conducted by computing the average ratio of modelled vs monitored concentrations across each of the monitoring locations in an airshed. This produces a time series of ratio values, including one for each day of the year for NO_2 and O_3. The 95th percentile range of this series is approximately 50 per cent of modelled concentrations to 200 per cent of modelled concentrations. This range was used to assess how uncertainty in air quality modelling propagates to uncertainty in the CBA results.

Low or high health response

The literature sources for CRFs provide a range of values to reflect uncertainty in the epidemiological data used to derive the CRF. The uncertainty range is normally presented as a 95 per cent confidence interval. The low and high values from this range have been used in the sensitivity analysis.

6.2   Results of the sensitivity analysis

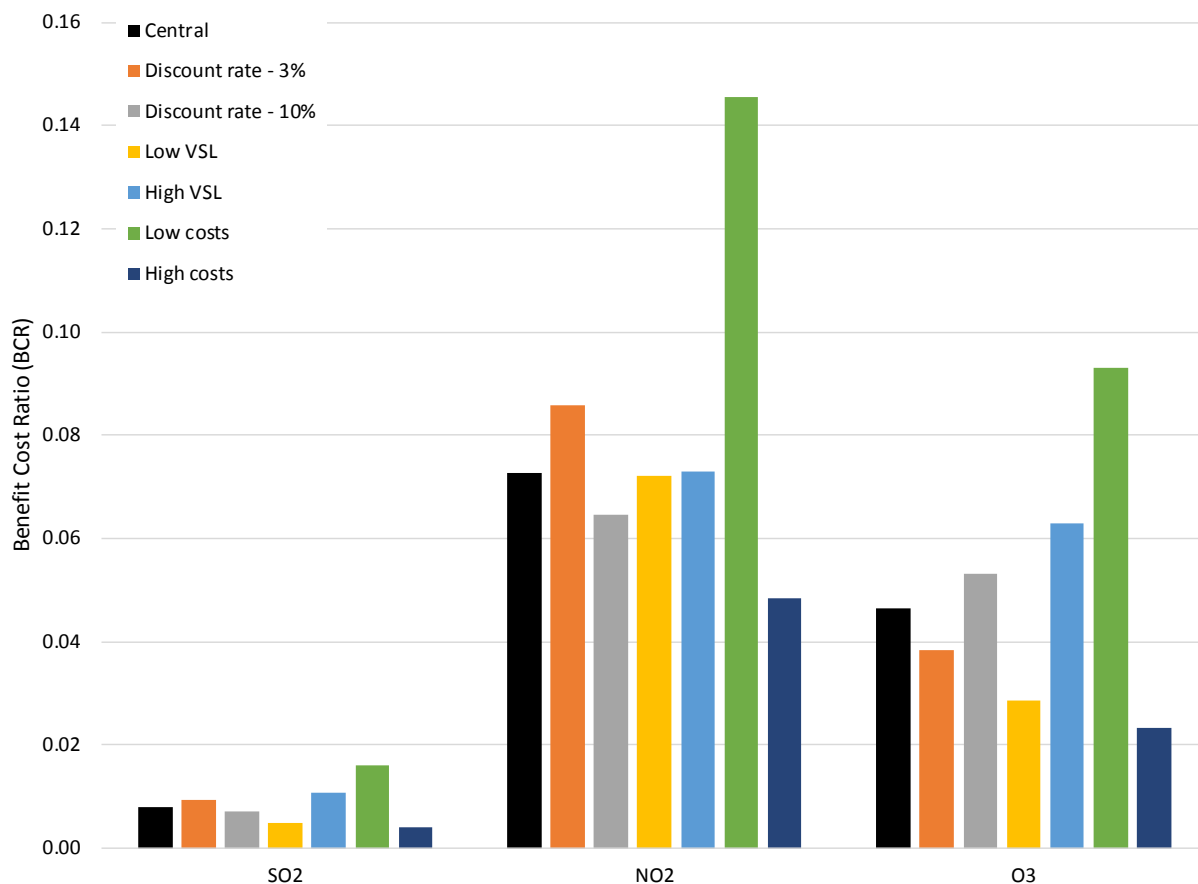The results of the sensitivity analysis are presented in Figure 2 and Figure 3 below.

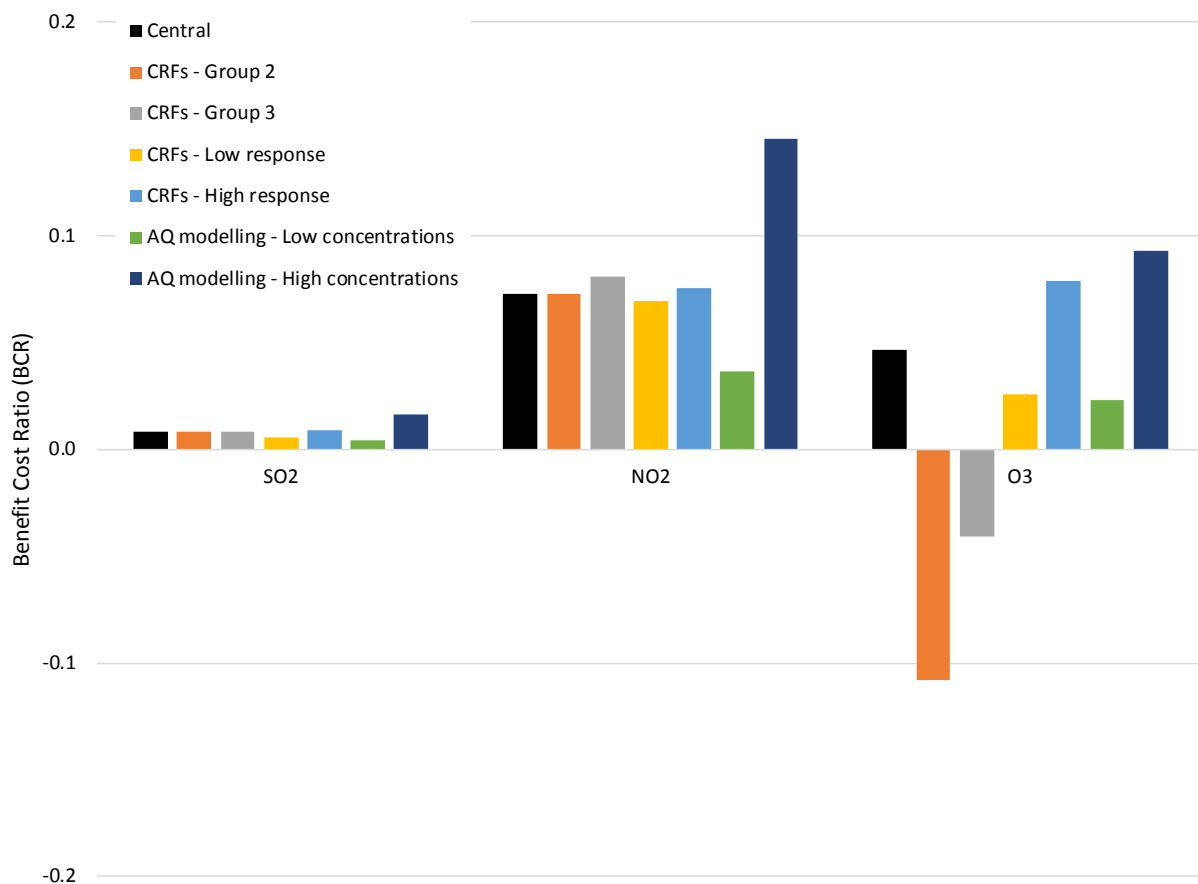**Figure 2 Sensitivity of CBA results to changes in economic assumptions**

Figure 3 Sensitivity of CBA results to changes in technical assumptions

The CBA results are more sensitive to changes in economic assumptions than technical assumptions. In particular, lower assumed costs result in an improvement in BCR for NO_2 and O_3, reflecting that the costs of the Abatement Package scenario nationally are high, relative to national benefits.

Furthermore, a negative BCR is estimated for O_3 when using the alternate groups of CRFs (groups 2 and 3), as opposed to a positive BCR as estimated with the application of Group 1 CRFs. This is because:

- according to the air quality modelling, concentrations of O_3 are projected to reduce with the implementation of measures in the Abatement Package scenario on some days, but increase on other days

- as such, health outcomes reduce on some days resulting in an incremental benefit, but health outcomes increase on other days resulting in an incremental cost

- with the application of Group 1 CRFs, the benefit from days with reduced O_3 concentrations more than offsets the cost from days with increased O_3 concentrations

- this result is driven by the application of a 'cut-off' when applying the Group 1 CRFs (i.e. on some days where O_3 concentrations reduce, they reduce below a point where there are no longer any mortality health outcomes predicted, providing a very large benefit that more than offsets any incremental costs)

- however, with the application of Group 2 or Group 3 CRFs, the benefit from days with reduced O_3 concentrations is more moderate because, unlike when applying the Group 1 CRFs, there is no longer a cut-off below which mortality health outcomes are completely avoided.

As such, there are net positive health benefits with the Abatement Package scenario using the Group 1 CRFs, but net negative health benefits using the alternate groups of CRFs.

7 Conclusions

The CBA provides economic analysis to support the review of the AAQ NEPM standards for SO_2, NO_2, O_3. The analysis presented in the CBA supplements other analyses that support the review. These include a HRA, which assesses the potential health benefits from implementing a hypothetical Abatement Package scenario and adopting alternative air quality standards, and an Impact Statement, which reviews standards adopted internationally and the evidence supporting these standards.

The results of the CBA show that the costs of the Abatement Package scenario are likely to significantly outweigh the health benefits. The BCR for the Abatement Package scenario corresponding to SO_2, NO_2 and O_3 are estimated at 0.01, 0.06 and 0.05 respectively. However:

- there are a number of benefits which 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 estimates the costs and benefits of an Abatement Package scenario at a national level, it does not necessarily provide an indication of the likely costs and benefits of meeting alternative AAQ standards. This is because in practice, while some measures to meet standards are implemented at a national level, individual states and territory governments implement much of the regulation and policy designed to meet the standards in that state or territory. Moreover, some tightened standards could be met without the need for abatement and therefore without additional cost.

As such, each jurisdiction assesses and implements abatement measures following their own policy processes, which may include jurisdiction-specific CBAs and other analyses to select the most appropriate set of abatement 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 AAQ standards should only be implemented if appropriate state-level policy assessment processes support their implementation, or if a national assessment, including 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.

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Annexure A

Overview of health risk assessment

A health risk assessment (HRA) was used to project the changes in health outcomes associated with changes in pollutant concentrations. The HRA focuses on health outcomes that are known to be associated with exposure to the pollutants being analysed. A HRA estimates these changes by:

- estimating the business as usual incidence rates of selected health outcomes (e.g. rate of hospital visits for respiratory illness per 100,000 of population)

- obtaining estimates of the relationships between changes in concentration and changes in health outcomes based on reviews of epidemiological and other health studies

- applying these relationships, referred to as concentration response functions (CRFs) to projected changes in pollutant concentration

- presenting the results as the number of fewer or greater health outcomes for selecting endpoints.

In the HRA for this review, health outcomes avoided have been calculated using the general approach used in previous studies (e.g. Golder Associates, 2013). That is, the change in health outcomes (denoted Δy) is expressed as a function of:

- the change in pollutant concentrations (denoted Δx)

- a baseline incidence rate (denoted y_0)

- a concentration response function (CRF).

The general equation is provided below.

$$\Delta y = f(\Delta x, y_0, CRF)$$

Golder Associates expresses the CRF as a 'Beta' (β) coefficient, which results in the following equation (Golder Associates, 2013, p.9):

$$\Delta y = \left(e^{\beta \Delta x} - 1\right)y_o$$

In the HRA used for this review, the CRF is expressed as a Relative Risk (RR), which is the form normally used by the source literature to express the CRF[3]. The relationship between RR and β is presented in the equation below (Golder Associates, 2013, p.12):

$$\beta = {\log RR}/{\Delta x}$$

This results in the use of the following equation in this study, which is a transformed version of the Golder Associates (2013) version:

$$\Delta y = \Delta x . (RR - 1) . y_o$$

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[3] The RR is provided by the source literature for a corresponding change in concentration (Δx). In this HRA for this review, the RR is 'normalised' into a per unit change (e.g. relative risk per ppb).

Annexure B

Estimation of damage costs

The CBA uses a damage cost approach to estimate the health benefits of changes in SO_X and NO_X emissions where data were not available to use an impact pathway approach. This was done by estimating the following for each combination of pollutant, airshed, scenario (BAU or Abatement) and year (2021, 2031 or 2040) for which impact pathway results were available:

- the $ per tonne, calculated by dividing the avoided health costs by the emission reduction

- the population density of the corresponding airshed.

Note that the calculation of damage costs was based on the results from applying Group 1 CRFs only. The health outcomes included in the results include short-term (acute) mortality and morbidity associated with exposure to SO_2 and NO_2. A similar approach for O_3 could not be applied because O_3 is a secondary pollutant, and is therefore not formed directly due to the emission of any single pollutant. Moreover, a similar approach was not required for $PM_{2.5}$ because damage costs for this pollutant were already available from the literature (refer to Section 3.5.2).

Regression analysis was used to estimate the relationship between unit damage costs ($ per tonne) and population density (persons per km^2). The results of this regression were used to estimate a unique unit damage cost for each airshed where no impact pathway results were available. The unit damage cost ($ per tonne) is then applied to the estimated emission reduction (tonnes) to arrive at an estimate of the avoided health costs ($).

Population density estimates were based on ABS data on the population and area of Significant Urban Areas (SUAs) corresponding to each airshed, except for Latrobe Valley where Local Government Areas (LGA) population and area estimates are used because there is no corresponding SUA.

Annexure C
Analysis of abatement measures

Abatement measures selected for inclusion in the CBA are shown in Table C-1.

Table C-1 Abatement measures selected for cost-benefit analysis

Pollutant	Measure No.	Abatement Description
SO_2	Measure 9	De-SO_X and NO_X, and for power stations
SO_2	Measure 14	De-SO_X at petrol refineries
SO_2	Measure 15	De-SO_X at iron and steel production facilities
NO_2	Measure 9	De-SO_X and NO_X for power stations
NO_2	Measure 6	Non-road diesel engine standards
NO_2	Measure 13	Industry NO_X control technology (cement, iron and steel, and aluminium industries)
O_3	Measure 1	On-board refuelling vapour recovery
O_3	Measure 10	Surface coating standards
O_3	Measure 16	VOC control for solvent aerosol use

The following subsections describe the approach used to estimate costs and emission reductions. Capital and operating costs are based mainly on publicly available literature. Administration costs are based on the expected level of effort for government to introduce regulations to require the adoption of these measures, and the expected level of administrative effort for industry to comply with these regulations.

Emission reductions are based on the assumed time profile for implementing the abatement measures during the 2021-2040 evaluation period, and based on modelling by Pacific Environment on the effectiveness of the measures in reducing emissions (e.g. considering changes to emission factors, capture efficiency etc.).

Measure 1: On-board refuelling vapour recovery (ORVR) (O_3)

On-board refuelling vapour recovery (ORVR) is a vehicle emission control system that captures volatile organic compounds (VOC) from the vehicle's petrol tank during refuelling. Fuel vapour contains VOCs which contribute to atmospheric ozone concentrations.

Capital costs

The following assumptions have been used to estimate capital costs:

- ORVR was assumed to be fitted in new vehicles sold in targeted abatement areas from 2021 onwards.

- The assumed uptake of ORVR in new vehicles is 20% in 2021, 50% in 2031 and 100% in 2040.

- The cost of ORVR was estimated to be $18 per vehicle based on data from Caltex (2014), which was in turn sourced from original equipment manufacturers (OEMs) in the United States (US).

- Projections of the number new motor vehicle sales (Table C-2) was used to estimate the total cost per year for each state.

- An annual average growth rate for new motor vehicles between was assumed.

Table C-2 Number of new motor vehicles per state (2015)

Location	Number of New Motor Vehicles (2015)
ACT	18,038
NSW	380,865
NT	10,524
QLD	235,674
SA	69,047
VIC	315,389
WA	106,188

Source: ABS Cat. No 9314 – Sales of New Motor Vehicles Australia

Operating and maintenance costs

Operating and maintenance costs for Measure 1 are assumed to be negligible, as ORVR is not assumed to affect operating and maintenance costs for vehicles or petrol stations.

Co-benefits and dis-benefits

ORVR was assumed to provide fuel savings to consumers. ORVR returns fuel vapour to the vehicle fuel tank and thus results in gross petrol savings. Over the average life of a vehicle (10 years), these savings would equate to $15 per vehicle (Caltex, 2014). The number of new motor vehicles (Table C-2) has also been used to quantify this co-benefit.

Emission reductions

Emission reductions were estimated based on the profile of gradual uptake of ORVR across the fleet. Table C-3 summarises the estimated emission reductions.

Table C-3 Abatement measure 1 emissions reductions (O_3)

Year	O_3 Reduction (tonnes per year)
2021	2,194
2030	5,926
2040	13,758
Total (2016 – 2040)	**138,531**

Measure 10: Surface coating standards (O_3)

VOC emissions result from the evaporation of solvents in solvent-based and water-based coatings. Abatement measure 10 focuses on reducing VOC emissions in architectural, industrial and automotive refinishing segments by implementing re-formulated low VOC coating technology for all solvents in these segments, which will meet new surface coating standards.

The standards are assumed to commence in 2021, but are assumed to increase in stringency over time, consistent with the legislative approach used in Europe.

Capital costs

The following assumptions have been used to estimate capital costs:

- The amortised capital cost of reducing VOC emissions in surface coatings were estimated to be $3,000 per tonne of VOC reduced (California Air Resources Board, 2007).

- The capital costs will be incurred when the equipment is installed (i.e. upfront), but for modelling purposes have been amortised (spread over) the evaluation period in proportion to annual emission reductions.

Operating and maintenance costs

Operating and maintenance costs for Measure 10 are assumed to be negligible, as the re-formulation of coating products was assumed to not affect operation and maintenance costs for manufacturers.

Emissions reductions

Emission reductions were estimated based on the profile of gradual up-take of re-formulating surface coating products in industry. Table C-4 summarises the estimated emission reductions.

Table C-4 Abatement measure 10 emissions reductions (O_3)

Year	O_3 Reduction (tonnes per year)
2021	3,719
2030	21,384
2040	45,019
Total (2016 – 2040)	**536,872**

Measure 16: VOC control for solvent aerosol use (O_3)

Abatement measure 16 seeks to reduce VOC content in aerosols by implementing California Air Resource Board (CARB) regulations for domestic solvents and aerosols. This involves phasing out non-compliant household aerosol products from the market, which in turn incurs an additional production cost to manufacturers.

Capital and operating costs

The following assumptions have been used to estimate operating and maintenance costs:

- The phasing out of non-compliant products was assumed to begin in 2021.

- The measure assumes the coverage of products required to be re-formulated will increase from 2021 to 2040, after which all household aerosol products are required to be re-formulated.

- It was estimated that there is a 20% cost premium for compliant products versus non-compliant aerosol products (SKM, 2010). This equates to an additional $0.6 spend per household per week, with an increase in price reflecting the increase in the costs of production. This additional cost is multiplied by the number of households (Table C-5) to quantify costs incurred per state.

- The annual average growth in number of households of 1.6% was assumed.

Table C-5 Australian household assumptions

State	Number of Households (2016)
ACT	78,162
NSW	2,889,877
NT	215,656
QLD	1,868,125
SA	701,538
VIC	2,310,623
WA	1,023,042

Source: ABS Cat. No 3236 – Household and Family Projections Australia

Administrative and regulatory costs

A one-off administration cost for set-up and the implementation of regulations of $1,000,000 was assumed to be incurred in 2021. This cost is apportioned equally across all affected airsheds.

Emission reductions

Emission reductions were estimated based on the profile of gradual uptake of compliant household aerosol products. Table C-6 summarises the estimated emission reductions.

Table C-6 Abatement measure 16 emissions reductions (O_3)

Year	O_3 Reduction (tonnes per year)
2021	9,484
2030	26,064
2040	59,929
Total (2016 – 2040)	628,918

Measure 9: De-SO$_X$ and de-NO$_X$ for power stations (SO$_2$, NO$_2$)

Abatement measure 9 involves the installation of wet flue gas de-sulfurisation (FGD) scrubbers to reduce SO$_X$ emissions, and the installation of selective catalytic reduction (SCR) to reduce NO$_X$ emissions at power stations.

FGD involves scrubbing flue gas released from power stations by absorbing SO$_X$ compounds in a chemical solution. SCR involves injecting a reagent into the flue gas in the furnace which reacts with NO$_X$ compounds to form N$_2$ gas and water.

These technologies are assumed to affect the power stations listed in Table C-7. Note that FGD would only apply to the coal power stations in Table C-7. Furthermore, some of the coal power stations are likely to close by 2040. Therefore, the costs and emission reductions could be lower than estimated in this CBA. The sensitivity analysis (refer to section 6) tests a range of assumptions for costs and benefits, which incorporates the effect of these and other uncertain assumptions. This simplification is likely to result in a reduction in the magnitude of the NPV for SO$_2$ (i.e. both reduced costs and benefits), but not the sign.

Table C-7 Affected power stations

State	Affected power stations	Total Capacity (kW)
ACT	None	None
NSW	Appin, Eraring, Kurri Kurri, Vale Point, Bayswater, Liddell, Mt Piper, Smithfield, Tahmoor, Teralba, Tallawarra	11,000
NT	Channel Island, Weddell	400
QLD	Millmerran, Darling Downs, Tarong, Raceview	3,700
SA	Torrens Island, Lonsdale, Pt Stanvac, Quarantine, Osborne, Pelican Point, Dry Creek	2,400
VIC	Somerton, Newport, Laverton North, Loy Yand A, Jeeraland, Yallourn, Loy Yang B, Hazelwood, Valley	8,000
WA	Newgen Neerabup, Cockburn, Kwinana, Pinjar	1,900

Capital costs

FGD and SCR technologies are assumed to be installed at power stations from 2021. The estimated capital costs are based on publicly available data (Electric Power Research Institute, 2015; Cichanowicz, 2010), by estimating a unit rate for FGD and SCR per kW of power station capacity (Table C-8).

Table C-8 Abatement measure 9 – Capital costs

Capital costs for	Cost ($/kW)
FGD	$1,090
SCR	$858

Operating and maintenance costs

Operating and maintenance costs for FGD and SCR are calculated as a unit rate per kW of power station capacity per year. Cost rate values are presented in Table C-9.

Table C-9 Abatement measure 9 – Operating and maintenance costs

Costs	Cost ($/kW/year)
FGD	$45
SCR	$7

Administrative and regulatory costs

A one-off administration cost for the set-up and implementation of regulations of $8,600,000 has been assumed in 2021. This cost has been apportioned equally across all affected airsheds.

Emission reductions

Emission reductions were estimated based on the profile of gradual uptake of FGD and SCR technology in power stations across Australia. Table C-10 summarises the estimated emission reductions.

Table C-10 Abatement measure 9 emissions reductions (NO_X, SO_X)

Year	NO_X Reduction (tonnes per year)	SO_X Reduction (tonnes per year)
2021	13,374	27,196
2030	34,285	100,660
2040	76,887	190,266
Total (2016 – 2040)	**792,027**	**1,963,365**

Measure 14: De-SO_X at petrol refineries (SO_2)

Abatement measure 14 involves the installation of wet gas scrubbing (WSG) technology at petrol refineries to reduce SO_X emissions. WGS technology removes particulates and SO_X by intimate mixing with an aqueous scrubbing liquid in a vessel.

Capital costs

WSG technology was assumed to be installed at petrol refineries included in the 2011 Emissions Inventory published by the NSW EPA in 2013. The technology was assumed to be installed from 2030. Since the publication of the inventory, there has been a closure of petrol refineries in NSW and QLD. Therefore, the costs and emission reductions could be lower than estimated in this CBA. This simplification is likely to result in a reduction in the magnitude of the NPV for SO_2 (i.e. both reduced costs and benefits), but not the sign. The sensitivity analysis (refer to section 6) tests a range of assumptions for costs and benefits, which incorporates the effect of these and other uncertain assumptions.

The following assumptions were used for capital costs, based on data from CONCAWE (2011):

- The reference capital cost for a 50 MW unit is $21 million.
- Capital costs were estimated based on the reference costs and the assumed proportion of national production of petrol per state, as summarised below in Table C-11, using the formula below.

$$\frac{Cost\ of\ unit}{Cost\ of\ unit_{reference}} = \left(\frac{MW}{MW_{reference}}\right)^{0.6}$$

Table C-11 Abatement measure 14 – Capital costs

State	Assumed proportion of national production (%)	Assumed energy requirement (MW)	Cost ($M 2016)
ACT	-	-	-
NSW	7	30	16
NT	-	-	-
QLD	23	90	30
SA	-	-	-
VIC	42	180	45
WA	31	120	36

Operating and maintenance costs

The following assumptions have been used to estimate operating and maintenance costs:

- WSG technology was assumed to be operating and maintained at petrol refineries from 2030.

- The reference operating and maintenance cost is 4% of the capital cost per annum (MACTEC, 2005).

Administrative and regulatory costs

A one-off administration cost for set-up and the implementation of regulations of $300,000 has been assumed in 2021. This cost has been apportioned equally across all affected airsheds.

Emission reductions

Emission reductions were estimated based on the profile of gradual uptake of WGS technology in petrol refineries across Australia. Table C-12 summarises the estimated emission reductions.

Table C-12 Abatement measure 14 emissions reductions (SO$_X$)

Year	SO$_X$ reduction (tonnes per year)
2021	-
2030	24,043
2040	28,753
Total (2016 – 2040)	**290,376**

Measure 15: De-SO$_X$ at iron and steel facilities (SO$_2$)

Abatement measure 15 involves the installation of wet flue gas de-sulfurisation (FGD) at iron and steel production facilities to reduce SO$_X$ emissions. FGD involves scrubbing flue gas released from these facilities by absorbing SO$_X$ compounds in a chemical solution. The measure is only assumed to affect NSW, and the estimated costs and emission reductions are based on the Port Kembla facility near Wollongong.

Capital costs

FGD technology was assumed to be installed at iron and steel production facilities from 2021 in NSW. The following assumptions were used to estimate capital costs:

- An annual production of 3 million tonnes has been assumed, based on 2016 production levels at the Port Kembla facility.

- A capital cost of $100 million was assumed, based on MACTEC (2005).

Operating and maintenance costs

FGD technology was assumed to be operating and maintained at iron and steel production facilities from 2021. An operating and maintenance cost of $24 million per year was assumed based on MACTEC (2005).

Administrative and regulatory costs

A one-off administration cost for applying for relevant licenses, and monitoring and implementation of regulations of $300,000 was assumed in 2021.

Emission reductions

Emission reductions were estimated based on the uptake of FGD technology in iron and steel production facilities in NSW from 2030. Emission reductions increase over time due to assumed growth in production. Table C-13 summarises the estimated emission reductions.

Table C-13 Abatement measure 15 emissions reductions (SO$_X$)

Year	SO$_X$ Reduction (tonnes per year)
2020	1,457
2030	3,636
2040	7,589
Total (2016 – 2040)	**89,073**

Measure 6: Non-road diesel engine standards (NO$_2$)

Abatement measure 6 involves implementing non-road diesel engine standards. There are currently no national regulations for non-road diesel engines, which are used in agriculture, construction, mining, industrial, power generation, amongst other sectors. The standards are assumed to be implemented progressively between 2019 (Tier 3) and 2022 (Tier 4). and involve the installation of new engines and equipment for non-road diesel engines.

The measure assumes a fleet turnover, sector coverage, capital and operating costs consistent with a study by NSW EPA (2014). The data from Scenario 3 of this study ('Stepped introduction of emission standards') have been used for this CBA. This scenario assumes that the following equipment types are covered by the standards, and that only engines with a capacity greater than 19 kW are required to meet standards:

- diesel-powered construction and surface mining equipment and non-road vehicles
- general industrial equipment, light commercial equipment including pumps and compressors
- power generation units
- agricultural equipment and vehicles
- forestry and logging equipment
- lawn and garden equipment
- marine engines with power ratings below 37 kW.

The assumed average median life, load factor and hours of operation by engine category are provided in Appendix D of NSW EPA (2014). Note that due to the long life of the equipment, health benefits from this measure are likely to accrue beyond the CBA modelling period. However, the CBA does include these ongoing benefits.

Capital costs

Capital costs for each Tier were estimated based on the individual equipment type and power rating category, and are based on the study by NSW EPA (2014), which considered the costs and benefits across Australia. The measure in this CBA only considers the costs and benefits in the airsheds included in the CBA (refer to section 3.2). Therefore, the costs and emission reductions provided by NSW EPA were scaled using the ratio of the population of the selected airsheds to the Australian population.

Total capital costs of $5.4 billion PV are estimated across the affected airsheds.

Operating and maintenance costs

Operating costs for each Tier were estimated based on the individual equipment type and power rating category, and are based on a study by NSW EPA (2014). Total operating and maintenance costs of $1.9 million PV are estimated across the affected airsheds.

Co-benefits and dis-benefits

Fuel savings from the installation of Tier 4 engines were estimated based on a study by NSW Environment Protection Authority (2014). Total fuel savings of $1.7 million PV are estimated across the affected airsheds. The measure also reduces emissions of $PM_{2.5}$, CO and VOCs.

The estimate of health benefits in the CBA incorporates the effect of reduced health outcomes from exposure to $PM_{2.5}$, but only for the airsheds included in the CBA. Therefore, the benefits accruing to regional areas with large exposures to non-road diesel equipment emissions (such as Singleton and Muswellbrook in NSW) have not been included.

Emission reductions

Emission reductions were estimated based on the profile of gradual uptake of compliant non-road diesel engines. Table C-14 summarises the estimated emission reductions.

Table C-14 Abatement measure 6 emissions reductions (NO_X)

Year	NO_X Reduction (tonnes per year)
2020	4,350
2030	12,094
2040	27,303
Total (2016 – 2040)	**282,416**

Measure 13: Industry NO_X control technology (NO_2)

Abatement measure 13 involves the installation of selective catalytic reduction (SCR) technology to reduce NO_X emissions in cement and clinker, iron and steel and aluminium and alumina production plants. SCR involves injecting a reagent into the flue gas in the furnace which reacts with NO_X compounds to form N_2 gas and water.

The estimated annual production by plant type is provided below.

Cement and clinker facilities

Table C-15 Abatement measure 13 assumed annual production of cement/clinker

State	Assumed annual production (million tonnes) (2016)
NSW	5 million tonnes per annum
SA	4 million tonnes per annum
WA	2 million tonnes per annum

Iron and steel facilities

Table C-16 Abatement measure 13 assumed annual production of iron/steel

State	Assumed annual production (million tonnes) (2016)
NSW	3 million tonnes per annum

Aluminium and alumina facilities

Table C-17 Abatement measure 13 assumed annual production of aluminium/alumina

State	Assumed annual production (million tonnes) (2016)
NSW (aluminium)	0.7 million tonnes per annum
WA (alumina)	11 million tonnes per annum

Capital costs

The following assumptions were used to estimate capital costs for cement and clinker facilities:

- SCR was assumed to be implemented at cement/clinker production sites in 2021 in NSW and WA, and 2031 in SA.

- A capital cost of $4 million for a plant that produces a million tonne of cement/clinker per year was assumed based on Economic and Social Council, Economic Commission for Europe (2012)[4]. This capital cost was scaled according to the assumed annual production capacity in Table C-15 .

The following assumptions were used to estimate capital costs for iron and steel facilities:

- SCR was assumed to be implemented at iron/steel production sites in 2031 in NSW.

- A capital cost of $17 million, based on the average investment cost of SCR at iron/steel plants estimated by MACTEC (2005).

The following assumptions were used to estimate capital costs for aluminium and alumina facilities:

- Low-NOx burners were assumed to be installed at aluminium and alumina production sites in 2021 in NSW and WA.

- The production of aluminium was estimated to require 14,000 kWh of heat per tonne, and the production of alumina was estimated to require 3,015 kWh of heat per tonne (World Aluminium, 2016).

- A capital cost for fitting low-NO_X burners of $2,200 per MW of process heat capacity was assumed based on Economic and Social Council, Economic Commission for Europe (2012, Table 38), and assuming plant operation of 8,000 hours per year.

Operating and maintenance costs

The following assumptions were used to estimate operating and maintenance costs for cement and clinker facilities:

- Operating and maintenance costs of $3 per tonne of production are assumed based on Economic and Social Council, Economic Commission for Europe (2012)

The following assumptions were used to estimate operating and maintenance costs for iron and steel facilities:

- Operating and maintenance costs of $5 million per year are assumed based on MACTEC (2005).

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[4] Based on an investment cost of approximately €2.2 - €4.5 million for a kiln processing approximately 3,000 tonne clinker per day (Economic and Social Council, Economic Commission for Europe, 2012, Table 51, p.16)

The following assumptions were used to estimate operating and maintenance costs for aluminium and alumina facilities:

- Operating and maintenance costs of $3,300 per MW are assumed based on MACTEC (2005).

Administrative and regulatory costs

A one-off administration cost for set-up and the implementation of regulations of $1,300,000 was assumed to be incurred in 2021. This cost has been apportioned equally across all affected airsheds.

Emission reductions

Emission reductions were estimated based on the profile of gradual uptake of SCR technology Table C-18 summarises the estimated emission reductions.

Table C-18 Abatement measure 6 emissions reductions (NOx)

Year	NO$_X$ Reduction (tonnes per year)
2020	1,467
2030	13,720
2040	22,615
Total (2016 – 2040)	**230,467**

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