Reducing Emissions from Non-road Diesel Engines

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Acronyms and abbreviations

AAQ	Ambient air quality
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ACARP	Australian Coal Association Research Program
ADEDA	Australian Diesel Engine Distributors Association
ADO	Automotive diesel oil
ADR	Australian Design Rules
AIOH	Australian Institute of Occupational Hygienists
AUD	Australian dollars
BAU	Business as usual
CMEIG	Construction and Mining Equipment Industry Group
CO	Carbon monoxide
CO_2	Carbon dioxide
DAFF	Australian Department of Agriculture, Fisheries and Forestry
DEWHA	Australian Department of Environment, Water, Heritage and the Arts
DF	Deterioration factor
DPF	Diesel particulate filter
DPM	Diesel particulate matter
DSEWPaC	Australian Department of Sustainability, Environment, Water, Population and Communities
EC	Elemental carbon
EEO	Energy Efficiency Opportunities program
EGR	Exhaust gas recirculation
EPHC	Environment Protection and Heritage Council
EU	European Union
GDP	Gross domestic product
GMR	Greater Metropolitan Region
HC	Hydrocarbons
hp	Horsepower
IARC	International Agency for Research on Cancer
IDF	Industrial diesel fuel
kL	Kilolitre
kW	Kilowatt

kWh	Kilowatt hour
L	Litre
M	Million (dollars)
mg	Milligram
ML	Megalitre
NEPC	National Environment Protection Council
NHVAS	National Heavy Vehicle Accreditation Scheme
NMHC	Non-methane hydrocarbons
NO	Nitrous oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NPI	National Pollutant Inventory
NPV	Net present value
NRMM	Non-road mobile machinery
NRSC	Non-road steady cycle
NRTC	Non-road transient cycle
NSW EPA	NSW Environment Protection Authority
OHS	Occupational health and safety
PM	Particulate matter
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of less than 2.5 µm
PM_{10}	Particulate matter with an aerodynamic diameter of less than 10 µm
PPM	Parts per million; equivalent to mg/kg
RIA	Regulatory impact analysis
RIS	Regulatory impact statement
rpm	Revolutions per minute
SCR	Selective catalytic reduction
SO_2	Sulfur dioxide
SUA	Significant urban area, ABS designation for urban centres with more than 10,000 people
TAF	Transient adjustment factor
TMA	Tractor Machinery Association of Australia
TTMRA	Trans Tasman Mutual Recognition Agreement
µm	micrometre
US EPA	United States Environmental Protection Agency
VOC	Volatile organic compound
VOLY	Value of a life year
VSL	Value of a statistical life
WHO	World Health Organization
WHS	Workplace health and safety
WTP	Willingness to pay
ZHL	Zero hour emission level

Executive summary

Air pollution is a major environmental risk to health. Elevated levels of common air pollutants can result in an increase in respiratory and cardiovascular effects in humans and contribute to premature deaths and cancer risks. Although Australia's urban air quality is generally good, the concentration of ambient air pollutants and the impact they can have on community health and wellbeing remains a concern.

Combustion-related air pollution, such as from non-road diesel engines, is of particular concern given its health and climate effects. Non-road diesel engines are used in a wide range of sectors and applications, including construction and mining, industry, power generation, agriculture, marine applications, forestry and logging, and lawn and garden applications.

Emissions from non-road diesel engines include particulate matter (PM), oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and a range of air toxics (e.g. benzene, toluene and 1,3-butadiene). Particulate matter emitted from diesel combustion is mainly comprised of fine particles having an aerodynamic diameter of less than 2.5 micrometres ($PM_{2.5}$). Fine particle emissions are associated with premature deaths and adverse health effects such as cardiovascular and respiratory effects, and can lead to an increase in the number of emergency room presentations and hospital admissions.

The International Agency for Research on Cancer (IARC), which is part of the World Health Organization, recently classified diesel engine exhaust as carcinogenic to humans, based on sufficient evidence that exposure is associated with an increased risk of lung cancer[1]. NO_x and VOC emissions from the non-road diesel sector contribute to ground level ozone formation which is used as an indicator of photochemical smog. Particulate matter and ground-level ozone concentrations still sometimes exceed national standards in some Australian cities.

The need for action to manage non-road diesel engine emissions

Despite consuming less diesel fuel than road transport nationally, the non-road diesel sector is estimated to produce higher fine particle emissions than on-road diesel vehicles. Whereas on-road diesel vehicles have been subject to increasingly stringent emission standards and state and territory emission reduction programs, non-road diesel engine emissions have remained unregulated in Australia with the exception of engines applied in underground mining.

Regulations for non-road diesel equipment have been implemented in the United States (US) and the European Union (EU) since the 1990s, and have subsequently been introduced by other jurisdictions including Canada, Japan, India, China, Brazil and Russia. US emission standards (expressed as Tier 1 to Tier 4) and EU emission standards (Stage I to Stage IV) are the most widely referenced and applied emission standards for non-road diesel engines, with most other jurisdictions introducing either US, EU or a combination of these standards. International trends in non-road diesel engine standards include increased stringency of emission standards, improved harmonisation and more extensive coverage of engine power rating ranges.

Australia has benefited somewhat from the importation of cleaner engines compliant with non-road diesel emission standards issued by the US, EU and other jurisdictions; however, a review of the emission performance of new engines and equipment being sold into the Australian non-road diesel market indicates that a significant proportion of units are non-

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[1] IARC (2012)

compliant or are lagging in compliance relative to units being sold into the US and EU. Market forces within the non-road diesel engine sector in Australia have not therefore successfully driven the transition to cleaner (lower emission) engines. Furthermore, the more costly nature of engines compliant with the recent and most stringent standards (US Tier 4 and EU Stage IIIB), due to their incorporation of aftertreatment technologies, is expected to impede the future uptake of such engines in Australia. The number of 'dirtier' engines and equipment being sold into Australia may increase as other countries introduce or tighten regulations and manufacturers seek alternative markets.

Non-road diesel engine emissions are projected to grow significantly over the next two decades as a result of the forecast increase in fuel consumption by this sector, and given the cost impediment to the uptake of significantly cleaner non-road diesel engines and equipment. It is estimated that:

- annual NO_x and $PM_{2.5}$ non-road diesel engine emissions in 2012 of approximately 171,900 tonnes/year and 18,850 tonnes/year respectively will quadruple by 2050
- associated health costs will increase from $690 million per annum in 2012 to $4.6 billion per annum by 2050, with approximately 85% of the cost being due to direct $PM_{2.5}$ emissions and the remainder due to NO_x emissions.

The projected increase in health costs associated with non-road diesel engine emissions, and the failure of the market to successfully drive a transition toward cleaner engines, provides a strong case for additional action to manage non-road diesel engine emissions in Australia.

Equipment types and exclusions

Equipment types encompassed within the scope of this report include 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; and marine engines with power ratings below 37 kW. Marine engines over 37 kW, aircraft engines and railway locomotives are excluded from the scope, as are engines and equipment used in underground mining, as these engines are not typically included in international non-road diesel engine regulations[2] [3].

Non-road diesel engines of 19 kW to greater than 560 kW are included in the scope of the harmonisation scenarios considered in this report. Smaller engines (less than 19 kW) are not included, as an initial analysis showed their inclusion would significantly reduce the administrative ease of implementation and the cost-effectiveness of the proposed scenarios, without substantially contributing to overall emission reductions and associated health benefits[4].

Current US and EU emission standards are equivalent for the 19 kW to 560 kW power rating range. While the US has emission standards for engines greater than 560 kW, the EU is only currently considering extending standards to engines of this size. The effect of excluding engines greater than 560 kW to reflect current EU emission standards was considered in this report by way of sensitivity analysis.

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[2] The 37 kW threshold for excluding larger marine engines is based on the scope of US non-road diesel engine regulation.

[3] Non-road diesel engine emissions from equipment used in underground mining are regulated through workplace health and safety regulations.

[4] Van Zeebroeck et al. (2009)

Potential actions considered

This report assesses potential actions that could be employed to reduce non-road diesel engine emissions in Australia, thereby reducing associated adverse impacts on human health and the environment. Minimum emission standards for non-road diesel engines have been implemented in many overseas countries, specifically aimed at new equipment and in some cases replacement engines. Targeting new engines has been shown to be more cost effective and efficient than achieving emission reductions through retrofitting in-service engines[5]. Setting emission standards for on-road vehicles has been shown to reduce emissions from that sector both overseas and in Australia[6].

This report canvasses three possible scenarios for harmonisation of Australian emission standards with those in the US and EU. The three scenarios represent two alternative single phase approaches, and a stepped approach to introducing emission standards, respectively. The option of taking no action, business as usual (BAU), is also explored. Due to uncertainties regarding future changes in the emission performance of non-road diesel engines/equipment, a main base case, plus upper bound and lower bound base case scenarios were also defined for the BAU option, to enable a sensitivity analysis to be conducted (i.e. effect of reasonable variations in the main base case tested). Emissions and associated health costs, in the absence of intervention, were projected to increase to varying extents in all three base case scenarios. Table ES1 outlines the BAU base cases and the three harmonisation scenarios.

Table ES1: Summary of potential actions for impact analysis

Potential action	**Description**[(a)]
Business as usual (BAU) – no action	
BAU main base case	Emission performance of new engines/equipment assumed to remain unchanged
BAU lower bound base case	Emission performance of new engines/equipment assumed to improve
BAU upper bound base case	Emission performance of new engines/equipment assumed to decline
Harmonisation scenarios	
Scenario 1 Tier 3 / Stage III A emission standards only	US Tier 3 / EU Stage III A emission standards implemented in 2015 for new engines/equipment greater than 19 kW
Scenario 2 Tier 4 final / Stage III B / Stage IV emission standards only[(b)]	US Tier 4 final / EU Stage III A/Stage IV emission standards implemented in 2018 for new engines/equipment greater than 19 kW
Scenario 3 Stepped introduction of emission standards	Tier 3 / Stage III A emission standards implemented in 2015 & Tier 4 final/Stage III B /Stage IV emission standards implemented in 2018 for new engines/equipment greater than 19 kW

[(a)] US Tier 3 emission standards and EU Stage III A emission standards are currently in force in the US and EU respectively. US Tier 4 and EU Stage III B/Stage IV standards are progressively

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[5] US EPA (2004a)

[6] BTRE (2005)

being implemented in the US and EU, respectively, by 2015 and are already required for the majority of engine classes.

(b) The EU is tightening NO_x standards in two stages, Stage IIIB in 2011–12 and Stage IV by 2014.

The implementation schedule and stepped approach outlined in Table ES1 is based on inputs received from industry stakeholders during the study undertaken by ENVIRON[7] and further discussion with industry stakeholders during the development of this report. Note that the three scenarios and their implementation timetables are illustrative only and were derived during a study undertaken in 2013 using 2012 base year data. The stepped implementation schedule for harmonisation scenario 3 includes an implementation date of 2015 for EU Stage III A / US Tier 3 standards and 2018 for compliance with Stage III B / Stage IV and Tier 4 standards. These dates were selected to maximise the period for projecting costs/benefits given stock projections which are made to 2035. If the harmonisation scenarios were concluded to be feasible given these early implementation dates, later dates would be as feasible or more feasible, as demonstrated by way of the sensitivity analysis.

Impacts of potential actions

Key findings of the analysis of the BAU and harmonisation scenarios include:

- Non-road diesel engine emissions could be reduced by up to 67% for $PM_{2.5}$ emissions and up to 53% for NO_x emissions by 2035, compared to the BAU main base case.
- Non-road diesel engine emission intervention could result in health cost reductions peaking in the range of $540–1440 million per annum in 2035, compared to the BAU main base case.
- The present value of net benefits (i.e. health cost reductions less compliance costs), calculated over the 2015 to 2055 period could be in the range of approximately $1257 million to $2244 million.

The present values of net benefits for the three harmonisation scenarios are set out in Table ES2. The greatest health benefits and overall net benefits are predicted for harmonisation scenario 3, comprising a stepped introduction of Tier 3 / Stage III A emission standards and subsequent introduction of Tier 4 / Stage III B / Stage IV emission standards.

Table ES2: Present value of net benefits(a) for each harmonisation scenario (AUD$M 2012)

Action	Present value of net benefits, 2012 AUD$M
Harmonisation scenario 1: Tier 3 / Stage III A in 2015	1,257
Harmonisation scenario 2: Tier 4 / Stage III B / Stage IV in 2018	1,952
Harmonisation scenario 3: Stepped Tier 3 / Stage III A in 2015 and Tier 4 / Stage III B / Stage IV in 2018	2,244

(a) Present values were calculated for 2015 to 2055 using an annual real discount rate of 7%[8]

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[7] ENVIRON (2010)

[8] Australian Government (2010)

Sensitivity analysis

Results were tested for robustness to key assumptions. Net benefits were sensitive to:

- the social discount rate applied, with lower discount rates giving higher net benefits
- changes to the base case scenario: a higher uptake of lower emission engines in the absence of intervention results in lower net benefits; conversely, a market dominated by higher emission (Tier 2) engines in the absence of intervention results in higher net benefits
- exclusion of engines with a rated power of greater than 560 kW results in an increase in net benefits
- using a higher value for the value of a statistical life (VSL) results in higher net benefits; while using a lower value results in lower net benefits, and
- a delay in implementation results in higher net benefits.

Conclusion

In summary, the impact analysis undertaken during the development of this report provides a strong case for action in relation to non-road diesel engine emissions in Australia. The potential actions assessed are likely to make progress to varying degrees towards the objectives of intervention. To maximise the usefulness of the cost/benefit analysis, a start date of 2015 is assumed for implementation of the harmonisation scenarios. This is indicative only, and a later start date of three to four years is likely to be more realistic. Of the options assessed, harmonisation scenario 3, with its stepped implementation approach, provides the greatest estimated net benefits. For the purposes of this analysis, current in-service compliance of non-road diesel engines and equipment is assumed to be largely Tier 2/Stage II. The level of compliance has a key impact on results. Any further analysis should take account of the latest evidence of compliance.

1 Introduction

1.1 Context

The World Health Organization continues to emphasise air pollution as a major environmental risk to human health[9]. Recently, the focus in terms of health and climate effects has been on air pollution from combustion sources[10]. Elevated levels of some common air pollutants can result in an increase in respiratory and cardiovascular effects in humans and contribute to premature deaths and cancer risks.

Although Australia's urban air quality is generally good, the concentration of ambient air pollutants and the impact they can have on community health and wellbeing remains a concern. The *State of the Air in Australia: 1999–2008* report identified particles and ozone as air pollutants of concern in Australia due to levels exceeding the national standards in some cities[11]. The Australian Government has taken initial steps to manage particle emissions and increase understanding of the nature and impacts of particulate matter. For example, the development of options for actions to reduce particle pollution from products and equipment such as wood heaters and non-road spark ignition engines and equipment are under investigation. Air quality is also a headline indicator for Australia under the Measuring Sustainability program[12].

Emissions from non-road diesel engines and equipment contribute significantly to ambient air pollution in Australia, being a source of particulate matter (PM), oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and a range of air toxics (e.g. benzene, toluene and 1,3-butadiene). NO_x and VOCs emissions from the non-road diesel sector contribute to ground level ozone formation which is used as an indicator of photochemical smog. While urban air quality in Australia is generally good, particulate matter and ground-level ozone concentrations sometimes still exceed national standards in some Australian cities.

Particulate matter emitted from diesel combustion is mainly comprised of particles in the sub-micrometre diameter range, with almost all particles emitted being smaller than 2.5 micrometres (µm). Particulate matter with an aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$) is referred to as fine particles. Fine particle emissions are associated with premature deaths and adverse health effects such as cardiovascular and respiratory effects, and can lead to an increase in the number of emergency room presentations and hospital admissions. The International Agency for Research on Cancer (IARC), which is part of the World Health Organization, recently classified diesel engine exhaust as carcinogenic to humans, based on sufficient evidence that exposure is associated with an increased risk of lung cancer[13].

Whereas on-road diesel engines sold in Australia are regulated to meet strict emission limits, there are currently no regulations or standards that limit emissions from non-road diesel engines. Regulated emission limits for non-road diesel engines have been enforced in the United States (US) and European Union (EU) since the mid-1990s, and more recently in Canada, Japan, China and India.

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[9] WHO (2013)

[10] WHO (2012), IARC (2012), US EPA (2012), UNEP & WMO (2011)

[11] DSEWPaC (2010)

[12] *Measuring Sustainability* program: www.environment.gov.au/sustainability/measuring/indicators/index.html

[13] IARC (2012)

1.2 Equipment covered

Non-road diesel engines are used in a wide range of sectors and applications. Throughout this document the term *non-road diesel engines* refers to the following diesel-powered equipment:

- construction and surface mining equipment and non-road vehicles
- general industrial equipment and non-road vehicles, including aviation service equipment
- light commercial equipment, including pumps and compressors
- power generation units, including units with a power rating over 560 kW
- agricultural equipment and vehicles, including tractors and other self-propelled machinery, pumps and generators
- forestry and logging equipment
- lawn and garden equipment, and
- marine engines, specifically small engines with power ratings below 37 kW.

Large marine engines (over 37 kW), aircraft engines and railway locomotives are not included in the scope of this report, as they are not typically included in overseas non-road diesel engine standards. The 37 kW threshold for excluding larger marine engines is based on the scope of the US non-road diesel engine standards. Further explanation is provided in Section 3.3.2.

Diesel engines and equipment used in underground mining are also not included in the equipment addressed by this report, as provision has been made for this equipment within workplace health and safety (WHS) regulations through exposure limits targeting common pollutants (including PM and NO_x), and ventilation and personal protective equipment requirements.

1.3 Overview of the report's structure

Section 2 provides an extensive discussion of the problem posed by non-road diesel emissions. An overview of the non-road diesel engine sector is given, diesel exhaust emissions and associated impacts are described and the manner in which emissions from this sector are managed locally and abroad is considered. Information is provided on the emission performance of non-road diesel engines being sold into Australia, and the failure of the market to successfully drive a transition towards cleaner engines. Projected increases in emissions from this sector and their associated health costs are assessed.

Section 3 describes the three possible harmonisation scenarios proposed to address non-road diesel engine emissions, as well as the option to take no action (business as usual).

Section 4 outlines the methodology employed and presents the findings in relation to the impact analysis of the feasible harmonisation scenarios. A summary of the broader expected impacts of the harmonisation scenarios is provided.

Section 5 provides a summary of the conclusions reached based on the outcomes of the impact analysis of the harmonisation scenarios.

2 The problem posed by non-road diesel emissions

2.1 Overview of the problem

The non-road diesel engine sector in Australia is described in detail in Section 2.2 and Appendix A. Emissions from this sector contribute to elevated fine particle and ozone concentrations in the ambient air within populated urban areas. Emissions also impact on human health and are associated with climate effects (Section 2.3). There is growing evidence of the toxicity and cancer risks related to diesel exhaust emissions. The International Agency for Research on Cancer (IARC), which is part of the World Health Organization, recently classified diesel engine exhaust as carcinogenic to humans, based on sufficient evidence that exposure is associated with an increased risk of lung cancer[14]. The absence of a clear threshold for health effects associated with fine particles has prompted support for more stringent air quality standards for fine particles and for the adoption of an exposure reduction approach which seeks to gradually reduce general exposures to fine particle concentrations. The 2011 review of the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) recommended the specification of air quality standards for $PM_{2.5}$ and the introduction of an exposure reduction framework for managing general exposures to fine particles[15].

Non-road diesel combustion also contributes significantly to global black carbon emissions. Black carbon is a strong absorber of solar radiation and has been concluded to exert a positive (warming) radiative forcing[16]. Due to its shorter atmospheric lifetime and strong global warming potential, strategies to reduce black carbon emissions have recently been identified by the US Environmental Protection Agency (US EPA) as being able to provide climate benefits within the next several decades.

The non-road diesel engine sector currently consumes about 70% as much diesel as road transport nationally, but is estimated to emit more fine particles due to non-road diesel engines having greater emission intensities (Section 2.4). Non-road diesel engine emissions are estimated to account for about 1.4% of total national PM_{10}[17] emissions from all sources (natural and anthropogenic), whereas on-road motor vehicles (all fuels) contribute an estimated 1% of national PM_{10} emissions.

An overview of the current regulatory framework in Australia pertaining to the non-road and on-road diesel sectors is given in Section 2.5, with further detail provided in Appendix B. Whereas the on-road diesel sector is subject to increasingly stringent national emission standards for new vehicles and to various state and territory implemented programs for in-service vehicles, no national regulations have been issued in Australia for the non-road diesel engines sector. Furthermore, emissions from in-service non-road diesel engines and equipment have remained largely unregulated and unaddressed, with the exception of regulations for underground mining equipment and the NSW Clean Machine Program (small-scale, voluntary program). NSW is the only state to implement such a program.

Non-road diesel engine emissions are regulated in North America and Europe and parts of Asia and South America with international trends including increased stringency of

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[14] IARC (2012)

[15] NEPC (2011a)

[16] Radiative forcing is the change in the energy balance between incoming solar radiation and exiting infrared radiation. Positive radiative forcing tends to warm the surface of the Earth, while negative forcing generally leads to cooling. A pollutant that increases the amount of energy in the Earth's climate system is said to exert *positive radiative forcing* (US EPA 2012).

[17] Particulate matter with an aerodynamic diameter of less than 10 µm.

emission standards, improved harmonisation and more extensive coverage of engine power rating ranges (Section 2.6). Emission reductions achieved through the control of non-road diesel engine emissions in the US and Europe are reported to have assisted in addressing local air quality problems in areas where air quality limits are not met (non-attainment areas)[18].

Australia does benefit somewhat from the importation of cleaner engines compliant with US, EU and other international emission standards; however, a review of the emission performance of new engines and equipment being sold into the Australian non-road diesel engine and equipment market indicates that a significant proportion of units are non-compliant or are lagging in compliance relative to units being sold into the US and EU (Section 2.7). Furthermore, the more costly nature of engines compliant with the latest, most stringent standards (i.e. US Tier 4 and EU Stage III B), due to their incorporation of aftertreatment technologies, is expected to impede the uptake of such engines in Australia. There is also a risk of potential emission increases if equipment manufactured in countries with less stringent or no emission standards increases market share in Australia.

Finally, a significant growth in the consumption of non-road diesel equipment and the number of units of in-service non-road diesel equipment is projected for the next two decades (Section 2.8). This growth will result in an increase in non-road diesel engine emissions and associated impacts, with the extent of this increase depending on the extent to which the increased activity is offset by improved emission performance. Given business as usual, projections indicate that the non-road diesel sector could be responsible for significant and growing health costs due to inhalation exposures to exhaust emissions (Section 2.9).

2.2 Overview of the non-road diesel engine sector

Diesel engines are not manufactured locally but rather imported into Australia, either as loose diesel engines or already incorporated into equipment. In terms of new diesel engines entering Australia, industry includes companies supplying loose diesel engines[19] and companies importing equipment and machinery which have diesel engines. Most loose diesel engines are sold to various local equipment manufacturers over which the original engine supplier has no control. Although some local equipment suppliers import equipment with engines already in place, some Original Equipment Manufacturers in Australia import engines directly from overseas manufacturers, thus bypassing traditional distributor channels within Australia.

The main market segments for the Australian non-road diesel industry reflect the applications of diesel engines/equipment and include: agriculture, construction and mining, general industrial, power generation, light commercial (pumps and compressors), airport service equipment, logging, commercial marine, and commercial lawn and garden equipment. Unlike on-road vehicles, the non-road diesel category applies to a very broad range of engine sizes, types of equipment, and power ratings. Diesel engine rated power ranges from 1 kW to over 1000 kW. The equipment in which the engines are used is extremely diverse, with often the same engine being used in widely varying equipment applications. For example, the same engine type used in a backhoe can also be used in a drill rig or in an air compressor.

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[18] US EPA (2004a)

[19] *Loose diesel engines* refers to engines sold for use in new equipment or as replacement engines for in-service equipment.

Approximately 50 companies manufacture non-road diesel engines worldwide[20]. Many companies involved in the non-road diesel industry are not vertically integrated; that is, they do not produce both engines and the equipment applications that the engines are used in. The implications of this have been that emission management measures adopted abroad need to address the ability of both engine manufacturers and equipment manufacturers to provide adequate new non-road machines.

A review of industry associations indicates that industry is organised into three main groupings, namely: 'loose' diesel engine suppliers, 'construction and mining' equipment suppliers, and agricultural ('tractor and machinery') equipment suppliers. It is notable that the 'construction and mining' equipment types supplied have wider applications which include industrial, commercial and forestry uses. The most pertinent industry associations are the Australian Diesel Engine Distributors Association (ADEDA), the Construction and Mining Equipment Industry Group (CMEIG), and the Tractor and Machinery Association of Australia (TMA).

A list of non-road diesel engine applications by market segment is provided in Table 1. This list does not necessarily represent all non-road diesel engine applications currently employed in Australia.

Over 700,000 non-road diesel engines are projected to be in-service in Australia in 2012 (refer to Section 4.4.2). According to Australian Bureau of Statistics (ABS) import statistics, more than 70,000 non-road diesel engines and equipment are imported into Australia annually, with imports originating from over 60 different countries[21]. Japan, the US and China are the largest sources, together accounting for approximately 67% of total imports across these equipment categories. Further information on equipment imports and exports, and the size and structure of the sector is provided in Appendix A.

2.3 Diesel exhaust emissions and impacts

Health and environmental risks of diesel exhaust emissions are influenced by the composition of the emissions and the particle size distribution of diesel particulate matter. This subsection provides an overview of the nature of diesel exhaust emissions and the major health and environmental impacts associated with non-road diesel engine emissions.

2.3.1 Diesel exhaust emissions

Primary products of diesel fuel combustion are carbon dioxide (CO_2), water and oxides of nitrogen (NO_x); however, diesel exhaust emissions comprise a mixture of other gases, vapours and particles resulting from incomplete combustion. NO_x and volatile organic compound (VOC) emissions released from engine/equipment exhausts are of interest both individually and as precursors of photochemical smog including ozone. Other emissions associated with non-road diesel engines and equipment include carbon monoxide (CO), sulfur dioxide (SO_2), carbonyl compounds (e.g. formaldehyde, acetaldehyde), polycyclic aromatic hydrocarbons, dioxins and furans, and a range of individual volatile and semi-volatile organic compounds including air toxics such as benzene, toluene and 1,3-butadiene. The exact composition of emissions depends on operational parameters such as speed, motor load, and engine and equipment type, in addition to fuel composition, ambient air temperature and relative humidity[22]. The sulfur content of diesel, for example, influences the extent of both the SO_2 and particulate sulfur emissions.

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[20] US EPA (2004a)

[21] ABS (2008)

[22] Davies & McGinn (2004), Hesterberg et al. (2011)

Table 1: Market segments and application categories for non-road diesel engines/equipment which are typically included in non-road diesel regulations abroad

Market segment	Applications		
Agriculture	• Agricultural tractors • Self propelled sprayers	• Combine harvesters • Cherry pickers/orchard harvesters	• Other agricultural equipment • Windrower tractors
Construction and mining(a)	• Pavers • Tampers/rammers • Plate compactors • Off highway tractors • Off highway trucks • Portable compressors • Surfacing equipment • Backhoe loaders	• Bore/drilling rigs • Rough terrain forklifts • Trenchers • Wheeled loaders • Wheeled dozers • Scrapers • Crushing equipment • Other construction equipment	• Excavators • Cranes • Graders • Dumpers/tenders • Crawler tractors • Skid steer loaders • Rollers • Crawler dozers/loaders/tractors
General industrial	• Aerial lifts • Forklifts • Sweepers/scrubbers • Generator set, welder	• Refrigeration/AC • Concrete/industrial saw • Crushing equipment • Signal board	• Concrete pumping equipment • Oil & gas processing equipment • Other general industrial equipment
Lawn and garden	• Lawn and garden tractors • Rear engine riding mowers	• Commercial mover • Wood splitters	• Chippers/stump grinders
Airport service equipment	• Ground power unit • Air conditioning / heater unit • Air starter unit • Push out tractors • Fork lift • Passenger buses	• Passenger stairs • Belt loader • Baggage tug / tractor • Cargo/container loader • Cargo delivery • Bobtail truck	• Catering/service truck • Lavatory truck; potable water truck • Fuel hydrant truck • Fuel tanker truck • Maintenance lift • Miscellaneous vehicles
Recreational marine(b)	• Pleasure cruisers	• Pleasure fishing boats	• Yachts / motor sailors
Commercial marine(b)	• Charter vessels • Ferries, tugs & barges	• Patrol boats	• Commercial fishing vessels & trawlers
Pumps and compressors (light commercial equipment)(c)	• Air compressor • Hydro power unit	• Pump • Gas compressor	• Pressure washer • Irrigation pumps
Power generation(c)	• Prime power	• Standby power	• Marine auxiliary
Logging equipment	• Chainsaws • Skidders	• Shredders	• Fellers

(a) US and EU non-road diesel engine emission regulations exclude underground mining equipment.

(b) US non-road diesel engine emission regulations only include marine engines below 37 kW (50 hp). EU non-road mobile machinery emission regulations include only ‘inland water vessels’ of specific sizes and applications.

(c) Depending on the power rating of the engines, a fraction of the applications indicated in the table such as air compressors, generator sets, hydropower units, irrigation sets, pumps and welders may be classified as stationary sources and therefore not subject to the US non-road diesel engine emission standards, which refer to mobile engines.

Diesel particulate matter (DPM) is complex and variable, encompassing a range of sizes and morphologies, and has numerous inorganic and organic chemical components depending on engine characteristics, operations and fuels. The composition of DPM varies markedly by engine type and condition, fuel, operating conditions, environmental conditions and exhaust aftertreatment. New technology DPM is very different in composition from traditional technology DPM[23]. DPM from older technology comprises carbon, ash and sulfate in addition to unburned oil and fuel. DPM from new technology is comprised mainly of sulfates and organic and elemental carbon.

Particles in DPM are mainly present in the sub-micrometre (µm) diameter range in two main size modes: nuclei mode (3–30 nanometres (nm) diameter, containing over 90% of the particle number but less than 1% of the particle mass), and accumulation mode (30–500 nm range, containing most of the particle mass). Approximately 80–95% of the particles in diesel exhaust by mass is below 1.0 µm in diameter, with a mean particle diameter of about 0.2 µm[24]. Following its release DPM has a longer atmospheric residence time (days to weeks) compared to coarser particles. Coagulation, comprising a process of collision and adhesion of particles to form much larger particles, represents the primary mechanism for removing nuclei mode particles from the atmosphere[25]. Rainout (removal through incorporation into raindrops as condensation nuclei) and washout (removal by raindrops) represent the main mechanisms for removing accumulation mode particles.

Diesel exhaust emissions also contribute to secondary pollutants formed in the atmosphere from chemical reactions involving the primary pollutants released. Secondary pollutants from diesel combustion exhaust emissions include a wide range of secondary organic aerosols formed in the atmosphere through reactions of gas-phase organics, inorganic aerosols such as nitrates and sulfates, and ozone formed from VOC and NO_x precursors. The formation of secondary pollutants is regionally specific, depending on the local levels of other air pollutants and the specific meteorological conditions. In some countries the impacts of secondary pollutants are higher in rural areas, possibly due to secondary pollutants forming over time and distance in the atmosphere and manifesting at distances away from the source[26].

2.3.2 Health risks

Diesel particulate matter represents a significant health risk due to the small size and chemical composition of the particles. Fine particles with an equivalent aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$) are considered a greater health risk than larger particles, as fine particles are more readily deposited in, and damaging to, the lower airways and gas-exchanging portions of the lung[27]. DPM represents a component of $PM_{2.5}$. The composition of diesel particles includes elemental carbon with adsorbed compounds such as polycyclic aromatic hydrocarbons, sulfates, nitrates, heavy metals and other trace elements.

Adverse health effects related to inhalation of fine particulate matter include exacerbation of existing pulmonary diseases, oxidative stress and inflammation, changes in cardiac autonomic functions and reduced defence mechanisms, and lung damage[28]. Significant health costs are associated with inhalational exposure of fine particulate matter[29].

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[23] Davies & McGinn (2004), Hesterberg et al. (2011), Holgate et al. (2002)

[24] US EPA (2002)

[25] Friedlander (1977)

[26] PAE Holmes (2013)

[27] US EPA (2009)

[28] Pope & Dockery (2006)

[29] BTRE (2005)

Acute effects associated with exposure to diesel exhaust emissions are reported to include eye, nose, throat and lung irritation, neurological effects, cough, nausea, asthma exacerbation and enhanced allergic sensitisation. Chronic effects include lung inflammation and cellular changes in the lung, immunological effects, and respiratory and cardiovascular effects[30]. Various factors influence the likelihood, nature and extent of health effects from exposure to diesel exhaust emissions, including the susceptibility of persons exposed, and the magnitude and duration of exposure.

In June 2012 the IARC reclassified diesel engine exhaust as carcinogenic to humans (Group 1 carcinogen), based on sufficient evidence that exposure is associated with an increased risk of lung cancer[31]. The IARC Working Group also noted a positive association (limited evidence) between diesel engine exhaust and an increased risk of bladder cancer.

NO_x emissions from non-road diesel engines contribute to photochemical smog, notably ground level ozone. Ozone exposures can induce serious respiratory tract responses including reduction in lung function, aggravation of pre-existing respiratory diseases (such as asthma), increases in daily hospital admissions, emergency department visits for respiratory causes, and excess mortality[32].

2.3.3 Urban air pollution and environmental risks

Non-road diesel exhaust emissions contribute to urban ambient air pollution, and are associated with a range of environmental risks including soiling of materials, potential impacts on fauna, visibility impairment and climate change.

While urban air quality in Australia is generally good, the AAQ NEPM goals for fine particles and ozone are exceeded in parts of Australia. Levels of CO, NO_2, SO_2 and lead in urban air are generally below the national standards, and decreased or remained steady in the period from 1999 to 2008; but ozone and particle levels did not decline and exceeded the national standards in some Australian cities and regions[33]. Given that road transport and industrial sources of PM and NO_x (a precursor of ozone) are already well regulated, increasing attention is being paid to the contribution of more diffuse sources of such pollutants, including non-road diesel combustion.

Non-road diesel engines and equipment emit CO_2, a greenhouse gas which contributes to atmospheric warming, and associated global climatic changes. Diesel combustion is also responsible for about 30% of the black carbon emitted on a global basis[34]. Black carbon is an air pollutant formed through the incomplete combustion of fossil fuels, biofuel and biomass. Black carbon is a strong absorber of solar radiation and has been determined to exert a positive (warming) radiative forcing[35]. The effect of black carbon aerosols is enhanced when combined with dust and other chemicals in air. These black carbon mixtures are conjectured to be the second biggest contributor to global warming, representing about 60% of the global warming effects of CO_2[36].

Despite some remaining uncertainties about black carbon, the US EPA recently concluded that the available scientific information provides a strong foundation for making mitigation decisions regarding black carbon, to achieve benefits for public health, the

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[30] AIOH (2007), US EPA (2002)

[31] IARC (2012)

[32] WHO (2003)

[33] DSEWPaC (2010)

[34] Bond et al. (2004)

[35] DEFRA (2007)

[36] Roberts & Jones (2004)

environment, and climate[37]. Due to its shorter atmospheric lifetime relative to other greenhouse gases and its strong global warming potential, targeted strategies to reduce black carbon emissions have recently been identified as being able to provide climate benefits within the next several decades[38]. In October 2012, Australia became a partner in the Climate and Clean Air Coalition; an alliance of approximately 60 nations, intergovernmental organisations, the private sector and civil society, committed to rapid action to reduce short-lived but highly potent pollution caused by methane, black carbon, tropospheric ozone and hydrofluorocarbons[39].

2.4 Contribution of non-road diesel emissions relative to other sources

Table 2 shows the contribution of non-road diesel engines/equipment to total national emissions of PM_{10}, NO_x and VOCs for 2010–11 and compares this with on-road motor vehicle emissions (all fuels).

Table 2: Contribution of on-road vehicle emissions (all fuels) and non-road diesel emissions to total national emissions[(a)]

Emission source	Data source	PM_{10} (tonnes/year)	NO_x (tonnes/year)	VOC (tonnes/year)
All sources	NPI	1,267,901	1,403,465	3,150,793
On-road motor vehicles[(b)(c)] [% of all sources]	NPI	12,270 [1%]	337,179 [24%]	233,106 [7.4%]
Non-road diesel engines/ equipment[(d)] [% of all sources]	ENVIRON estimate	17,930 [1.4%]	158,733 [11%]	16,851 [1%]

[(a)] On-road motor vehicle emissions given in the table are drawn from the National Pollutant Inventory (NPI). In interpreting and using the NPI figures, reference should be made to NPI records which document the emission estimation methodologies applied and the uncertainties and limitations of methods and data inputs.

[(b)] Includes vehicles of all fuel types including both petrol and diesel vehicles.

[(c)] Emission estimate for on-road motor vehicles is for urban airsheds only and does not represent a national estimate for on-road engines.

[(d)] Includes emissions from construction and mining, lawn and garden, airport service, recreational, light commercial, industrial, agricultural and logging diesel equipment in addition to some commercial marine engines. Excludes emissions from larger (greater than 37 kW) marine engines, aircraft engines and all diesel locomotives.

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[37] US EPA (2012)

[38] US EPA (2012), UNEP & WMO (2011)

[39] DCCEE (2012), www.unep.org/ccac

The NPI on-road vehicle emission estimates include emissions from both petrol and diesel powered vehicles. The on-road particulate emissions reported are primarily due to diesel-powered vehicles[40], with the gaseous releases (i.e. NO_x and VOCs) representing contributions from both petrol and diesel vehicles.

PM_{10} emissions from total non-road diesel engines are estimated to be about 46% higher than emissions from the urban on-road vehicles sector (Table 2). Non-road diesel engines (excluding rail and marine) annually consume volumes of automotive diesel oil (ADO) equivalent to approximately 70% of road transport ADO consumption (Figure 1); however, non-road diesel engines/equipment emit higher amounts of PM per litre of fuel burned[41]. Nationally, non-road diesel engine emissions of NO_x and VOCs are estimated to comprise about 47% and 7%, respectively, of the emissions emitted by urban on-road (diesel and petrol) vehicles (Table 2).

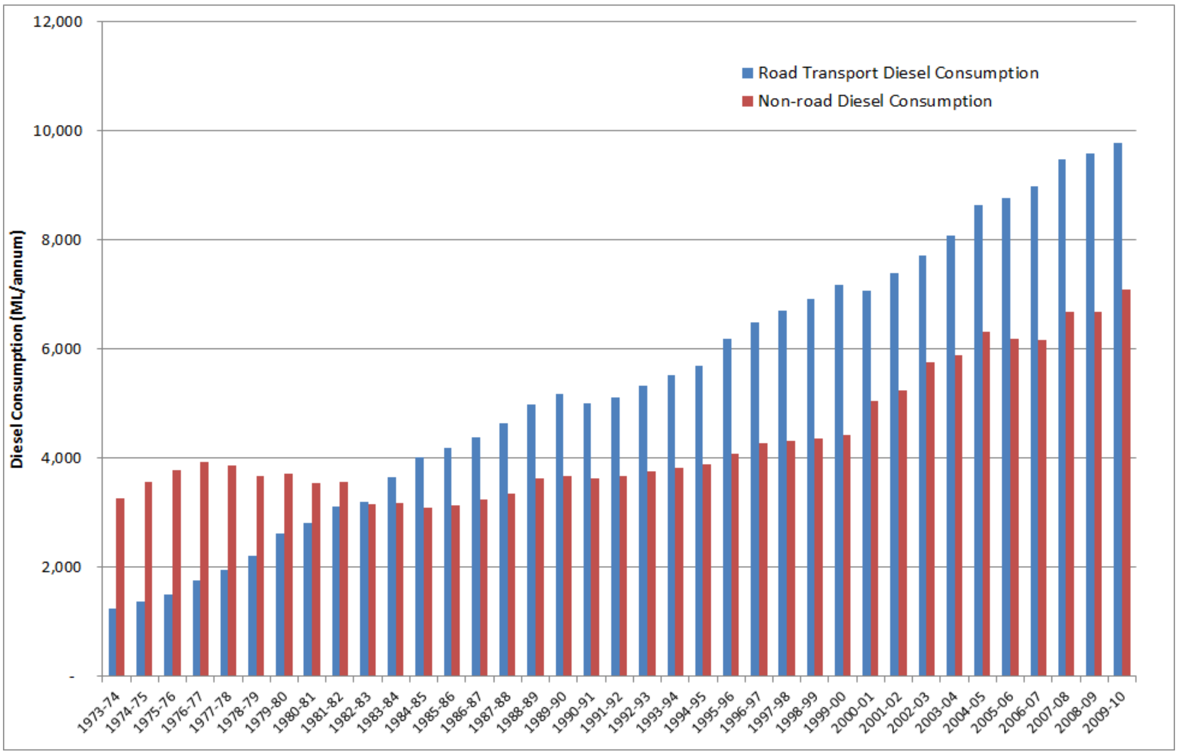

Figure 1: **On-road and non-road (excluding rail locomotives and large marine engines) diesel consumption (1973–74 to 2009–10)[42]**

National emissions information is inadequate to assess non-road diesel engine contributions to $PM_{2.5}$ emissions. Reference is therefore made to the NSW Greater Metropolitan Region (GMR) Emissions Inventory released for base year 2008[43]. However, the overall significance of the non-road diesel sector would be underestimated within the NSW GMR Emissions Inventory, given that the NSW GMR does not cover a significant proportion of mining, agricultural and forestry non-road diesel applications within NSW.

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[40] Particulate emissions for diesel-driven, on-road passenger vehicles are at least 30 times greater than petrol-driven on-road passenger vehicles per volume of fuel (Environment Australia 2008).

[41] DEWHA (2008)

[42] DAFF (2011)

[43] NSW EPA (2012a)

In the 2008 NSW GMR Emissions Inventory, non-road diesel engines and equipment account for 5.3% of total NSW GMR $PM_{2.5}$ emissions and 9.6% of total NSW GMR NO_x emissions (Table 3). $PM_{2.5}$ emissions released from such non-road diesel mobile equipment are equivalent to total on-road mobile emissions (including petrol and diesel vehicles), with NO_x and VOC emissions equivalent to about 50% and 10% of the emissions from the on-road mobile sector, respectively.

Heavy duty non-road diesel vehicles and equipment, which consume the majority of the non-road diesel fuel within the NSW GMR, are estimated to have a $PM_{2.5}$ emission intensity approximately six times higher than that of the on-road diesel vehicle fleet (Table 4). The $PM_{2.5}$ emission intensity calculated across the entire national non-road diesel sector for 2012 (2.5 grams per litre (g/L)) is estimated to be five times higher than the emission intensity given for the NSW GMR on-road sector (0.5 g/L). This means that for every litre of fuel combusted, non-road diesel engines emit five times more $PM_{2.5}$ when compared to on-road diesel vehicles.

Table 3: Contribution of on-road vehicle emissions (all fuels) and non-road diesel emissions to total emissions within the NSW Greater Metropolitan Region (2008)[44]

	Annual emissions (tonnes/annum)			
Pollutant	**Non-road mobile[(a)] [% of total]**	**On-road mobile [% of total]**	**Non-road mobile[(a)] as % of on-road mobile emissions**	**Total**
PM_{10}	2,116 [1.7%]	2,793 [2.3%]	76%	123,457
$PM_{2.5}$	2,053 [5.3%]	2,071 [5.3%]	99%	39,082
NO_x	30,491 [9.6%]	60,932 [19.1%]	50%	319,155
SO_2	63 [0.02%]	269 [0.09%]	24%	289,237
VOC	3,037 [1%]	29,504 [9.6%]	10%	306,595

(a) Non-road mobile emission figures given only for non-diesel engines and equipment used for airport ground operations and commercial, industrial and mining off-road vehicles and equipment. They exclude locomotives, shipping and marine diesel engines.

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[44] NSW EPA (2012b), (2012c)

Table 4: $PM_{2.5}$ emission intensity of non-road and on-road vehicles and equipment based on the NSW Greater Metropolitan Region (2008)[45]

Type	Source	$PM_{2.5}$ emission intensity (g/L)
Non-road[(a)]	Coal mining vehicles and equipment	2.73
	Other industrial vehicles and equipment (excluding coal mining)	2.86
	Aircraft (ground operations)	0.60
	Commercial boats	0.75
	Commercial off-road vehicles and equipment	3.26
	Recreational boats	1.56
On-road	Light and heavy on-road diesel vehicles	0.48

(a) Non-road diesel engine figures exclude locomotives, shipping and large marine diesel engines.

2.5 Current regulatory framework and programs in Australia

The current regulatory framework for non-road diesel engines in Australia primarily includes specifications for fuel quality and the regulation of ambient air quality. Whereas emission standards are applied for on-road vehicles in Australia, no emission standards have been issued for non-road diesel vehicles and equipment. The national Energy Efficiency Opportunities (EEO) program, administered by the Commonwealth Department of Resources, Energy and Tourism also indirectly impacts on diesel consumption for large emitters. Further discussion on components of the current regulatory framework in Australia relevant to non-road diesel engine emissions is given in subsequent subsections. Reference is also made to emission standards and emission reduction measures implemented for on-road vehicles. Standards and measures for diesel engines used in underground mining are provided, for comparison, in Appendix C.

2.5.1 Fuel quality specifications

The non-road diesel sector is reported to use mainly automotive diesel oil (ADO)[46]. During the 1970s, industrial diesel fuel (IDF) consumption was reported to account for approximately 26% of non-road diesel consumption nationally; however, IDF consumption gradually reduced over subsequent years, comprising only 0.5% of non-road diesel consumption by 1998[47]. Consequently, no distinction is made between IDF and ADO within national diesel consumption reporting in more recent years.

The quality of fuel in Australia is regulated by the *Fuel Quality Standards Act 2000* and the Fuel Quality Standards Regulations 2001. This legislation places an obligation on the fuel industry, including fuel suppliers, to supply fuels that meet strict environmental requirements[48]. The Fuel Standard (Automotive Diesel) Determination 2001, incorporating the Fuel Standard (Automotive Diesel) Amendment Determination 2009 (No. 1), limits the sulfur, ash, polycyclic aromatic hydrocarbon and biodiesel content of ADO. The maximum sulfur limit of diesel has gradually been reduced from 500 parts per million (ppm) to 10 ppm. Reducing the sulfur content reduces the emission rate of particles and SO_2, and makes it possible to use aftertreatment equipment on diesel engines.

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[45] NSW EPA (2012b), (2012c)

[46] DAFF (2011)

[47] DAFF (2011)

[48] www.environment.gov.au/atmosphere/fuelquality/index.html

2.5.2 Ambient air quality regulations

The National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) sets national ambient air quality standards for six common pollutants, namely particles (PM_{10}), ozone, SO_2, NO_2, CO and lead. There are currently Advisory Reporting Standards for $PM_{2.5}$. $PM_{2.5}$ standards are more relevant than PM_{10} standards in addressing DPM, since DPM is primarily in the fine particulate fraction.

The current approach to air quality management in Australia focuses on reducing exceedances of ambient air quality standards at specific locations. The standards are designed to be protective of health; however, for PM, evidence indicates that there is no clear threshold for health effects. Therefore, while PM concentrations in Australian cities are significantly below the standards most of the time, health costs are driven by large-scale exposure to relatively low pollution levels[49].

2.5.3 On-road vehicle regulations

Emission standards for new vehicles are set by Australian Design Rules (ADRs) which are national standards under the *Motor Vehicle Standards Act 1989*. Ongoing tightening of ADRs over the last 20 years has resulted in significant reductions in emissions of lead, CO, NO_x, hydrocarbons and particles[50]. Australian on-road vehicle emission and fuel quality standards have been progressively tightened to require more sophisticated vehicle engine and emission-control systems and improved fuel quality. Recent improvements in fuel quality have focused on significantly reducing sulfur content[51] and lowering the volatility of fuels to reduce evaporative losses, which represent a major source of VOCs.

Euro 5 emission standards (EU emission standards for light vehicles) are being adopted in Australia and apply to all new-model vehicles from 1 November 2013, with existing models to comply from 1 November 2016. All new-model vehicles must comply with Euro 6 standards from 1 July 2017. Existing model vehicles must meet Euro 6 standards from 1 July 2018. The implementation of Euro 5/6 light vehicle standards is projected to achieve significant further reductions in NO_x emissions from petrol vehicles, and hydrocarbons, PM and NO_x emissions from diesel vehicles. These improvements, together with the earlier introduction of Euro 3 and Euro 4 standards are expected to continue to counter the effect of further growth in vehicle numbers and distances travelled[52]. The adoption of Euro 6 emission standards for heavy vehicles is also being considered[53].

The National Environment Protection (Diesel Vehicle Emissions) Measure was established in 2001 to reduce exhaust emissions from diesel vehicles. Unlike the ADRs that set standards for new petrol and diesel vehicles, the diesel emissions NEPM targets in-service vehicles (which are a state responsibility), establishing a range of strategies for governments to employ to reduce emissions[54]. Guidelines are provided for the Smoky Vehicle Program, Emission Testing and Repair Program, Audited Maintenance Program and Diesel Vehicle Retrofit Program. Programs being implemented by state and territory governments under the diesel emissions NEPM are listed in Appendix B.

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[49] Australian State of the Environment Committee (2011)

[50] DSEWPaC (2011)

[51] Reductions in sulfur content are particularly important for diesel engines, since high sulfur levels prevent the use of catalytic particle filters and NO_x adsorbers for on-road vehicles.

[52] BITRE (2010)

[53] www.infrastructure.gov.au/roads/environment/index.aspx

[54] DIT (2010a)

2.5.4 Non-road diesel emission programs by states

While most states implement a range of programs targeting on-road engine emissions, NSW is the only state in Australia which reports initiatives relating to non-road diesel engines. The NSW Clean Machine Program, initiated in 2010, aims to reduce diesel exhaust emissions from new and in-service diesel plant and equipment used mainly in construction and industrial activities, such as cranes, dozers, loaders, graders, tractors and pumps.

The NSW Environment Protection Authority partners with public-sector and private-sector organisations to implement the Clean Machine Program through improved procurement practices, worksite guidelines and the subsidised retrofit of older engines with emission reduction devices. The Clean Machine Program targets owners and operators of diesel plant and equipment which conform to older overseas emission standards and are well utilised. The NSW Government is providing a 50–90% subsidy to eligible engines. The focus of this program is primarily on cleaning up in-service equipment contributing to particulate emissions within the GMR. As at May 2013, more than 25 organisations had participated in the program and over 80 machines had been retrofitted with diesel particulate filters.

2.5.5 Energy Efficiency Opportunities program

Non-road diesel equipment may be indirectly regulated through the Energy Efficiency Opportunities (EEO) program[55] administered by the Commonwealth Department of Resources, Energy and Tourism. This program requires businesses to identify, evaluate and report publicly on cost effective energy savings opportunities. For companies that consume diesel, the EEO represents a driver for identification of improvements targeting reduced diesel consumption, and hence reduced diesel fuel combustion related emissions. Case studies have, for example, been published on measures to reduce diesel consumption from diesel-powered haul trucks within the mining industry[56].

2.5.6 Regulation of diesel emissions and exposures in underground mining

Diesel exhaust emissions within the underground mining sector have prompted greater regulatory focus due to the potential for significant occupational risk due to confined work environments. Although non-road diesel equipment used in underground mining is beyond the scope of this report, it is worth noting the significant developments in the regulation of diesel engine exhaust within underground mining applications. Approaches to address diesel emission exposures underground include diesel engine and fuel quality requirements, ventilation provisions and personal exposure limits. Further information on the regulation of diesel exhaust emissions within underground mining is given in Appendix C.

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[55] The program's requirements are legislated in the *Energy Efficiency Opportunities Act 2006* and Energy Efficiency Opportunities Regulations 2006.

[56] *Energy Efficiency Opportunities Case Study: Analyses of Diesel Use for Mine Haul and Transport Operations*, http://eeo.govspace.gov.au/files/2012/11/Analyses-of-Diesel-Use-for-Mine-Haul-and-Transport-Operations.pdf

2.6 Management of non-road diesel engine emissions overseas

2.6.1 Non-road diesel engine regulations

As discussed, there are no regulations currently in place in Australia that limit emissions from non-road diesel engines and equipment; however, as all diesel engines are manufactured in other countries, the standards and regulations imposed in these countries influence the standard of engines available in Australia.

Non-road diesel engine emission regulations applied internationally are typically applicable for new equipment and in some cases replacement engines. Emission standards regulate pollutants released at the exhaust manifold and do not include evaporative emissions from the vehicle.

International trends in non-road diesel emission standards include:

- an increase in the number of countries promulgating non-road diesel emission standards
- growing harmonisation of non-road diesel engine emission standards
- an increase in the power rating ranges covered by standards, and
- introduction of increasingly stringent standards.

Regulations for non-road diesel equipment have been introduced in the US (1994), Europe (1997), Canada (2005), Japan (2006), India (2006), China (2007) and Brazil (2011). Emission standards for non-road diesel engines/equipment are also applied in Russia and are proposed for adoption in South Korea. Such standards apply primarily to new engines and equipment.

US emission standards (expressed as Tier 1 to Tier 4) and EU emission standards (Stage I to Stage IV) are the most widely referenced and applied emission standards for non-road diesel engines. US emission standards are relevant given that a significant portion of the engines sold into the Australian non-road diesel market are manufactured in the US or in countries which have implemented US standards (refer to Appendix A).

The applicability of the EU standards has been highlighted by submissions received previously from the Australian Diesel Engine Distributors Association (ADEDA)[57]. ADEDA noted that Australia is a signatory to the 1958 Geneva Convention of the High Seas, the Australian Government having re-ratified the convention in 2008. This convention emphasises uniform conditions of approval, aiming to avoid duplication of compliance standards and specifically stipulates that Australian Standards be based on the corresponding EU model. Furthermore, Australian on-road emission standards are based on the comparable EU model.

Given that US and EU emission standards are referenced within the potential actions considered within this report, more detailed information on these standards is provided in the following sections.

United States emission standards

US non-road diesel emission standards are generally applicable to mobile non-road diesel engines of all sizes used in a wide range of construction, agricultural and industrial equipment. The US EPA definition of the non-road engine is based on the principle of mobility and includes engines installed on (a) self-propelled equipment, (b) equipment that

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[57] ENVIRON (2010)

is propelled while performing its function, or (c) equipment that is portable or transportable, as indicated by the presence of wheels, skids, carrying handles, a dolly, trailer or platform[58].

US non-road emission standards are based on engine horsepower (hp) and model year[59]. US federal standards (Tier 1) were first implemented for new non-road diesel engines in 1994 for engines over 37 kW, to be phased-in from 1996 to 2000. In 1998, a regulation was passed introducing Tier 1 standards for equipment under 37 kW and more stringent Tier 2 and Tier 3 standards for all other equipment, with phased-in schedules from 2000 to 2008[60].

Tier 2 and Tier 3 standards are met through advanced engine design, with either no or only limited use of exhaust gas aftertreatment. Tier 3 standards for NO_x and hydrocarbons (HC) are similar in stringency to the 2004 standards for highway engines. Tier 3 standards were not adopted for PM, with compliance with Tier 2 emission standards for PM continuing, until finally being replaced by Tier 4 standards.

Tier 4 emission standards were introduced in 2004 as part of the US *Clean Air Non-road Diesel – Tier 4 Final Rule*[61]. This marked a shift towards the integration of engine and fuel control measures to further cost-optimise emission reductions from non-road diesel engines. Tier 4 emission standards are to be phased-in over the period 2008 to 2015. The initial set of Tier 4 emission standards, implementable from 2008 onwards, are termed Tier 4a, Tier 4i or Tier 4 interim standards. Tier 4 emission standards implementable from 2011 onwards are more stringent and are termed Tier 4b, Tier 4ii or Tier 4 final standards. Compliance with Tier 4 final standards requires that emissions of PM and NO_x be further reduced to about 90% compared to non-compliant engines. Tier 4 final emission standards can be achieved through the use of control technologies, including advanced exhaust gas aftertreatment, similar to those required by the 2007–2010 standards for highway engines.

The sulfur content of non-road diesel fuels was not limited by environmental regulations during the Tier 1 to Tier 3 stages. At that time, the oil industry specification was 0.5% (maximum, by weight), with the average in-use sulfur level being in the range of 0.3% (3000 ppm). Tier 4 engines, which incorporate sulfur-sensitive control technologies such as catalytic particulate filters and NO_x adsorbers, necessitated the mandated reduction of sulfur content in non-road diesel fuels. The sulfur content of diesel used by non-road diesel engines was reduced to 500 ppm in 2007, and further reduced to 15 ppm (ultra-low sulfur diesel) in 2010.

US Tier 1 to Tier 3 emission standards, expressed in grams of pollutant per kWh, are listed in Table 5. US Tier 4 emission standards are given in Table 6 for engines up to 560 kW, and in Table 7 for larger engines including generator sets greater than 900 kW.

The Tier 1 emission standards for non-methane hydrocarbons (NMHCs) plus NO_x and PM standards are approximately 15–50% lower than the uncontrolled levels. Tier 1 to Tier 2 emission standards reflected a 70% reduction in CO for greater than 130 kW engine sizes, a 30% reduction in NMHC and NO_x, and a 20–60% reduction in PM emissions. The shift from Tier 2 to Tier 3 emission standards introduced a further 40% reduction in NMHC and NO_x emissions.

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[58] Effective 14 May 2003, the definition of non-road engines was changed to also include all diesel powered engines, including stationary ones, used in agricultural operations in California. This change applies only to engines sold in the state of California, with stationary engines sold in other states not classified as non-road engines.

[59] US Code of Federal Regulations, Title 40, Part 89 *[40 CFR Part 89]*.

[60] US Code of Federal Regulations, Title 40, Part 89 *[40 CFR Part 89]*.

[61] www.gpo.gov/fdsys/pkg/FR-2004-06-29/pdf/04-11293.pdf

Tier 4 emission standards make provision for the following reductions compared to Tier 1 emission standards:

- 95% reduction in NO_x for engines less than 560 kW and 60% reduction for larger engines
- 85% reduction in HC for engines less than 560 kW and 70% reduction for larger engines, and
- 50–60% reduction in PM during first phase (2008), and 80–95% reduction in second phase (2013–2015).

Tier 4 emission standards for CO remain unchanged from the Tier 2 and Tier 3 standards.

As an alternative to introducing the required percentage of Tier 4 compliant engines, manufacturers in the US may certify all their engines to an alternative NO_x limit in each model year during the phase-in period. Reference should be made to the US *Clean Air Non-road Diesel – Tier 4 Final Rule*[62] for the alternative options.

US emission standards also make provisions for averaging, banking and trading of emission credits and maximum 'family emission limits' for emission averaging.

US emission standards are applicable over the useful life of the engine. The US EPA requires the application of deterioration factors to all engines covered by the rule. These factors are applied to the certification emission test data to represent emissions at the end of the useful life of the engine. The useful life is given as five years (3000 hours) for all less than 19 kW and constant speed 19–37 kW engines (greater than 3000 rpm) and as seven years (5000 hours) for all other 19–37 kW engines. The useful life of engines greater than 37 kW is given as 10 years (8000 hours). It should be noted that due to the nature of their design, diesel engines are long-lived and would be expected to be in operation beyond the above definition of 'useful life'.

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[62] www.gpo.gov/fdsys/pkg/FR-2004-06-29/pdf/04-11293.pdf

Table 5: US EPA Tier 1 to Tier 3 non-road diesel engine emission standards (g/kWh)

Engine power	Tier	Year	CO	HC(a)	NMHC(b)+NO$_x$	NO$_x$	PM(c)
<8kW (<11hp)	Tier 1	2000	8	–	10.5	–	1
	Tier 2	2005	8	–	7.5	–	0.8
≥8kW to <19kW (≥11hp to <25hp)	Tier 1	2000	6.6	–	9.5	–	0.8
	Tier 2	2005	6.6	–	7.5	–	0.8
≥19kW to <37kW (≥25hp to <50hp)	Tier 1	1999	5.5	–	9.5	–	0.8
	Tier 2	2004	5.5	–	7.5	–	0.6
≥37kW to <75kW (≥50hp to <100hp)	Tier 1	1998	-	–	–	9.2	–
	Tier 2	2004	5	–	7.5	–	0.4
	Tier 3	2008	5	–	4.7	–	(d)
≥75kW to <130kW (≥100hp to <175hp)	Tier 1	1997	-	–	–	9.2	–
	Tier 2	2003	5	–	6.6	–	0.3
	Tier 3	2007	5	–	4	–	(d)
≥130kW to <225kW (≥175hp to <300hp)	Tier 1	1996	11.4	1.3	–	9.2	0.54
	Tier 2	2003	3.5	–	6.6	–	0.2
	Tier 3	2006	3.5	–	4	–	(d)
≥225kW to <450kW (≥300hp to <600kW)	Tier 1	1996	11.4	1.3	–	9.2	0.54
	Tier 2	2001	3.5	–	6.4	–	0.2
	Tier 3	2006	3.5	–	4	–	(d)
≥450kW to <560kW (≥600hp to <750hp)	Tier 1	1996	11.4	1.3	–	9.2	0.54
	Tier 2	2002	3.5	–	6.4	–	0.2
	Tier 3	2006	3.5	–	4	–	(d)
≥560kW (≥750hp)	Tier 1	2000	11.4	1.3	–	9.2	0.54
	Tier 2	2006	3.5	–	6.4	–	0.2

(a) HC – hydrocarbon

(b) NMHC – non-methane hydrocarbon

(c) PM – particulate matter. Particle size fraction not indicated in the standard, but diesel emissions are primarily in the fine fraction, i.e. below 2.5 µm.

(d) Not adopted, engines must meet the Tier 2 PM standard.

Table 6: US EPA Tier 4 emission standards for engines up to 560 kW (g/kWh)[(a)]

Engine power	Year	CO	NMHC	NMHC+NO_x	NO_x	PM[(b)]
<8kW (<11hp)	2008	8	–	7.5	–	0.4[(c)]
≥8kW to <19kW (≥11hp to <25hp)	2008	6.6	–	7.5	–	0.4
≥19kW to <37kW (≥25hp to <50hp)	2008	5.5	–	7.5	–	0.3
	2013	5.5	–	4.7	–	0.03
≥37kW to <56kW (≥50hp to <75hp)	2008	5	–	4.7	–	0.3[(d)]
	2013	5	–	4.7	–	0.03
≥56kW to <130kW (≥75hp to <175hp)	2012–2014[(e)]	5	0.19	–	0.4	0.02
≥130 kW to ≤560kW (≥175hp to ≤750hp)	2011–2014[(f)]	3.5	0.19	–	0.4	0.02

[(a)] The initial set of Tier 4 emission standards, which came into force in 2008, are termed Tier 4a, Tier 4i or Tier 4 interim standards. Tier 4 emission standards in force from 2011 onwards are more stringent and are termed Tier 4b, Tier 4ii or Tier 4 final standards.

[(b)] Particle size fraction not indicated in the standard, but diesel emissions are primarily in the fine fraction, i.e. below 2.5 µm.

[(c)] Hand start, air-cooled, direct injection engines may be certified to Tier 2 standards until 2009 and to an optional PM standard of 0.6 g/kWh starting in 2010.

[(d)] 0.4 g/kWh (Tier 2) if manufacturer complies with the 0.03 g/kWh standard from 2012.

[(e)] PM/CO: full compliance from 2012; NO_x/HC: Option 1 (if banked Tier 2 credits used) – 50% of engines must comply in 2012–13; Option 2 (if no Tier 2 credits claimed) – 25% of engines must comply in 2012–2014, with full compliance from the end of 2014.

[(f)] PM/CO: full compliance from 2011; NO_x/HC: 50% of engines must comply in 2011–2013.

Table 7: US EPA Tier 4 emission standards for engines above 560 kW (g/kWh)

Year	Category	CO	NMHC	NO_x	PM[(a)]
2011–2014	Generator sets >900 kW	3.5	0.40	0.67	0.10
	All engines except generators (gen sets) >900 kW	3.5	0.40	3.5	0.10
2015	Generator sets	3.5	0.19	0.67	0.03
	All engines except generators (gen sets)	3.5	0.19	3.5	0.04

[(a)] Particle size fraction not indicated in the standard, but diesel emissions are primarily in the fine fraction, i.e. below 2.5 µm.

European Union emission standards

Australia imports engines from various European countries including the United Kingdom, Germany, France, Sweden and Italy.

Non-road mobile equipment regulations were first promulgated in the EU in 1997[63], with non-road diesel standards for new diesel engines introduced in two stages: Stage I implemented in 1999 and Stage II implemented from 2001 to 2004 (depending on the engine power output) (Table 8). Directive 97/68/EC is termed the EU 1997 Non-Road Mobile Machinery (NRMM) Directive. Although this initial directive covered emissions from variable speed diesel engines in equipment such as excavators, dozers, loaders and backhoes, it was intended to be extended to almost all engines used for mobile applications that are not subject to vehicle approval requirements. This would represent an extension to include small mobile machinery, such as garden equipment, generators and welders, construction machinery, industrial trucks, forklifts and mobile cranes.

Directive 2000/25/EC amended the 1997 Directive to include agricultural and forestry tractors, which were covered by the same emission standards but given different implementation dates. Engines used in ships, railway locomotives, aircraft and generating sets are not covered by the EU Stage I and II standards.

Directive 2002/88/EC amended the 1997 Directive to further reduce diesel engine emissions in general non-road application to reflect technological developments. This Directive also extended the scope of non-road engine regulation to include engines in inland waterway vessels, constant speed diesel engines, and imports of used engines. The utility engine emission standards incorporated are largely aligned with US emission standards for small utility engines.

Directive 2004/26/EC introduced Stage III and IV emission standards for non-road engines. Such standards were adopted for agricultural and forestry tractors in 2005 (2005/13/EC) (Table 8). Stage III standards were phased-in over the period 2006 to 2013, with Stage IV standards entering into force in 2014.

Stage III and IV emission standards apply only to new engines. Replacement engines to be used in machinery already in use (except for some large engines such as inland waterway vessel propulsion engines) are required to comply with the standards which were in place when the engine to be replaced was placed on the market.

Stage III B standards introduced a PM limit of 0.025 g/kWh, representing about a 90% emission reduction relative to Stage II. To meet this limit value, engines have to be equipped with particulate filters. Stage IV also introduces a very stringent NO_x limit of 0.4 g/kWh, which is expected to require NO_x aftertreatment.

To determine compliance with EU emission standards, emissions have been measured on the ISO 8178 C1 8-mode cycle (termed the Non-road Steady Cycle, NRSC) and expressed in g/kWh. Stage I and II engines are tested using fuel of 0.1–0.2% by weight sulfur content (equivalent to 1000–2000 ppm sulfur).

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[63] Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery.

Table 8: EU emission standards for non-road diesel engines

Stage I/II emission standards						
Cat.	**Net power**	**Implementation date (year.month)**	**CO**	**HC**	**NO_x**	**PM(b)**
	kW		g/kWh			
Stage I						
A	P(a) ≥130 to ≤560	1999.01	5.0	1.3	9.2	0.54
B	P ≥75 to <130	1999.01	5.0	1.3	9.2	0.70
C	P ≥37 to <75	1999.04	6.5	1.3	9.2	0.85
Stage II(c)						
E	P ≥130 to ≤560	2002.01	3.5	1.0	6.0	0.2
F	P ≥75 to <130	2003.01	5.0	1.0	6.0	0.3
G	P ≥37 to <75	2004.01	5.0	1.3	7.0	0.4
D	P ≥18 to <37	2001.01	5.5	1.5	8.0	0.8
Stage III A emission standards						
Cat.	**Net Power**	**Date(d)**	**CO**	**NO_x+HC**		**PM(b)**
	kW		g/kWh			
H	P ≥130 to ≤560	2006.01	3.5	4.0		0.2
I	P ≥75 to <130	2007.01	5.0	4.0		0.3
J	P ≥37 to <75	2008.01	5.0	4.7		0.4
K	P ≥19 to <37	2007.01	5.5	7.5		0.6
Stage III B emission standards						
Cat.	**Net Power**	**Date**	**CO**	**HC**	**NO_x**	**PM(b)**
	kW		g/kWh			
L	P ≥130 to ≤560	2011.01	3.5	0.19	2.0	0.025
M	P ≥75 to <130	2012.01	5.0	0.19	3.3	0.025
N	P ≥56 to <75	2012.01	5.0	0.19	3.3	0.025
P	P ≥37 to <56	2013.01	5.0	4.7(e)		0.025
Stage IV emission standards						
Cat.	**Net Power**	**Date**	**CO**	**HC**	**NO_x**	**PM(b)**
	kW		g/kWh			
Q	P ≥130 to ≤560	2014.01	3.5	0.19	0.4	0.025
R	P ≥56 to <130	2014.10	5.0	0.19	0.4	0.025

(a) P = Power

(b) Particle size fraction not indicated in the standard, but diesel emissions are primarily in the fine fraction, i.e. below 2.5 µm.

(c) Stage II also applies to constant speed engines effective 2007.01

(d) Dates for constant speed engines are: 2011.01 for categories H, I and K; 2012.01 for category J.

(e) NO_x+HC

Harmonisation and extension of US and EU emission standards

The US and EU emission standards have increasingly been harmonised and there has also been increasing cooperation in the development of test methods for evaluating the compliance of engines. A new transient test procedure, termed the Non-road Transient Cycle (NRTC), was developed in the EU in cooperation with the US EPA to represent emissions during real conditions; NRTC is to be used in parallel with the NRSC test procedure.

While earlier tiered/staged standards (i.e. Tier 2/Stage II and Tier 3/Stage III A) are met though advanced engine design, the latest and most stringent standards (i.e. US Tier 4 final and EU Stage III B) require the use of control technologies, including advanced exhaust gas aftertreatment, to reduce emissions of PM and NO_x by about 90% compared with the previous tiered/staged standards. These control technologies are similar to those required by the 2007–2010 standards for on-road engines. Tier 4 engines, which incorporate sulfur-sensitive control technologies such as catalytic particulate filters and NO_x adsorbers, necessitated the mandated reduction of sulfur content in non-road diesel fuels. This resulted in reductions in the sulfur content of diesel in the US to 15 ppm (ultra-low sulfur diesel) for non-road fuel (effective June 2010).

A key difference between current US and EU emission standards relates to the engine classes and applications covered. US emission standards have wider coverage including smaller engines (less than 19 kW) and large engines (greater than 560 kW) and include generation sets of greater than 900 kW[64]. EU emission standards are generally only applicable to mobile plant with engines greater than 19 kW and less than 560 kW[65].

In January 2013 a stakeholder consultation discussion document was issued on the revision of the EU 1997 NRMM Directive[66]. Options outlined in the discussion document for consideration included the extension of the scope of the NRMM Directive to cover engines smaller than 19 kW and greater than 560 kW, and to include stationary engines. An impact assessment on the recommended options for revision of the EU's 1997 NRMM Directive considered the compliance costs, socio-economic impacts, environmental impacts and efficiency (costs versus benefits) of the recommended options[67]. The findings of the impact assessment support the setting of US equivalent emission limits for 8–18 kW and greater than 560 kW engines.

Reference is also made within the NRMM Directive stakeholder consultation discussion document to the possible introduction of a new emission stage (Stage V) in line with on-road emission standard developments. Stage V standards would target particle number limits rather than particle mass limits and focus on engines in the 56–560 kW range, which provide the largest contribution to non-road diesel emissions. Key questions being considered in the current review of the EU's 1997 NRMM Directive are whether Stage V emission limits for larger engine categories would trigger innovation such as the accelerated deployment of liquefied natural gas technology and whether for certain engine categories (e.g. 19–36 kW engines to which only Stage III A emission limits apply), the introduction of Stage IV levels may be skipped in favour of immediately introducing Stage V emission limits. Stakeholder views on the framework conditions for this innovation to happen and on lead-time needed for introducing Stage V levels have been invited. The consultation discussion document also notes that alternative fuel engines based on ethanol, dual fuel (gas–liquid mixture) or gas (natural or biogas) are currently not covered

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[64] US Tier 4 emission standards apply only to engines less than 560 kW.

[65] UK Stage IV emission standards apply to engines greater than 56 kW and less than 560 kW.

[66] European Commission (2013)

[67] Van Zeebroeck et al. (2009)

by the Directive. Given that the market for such engines is expected to increase rapidly over the next decade, with alternative fuel engines potentially becoming significant emission sources in the future, the inclusion of alternative fuel engines within the scope of the Directive is under consideration. Such a step has already been discussed with general stakeholder approval.

Emission standards issued by other countries

Canadian standards closely reflect US emission limits, with the emission standards of other countries referencing either US, EU or a combination of these standards.

China adopted emission standards for mobile non-road engines in 2008[68]. The standards promulgated by China are based on the EU Stage I/II emission standards for mobile non-road engines, but also cover small (<19 kW) diesel engines which were not subject to EU standards. Emission standards for small engines are consistent with US Tier 1 and Tier 2 non-road diesel standards. India has similarly based its non-road emission standards primarily on the EU Stage I/II emission standards for mobile non-road engines, while including emission standards for small engines based on US Tier 1 and Tier 2 non-road diesel standards[69].

Japan issues emission standards for non-road vehicles and machinery rated from 19–560 kW, including *Special Motor Vehicles* (self-propelled non-road vehicles and machinery that is registered for operation on public roads, i.e. fitted with licence plates) and *Non-road Motor Vehicles* that are self-propelled and non-registered non-road vehicles and machinery[70]. The emission standards for the two vehicle categories are the same, despite their being introduced by separate regulatory acts. The Japanese emission standards, despite being similar in stringency to the US Tier 3 and the EU Stage III A (2005–2007) emission standards, are not harmonised with US and EU regulations. The standards do not require the use of exhaust aftertreatment devices, such as diesel particulate filters; however, the Japanese Ministry of the Environment's Central Environmental Council is considering adopting standards that will require the implementation of aftertreatment technologies.

Russia has adopted EU Stage I emission standards for mobile non-road engines[71]. Brazil's non-road diesel emission standards set limits for non-road diesel engines in the 19–560 kW range, with standards set equivalent to US Tier 3 and EU Stage III A emission standards[72]. Emission limits are to be phased in from 2015 to 2019. The implementation dates depend on the power category and type of machinery (construction or farm).

South Korea has proposed emission standards for mobile non-road diesel engines used in construction and industrial equipment[73]. The standards would apply to engines in the 19–560 kW range, in such applications as excavators, bulldozers, loaders, cranes, graders, rollers and forklift trucks. South Korea's Tier 2 emission standards are equivalent to US Tier 2 emission standards.

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[68] Regulation GB 20891–2007

[69] www.dieselnet.com/standards/in/nonroad.php

[70] Ministry of Environment (MOE) Government of Japan, Enforcement Regulations for the Act on Regulation of Emissions from Non-road Special Motor Vehicle (www.env.go.jp)

[71] www.dieselnet.com/standards/ru/

[72] www.dieselnet.com/standards/br/nonroad.php

[73] www.dieselnet.com/standards/kr/nonroad.php

2.6.2 Voluntary programs implemented overseas for new engines

This section provides selected examples of cases where industry agreements and voluntary programs have been used to implement emission standards for the non-road diesel sector.

US Blue Sky Series Engine Program

This program administered by the US EPA comprises voluntary standards designed to encourage early introduction of ultra-low emission engines through offering incentives. Blue Sky Series engines are required to be typically about 40% cleaner and to retain their performance with Blue Sky Series emission standards (Table 9) throughout their useful life. These emission levels are typically achieved by adding aftertreatment technologies or by using alternative fuels such as natural gas.

Table 9: US EPA voluntary Blue Sky Series emission standards for non-road diesel engines

Rated power	NMHC[(a)]+NO_x (g/kWh)	PM (g/kWh)
<8 kW	4.6	0.48
≥8 kW to <19 kW	4.5	0.48
≥19 kW to <37 kW	4.5	0.36
≥37 kW to <75 kW	4.7	0.24
≥75 kW to <130 kW	4.0	0.18
≥130 kW to <560 kW	4.0	0.12
≥560 kW	3.8	0.12

(a) NMHC – non-methane hydrocarbon

Canadian initiatives

Prior to the promulgation of regulations for non-road engines, Environment Canada signed memoranda of understanding with 13 engine manufacturers in 2000. Under the terms of these memoranda, manufacturers agreed to supply non-road diesel engines designed to meet US Tier 1 standards.

2.7 Emission performance of engines sold in Australia

To determine the emission performance profile of non-road diesel engines in Australia, the overall compliance status of the non-road diesel engines/equipment sold into the Australian market during 2008 with EU and US emission standards was evaluated[74]. The emission performance of non-road diesel engines/equipment inventoried as being sold into Australia during 2008, given in terms of likely compliance with international standards, is illustrated in Figure 2.

About 22% of non-road diesel engines sold in 2008 were assessed to be either non-compliant with US or EU emission standards, or only compliant with 1996–2000 US Tier 1

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[74] ENVIRON (2010)

(EU Stage I) emission standards. The compliance status of a further 9% of engines/equipment was unknown, and potentially non-compliant.

A significant proportion (47%) of engines was found likely to be compliant with older 2000–2006 US Tier 2/EU Stage II standards. Only 5% of engines were reported by industry as meeting 2008 US Tier 4i (2008) standards. Small engines (less than 19 kW) are mainly non-compliant or Tier 2/Stage II compliant. The percentage of Tier 3 and Tier 4 interim compliant engines increases with higher power ratings.

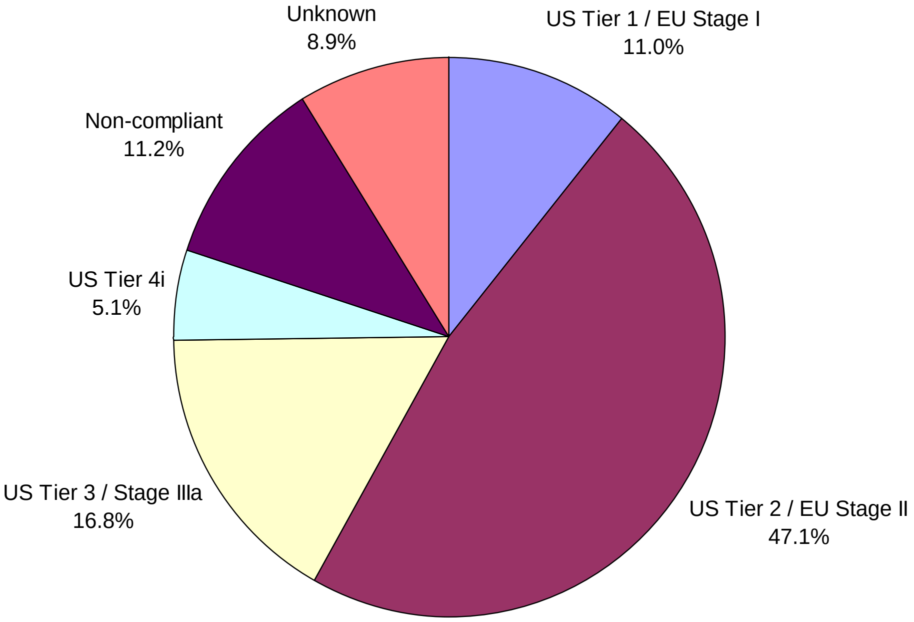

Figure 2: Emission performance status of non-road diesel engines/equipment sold into Australia during 2008 (in terms of compliance with international standards)[75] [76]

2.7.1 Market failure

Australia has benefited somewhat from the importation of cleaner engines compliant with non-road diesel emission standards issued by the US, EU and other jurisdictions; however, the data illustrated in Figure 2 indicate that a significant proportion of units are non-compliant or are lagging in compliance relative to units being sold into the US and EU. Market forces within the non-road diesel engine sector in Australia have therefore not successfully driven the transition to cleaner (lower emission) engines.

Furthermore, the more costly nature of engines compliant with the recent, most stringent standards (US Tier 4 and EU Stage III B), due to their incorporation of aftertreatment technologies, is expected to impede the future uptake of such engines in Australia[77]. It is also speculated that the number of ‘dirtier’ engines and equipment being sold into Australia may increase as other countries introduce or tighten regulations and engine/equipment manufacturers seek alternative markets. Some industry representatives

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[75] ENVIRON (2010)

[76] Implementation dates for US standards are: Tier 1 (1996–2000), Tier 2 (2001–2005), Tier 3 (2006–2008), Tier 4 interim (2008) and Tier 4 final (2011–2015).

[77] Comments made anonymously by several industry stakeholders during the development of this report.

caution that there may be an increase in the local market for used engines/equipment with higher emissions relative to new units.

Based on discussions with major engine suppliers during the development of this report, it is understood that there has not been a significant change in the emission performance of new engines sold into the Australian market. In some cases suppliers indicated that the proportion of cleaner engines may have increased marginally, in other cases suppliers indicated they have had to revert to selling higher emitting engines due to increased competition by competitors marketing lower-tier compliant engines and equipment.

2.8 Projected growth in the non-road diesel sector

Historically, diesel consumption by the non-road diesel sector nationally doubled between 1974 and 2009, increasing from 3.3 ML to 7.1 ML during this period[78]. The increase in the demand for diesel within the non-road sector has been noted to coincide with the increase in mining activity in Australia, which uses diesel powered engines and unregistered diesel vehicles for off-road purposes. The value of Australian mining exports is reported to have doubled between 2003–04 and 2006–07 from $31.3 billion to $62.7 billion, while the demand for diesel has been steadily increasing since 2002–03 with growth averaging 5.2% per annum[79]. The average annual growth in primary energy consumption from 2008–09 to 2034–35 is projected to be 5.2% for mining, 1.8% for agriculture, 0.9% for commercial and residential, and 0.5% for manufacturing[80]. Past diesel consumption by the non-road diesel sector, and projected future diesel consumption to 2035 based on the aforementioned annual growth rates, are illustrated in Figure 3.

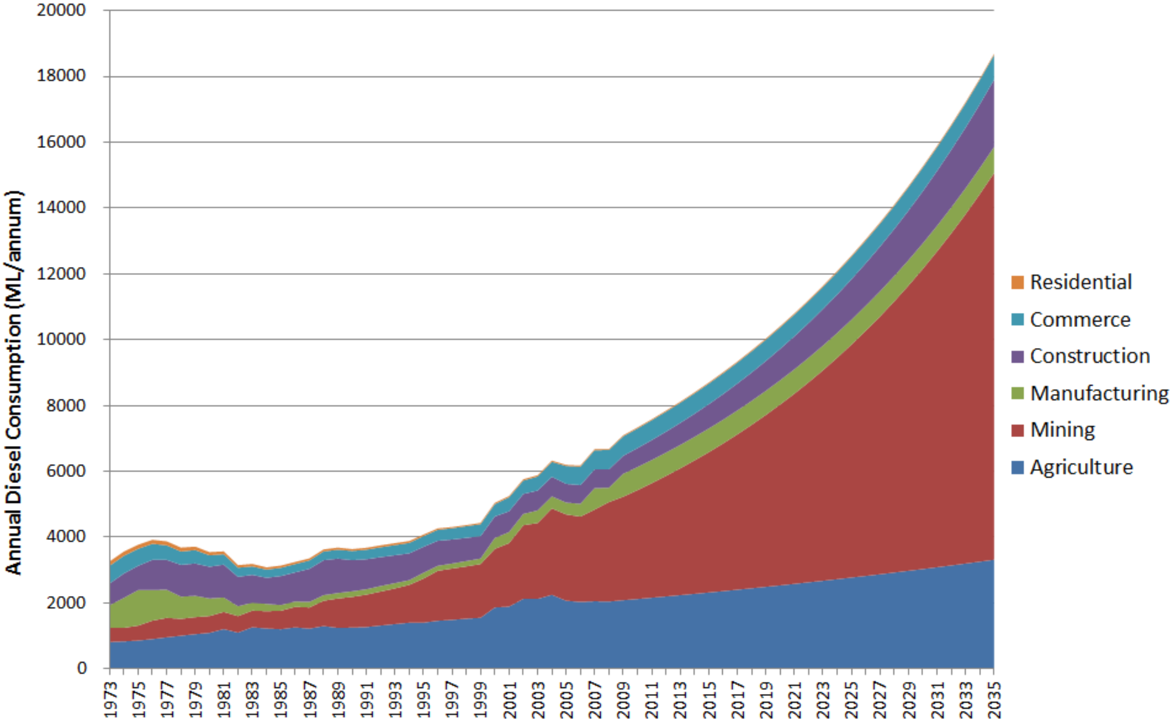

Figure 3: Reported (1974 to 2009)[81] and projected[82] diesel consumption by the non-road diesel sector nationally (excluding rail locomotives and large marine engines)

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[78] DAFF (2011)

[79] ACIL Tasman (2008)

[80] Australian Bureau of Resources and Energy Economics (2011)

[81] DAFF (2011)

2.9 Projected growth in health costs

The estimated growth in NO_x and $PM_{2.5}$ emissions due to non-road diesel engine applications in Australia is illustrated in Figure 4, with the associated health costs projected to occur as a result of such emissions shown in Figure 5. The basis for the emission estimates and health cost projections are described in detail in Section 4 with a summary of the method and key assumptions given below.

Stock was projected and emissions calculated based on methods developed by the US EPA, as applied in the US EPA NON-ROAD2008 model[83], for the period to 2055. Stock projections accounted for new engines and equipment being sold into Australia, non-road diesel sector growth rates and engine/equipment scrapping taking into account the useful life of engines. Emissions were estimated based on US EPA emission factors and deterioration factors for each engine power rating and application. The emission performance profile of new diesel engines being sold into Australia, as documented in Section 2.7, was assumed to remain unchanged for the projection period.

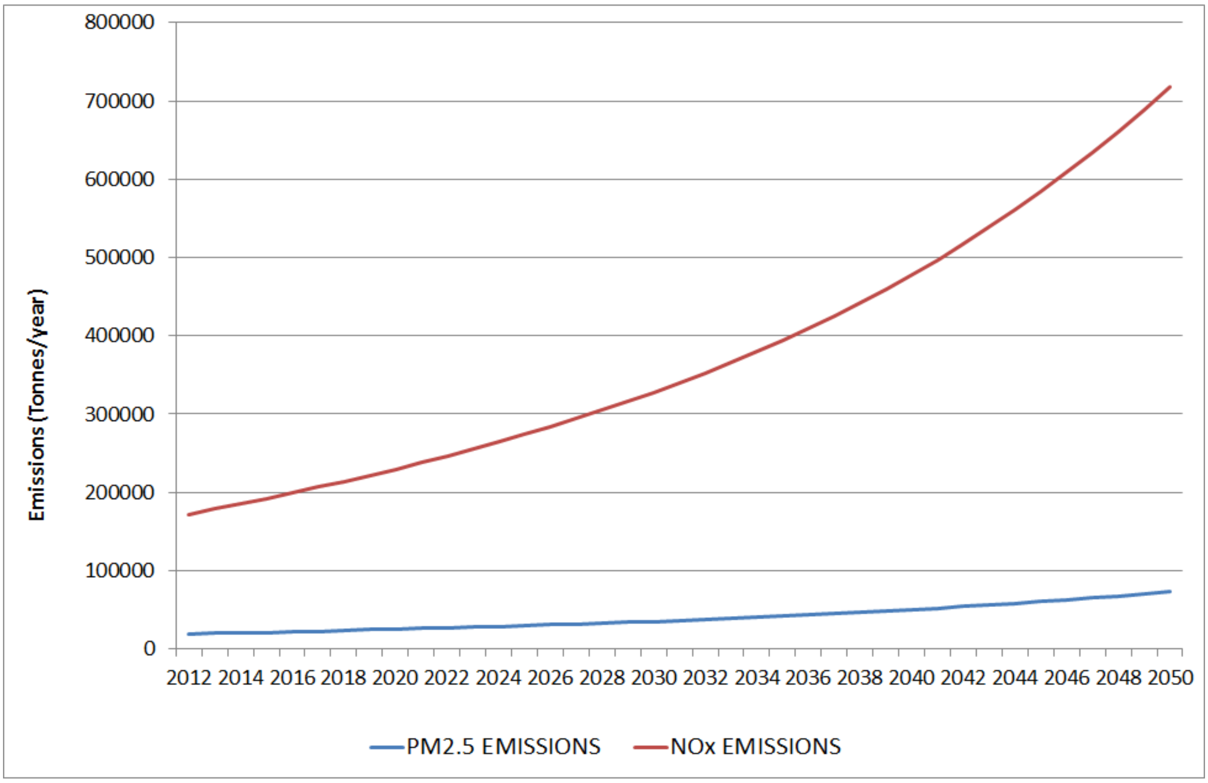

Figure 4: Estimated growth in NO_x and $PM_{2.5}$ emissions due to non-road diesel engine emissions in Australia (2012 to 2050)

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[82] Projections based on recent non-road diesel consumption and the average annual per cent increase in primary energy consumption by market sector for the 2009–10 to 2034–35 period within Australian Bureau of Resources and Energy Economics report *Australian energy projections to 2034–35*, December 2011.

[83] US EPA (2010)

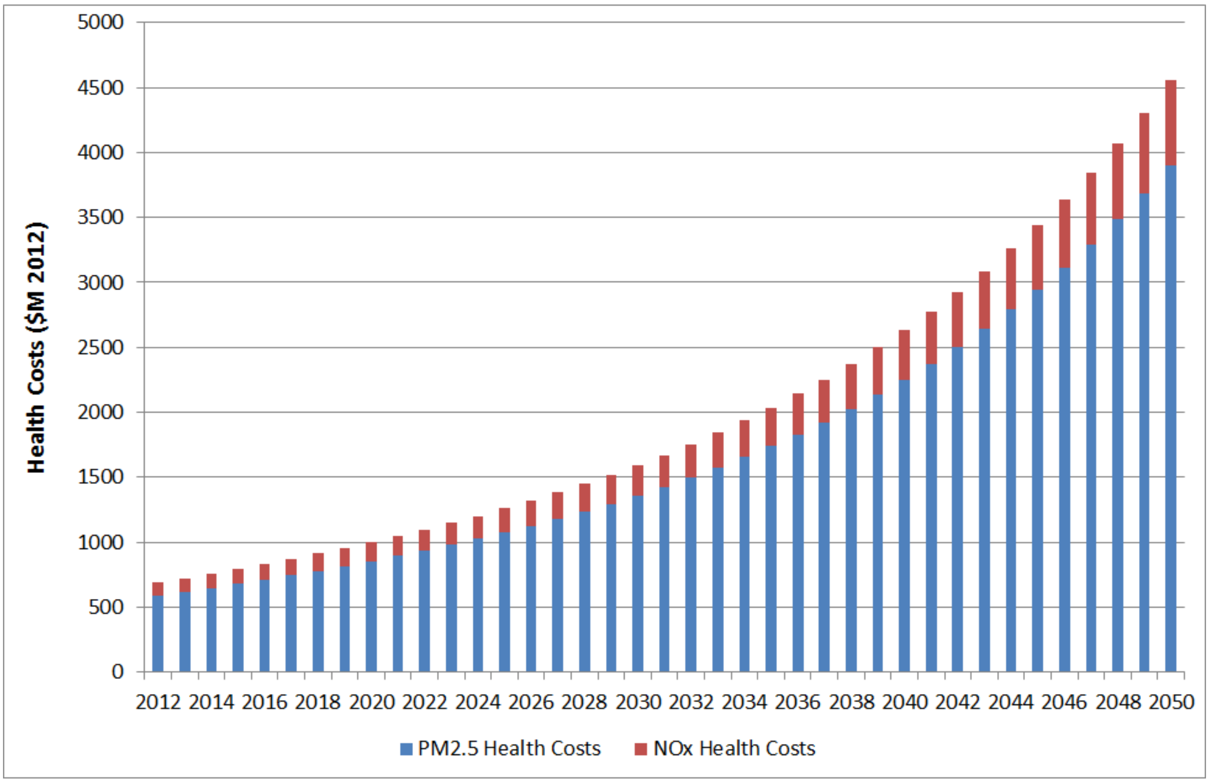

Figure 5: **Projected health costs due to estimated NO_x and $PM_{2.5}$ emissions from non-road diesel engine applications in Australia (2012 to 2050)**

Non-road diesel emissions were spatially disaggregated to account for lower exposures in non-urban applications and higher exposures within more densely populated urban areas, based on the spatial allocation process documented in Section 4.3.5. Health costs were quantified based on disaggregated $PM_{2.5}$ and NO_x emissions and projected health damage functions varied to account for different population densities; such functions are expressed as health costs in dollars per tonne of emissions ($/tonne) (refer to Section 4.3.8). Health costs are expressed in 2012 Australian dollars, with an annual economic uplift of 2.1% and a discount rate of 7% applied.

Annual NO_x and $PM_{2.5}$ emissions in 2012 were estimated to be approximately 171,900 tonnes/year and 18,850 tonnes/year respectively; with emissions increasing by a factor of four by 2050 (Figure 4). Resultant health costs were projected to increase from $690 million in 2012 to $4.6 billion by 2050, with approximately 85% of the health cost being due to direct $PM_{2.5}$ emissions and the remainder being associated with NO_x emissions (Figure 5). Although $PM_{2.5}$ emissions are lower than NO_x emissions, significantly higher unit health damages are associated with $PM_{2.5}$, as discussed further in Section 4.3.8.

Other effects associated with non-road diesel emissions which have not been costed within this study include health effects due to exposure to ozone and air toxics such as benzene and 1,3-butadiene, and climate effects due to CO_2 and elemental carbon emissions.

2.10 Summary

Emissions from non-road diesel applications in Australia contribute to elevated fine particle and ozone concentrations, impact on human health and are associated with potential climate effects. The non-road diesel sector currently consumes about 70% as much diesel as on-road transport nationally, but is estimated to emit more fine particles due to non-road diesel engines emitting higher amounts of PM per litre of fuel burned. Whereas the on-road diesel sector is subject to increasingly stringent national emission standards for new vehicles and to various state and territory implemented programs for in-service vehicles, no national regulations have been issued in Australia for the non-road diesel sector. Furthermore, emissions from in-service non-road diesel engines and equipment have remained largely unregulated and unaddressed nationally, with the exception of regulations for underground mining equipment and the small-scale, voluntary NSW Clean Machine Program.

Non-road diesel engine emissions are regulated in North America and Europe and parts of Asia and South America with international trends including increased stringency of emission standards, improved harmonisation and more extensive coverage of engine power rating ranges. Australia does benefit somewhat from the importation of cleaner engines compliant with US, EU and other international emission standards; however, a review of the emission performance of new engines and equipment being sold into the Australian non-road diesel market indicates that a significant portion of units are non-compliant or are lagging in compliance relative to units being sold into the US and EU. Furthermore, the more costly nature of engines compliant with the latest, most stringent standards (i.e. US Tier 4 and EU Stage III B), due to their incorporation of aftertreatment technologies, is expected to impede the uptake of such engines in Australia. There is also a risk of potential emission increases if equipment manufactured in countries with less stringent or no emission standards increases its market share in Australia.

A significant growth in non-road diesel engine and equipment stock numbers and diesel consumption rates is projected, resulting in an increase in non-road diesel engine emissions and associated health costs. In the absence of action, the extent of such increases will depend on the voluntary uptake of cleaner engines. Should the emission performance profile of new non-road diesel engines sold into the Australian market remain relatively unchanged in the next two decades, health costs are projected to exceed $2 billion (2012 AUD) per annum by 2035.

3 Harmonisation scenarios

3.1 Review of potential actions

Two main options are available for the non-road diesel engine and equipment sector. Firstly, there is a no action or business as usual (BAU) option, referring to a case where there are no measures to reduce emissions by any means. In the absence of any intervention, the emission performance of non-road diesel engines is assumed to be governed by market trends and international developments.

Secondly, the option exists to manage emissions from the non-road diesel sector through the setting of product-based emission limits. The implementation of national emission standards for non-road diesel engines represents a widely applied method internationally for managing emissions from this sector. Non-road diesel engine emission regulations applied internationally specifically target new equipment and in some cases replacement engines. Regulating new engines has been shown to be more cost effective and efficient than achieving emission reductions through retrofitting in-service engines[84]. Furthermore, the setting of vehicle emission standards has resulted in major emission reductions from on-road motor vehicles, both overseas and in Australia[85].

A number of factors were considered when reviewing the potential actions, including the possible emission reductions achievable, administrative ease of the measure, stakeholder readiness, urban/rural impacts of the measure, and possible additional benefits due to increased fuel efficiency or reduced greenhouse gas emissions.

3.1.1 Business as usual (BAU) – no action

This option comprises no action being taken, with the outcomes of such inaction being considered. In addressing BAU emission trends it is necessary to account for the projected growth in non-road diesel consumption as documented in Section 2.8. Such growth will result in an increase in non-road diesel engine emissions and associated impacts, with the extent of this increase depending on the extent to which the increased activity is offset by improved emission performance.

Australia has benefited somewhat from non-road diesel engine emission regulation implemented by other countries, notably the US and the EU, with the partial uptake of cleaner engines[86] locally (refer to Section 2.7). Some local industries promote the use of engines with improved emission performance but support for the uptake of cleaner technologies has also occurred collectively, with the Construction and Mining Equipment Industry Group encouraging progress towards Tier 3 / Stage III A compliant construction and mining equipment in 2007–08.

Relative to units being sold into the US and EU, a significant proportion of non-road diesel engines and equipment sold into the Australian market are non-compliant or are lagging in compliance with US/EU emission standards (Section 2.7). Several concerns have also been raised in regard to future trends in the emission performance of non-road diesel engines sold into Australia in the absence of local emission standards[87]. The higher cost of US Tier 4 and EU Stage IV compliant engines is expected to deter the voluntary uptake of such engines in Australia. The number of ‘dirtier’ engines and equipment being sold into Australia may also increase as other countries introduce or tighten regulations and

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[84] US EPA (2004a)

[85] BTRE (2005)

[86] That is, engines that comply with US or EU standards.

[87] Comments made by several industry stakeholders during the development of this report.

engine/equipment manufacturers seek alternative markets for older engine models or used equipment is offloaded here.

Furthermore, as regulation progresses in the US, Tier 3 and Tier 4 interim engines may no longer be manufactured, reducing the availability of such engines for sale within Australia. This case, put forward by some industry representatives, is projected to be the result of the progression of non-road diesel engine standards elsewhere with engine manufacturers assumed to simplify their ranges to Tier 2 and Tier 4 final compliant engines. Given the higher cost of Tier 4 final engines, current consumers of Tier 3 (Stage III) engines may revert to purchasing Tier 2 or higher emitting engines. Given that Tier 2 engines continue to have a market outside the US, due to the introduction of non-road diesel regulations within parts of Asia and South America, it is considered that this tier of engine may continue to be supported by manufacturers.

Due to uncertainties regarding future changes in the emission performance of non-road diesel engines/equipment given business as usual, the implications of taking action will need to be assessed against a range of base case scenarios (refer to Appendix I).

3.1.2 Harmonisation with US non-road diesel engine emission standards

Establishing national emission standards would provide certainty to the market in that the same standards would apply across jurisdictions, and engine distributors would only need to comply with one authority to ensure that their engines can be sold anywhere in Australia. Given that all engines used in the non-road diesel sector are imported, either as loose engines or incorporated in imported machinery and equipment, national standards would provide complete coverage of the non-road diesel engine and equipment sector.

Costs to industry would include costs associated with certifying test engines in accordance with emission standards and meeting any reporting or registration requirements. Costs to industry could be reduced by accepting international test results to forego the need for re-testing in Australia; however, should the emission standards issued in Australia lag significantly behind the standards issued in other countries, such that certification and testing against the now superseded standards would have already been suspended in those countries, this saving would not be realised[88].

Administrative and compliance monitoring costs would be relatively minor in relation to other costs but have been considered in the impact analysis.

3.2 Business as usual base case scenario

The business as usual (hereafter referred to as main base case) scenario builds on the previous work undertaken by ENVIRON[89], integrating additional inputs obtained from consultation with industry representatives.

The main base case scenario (Figure 6) assumes that the emission performance status of engines/equipment inventoried for 2008 remains representative of the emission performance status of the engines/equipment sold into Australia during the 2009 to 2035 period.

Two other base cases, a lower bound (best case) scenario and an upper bound (conservative) scenario have also been considered, to account for inherent improvements over time in the emission performance of non-road diesel engines due to market forces and voluntary measures on the one hand, or, on the other hand, worsening of engine emission performance over time if in the absence of local action, the share of cheaper Tier 2

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[88] Although US Tier 4 final and EU Stage IV emission standards will be implemented post-2015, engine suppliers may continue to certify lower tier/stage engines due to less stringent standards having been adopted in countries such as China, Russia, Japan and Brazil (refer to Section 2.6.1).

[89] ENVIRON (2010)

compliant engines grows to the detriment of Tier 3 and Tier 4 market segments. These two variation base cases are included in Appendix I as part of the sensitivity analysis.

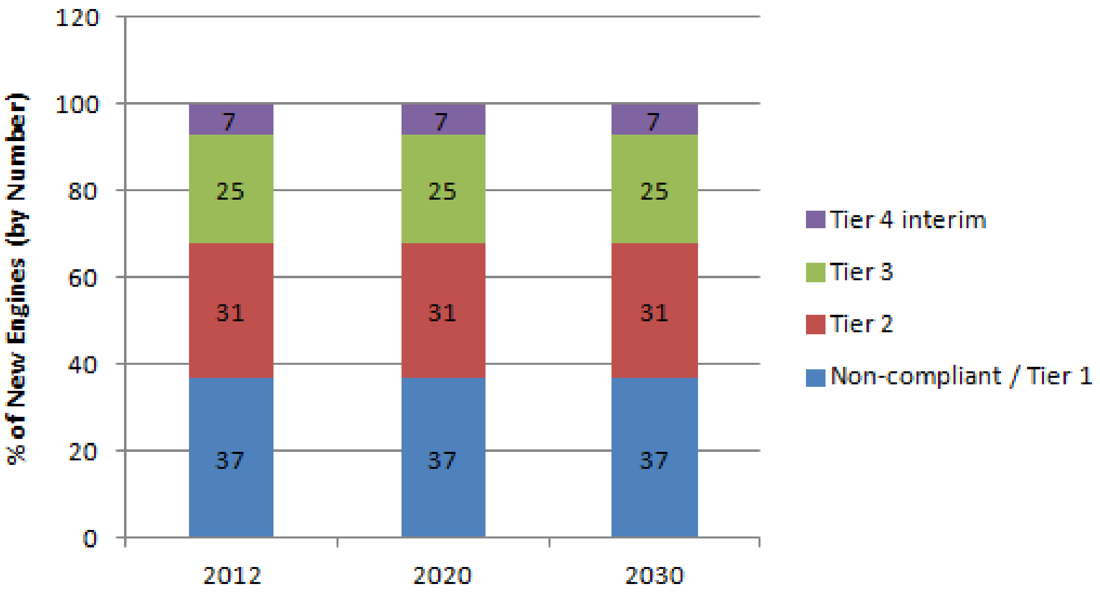

Figure 6: **Emission performance of new non-road diesel engines/equipment greater than 19 kW assumed for the main base case scenario**

3.3 Definition of emission standards for potential actions

3.3.1 Selection of emission standards

Given the trend towards harmonisation of non-road diesel standards internationally, and the disadvantages of implementing unique standards in Australia due to the nature of the market, the assessment of widely-referenced international standards is supported. The EU and US non-road diesel engine emission standards are the most widely referenced standards for non-road diesel engines and equipment and have formed the basis for non-road diesel engine regulations in other countries (refer to Section 2.6.1). Reference is therefore made to EU and US emission standards in this analysis.

Non-road diesel engine emission standards are referenced within the EU *Non-road Mobile Machinery Directive (97/68/EC)* (EU NRMM Directive). US non-road emission standards (Tier 2 and Tier 3) are documented in the *US Code of Federal Regulations, Title 40, Part 89 (40 CFR Part 89)*, with Tier 4 standards introduced in 2004 as part of the US *Clean Air Non-road Diesel – Tier 4 Final Rule*[90]. A detailed overview of these standards is provided in Section 2.6.1.

As indicated previously, the applicability of the EU standards has been highlighted by submissions received previously from the Australian Diesel Engine Distributors Association (ADEDA)[91]. ADEDA noted that Australia is a signatory to the 1958 Geneva Convention of the High Seas, the Australian Government having re-ratified the convention in 2008. This convention emphasises uniform conditions of approval, aiming to avoid duplication of compliance standards and specifically stipulates that Australian Standards

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[90] US EPA (2004c)

[91] ENVIRON (2010)

be based on the corresponding EU model. Furthermore, Australian ‘on-road’ emission standards are based on the comparable EU model.

US emission standards are relevant given that a significant proportion of the engines sold into the Australian non-road diesel market are manufactured in the US or in countries that implement the US standards (refer to Appendix A).

3.3.2 Coverage of emission standards

Product-based emission measures range from measures with broad coverage across engine/equipment sub-populations to more specific measures targeting prioritised sub-populations. Non-road diesel engine emission standards implemented internationally tend to have relatively broad coverage in terms of the engine sizes and market segments covered.

To maximise the efficiency of control measures, and given that the same diesel engines are used in equipment and vehicles implemented within several market segments, non-road diesel standards are typically applicable across equipment types/applications but specified by power rating class. Engine power rating ranges covered by overseas non-road diesel standards are summarised in Table 10.

Table 10: Coverage of emission standards by power rating class

Rated power	Countries with non-road diesel engine emission standards
<8 kW	US; Canada; China; India; being considered by EU
8 – 19 kW	US; Canada; China; India; being considered by EU
19 – 560 kW (various bands)	US; Canada; China; India; EU; Japan
>560 kW	US; Canada; being considered by EU

Although EU non-road diesel engine emission standards currently exclude engine power classes below 19 kW and above 560 kW, the extension of the EU NRMM Directive to cover engines smaller than 19 kW and greater than 560 kW, and stationary engines, is under consideration[92] (refer to Section 2.6). An impact assessment was previously conducted to assess the compliance costs, socio-economic impacts, environmental impacts and efficiency (costs versus benefits) of the recommended EU options[93]. In assessing the significance of engines in the less than 19 kW power band, the contributions of 0–8 kW and 8–19 kW engines to total land based compression ignition engine emissions were considered. Engines less than 19 kW were noted to contribute only 1% of NO_x and 2% of PM total land based compression ignition engine emissions (despite comprising 23% of engine sales), of which the 0–8 kW engines contributed only 0.04% and 0.1% of total NO_x and PM emissions respectively. The 0–8 kW engine NO_x and PM emissions therefore comprised only 3% of the entire 0–19 kW engine emission contribution. Engines greater than 560 kW were noted to comprise only 1% of engine sales, but contributed 9% of the total NO_x and 7% of total PM emissions across all land based compression ignition engines. The findings of the impact assessment supported the setting of US equivalent emission limits for 8–19 kW and greater than 560 kW engines, whilst excluding 0–8 kW engines; however, the option of including the less than 8 kW engine class in EU standards is under EU consideration.

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[92] European Commission (2013)

[93] Van Zeebroeck et al. (2009)

Emission reductions achievable through the implementation of US non-road diesel emission standards within Australia were previously estimated by ENVIRON[94]. Small engines (less than 19 kW) were estimated to account for 2.1% of the overall PM_{10} and $PM_{2.5}$ emission reductions. Similar to engine power rating class contributions estimated for the EU, very small engines (below 8 kW) were only estimated to be responsible for 0.1% of the overall reductions in PM_{10} emissions for Australia.

The inclusion of smaller engines (less than 19 kW) is considered to significantly reduce the administrative ease of implementation and the cost-effectiveness of reduction measures, without substantially contributing to overall emission reductions and associated health benefits[95]. Less than 19 kW engines have therefore been excluded from the potential actions considered in this report.

Non-road diesel engines of ≥19 kW through to those >560 kW are considered in this report. Given that US and EU emission standards are equivalent for the 19–560 kW engine power rating range, and that the EU is considering the extension of standards to engines >560 kW and stationary engines, a single reduction measure is possible for the ≥19 kW to >560 kW range; however, given that the EU NRMM Directive currently excludes >560 kW engines and stationary engines, the consequences of excluding such engines is considered as part of the sensitivity analysis (refer Appendix I).

Whereas US non-road diesel engine standards include marine engines less than 37 kW, the EU NRMM Directive includes a more complex definition of marine engines. The EU directive includes engines used in 'inland waterway vessels' with such vessels being defined based on vessel length, engine size, vessel use and areas of application. Given the complexity of the EU definition and the lack of Australian stock and cost data for marine engines greater than 37 kW[96], the US classification of marine engines for inclusion is adopted in this report.

3.4 Considerations for an implementation schedule

US Tier 3 emission standards and EU Stage III A emission standards are currently in force. US Tier 4 and EU Stage III B/Stage IV standards are progressively being implemented in the US and Europe respectively, by 2015. Tier 4/Stage III B/Stage IV standards are already required for the majority of engine classes.

During a previous study[97] and further discussion with industry stakeholders during the development of this report, the following feedback was received, and closely considered, in developing implementation schedules for any potential action:

- The implementation schedule should comprise a stepped approach, starting with EU Stage III A (US Tier 3) standards and stepping directly to Stage III B/Stage IV (Tier 4 final) standards.
- EU Stage III A / US Tier 3 emission standards should be adopted to ensure that Australian standards are aligned with international emission standards.
- There should be a minimal lag period in adopting EU Stage III A / US Tier 3 emission standards, whilst providing a sufficient period to ensure industry transition (industry feedback suggested three years).

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[94] ENVIRON (2010)

[95] ENVIRON (2010)

[96] Marine engines greater than 37 kW were excluded from the non-road diesel engines inventoried in the previous scoping study (ENVIRON 2010), due to the scope of this work being informed by the US approach.

[97] ENVIRON (2010)

- Provision should be made in the stepped approach for a review period to incorporate lessons learned by the EU and the US in introducing Stage III B/Stage IV and Tier 4 standards, respectively. Industry feedback suggested that the adoption of such emission standards should be required by 2020, to allow for a review in 2016–17.

The stepped implementation schedule for harmonisation scenario 3 includes an implementation date of 2015 for EU Stage III A / US Tier 3 standards, and 2018 for compliance with Stage III B/Stage IV and Tier 4 standards. This schedule is illustrative only, and originates from a report undertaken in 2013 using 2012 base year data. A later start date (i.e. three to four years) is likely to be more realistic given the time needed to establish any new standards and to allow for a transition period as recommended by industry. The expected impacts of a delay on estimated benefits for all potential actions considered in this report have been assessed by way of sensitivity testing in Appendix I. If implementation of Stage III A/Tier 3 standards in 2015 followed by Stage III B/Stage IV/Tier 4 standards in 2018 is concluded to be feasible, later dates would be as feasible or more feasible, as delays in incurred costs result in a relative cost reduction when discounted to present values.

In addition to the stepped harmonisation scenario, two other harmonisation scenarios were outlined for analysis to enable an assessment of the individual effects of the two levels of standards, i.e. implementation of Stage III A/Tier 3 standards only in 2015 (harmonisation scenario 1), and implementation of Stage III B/Tier 4 final standards only in 2018 (harmonisation scenario 2).

4 Impact analysis of feasible harmonisation scenarios

4.1 Introduction

Three harmonisation scenarios were identified as feasible options for managing emissions from non-road diesel engines in Australia, the first two with a single phase approach to the introduction of standards and the third with a stepped approach. Given uncertainties regarding future changes in the emission performance of engines and equipment sold into the Australian market, it was necessary to evaluate these harmonisation scenarios against a range of BAU base case scenarios. A summary of the BAU base cases and the three harmonisation scenarios is given in Table 11.

Table 11: Summary of potential actions for impact analysis

Potential action	**Description**[(a)]
Business as usual (BAU) – no action	
BAU main base case	Emission performance of new engines/equipment assumed to remain unchanged
BAU lower bound base case	Emission performance of new engines/equipment assumed to improve
BAU upper bound base case	Emission performance of new engines/equipment assumed to decline
Harmonisation scenarios	
Scenario 1 Tier 3 / Stage III A emission standards only	US Tier 3 / EU Stage III A emission standards implemented in 2015 for new engines/equipment greater than 19 kW
Scenario 2 Tier 4 final / Stage III B / Stage IV emission standards only(b)	US Tier 4 final / EU Stage III A/Stage IV emission standards implemented in 2018 for new engines/equipment greater than 19 kW
Scenario 3 Stepped introduction of emission standards	Tier 3 / Stage III A emission standards implemented in 2015 and Tier 4 final / Stage III B/Stage IV emission standards implemented in 2018 for new engines/equipment greater than 19 kW

(a) US Tier 3 emission standards and EU Stage III A emission standards are currently in force in the US and EU respectively. US Tier 4 and EU Stage III B/Stage IV standards are progressively being implemented in the US and EU, respectively, by 2015 and are already required for the majority of engine classes.

(b) The EU is tightening NO_x standards in two stages, Stage IIIB in 2011–12 and Stage IV by 2014.

4.2 Approach overview

A cost benefit analysis was conducted for the period 2012 to 2055. Specific elements of the analysis included:

- well-defined potential actions, with well-defined timelines and emission limit criteria. It is assumed that only compliant engines could be purchased from the specified timelines
- urban and non-urban exposure potentials. Emissions data and achievable emission reductions were spatially disaggregated and coincident human exposure potentials estimated to inform the estimation of health costs/benefits. This was done to account for the fact that health costs of emissions and benefits of emission reduction would be lower in less populous regions due to lower exposure rates to harmful air emissions
- collation and verification of industry cost data and compliance costs. Assumptions underpinning the analysis were based on a collation of available data and supplementary disaggregated industry-specific data obtained through surveys, structured interviews and consultation with engine/equipment suppliers and other stakeholders
- inclusion of administrative costs. Estimation of administrative costs of identified potential actions was based on published data on costs from similar schemes
- estimation of emission reductions and health benefits achievable for all potential actions and consequent health costs avoided for Australia using a stock model of equipment that projected sales and scrappage rates for all engine classes by end use activities. Emissions levels were based on activity levels for each class and type of engine. Health costs and benefits were calculated through the application of unit damage costs which relate health costs (benefits) to each tonne of $PM_{2.5}$ and NO_x emitted (reduced)
- qualitative evaluation of unpriced benefits and costs (e.g. global harmonisation of standards, avoidance of air toxics, impacts on fuel efficiency, greenhouse effects)
- sensitivity analysis of the costs and benefits for key assumptions, such as whether engines greater than 560 kW or stationary engines (not currently covered by EU non-road diesel regulations) are excluded.

4.3 Description of modelling method

4.3.1 Model overview

The impact analysis was conducted by developing a base case stock model for Australia comprising new and in-service engines, and evaluating results from perturbing the model in accordance with the potential actions.

Stock was projected and emissions calculated based on methods developed by the US EPA, as applied in the US EPA NON-ROAD2008 model[98]. Stock projections accounted for new engines and equipment being sold into Australia, non-road diesel sector growth rates and engine/equipment scrapping taking into account the useful life of engines. Emissions were estimated based on US EPA zero hour emission factors and deterioration factors applicable for each engine power rating and application.

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[98] www.epa.gov/otaq/nonrdmdl.htm

The three (lower bound, main and upper bound) base case scenarios were used as benchmarks against which the harmonisation scenarios were compared. Each harmonisation scenario is modelled as a perturbation of the base case scenarios. Specifically, the emission and deterioration factors used for the stock of engines were changed based on the standards proposed in the relevant harmonisation scenario.

The detailed impact analysis modelling comprised the following:

- a base case year of 2012
- implementation from 2015
- stock, emission and cost projections for the period 2015 to 2055, with implementation restricted to 2035
- health benefit calculations for the period 2015 to 2055, to account for benefits manifesting with a lag time
- discounting of costs to 2012 Australian dollars.

The approach for analysing the impacts of the potential actions is as follows:

- development and validation of a stock model, with in-service non-road diesel engine/equipment stock projected to 2055 for BAU scenarios, and the stock described by equipment type, engine power rating range, age and emission performance
- estimation of PM_{10}, $PM_{2.5}$ and NO_x emissions from non-road diesel exhaust emissions to 2055 based on the stock projections and emission performance of stock for the BAU scenarios
- modelling of changes in the in-service stock emission performance profiles due to the implementation of the harmonisation scenarios, and resultant changes in emissions to 2055 relative to the BAU scenarios
- spatial disaggregation of emissions due to BAU scenarios and emission reductions due to harmonisation scenarios by ABS Significant Urban Area (SUA)
- application of unit damage costs for each SUA to estimate health costs due to BAU scenarios, and reductions in health costs due to harmonisation scenarios; summing of health costs/benefits across SUAs
- calculation of monetised costs associated with administration and compliance for each harmonisation scenario. Results for different scenarios are expressed as changes from the outcomes of the associated BAU scenarios. Time-lagged benefits are accounted for and discount rates applied to derive net present values (NPVs)
- key non-monetised factors that may affect the selection of a preferred scenario are specified, and the potential impacts on competition and small business discussed in Section 4.5
- potential information gaps to be addressed are identified.

Further discussion on the specific methods applied in undertaking several of the steps mentioned is provided in the following subsections.

4.3.2 Stock calculations

A stock model was developed to take into account new non-road diesel engine sales from 2008, as inventoried by ENVIRON[99], and project sales forward to 2035 and back to 1990. The stock model for non-road diesel engines was designed to track movements of the stock of non-road diesel engines by engine type and region. The model was used to predict the number of engines required in the future by engine type and technology. The annual stock model accounts for:

- opening stock of engines (at the beginning of the year)
- disposal (retirements) of engines during the year
- sale of engines in Australia
- apparent domestic consumption of engines.

The apparent domestic consumption of engines is the number of engines in use in each year. It can be mathematically represented by:

$$ADC_{te} = OS_{te} - D_{te} + S_{te}$$

where:

ADC_{te} = apparent number of engines used in Australia in year *t* for non-road diesel engine type *e*. In the historical period, ADC_{te} was determined using the formula listed above, with projected numbers of engines during the prediction period taking into account sector growth factors as discussed further in this section

OS_{te} = opening stock (apparent domestic consumption from the previous year) at the beginning of year *t* for non-road diesel engine type *e*

D_{te} = disposals (scrappage) of engines of type *e* in year *t* defined as the average turnover span (or life) of each engine. This was based on industry data on average turnover times for engines

S_{te} = sales of engine type *e* in year *t* in Australia.

Once the apparent number of engines used, by engine age and category, is calculated, this can be used to estimate emissions from such engine categories through the application of emission factors and deterioration factors.

The stock model was initiated based on the detailed 2008 engine/equipment sales data set described within a previous scoping study report[100]. This data set included information on the market segment into which the unit was sold (agriculture and forestry, construction and mining, industry, marine, lawn and garden, power generation drive, power generation set), the engine type or application (e.g. pump, scraper, standby generator set), and the power rating and emission performance of the engine.

To facilitate the back-casting and forecasting of engine sales, specific growth factors were derived for each market segment. The growth factors were based on the projected annual growth in primary energy consumption for the 2008–09 to 2034–35 period which was predicted by the Australian Bureau of Resources and Energy Economics to be 5.2% for mining, 1.8% for agriculture, 0.9% for industrial, power generation and lawn and garden[101] (refer to Section 2.8).

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[99] ENVIRON (2010)

[100] ENVIRON (2010)

[101] DRET (2011)

The growth rate adopted for construction and mining (5.2%) is within the economic growth range of 4.2% to 5.7% indicative of the relationship between GDP and construction turnover growth[102]. The growth rate adopted for agriculture (1.8%) is supported by the ~2% average annual growth in combined tractor and combine harvester sales over the past four years (refer to Appendix A), and the 2% annual growth rate in agricultural production for the 1990–2010 period[103]. This rate is also comparable to the long-term historical growth rate for the gross value of agricultural production. The growth rate reflects the ongoing use of capital to improve agricultural productivity through either replacement of older plant with more efficient new plant and/or expanding the use of plant and equipment. The growth rate applied for industrial, power generation and lawn and garden (0.9%) is noted to be lower than population growth projections, which are generally in the range of 1.1% to 1.5%[104].

The scrapping functions were based on a similar methodology to that applied in the US EPA NON-ROAD2008 model[105]. Scrappage rates were estimated based on the annual operating hours, load factors and the equipment median life[106]. The life of an engine is specified by a cumulative normal distribution with a mean and variance specific to the engine being considered.

The median life, load factor and hours of operation by engine category used in the model are given in Appendix D. Stock model and emission calculations are documented in Appendix E.

4.3.3 Verification of stock projections

Automotive diesel oil (ADO) fuel use for non-road diesel engines calculated using the stock model was compared with historic ADO consumption data and projections published by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) within the Department of Agriculture, Fisheries and Forestry[107] (refer to Section 2.8).

Back-casting of diesel consumption using the stock model for 2008–09 was shown to give comparable results to actual diesel consumption records, with 6996 kilolitres (kL) of diesel calculated from the model in comparison with recorded diesel consumption of 6685 kL. Given the complexity of distinguishing the exact diesel consumption rates by the non-road diesel sector (as defined for the purpose of this study) based on the ABARES classified records, the correlation was considered to be sufficiently representative. The model calculations of relative diesel consumption by market segment for 2008 were also found to correlate sufficiently with ABARES records for 2008–09 (Figure 7). Given that the growth rates assumed in the stock model were made equivalent to ABARES' primary energy growth factors given by market sector, the stock model diesel consumption projections are comparable to the ABARES consumption projections (Figure 8).

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[102] ABS Catalogue 5206.0 Australian National Accounts OECD GDP Forecasts Australian Industry Group.

[103] ABS Catalogue 5220.0 Australian National Accounts: State Accounts (per annum growth 1990–2010).

[104] ABS Catalogue 3222.0 Population Projections, Australia

[105] US EPA (2010)

[106] The median life represents the period of time over which 50% of the engines in a given model-year cohort are scrapped. The value assumes that engines are run at full load until failure and equipment scrappage follows a scrappage curve.

[107] DAFF (2011)

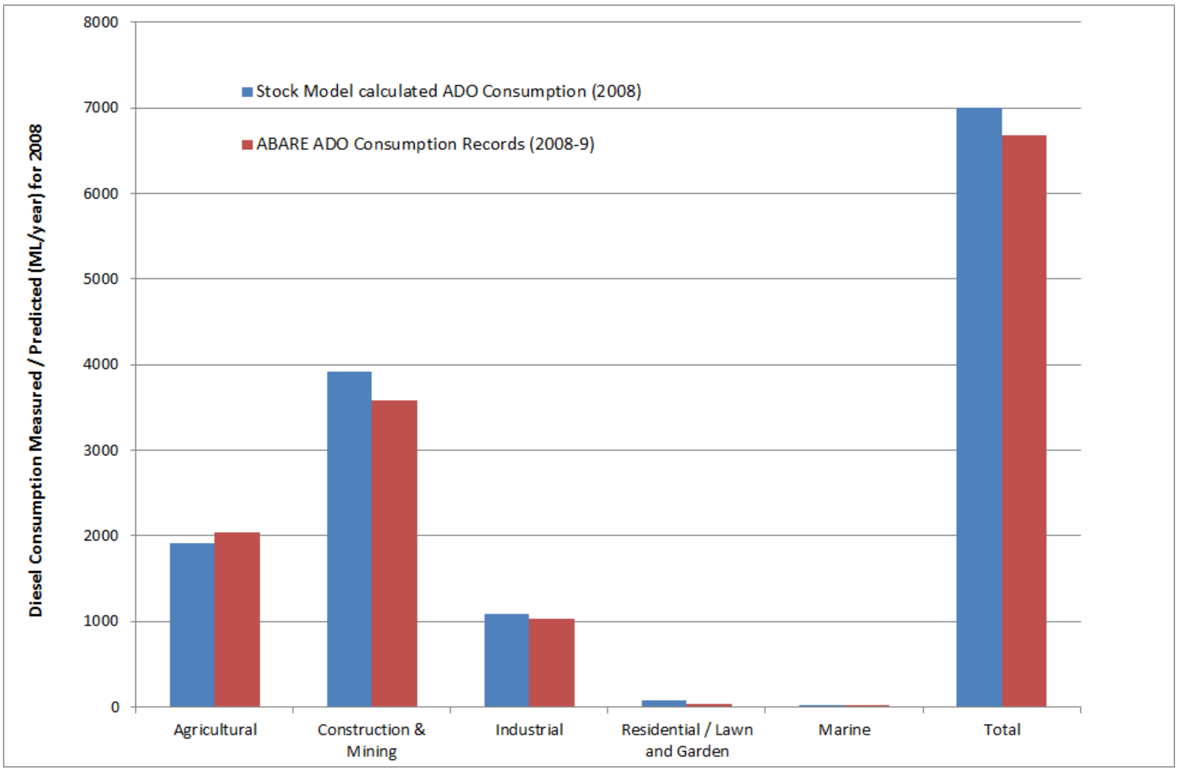

Figure 7: Comparison of modelled and actual ADO fuel usage for 2008

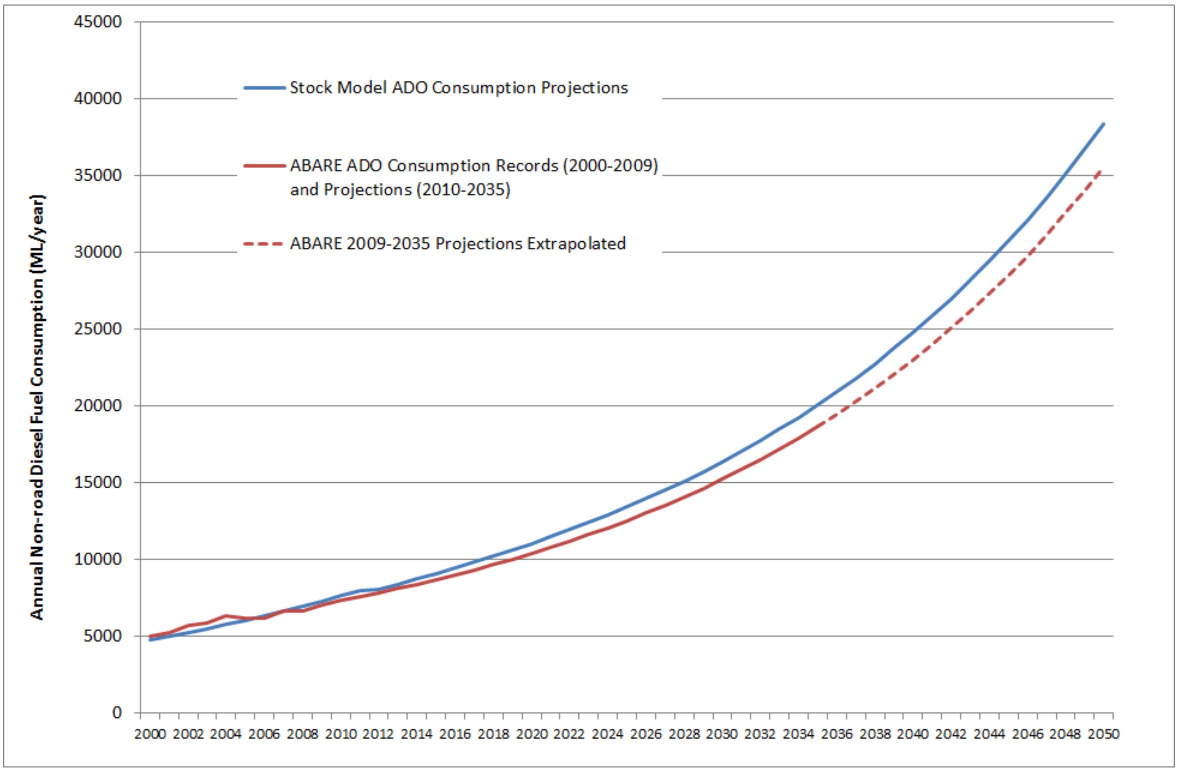

Figure 8: Comparison of modelled and ABARES ADO fuel consumption records and projections for the 2000–2050 period

4.3.4 Emission calculations

PM and NO_x emissions were calculated. PM and NO_x are exhaust emissions emitted directly as a result of diesel fuel combustion in the engine. $PM_{2.5}$ emissions were quantified for the health risk analysis. This size fraction comprises 97% of PM_{10} emissions for non-road diesel emissions[108]. This size fraction was used for analysis as it is equivalent to the size fraction used within the NSW GMR Emissions Inventory[109].

US EPA NON-ROAD2008 emission factors were used in the quantification of non-road diesel engine exhaust emissions[110]. Reference was made to engine application/rating specific annual activity, load factors, useful life and emission deterioration factors from the US EPA NON-ROAD2008 model. Information on engine life, load factors and annual hours of operation obtained from some engine/equipment distributors supplying the Australian market were used to confirm the applicability and supplement the inputs obtained from the NON-ROAD2008 model[111]. Use was made of equipment-specific average power ratings obtained from industry. This information was supplemented with values from NON-ROAD2008 where data was not locally available.

The median life, load factor and hours of operation by engine category used in the model are given in Appendix D.

NON-ROAD2008 exhaust emission factors comprise three components: a ‘zero-hour’ emission level (ZHL), a transient adjustment factor (TAF) and a deterioration factor (DF)[112]. The ZHL represents the emission rate for recently manufactured engines with few operating hours and is typically derived directly from laboratory measurements conducted on new or nearly new engines across several commonly used duty cycles.

Given that the emission measurement data used for ZHL have been collected under steady-state conditions (constant engine speed and load), it is necessary to apply a TAF to account for in-field operations which typically involve transient conditions (variable speed and load). The baseline emission factor is therefore the product (ZHL*TAF)[113].

Deterioration factors are applied to account for increased emissions during subsequent years. Such factors are calculated and applied as a function of the operational age of the engine/equipment. Engines/equipment are assumed to deteriorate to the median engine/equipment life (i.e. life at which 50% of the sub-population is retired), following which they are assumed to be maintained at the same state. Further deterioration of engines used beyond their median life could potentially result in higher emissions; however, the quantification of such increases is not facilitated within the available NON-ROAD2008 emission profiles.

The emissions in a given year are calculated as the sum of emissions from engines bought in that year plus the emissions from all surviving engines purchased in previous years.

The calculation of the total emissions for a given pollutant is described mathematically in Appendix E.

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[108] US EPA (2004b)

[109] NSW EPA (2012b)

[110] US EPA (2004b)

[111] ENVIRON (2010)

[112] US EPA (2004b)

[113] US EPA (2004b)

4.3.5 Spatial allocation of emissions/emission reductions

Non-road diesel emissions were spatially disaggregated to account for lower exposures in non-urban applications and higher exposures within more densely populated urban areas. The following steps were used in the spatial allocation process.

Initially, emissions/emission reductions were disaggregated by state/territory based on non-road diesel consumption data for relevant market segments within each state/territory for 2008–09[114] (Table 12).

Table 12: Allocation of emissions/emission reductions by sector and state/territory based on diesel consumption information for 2008–09

	Agricultural (%)	Industry[(a)] (%)	Lawn and garden[(b)] (%)	Mining[(c)] (%)	Construction[(c)] (%)	Marine (%)
NSW	30.8	13.2	8.3	18.5	20.1	9.4
VIC	14.1	10.2	16.7	1.3	15.0	10.8
QLD	24.5	27.7	33.3	39.0	29.4	13.5
WA	17.2	37.6	16.7	35.4	22.0	55.2
SA	8.4	5.3	16.7	2.1	4.7	1.3
TAS	3.8	3.0	–	1.2	7.0	0.9
NT	1.3	3.0	8.3	2.5	1.9	9.0
Australia	**100**	**100**	**100**	**100**	**100**	**100**

(a) Based on diesel consumption for both commercial and manufacturing sectors.

(b) Based on diesel consumption for residential sector.

(c) Mining and construction emissions were differentiated based on the relative diesel consumption of these sectors, as shown in Table 13.

Information on non-road diesel engines and equipment being sold into the mining and construction markets does not differentiate between the units used in each of these market segments. Equipment such as dozers, scrapers, excavators and haul trucks can be used in both mining and construction. Sector-specific diesel consumption information was therefore used as the basis for allocating non-road diesel emissions to the mining and construction sectors within each state. The relative proportions of diesel consumption for the mining and construction sectors in each state and territory, and nationally, are provided in Table 13. Non-road diesel engine emissions were allocated to ABS SUAs and non-SUAs on the basis outlined in Table 14.

Industrial, lawn and garden, construction and marine emissions were assumed to vary based on population numbers, with emissions from these sectors being allocated to SUAs and non-SUAs based on the total population numbers of such areas. An attempt was initially made to disaggregate construction activity based on the value of building approvals from ABS Building Approvals (Residential and Non-residential) statistics; however, population figures were determined to be a more robust method of allocating construction emissions by SUA.

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[114] Australian Bureau of Agricultural and Resource Economics and Sciences (2011). Australian total final energy consumption, by sector, by fuel.

Table 13: Proportion of emissions allocated to mining and construction sectors based on diesel consumption information for 2008–09

Jurisdiction	Mining[a](%)	Construction[a](%)
NSW	83.4	16.6
VIC	31.9	68.1
QLD	87.9	12.1
WA	89.8	10.2
SA	71.4	28.6
TAS	48.3	51.7
NT	87.9	12.1
Nationally	84.5	15.5

[a] Percentage of 'Mining and Construction' emissions allocated to the mining and construction sectors respectively based on diesel consumption.

Table 14: Basis for allocating state/territory emissions/emission reductions to specific SUAs

Sector	Basis for allocation
Agriculture	Allocated to non-SUAs within each state/territory
Industry	Allocated to SUAs and non-SUAs based on population numbers
Lawn and garden	
Construction	
Marine	Allocated to coastal SUAs based on population numbers
Mining	Allocated to SUAs and non-SUAs based on the location and diesel consumption of individual mines

Mining emissions within each state/territory were allocated to points coinciding with operating mines as derived from the Geosciences Australia – Australian Mine Atlas (October 2012) based on fuel consumption data for mining operations. A total of 405 operating mines are listed in the atlas. The mine location (and corresponding emissions) was designated to the SUA or non-SUA within which the mine is located.

In allocating agricultural emissions attention was paid to crop production areas as derived from the Australian Collaborative Land Use Mapping Program Geographic Information System database which includes spatial data for dry land and irrigated cropping and horticulture. Crop production areas were found to fall largely outside of SUAs and were therefore designated to non-SUAs within each state/territory.

4.3.6 Modelling the harmonisation scenarios

The harmonisation scenarios limit higher emission engines from being added to the stock, thus reducing the number of higher emitting engines over time. These scenarios are modelled by assuming that the total number of engines sold in each year does not change, other than to account for sector growth, but that the emission performance profile of the stock changes based on the proposed emission standards. The only differences between the base case and the harmonisation scenarios are the emissions and deterioration factors applied to the engines sold in a given year.

4.3.7 Modelling equipment, operational and certification costs

Engine and equipment costs

Engine costs were estimated based on data provided by industry stakeholders and information published in the literature including within the regulatory impact assessments conducted within other jurisdictions[115]. The data for non-compliant, Tier 2 and Tier 3 compliant engines is illustrated in Figure 9.

The data indicates a small retail price difference between Tier 2 and non-compliant engines (around 3%), and a modest retail price difference between Tier 3 and Tier 2 engines (around 10%), with larger price differentials indicated for small engines (19–37 kW: 11.5%) compared to large engines (>560 kW: 8%).

Tier 4 equipment costs include costs associated with engine improvements, aftertreatment technologies and equipment modifications necessary to support the engine and aftertreatment requirements. Incremental costs were estimated for Tier 4 compliant engines/equipment based on information received from suppliers to the Australian market. This information included incremental costs for bare engines and aftertreatment equipment, and price differentials from Tier 2 and Tier 3 equipment expressed as the percentage increase in overall equipment costs associated with Tier 4 compliance equipment. Such information was received from several major engine/equipment suppliers, including companies with significant market share within the construction and mining, agricultural and power generation segments.

Retail costs to consumers of Tier 4 compliant equipment include not only costs related directly to technology changes to meet emission standards, but also costs associated with broader improvements and technological advances. Given that the cost savings arising from broader productivity improvements cannot be accounted for within the impact analysis (due to such improvements varying substantially between models), it is justifiable to restrict incremental costs associated with Tier 4 compliant equipment to equipment modifications directly related to meeting emission standards.

In using the cost information collated from Australian suppliers, emphasis was therefore placed on data sets which specifically sought to exclude costs related to engine and equipment improvements not directly associated with achieving compliance with emission standards. This approach is in accordance with the methodologies applied in non-road diesel regulation impact assessment studies conducted in the US and Europe. Further information on the US and European approaches are provided in Appendix F.

The cost information received from industry stakeholders for Tier 4 compliant equipment varied substantially between equipment types and power rating categories. For this reason cost differentials were applied for individual equipment types and power rating categories, with stock-weighted average costs subsequently derived based on the engines/equipment inventoried to be sold into the Australian market on an annual basis[116].

The stock-weighted average costs were calculated over the range of non-road diesel engines/equipment including bare (loose) replacement engines, power generation sets and drives, and agricultural and construction and mining equipment.

Australian annual sales stock-weighted average incremental costs, based on Tier 2 and Tier 3 to Tier 4 price differential data received from industry suppliers, are illustrated in Figure 10. The projected stock-weighted average incremental costs were compared to cost information sourced from the US and European non-road diesel impact

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[115] US EPA (2004a), Van Zeebroeck et al. (2009)

[116] ENVIRON (2010)

assessments[117] and Australian on-road diesel emission standard cost-benefit studies[118], as documented in Appendix F. The projected costs were concluded, based on such comparisons, to be sufficiently conservative to account for bare engine costs, aftertreatment equipment and costs related to engine modifications directly associated with meeting Tier 4 emission standards.

Figure 9: **Costs of non-compliant, Tier 2 and Tier 3 engines based on industry data collated**

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[117] Van Zeebroeck et al. (2009), US EPA (2004a)

[118] Coffey Geosciences (2003)

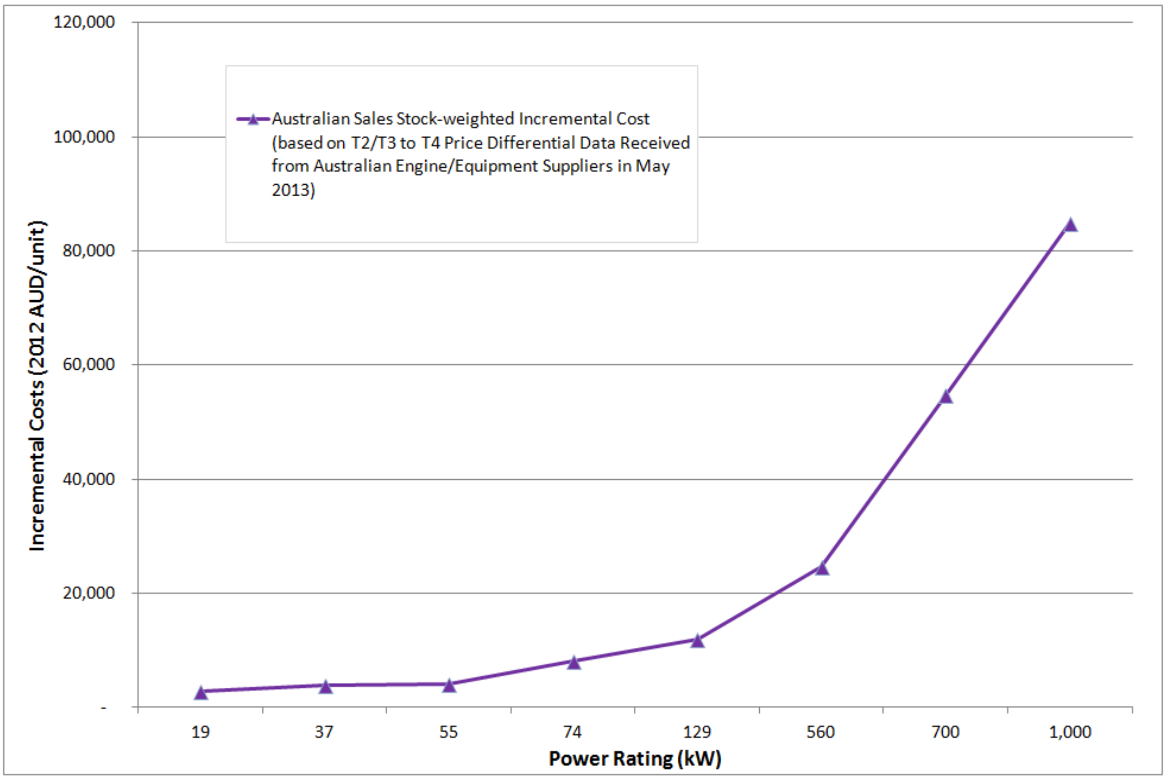

Figure 10: Incremental costs for Tier 4 compliant equipment based on industry data collated

The stock-weighted average percentage increase in non-road diesel equipment costs associated with Tier 4 compliance was estimated to be in the range of 7–10% across power rating categories. (Note that this percentage is expressed as the percentage increase in the cost of the overall piece of equipment, rather than a percentage increase in the cost of the diesel engines only.) These percentages are in accordance with the projections received from individual agricultural, construction and mining equipment suppliers, which were generally in the range of 5–11%, and accord with the percentages within the US and European regulatory impact analyses[119].

Operating and maintenance costs

Consideration was given to fuel, operating and maintenance costs (and possible cost reductions in the case of fuel savings).

Industry indicated that non-compliant and Tier 1 engines are likely to continue to be used due to their higher fuel efficiency (about 5%) compared to Tier 2 engines[120]. Incremental costs associated with a potential 5% increase in fuel consumption were taken into account in the report for the uptake of Tier 2 engines in place of non-compliant or Tier 1 engines.

Information received from several major non-road diesel engine and equipment suppliers during the development of this report indicates that Tier 4 final engines and equipment will result in significant fuel savings compared to Tier 2 and Tier 3 engines, although these savings vary depending on the aftertreatment technologies applied. Fuel savings in the

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[119] Van Zeebroeck et al. (2009), US EPA (2004a)

[120] Information provided by a major construction and mining equipment supplier, and confirmed by other industry stakeholders.

range of 5–20% are reported for Tier 4 engines compared to Tier 2 engines[121]. Fuel savings for Tier 4 engines compared to Tier 3 engines are estimated to be up to 5% according to one industry representative[122] and 5% or greater according to another[123]; however, the fuel savings due to reduced diesel consumption by Tier 4 engines may be partially offset by the diesel exhaust fluid costs in the event that selective catalytic reduction (SCR) technology is used. In such cases, the use of diesel exhaust fluid is estimated to increase fluid costs by 2–3%. Fuel efficiency improvements of Tier 4 may also be offset, or partially offset, by reductions in fuel efficiency if exhaust gas recirculation (EGR) technology is used, with a reduction in fuel efficiency of 2–5% estimated. Taking into account the factors affecting overall fluid costs (i.e. fuel and diesel exhaust fluid related costs) a fuel cost saving of 2.5% was conservatively assumed for Tier 4 engines, with this assumption broadly supported by industry stakeholders[124].

Fuel costs related to the uptake of Tier 2 engines, and fuel savings due to the uptake of Tier 4 engines, were calculated based on a diesel retail cost of 150 cents per litre. The price of diesel was projected to increase over the 2011 to 2040 period in accordance with the US Energy Information Administration price forecast[125]. The projected 2040 retail price was held constant for subsequent years.

There is no substantial change in other operational costs associated with the uptake of Tier 2 and Tier 3 engines; however, for Tier 4 compliant engines, associated operational and maintenance costs arise for diesel particulate filter cleaning and SCR catalyst replacement. Incremental annual operating costs were noted to vary significantly by equipment type and power rating class. Based on the literature[126], and taking into account the projected Australian Tier 4 stock mix, maintenance costs were estimated to range from 0.4% for 19–37 kW equipment to 2.5% for greater than 560 kW equipment. Maintenance costs for middle power rated equipment are estimated at about 1.2%. These incremental annual operating costs are expressed as percentages of the purchase cost of Tier 4 compliant equipment.

Engine certification costs

Engine certification costs may be incurred by manufacturers to demonstrate compliance with any new emission standards. Costs to cover new engine certification and testing, and administrative costs are estimated to be in the range of $60,000–90,000 per engine family[127]. Such costs apply equally to all engine families for all manufacturers regardless of the markets into which the manufacturer sells. If certification and testing carried out by manufacturers to meet US and EU regulations are accepted in Australia, additional certification costs will not be incurred by companies with significant local market share[128]; however, if local standards do not recognise foreign certification and testing, additional costs will be imposed on such manufacturers. Furthermore, industry suppliers which do not sell into US and EU markets may not currently carry out certification and testing of their engine families. Provision was therefore made for compliance costs within the impact analysis.

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[121] Kobelco, Cummins, Clark Equipment

[122] Caterpillar

[123] Clark Equipment, Kobelco

[124] Based on the outcomes of the non-road diesel engine industry consultation meeting held on 17 April 2013.

[125] US EIA (2013)

[126] US EPA (2004a), Van Zeebroeck et al. (2009), MJ Bradley & Associates (2008)

[127] US EPA (2004a)

[128] The leading five brands account for about 60% of non-road diesel engines sold into the Australian market, either as loose engines or integrated within equipment, with the top 10 brands representing more than 80% of the units sold nationally. Further information is provided in Appendix A.

It is noted that certification costs represent a very minor compliance cost compared to engine and equipment costs associated with Tier 4 (Stage IV) equipment. The impact analysis is therefore not particularly sensitive to the assumptions made in relation to such costs. The cost benefit analysis undertaken to inform possible revisions to the EU NRMM Directive, for example, excluded consideration of certification costs on the grounds that such costs were unlikely to be significant in terms of overall assessment outcomes[129].

4.3.8 Monetisation of benefits

Health costs and benefits arising from emissions are estimated using unit damage costs which relate costs (benefits) in dollars to each tonne of primary $PM_{2.5}$ and NO_x emitted (reduced). A more detailed discussion of the approach to monetising benefits is provided in Appendix G.

For primary $PM_{2.5}$, reference was made to the unit damage costs developed for Australia by Aust et al. (2013) which accounted for the following impacts:

- mortality associated with chronic exposure to $PM_{2.5}$
- acute effects on morbidity:
  - respiratory hospital admissions associated with $PM_{2.5}$
  - cardiovascular hospital admissions associated with $PM_{2.5}$
- building soiling.

Mortality associated with acute exposure to $PM_{2.5}$ was not included in the derivation of the unit damage costs. The damage costs results are therefore likely to represent conservative estimates of total health impacts from exposure to $PM_{2.5}$.

Mortality, and specifically chronic mortality, has been identified as the most important health endpoint in the valuation of PM health effects[130]. To assess this effect it is necessary to place a monetary value on the so-called ‘value of a statistical life’ (VSL). This is typically derived based on the ‘willingness to pay’ approach in which the willingness of individuals to pay to avoid a specific health effect is established. The VSL is defined as the aggregated economic value society places on reducing the average number of deaths by one. The ‘value of a life year’ (VOLY) is an estimate of the value society places on reducing the risk of premature death, expressed in terms of saving a statistical life year. Health effects due to PM emissions have typically been monetised in international studies based on the unit costs for the VSL, the VOLY, hospitalisation for respiratory disease and hospitalisation for cardiovascular disease.

Based on damage costs established for the United Kingdom (UK), Aust et al. (2013) developed unit damage costs for application in Australia by adjusting to account for differences between the VOLY in the UK and Australia, as well as differences in currency and inflation[131]. Aust et al. (2013) based the Australian VOLY on the Australian Safety and Compensation Council (ASCC) valuation of VOLY[132]. While noting the inherent uncertainties in VSL estimates, the ASCC recommended a ‘ballpark average’ of $6 million for VSL (in AUD 2008), with sensitivity analysis recommended at $3.7 million and $8.1 million.

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[129] Van Zeebroeck et al. (2009)

[130] Aust et al. (2013)

[131] Aust et al. (2013)

[132] ASCC (2008)

The Australian Department of Finance and Deregulation's Office of Best Practice Regulation (OBPR) considers a value of \$3.7 million to be the most credible estimate of the VSL, and \$151,000 the best estimate for the VOLY[133]; however, subsequent studies have supported the use of a \$6 million VSL with sensitivity analysis at \$3.7 million and \$8.1 million as recommended by the ASCC[134].

A VSL of \$6 million has been used in air pollution-related regulatory impact statements recently accepted by OBPR. The regulatory impact statement (RIS) for adopting Euro 5/6 standards for light vehicles applied a VSL of \$6 million (in AUD 2008) in the impact analysis and conducted sensitivity analysis at \$3.7 million and \$8.1 million[135]. The RIS on options to reduce emissions from wood heaters[136] used damage costs derived for the *Australian Government Fuel Taxation Inquiry: The Air Pollution Costs of Transport in Australia*, which in turn were based on a VSL of \$6 million, adjusted to reflect years of life lost[137].

This report similarly adopts the ASCC recommended values for average VSL, with the recommended lower and upper bound values tested in the sensitivity analysis (refer to Appendix I).

Unit damage costs for NO_x derived for use in the economic analysis to inform the Ambient Air Quality National Environment Protection Measure variation were used in the impact analysis for non-road diesel engines[138].

Health costs (benefits) were quantified based on disaggregated $PM_{2.5}$ and NO_x emissions (emission reductions) and projected health damage functions for each ABS SUA and non-SUA within which such emissions (emission reductions) occurred. Health damage functions indicate the health costs likely to be incurred as a result of emissions and are given on an SUA-specific basis to account for different population densities. These functions are expressed as health costs in dollars per tonne of emission (\$/tonne). This accounts for different exposure potentials, and hence health costs/benefits depending on the location at which the emission/emission reduction is projected to occur. The manner in which unit damage functions were derived for each SUA and non-SUA for 2011 and projected for future years, taking into account population and economic growth rates, is documented in Appendix G.

$PM_{2.5}$ emissions quantified represent 'primary pollutants' emitted directly from the engine as exhaust emissions. Exposure to primary pollutants is greatest closest to the source of the release. Unit damage costs are therefore assigned based on the specific location at which $PM_{2.5}$ emissions are projected to occur; however, health damage costs due to NO_x emissions are dominated by exposure to nitrate particles which represent a 'secondary pollutant' formed in the atmosphere from chemical reactions. Given the time for secondary particle formation, and the rate of such formation being a function of the local environment (e.g. meteorology, presence of other air pollutants such as ammonia), the relationship between NO_x emissions and associated health effects is less certain. The compilation of detailed source inventories and chemical transformation modelling would be required for the quantitative assessment of health costs (benefits) due to secondary pollutants (pollutant reductions). Data availability and modelling limitations in Australia preclude the implementation of such an approach to quantify health costs and benefits in this report. So as not to ignore the health effects of NO_x emissions, and the benefits of realising health

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[133] Office of Best Practice Regulation (OBPR), Value of Statistical Life, www.dpmc.gov.au/deregulation/obpr/docs/ValuingStatisticalLife.pdf

[134] Jalaludin et al. (2009), NEPC (2011b)

[135] DIT (2010b)

[136] BDA Group (2013)

[137] AEA Technology Environment (2002)

[138] Pacific Environment (2013a)

benefits through emission reductions, damage functions for NO_x are primarily applied within larger metropolitan areas where nitrate formation and population exposure is most likely to coincide with emissions, hence capturing the majority of likely NO_x benefits for the purpose of this report. The NO_x unit damage functions for each SUA and non-SUA applied in the study are documented in Appendix G.

4.4 Impact analysis results

4.4.1 Overview

Benefits and costs of the impact analysis are presented in this section. The key costs are associated with the following:

- higher engine costs, measured at the retail level for equipment to account for changes in equipment required to accommodate the new engines
- administration costs to implement, oversee and monitor the new standards
- industry compliance costs
- potential increments in operating, maintenance and fuel consumption costs.

The key benefits are measured as reduced health costs resulting from lower emissions of harmful air pollutants. Fuel savings within some scenarios represent a further benefit.

The benefits and costs related to the harmonisation scenarios documented are compared to the main base case scenario in this section. Comparisons with upper bound and lower bound base cases are provided in a sensitivity analysis (refer to Appendix I).

Benefits and costs were discounted using a social discount rate of 7% (in real terms). Results from sensitivity analysis conducted using social discount rates of 3% and 10% are documented in Appendix I.

Whereas measures applicable to both mobile and stationary engines in the range of less than 19 kW to over 560 kW are considered in this section, sensitivity analysis is conducted on the effects of excluding stationary and greater than 560 kW engines to reflect the coverage of the current EU NRMM Directive (refer to Appendix I).

4.4.2 Stock projections

The sale of new ≥19 kW engines as projected by the model is shown in Figure 11. Sales of engines are projected to grow at around 3% per annum. Over 90% of engine sales occur for industrial, construction/mining and agricultural applications. Although engine sales for all activities are projected to increase, sales growth is fastest in the construction/mining and industrial sectors. These two activities cover around two-thirds of all sales. The high sales growth for these sectors reflects strong growth in output for the mining and construction industries. Projected in-service stock numbers are illustrated by market sector in Figure 12.

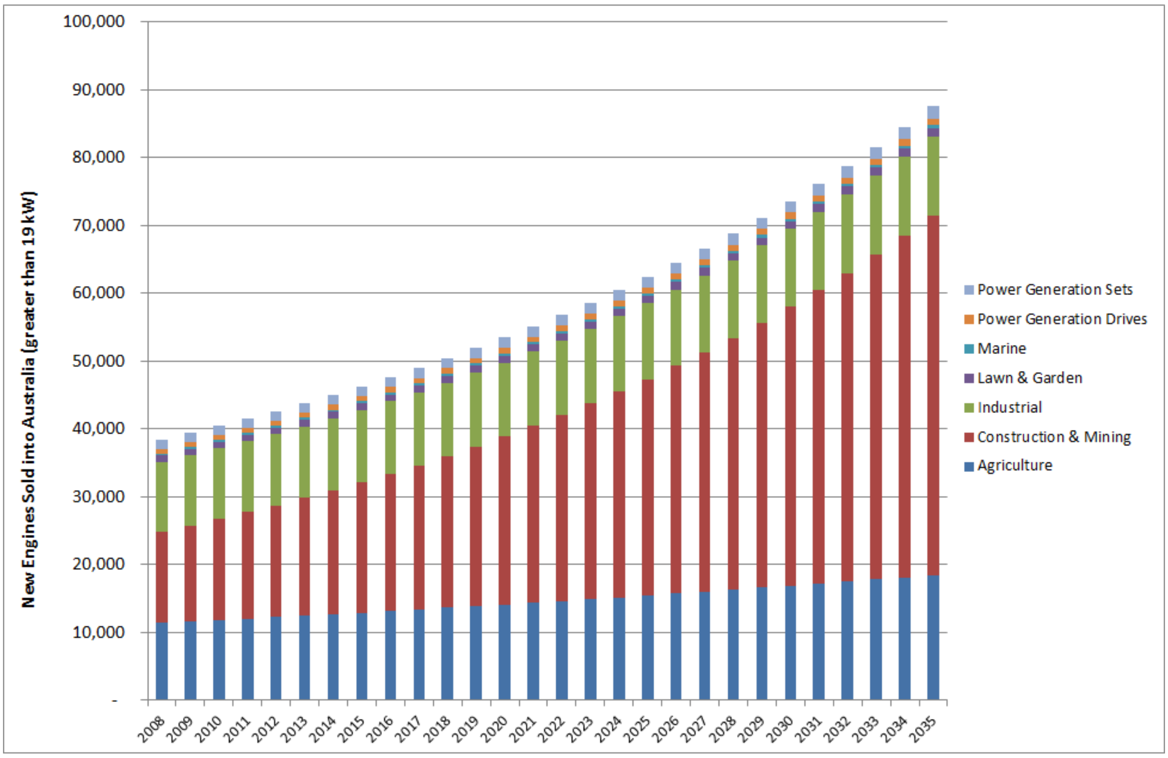

Figure 11: Projected new engines/equipment sales by activity for ≥19 kW engines

4.4.3 Costs

There are three categories of costs computed for introducing new emission standards:

- capital costs, comprising additional engine and equipment costs
- ongoing costs, covering operating, maintenance and fuel costs
- administration and compliance costs, comprising the set-up costs for the standards and ongoing administration costs.

The costs are detailed for each harmonisation scenario in Appendix H. A breakdown of the costs by year for the stepped harmonisation scenario 3 is shown in Figure 13. Annual costs, and the present values of costs, are shown for each harmonisation scenario in Figure 14 and Figure 15 respectively.

The present values of the costs of the harmonisation scenarios are in the range of $2–6 billion. The most significant component of costs covers additional engine and equipment costs, which represents approximately 65% of the total costs for harmonisation scenario 1, and over 80% of the total costs for the two harmonisation scenarios involving Tier 4 standards, on a present value basis.

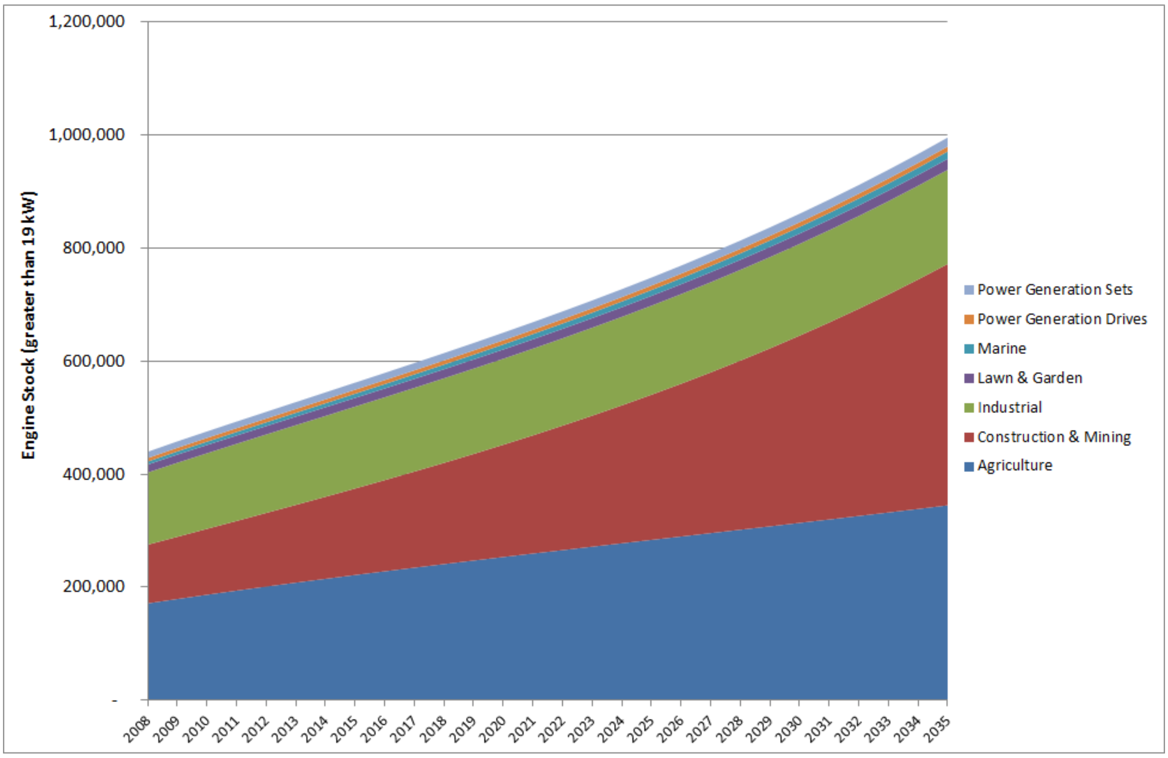

Figure 12: **Projected total stock of equipment/engines by activity for ≥19 kW engines**

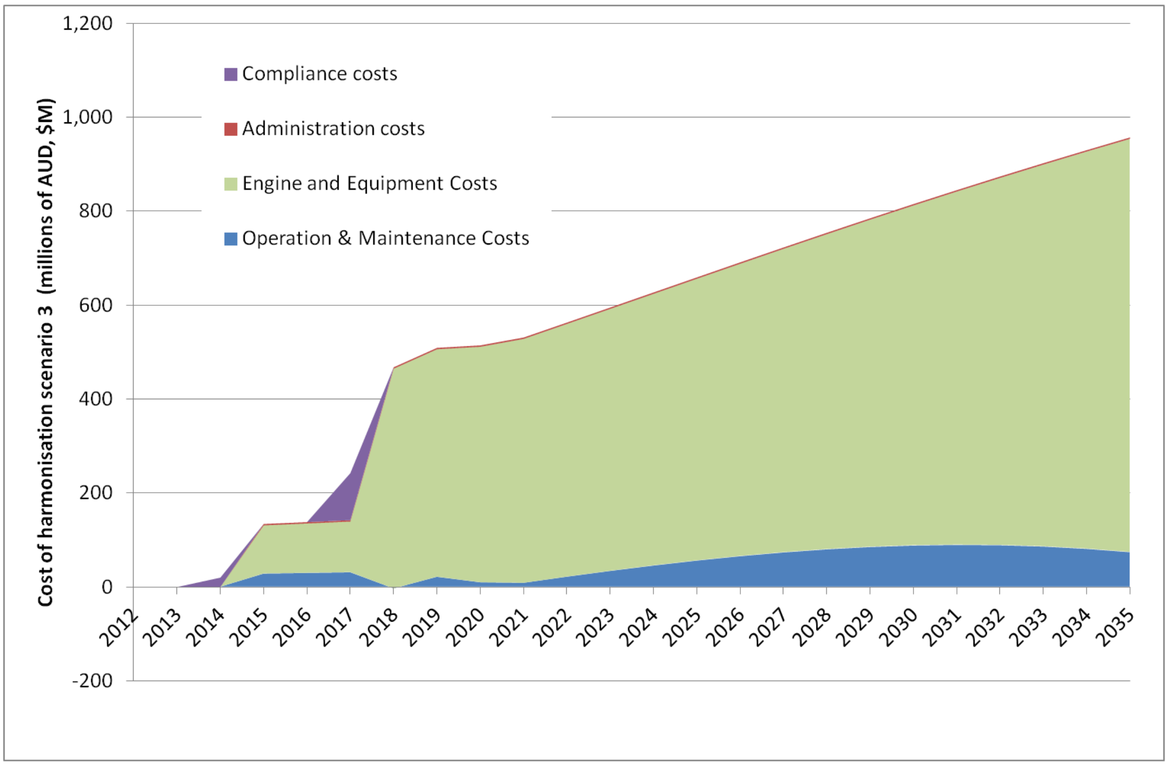

Figure 13: **Costs by year of harmonisation scenario 3, including incremental fuel costs/savings**

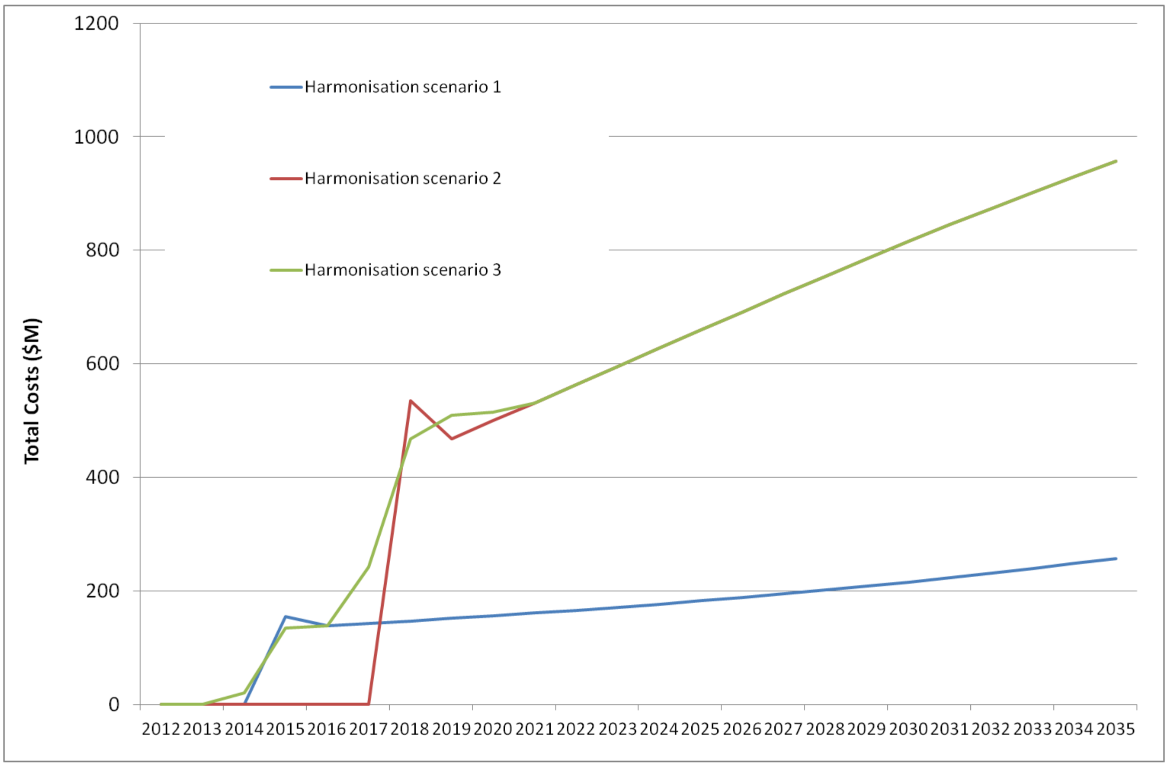

Figure 14: Total costs by year for each of the three harmonisation scenarios, including incremental fuel costs/savings

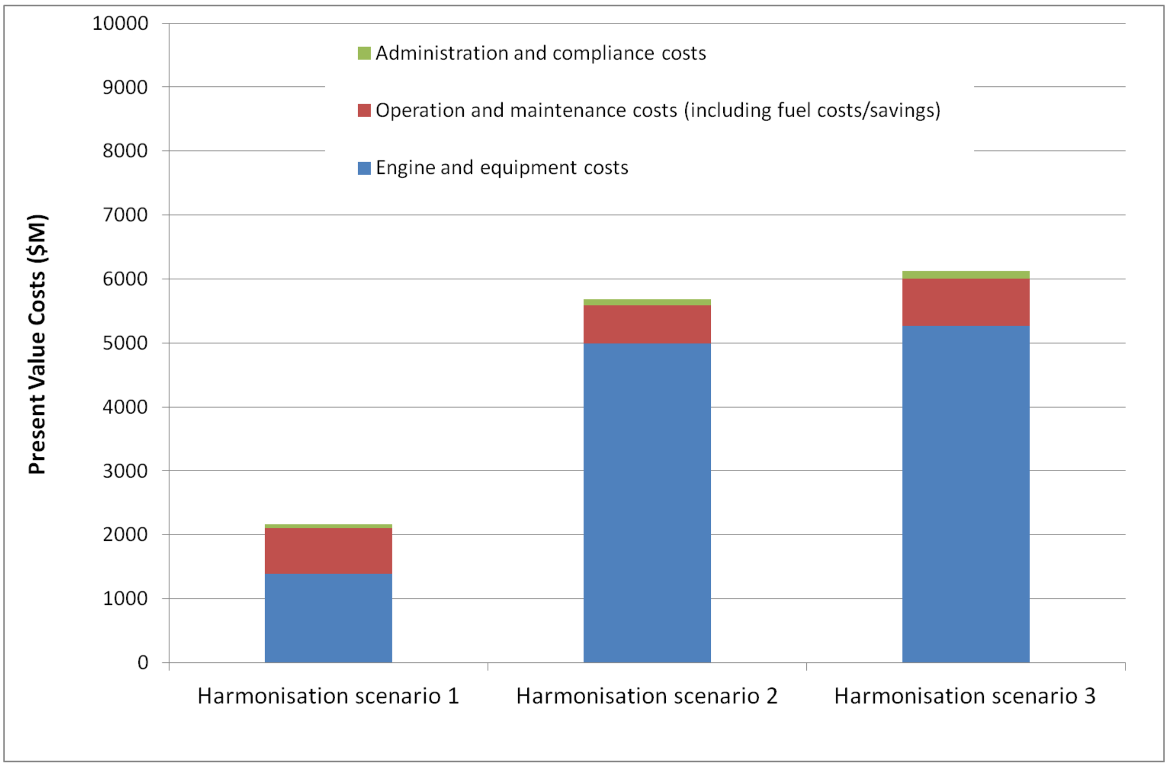

Figure 15: Present values of costs[139]

4.4.4 Benefits

The main benefit arises from reduced health costs due to lower emissions of harmful air pollutants. Projected emission reductions achievable under the three harmonisation scenarios are shown for 2035 in Figure 16. Several key results emerge in evaluating the emission reductions achieved by 2035:

- Harmonisation scenario 1, comprising the implementation of Tier 3 / Stage III A emission standards only, was associated with an approximate 23% reduction in NO_x and $PM_{2.5}$ emissions. The emission reductions under this scenario are lower than under the two scenarios incorporating Tier 4/ Stage III B/ Stage IV emission standards (discussed below), due to the less stringent controls associated with Tier 3/ Stage III A emission standards.
- Harmonisation scenarios 2 and 3, comprising the implementation of Tier 4 / Stage III B / Stage IV emission standards, resulted in a greater than 60% reduction in $PM_{2.5}$ emissions and about a 50% reduction in NO_x emissions. The stepped harmonisation scenario 3 was associated with the highest reductions in $PM_{2.5}$ emissions (67% reduction) and NO_x emissions (53% reduction) relative to the main base case.

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[139] Present values of costs calculated using an annual discount rate of 7% and covering costs from 2015 to 2055.

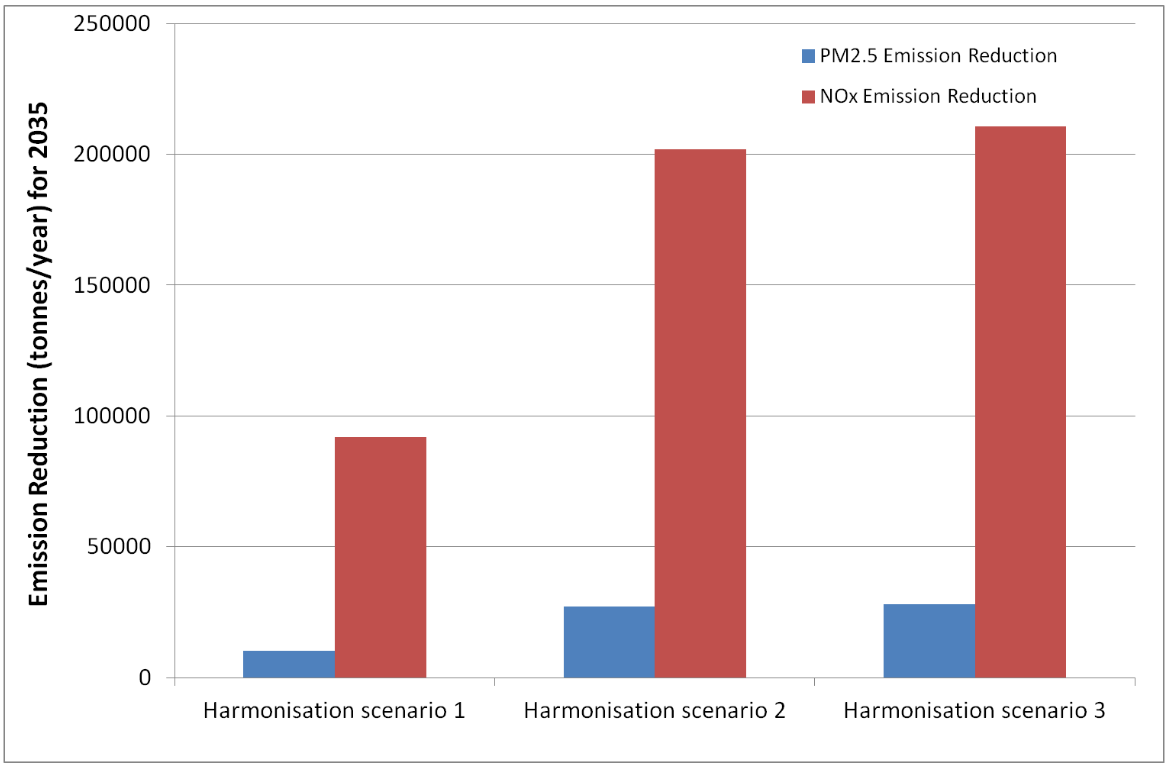

Figure 16: Projected emission reduction compared to main base case for 2035

Estimated annual reductions in health costs for the three harmonisation scenarios are shown in Figure 17. Peak annual and average annual health cost reductions for each scenario during the 2015 to 2055 period are tabulated in Table 15. The stepped harmonisation scenario 3 was projected to result in the greatest benefits, followed by scenario 2. Significantly lower benefits were projected for harmonisation scenario 1, which involved the implementation of Tier 2 / Tier 3 emission standards only.

Table 15: Projected average annual and peak annual health cost reductions over the 2015 to 2055 period by harmonisation scenario

Harmonisation scenario	Average annual health cost reduction (AUD$M 2012)	Peak annual health cost reduction (AUD$M 2012)
1	353	538
2	864	1,385
3	915	1,439

Although implementation of the harmonisation scenarios is restricted to 2035, emission reductions are projected to continue post-2035 due to the proportion of lower emitting engines within the in-service fleet having increased relative to the main base case. The peak in annual health cost reduction is projected to occur in 2035, with health cost reductions gradually reducing in subsequent years due to the gradual decline in the proportion of lower emitting engines over time following the end of the implementation period in 2035.

Figure 17: Projected health cost reductions of harmonisation scenarios compared to main base case

Despite the harmonisation scenarios being associated with higher NO_x emission reductions (Figure 16), the bulk of the savings in health costs come from the reduction in $PM_{2.5}$ emissions, as illustrated in Figure 18 for harmonisation scenario 3. This is due to the higher damage costs associated with $PM_{2.5}$ emissions (refer to Appendix G). $PM_{2.5}$ emission reductions comprise 82% of the health cost reduction in 2035 for harmonisation scenario 1, and 87% of the health cost reduction in 2035 for scenarios 2 and 3.

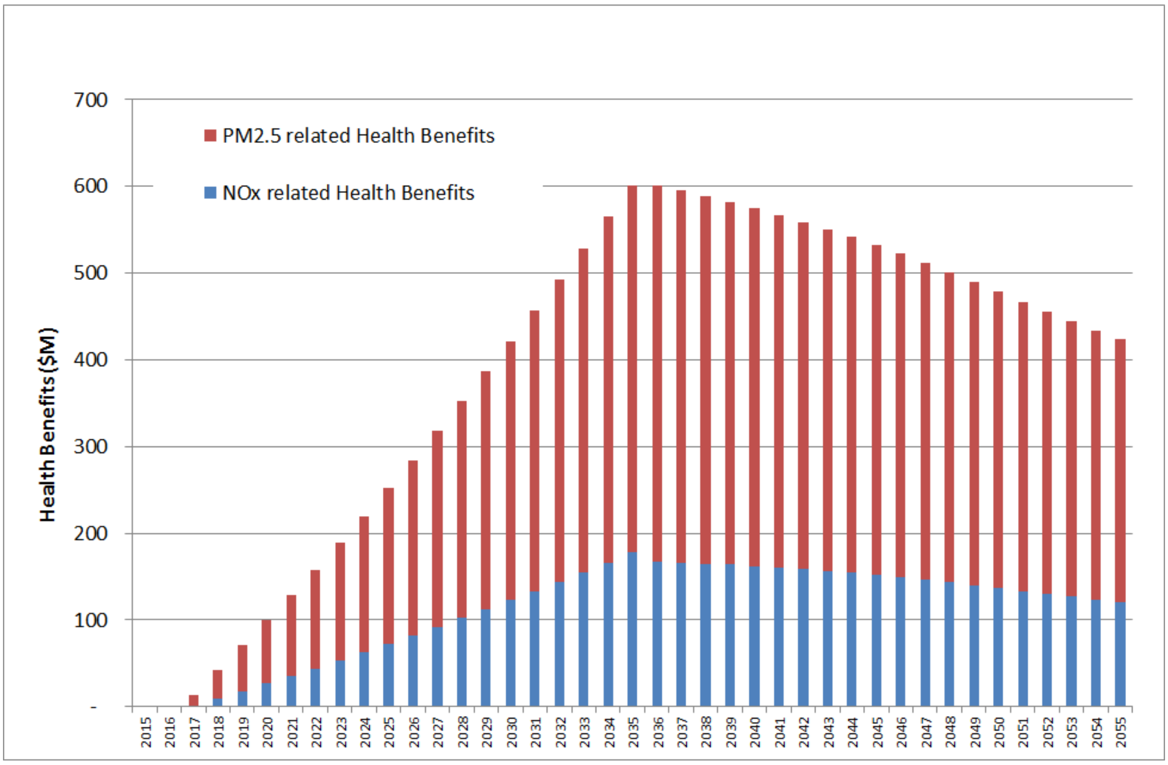

Figure 18: **Projected health cost reductions by pollutant, based on harmonisation scenario 3, compared to the main base case**

4.4.5 Net benefits

The net benefit of each harmonisation scenario in each year was calculated by subtracting the discounted cost from the discounted benefit for each year. The present value was then calculated by summing the net benefit in each year over the period 2015 to 2055. Estimates of the net benefits are shown in Table 16.

Table 16: Present value of net benefits for harmonisation scenarios (AUD$M 2012)

Harmonisation scenario	Description	Present value of net benefits[a] (AUD$M 2012)
1	Tier 3 / Stage III A in 2015	1,257
2	Tier 4 / Stage III B / Stage IV in 2018	1,952
3	Stepped Tier 3 / Stage III A in 2015 and Tier 4 / Stage III B / Stage IV in 2018	2,244

(a) Present values are calculated over the period from 2015 to 2055 using a social discount rate of 7% real.

Temporal variations in projected benefits and costs associated with the stepped harmonisation scenario 3 are illustrated in Figure 19. Projected net benefits for all three harmonisation scenarios are illustrated in Figure 20, compared to the main base case.

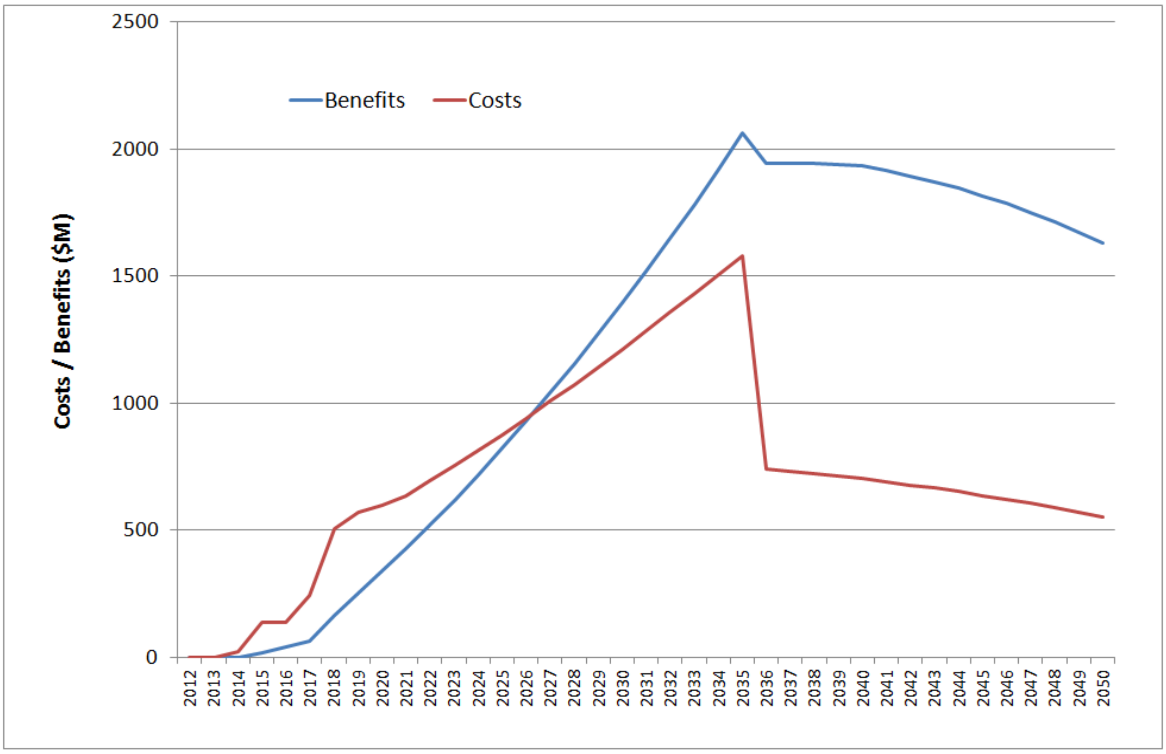

Figure 19: Projected benefits and costs for stepped harmonisation scenario 3

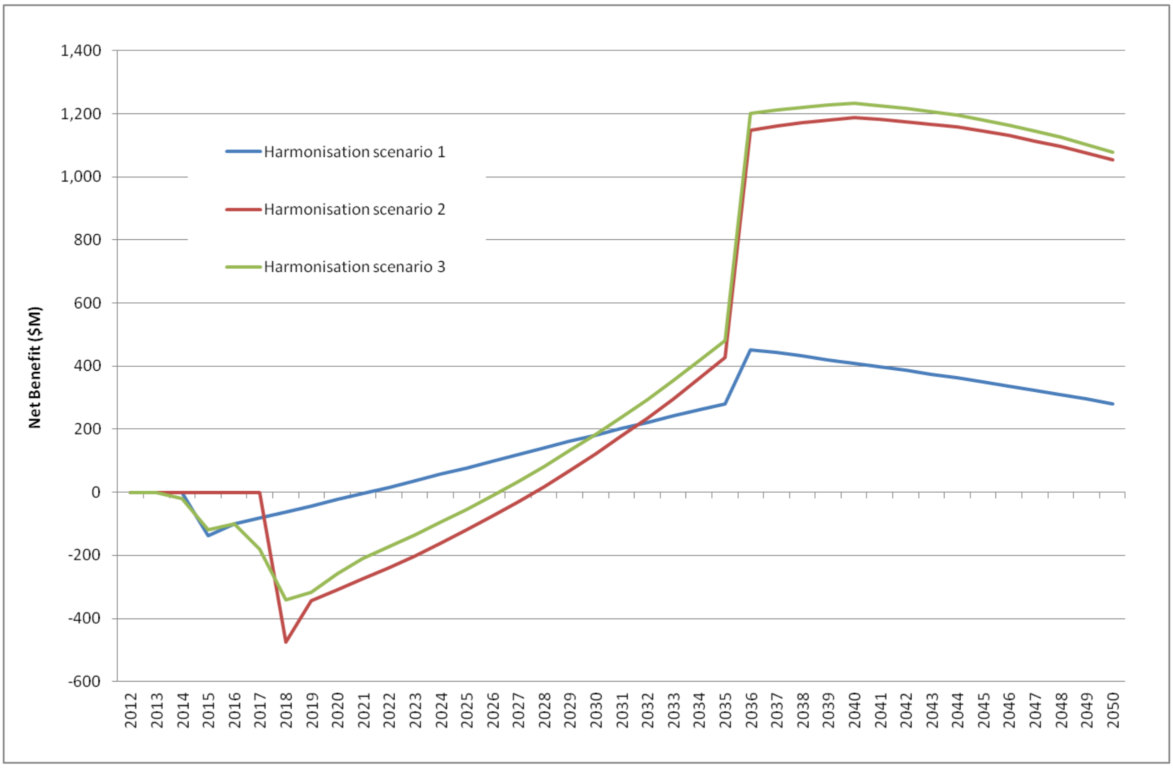

Figure 20: Projected net benefit for harmonisation scenarios across the modelling period

For harmonisation scenario 2 in which Tier 4 / Stage III B / Stage IV standards are implemented, cumulative benefits take 10 years from the date of implementation to exceed cumulative costs. This reduces to nine years when preceded by Tier 3 / Stage III A standards in the stepped approach of harmonisation scenario 3. The delay in realising a positive net benefit reflects the high relative cost margin for installed Tier 4 engines, with the cost of purchasing the engines being born upfront, whereas the health benefits are spread out over the longer term. Discounting procedures therefore tend to discount the health benefits more than the costs.

For harmonisation scenario 1, in which only Tier 3 / Stage III A standards are implemented, cumulative benefits take about five years from the date of implementation to exceed cumulative costs, although the overall net benefit to be gained is significantly lower than for the scenarios with Tier 4 requirements.

4.5 Broader impacts

The following section provides an indication of the impact of the harmonisation scenarios evaluated on each stakeholder group likely to be affected by their implementation. The continuation of business as usual will also impact on stakeholder groups; however, these impacts are not discussed in detail here. Most notable is the increase in health effects and costs associated with increasing diesel engine exhaust emissions.

4.5.1 Administration

The three harmonisation scenarios would incur costs associated with the development of new standards, in addition to monitoring of compliance and enforcement. It has been assumed that administrative costs would be in the order of $3 million per year for each year that the standards are in place based on administrative costs for product-based standards.

4.5.2 Engine manufacturers (abroad) and engine distributors (Australia)

Costs that may be incurred by engine manufacturers include variable costs, such as incremental hardware and assembly costs and associated mark-ups, and fixed costs for research and development, engine tooling, engine certification and equipment redesign.

All non-road diesel engines sold in Australia are manufactured in other countries and imported. The leading five brands account for about 60% of non-road diesel engines sold into the Australian market, either as loose engines or integrated within equipment, with the top 10 brands representing more than 80% of the units sold nationally. In each of the non-road diesel engine size categories above 19 kW, the five most popular brands account for between 60% and 90% of units sold. Sales within the large engine power rating category (>560 kW) are dominated by three brands. All of the leading non-road diesel engine brands marketed in Australia with significant market share sell engines into US and/or European markets.

Fixed costs related to research and development and engine tooling are unlikely to be significant given that all engines are manufactured abroad, and that major manufacturers with significant local market share also supply other countries already implementing non-road diesel standards.

Variable engine costs associated with Tier 2 / Tier 3 / Stage III A compliant engines are evident within retail price differentials, as these costs are frequently passed on to the consumer. In Australia, the retail cost of Tier 2 engines is on average 3% higher than non-compliant and Tier 1 engines. Tier 3 engines are on average about 10% more costly than Tier 2 engines. No equipment modifications are generally required to accommodate the uptake of Tier 2 and Tier 3 engines. Significantly higher engine costs are associated with Tier 4 / Stage III B / Stage IV compliant engines, with such engines typically requiring additional hardware (aftertreatment devices) in addition to equipment modifications which add to the cost. The increase in non-road diesel equipment costs associated with Tier 4 compliance is in the range of 5–10% across power rating categories, compared to Tier 2 and Tier 3 compliant engines[140] (refer to Appendix F).

Engine certification costs may be incurred by manufacturers to demonstrate compliance with new standards. Costs to cover new engine certification, testing and administrative costs are estimated to be in the range of $60,000–90,000 per engine family[141]. Such costs apply equally to all engine families for all manufacturers regardless of the markets into which the manufacturer sells. If certification and testing carried out by manufacturers to meet US and EU regulations is accepted in Australia, additional certification costs will not be incurred by companies with significant local market share. Furthermore, as non-road diesel engine emission standards are being implemented by a growing number of other countries (e.g. Canada, Russia, China, Brazil, South Korea and India), the proportion of engine manufacturers undergoing foreign engine certification and testing is expected to increase.

If the new standards do not recognise foreign certification and testing, additional costs will be imposed on engine manufacturers abroad. Furthermore, industry suppliers which do not sell into US and EU markets may not currently carry out certification and testing of their engine families. Some provision was therefore made within the impact analysis for compliance costs based on the costs per engine family given above; with $20 million allocated for compliance costs related to Tier 3 / Stage III A emission standards and $100 million for compliance costs for Tier 4 / Stage IIIB / Stage IV emission standards. Given that certification costs represent a very minor compliance cost compared to engine and equipment costs associated with Tier 4 (Stage IV) equipment, the impact analysis was not particularly sensitive to the assumptions made in relation to such costs. The cost benefit analysis undertaken to inform possible revisions to the EU NRMM Directive, for example, excluded consideration of certification costs on the grounds that such costs were unlikely to be significant in terms of overall assessment outcomes[142].

Engine distributors within Australia are likely to be impacted by the need to alter product lines. This may result in administrative and operational costs associated with communications both with engine manufacturers abroad, and with equipment and machinery manufacturers and customers within Australia. In some cases, distributors may be required to source equipment from alternative sources to continue providing the required equipment to existing customers.

In summary, it is not expected that engine manufacturers or distributors that currently sell non-road diesel engines and equipment in other regulated markets would incur significant additional compliance costs. Distributors that do not currently sell engines and equipment in regulated markets may incur additional compliance costs, including emissions testing and administrative costs.

4.5.3 Equipment and machinery manufacturers (Australian)

Most non-road diesel machinery sold into the Australian market is manufactured and assembled abroad, including agricultural, industrial, mining and construction equipment (refer to Appendix A). Non-road diesel engine and equipment imports originate from over 60 different countries[143]. In cases where non-road diesel machinery is assembled locally, the design and component manufacture may be conducted abroad. Non-road diesel machinery

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[140] Note that this percentage is expressed as the percentage increase in the cost of the overall piece of equipment, rather than a percentage increase in the cost of the diesel engines only.

[141] US EPA (2004a)

[142] Van Zeebroeck et al. (2009)

[143] ABS (2009)

which is designed, manufactured and assembled in Australia represents a minor share of the overall non-road diesel equipment market. The construction and mining sector is dominated by equipment imports. Within the agricultural sector, local manufacturers tend to be small firms specialising in lower value products tailored to niche markets. Although the lawnmower segment is heavily concentrated in Australia, with Victa and Honda Australia supplying a large share of the Australian market[144], it is noted that Victa is the only local manufacturer of garden equipment engines[145]. In mid-2008, Victa was acquired by US-based engine manufacturer Briggs and Stratton, with Briggs and Stratton (Australia) known to import some engines from the US that comply with US regulations[146].

The integration of Tier 2 / Tier 3 / Stage III A compliant engines within equipment and machinery is not expected to result in any additional costs other than that related to purchasing the lower emitting bare engine. The retail cost of Tier 3 engines is on average about 10% higher than Tier 2 engines, with the cost of Tier 2 engines being about 3% higher than non-compliant engines (refer to Section 4.3.7). Significantly higher variable engine costs are associated with Tier 4 / Stage III B / Stage IV compliant engines, with such engines typically requiring hardware (aftertreatment devices) in addition to equipment modifications, which adds to the cost. The increase in non-road diesel equipment costs associated with Tier 4 compliance is in the range of 5–10% across power rating categories, compared to Tier 2 and Tier 3 compliant equipment[147] (refer to Appendix F). Variable costs may be passed on to the consumer.

Equipment and machinery manufacturers which do not supply US or European markets may incur fixed costs associated with the re-engineering of equipment and re-tooling of manufacturing facilities. Given that most non-road diesel machinery sold into Australia is manufactured abroad, and in many cases also assembled abroad, such costs are not expected to impact many Australian-based companies.

Equipment and machinery manufacturers in Australia may also incur fixed costs associated with the testing of imported engines as documented for engine manufacturers. As in the case of engine manufacturers and distributors, companies that currently sell non-road diesel equipment in other regulated markets would not incur significant additional compliance costs. Companies that do not currently sell engines and equipment in regulated markets may incur additional compliance costs, including emissions testing and administrative costs. If certification and testing carried out by manufacturers to meet US and EU standards is accepted in Australia, additional certification costs will not be incurred by companies with significant local market share.

Fixed and variable equipment costs and administrative costs incurred by manufacturers may be passed on to consumers.

4.5.4 Consumers

Consumers of non-road diesel engines and equipment range from large-scale industrial, mining and agricultural operations, to construction companies and commercial facilities, and small-scale land practices using diesel-powered lawn and garden equipment (e.g. golf course and estate maintenance).

Engine and equipment costs faced by suppliers may be passed on to consumers. The introduction of Tier 3 / Stage III A emission standards is projected to result in a 10%

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[144] IBIS (2012a)

[145] EPHC (2010)

[146] EPHC (2010)

[147] Note that this percentage is expressed as the percentage increase in the cost of the overall piece of equipment, rather than a percentage increase in the cost of the diesel engines only.

increase in engine retail prices compared to Tier 2 engines, with an increase in the range of 10–15% compared to non-compliant engines. Significantly higher engine costs are associated with Tier 4 / Stage III B / Stage IV compliant engines, with such engines typically requiring hardware (aftertreatment devices) in addition to equipment modifications, which adds to the cost. The increase in non-road diesel equipment costs associated with Tier 4 compliance is in the range of 5–10% across power rating categories[148] (refer to Appendix F); however, retail costs for Tier 4 compliant equipment include not only costs related directly to technology changes to meet emission standards, but also costs associated with broader improvements and technological advances, which have not been accounted for in the impact analysis.

There is no substantial change in other operational costs associated with the uptake of Tier 2 and Tier 3 engines. In some cases incremental operating costs may be incurred due to some Tier 2 engines being less fuel efficient than non-compliant or Tier 1 engines (approximately 5% less fuel efficient). Tier 4 compliant engines incur operational and maintenance costs associated with diesel particulate filter cleaning and SCR catalyst replacement. Incremental annual operating costs vary significantly by equipment type and power rating class, ranging from 0.4% of the equipment cost for 19–37 kW equipment, to 2.5% for greater than 560 kW equipment, and 1.2% for equipment in middle power rating classes[149]. Running costs for Tier 4 equipment are partly offset by reductions in fuel-related costs. Taking into account fuel savings associated with Tier 4 engines, partially offset by diesel exhaust fluid costs in the event that SCR technology is used, an overall reduction in fluid cost in the range of 2–3% is projected.

With new standards, access to less expensive, non-compliant or lower-tier engines and equipment will be restricted. This is likely to result in an increase in retail price for equipment and engines due to the additional costs associated with the production of Tier 4 compliant engines and equipment. An increase in operating costs is also anticipated; however, such costs are projected to be minor in comparison to engine and equipment costs, and partly offset by overall fluid cost savings.

4.5.5 Community/equipment operators

The harmonisation scenarios are expected to result in an improvement in the emission performance of engines imported into Australia. As such, it is expected that community members and equipment operators will have fewer adverse health effects associated with non-road diesel engine emissions, compared to business as usual. Average annual health cost reductions from 2015–2055 are estimated to be $915 million for harmonisation scenario 3, $864 million for scenario 2 and $353 million for scenario 1 (Table 15).

4.6 Other benefits

4.6.1 Additional health and environmental benefits

Only health benefits associated with exposures to primary and secondary particles due to $PM_{2.5}$ and NO_x emissions were costed during the current study. Health benefits due to reduced exposure to air toxics, such as benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, dioxin, and polycyclic organic matter were not accounted for. Furthermore, health costs associated with ozone exposures are expected to reduce due to reductions in NO_x emissions, which are a precursor of ozone concentrations.

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[148] Note that this percentage is expressed as the percentage increase in the cost of the overall piece of equipment, rather than a percentage increase in the cost of the diesel engines only.

[149] These incremental annual operating costs are expressed as percentages of the purchase cost of Tier 4 compliant equipment.

Other potential environmental benefits not quantified during the study include reduced building and material damages, reductions in crop losses and reduced impacts on ecosystems.

4.6.2 Climate benefits

Non-road diesel engine emissions have the potential to impact the global climate due to the emission of CO_2 and elemental carbon (black carbon). CO_2 is a greenhouse gas which contributes to global warming, and associated global climatic changes. Diesel combustion also contributes significantly to global black carbon emissions[150]. Black carbon is an air pollutant formed through the incomplete combustion of fossil fuels as well as bio-based fuels. As discussed in Section 2.3.3, black carbon is a strong absorber of solar radiation and has been concluded to exert a positive (warming) radiative forcing[151]. The effect of black carbon aerosols is enhanced when combined with dust and other chemicals in air. These black carbon mixtures are conjectured to be the second biggest contributor to global warming, representing about 60% of the global warming effects of CO_2[152].

The impact of new emission standards on energy (and greenhouse gas emissions) is a function of the effect of such standards on fuel consumption from compliant engines. The projection of impacts on fuel economy is complicated by the range of engine technology designs which can be developed to meet emission standards. Whereas a reduction in fuel efficiency was associated with progression from non-compliant/Tier 1 to Tier 2 compliant engines, overall in the US there has been a slight improvement in fuel consumption across the progressive implementation of emission reduction tiers up to Tier 3[153]. This fuel economy improvement was most pronounced during the latter half of the 1990s when the first emission standards came into effect; however, shorter-term trends in fuel efficiency are noted to have varied between individual emission reduction stages (i.e. moving from Tier 1 to Tier 2, Tier 2 to Tier 3, Tier 2 to Tier 4 or Tier 3 to Tier 4).

Based on information received from non-road diesel engine manufacturers during the development of this report, it was concluded that Tier 4 final engines are likely to result in significant fuel savings compared to Tier 2 and Tier 3 engines. Fuel savings in the range of 5–20% are generally reported for Tier 4 engines compared to Tier 2 engines; however, fuel efficiency improvements may be partially offset by reductions in fuel efficiency if EGR technology is used, with an estimated reduction in fuel efficiency of 2–5% due to such technology.

Fuel reductions have climate benefits due to reductions in CO_2 emissions; however, reductions in PM emissions also have significant climate benefits. Despite some remaining uncertainties about black carbon that require further research, the US EPA recently concluded that currently available scientific and technical information provides a strong foundation for making mitigation decisions to achieve lasting benefits for public health, the environment, and climate. Due to its shorter atmospheric lifetime and strong global warming potential, targeted strategies to reduce black carbon emissions have been identified as being able to provide climate benefits within the next several decades[154]. In October 2012, Australia became a partner in the Climate and Clean Air Coalition, an alliance of approximately 60 nations, intergovernmental organisations, the private sector and civil society, committed to rapid action to reduce short-lived but highly potent pollution including black carbon and tropospheric ozone[155].

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[150] Bond et al. (2004)

[151] DEFRA (2007)

[152] Roberts & Jones (2004)

[153] US EPA (2004a)

[154] US EPA (2012), UNEP & WMO (2011)

[155] DCCEE (2012), www.unep.org/ccac

5 Conclusion

Air pollution remains a major risk to health and the environment, with combustion-related air pollution receiving particular focus in terms of health and climate effects[156]. Elevated levels of some common air pollutants can result in an increase in respiratory and cardiovascular effects in humans and contribute to premature deaths and cancer risks. Although Australia's urban air quality is generally good, the concentration of ambient air pollutants and the impact they can have on community health and wellbeing remains a concern. The Australian Government is investigating measures to manage particle emissions, including options for actions to reduce particle pollution from products such as wood heaters and non-road spark ignition engines and equipment.

Emissions from non-road diesel engine applications in Australia contribute to elevated fine particle and ozone concentrations, impact on human health and are associated with potential climate effects. Despite consuming less diesel fuel than road transport nationally, the non-road diesel sector is estimated to emit higher fine particle emissions than on-road diesel vehicles. Whereas on-road diesel vehicles have been subject to increasingly stringent emission standards and state and territory management programs, non-road diesel engine emissions have remained unregulated in Australia with the exception of engines applied in underground mining.

Australia has benefited somewhat from the importation of cleaner engines compliant with non-road diesel emission standards issued by the US, EU and other jurisdictions; however, a review of the emission performance of new engines and equipment sold into the Australian non-road diesel market indicates that a significant portion of units are non-compliant or are lagging in compliance relative to units sold into the US and EU markets. Market forces within the non-road diesel engine sector in Australia have not, therefore, successfully driven the transition to cleaner (lower emission) engines. Furthermore, the more costly nature of engines compliant with the recent, most stringent standards (US Tier 4 and EU Stage III B), due to their incorporation of aftertreatment technologies, is expected to deter the future uptake of such engines in Australia. It is also speculated that the number of 'dirtier' engines and equipment being sold into Australia may increase as other countries introduce or tighten regulations and manufacturers seek alternative markets.

Non-road diesel engine emissions are projected to grow significantly over the next two decades as a result of the forecast increase in fuel consumption by this sector, and given the cost impediment to the uptake of significantly cleaner non-road diesel engines and equipment. This growth in emissions will increase associated health costs. Should the emission performance profile of new non-road diesel engines sold into the Australian market remain relatively unchanged in the next two decades, annual health costs are projected to exceed $2 billion (AUD 2012) by 2035. The projected increase in health costs associated with non-road diesel engine emissions, and the failure of the market to successfully drive a transition toward cleaner engines, provides a strong case for action.

This report assesses three harmonisation scenarios that could be employed to reduce non-road diesel engine emissions in Australia so as to reduce the associated adverse impacts on human health and the environment. Due to uncertainties regarding future changes in the emission performance of non-road diesel engines/equipment, given business as usual, a main base case was defined with upper and lower bound scenarios to accommodate options identified in consultation with stakeholders. Despite variations in the extent of the increase, all three BAU scenarios were associated with projected

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[156] WHO (2013), WHO (2012), IARC (2012), US EPA (2012), UNEP & WMO (2011)

increases in non-road diesel engine emissions and associated health costs in the absence of any intervention.

The analysis of the harmonisation scenarios found that non-road diesel engine emissions could be reduced up to 67% for $PM_{2.5}$ emissions and up to 53% for NO_x emissions by 2035, compared to the main base case. Additionally, the analysis indicated that new standards could result in health cost reductions peaking in the range of $540–1440 million per annum in 2035, compared to the main base case. Taking into account compliance costs, the present value of net benefits, calculated over the 2015 to 2055 period, was estimated to be in the range of $1257–2244 million.

The greatest health benefits and overall net benefits are associated with harmonisation scenario 3, which comprises the stepped introduction of Tier 3 / Stage III A emission standards followed by Tier 4 / Stage III B / Stage IV emission standards.

In summary, the analysis provides a strong case for action in relation to non-road diesel engine emissions in Australia. The harmonisation scenarios assessed are likely to make progress to varying degrees towards reducing emissions and their associated health impacts. For the purposes of this report, current in-service compliance of non-road diesel engines and equipment is assumed to be largely Tier 2/Stage II. The level of compliance has a key impact on results. Any further analysis should take account of the latest evidence of compliance. The analysis also assumes start dates from 2015 and 2018, which are illustrative only. A later start date of three to four years is likely to be more realistic.

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Appendix A: Overview of the non-road diesel engine sector

A1 Industry associations

The most pertinent industry associations are the Australian Diesel Engine Distributors Association (ADEDA); the Construction and Mining Equipment Industry Group (CMEIG); and the Tractor and Machinery Association of Australia (TMA).

ADEDA was formed by a number of loose diesel engine distributors and it is estimated that its members represent over 70% of total sales for this sector. CMEIG is a non-profit organisation representing the construction and mining equipment industry and allied equipment and services on issues impacting business delivery. CMEIG members represent over 80% of annual sales in this sector. The TMA is a member based industry organisation representing the interests of manufacturers, distributors, importers, dealers and other companies active in the Australian agricultural mechanisation industry.

Other associations identified include: Heavy Engineering Manufacturers' Association, Australian Construction Industry Forum, Airport Industries Australia, Australian Marine Industry Federation, Association of Mining and Exploration Companies, Association of Australasian Diesel Specialists, and Farm and Industrial Machinery Dealers Association of Australia.

A2 Non-road diesel engines and equipment sales

A2.1 Annual numbers sold into the Australian market

Detailed non-road diesel engine and equipment sales information was purchased from industry associations for 2008 during a previous scoping study[157]. This data set forms the basis for the description of the non-road diesel sector and the establishment of projections to inform the development of this report, with reference made to more recent sales information where such information was made available at no additional cost.

Non-road diesel engine and equipment sales estimates inventoried for 2008 are given in Table A1, and illustrated by market segment in Figure A1[158]. Broad industrial applications (including industrial, commercial, construction and mining applications) are estimated to account for 50% of non-road diesel engine/equipment sales. Agricultural applications represent around 30%, and power generation 11%. Other applications include lawn and garden (3.4%), light commercial (1.8%), marine propulsion (0.9%) and forestry (0.1%).

The heavy construction, mining, industrial and commercial equipment sales were dominated by hydraulic excavator sales, accounting for 38% of equipment nationally. Other significant equipment types included: skid steer loaders (27%), road rollers (10%), wheel loaders (9%), dump trucks (6%), motor graders (4%) and backhoe loaders (3%).

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[157] ENVIRON (2010)

[158] ENVIRON (2010)

Table A1: Estimated non-road diesel engine/equipment sales for 2008

Market segment	Engine/equipment description	Estimated number of units sold (2008)	Basis for estimate
Industrial (Industrial, Commercial, Construction, Mining)	Engines for construction & mining equipment	3,422	(a)
	Engines for industrial pumps	2,903	(a)
	Engines for 'other' industry equipment (f)	3,726	(a)(h)
	Engines for miscellaneous industry applications	1,611	(a)
	Tractors (expected to include airport equipment)	562	(b)
	Forklifts	609	(b)
	Cranes and lifting equipment	2,850	(b)(h)
	Heavy construction, mining, industrial & commercial equipment (e.g. loaders, rollers, dumpers)	12,441	(c)(h)
Agricultural	Engines for pumps & irrigation	3,964	(a)
	Engines for agricultural vehicles	20	(a)
	Engines for 'other' agricultural applications(g)	60	(a)
	Agricultural tractors	12,101	(d)(h)
	Combine harvester-threshers	538	(d)
	Windrowers	66	(e)
	Self-propelled sprayers	333	(d)
	Balers	0	(j)
Power generation (various markets)	Power gen drives – prime power	1,320	(a)
	Power gen drives – standby power	1,326	(a)
	Power gen drives – marine auxiliary	118	(a)
	Power gen sets – prime power	1,382	(a)
	Power gen sets – standby power	1,190	(a)
	Power gen sets – marine auxiliary	202	(a)
	Power gen sets – miscellaneous	869	(a)
Lawn and garden	Ride on or tractor lawn mowers	1,900	(b)
Light commercial	Welders, air compressors, pressure washers	1,000	(b)
Marine (<37 kW)(i)	Propulsion engines for pleasure boats (<37 kW)	440	(a)
	Propulsion engines for work boats (<37 kW)	28	(a)
	Propulsion engines for fishing boats (<37 kW)	6	(a)
	Marine propulsion engines (not specified) (<37 kW)	17	(a)
Forestry	Log skidders	30	(c)
Potential non-road applications	*Vehicle propulsion (used)*	*1,199*	(h)
TOTAL		**56,233**	

(a) ERG International ‘Loose Diesel Engine and Gen Set Sales Data’ for 2008, supplemented by data from several industries not reporting to ERG.

(b) Assumed equivalent to estimated imports.

(c) ERG International ‘Construction and Mining Machinery Sales Data Set’ for 2008. Specific equipment types include: hydraulic excavators, mini excavators, wheel loaders, dozers, crawler loaders, motor graders, scrapers, dump trucks (rigid and articulated), backhoe loaders, skid steer loaders and road rollers.

(d) Sales data obtained for 2008 from the TMA.

(e) Based on 2004 sales data, taking into account PAE (2005) estimate that 99.2% of in-service combines are diesel.

(f) Includes engines for waste removal equipment, road sweeping and cleaning equipment, hydraulic power packs and welding sets.

(g) Includes engines for hay making machinery, oil tresses, lawn and garden outdoor power equipment.

(h) Includes used engine imports. Data received from Australian Quarantine and Inspection Service (2009).

(i) Only marine engines smaller than 37 kW were included in the inventory, given that such engines are covered specifically by US non-road diesel emission standards.

(j) No self-propelled balers are used in Australia according to the TMA (pers. comm. October 2009).

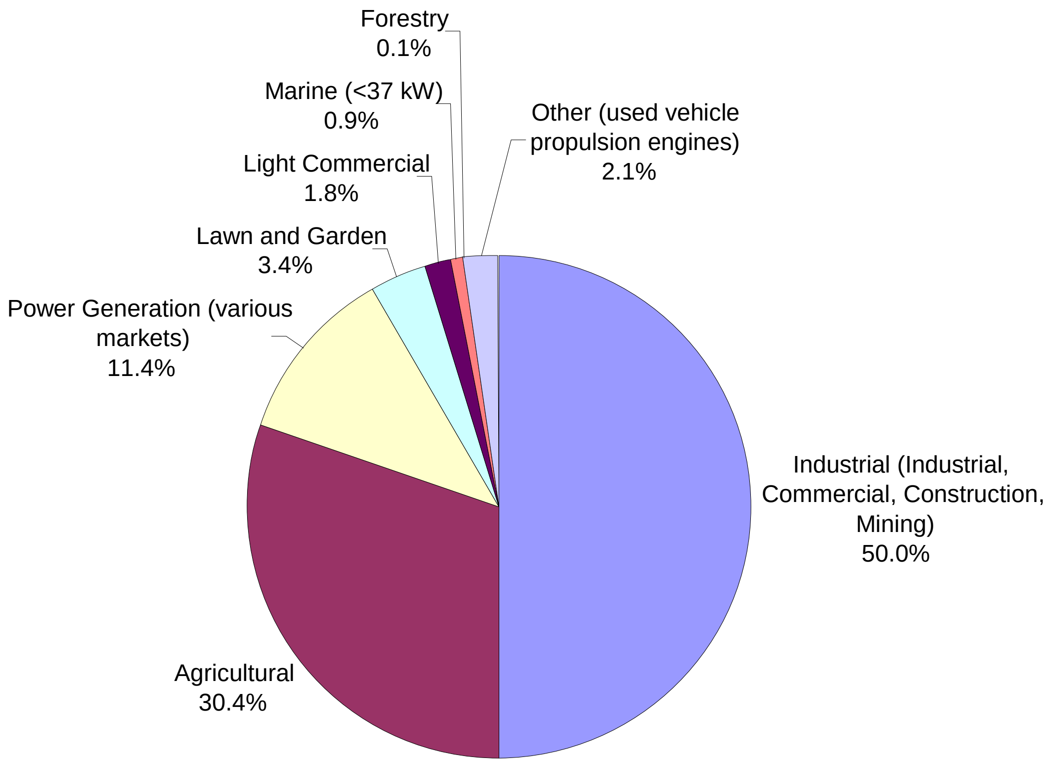

Figure A1: Non-road diesel engines and equipment sold in Australia (2008) by market segment, excluding locomotive engines and large (>37 kW) marine engines[159]

Estimated annual sales of non-road diesel engine/equipment in 2008 (56,233 units) represents about 9% of the extrapolated in-service non-road diesel population for that year (~620,000 units). This percentage is comparable to that documented for the US (10%)[160].

Based on 2011–12 sales information, tractor sales were noted to have grown in terms of the numbers of tractors sold by about 1.4% since 2008–09[161], with approximately 13,000 tractors sold into the Australian market in 2011–12. The numbers of combine harvesters was noted to almost double over this period. When tractors and combine harvesters are considered together, these implements dominate agricultural non-road diesel equipment sales, an annual average increase of about 2% in the number of units sold is estimated. However, 2011–12 loose engine sales to the agricultural sector were about 23% lower by number of engines than was reported in 2008, primarily due to the decrease in the number of engines sold for pumping and irrigation applications[162]. Recent sales data for non-road diesel equipment sold into the construction and mining sector was sought during the development of this report, but was not available without additional data acquisition costs being incurred.

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[159] Data sources: ERG International (2009), TMA (2009), supplemented by industry data

[160] Over 650,000 pieces of diesel equipment, which are covered by non-road diesel rulemaking, are reported to be sold in the US each year (US EPA 2004a). The in-service numbers are given as six million pieces of non-road diesel equipment. Non-road diesel equipment sales therefore comprise about 10% of in-service non-road diesel equipment numbers in the US.

[161] 2001–02 to 2011–12 sales data provided by the TMA (March 2013).

[162] 2012 sales data provided by ADEDA (March 2013).

A2.2 Sales by state and territory

Non-road diesel engine/equipment sales data by state was available for 76% of total units sold in 2008. The bulk of the sales were within Queensland (30%), NSW (25%), Victoria (21%) and Western Australia (14%) (Figure A2).

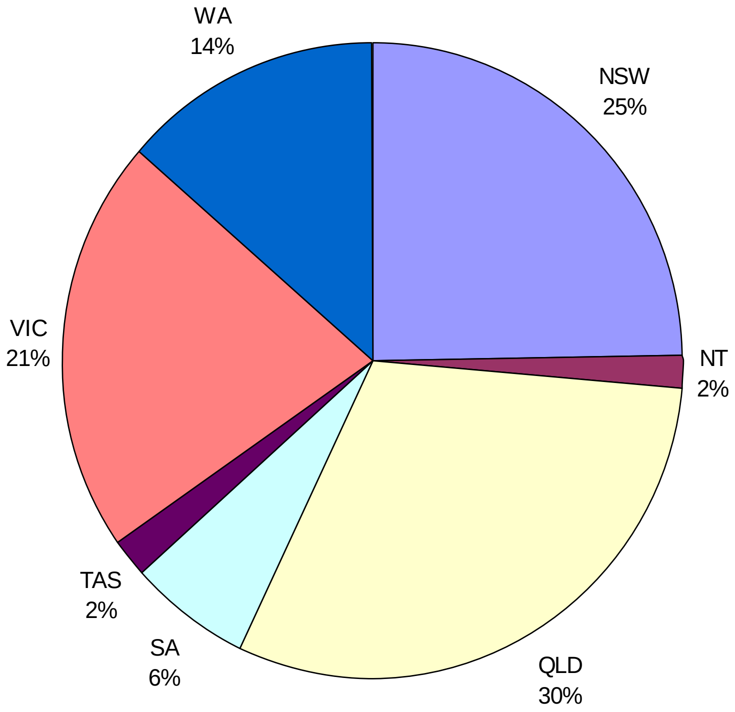

Figure A2: Non-road diesel equipment sales by state (2008; % of units sold)[163]

A2.3 Sales by power rating

Engine rating information, available for approximately 85% of 2008 non-road diesel engine/equipment sales, is summarised in Table A2. Small diesel engines (less than 19 kW) make up almost 30% of the total market and 4% of engines sold are greater than 560 kW. Almost 50% of the diesel engines and equipment sold into the Australian market are in the 19–130 kW power rating range.

Agricultural pumps and irrigation applications are dominated by small engines, with over 80% having a power rating of less than 19 kW[164]. In comparison, industrial pumps tend to comprise larger engines with about 25% being less than 19 kW. About 20% of agricultural tractors are in the less than 19 kW range, with about 65% of tractors being in the 19–130 kW range[165]. Over 60% of ride-on/tractor mowers are estimated to fall in the less than 19 kW range.

A wide range of engine sizes are used for construction and mining equipment and other industrial applications, reflecting the diversity of the equipment used by the industrial market segment. About 86% of heavy industrial (construction, mining) equipment falls in the 19–

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[163] Data sources: ERG International (2009), TMA (2009), supplemented by industry data.

[164] 2008 and 2012 sales data provided by ADEDA.

[165] 2001–02 to 2011–12 sales data provided by the TMA (March 2013).

560 kW range, with only 6% less than 19 kW[166]. Loose diesel engines reported to be sold into the construction and mining equipment market comprise a significantly larger proportion of small engines, with 38% being less than 8 kW. This may be due to smaller engines having shorter useful lives and requiring more frequent replacement, or may be indicative of engines reported as being for construction and mining application being applied for other applications.

Table A2: Engine ratings of non-road diesel engines sold in Australia (2008)[167]

Percent of engines by category		Cumulative percentage	
Power rating	**Share of total (%)**	**Power rating**	**Cumulative share of total (%)**
<8 kW	19	<8 kW	19
8–19 kW	11	<19 kW	30
19–37 kW	16	<37 kW	46
37–56 kW	18	<56 kW	64
56–130 kW	14	<130 kW	78
130–225 kW	9	<225 kW	87
225–560 kW	9	<560 kW	96
>560 kW	4		100

Almost 60% of power generation drives sold are in the less than 19 kW range, compared to 28% of generator sets. Gen sets sold also include a higher percentage (11%) of greater than 560 kW engines compared to power generation drives (2%).

In line with US non-road diesel regulations only marine propulsion engines in the range under 37 kW are included in the study. Based on sales information for 2008 and 2012, between 40% and 60% of such marine engines are under 19 kW in power rating[168].

A3 Non-road diesel engine/equipment imports and exports

A3.1 New engine/equipment imports and exports

Based on ABS import statistics it is estimated that 73,900 non-road diesel engines and equipment were imported into Australia in 2008, with imports having originated on an annual basis from over 60 different countries[169]. Imports accounted for all the non-road diesel engines sold into Australia and for over 90% of the non-road diesel machinery sold into Australia for above-surface applications. The percentage of imports by country of origin for the most significant equipment categories is given in Table A3.

Japan, the US and China are the largest sources, together accounting for approximately 67% of total imports across these equipment categories. The US accounts for about 22% of all imported diesel engines. Japan accounts for over 40% of self-propelled construction equipment, over 30% of compression-ignition engines and almost 20% of agricultural tractors. China is a significant source of cranes and lifting equipment, accounting for about 70% of such imports, and also contributing 12% of diesel engine imports. Germany, Italy, the UK, South Korea, Sweden, France and India represent minor sources of total imports.

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[166] 2008 sales data provided by CMEIG.

[167] Data sources: ERG International (2009), TMA (2009), supplemented by industry data

[168] 2008 and 2012 sales data provided by ADEDA.

[169] ABS (2009)

Table A3: Country of origin of equipment categories comprising significant numbers of non-road diesel engine/equipment, given as a percentage of total imports for each category (excluding light commercial equipment such as generators, pumps and compressors)[170]

Country of origin	Percentage of imports within equipment category[(a)]					Percentage of total imports
	Agricultural tractors	Compression-ignition engines (diesel or semi-diesel engines)	Self-propelled construction and mining equipment	Ships, derricks, cranes, etc.	Tractor (other than agricultural tractors)	
Japan	19.28	32.61	43.66	2.27	1.10	27.30
USA	28.75	24.50	24.26	1.33	26.65	21.87
China	4.91	12.03	5.79	69.48	7.71	18.02
Germany	11.07	5.78	2.56	1.24	63.22	5.84
Italy	7.76	4.96	0.00	13.16	0.88	5.83
United Kingdom	1.95	6.79	2.59	1.54	0.22	4.28
Korea, Republic of	6.67	0.95	5.15	0.15	0.00	2.71
Sweden	0.01	3.83	1.72	1.98	0.00	2.41
France	2.87	1.75	1.87	0.40	0.00	1.78
India	5.97	0.21	0.00	0.45	0.00	1.35
Thailand	0.00	1.86	0.26	0.00	0.00	0.92
Indonesia	0.00	1.92	0.03	0.00	0.00	0.91
Austria	3.10	0.11	0.13	0.96	0.00	0.83
Netherlands	0.02	0.40	0.25	3.33	0.00	0.73
Viet Nam	3.09	0.02	0.29	0.01	0.22	0.67
No country details	0.00	0.00	3.74	0.00	0.00	0.67
Canada	2.12	0.12	0.31	0.12	0.00	0.55
Brazil	0.11	0.14	2.58	0.00	0.00	0.55
Malaysia	0.00	0.43	1.85	0.02	0.00	0.54
Turkey	1.93	0.01	0.02	0.00	0.00	0.39
Singapore	0.00	0.45	0.58	0.12	0.00	0.33
Spain	0.00	0.21	0.27	0.53	0.00	0.22
Belgium	0.00	0.08	0.18	0.88	0.00	0.20
New Zealand	0.03	0.09	0.16	0.61	0.00	0.17
Czech Republic	0.00	0.00	0.90	0.00	0.00	0.16
Mexico	0.00	0.32	0.00	0.00	0.00	0.15
Finland	0.30	0.01	0.37	0.05	0.00	0.14
Australia (re-imports)	0.03	0.16	0.11	0.10	0.00	0.11
Denmark	0.00	0.00	0.01	0.74	0.00	0.11

(a) Only includes countries accounting for greater than 0.1% of imports.

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[170] ABS (2009)

Availability of non-road diesel engine/equipment export data from the ABS is restricted for certain categories (e.g. construction and mining equipment) due to confidentiality considerations. Based on the available data, exports were projected to exceed 13,400 units in 2008. Sales of new non-road diesel engine/equipment are therefore expected to be about 60,000 units per year, thus confirming the new engine/equipment sales numbers inventoried.

A3.2 Used diesel engine/equipment imports

To identify the number of used engines/equipment, reference was made to data obtained from the Machinery and Military National Co-ordination Centre of the Australian Quarantine and Inspection Service[171]. Based on this information the number of used diesel imports was found to be relatively small, comprising about 1650 units (approximately 3% of total sales)[172]. However, it is important to note that used engines/equipment are only identified as being such based on the word ‘used’ being included on the paperwork accompanying imports. This number should therefore be viewed as a lower estimate of the number of used non-road diesel engines/equipment entering Australia annually.

A3.3 Major manufacturers, importers and distributors

Engine and equipment manufacturers/distributors/suppliers were identified based on industry association memberships, internet searches of popular brands and Australian representatives of such brands, and on market data obtained from the Equipment Research Group Pty Ltd (ERG International) and from IBISWorld Industry Reports[173]. ERG International is a market research company which collates data directly from industry suppliers including suppliers of non-road diesel engines and equipment. ERG International is affiliated with ADEDA and CMEIG.

A3.4 Engine manufacturers

All non-road diesel engines are manufactured abroad and imported for sale within Australia. Brands sold into the Australian market include the following (in alphabetical order):

- AGCO SISU POWER
- Ammann
- Bedford
- Bobcat
- Bomag
- CASE
- Caterpillar
- Clark Equipment
- Crossley
- Cummins
- Deutz
- Detroit
- Doosan / Daewoo
- Fiat
- Genesis
- Hitachi
- Iveco
- John Deere
- Kawasaki
- Kobelco
- Komatsu
- Kubota
- Lombardini
- Mercedes Benz
- Mitsubishi
- MTU
- Mustang
- New Holland
- Perkins
- Ruggerini
- Scania
- Sumitomo
- Toyota
- VM
- Volvo
- Volvo Penta
- Yanmar

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[171] Australian Quarantine and Inspection Service (2009)

[172] ENVIRON (2010)

[173] IBIS (2012a), (2012b), (2012c)

The leading five brands account for about 60% of non-road diesel engines sold into the Australian market, either as loose engines or integrated within equipment, with the top 10 brands representing more than 80% of the units sold nationally. In each of the non-road diesel engine size categories above 19 kW[174], the five most popular brands account for between 60% and 90% of units sold. Sales within the large engine power rating category (>560 kW) are dominated by three brands.

Some of the Original Equipment Manufacturers are involved in the manufacture of machinery and equipment for the construction, mining, industrial and agricultural sectors. These companies are discussed further in the following sections.

A3.5 Major machinery manufacturers

Over 90% of non-road diesel machinery sold into the Australian market for use in above-ground applications is designed and manufactured abroad, and imported into Australia for sale. Although some machinery is assembled locally, a significant proportion of machinery is imported already assembled.

Market information is not specifically available for the non-road diesel machinery manufacturing sector within Australia. Reference is therefore made in this section to broader market information published by IBISWorld on the machinery manufacturing sector, which includes manufacturers of a wide range of agricultural, industrial, construction and mining machinery including machinery which does not contain diesel engines and machinery used for underground mining applications. Although such information provides an indication of trends in the machinery manufacturing sector, it does not specifically relate to the local manufacture of non-road diesel equipment for use in above ground applications.

Agricultural machinery/equipment

Approximately 20 suppliers of new tractors in Australia were identified during the study, of which there are a small number of leading brands with a significant market share. Detailed information on market share could not be obtained.

Harvesters and windrower tractors and other self-propelled agricultural equipment are also imported into Australia. Sprayers and other smaller equipment, which make up a minor component of non-road diesel agricultural equipment, are either imported or manufactured in Australia; however, locally manufactured units are fitted with imported engines. Seven suppliers of self-propelled sprayers and windrower tractors in Australia were identified during the course of the study. Detailed information on market share could not be obtained.

There are a range of agricultural machinery manufacturers supplying the Australian market. The four largest industry players account for less than 10% of market share[175]. Local manufacturers tend to be small firms specialising in lower value products tailored to niche markets. Globally, large multinational companies such as John Deere and CNH which do not have manufacturing operations in Australia, dominate the industry[176]. The lawnmower segment is heavily concentrated in Australia, with Victa and Honda Australia supplying a large share of the Australian market[177].

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[174] Refer to Table A2 for power rating categories.

[175] IBIS (2012a)

[176] IBIS (2012a)

[177] IBIS (2012a)

Heavy industrial (construction, mining) machinery/equipment

The mining and construction machinery manufacturing industry has a medium level of concentration, with the top four major manufacturers accounting for about 55% of industry revenue in 2011–12[178]. This has increased in recent years, as the mining machinery segment increased in size relative to the construction equipment segment.

Industrial machinery/equipment

The industrial machinery manufacturing industry is highly fragmented. It mainly produces intermediary products used by other manufacturing industries that produce final marketable goods. The mining sector is a large downstream market for the industry. Industry concentration is low, with the top four operators accounting for an estimated 10.5% of industry revenue in 2011–12. There are over 2500 business entities in the industrial machinery manufacturing industry, and most segments of the industry are fragmented[179].

Table A4 provides a list of the companies with the most significant market shares for the mining and construction, industrial, and agricultural machinery manufacturing sectors.

A3.6 Major non-road diesel engine distributors

A significant number of major loose diesel engine distributors in Australia are members of ADEDA. Loose diesel engine distributors (and brands offered) include the following:

- Allight (Perkins, Kubota)
- Cummins (Cummins)
- Energy Power Systems (Caterpillar)
- John Deere (John Deere)
- Kubota (Kubota)
- Mercruiser (BAPG)
- MTU Detroit Diesel Australia Pty Ltd (MTU, Detroit)
- Power Equipment (Yanmar, JCB, MACE)
- SeaPower (MAN)
- Scania Australia Pty Ltd (Scania)
- Volvo / Volvo Penta (Volvo, Volvo Penta)
- Welling and Crossley (Doosan, Daewoo, Fiat/Iveco, Crossley)
- Isuzu (Isuzu)
- BT Equipment (Bomag; Kawasaki, Mitsubishi, Mustang, Sumitomo, Yanmar)
- Clark Equipment (Clark Equipment, Doosan, Bobcat).

A number of engine manufacturers import engines for direct distribution in Australia through their own distribution channels.

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[178] IBIS (2012b)

[179] IBIS (2012c)

Table A4: Machinery manufacturers and market share

Company	Estimated market share[(a)]	Source
Agricultural machinery manufacturers		
Victa	3.5%	IBIS 2012a
John Shearer (Holdings) Ltd	2.1%	IBIS 2012a
Silvan Australia	2.0%	IBIS 2012a
AF Gason Pty Ltd	1.5%	IBIS 2012a
Howard Australia Pty Ltd	1.0%	IBIS 2012a
Challenge Implements	1.0%	IBIS 2012a
Croplands	1.0%	IBIS 2012a
Mining and construction machinery manufacturers[(b)]		
Sandvik Australia	16.4%	IBIS 2012b
Atlas Copco South Pacific Holdings Pty Ltd	15.1%	IBIS 2012b
Joy Global Australia Holding Company Pty Ltd	12.6%	IBIS 2012b
Bradken Limited	11.3%	IBIS 2012b
Caterpillar Commercial Australia Pty Ltd / Caterpillar Underground Mining Pty Ltd	7.6%	IBIS 2012b
Boart Longyear Limited	7.3%	IBIS 2012b
Ludowici Limited	3.9%	IBIS 2012b
CQMS Group	2.2%	IBIS 2012b
Terex Jaques Pty Ltd	1.0%	IBIS 2012b
Industrial machinery manufacturers		
ABB Australia Pty Limited	5.4%	IBIS 2012c
Pall Filtration and Separations Pty Limited	2.5%	IBIS 2012c
RCR Tomlinson Ltd	1.4%	IBIS 2012c
Alstom Australia Holdings Limited	1.2%	IBIS 2012c
Shinagawa Refractories Australasia Pty Ltd	1.0%	IBIS 2012c
CESCO Australia Ltd	0.4%	IBIS 2012c

(a) Market share based on all machinery, not just non-road diesel machinery used in above-ground applications.

(b) A significant proportion of the machinery manufactured locally does not include diesel engines. Furthermore much of the non-road diesel machinery manufactured by companies such as Joy Global, Sandvik Australia and Caterpillar Underground Mining are used for underground mining applications.

A4 Overview of general machinery sector turnover

Imports, exports and revenue information provided in these sections relates to all machinery used in these sectors, including those that do not contain diesel engines and machinery used in underground mining applications. Information pertaining exclusively to the value of non-road diesel machinery manufacturing, import and export is not publically available. The following section should be seen as a broad indication of the machinery manufacturing sectors in Australia, rather than an indication of the level of imports, exports and revenue from non-road machinery and equipment containing diesel engines.

A4.1 Value of machinery imports

Imports of agricultural machinery grew solidly in the five years to 2011–12, in particular, from the US and China. Import penetration in the industry is forecast to increase over the next five years. Foreign multinationals, such as John Deere and CNH, dominate the industry[180].

Mining and construction machinery imports contracted at an annualised 2.6% in the five years to 2011–12. Imports as a share of domestic demand measured 63.7% in 2007–08, with an estimated decrease to 57.7% in 2012–13. This indicates a fall in the reliance on overseas producers and a more competitive domestic industry[181]. Imports grew by 78.8% in 2011–12 due to increased construction activities in Queensland. This is a one-time anomaly and IBISWorld expects imports to fall again in 2012–13.

The industrial machinery manufacturing sector produces a wide range of products, including diesel generators. Imports in industrial machinery increased by 1.4% over the past five years due to recovering economic conditions and an increase in demand for products from downstream divisions such as mining and construction. Imports are expected to satisfy 62.8% of domestic demand in 2012–13, rising to 68.2% by 2017–18[182].

The value of imports of agricultural, mining and construction, and industrial machinery in 2010–11 and 2011–12, as well as forecasts for 2012–13 are illustrated in Figure A3.

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[180] IBIS (2012a)

[181] IBIS (2012b)

[182] IBIS (2012c)

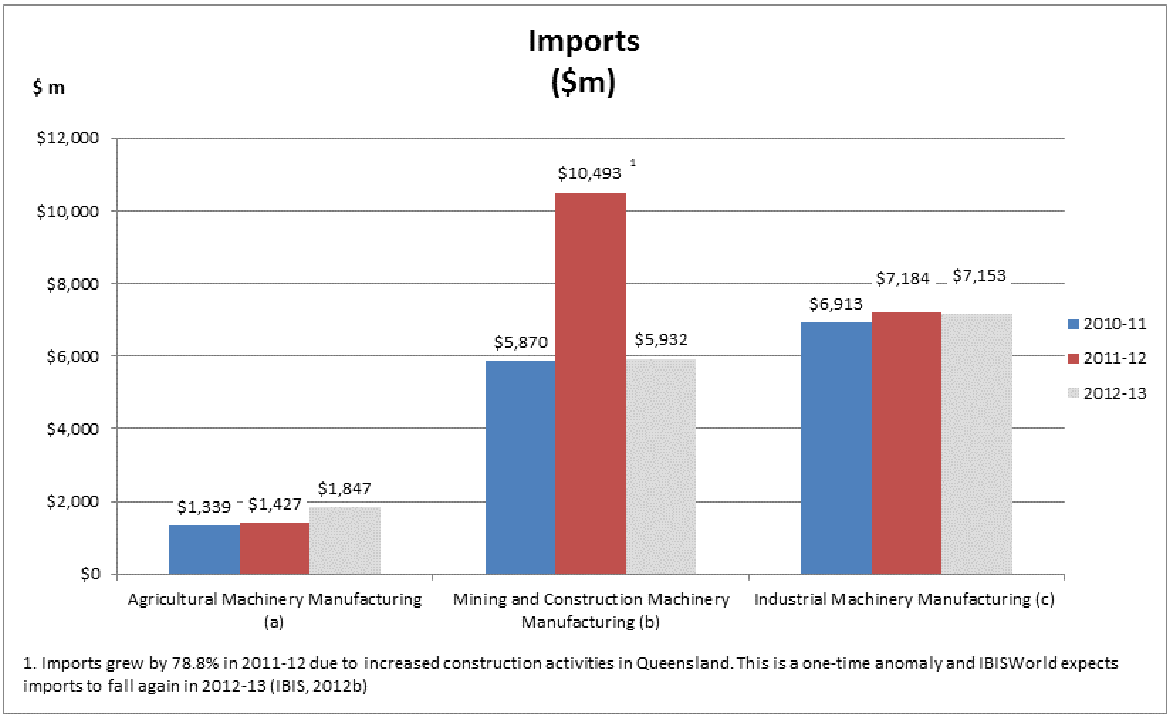

Figure A3: Import value ($million) of agricultural, mining and construction and industrial machinery 2010–11, 2011–12, and forecast for 2012–13[183].
Sources: (a) IBIS 2012a, (b) IBIS 2012b, (c) IBIS 2012c.

A4.2 Value of machinery exports

Exports of construction and agricultural equipment by Australian farm and construction machinery wholesaling operators are estimated to be insignificant[184]. However, exports currently generate 13.3% of the agricultural machinery manufacturing industry revenue[185].

Exports of mining and construction machinery grew over much of the past five years, with the exception of 2009–10 when they contracted by 3.7%. Exports are estimated to total $1.39 billion in 2012–13, or 24.2% of mining and construction manufacturing industry revenue[186].

Exports of industrial machinery are estimated to be worth $1.35 billion to the industrial machinery manufacturing industry in 2012–13. Exports have declined by 1.0% per annum over the past five years due to slowing global economic conditions and a strong Australian dollar.

The value of exports of agricultural, mining and construction and industrial machinery in 2010–11 and 2011–12, as well as forecasts for 2012–13 are illustrated in Figure A4.

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[183] Information is given for all machinery, not just non-road diesel machinery.

[184] IBIS (2012d)

[185] IBIS (2012a)

[186] IBIS (2012b)

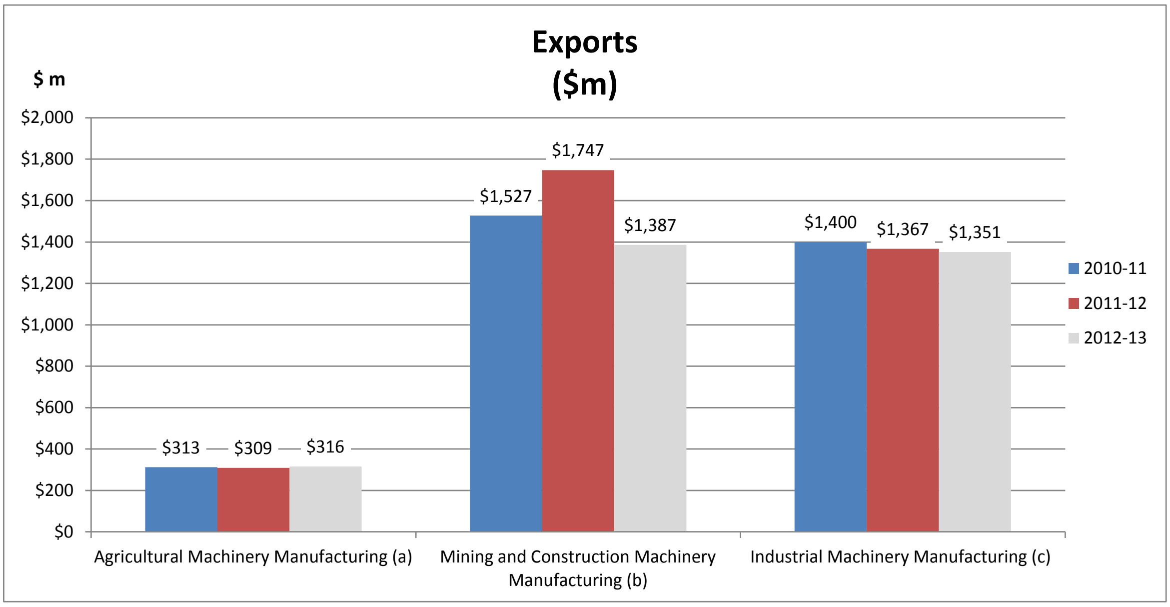

Figure A4: Export value ($million) of agricultural, mining and construction and industrial machinery 2010–11, 2011–12, and forecast for 2012–13[187]
Sources: (a) IBIS 2012a, (b) IBIS 2012b, (c) IBIS 2012c.

A4.3 Machinery manufacturing sector revenue

In 2011–12, the Australian agricultural, mining and construction, and industrial machinery manufacturing sectors reported revenues of $2267 million, $5458 million and $5735 million, respectively (Figure A5). IBISWorld forecasts that revenue will increase slightly for the agricultural and mining and construction machinery manufacturing sectors, but will decrease slightly for the industrial machinery manufacturing sector in 2012–13.

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[187] Information is given for all machinery, not just non-road diesel machinery.

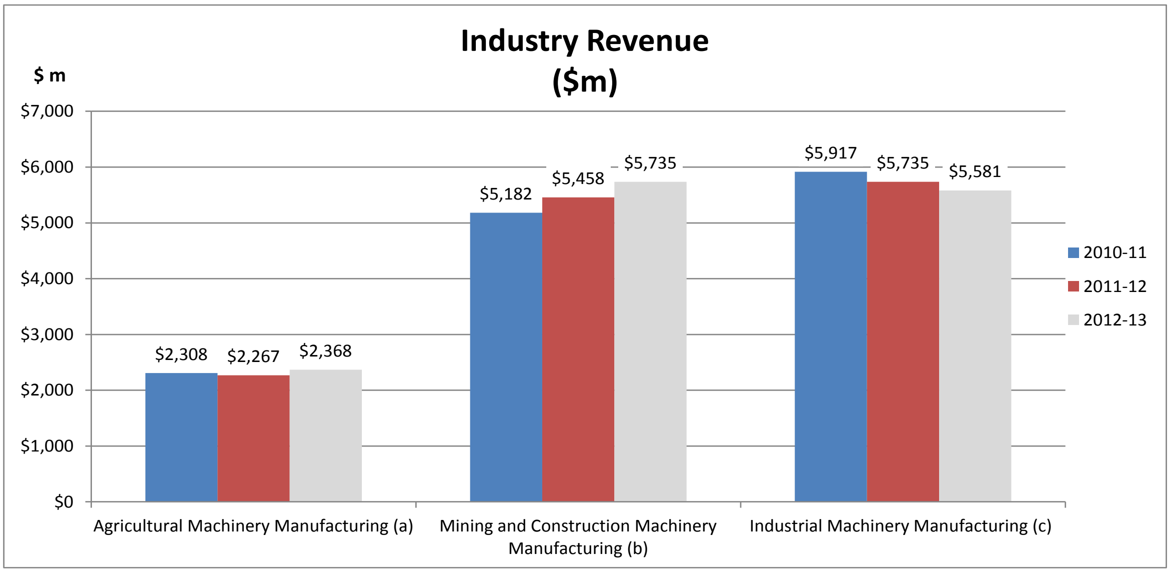

Figure A5: Industry revenue ($million) of agricultural, mining and construction and industrial machinery manufacturing sectors 2010–11, 2011–12, and forecast for 2012–13[187]

Sources: (a) IBIS 2012a, (b) IBIS 2012b, (c) IBIS 2012c.

A5 Annual turnover due to non-road diesel engine sales

Given that published information is not available for the non-road diesel engine/equipment sector specifically, an estimate of the annual turnover of this sector was made. This estimate was derived specifically based on the retail value of diesel engines being sold into the non-road diesel market, including loose engines and engines sold within equipment. The estimate excludes the value of the equipment unrelated to the bare engine. Engine/equipment sales data by power rating range, and estimated retail prices for units sold, provides the basis for the estimate.

The annual turnover of the non-road diesel engines sector, including loose engines sold and engines integrated within equipment, is estimated to be of the order of $2000 million based on projected sales using the 2008 sales data as the basis. Sales of engines less than 19 kW are estimated to comprise less than 10% of the turnover, with engines in the 130–560 kW range accounting for 45% and large, greater than 560 kW engines responsible for about 10% of the annual turnover. The annual turnover is projected to increase by about 3% annually based on the projected growth of the sector.

A6 Employment in the machinery manufacturing sectors

Employment in the agricultural and industrial machinery manufacturing sectors in Australia decreased between 2010–11 and 2011–12, while employment in mining and construction machinery manufacturing increased in 2011–12. IBISWorld has forecast that employment in agricultural, mining and construction and industrial machinery manufacturing will decrease in 2012–13. Employment in the machinery manufacturing sector is summarised in Figure A6.

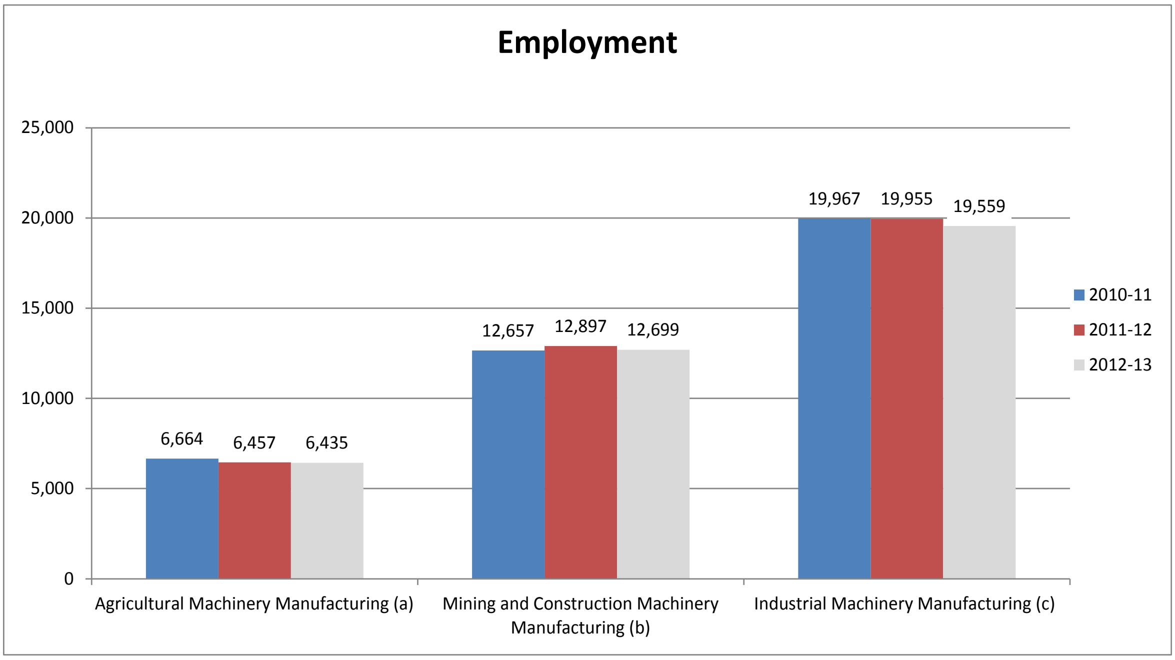

Figure A6: Employment in the agricultural, mining and construction, and industrial machinery industries 2010–11, 2011–12, and forecast for 2012–13[188]
Sources: (a) IBIS 2012a, (b) IBIS 2012b, (c) IBIS 2012c.

A7 Employment in the non-road diesel engine wholesale and distribution sectors

Given that all diesel engines for the non-road sector are manufactured abroad, no local employment is associated with the engine manufacturing sector.

Data on employment within the non-road diesel engine distributors sector specifically is not publically available. ABS labour statistics indicate that the machinery and equipment wholesaling sector employed 92,400 full-time employees in November 2012[189].

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[188] Information is given for all machinery, not just non-road diesel machinery.

[189] 6291.0.55.003 Labour Force, Australia, Detailed, Quarterly, Table 06. Employed persons by Industry Subdivision and Sex.

Appendix B: On-road vehicle emission reduction programs by Australian states and territories

Each Australian state and territory has a number of programs in place to reduce emissions from on-road diesel vehicles, as outlined in Table B1.

Table B1: Programs addressing on-road vehicle emissions

State	Program	Notes
NSW	Smoky vehicles program	Significant participation in the program by the general public.
	Audited maintenance guidelines	Continued implementation of the Clean Fleet Program with more than 6700 vehicles currently in the program. The Clean Fleet Program, launched in 2006, encourages diesel operators to reduce diesel vehicle emissions through testing, repair and maintenance.
	Diesel vehicle retrofit program	Expansion of the diesel vehicle retrofit program to retrofit particle filters to older diesel vehicles (see Diesel vehicle emission testing and repair programs below). More than 520 vehicles have been retrofitted since the program's inception, at a total cost of $3.1 million, producing estimated particle emissions reductions of 4.7 tonnes per year and avoiding $1.2 million annually in health costs. The investment in retrofits is expected to avoid $10 million in health costs over the likely remaining life of the diesel vehicles.
	Diesel vehicle emission testing and repair programs	Over several years, the Roads and Traffic Authority has established diesel vehicle exhaust emissions testing equipment with National Environment Protection (Diesel Vehicle Emissions) Measure (hereafter Diesel NEPM) funding.
	Other initiatives	Industry training to achieve improved maintenance practices and emission performance continued throughout 2010–11 at urban and regional TAFE colleges. Expansion of the diesel vehicle retrofit program to retrofit particle filters to older diesel vehicles.
QLD	Smoky vehicles program	The continuation of the smoky vehicles program meets the requirements of Schedule A(1) of the Diesel NEPM, Guideline on Smoky Vehicle Programs. The Smoky Vehicle Hotline provides the community with an avenue for reporting vehicles exceeding the 10-second smoke rule, via the internet or telephone.
	Audited maintenance guidelines	The Queensland Government encourages the heavy vehicle industry to participate in the National Heavy Vehicle Accreditation Scheme (NHVAS), which encourages heavy vehicle operators to take more responsibility for servicing their vehicles and ensuring vehicles are compliant with scheme accreditation requirements.
	Diesel vehicle retrofit program	Queensland has no diesel retrofit programs at this time.
	Diesel vehicle emission testing and repair programs	Brisbane City Council (BCC) maintains the only accredited DT80 diesel emission testing facility in Queensland. BCC tests vehicles from the BCC fleet and offers the service to privately owned vehicles testing for the purpose of confirmed compliance for the Commonwealth fuel tax credit.

State	Program	Notes
QLD cont.	Other initiatives	Heavy vehicle fuel-efficiency industry awareness initiative – produced fact sheets and distributed materials from other jurisdictions at the Queensland Truck Show, promoting inexpensive technology changes and the adoption of simple driving techniques, known as eco driving. Adopting these techniques has been shown to improve fuel efficiency by 10–20%. FreightSmart and Port of Brisbane trial – aims to demonstrate and increase the use of fuel efficient transport and logistics practices. Performance Based Standards and innovative heavy vehicles – working to assess road networks of strategic significance across Queensland for Performance Based Standards Class B vehicles. Performance Based Standards Class B vehicles are longer than the currently allowed freight vehicles for the particular road network; however, their on-road performance and safety are commensurate, or better than, existing vehicles on approved Performance Based Standards routes. PBS Level 2B vehicles have the potential to reduce the number of trips by up to 50%, meaning an estimated saving of about 230,000 litres of fuel and a greenhouse emissions reduction of about 490 tonnes every year. Hybrid bus trials – the Queensland Government has invested $1.4 million to undertake a trial of low-emission diesel-electric buses in the public transport fleet. AirCare program – the Department of Transport and Main Roads is currently reviewing the 'AirCare' program in South-East Queensland.
VIC	Smoky vehicles program	EPA Victoria has operated a public smoky vehicle reporting program for a number of years. The EPA also operates a separate official smoky vehicle enforcement program where EPA or police officers can report vehicles identified as emitting greater than 10 seconds of continuous smoke
	Audited maintenance guidelines	Victoria does not have an audited maintenance program for diesel vehicles. Victoria has other programs that aim to meet the objectives of the Diesel NEPM.
	Diesel vehicle retrofit program	Victoria does not have a diesel vehicle retrofit program. Victoria is considering the air quality implications of retrofit programs. Victoria has other programs that aim to meet the objectives of the Diesel NEPM.
	Diesel vehicle emission testing and repair programs	The project involves the installation, commissioning and operation of diesel vehicle emission test equipment that can undertake the DT80 test for heavy vehicles in support of Victoria's official smoky vehicle reporting program.
	Other initiatives	Heavy vehicle maintenance training program – involves the acquisition, installation and operation of chassis diesel emission testing equipment, and engagement and training of staff to allow the training of heavy vehicle mechanics. The EcoStation Pilot – partnership project initiated by EPA Victoria and VTA, with the intention of consulting and involving industry in the design of a voluntary emissions reductions program appropriate for the Australian context and determining what emissions gains are possible. The Freight Partnership EcoStation Program, once implemented, is expected to contribute to significant reductions in greenhouse gas and air emissions (NO_x and particles) due to reduced fuel use and increased uptake of emission reduction technologies. The US EPA SmartWay program provides a working example of the potential of this project; savings and reductions include: • saves 616 million gallons (2331 million litres) per annum • reduces carbon dioxide by 6.8 million tonnes per annum • reduces NO_x by 40,000 tonnes per annum • reduces particulate matter by 1000 tonnes per annum.

State	Program	Notes
WA	Smoky vehicles program	The 10-second rule for smoky vehicles was introduced from 1 November 2002.
	Audited maintenance guidelines	The National Heavy Vehicle Accreditation Scheme (NHVAS) encourages heavy vehicle operators to take more responsibility for servicing their vehicles and ensuring vehicles are compliant with scheme accreditation requirements. In WA, operators of certain types of heavy vehicles must become accredited to gain a permit from Main Roads.
	Diesel vehicle retrofit program	The WA Government, through the Department of Environment and Conservation (DEC), is currently focusing on diesel vehicle emissions, primarily through the CleanRun RS program and community education programs.
	Diesel vehicle emission testing and repair programs	CleanRun RS program – includes the utilisation of a portable roadside gas analyser that provides an efficient, cost effective method of characterising vehicle emissions and raising community awareness of vehicle emissions.
	Other initiatives	Communication delivery and community education. The CleanRun campaign prompts community action in reducing emissions through highlighting the benefits of a well-maintained vehicle and working with drivers to take on more environmentally-friendly driving habits. CleanRun Behaviour Change Initiative – aims to reduce diesel emissions through encouraging driver behaviour change. It is estimated that fleet operating organisations who implement the CleanRun EcoDrive program can reduce fuel use and related emissions by up to 10%. Industry training Polytechnic West colleges continued industry training to achieve improved maintenance practices and emission performance. DEC provided funding for Polytechnic West to purchase emission testing, control and abatement equipment to enhance delivery of their apprentice mechanic training programs.
SA	Smoky vehicles program	Not applicable
	Audited maintenance guidelines	The Department for Transport, Energy and Infrastructure is currently investigating the application of a maintenance and eco-driving program for South Australian heavy vehicle companies.
	Diesel vehicle retrofit program	Not applicable
	Diesel vehicle emission testing and repair programs	Not applicable
	Other initiatives	Not applicable
TAS	Smoky vehicles program	The Department of Infrastructure, Energy and Resources maintains a strong focus on road safety rather than on vehicle emissions; however, the department does utilise the ‘10-second rule’ for smoky exhausts and issues Traffic Infringement Notices requiring identified vehicles to undergo servicing to reduce smoke emissions.
	Audited maintenance guidelines	There is no audited maintenance program for diesel vehicles in Tasmania.
	Diesel vehicle retrofit program	Statistics are not compiled on diesel vehicle retrofitting.

State	Program	Notes
TAS cont.	Diesel vehicle emission testing and repair programs	The Department of Infrastructure, Energy and Resources does not possess vehicle emission measurement facilities, and does not compile records of vehicle testing or repairs.
	Other initiatives	Not applicable
ACT	Smoky vehicles program	Not applicable
	Audited maintenance guidelines	Not applicable
	Diesel vehicle retrofit program	Not applicable
	Diesel vehicle emission testing and repair programs	Not applicable
	Other initiatives	Not applicable
NT	Smoky vehicles program	A smoky vehicle program is undertaken as part of the Territory's vehicle registration and roadworthiness testing procedures.
	Audited maintenance guidelines	Vehicle roadworthy inspections are undertaken for all light and heavy vehicles and these inspections include checking that all required emission control equipment is fitted as well as the detection of smoky vehicles. Periodic roadworthiness inspections are required at registration renewal and the frequency of inspections is determined by the vehicle type and category.
	Diesel vehicle retrofit program	The majority of the NT road-train fleet is less than five years old and employs the latest technology in engine management systems to minimise fuel consumption.
	Diesel vehicle emission testing and repair programs	Pollutants associated with diesel emissions in the NT are well below emission standards. Therefore, the current air quality is not considered a 'trigger' for change in relation to managing diesel emissions in the NT. The NT will continue to monitor the need for action on diesel emissions and will take appropriate action as required.
	Other initiatives	The NT's open access policy provides for 'as of right' access for road trains and 100% network access for vehicles operating at higher mass limits. In addition the NT's innovative vehicle policy promotes the development of high-productivity innovative vehicle combinations that can deliver further efficiency benefits. The Darwin region Heavy Vehicle Task Force Report (June 2011) has made a number of recommendations to improve the safety of sharing our roads with heavy vehicles in the greater Darwin area. The 29 recommendations include approved road-train routes into industrial areas and continued 'as of right' access for heavy vehicles (excluding road trains).

Appendix C: Regulation of diesel exhaust emissions within the underground mining sector

C1 Regulation of non-road diesel engines within underground mining

Diesel exhaust emissions are a significant concern within underground mining operations as the likelihood of occupational exposure increases due to poor ventilation of confined spaces and the close proximity to operating diesel equipment. Approaches to address diesel emission exposures include diesel engine and fuel quality requirements, ventilation provisions and personal exposure limits.

Work health and safety in the mining industry is regulated by states and territories. NSW, Queensland and Western Australia have separate mining work health and safety regulations, with regulations for mining being covered under the general work health and safety regulations in the other jurisdictions with smaller mining industries. The following sections detail recent national developments related to diesel engine emissions, followed by developments in some states.

Provision has been made within workplace health and safety (WHS) regulations for exposure limits targeting common pollutants (including PM and nitrogen dioxide (NO_2)), ventilation requirements and personal protective equipment. In 2007, the Australian Institute of Occupational Hygienists (AIOH) released a position paper on diesel particulates, recommending the adoption of an occupational exposure limit for underground mineworkers of 0.1 mg/m^3 as elemental carbon, measured as a time-weighted average over eight hours[190]. This recommended exposure limit has been adopted by a number of regulatory agencies in Australia responsible for regulating exposures within underground mining environments.

A recent Australian Coal Association Research Program study[191] investigated the relationship between measurable properties of diesel particulate matter (DPM) and the resulting risk to occupationally exposed underground coal mine workers. The study found that elemental carbon mass is an inadequate surrogate for measuring DPM from a health perspective. The size, number and lung deposited surface area of a DPM sample are critical to determining its health risk and the mass of organic carbon plays a disproportionately large role. This study also noted that direct measurement of the size distribution of diesel exhaust emitted after an exhaust system, as seen on Australian underground vehicles, has not been published. The cooling of the exhaust without dilution, in such systems, is given as being likely to greatly modify the exhaust mixture, increasing the formation of nanoparticles[192], deposition of toxic organic compounds, and the potential for adverse health effects. The study recommends the development of a tool to compare different exhaust emission profiles.

Whereas attention has been paid to diesel exhaust exposures within underground mining environments, diesel exhaust emissions at surface mining operations have received less focus due to emission sources being more dispersed and atmospheric dispersion improved at such operations.

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[190] AIOH (2007)

[191] Surawski et al. (2011)

[192] Particles having one or more dimensions of the order of 100 nanometres (nm) or less.

C2 National developments

There are no national emission standards for diesel engines used within underground mining; however, some state regulations make reference to the Australian Standard AS/NZS 3584:2008 – 'Diesel Engine Systems for Underground Coal Mines'. This standard includes performance requirements for a range of safety and emissions-related operating parameters. This standard is currently being revised and it is anticipated that the DPM emission testing sections of the standard will be revised to include more effective test procedures and reflect advances in DPM measurement systems.

There is currently no national exposure standard for DPM; however, a number of regulatory agencies in Australia have adopted the Australian Institute of Occupational Hygienists exposure limit recommendation of 0.1 mg/m^3 (as elemental carbon measured as a time-weighted average over eight hours)[193]. This has been recommended as an exposure limit for mine workers and is being referenced within recent guidelines and draft guidelines as documented in subsequent subsections for specific states.

The National Mine Safety Framework aims to achieve a nationally consistent occupational health and safety (OHS) regime in the Australian mining industry. Work being undertaken under this framework is being integrated with the broader OHS harmonisation work being undertaken by Safe Work Australia under the direction of the Select Council on Workplace Relations, which commenced in April 2008 with the National Review into Model Occupational Health and Safety Laws. The model WHS Act and the model WHS Regulations as adopted by the Commonwealth, the ACT, NSW and the Northern Territory apply to mining in those jurisdictions and apply in Tasmania and South Australia since 1 January 2013. Safe Work Australia has developed model Work Health and Safety (Mines) Regulations in cooperation with the National Mine Safety Framework Steering Group to be included in the model WHS Regulations. Once these regulations are finalised it is intended they will be progressively implemented by the jurisdictions. Although the WHS Regulations and the codes of practice issued for public comment to date do not specifically address diesel engines and DPM exposures, these developments are indicative that measures addressing this issue are likely to be more harmonised and widely applied in future years.

C3 New South Wales

NSW was the first state to publish a guideline addressing tailpipe DPM emissions and exposures within underground mining. Diesel engine emissions at underground mines are addressed within the NSW Department of Primary Industries *Guideline for the Management of Diesel Engine Pollutants in Underground Environments*, April 2008 (MDG29). This guideline specifies workplace exposure limits for gaseous pollutants (CO, NO, NO_2, SO_2) and particulate matter emitted from diesel combustion. The workplace particulate matter exposure limit is expressed as 0.1 mg/m^3 elemental carbon, which is approximately equal to 0.2 mg/m^3 or 200 µg/m^3 DPM.

MDG29 also provides for a minimum ventilation quantity based on the total number and power of diesel engines operating in the same ventilation current at any one time. For a newly developing mine, good practice is given as providing 0.1 m^3/s/kW of diesel engine power to overcome diesel emissions (gaseous, particulate) and heat stress. Minimum ventilation quantities are also specified for gaseous emissions for application in areas where diesel engines are in operation.

MDG29 requires that diesel fuels used in underground mines comply with the Fuel Standard (Automotive Diesel) Determination 2001, incorporating the Fuel Standard

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[193] AIOH (2007)

(Automotive Diesel) Amendment Determination 2009 (No. 1), which limits the sulfur content of diesel to 10 ppm. Furthermore, only diesel fuel additives that have been registered by the US EPA may be used.

MDG29 generally recommends test methods and exposure limits consistent with those established in Queensland.

C4 Queensland

Queensland is working actively to reduce underground DPM emissions and exposures. Initiatives include an active government/industry/supplier forum which meets quarterly, a commitment to effective technical and procedural strategies for DPM exposure reductions and a draft *Code of Practice for the Management of Diesel Engine Exhaust Pollutants in Underground Environments*. This draft code is consistent with the NSW MDG29 management guidelines and was due for release in 2013.

The Queensland Department of Mines and Energy brought together representatives of the underground coal mining and allied industries to discuss and develop strategies for reducing worker exposure to DPM. This was done in place of the department issuing prescriptive regulations. Industry was reported to have responded positively, and over a 12 month period agreement was reached on common approaches, test methods and test reporting procedures. This represented the basis on which mines would be subject to audit, with the prospect of government intervention if air quality targets were not achieved.

Industry also collectively funded the mines safety testing and research agency SIMTARS to design and manage a database, into which the results of all routine DPM testing can be uploaded directly by individual mines. This growing database serves as a repository where mines can store their test records and collectively set benchmarks for the performance of engine types used in the mining industry.

Aspects of the cooperative approach adopted by the Queensland Government are comparable to the Canadian Diesel Emissions Evaluation Program.

C5 Western Australia

In February 2013 the WA Department of Mines and Petroleum released a draft guideline entitled *Managing Diesel Emissions in Underground Metalliferous Mines* for public comment. This draft guideline references the AIOH exposure limit of 0.1 mg/m^3 (as elemental carbon measured as a time-weighted average over eight hours) and includes source control recommendations in regard to fuel and engine selection, engine refurbishment, maintenance and repairs, engine control devices and engine operation. In terms of fuel selection it is recommended that ultra-low sulfur and other low-emission diesel fuels and low-sulfur lubricants should be used where practicable. In regard to engine selection it is specified that mine management should require suppliers to provide equipment that meets specific emission standards. No specific reference is made in the draft guideline as to the emission standard to be met; however, it is noted that although US EPA Tier 3 and 4 engines have the lowest emissions, Tier 1 and 2 engines are still used in Australia. It is recommended that engines be operated in a manner which optimises combustion to reduce diesel emissions, including driving to prevailing conditions, limiting idling and limiting over-revving.

C6 Summary

There are currently no national or state regulations pertaining to DPM emission measures; however, states are publishing guidelines which address such measures, and progress is being made towards harmonisation between states with significant mining industries. It is also noted that an increasing number of mining companies have voluntarily established their own programs addressing DPM emissions and exposures.

Appendix D: Average median life, load factor and hours of operation by engine category

In the emission calculations operating hours, load factors and median lives are allocated and emissions calculated based on engine/equipment-specific engine ratings. To enable the presentation of information, operating hours, load factors and median lives are presented as averages by engine rating class as shown in Table D1.

Table D1: Average median life, load factor and hours of operation by engine category

Market segment	Equipment type/application	Engine rating class (kW)	Median life (hours)	Hours of operation (h/annum)	Load (%)
Agricultural	Agricultural tractors	56 – 130	4,667	475	59
Agricultural	Combine harvester-threshers	56 – 130	2,500	150	59
Agricultural	Engines for agricultural vehicles	37 – 56	4,667	381	59
Agricultural	Engines for 'other' agricultural applications	37 – 56	4,667	381	59
Agricultural	Pumps & irrigation	<8	2,500	403	43
Agricultural	Pumps & irrigation	8 – 19	2,500	403	43
Agricultural	Pumps & irrigation	19 – 37	2,500	403	43
Agricultural	Pumps & irrigation	37 – 56	4,667	403	43
Agricultural	Pumps & irrigation	56 – 130	4,667	403	43
Agricultural	Pumps & irrigation	130 – 560	4,667	403	43
Agricultural	Pumps & irrigation	130 – 560	5,056	403	43
Agricultural	Self-propelled sprayers	56 – 130	2,500	90	59
Agricultural	Windrowers	56 – 130	2,500	110	59
Forestry	Log skidders	56 – 130	4,667	1,276	59
Forestry	Log skidders	130 – 560	4,667	1,276	59
General industrial	Airport tractors	56 – 130	4,667	1,257	59
General industrial	Cranes & lifting equipment	19 – 37	2,500	990	43
General industrial	Forklifts	56 – 130	4,667	1,700	59
General industrial	Industrial pumps	<8	2,500	403	43
General industrial	Industrial pumps	8 – 19	2,500	403	43
General industrial	Industrial pumps	19 – 37	2,500	403	43
General industrial	Industrial pumps	37 – 56	4,667	403	43
General industrial	Industrial pumps	56 – 130	4,667	403	43
General industrial	Industrial pumps	130 – 560	4,667	403	43
General industrial	Industrial pumps	>560	7,000	403	43
General industrial	Misc. industrial engines	8 – 19	2,500	878	43
General industrial	Misc. industrial engines	19 – 37	2,500	878	43
General industrial	Misc. industrial engines	37 – 56	4,667	878	43
General industrial	Misc. industrial engines	56 – 130	4,667	878	43
General industrial	Misc. industrial engines	130 – 560	4,667	878	43
General industrial	Other industrial engines	<8	2,500	878	43
General industrial	Other industrial engines	19 – 37	2,500	878	43
General industrial	Other industrial engines	37 – 56	4,667	878	43
General industrial	Other industrial engines	56 – 130	4,667	878	43
General industrial	Other industrial engines	130 – 560	4,667	878	43
General industrial	Other industrial engines	>560	7,000	878	43
Heavy industrial	Backhoe loaders	19 – 37	4,667	1,135	21
Heavy industrial	Backhoe loaders	37 – 56	4,667	1,135	21
Heavy industrial	Backhoe loaders	56 – 130	4,667	1,135	21

Market segment	Equipment type/application	Engine rating class (kW)	Median life (hours)	Hours of operation (h/annum)	Load (%)
Heavy industrial	Construction & mining engines	<8	2,500	2,500	59
Heavy industrial	Construction & mining engines	8 – 19	2,500	2,500	59
Heavy industrial	Construction & mining engines	19 – 37	2,500	2,500	59
Heavy industrial	Construction & mining engines	37 – 56	4,667	2,500	59
Heavy industrial	Construction & mining engines	56 – 130	4,150	2,027	59
Heavy industrial	Construction & mining engines	130 – 560	4,667	2,500	59
Heavy industrial	Construction & mining engines	>560	7,000	2,500	59
Heavy industrial	Crawler loaders	56 – 130	4,667	1,135	21
Heavy industrial	Crawler loaders	130 – 560	4,667	1,135	21
Heavy industrial	Dozers	56 – 130	4,667	899	59
Heavy industrial	Dozers	130 – 560	5,834	899	59
Heavy industrial	Dozers	>560	7,000	899	59
Heavy industrial	Hydraulic excavators	<8	2,500	1,092	59
Heavy industrial	Hydraulic excavators	8 – 19	2,500	1,092	59
Heavy industrial	Hydraulic excavators	19 – 37	2,500	1,092	59
Heavy industrial	Hydraulic excavators	37 – 56	4,667	1,092	59
Heavy industrial	Hydraulic excavators	56 – 130	4,667	1,092	59
Heavy industrial	Hydraulic excavators	130 – 560	4,667	1,092	59
Heavy industrial	Hydraulic excavators	>560	7,000	1,092	59
Heavy industrial	Landfill & earthworks	130 – 560	6,222	1,092	59
Heavy industrial	Misc. construction & mining equipment	56 – 130	4,667	855	59
Heavy industrial	Misc. construction & mining equipment	130 – 560	7,000	899	59
Heavy industrial	Motorgraders	56 – 130	4,667	962	59
Heavy industrial	Motorgraders	130 – 560	4,667	962	59
Heavy industrial	Off-highway dump trucks	130 – 560	7,000	1,641	59
Heavy industrial	Off-highway dump trucks	>560	7,000	1,641	59
Heavy industrial	Road rollers	<8	2,500	760	59
Heavy industrial	Road rollers	8 – 19	2,500	760	59
Heavy industrial	Road rollers	19 – 37	2,500	760	59
Heavy industrial	Road rollers	37 – 56	4,667	760	59
Heavy industrial	Road rollers	56 – 130	4,667	760	59
Heavy industrial	Road rollers	130 – 560	4,667	760	59
Heavy industrial	Scrapers	130 – 560	7,000	914	59
Heavy industrial	Skid steer loaders	8 – 19	2,500	818	21
Heavy industrial	Skid steer loaders	37 – 56	4,667	818	21
Heavy industrial	Skid steer loaders	56 – 130	4,667	818	21
Heavy industrial	Wheel loaders	19 – 37	2,500	761	59
Heavy industrial	Wheel loaders	37 – 56	4,667	761	59
Heavy industrial	Wheel loaders	56 – 130	4,667	761	59
Heavy industrial	Wheel loaders	130 – 560	5,600	761	59
Heavy industrial	Wheel loaders	>560	7,000	761	59
Lawn and garden	Ride on or tractor lawn mowers	8 – 19	2,500	544	43
Light commercial	Air compressors	19 – 37	2,500	815	43
Light commercial	Pressure washers	8 – 19	2,500	145	43
Light commercial	Welders	19 – 37	2,500	643	21
Marine	Fishing boats	8 – 19	2,500	2,000	60
Marine	Pleasure boats	<8	2,500	300	21
Marine	Pleasure boats	19 – 37	2,500	300	21
Marine	Work boats	8 – 19	2,500	2,500	70
Marine	Work boats	19 – 37	2,500	2,500	70

Market segment	Equipment type/application	Engine rating class (kW)	Median life (hours)	Hours of operation (h/annum)	Load (%)
Power generation drive	Prime power	<8	2,500	2,000	70
Power generation drive	Prime power	8 – 19	2,500	338	43
Power generation drive	Prime power	19 – 37	2,500	2,000	70
Power generation drive	Prime power	37 – 56	4,667	2,000	70
Power generation drive	Prime power	56 – 130	4,667	2,000	70
Power generation drive	Prime power	130 – 560	4,667	2,000	70
Power generation drive	Standby power	<8	2,500	300	80
Power generation drive	Standby power	8 – 19	2,500	313	68
Power generation drive	Standby power	19 – 37	2,500	300	80
Power generation drive	Standby power	37 – 56	4,667	300	80
Power generation drive	Standby power	56 – 130	4,667	300	80
Power generation drive	Standby power	130 – 560	4,667	300	80
Power generation drive	Standby power	>560	4,667	300	80
Power generation sets	Marine auxiliary	<8	2,500	1,500	35
Power generation sets	Marine auxiliary	8 – 19	2,500	1,500	35
Power generation sets	Marine auxiliary	19 – 37	2,500	1,500	35
Power generation sets	Misc. gen sets	8 – 19	2,500	1,580	70
Power generation sets	Misc. gen sets	19 – 37	2,500	1,580	70
Power generation sets	Misc. gen sets	37 – 56	4,667	1,580	70
Power generation sets	Misc. gen sets	56 – 130	4,667	1,580	70
Power generation sets	Misc. gen sets	130 – 560	4,667	1,580	70
Power generation sets	Misc. gen sets	>560	7,000	1,580	70
Power generation sets	Prime power	<8	2,500	2,000	70
Power generation sets	Prime power	19 – 37	2,500	2,000	70
Power generation sets	Prime power	37 – 56	4,667	2,000	70
Power generation sets	Prime power	56 – 130	4,667	2,000	70
Power generation sets	Prime power	130 – 560	5,056	2,000	70
Power generation sets	Prime power	>560	7,000	2,000	70
Power generation sets	Standby power	8 – 19	2,500	300	80
Power generation sets	Standby power	19 – 37	2,500	300	80
Power generation sets	Standby power	56 – 130	4,667	300	80
Power generation sets	Standby power	130 – 560	4,667	300	80
Power generation sets	Standby power	>560	7,000	300	80

Appendix E: Stock model and emission calculations

E1 Scrappage function and stock model

The scrappage functions were based on a methodology similar to that applied in the US EPA NON-ROAD2008 model, as documented in US EPA (2010). The life of an engine is specified by a cumulative normal distribution with a mean and variance specific to the engine being considered. This is done as follows.

Let s_{ky} denote sales of new engines of type k in year y; μ_k denote the median lifetime of engines of technology v; v_k denote the technology of engine type k; and $\Phi(x; \mu,\sigma)$ denote a cumulative normal distribution with mean μ and standard deviation σ. The total stock, t_{ky} of engines of type k in year y is then:

$$t_{ky} = s_{ky} + \sum_{i<y} s_{ki} \left[1 - \Phi\left(y - i; \mu_k, 3.33\right)\right]$$

Predictions of future engine numbers, as determined through the stock models and associated econometric equations, were verified in three ways:

- by comparison with industry predictions based on expert judgments garnered during the consultation process
- by comparison with published predictions in the growth of output for selected industries that use the engines
- by testing the accuracy of the predictive model against an historical period with known data. For example, if data is available for a period to 2008, we can test model outcomes for the period say from 2005 to 2008 with actual outcomes for that period to observe the closeness of fit. Historical stock data were available for agricultural and some mining machinery.

E2 Emission calculation

Particulate matter (PM) and oxides of nitrogen (NO_x) emissions were estimated based on non-road diesel engine exhaust emission factors. Exhaust emissions were estimated using the following equation[194]:

$$I_{exh} = EF_{exh} * A * L * P * N$$

I_{exh} = exhaust emissions (grams/hour)

EF_{exh} = exhaust emission factor (grams/kWh)

A = equipment activity (operating hours/year)

L = load factor (average portion of rated power used during operation, per cent)

P = average rated power (kW)

N = equipment population (units)

Emissions are converted and reported as tonnes/annum. Engine numbers for each year are provided by the stock model. Operating hours, load factors and average rated power for each engine category are given in Appendix D. Emission factors differ between sub-populations of equipment, such as engine/equipment application and type, rated power class and emission performance (expressed as non-compliant, Tier 1, Tier 2, Tier 3, Tier 4 interim and Tier 4 final).

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[194] US EPA (2004b)

E2.1 Exhaust emission factors

Use was made of NON-ROAD2008 emission factors, as extracted from the model database, with reference to application methodologies documented by the US EPA. Reference was made to engine application/rating specific annual activity (A), load factors (L), useful life and emission deterioration factors from the US EPA NON-ROAD2008 model. Information on engine life, load factors and annual hours of operation obtained from some engine/equipment distributors supplying the Australian market, collated during the emission performance survey, were used to confirm the applicability and supplement the inputs obtained from the NON-ROAD2008 model. Use was made of engine/equipment-specific average rated power obtained from the survey conducted, supplemented with values from NON-ROAD2008 where not locally available.

NON-ROAD2008 exhaust emission factors comprise three components: a ‘zero-hour’ emission level (ZHL), a transient adjustment factor (TAF) and a deterioration factor (DF). The ZHL represents the emission rate for recently manufactured engines with few operating hours and is typically derived directly from laboratory measurements conducted on new or nearly new engines across several commonly used duty cycles.

Given that the emission measurement data used for ZHL have been collected under steady-state conditions (constant engine speed and load), it is necessary to apply a TAF to account for in-field operations which typically involve transient conditions (variable speed and load). The baseline emission factor is therefore the product (ZHL*TAF).

Deterioration factors are applied to account for increased emissions during subsequent years. Such factors are calculated and applied as a function of the operational age of the engine/equipment (i.e. A*L). Engines/equipment are assumed to deteriorate up to the median engine/equipment life (i.e. life at which 50% of the sub-population is retired), following which they are assumed to be maintained at the same state.

The DF for a specific pollutant/tier/year is calculated as follows:

$$DF = 1+d_{\text{pollutant,tier}}\ (\text{age}_{\text{year}}/\text{annualised median life})$$

where, *d* is the relative deterioration rate for a given pollutant (% increase in emission factor/% useful life expended) and regulatory tier; *age* is the age of a specific model-year group of engines; and *annualised median life* is calculated as the median life in hours divided by the product of activity and load factor.

E2.2 NO_x emission estimation

NO_x emissions were estimated based on the generic exhaust emission calculation given previously.

E2.3 PM emission estimation

In the estimation of PM emissions it is necessary to apply an additional adjustment to the emission factor to account for the in-use sulfur level of diesel fuel. The PM emission factor was adjusted by subtracting S_{PMadj} (g/hp-hr) which is calculated as follows:

$$S_{PMadj} = BSFC * m_{PM,S} * 0.01 * (S_{base} – S_{in\text{-}use})$$

where:

BSFC = brake-specific fuel consumption (g/fuel/hp-hr)

$m_{SO4,S}$ = constant, representing the sulfate fraction of total particulate sulfur (7.0 g PM SO_4/g PMS)

0.01 = conversion factor from wt% to wt fraction

S_{base} = base sulfur level included in NON-ROAD2008 emission factors (i.e. 0.33 wt%, 3300 ppm for non-compliant and Tier 1 engines; 0.2 wt%, 2000 ppm for Tier 2–3 engines)

$S_{in\text{-}use}$ = in-use diesel sulfur levels (wt%)

Given that most large industrial facilities and mines source their diesel from major petrochemical suppliers (compliant fuel), and given the absence of quantitative information on off-spec diesel use for non-road applications, for the purpose of estimating emissions it was assumed that fuel compliant with fuel standards is being used. The Fuel Standard (Automotive Diesel) Determination 2001, incorporating the Fuel Standard (Automotive Diesel) Amendment Determination 2009 (No. 1), specified a sulfur content of 10 mg/kg (10 ppm) for the post 1 January 2009 period. This sulfur content was assumed for the 2009 to 2050 period for both base case and harmonisation scenarios.

$PM_{2.5}$ emissions were estimated as a component of PM_{10} emissions, with the $PM_{2.5}$ fraction estimated to compose 97% of PM_{10} emissions[195]. This fraction is in accordance with the $PM_{2.5}$ fraction applied in the estimation of non-road diesel engine emissions within the NSW GMR Emissions Inventory[196].

E2.4 Summing of exhaust emissions

Exhaust emissions were summed over all engine/equipment types, rated power classes and model-year cohorts as follows[197]:

$$I_{\text{exh,poll}} = \overbrace{\sum \overbrace{\left[\sum \left(\overbrace{\sum \left(E_{\text{exh,poll}} \cdot A \cdot L \cdot P \cdot N \right)}^{\text{sum over all model-year cohorts within a rated-power class}} \right) \right]}^{\text{sum over all rated-power classes within an equipment type}}}^{\text{sum over all equipment types}}$$

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[195] US EPA (2004b)

[196] NSW EPA (2012b)

[197] US EPA (2004b)

Appendix F: Costs for Tier 4 engines/equipment

Price differentials for Tier 2 and Tier 3 compliant engines were estimated based on information provided by industry stakeholders during the development of the report; however, complexities arose in costing price differentials associated with Tier 4 compliant equipment. The main reason for this is that the cost of Tier 4 equipment includes costs associated with engine improvements, the addition of aftertreatment, equipment modifications necessary to support the engine and aftertreatment requirements, and equipment improvements unrelated to meeting emission standards.

In assessing compliance costs associated with Tier 4 compliant engines and equipment, attention was paid to methods applied within regulatory impact assessments for the implementation of on-road vehicle emission standards in Australia, and non-road diesel engine regulatory impact assessments conducted in the US and Europe. The main findings of this evaluation, and the compliance costs derived for use in the current study for Tier 4 compliant equipment, are documented in this appendix.

F1 Costing method applied in the US non-road diesel regulatory impact analysis

In estimating engine and equipment costs for complying with Tier 4 emission standards, the US EPA assumed a single technology recipe for each power category[198]. The US EPA also conservatively assumed that industry would use neither the transition program for equipment manufacturers nor the averaging, banking, and trading program made provision for in US non-road diesel regulations, both of which offer the opportunity for significant cost reductions. The US EPA therefore considered its cost projections to probably overestimate the costs of the different approaches toward compliance that manufacturers may ultimately take.

Costs of compliance accounted for in the US EPA Tier 4 regulatory impact assessment (RIA) included variable costs (for incremental hardware costs, assembly costs, and associated mark-ups) and fixed costs (for research and development, engine tooling, engine certification, and equipment redesign). The analysis also included lifetime operating costs where applicable, including costs associated with the higher cost of fuel, expected fuel economy impacts, increased maintenance demands resulting from the addition of new emission-control hardware, and expected savings associated with lower oil-change maintenance costs as a result of the low-sulfur fuel.

For engine variable costs (i.e. emission-control hardware), the US EPA first estimated the cost per piece of technology/hardware. Consideration was then given to the Power Systems Research database comprising engine characteristics and sales information for each of the over 4500 unique equipment models sold in the US. Using the baseline engine characteristics of each engine, the projected technology package for that engine, and the variable cost per technology/hardware, variable costs were calculated for each equipment model.

No provision was made in the US EPA Tier 4 RIA for costs related to engine and equipment improvements which were not directly associated with achieving compliance with emission standards.

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[198] US EPA (2004a)

F2 Costing method applied in Europe

In considering the method applied in Europe for addressing compliance costs reference is made to the impact assessment on the recommended options for revision of the EU's 1997 NRMM Directive[199]. This assessment considered the compliance costs, socio-economic impacts, environmental impacts and efficiency (costs versus benefits) of various options including the implementation of US equivalent emission limits for engines and equipment in the greater than 560 kW range.

The method for estimating compliance costs applied in Europe was very similar to that applied by the US EPA in the 2004 Tier 4 RIA[200]. Fixed costs (research and development, certification, retooling) were taken into account, in addition to variable costs relating to changes in the engine and addition of aftertreatment equipment. Annual operation and maintenance costs were also accounted for. In the case of construction and mining equipment, the engine variable costs accounted for aftertreatment (SCR and DPF) costs, and the extra engine costs due to the engine modifications. The extra costs related to cooled exhaust gas recirculation (EGR) for internal engine modifications, and to engine modifications related to EGR valves, controllable turbo pressure, two-stage turbo charging, extra cooling capacity, and high cylinder pressure capability.

Although related engine modifications and equipment installation costs were taken into account, no provision was made for costs related to engine and equipment improvements which were not directly associated with achieving compliance with emission standards.

F3 Costing for on-road heavy duty vehicles within Australia

Coffey Geosciences (2003) quantitatively assessed costs associated with meeting fuel quality and vehicle emission standards in Australia. In estimating costs of applying Euro 4 and Euro 5 standards for heavy diesel vehicles, with sulfur in diesel limited to 10 ppm, Coffey Geosciences made reference to cost data from the DG Enterprise (2002) report to the European Commission on heavy vehicle emission control technology. The use of these data was given as having been supported in informal industry discussions. Further reference is made to the cost estimates for progressing from Euro 3 to Euro 5 in the comparison presented in the next section.

F4 Derivation of costs for impact analysis and comparison with other studies

Incremental costs were estimated for Tier 4 compliant engines/equipment based on information received by ENVIRON from suppliers to the Australian market. This information included incremental costs for bare engines and including the costs of aftertreatment equipment, and price differentials expressed as the percentage increase in overall equipment costs associated with Tier 4 compliance equipment. Such information was received from several major engine/equipment suppliers, including companies with significant market share within the construction and mining, agricultural and power generation segments.

Retail costs for Tier 4 compliant equipment include not only costs related directly to technology changes to meet emission standards, but also costs associated with broader improvements and technological advances. Given that the cost savings arising from productivity improvements are not accounted for within this report's cost benefit analysis, it is justifiable to restrict incremental costs associated with Tier 4 compliant equipment to equipment modifications directly related to meeting emission standards. In using the cost information collated from Australian suppliers, emphasis was therefore placed on data

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[199] Van Zeebroeck et al. (2009)

[200] Van Zeebroeck et al. (2009)

sets which specifically sought to exclude costs related to engine and equipment improvements which were not directly associated with achieving compliance with emission standards. This approach is in accordance with the methodologies applied in non-road diesel regulation impact assessment studies conducted in the US and Europe.

The cost information received from industry stakeholders varied substantially between equipment types and power rating categories. For this reason cost differentials were applied for individual equipment types and power rating categories, with stock-weighted average costs subsequently derived based on the engine/equipment inventoried to be sold into the Australian market on an annual basis[201]. The stock-weighted average costs were calculated over the range of non-road diesel engines/equipment including bare (loose) replacement engines, power generation sets and drives, and agricultural and construction and mining equipment.

Australian annual sales stock-weighted average incremental costs, based on Tier 2/Tier 3 to Tier 4 price differential data received from industry suppliers, are illustrated in Figure F1 (purple solid line). For the purposes of comparison, incremental cost information was sourced from US and European non-road diesel RIAs and the Coffey Geosciences (2003) on-road cost-benefit study, with costs adjusted to 2012 AUD. The comparison is illustrated in Figure F1. The conclusion drawn is that the incremental costs projected for application within this report’s cost benefit analysis are sufficiently conservative to account for bare engine costs, aftertreatment equipment and costs related to engine modifications directly associated with meeting Tier 4 emission standards.

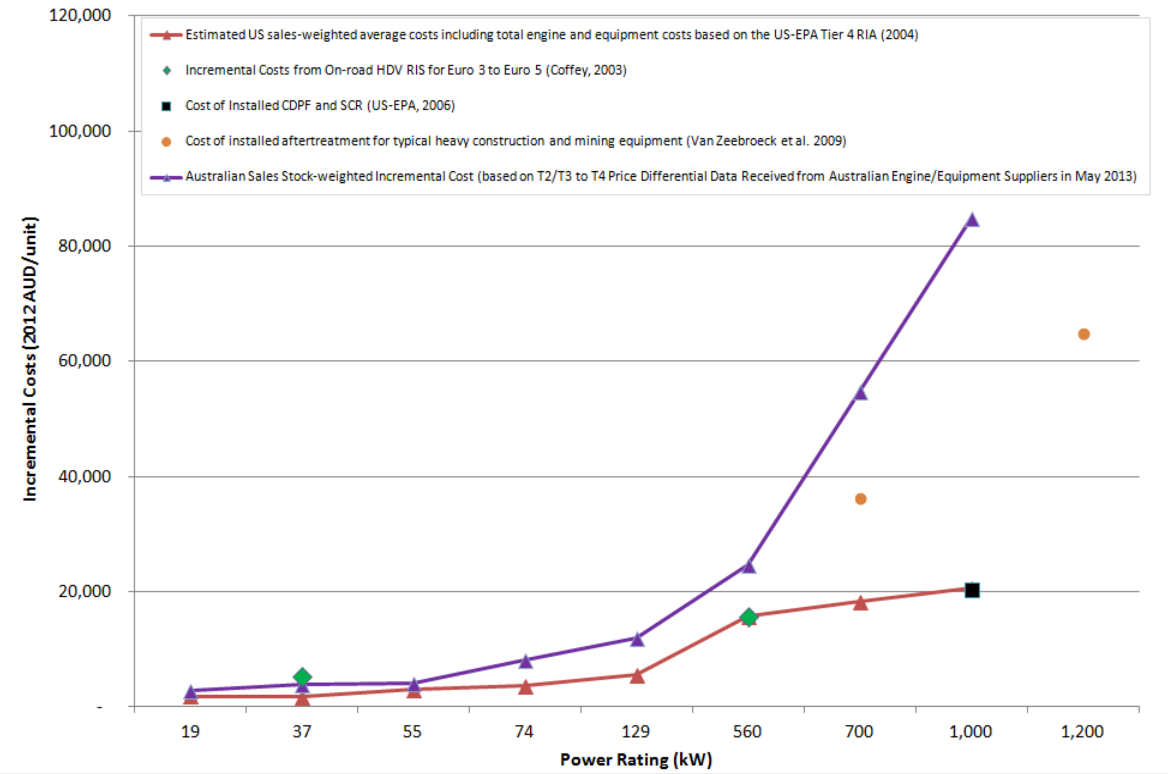

Figure F1: Comparison of incremental cost estimates for meeting non-road and on-road diesel engine emission standards

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[201] ENVIRON (2010)

The stock-weighted average percentage increase in non-road diesel equipment costs associated with Tier 4 compliance was estimated to be in the range of 7–10% across power rating categories (note that this percentage is expressed as the percentage increase in the cost of the overall piece of equipment, rather than a percentage increase in the cost of the diesel engines only). These percentages accord with the projections received from individual agricultural, construction and mining equipment suppliers, which were generally in the range of 5–11%, and with the percentages within the US and European RIAs[202].

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[202] Van Zeebroeck et al. (2009), US EPA (2004a)

Appendix G: Monetisation of health costs and benefits, and $PM_{2.5}$ and NO_x unit damage costs by significant urban area

G1 Valuing the health impacts of air pollution

The most comprehensive method for valuing the health impacts of air pollution is the ‘impact pathway’ approach which has been applied in a number of EU, UK and US studies[203]. It involves quantifying air pollutant emissions, analysing pollutant dispersion and chemistry, quantifying population exposure to pollutants, quantifying the impacts of air pollution in terms of defined health endpoints (e.g. mortality, hospital admissions for respiratory disease), and valuing the impacts, usually using a ‘willingness to pay’ (WTP) approach based on stated and revealed preference techniques.

The impact pathway approach is the recommended best practice for monetising the impacts of major new air quality standards and policies because it uses detailed location-specific data and has the potential to provide a relatively high degree of precision; however, the approach is resource intensive, prohibitively so for many impact assessments, with a large volume of information being required.

Consequently, simplified approaches have been developed. Tables or models known as ‘damage costs’ or ‘unit costs’ allow valuation of air quality impacts based solely on the change in the amount of pollutant emitted. Specific damage costs for a particular country or region are usually developed from a detailed impact pathway assessment. The damage cost approach is typically used where the impact pathway approach is not practical, or to verify the results from the impact pathway approach. Damage costs are commonly used in regulatory assessments for specific sectors.

This study uses an enhanced intermediate approach which utilises Australian data to best advantage. Health benefits are estimated using unit damage costs ($ per tonne). Damage costs are adjusted to take into account Australian population exposure. The unit damage costs are proportional to population density and relate to geographic areas of Australia.

G2 $PM_{2.5}$ health benefits

In this report health costs and benefits arising from emissions are estimated using unit damage costs which relate costs (benefits) in dollars to each tonne of primary $PM_{2.5}$ emitted (reduced). Reference was made to the unit damage costs developed for Australia by Aust et al. (2013). As noted above, the unit damage costs are proportional to population density. They relate to specific geographical areas of Australia based on the ABS Significant Urban Area (SUA) structure for urban centres with more than 10,000 people. This enables the health costs/benefits of emissions to be varied according to the location at which they occur, on the basis of population-weighted exposure. In other words, one tonne of $PM_{2.5}$ emissions (emission reductions) occurring in a more populated area is associated with higher health costs (benefits) compared to one tonne of $PM_{2.5}$ emissions (emission reductions) occurring in a less populated area.

Unit damage costs for primary $PM_{2.5}$ derived by Aust et al. (2013) include the following impacts:

- mortality associated with chronic exposure to $PM_{2.5}$
- acute effects on morbidity:
  - respiratory hospital admissions associated with $PM_{2.5}$
  - cardiovascular hospital admissions associated with $PM_{2.5}$
- building soiling.

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[203] Pacific Environment (2013b)

Mortality associated with acute exposure to $PM_{2.5}$ was not included in the derivation of the unit damage costs. The damage costs results are therefore likely to represent a conservative estimate of total health impacts from exposure to $PM_{2.5}$. Further information on the derivation of damage costs is provided in Section G2.1.

Mortality, and specifically chronic mortality, has been identified as the most important health endpoint in the valuation of PM health effects[204]. Estimates for Europe indicate that overall morbidity benefits, which include restricted activity days and lost work days, represent less than 0.1% compared to the mortality health impacts[205].

To assess the effect of mortality it is necessary to place a monetary value on the so-called 'value of a statistical life' (VSL). This is typically derived based on the WTP approach in which the willingness of individuals to pay to avoid a specific health effect is established. The VSL is defined as the aggregated economic value society places on reducing the average number of deaths by one. The 'value of a life year' (VOLY) is an estimate of the value society places on reducing the risk of premature death, expressed in terms of saving a statistical life year. Health effects due to PM emissions have typically been monetised in international studies based on the unit costs for the VSL, the VOLY, hospitalisation for respiratory disease and hospitalisation for cardiovascular disease.

Based on damage costs established for the UK, Aust et al. (2013) developed unit damage costs for application in Australia by adjusting to account for differences between the VOLY in the UK and Australia, as well as differences in currency and inflation. Aust et al. (2013) based the Australian VOLY on the Australian Safety and Compensation Council (ASCC) valuation of VOLY, which drew on an extensive review of international literature on the values of human life and issues related to their application[206]. While noting the inherent uncertainties in VSL estimates, the ASCC recommended a 'ballpark average' of $6 million for VSL (in AUD 2008), with sensitivity analysis recommended at $3.7 million and $8.1 million. The implications of this range in VSL is considered within the sensitivity testing conducted for this report.

The Australian Department of Finance and Deregulation's Office of Best Practice Regulation (OBPR) considers a value of $3.7 million to be the most credible estimate of the VSL, and $151,000 the best estimate for the VOLY[207] but recommends sensitivity testing given the range of values derived for VSL and VOLY from different empirical studies. The OBPR recommended estimates were derived from a study by Abelson (2008) which recommended a value of life of $3–4 million. While these estimates were developed with reference to selected international studies an exact method (i.e. meta-analysis) was not used.

Subsequent studies have supported the use of a $6 million VSL, including Jalaludin et al. (2009) and NEPC (2011b). Jalaludin et al. (2009) provided a critical evaluation of the methodology and uncertainty associated with cost benefit assessments relating to ambient air pollution, health effects and monetary valuation. The study recommended the adoption of a VSL of $6 million, with sensitivity analysis at $3.7 million and $8.1 million (in AUD 2008). In outlining a framework for setting air quality standards in Australia, including guidance for hazard assessment, risk characterisation and policy considerations, NEPC (2011b) similarly recommended the adoption of a VSL of $6 million (in AUD 2008) with sensitivity analysis as proposed by the ASCC. This sensitivity range is adopted in this report.

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[204] Aust et al. (2013)

[205] AEA (2005), as cited in Aust et al. (2013)

[206] ASCC (2008)

[207] Office of Best Practice Regulation (OBPR), Value of Statistical Life, www.dpmc.gov.au/deregulation/obpr/docs/ValuingStatisticalLife.pdf

A VSL of $6 million has been used in air pollution related regulatory impact statements recently accepted by the OBPR. The RIS for adopting Euro 5/6 standards for light vehicles applied a VSL of $6 million (in AUD 2008) in the impact analysis and conducted sensitivity analysis at $3.7 million and $8.1 million[208]. The RIS on options to reduce emissions from wood heaters[209] used damage costs derived for the Australian Government *Fuel Taxation Inquiry: The Air Pollution Costs of Transport in Australia*, which in turn were based on a VSL of $6 million, adjusted to reflect years of life lost[210]. Three bands of damage costs were applied in the wood heaters RIS to reflect population densities – large metropolitan centres (i.e. Sydney, Melbourne), smaller capital cities (i.e. Brisbane, Adelaide, Perth) and all other areas (including all regional centres and rural communities).

The economic analysis to inform the National Plan for Clean Air uses the damage costs developed by Aust et al. (2013) to value the health impacts of $PM_{2.5}$. In that analysis Pacific Environment (2013b) used a simplified impact pathway approach to validate the $PM_{2.5}$ damage costs. The simplified impact pathway approach produced health benefit estimates around 50% higher than those for the damage cost method. Pacific Environment (2013b) note that large discrepancies have also arisen between damage cost and impact pathway approaches in European studies, and conclude that damage costs results are likely to represent a conservative estimate of health benefits[211].

G2.1 Derivation of unit damage functions by SUA for $PM_{2.5}$

Previous impact analyses such as the RIS for adopting Euro 5/6 standards for light vehicles and the wood heaters RIS use a limited range of damage costs for different population densities; however, the damage costs developed by Aust et al. (2013) were for Australian-specific population densities to the finest ABS spatial scale available.

A linear regression function was fitted by Aust et al. (2013) to the UK damage costs which were available for areas with different population densities, in order to adjust the damage costs based on Australian population density data. Unit damage costs were then developed for specific geographical areas of Australia based on the ABS SUA structure for urban centres with more than 10,000 people. The population density for each SUA was used in conjunction with the regression function to determine a SUA-specific unit damage cost. SUA-specific unit damage costs for $PM_{2.5}$ were derived and projected for future years as follows:

- Unit damage costs were scaled based on the 2011 population density from the ABS (2008), and an annual population growth factor applied based on ABS population growth projections[212].
- An economic uplift factor, taken to be 2.1% per annum, was applied.
- A discount rate was applied to adjust for changes in the willingness to pay (7%).

This approach of using a wide range of Australian population-weighted damage costs in all health benefit calculations in this report, given that VSL/VOLY itself is independent of population density, provides a more conservative estimate of health benefits than would be obtained using the limited range of damage costs (e.g. capital city, non-urban) applied in Australian studies to date.

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[208] DIT (2010b)

[209] BDA Group (2013)

[210] AEA Technology Environment (2002)

[211] Pacific Environment (2013b)

[212] ABS population growth projections to 2056 given for the major city within each state/territory and for the balance of the state/territory (www.abs.gov.au/Ausstats/abs@.nsf/mf/3222.0).

G3 NO_x health benefits

Reference was made to the unit damage costs for NO_x derived for use in the economic analysis being undertaken to inform the National Plan for Clean Air[213]. Reference should be made to this study for a detailed description of the derivation of these costs, with a brief summary provided below.

NO_x related impacts include health effects associated with nitrogen dioxide (NO_2) exposures and health impacts associated with secondary pollutants such as ozone and the nitrate component of secondary PM (i.e. particles formed in the atmosphere). Other impacts associated with NO_x emissions include visibility reduction, acidification, eutrophication and radiative forcing of climate through secondary PM and tropospheric ozone formation. However, the unit damage functions for NO_x derived by Pacific Environment (2013a) address only the role of NO_x in contributing to the health impacts of secondary PM.

NO_X emission sources typically contribute to secondary PM at varying distances (typically tens to hundreds of kilometres) downwind from a source. The exposure to nitrates therefore tends to occur away from urban areas. As a consequence, there is also a reasonably even distribution of secondary PM on a regional scale, with fewer differences between urban and rural areas than for primary particles.

In deriving the damage functions Pacific Environment (2013a) transferred UK damage costs as documented by DEFRA (2011). Given the potential differences in nitrate formation between the UK and Australia, and the lack of detailed information on nitrates in Australia (including the absence of a model for secondary PM), a simple approach was applied to provide an approximation of damages. This approach involved adopting the UK national unit damage cost PM:NO_x ratio of around 50:1, which is essentially driven by the difference in years of life lost per tonne (2.1 for PM compared with 0.04 for NO_X). After accounting for Australian health metrics, notably VOLY (value of a life year) and the unit costs for hospital admissions, a PM:NO_X ratio of 52.5 was calculated. For PM Aust et al. (2013) derived a unit damage cost for $PM_{2.5}$ of \$280/tonne/person/km^2. Dividing this by 52.5 gave a value for NO_x of \$5.3/tonne/person/km^2.

Unit damage costs for $PM_{2.5}$ and NO_x are given in Tables G1 and G2 respectively.

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[213] Pacific Environment (2013a)

Table G1: Unit damage costs for $PM_{2.5}$

State	SUA code	SUA name	Area (km²)	Total popn (2011)	Popn density (people/km²)	Damage cost/tonne of $PM_{2.5}$ (A$, 2011)	Annual popn growth factor
NSW	1030	Sydney	4,064	4,028,525	991	280,000	1.010
NSW	1009	Central Coast	566	304,755	538	150,000	1.004
NSW	1035	Wollongong	572	268,944	470	130,000	1.004
NSW	1027	Port Macquarie	96	41,722	433	120,000	1.004
NSW	1013	Forster – Tuncurry	50	19,501	394	110,000	1.004
NSW	1023	Newcastle – Maitland	1,019	398,770	391	110,000	1.004
NSW	1014	Goulburn	65	21,485	332	93,000	1.004
NSW	1003	Ballina	73	23,511	320	90,000	1.004
NSW	1018	Lismore	89	28,285	319	89,000	1.004
NSW	1016	Griffith	56	17,900	317	89,000	1.004
NSW	1033	Ulladulla	47	14,148	303	85,000	1.004
NSW	1010	Cessnock	69	20,262	294	82,000	1.004
NSW	1034	Wagga Wagga	192	52,043	272	76,000	1.004
NSW	1025	Orange	145	36,467	252	71,000	1.004
NSW	1022	Nelson Bay – Corlette	116	25,072	217	61,000	1.004
NSW	1012	Dubbo	183	33,997	186	52,000	1.004
NSW	1017	Kurri Kurri – Weston	91	16,198	179	50,000	1.004
NSW	1015	Grafton	106	18,360	173	48,000	1.004
NSW	1004	Batemans Bay	94	15,732	167	47,000	1.004
NSW	1024	Nowra – Bomaderry	202	33,340	165	46,000	1.004
NSW	1029	St Georges Basin – Sanctuary Point	77	12,610	164	46,000	1.004
NSW	1031	Tamworth	241	38,736	161	45,000	1.004
NSW	1005	Bathurst	213	32,480	152	43,000	1.004
NSW	1032	Taree	187	25,421	136	38,000	1.004
NSW	1001	Albury – Wodonga	628	82,083	131	37,000	1.004
NSW	1011	Coffs Harbour	506	64,242	127	36,000	1.004
NSW	1028	Singleton	127	16,133	127	36,000	1.004
NSW	1007	Broken Hill	170	18,519	109	30,000	1.004
NSW	1019	Lithgow	120	12,251	102	29,000	1.004
NSW	1006	Bowral – Mittagong	422	34,861	83	23,000	1.004
NSW	1002	Armidale	275	22,469	82	23,000	1.004
NSW	1020	Morisset – Cooranbong	341	21,775	64	18,000	1.004
NSW	1026	Parkes	235	10,939	47	13,000	1.004

State	SUA code	SUA name	Area (km²)	Total popn (2011)	Popn density (people/km²)	Damage cost/tonne of $PM_{2.5}$ (A$, 2011)	Annual popn growth factor
NSW	1021	Muswellbrook	262	11,791	45	13,000	1.004
NSW	1008	Camden Haven	525	15,739	30	8,400	1.004
NSW	1000	Not in any Significant Urban Area (NSW)	788,116	999,873	1	360	1.004
VIC	2011	Melbourne	5,679	3,847,567	677	190,000	1.011
VIC	2016	Sale	46	14,259	313	88,000	1.004
VIC	2020	Wangaratta	58	17,687	307	86,000	1.004
VIC	2004	Bendigo	287	86,078	299	84,000	1.004
VIC	2003	Ballarat	344	91,800	267	75,000	1.004
VIC	2005	Colac	55	11,776	215	60,000	1.004
VIC	2010	Horsham	83	15,894	191	54,000	1.004
VIC	2008	Geelong	919	173,450	189	53,000	1.004
VIC	2017	Shepparton – Mooroopna	249	46,503	187	52,000	1.004
VIC	2006	Drysdale – Clifton Springs	65	11,699	180	50,000	1.004
VIC	2012	Melton	266	47,670	179	50,000	1.004
VIC	2022	Warrnambool	183	32,381	177	50,000	1.004
VIC	2019	Traralgon – Morwell	235	39,706	169	47,000	1.004
VIC	2014	Moe – Newborough	105	16,675	158	44,000	1.004
VIC	2018	Torquay	126	15,043	119	33,000	1.004
VIC	2015	Ocean Grove – Point Lonsdale	219	22,424	103	29,000	1.004
VIC	2001	Bacchus Marsh	196	17,156	87	24,000	1.004
VIC	2002	Bairnsdale	155	13,239	85	24,000	1.004
VIC	2013	Mildura – Wentworth	589	47,538	81	23,000	1.004
VIC	2007	Echuca – Moama	351	19,308	55	15,000	1.004
VIC	2009	Gisborne – Macedon	367	18,014	49	14,000	1.004
VIC	2021	Warragul – Drouin	680	29,946	44	12,000	1.004
VIC	2000	Not in any Significant Urban Area (Vic.)	216,296	693,578	3	900	1.004
QLD	3003	Cairns	254	133,912	527	150,000	1.014
QLD	3008	Hervey Bay	93	48,678	523	150,000	1.014
QLD	3006	Gold Coast – Tweed Heads	1,403	557,823	398	110,000	1.014
QLD	3001	Brisbane	5,065	1,977,316	390	110,000	1.015
QLD	3010	Mackay	208	77,293	371	100,000	1.014

State	SUA code	SUA name	Area (km²)	Total popn (2011)	Popn density (people/km²)	Damage cost/tonne of $PM_{2.5}$ (A$, 2011)	Annual popn growth factor
QLD	3004	Emerald	39	13,219	337	94,000	1.014
QLD	3012	Mount Isa	63	20,569	328	92,000	1.014
QLD	3007	Gympie	69	19,511	282	79,000	1.014
QLD	3016	Townsville	696	162,291	233	65,000	1.014
QLD	3002	Bundaberg	306	67,341	220	62,000	1.014
QLD	3015	Toowoomba	498	105,984	213	60,000	1.014
QLD	3018	Yeppoon	79	16,372	208	58,000	1.014
QLD	3005	Gladstone – Tannum Sands	240	41,966	175	49,000	1.014
QLD	3014	Sunshine Coast	1,633	270,771	166	46,000	1.014
QLD	3011	Maryborough	171	26,215	154	43,000	1.014
QLD	3013	Rockhampton	580	73,680	127	36,000	1.014
QLD	3017	Warwick	159	14,609	92	26,000	1.014
QLD	3009	Highfields	230	16,820	73	20,000	1.014
QLD	3000	Not in any Significant Urban Area (Qld)	1,718,546	755,687	0.4	120	1.014
SA	4001	Adelaide	2,024	1,198,467	592	170,000	1.007
SA	4006	Port Pirie	75	14,044	187	52,000	1.005
SA	4008	Whyalla	121	21,991	181	51,000	1.005
SA	4003	Murray Bridge	98	16,706	171	48,000	1.005
SA	4002	Mount Gambier	193	27,754	144	40,000	1.005
SA	4005	Port Lincoln	136	15,222	112	31,000	1.005
SA	4007	Victor Harbor – Goolwa	309	23,851	77	22,000	1.005
SA	4004	Port Augusta	249	13,657	55	15,000	1.005
SA	4000	Not in any Significant Urban Area (SA)	980,973	264,882	0.3	76	1.005
WA	5009	Perth	3,367	1,670,952	496	140,000	1.015
WA	5007	Kalgoorlie – Boulder	75	30,839	411	110,000	1.010
WA	5003	Bunbury	223	65,608	295	83,000	1.010
WA	5005	Ellenbrook	105	28,802	276	77,000	1.010
WA	5002	Broome	50	12,765	255	71,000	1.010
WA	5006	Geraldton	271	35,749	132	37,000	1.010
WA	5008	Karratha	134	16,474	123	34,000	1.010
WA	5010	Port Hedland	116	13,770	118	33,000	1.010
WA	5001	Albany	297	30,656	103	29,000	1.010
WA	5004	Busselton	1,423	30,286	21	6,000	1.010
WA	5000	Not in any Significant	2,520,513	30,654	0.01	3	1.010

State	SUA code	SUA name	Area (km²)	Total popn (2011)	Popn density (people/km²)	Damage cost/tonne of $PM_{2.5}$ (A$, 2011)	Annual popn growth factor
		Urban Area (WA)					
TAS	6001	Burnie – Wynyard	131	29,050	223	62,000	1.000
TAS	6004	Launceston	435	82,222	189	53,000	1.000
TAS	6003	Hobart	1,213	200,498	165	46,000	1.006
TAS	6005	Ulverstone	130	14,110	108	30,000	1.000
TAS	6002	Devonport	290	26,871	93	26,000	1.000
TAS	6000	Not in any Significant Urban Area (Tas.)	65,819	142,598	2	610	1.000
NT	7002	Darwin	295	106,257	361	100,000	1.014
NT	7001	Alice Springs	328	25,187	77	22,000	1.010
NT	7000	Not in any Significant Urban Area (NT)	1,347,577	80,504	0.06	17	1.010
ACT	8001	Canberra – Queanbeyan	482	391,643	812	230,000	1.008
ACT	8000	Not in any Significant Urban Area (ACT)	1,914	1,622	0.85	240	1.008
Other	9000	Not in any Significant Urban Area (OT)	218	3,029	14	3,900	1.003

Table G2: Unit damage costs for NO_x

State	Area name	Constituent SUAs					Total area (km²)	Total 2011 popn	Total 2011 popn density (people/ km²)	Unit 2011 damage costs (A$)
		SUA code	SUA name	SUA area (km²)	SUA 2011 popn	SUA 2011 popn density (people/ km²)				
NSW	Greater Sydney	1030	Sydney	4,064	4,028,525	991	4,630	4,333,280	936	4,992
		1009	Central Coast	566	304,755	538				
	Other NSW	–	–	–	–	–	795,710	2,505,659	3.1	17
VIC	Greater Melbourne	2011	Melbourne	5,679	3,847,567	677	6,508	3,930,407	604	3,221
		2012	Melton	266	47,670	179				
		2001	Bacchus Marsh	196	17,156	87				
		2009	Gisborne – Macedon	367	18,014	49				
	Other VIC	–	–	–	–	–	221,045	1,398,984	6.3	34
QLD	Greater Brisbane	3001	Brisbane	5,065	1,977,316	390	5,065	1,977,316	390	2,082
	Other QLD	–	–	–	–	–	1,725,267	2,422,741	1.4	7
SA	Greater Adelaide	4001	Adelaide	2,024	1,198,467	592	2,024	1,198,467	592	3,158
	Other SA	–	–	–	–	–	982,154	398,107	0.4	2
WA	Greater Perth	5009	Perth	3,367	1,670,952	496	3,472	1,699,754	490	2,611
		5005	Ellenbrook	105	28,802	276				
	Other WA	–	–	–	–	–	2,523,102	266,801	0.1	1
TAS	Greater Hobart	6003	Hobart	1,213	200,498	165	1,213	200,498	165	882
	Other TAS	–	–	–	–	–	66,805	294,851	4.4	24
NT	Greater Darwin	7002	Darwin	295	106,257	360	295	106,257	360	1,921
	Other TAS	–	–	–	–	–	1,347,905	105,691	0.1	0.4
ACT	Greater Canberra	8001	Canberra – Queanbeyan	482	391,643	813	482	391,643	813	4,334
	Other ACT	8000	Not in any Significant Urban Area (ACT)	1,914	1,662	0.9	1,914	1,662	0.9	5

Appendix H: Detailed cost projections for harmonisation scenarios

Table H1: Scenario 1 projected for the main base case

ITEM	UNIT	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055
Social discount rate	%																																									
Sales (relative to BAU)																																										
Non compliant																																										
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	-2,172	-2,190	-2,208	-2,227	-2,246	-2,265	-2,285	-2,305	-2,326	-2,347	-2,369	-2,391	-2,414	-2,437	-2,461	-2,486	-2,511	-2,537	-2,564	-2,591	-2,619	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	-5,188	-5,247	-5,306	-5,367	-5,428	-5,490	-5,553	-5,618	-5,683	-5,749	-5,817	-5,885	-5,955	-6,026	-6,097	-6,170	-6,245	-6,320	-6,397	-6,474	-6,554	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	-1,646	-1,675	-1,705	-1,736	-1,768	-1,800	-1,833	-1,866	-1,901	-1,936	-1,972	-2,009	-2,047	-2,085	-2,125	-2,166	-2,207	-2,250	-2,294	-2,339	-2,385	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	-5,299	-5,475	-5,658	-5,850	-6,050	-6,259	-6,477	-6,705	-6,944	-7,193	-7,454	-7,727	-8,012	-8,310	-8,622	-8,949	-9,291	-9,648	-10,023	-10,415	-10,826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	-2,166	-2,205	-2,245	-2,286	-2,329	-2,373	-2,418	-2,464	-2,512	-2,561	-2,611	-2,663	-2,717	-2,772	-2,829	-2,888	-2,949	-3,011	-3,076	-3,143	-3,212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	-90	-93	-96	-99	-102	-105	-109	-112	-116	-120	-124	-128	-132	-137	-142	-147	-152	-158	-164	-170	-176	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 2																																										
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	2,172	2,190	2,208	2,227	2,246	2,265	2,285	2,305	2,326	2,347	2,369	2,391	2,414	2,437	2,461	2,486	2,511	2,537	2,564	2,591	2,619	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	-3,093	-3,161	-3,232	-3,305	-3,382	-3,461	-3,544	-3,630	-3,719	-3,812	-3,909	-4,010	-4,115	-4,224	-4,338	-4,457	-4,581	-4,711	-4,845	-4,986	-5,133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	-2,838	-2,885	-2,934	-2,984	-3,036	-3,090	-3,145	-3,203	-3,263	-3,324	-3,389	-3,455	-3,524	-3,596	-3,670	-3,748	-3,828	-3,912	-3,999	-4,089	-4,183	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	-1,081	-1,121	-1,163	-1,206	-1,252	-1,300	-1,351	-1,404	-1,460	-1,518	-1,579	-1,643	-1,711	-1,782	-1,856	-1,934	-2,016	-2,102	-2,192	-2,287	-2,386	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	-1,872	-1,948	-2,027	-2,110	-2,197	-2,288	-2,384	-2,484	-2,590	-2,700	-2,817	-2,939	-3,067	-3,201	-3,342	-3,491	-3,646	-3,810	-3,981	-4,162	-4,351	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	90	93	96	99	102	105	109	112	116	120	124	128	132	137	142	147	152	158	164	170	176	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 3																																										
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	8,281	8,408	8,538	8,672	8,810	8,952	9,097	9,248	9,402	9,562	9,726	9,895	10,070	10,250	10,436	10,628	10,826	11,030	11,242	11,461	11,687	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	4,484	4,561	4,639	4,720	4,803	4,889	4,978	5,069	5,163	5,260	5,361	5,464	5,571	5,681	5,796	5,914	6,036	6,162	6,293	6,428	6,568	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	6,380	6,596	6,821	7,056	7,302	7,559	7,828	8,109	8,404	8,711	9,033	9,370	9,723	10,092	10,478	10,883	11,306	11,750	12,215	12,702	13,212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	4,038	4,152	4,272	4,396	4,526	4,661	4,801	4,948	5,101	5,261	5,428	5,602	5,784	5,973	6,172	6,379	6,595	6,821	7,057	7,304	7,562	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 4 (all)																																										
<19 kW	No.	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Check	No.																																									
Costs																																										
Installed Engine costs																																										
NC	$M	-585	-598	-611	-624	-638	-652	-667	-683	-699	-716	-733	-751	-769	-789	-809	-829	-851	-873	-897	-921	-946	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	-568	-580	-592	-605	-618	-632	-647	-661	-677	-693	-709	-726	-744	-762	-781	-801	-822	-843	-865	-888	-912	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	-17	-18	-18	-19	-20	-20	-21	-22	-22	-23	-24	-25	-25	-26	-27	-28	-29	-30	-31	-33	-34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 2	$M	-326	-338	-350	-363	-376	-390	-405	-420	-436	-453	-471	-490	-509	-529	-551	-573	-597	-622	-648	-675	-704	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	-344	-356	-369	-382	-396	-411	-426	-442	-459	-477	-495	-515	-535	-557	-579	-602	-627	-653	-680	-709	-738	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	18	18	19	19	20	21	21	22	23	24	24	25	26	27	28	29	30	31	32	34	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 3	$M	1,014	1,041	1,069	1,098	1,128	1,160	1,192	1,227	1,262	1,299	1,338	1,379	1,421	1,465	1,511	1,559	1,609	1,661	1,715	1,772	1,832	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	1,014	1,041	1,069	1,098	1,128	1,160	1,192	1,227	1,262	1,299	1,338	1,379	1,421	1,465	1,511	1,559	1,609	1,661	1,715	1,772	1,832	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 4	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total (Engine Costs)	**$M**	**103**	**106**	**108**	**111**	**114**	**117**	**120**	**124**	**127**	**131**	**135**	**138**	**142**	**147**	**151**	**156**	**161**	**166**	**171**	**176**	**182**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Operation & Maintenance costs																																										
NC/T1 to T2 Engines - fuel cost	$M	28	30	31	32	34	36	37	39	41	43	45	47	49	52	54	57	60	63	66	69	72	76	80	84	88	93	96	99	102	106	109	113	117	121	126	130	**135**	**140**	**145**	**150**	**156**
Tier 4 engines maintenance	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total (Operation & Maintenance)	**$M**	**28**	**30**	**31**	**32**	**34**	**36**	**37**	**39**	**41**	**43**	**45**	**47**	**49**	**52**	**54**	**57**	**60**	**63**	**66**	**69**	**72**	**76**	**80**	**84**	**88**	**93**	**96**	**99**	**102**	**106**	**109**	**113**	**117**	**121**	**126**	**130**	**135**	**140**	**145**	**150**	**156**
Administration costs	$M	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compliance costs	$M	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL COSTS	**$M**	**154**	**138**	**142**	**147**	**151**	**156**	**161**	**166**	**171**	**177**	**183**	**189**	**195**	**201**	**208**	**216**	**223**	**231**	**239**	**248**	**257**	**76**	**80**	**84**	**88**	**93**	**96**	**99**	**102**	**106**	**109**	**113**	**117**	**121**	**126**	**130**	**135**	**140**	**145**	**150**	**156**
Benefits																																										
Fuel savings																																										
Tier 4 engines- fuel savings	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					
Health benefits																																										
NOx	$M	3.8	8.5	13.1	17.7	22.2	26.7	31.2	35.8	40.4	45.1	49.8	54.6	59.4	64.2	69.1	73.9	78.8	83.7	88.6	93.5	98.5	94.9	93.5	92.1	90.6	89.1	87.4	85.7	83.9	82.0	80.0	78.0	75.9	73.7	71.4	69.1	67	65	63	61	59
PM2.5	$M	13.0	31.0	49.2	67.6	86.5	105.8	125.7	146.1	167.0	188.5	210.4	232.6	255.2	278.0	300.9	323.9	346.9	370.0	393.1	416.3	439.6	433.6	428.7	423.5	417.9	412.2	406.2	399.9	393.5	386.8	380.0	372.8	365.4	357.7	349.8	341.5	333	326	318	310	303
Total (Health Benefits)	**$M**	**17**	**40**	**62**	**85**	**109**	**132**	**157**	**182**	**207**	**234**	**260**	**287**	**315**	**342**	**370**	**398**	**426**	**454**	**482**	**510**	**538**	**529**	**522**	**516**	**509**	**501**	**494**	**486**	**477**	**469**	**460**	**451**	**441**	**431**	**421**	**411**	**400**	**390**	**380**	**371**	**362**
TOTAL BENEFITS		**17**	**40**	**62**	**85**	**109**	**132**	**157**	**182**	**207**	**234**	**260**	**287**	**315**	**342**	**370**	**398**	**426**	**454**	**482**	**510**	**538**	**529**	**522**	**516**	**509**	**501**	**494**	**486**	**477**	**469**	**460**	**451**	**441**	**431**	**421**	**411**	**400**	**390**	**380**	**371**	**362**
Net benefit/cost	$M	**-138**	**-99**	**-80**	**-61**	**-43**	**-23**	**-4**	**16**	**36**	**57**	**78**	**99**	**120**	**141**	**162**	**182**	**202**	**223**	**242**	**262**	**281**	**453**	**442**	**432**	**420**	**408**	**398**	**387**	**375**	**363**	**351**	**338**	**324**	**310**	**295**	**280**	**266**	**252**	**239**	**227**	**216**
NPV	$M	**1,257**																																								

Table H2: Scenario 2 projected for the main base case

ITEM	UNIT	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Social discount rate	%	7%																				
Sales (relative to BAU)																						
Non compliant																						
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	-2,227	-2,246	-2,265	-2,285	-2,305	-2,326	-2,347	-2,369	-2,391	-2,414	-2,437	-2,461	-2,486	-2,511	-2,537	-2,564	-2,591	-2,619
37 to 55 kW	No.	0	0	0	-5,367	-5,428	-5,490	-5,553	-5,618	-5,683	-5,749	-5,817	-5,885	-5,955	-6,026	-6,097	-6,170	-6,245	-6,320	-6,397	-6,474	-6,554
56 to 74 kW	No.	0	0	0	-1,736	-1,768	-1,800	-1,833	-1,866	-1,901	-1,936	-1,972	-2,009	-2,047	-2,085	-2,125	-2,166	-2,207	-2,250	-2,294	-2,339	-2,385
75 to 129 kW	No.	0	0	0	-5,850	-6,050	-6,259	-6,477	-6,705	-6,944	-7,193	-7,454	-7,727	-8,012	-8,310	-8,622	-8,949	-9,291	-9,648	-10,023	-10,415	-10,826
130 to 560 kW	No.	0	0	0	-2,286	-2,329	-2,373	-2,418	-2,464	-2,512	-2,561	-2,611	-2,663	-2,717	-2,772	-2,829	-2,888	-2,949	-3,011	-3,076	-3,143	-3,212
>560 kW	No.	0	0	0	-99	-102	-105	-109	-112	-116	-120	-124	-128	-132	-137	-142	-147	-152	-158	-164	-170	-176
Tier 2																						
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	-5,044	-5,154	-5,266	-5,383	-5,505	-5,630	-5,760	-5,895	-6,035	-6,181	-6,332	-6,488	-6,651	-6,820	-6,995	-7,177	-7,367	-7,564
37 to 55 kW	No.	0	0	0	-3,305	-3,382	-3,461	-3,544	-3,630	-3,719	-3,812	-3,909	-4,010	-4,115	-4,224	-4,338	-4,457	-4,581	-4,711	-4,845	-4,986	-5,133
56 to 74 kW	No.	0	0	0	-2,984	-3,036	-3,090	-3,145	-3,203	-3,263	-3,324	-3,389	-3,455	-3,524	-3,596	-3,670	-3,748	-3,828	-3,912	-3,999	-4,089	-4,183
75 to 129 kW	No.	0	0	0	-1,206	-1,252	-1,300	-1,351	-1,404	-1,460	-1,518	-1,579	-1,643	-1,711	-1,782	-1,856	-1,934	-2,016	-2,102	-2,192	-2,287	-2,386
130 to 560 kW	No.	0	0	0	-2,110	-2,197	-2,288	-2,384	-2,484	-2,590	-2,700	-2,817	-2,939	-3,067	-3,201	-3,342	-3,491	-3,646	-3,810	-3,981	-4,162	-4,351
>560 kW	No.	0	0	0	-737	-774	-813	-855	-898	-944	-992	-1,042	-1,095	-1,151	-1,210	-1,272	-1,337	-1,405	-1,477	-1,553	-1,632	-1,716
Tier 3																						
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	-2,784	-2,908	-3,039	-3,176	-3,321	-3,472	-3,631	-3,798	-3,974	-4,158	-4,351	-4,555	-4,768	-4,992	-5,228	-5,475	-5,736	-6,009
37 to 55 kW	No.	0	0	0	-2,198	-2,279	-2,364	-2,452	-2,545	-2,642	-2,744	-2,850	-2,962	-3,079	-3,202	-3,330	-3,465	-3,606	-3,755	-3,910	-4,073	-4,243
56 to 74 kW	No.	0	0	0	-2,718	-2,812	-2,909	-3,011	-3,118	-3,229	-3,345	-3,466	-3,592	-3,724	-3,862	-4,007	-4,157	-4,315	-4,480	-4,652	-4,832	-5,020
75 to 129 kW	No.	0	0	0	-1,894	-1,988	-2,086	-2,190	-2,299	-2,413	-2,534	-2,661	-2,794	-2,934	-3,081	-3,236	-3,399	-3,570	-3,750	-3,939	-4,138	-4,347
130 to 560 kW	No.	0	0	0	-3,817	-4,000	-4,193	-4,396	-4,608	-4,832	-5,067	-5,314	-5,574	-5,847	-6,134	-6,435	-6,753	-7,086	-7,436	-7,805	-8,192	-8,599
>560 kW	No.	0	0	0	-399	-415	-432	-450	-469	-488	-509	-530	-553	-577	-602	-628	-656	-685	-715	-747	-780	-816
Tier 4 (all)																						
<19 kW	No.	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19 to 37 kW	No.	0	0	0	10,055	10,307	10,571	10,845	11,131	11,428	11,739	12,062	12,400	12,752	13,120	13,504	13,904	14,323	14,760	15,216	15,694	16,192
37 to 55 kW	No.	0	0	0	10,870	11,089	11,315	11,550	11,793	12,044	12,306	12,576	12,857	13,149	13,452	13,766	14,093	14,432	14,785	15,152	15,533	15,930
56 to 74 kW	No.	0	0	0	7,438	7,615	7,799	7,989	8,187	8,392	8,605	8,826	9,056	9,295	9,544	9,802	10,071	10,351	10,642	10,944	11,260	11,588
75 to 129 kW	No.	0	0	0	8,950	9,290	9,646	10,018	10,408	10,817	11,245	11,694	12,164	12,656	13,173	13,714	14,281	14,876	15,500	16,154	16,840	17,560
130 to 560 kW	No.	0	0	0	8,213	8,526	8,854	9,197	9,557	9,933	10,328	10,742	11,176	11,631	12,107	12,607	13,131	13,681	14,257	14,862	15,496	16,162
>560 kW	No.	0	0	0	1,235	1,291	1,351	1,413	1,479	1,548	1,620	1,696	1,776	1,861	1,949	2,042	2,139	2,242	2,350	2,463	2,583	2,708
Check	No.																					
Costs																						
Installed Engine costs																						
NC	$M	0	0	0	-624	-638	-652	-667	-683	-699	-716	-733	-751	-769	-789	-809	-829	-851	-873	-897	-921	-946
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	-605	-618	-632	-647	-661	-677	-693	-709	-726	-744	-762	-781	-801	-822	-843	-865	-888	-912
>560 kW	$M	0	0	0	-19	-20	-20	-21	-22	-22	-23	-24	-25	-25	-26	-27	-28	-29	-30	-31	-33	-34
Tier 2	$M	0	0	0	-616	-639	-663	-688	-715	-743	-772	-802	-834	-867	-902	-939	-978	-1,018	-1,061	-1,105	-1,152	-1,201
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	-471	-487	-503	-520	-538	-557	-576	-597	-618	-640	-664	-689	-714	-741	-770	-799	-831	-863
>560 kW	$M	0	0	0	-145	-153	-160	-168	-177	-186	-195	-205	-216	-227	-238	-251	-263	-277	-291	-306	-322	-338
Tier 3	$M	0	0	0	-788	-824	-861	-901	-943	-986	-1,032	-1,080	-1,131	-1,184	-1,240	-1,298	-1,360	-1,424	-1,492	-1,564	-1,639	-1,718
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	-703	-735	-770	-805	-843	-882	-924	-967	-1,013	-1,061	-1,111	-1,164	-1,220	-1,279	-1,340	-1,405	-1,473	-1,544
>560 kW	$M	0	0	0	-85	-88	-92	-96	-100	-104	-108	-113	-118	-123	-128	-134	-140	-146	-152	-159	-166	-174
Tier 4	$M	0	0	0	2,497	2,586	2,679	2,777	2,879	2,986	3,098	3,215	3,338	3,467	3,601	3,743	3,891	4,046	4,208	4,379	4,558	4,745
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	2,149	2,222	2,298	2,378	2,462	2,549	2,641	2,737	2,837	2,942	3,052	3,167	3,287	3,414	3,546	3,684	3,829	3,982
>560 kW	$M	0	0	0	348	364	381	399	417	436	457	478	501	525	550	576	603	632	663	695	728	764
Total (Engine Costs)	**$M**	**0**	**0**	**0**	**469**	**485**	**502**	**520**	**539**	**558**	**579**	**600**	**623**	**646**	**671**	**697**	**724**	**752**	**782**	**813**	**846**	**880**
Operation & Maintenance costs																						
NC/T1 to T2 Engines - fuel cost	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 4 engines maintenance	$M	0	0	0	0	38	75	113	152	191	232	273	315	357	400	443	486	528	571	614	656	699
Total (Operation & Maintenance)	**$M**	**0**	**0**	**0**	**0**	**38**	**75**	**113**	**152**	**191**	**232**	**273**	**315**	**357**	**400**	**443**	**486**	**528**	**571**	**614**	**656**	**699**
Administration costs	$M	0	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Compliance costs	$M	0	0	0	100																	
TOTAL COSTS	**$M**	**0**	**0**	**0**	**572**	**526**	**580**	**636**	**693**	**752**	**813**	**876**	**941**	**1,007**	**1,074**	**1,143**	**1,212**	**1,284**	**1,356**	**1,430**	**1,505**	**1,582**
Benefits																						
Fuel savings																						
Tier 4 engines- fuel savings	$M	0	0	0	36	58	81	105	130	157	186	217	249	284	320	358	397	439	482	527	575	624
Health benefits																						
NOx	$M	0.0	0.0	0.0	9.1	17.9	26.6	35.4	44.3	53.5	62.8	72.3	82.1	92.0	102.1	112.4	122.9	133.5	144.3	155.3	166.5	178.0
PM2.5	$M	0.0	0.0	0.0	50.2	106.9	163.7	221.5	280.5	341.2	403.6	467.8	533.8	601.6	671.1	742.3	815.1	889.5	965.7	1043.8	1124.0	1206.7
Total (Health Benefits)	**$M**	**0**	**0**	**0**	**59**	**125**	**190**	**257**	**325**	**395**	**466**	**540**	**616**	**694**	**773**	**855**	**938**	**1023**	**1110**	**1199**	**1291**	**1385**
TOTAL BENEFITS		**0**	**0**	**0**	**96**	**183**	**271**	**362**	**455**	**552**	**653**	**757**	**865**	**977**	**1093**	**1212**	**1335**	**1462**	**1592**	**1726**	**1865**	**2009**
Net benefit/cost	$M	0	0	0	-476	-343	-309	-274	-238	-200	-161	-119	-75	-29	19	70	123	178	236	297	361	428
NPV	$M	1,952																				

ITEM	UNIT	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055
Social discount rate	%																				
Sales (relative to BAU)																					
Non compliant																					
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 2																					
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 3																					
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 4 (all)																					
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Check	No.																				
Costs																					
Installed Engine costs																					
NC	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 2	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 3	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 4	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total (Engine Costs)	**$M**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Operation & Maintenance costs																					
NC/T1 to T2 Engines - fuel cost	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**
Tier 4 engines maintenance	$M	741	732	723	712	701	690	677	664	651	636	621	604	588	570	552	534	517	501	485	469
Total (Operation & Maintenance)	**$M**	**741**	**732**	**723**	**712**	**701**	**690**	**677**	**664**	**651**	**636**	**621**	**604**	**588**	**570**	**552**	**534**	**517**	**501**	**485**	**469**
Administration costs	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compliance costs	$M																0	0	0	0	0
TOTAL COSTS	**$M**	**741**	**732**	**723**	**712**	**701**	**690**	**677**	**664**	**651**	**636**	**621**	**604**	**588**	**570**	**552**	**534**	**517**	**501**	**485**	**469**
Benefits																					
Fuel savings																					
Tier 4 engines- fuel savings	$M	562	568	574	578	583	575	567	559	549	538	527	515	502	489	474	461	447	434	421	409
Health benefits																					
NOx	$M	167.4	166.4	165.2	163.9	162.4	160.7	158.9	156.8	154.6	152.1	149.5	146.6	143.5	140.3	136.8	133	130	127	124	121
PM2.5	$M	1161.0	1158.4	1154.7	1149.8	1143.7	1136.2	1127.2	1116.6	1104.4	1090.4	1074.6	1057.1	1037.8	1016.8	994.3	972	951	930	909	889
Total (Health Benefits)	**$M**	**1328**	**1325**	**1320**	**1314**	**1306**	**1297**	**1286**	**1273**	**1259**	**1243**	**1224**	**1204**	**1181**	**1157**	**1131**	**1,106**	**1,081**	**1,057**	**1,033**	**1,010**
TOTAL BENEFITS		**1890**	**1893**	**1893**	**1892**	**1889**	**1872**	**1853**	**1832**	**1808**	**1781**	**1751**	**1719**	**1684**	**1646**	**1606**	**1566**	**1528**	**1491**	**1454**	**1419**
Net benefit/cost	$M	1,149	1,160	1,171	1,180	1,187	1,183	1,176	1,168	1,157	1,145	1,131	1,114	1,096	1,076	1,054	1,032	1,011	990	970	950
NPV	$M																				

Table H3: Scenario 3 projected for the main base case

ITEM	UNIT	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055
Social discount rate	%	7%																																								
Sales (relative to BAU)																																										
Non compliant																																										
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	-2,172	-2,190	-2,208	-2,227	-2,246	-2,265	-2,285	-2,305	-2,326	-2,347	-2,369	-2,391	-2,414	-2,437	-2,461	-2,486	-2,511	-2,537	-2,564	-2,591	-2,619	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	-5,188	-5,247	-5,306	-5,367	-5,428	-5,490	-5,553	-5,618	-5,683	-5,749	-5,817	-5,885	-5,955	-6,026	-6,097	-6,170	-6,245	-6,320	-6,397	-6,474	-6,554	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	-1,646	-1,675	-1,705	-1,736	-1,768	-1,800	-1,833	-1,866	-1,901	-1,936	-1,972	-2,009	-2,047	-2,085	-2,125	-2,166	-2,207	-2,250	-2,294	-2,339	-2,385	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	-5,299	-5,475	-5,658	-5,850	-6,050	-6,259	-6,477	-6,705	-6,944	-7,193	-7,454	-7,727	-8,012	-8,310	-8,622	-8,949	-9,291	-9,648	-10,023	-10,415	-10,826	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	-2,166	-2,205	-2,245	-2,286	-2,329	-2,373	-2,418	-2,464	-2,512	-2,561	-2,611	-2,663	-2,717	-2,772	-2,829	-2,888	-2,949	-3,011	-3,076	-3,143	-3,212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	-90	-93	-96	-99	-102	-105	-109	-112	-116	-120	-124	-128	-132	-137	-142	-147	-152	-158	-164	-170	-176	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 2																																										
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	2,172	2,190	2,208	-5,044	-5,154	-5,266	-5,383	-5,505	-5,630	-5,760	-5,895	-6,035	-6,181	-6,332	-6,488	-6,651	-6,820	-6,995	-7,177	-7,367	-7,564	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	-3,093	-3,161	-3,232	-3,305	-3,382	-3,461	-3,544	-3,630	-3,719	-3,812	-3,909	-4,010	-4,115	-4,224	-4,338	-4,457	-4,581	-4,711	-4,845	-4,986	-5,133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	-2,838	-2,885	-2,934	-2,984	-3,036	-3,090	-3,145	-3,203	-3,263	-3,324	-3,389	-3,455	-3,524	-3,596	-3,670	-3,748	-3,828	-3,912	-3,999	-4,089	-4,183	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	-1,081	-1,121	-1,163	-1,206	-1,252	-1,300	-1,351	-1,404	-1,460	-1,518	-1,579	-1,643	-1,711	-1,782	-1,856	-1,934	-2,016	-2,102	-2,192	-2,287	-2,386	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	-1,872	-1,948	-2,027	-2,110	-2,197	-2,288	-2,384	-2,484	-2,590	-2,700	-2,817	-2,939	-3,067	-3,201	-3,342	-3,491	-3,646	-3,810	-3,981	-4,162	-4,351	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	90	93	96	-737	-774	-813	-855	-898	-944	-992	-1,042	-1,095	-1,151	-1,210	-1,272	-1,337	-1,405	-1,477	-1,553	-1,632	-1,716	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 3																																										
<19 kW	No.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	-2,784	-2,908	-3,039	-3,176	-3,321	-3,472	-3,631	-3,798	-3,974	-4,158	-4,351	-4,555	-4,768	-4,992	-5,228	-5,475	-5,736	-6,009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	8,281	8,408	8,538	-2,198	-2,279	-2,364	-2,452	-2,545	-2,642	-2,744	-2,850	-2,962	-3,079	-3,202	-3,330	-3,465	-3,606	-3,755	-3,910	-4,073	-4,243	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	4,484	4,561	4,639	-2,718	-2,812	-2,909	-3,011	-3,118	-3,229	-3,345	-3,466	-3,592	-3,724	-3,862	-4,007	-4,157	-4,315	-4,480	-4,652	-4,832	-5,020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	6,380	6,596	6,821	-1,894	-1,988	-2,086	-2,190	-2,299	-2,413	-2,534	-2,661	-2,794	-2,934	-3,081	-3,236	-3,399	-3,570	-3,750	-3,939	-4,138	-4,347	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	4,038	4,152	4,272	-3,817	-4,000	-4,193	-4,396	-4,608	-4,832	-5,067	-5,314	-5,574	-5,847	-6,134	-6,435	-6,753	-7,086	-7,436	-7,805	-8,192	-8,599	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	0	0	0	-399	-415	-432	-450	-469	-488	-509	-530	-553	-577	-602	-628	-656	-685	-715	-747	-780	-816	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 4 (all)																																										
<19 kW	No.	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 37 kW	No.	0	0	0	10,055	10,307	10,571	10,845	11,131	11,428	11,739	12,062	12,400	12,752	13,120	13,504	13,904	14,323	14,760	15,216	15,694	16,192	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37 to 55 kW	No.	0	0	0	10,870	11,089	11,315	11,550	11,793	12,044	12,306	12,576	12,857	13,149	13,452	13,766	14,093	14,432	14,785	15,152	15,533	15,930	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56 to 74 kW	No.	0	0	0	7,438	7,615	7,799	7,989	8,187	8,392	8,605	8,826	9,056	9,295	9,544	9,802	10,071	10,351	10,642	10,944	11,260	11,588	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75 to 129 kW	No.	0	0	0	8,950	9,290	9,646	10,018	10,408	10,817	11,245	11,694	12,164	12,656	13,173	13,714	14,281	14,876	15,500	16,154	16,840	17,560	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130 to 560 kW	No.	0	0	0	8,213	8,526	8,854	9,197	9,557	9,933	10,328	10,742	11,176	11,631	12,107	12,607	13,131	13,681	14,257	14,862	15,496	16,162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	No.	0	0	0	1,235	1,291	1,351	1,413	1,479	1,548	1,620	1,696	1,776	1,861	1,949	2,042	2,139	2,242	2,350	2,463	2,583	2,708	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Check	No.																																									
Costs																																										
Installed Engine costs																																										
NC	$M	-585	-598	-611	-624	-638	-652	-667	-683	-699	-716	-733	-751	-769	-789	-809	-829	-851	-873	-897	-921	-946	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	-568	-580	-592	-605	-618	-632	-647	-661	-677	-693	-709	-726	-744	-762	-781	-801	-822	-843	-865	-888	-912	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	-17	-18	-18	-19	-20	-20	-21	-22	-22	-23	-24	-25	-25	-26	-27	-28	-29	-30	-31	-33	-34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 2	$M	-326	-338	-350	-616	-639	-663	-688	-715	-743	-772	-802	-834	-867	-902	-939	-978	-1,018	-1,061	-1,105	-1,152	-1,201	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	-344	-356	-369	-471	-487	-503	-520	-538	-557	-576	-597	-618	-640	-664	-689	-714	-741	-770	-799	-831	-863	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	18	18	19	-145	-153	-160	-168	-177	-186	-195	-205	-216	-227	-238	-251	-263	-277	-291	-306	-322	-338	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 3	$M	1,014	1,041	1,069	-788	-824	-861	-901	-943	-986	-1,032	-1,080	-1,131	-1,184	-1,240	-1,298	-1,360	-1,424	-1,492	-1,564	-1,639	-1,718	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	1,014	1,041	1,069	-703	-735	-770	-805	-843	-882	-924	-967	-1,013	-1,061	-1,111	-1,164	-1,220	-1,279	-1,340	-1,405	-1,473	-1,544	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	0	0	0	-85	-88	-92	-96	-100	-104	-108	-113	-118	-123	-128	-134	-140	-146	-152	-159	-166	-174	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tier 4	$M	0	0	0	2,497	2,586	2,679	2,777	2,879	2,986	3,098	3,215	3,338	3,467	3,601	3,743	3,891	4,046	4,208	4,379	4,558	4,745	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<19 kW	$M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19 to 560 kW	$M	0	0	0	2,149	2,222	2,298	2,378	2,462	2,549	2,641	2,737	2,837	2,942	3,052	3,167	3,287	3,414	3,546	3,684	3,829	3,982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>560 kW	$M	0	0	0	348	364	381	399	417	436	457	478	501	525	550	576	603	632	663	695	728	764	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total (Engine Costs)	**$M**	**103**	**106**	**108**	**469**	**485**	**502**	**520**	**539**	**558**	**579**	**600**	**623**	**646**	**671**	**697**	**724**	**752**	**782**	**813**	**846**	**880**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Operation & Maintenance costs																																										
NC/T1 to T2 Engines - fuel cost	$M	28	30	31	32	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**
Tier 4 engines maintenance	$M	0	0	0	0	45	90	113	152	191	232	273	315	357	400	443	486	528	571	614	656	699	741	732	723	712	701	690	677	664	651	636	621	604	588	570	552	534	517	501	485	469
Total (Operation & Maintenance)	**$M**	**28**	**30**	**31**	**32**	**80**	**90**	**113**	**152**	**191**	**232**	**273**	**315**	**357**	**400**	**443**	**486**	**528**	**571**	**614**	**656**	**699**	**741**	**732**	**723**	**712**	**701**	**690**	**677**	**664**	**651**	**636**	**621**	**604**	**588**	**570**	**552**	**534**	**517**	**501**	**485**	**469**
Administration costs	$M	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Compliance costs	$M	0		100	0																																	0	0	0	0	0
TOTAL COSTS	**$M**	**134**	**138**	**242**	**504**	**567**	**595**	**636**	**693**	**752**	**813**	**876**	**941**	**1,007**	**1,074**	**1,143**	**1,212**	**1,284**	**1,356**	**1,430**	**1,505**	**1,582**	**741**	**732**	**723**	**712**	**701**	**690**	**677**	**664**	**651**	**636**	**621**	**604**	**588**	**570**	**552**	**534**	**517**	**501**	**485**	**469**
Benefits																																										
Fuel savings																																										
Tier 4 engines- fuel savings	$M	0	0	0	36	58	81	105	130	157	186	217	249	284	320	358	397	439	482	527	575	624	562	568	574	578	583	575	567	559	549	538	527	515	502	489	474	461	447	434	421	409
Health benefits																																										
NOx	$M	3.8	8.5	13.1	22.6	31.1	39.6	48.2	57.0	66.0	75.2	84.5	94.1	103.8	113.7	123.7	133.9	144.2	154.7	165.4	176.2	187.3	176.4	174.9	173.4	171.6	169.8	167.7	165.5	163.1	160.5	157.7	154.7	151.5	148.1	144.5	140.7	137	133	130	127	123
PM2.5	$M	13.0	31.0	49.2	103.4	159.9	216.7	274.4	333.4	394.0	456.3	520.4	586.1	653.6	722.6	793.1	865.2	938.8	1014.1	1091.2	1170.3	1251.7	1204.8	1200.8	1195.7	1189.4	1181.8	1172.7	1162.1	1149.9	1136.0	1120.3	1102.9	1083.7	1062.8	1040.2	1016.1	992	969	947	925	904
Total (Health Benefits)	**$M**	**17**	**40**	**62**	**126**	**191**	**256**	**323**	**390**	**460**	**531**	**605**	**680**	**757**	**836**	**917**	**999**	**1083**	**1169**	**1257**	**1347**	**1439**	**1381**	**1376**	**1369**	**1361**	**1352**	**1340**	**1328**	**1313**	**1296**	**1278**	**1258**	**1235**	**1211**	**1185**	**1157**	**1,130**	**1,103**	**1,077**	**1,052**	**1,027**
TOTAL BENEFITS		**17**	**40**	**62**	**162**	**249**	**337**	**428**	**521**	**617**	**718**	**822**	**930**	**1041**	**1156**	**1274**	**1396**	**1522**	**1651**	**1784**	**1921**	**2064**	**1943**	**1944**	**1943**	**1940**	**1934**	**1916**	**1895**	**1872**	**1845**	**1816**	**1785**	**1750**	**1713**	**1673**	**1631**	**1590**	**1550**	**1511**	**1473**	**1436**
Net benefit/cost	$M	-118	-99	-180	-342	-318	-258	-208	-173	-135	-96	-54	-11	35	82	132	184	238	295	354	416	482	1,202	1,211	1,220	1,227	1,233	1,226	1,218	1,207	1,195	1,181	1,164	1,146	1,125	1,103	1,079	1,056	1,033	1,011	989	967
NPV	$M	2,244																																								

Appendix I: Sensitivity analysis

Results of the modelling were tested for robustness to changes in key assumptions with sensitivity analysis of the following:

- range in social discount rates of 3% and 10%; a discount rate of 7% was assumed for the main case
- variations in business as usual (BAU) emission performance profile projections, with lower and upper base case scenarios tested
- exclusion of engines greater than 560 kW in accordance with the current scope of the EU NRMMD
- a four year delay in the implementation date for each of the policy options
- variations in the VSL used in the health benefit costing, with sensitivity analysis conducted for scenarios with a four year implementation delay using a VSL of \$3.7 million and \$8.1 million (in AUD 2008) as recommended by the ASCC; the average VSL of \$6 million recommended by the ASCC was adopted for the main case.

The results obtained through varying the assumptions listed above are presented in subsequent subsections.

I1 Discount rates

The net benefits are sensitive to the social discount rate assumed, with lower discount rates giving higher net benefits. Net benefits are significantly lower but still positive when a 10% discount rate is applied.

Table I1: Present value of net benefits for each policy option (AUD$M 2012)

Harmonisation scenario	Description	Present value of net benefits, AUD$M 2012		
		10%	7%	3%
1	Tier 3 / Stage III A in 2015	533	1,257	3,681
2	Tier 4 / Stage III B / Stage IV in 2018	409	1,952	8,086
3	Stepped Tier 3 / Stage III A in 2015 and Tier 4 / Stage III B / Stage IV in 2018	538	2,244	8,812

Note: Present values are calculated over the period from 2015 to 2055 using a social discount rate of 3%, 7% and 10% real.

I2 Variations in base case assumptions

The base case for the impact analysis assumes the proportion of engine sales by tier will remain constant (at 2008 rates) over the projection period; however, future trends in the emission performance of new engines sold into the Australian market are uncertain. Some industry stakeholders argue that there is an inherent trend towards greater sales of cleaner engines (i.e. Tier 2 and Tier 3 engines rather than Tier 1 or non-compliant engines). Other industry stakeholders argue that with proposed changes to regulations in Europe and the US towards Tier 4 final engines, international manufacturers may stop producing Tier 3 and Tier 4 interim engines. According to stakeholders, this would result in a higher proportion of total stock sold in Australia being Tier 2 engines, as in the absence of emission standards, the substantially higher cost of Tier 4 engines relative to Tier 2 engines would restrict uptake of Tier 4 engines.

The sensitivity of net benefits was therefore tested against two alternative base case scenarios; namely:

- **Lower bound (best case) base case scenario (Figure I1)**. This scenario is based on the premise that there will be a gradual improvement in the overall emission performance of non-road diesel engines/equipment over time. It was assumed that all engines/equipment would be at least Tier 2 compliant by 2020 with 50% of the Tier 2 compliant engines (as at 2008) becoming Tier 3 compliant[214]. Tier 3 compliant engines (as at 2008) were assumed to remain Tier 3 compliant. The fraction of Tier 4 interim compliant engines (as at 2008) was assumed to remain Tier 4 interim compliant. No uptake of Tier 4 final compliant engines was assumed due to potential cost barriers.

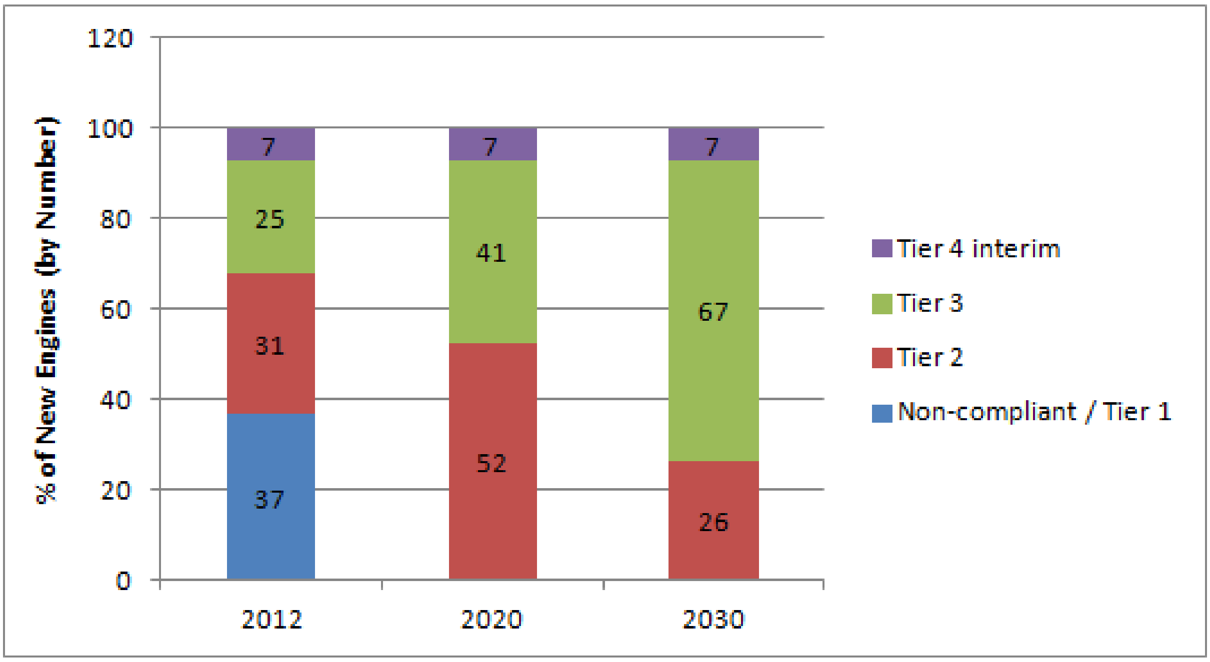

Figure I1: Emission performance of new non-road diesel engines/equipment greater than 19 kW assumed for the lower bound base case scenario

- **Upper bound (conservative) base case scenario (Figure I2)**. This scenario is based on the case put forward by some industry representatives that Tier 3 and Tier 4 interim compliant engines will no longer be sold into the Australian market by 2020 due to the progression of non-road diesel engine standards elsewhere. The assumption is that engine manufacturers will rationalise their ranges to Tier 2 and Tier 4 final compliant engines. The upper bound base case thus assumes that previously Tier 3 and Tier 4 interim compliant engines will be replaced by Tier 2 engines due to these engines being substantially less expensive than Tier 4 final compliant engines.

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[214] Assumptions were made based on information provided by industry stakeholders during a scoping study (ENVIRON 2010) and during the development of this report.

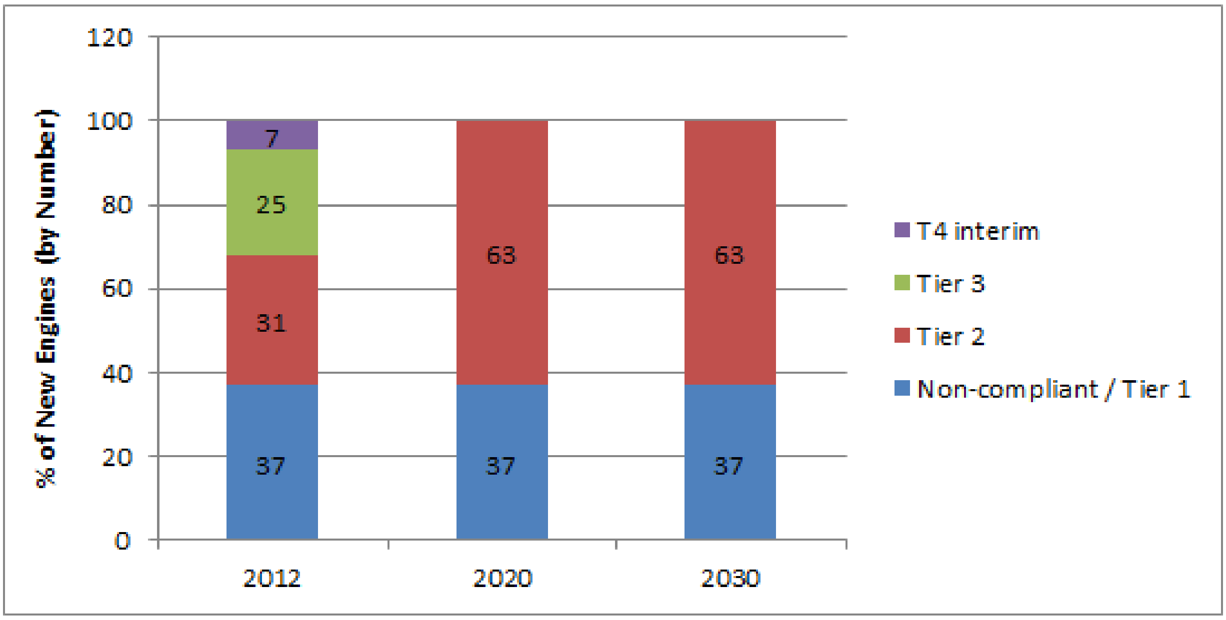

Figure I2: **Emission performance of new non-road diesel engines/equipment greater than 19 kW assumed for the upper bound base case scenario**

The net benefits of the proposed harmonisation scenarios vary depending on the base case emission performance profile (Table I2). Given the assumption underpinning the upper bound base case scenario that Tier 3 / Stage III A compliant engines are no longer available for sale into the Australian market, net benefits were not calculated for the two harmonisation scenarios requiring the uptake of Tier 3 / Stage III A compliant engines (scenarios 1 and 3). Net benefits were therefore only calculated for the upper reference base case for the harmonisation scenario comprising the introduction of Tier 4 / Stage III B / Stage IV emission standards (scenario 2).

Positive net benefits are found across all lower bound and upper bound base cases. The lower bound base case produces lower net benefits than the main base case because the increasing share over time of Tier 3 relative to Tier 2 engines in the absence of standards offers less emission reduction potential and therefore less health benefits than shifting from Tier 2 and Tier 3 to Tier 4 engines in the main base case. This is despite the lower cost differentials between Tier 2 and Tier 3 engines compared to Tier 2, Tier 3 and Tier 4 engines.

The upper base case produces higher net benefits than the main base case because, while the implementation cost is higher than in the other base case scenarios (due to the higher cost differential between Tier 2 engines and Tier 4 engines than between Tier 3 and Tier 4 engines), the incrementally higher emission reductions and associated health benefits in moving from predominantly Tier 2 to Tier 4 engines substantially outweigh the additional costs.

Table I2: Present value of net benefits for each harmonisation scenario (AUD$M 2012) – given lower bound, main and upper bound base case projections

Harmonisation scenario	Description	Present value of net benefits, AUD$M 2012[(a)]		
		Lower	Central	Upper[(b)]
1	Tier 3 / Stage III A in 2015	266	1,257	NA
2	Tier 4 / Stage III B / Stage IV in 2018	728	1,952	2,151
3	Stepped Tier 3 / Stage III A in 2015 and Tier 4 / Stage III B / Stage IV in 2018	715	2,244	NA

(a) Present values are calculated over the period from 2015 to 2055 using an annual real discount rate of 7%[215].

(b) NA – not applicable. Given the assumption underpinning the upper reference case base case scenario that Tier 3 / Stage III A compliant engines are no longer available, net benefits could not be calculated for the scenarios requiring the uptake of Tier 3 / Stage III A emission standards (scenarios 1&3).

I3 Exclusion of >560 kW engines

Sensitivity analysis has been conducted on the effects of excluding non-road diesel engines greater than 560 kW engines to reflect the coverage of the current EU NRMM Directive. Results are presented in Table I3. The exclusion of non-road diesel engines greater than 560 kW in power rating would result in an overall increase in net benefits because the cost of including these larger engines substantially outweighs the emission reductions and health benefits achievable by their inclusion.

Table I3: Present value of net benefits for each harmonisation scenario (AUD$M 2012) given US non-road diesel regulation scope and the current EU NRMM Directive scope

Harmonisation scenario	Description	Present value of net benefits, AUD$M 2012[(a)]	
		US scope	EU scope[(b)]
1	Tier 3 / Stage III A in 2015	1,257	1,874
2	Tier 4 / Stage III B / Stage IV in 2018	1,952	2,810
3	Stepped Tier 3 / Stage III A in 2015 and Tier 4 / Stage III B / Stage IV in 2018	2,244	3,206

(a) Present values are calculated over the period from 2015 to 2055 using an annual real discount rate of 7%. Benefits are calculated for the main base case scenario.

(b) EU 1997 NRMM Directive scope excludes engines greater than 560 kW.

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[215] Australian Government (2010)

I4 Variation in value of a statistical life and delay in implementation dates

The unit damage functions developed by Aust et al. (2013) used in the impact analysis within this report, adopted a value of a statistical life (VSL) of $6 million (in AU$ 2008)[216]. The Australian Safety and Compensation Council (ASCC) recommended a 'ballpark average' of $6 million for VSL (in AUD 2008), with sensitivity analysis recommended at $3.7 million and $8.1 million[217].

The implications of the above range in VSL were considered within the sensitivity testing conducted for scenarios with a four year delay in implementation. The assumption of a VSL of $3.7 million (2008 AUD) would result in positive net benefits for all three harmonisation scenarios while, as may be expected, the assumption of a VSL of $8.1 million (in AU$ 2008) would significantly increase the net benefits for all three scenarios, as indicated in Table I4.

The Australian Department of Finance and Deregulation's Office of Best Practice Regulation (OBPR) considers a value of $3.7 million to be the most credible estimate of the VSL[218]; however, the analysis undertaken by the ASCC and Aust et al. (2013), and the subsequent analysis by Pacific Environment to inform the economic analysis underpinning the National Plan for Clean Air, support the application of a VSL of $6 million (AU$ 2008)[219].

Table I4: Present value of net benefits for each harmonisation scenario (AUD$M 2012) – given a four year delay in the implementation dates for policy options and a range of VSL values

Harmonisation scenario	Description	Present value of net benefits, AUD$M 2012[(a)]		
		VSL[(b)] $3.7M (2008 AUD)	VSL $6M (2008 AUD)	VSL $8.1M (2008 AUD)
1	Tier 3 / Stage III A in 2015	384	2,004	3,484
2	Tier 4 / Stage III B / Stage IV in 2018	108	3,717	7,012
3	Stepped Tier 3 / Stage III A in 2015 & Tier 4 / Stage III B / Stage IV in 2018	359	4,318	7,932

(a) Present values are calculated over the period from 2017 to 2057 using a social discount rate of 7% real. Benefits are calculated for the main base case scenario.

(b) VSL – value of a statistical life

The implementation schedule adopted for the harmonisation scenarios is 2015 for Stage III A/Tier 3 standards and 2018 for Stage III B/Stage IV/Tier 4 standards. These implementation dates were selected to maximise the period for projecting costs/benefits given stock projections which are made to 2035, and are illustrative only. If the policy options were concluded to be feasible given these implementation dates, later implementation dates would be as feasible or more feasible due to the relative reduction in costs when discounted to present values.

New emission standards likely to take at least two years to establish. The Australian Diesel Engine Distributors Association has recommended that industry is given a three year transition period. Taking these timetables into account, a more realistic

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[216] Aust et al. (2013)

[217] ASCC (2008)

[218] Office of Best Practice Regulation (OBPR), Value of Statistical Life, www.dpmc.gov.au/deregulation/obpr/docs/ValuingStatisticalLife.pdf

[219] Aust et al. (2013), ASCC (2008), Pacific Environment (2013b)

implementation date is likely to be three to four years beyond the start dates assumed in the main base case. Testing was therefore conducted for a four year delay in the implementation schedule across all three harmonisation scenarios, giving an implementation date of 2017 for Stage III A/Tier 3 standards and 2020 for Stage III B/Stage IV/Tier 4 standards.

Appendix J: Consultation with industry stakeholders

ENVIRON consulted with a range of industry stakeholders between December 2012 and June 2013, seeking and collecting information for the definition and analysis of the main base case and harmonisation scenarios. The objective of this initial informal consultation was to ensure that the information and assumptions incorporated into the analysis of the potential actions were realistic and representative of the Australian market.

An industry meeting was held in mid-April 2013 and was attended by representatives from industry associations and engine and equipment manufacturers and distributors. The main purpose of this meeting was to present the purpose of the study, its scope and method, including assumptions applied in the cost benefit analysis.

Table J1 summarises the industry stakeholders who were consulted, including stakeholders who provided information for consideration in the study. A number of other companies were contacted, but did not take up the invitation to provide inputs or attend the industry meeting.

Table J1: Industry stakeholders consulted during information collation phase

Group	Stakeholder
Industry associations	Australian Diesel Engine Distributors Association (ADEDA) Construction and Mining Equipment Industry Group (CMEIG) Tractor and Machinery Association of Australia (TMA) Agriview Pty Ltd Truck & Engine Manufacturers Association (USA)
Engine equipment manufacturers/distributors	BT Equipment Pty Ltd Case IH Australia Caterpillar Inc Clark Equipment Cummins / Cummins South Pacific Cummins Power Generation Deutz Australia Pty Ltd EPG Engines Hitachi Construction Machinery (Australia) Pty Ltd JCB Construction Equipment Australia John Deere Kobelco Construction Machinery Australia / Kobelco CNH Australia Komatsu Australia Pty Ltd Kubota Tractor Australia Mercury Marine Australia MTU Detroit Diesel Australia New Holland - Agricultural Scania Australia Toyota Material Handling Australia Pty Ltd Tutt Bryant Equipment Volvo / Volvo Construction Equipment Welling and Crossley Pty Ltd Yanmar / Yanmar (Power Equipment Ltd)