Final Report to

Department of the Environment, Water, Heritage and the Arts

COST BENEFIT ANALYSIS OF OPTIONS TO MANAGE EMISSIONS FROM SELECTED NON-ROAD ENGINES

August 2008

McLennan Magasanik Associates

242 Ferrars Street
South Melbourne, Vic 3205
Tel: +61 3 9699 3977
Fax: +61 3 9690 9881

Email: mma@mmassociates.com.au
Website: www.mmassociates.com.au

Ref: J1587

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The Department of the Environment, Water, Heritage and the Arts (DEWHA), on behalf of the Environment Protection and Heritage Council (EPHC), commissioned McLennan Magasanik Associates (MMA) to develop a cost benefit analysis of three policy options for reducing the impact of emissions from mobile sources of non-road engines on air quality and human health:

(1) a voluntary agreement among outboard marine engine suppliers,

(2) Commonwealth Government regulation, and

(3) a National Emissions Protection Measure (NEPM) implemented by the states and territories

Lawn and garden, commercial marine and recreational marine equipment were identified as a first priority group for management action based on urban inventory data of non-road engine emissions of volatile organic compounds and particulate matter (PAE 2005). To be compatible with international emissions regulations, this study was restricted to:

(1) marine spark ignition engines: - outboard engines and powered personal watercraft; and

(2) small non-road engines: any engine equal to or less than 19 kilowatts. Uses for small non-road engines include, but are not limited to, applications such as lawn mowers, weed trimmers, chain saws, generators and pumps.

However, due to emissions and sales data limitations for small non-road engines in Australia, the present study only quantifies the benefits of regulating emissions from specific gardening equipment, namely lawn mowers, brushcutters, hedge trimmers and hand held blowers. Given that other types of small non-road equipment have similar engines to those studied here, the benefits from regulation are likely to extend to these as well. Furthermore, again due to data limitations, only the effects of implementing US Phase 2 standards were considered, ignoring the effects of Phase 3 regulations scheduled for introduction in 2011/12. The failure to include them in this study is likely to significantly under-estimate the effects from regulating small non-road engines. This is in addition to the conservative approach taken to valuing the benefits of air pollution reductions in this report, which applies to both, the marine spark ignition engines as well as the small non-road engines.

The policy scenarios modelled in this study are presented in Table 0-1

Table 0-1 Policy scenarios modelled

	Name	Scenario description
Commonwealth regulation scenarios	OB-1	US 2006 outboard emission standards implemented in Australia in 2012, followed by US 2009 standards in 2014.
	OB-2	US 2009 outboard engine emission standards implemented in Australia in 2012.
	OB-3	US 2006 outboard emission standards implemented in Australia in 2010, followed by US 2009 standards in 2012.
	OB-4	US 2009 outboard engine emission standards implemented in Australia in 2010.
	PWC-1	US 2006 PWC emission standards implemented in Australia in 2012, followed by US 2009 standards in 2014.
	PWC-2	US 2009 PWC emission standards implemented in Australia in 2012.
	PWC-3	US 2006 PWC emission standards implemented in Australia in 2010, followed by US 2009 standards in 2012.
	PWC-4	US 2009 PWC emission standards implemented in Australia in 2010.
	Grd-1[1]	US Phase 2 gardening equipment emissions limits implemented in Australia in 2012.
	Grd-2[2]	US Phase 2 gardening equipment emissions limits implemented in Australia in 2010.
Industry agreement scenarios	IA-1	Sales of zero or one star engines under the Outboard Engine Distributor Association's (OEDA) Voluntary Emissions Labelling Scheme limited to 15% of total sales by 2012.
	IA-2	Sales of zero or one star engines under the Outboard Engine Distributor Association's (OEDA) Voluntary Emissions Labelling Scheme limited to 15% of total sales by 2020.
NEPM scenarios	The NEPM scenarios are identical to the Commonwealth regulation scenarios, except for the likely lag in implementation and the potential to effectively reduce the stringency of the Standard. To account for these effects, the NEPM policy scenarios (NEPM OB-1 to 4, NEPM PWC-1 to 4 and NEPM Grd-1-4) are discounted by 10% to account for the likely additional time needed for all States and Territories to implement legislation as compared to the respective Commonwealth policy scenarios.	

Our modelling suggests that the introduction of regulations for non-road engines can substantially reduce fuel consumption and HC, CO and PM_{10} emissions. Figure 0-1 depicts emissions projections from outboard engines or personal watercraft (PWC) and gardening equipment for the Commonwealth Government regulation scenario in which US emissions standards are adopted in 2010. NOx emissions are increased slightly by the policy intervention because, while the two stroke engines generate higher HC, CO and

1 For gardening equipment, only avoided emissions from lawn mowers, hedge trimmers, brush cutters and hand held blowers were assessed. Furthermore, due to data limitations, only the effects of implementing US Phase 2 standards were considered, ignoring the effects of Phase 3 regulations scheduled for introduction in 2011/12.

2 See footnote 1, above.

PM_{10} emissions, the four stroke engines that replace them generate slightly more NOx emissions.

Figure 0-1 Fuel consumption and emissions for the Commonwealth regulation scenario implementing US standards in 2010, all sectors (sum of scenarios OB-3, PWC-3 and Grd-2)

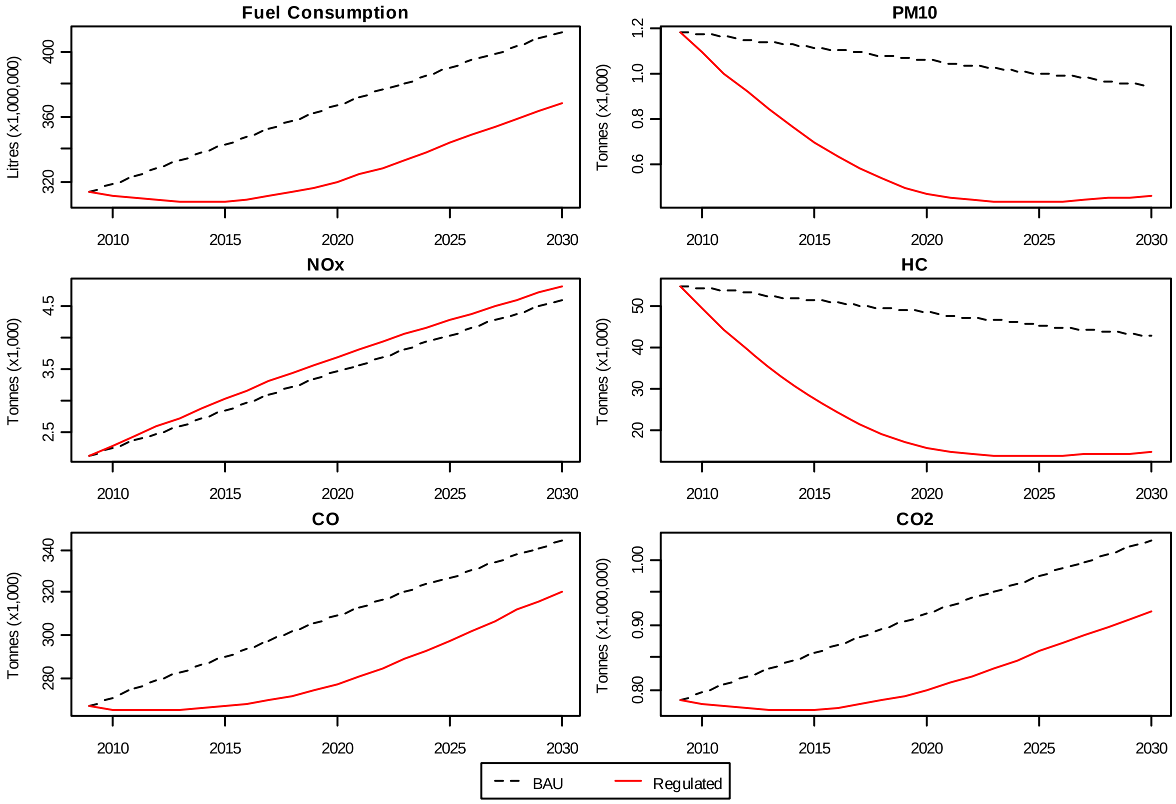


Table 0-2 provides the estimated net present value (NPV) of the Commonwealth regulation and NEPM policy options. Estimation of NPV includes the additional net costs associated with the removal of high emissions engines (higher purchase cost plus higher maintenance costs minus lower running costs).

A more detailed breakdown of the costs is shown in Table 0-3 for all modelled scenarios (noting that, as discussed in Table 0-1, the NPV estimates for the NEPM scenarios are 10% below the corresponding Commonwealth regulation scenarios).

Table 0-2 Net present value of Commonwealth regulation and NEPM policy options (2008 $million) [3]

Scenario	Commonwealth regulation NPV	NEPM NPV
1. Phased 2012 start – current US emissions limits implemented in Australia in 2012, 2009 US limits implemented in 2014	2,865	2,578
2. Non-phased 2012 start – 2009 US limits implemented in 2012	2,883	2,595
3. Phased 2010 start – current US limits implemented in 2010, 2009 US limits implemented in 2012	3,389	3,050
4. Non-phased 2010 start – 2009 US limits implemented in 2010	3,407	3,066

Table 0-3 Detailed breakdown of net present value of costs for all modelled scenarios

Option	Scenario name	Service costs	Expenditure costs	Fuel costs	Health costs	Total costs	NPV
Commonwealth regulation scenarios	OB-BAU	2,606	4,873	3,938	3,544	14,961	-
	OB-1	2,458	4,624	3,451	2,312	12,846	2,115
	OB-2	2,462	4,619	3,445	2,304	12,829	2,132
	OB-3	2,422	4,559	3,358	2,072	12,412	2,549
	OB-4	2,425	4,554	3,352	2,065	12,396	2,565
	PWC-BAU	97	316	281	139	834	-
	PWC-1	92	307	248	85	732	101
	PWC-2	92	307	247	84	730	103
	PWC-3	91	305	243	76	715	119
	PWC-4	91	305	242	75	713	121
	Grd-BAU	1,610	7,818	7,203	1,713	18,344	-
	Grd-1[4]	1,671	7,980	6,773	1,272	17,695	648
	Grd-2[4]	1,680	8,010	6,718	1,215	17,623	721
Industry agreement scenarios	OB-BAU	2,606	4,873	3,938	3,544	14,961	-
	OB-5	2,501	4,731	3,680	2,853	13,766	1,195
	OB-6	2,557	4,811	3,811	3,202	14,381	580

Note: All estimates in this table are aggregate expenditure estimates. Thus, for example, estimated **total** service costs fall from the BAU to the policy cases (eg OB-BAU vs OB-1 to 4), despite the fact that estimated service costs **per engine** are rising on average. This is simply because less engines are being serviced.

[3] Each entry in the table adds the relevant NPVs for the gardening equipment, outboard engine and PWC sectors to give an overall NPV estimate for each of the scenarios reported. For gardening equipment, only avoided emissions from lawn mowers, hedge trimmers, brush cutters and hand held blowers were assessed. Furthermore, due to data limitations, only the effects of implementing US Phase 2 standards were considered, ignoring the effects of Phase 3 regulations scheduled for introduction in the US in 2011/12.

[4] The estimated net present value of benefits to the gardening equipment sector from the introduction of US standards is likely to be significantly underestimated as it does not include benefits gained from the introduction of Phase 3 regulations. This is due to data limitations (see Sections 3.3 and 3.4).

The NPV of restricting the sale of higher emissions outboard marine engines to 15% by 2012 through a voluntary industry agreement is estimated to be around $1,195 million[5], and if the same 15% target is achieved in 2020 the estimate falls to $580 million as shown in Figure 4-2 on page 53. For comparison, the NPV of the Commonwealth regulation scenarios from marine outboard engines ranges from $2,115 million for the phased 2012 start, to $2,565 million for the non-phased 2010 start as shown in the same figure.

We emphasise that, although they do not account for scheme administration, all of the NPV estimates we have provided are conservative, in that they only assess the health impacts of avoided emissions of nitrogen oxides, hydrocarbons and particulate matter, and only the resulting reduction in direct health costs and lost income is considered. Our estimates ignore the resulting reduction in non-monetary losses in welfare associated with illness and the loss of life. Other avoided gas emissions and avoided water and noise pollution related damages are also not considered.

Furthermore, our estimates of the benefits to be gained by applying US standards to the gardening equipment sector do not take into account the move to Phase 3 emissions restrictions. This is due to data limitations (see Sections 3.3 and 3.4). Ignoring the move to Phase 3 is likely to have reduced the net present value of benefits significantly, and is the main reason that the NOx emissions are so much higher in the regulation scenario than under the business as usual scenario. Phase 2 mainly removes highly emitting two strokes which have lower NOx emissions than most four strokes while Phase 3 reduces emissions from all engines. For example, the US EPA estimated that a move from Phase 2 to Phase 3 emission standards would provide net benefits of about $1.3 billion per year by 2030 (in 2005 US$, US EPA 2007). Adjusting for the higher population in the USA, this same move is likely to provide an additional NPV in the order of AU$90 million per year by 2030, in Australia.

The net present value of benefits accounted for here is more than sufficient (by a large margin) to justify the introduction of emissions standards equivalent to those both in force and proposed in the USA. Indeed, this analysis suggests that more stringent standards may well be justified, although this would require additional and more detailed analysis based on better data (see Sections 3.3 and 3.4 for detail on the assumptions made and the data limitations).

Overall, it is clear that adopting the US emissions limits for non-road engines sold in Australia would bring significant benefits to the community. Bearing in mind that passing legislation takes time, the earlier the limits can be implemented, the greater the benefits that will be realised (because every non-compliant engine sold gives rise to more costs than benefits regardless of when it is sold).

Of the three policy options suggested, the Commonwealth Government regulation option stands out as the preferred option. As shown in Table 0-2, it gives rise to between $286

---

5 Higher emissions outboard marine engines are considered to be zero or one star engines under the Outboard Engine Distributor Association's (OEDA) Voluntary Emissions Labelling Scheme.

million and $341 million of additional NPV as compared to the NEPM option (this does not take into account the higher scheme implementation and administration costs from the NEPM option and is based on a conservative estimate of the likely delay in implementing legislation in all States and Territories). The Commonwealth regulation option also offers in the order of one to two billion dollars of additional benefits from restricting emissions in the marine outboard sector when compared to the industry agreement option (Table 0-3, OB 5 and 6 for the industry agreement versus OB1 to 4 for the Commonwealth regulation scenarios).

The voluntary industry agreement is the least effective of the three policy options, largely because it provides less stringent standards by still allowing outboard engines to be sold that are not compliant with US standards). Industry has also indicated that it will not be enforceable since importers could simply ignore any industry standards. Indeed, even if the analysis had shown larger net benefits from the industry agreement option, strong doubts about the merits of its implementation would remain. Industry does not consider it to be a viable option, and an industry agreement will only work if it receives strong support from industry.

The National Environment Protection Measure option is formulated to achieve the same standards as the Commonwealth regulation option. However, it suffers from requiring legislation to be implemented in each state and territory, thereby adding to the implementation cost. Under this option, greater compliance costs are also imposed on industry which has to operate across jurisdictions and comply with different jurisdictional requirements.

Furthermore, implementing the legislation through a NEPM may delay the starting date for emissions restrictions. Mutual Recognition Agreement (MRA) legislation allows goods sold legally in one state or territory to be sold in any other state or territory. Accordingly, the effective start date for all jurisdictions will be determined by the last jurisdiction to implement the NEPM. In making the NEPM, jurisdictions can set an implementation deadline that all agree to meet. While a deadline provides an effective implementation date, the agreed length of time for the deadline may be influenced, and hence delayed, by states or territories with less of a perceived need to act, or by the different processes for enacting legislation in the respective jurisdictions.

Table 0-2 also shows that bringing forward the start date of regulation by two years can provide additional NPV benefits of over $500 million (Scenarios 1 and 2 compared to Scenarios 3 and 4). Indeed, the earlier the start date the higher the NPV benefits because every non compliant engine sold prior to regulation has more costs than benefits associated with it. The implementation of legislation is subject to statutory processes, so it cannot be introduced instantaneously. However, estimates above show the benefits of starting as early as possible.

The additional benefits from the non-phased approaches are more modest and amount to under $20 million in NPV terms (Table 0-2, Scenario 1 compared to 2 and Scenario 3 compared to 4). However, the overall phased scenario estimates in Table 0-2 do not take into account any non-phasing related benefits in the gardening sector, given that phase 3 emissions were not possible to model for that sector. Furthermore, there is a risk that a phased approach may invite producers to 'dump' engines in the period when Australian standards lag behind the US standards. Firms wanting to sell any surplus stock that is compliant with the lower (older) US standard, but not compliant with the higher (newer) US standards may find Australia an attractive market. This has the potential to reduce the estimated benefits of implementing phased emissions limits in Australia, and thus increase the relative benefit of the non-phased options.

Overall, MMA concludes that of the policy options considered in this analysis, adopting the US emissions limits in Australia through Commonwealth regulation, as soon as practicable and without phasing is likely to yield the greatest net benefits.

LIST OF ACRONYMS

2c	Two stroke carburetted engine
2i	Two stroke injected engine
2di	Two stroke direct injected engine
4c	Four stroke carburetted engine
4i	Four stroke injected engine
ABT	Averaging, banking and trading
BAU	Business as usual
BTRE	Bureau of Transport and Regional Economics
CO	Carbon monoxide
CO_2	Carbon dioxide
DEWHA	Department of the Environment, Water, Heritage and the Arts
EC	European Commission
EPHC	Environment Protection and Heritage Council
Grd-1	Gardening equipment scenario one
Grd-2	Gardening equipment scenario two
HC	Hydrocarbon
IA-1	Industry agreement scenario one
IA-2	Industry agreement scenario two
MMA	McLennan Magasanik Associates
NPV	Net Present Value
NEPM	National Environment Protection Measure
OB-1	Marine outboard scenario one
OB-2	Marine outboard scenario two
OB-3	Marine outboard scenario three
OB-4	Marine outboard scenario four
PM	Particulate matter (subscripts indicate the PM size in microns (e.g. PM_{10} indicates particulate matter smaller

	than 10 µm)
PWC	Personal watercraft
PWC-1	Personal watercraft scenario one
PWC-2	Personal watercraft scenario two
PWC-3	Personal watercraft scenario three
PWC-4	Personal watercraft scenario four
NOx	Oxides of nitrogen
US EPA	United States Environment Protection Agency
VELS	Voluntary emissions labelling scheme
VOC	Volatile organic compounds
VTPI	Victoria Transport Policy Institute

1 INTRODUCTION

Non-road engines such as those used in gardening equipment, lawn mowers and outboard motors, have been shown to be significant contributors to urban air pollution. They are significant because they are utilised in large numbers and are not subject to the degree of pollution control regulation that exists for engines used in on-road vehicles. Many continue to be powered by high-polluting two stroke carburettor engines that do not comply with international standards. For example, older style outboard engines that do not comply with US EPA 2006 emission limits are likely to emit around 10 times the amount of pollution compared to conforming engines.

The Department of the Environment, Water, Heritage and the Arts (DEWHA) on behalf of the Environment Protection and Heritage Council (EPHC) has commissioned McLennan Magasanik Associates (MMA) to develop a cost benefit analysis of three policy options for reducing the impact on air quality and human health of emissions from mobile sources of non-road engines:

(1) a voluntary agreement among outboard marine engine suppliers,

(2) a National Emissions Protection Measure (NEPM) implemented by the states and territories and

(3) Commonwealth government regulation.

For the two regulatory options, the timing of the introduction of emissions constraints was also varied, resulting in ten policy scenarios that were evaluated in this study.

The policy options under consideration have the potential to significantly reduce air pollution from mobile non-road engines and lead to reduced human and environmental exposure to hydrocarbons (HC), carbon monoxide (CO) as well other greenhouse gases, including carbon dioxide (CO_2). They can also help avoid a range of adverse health and environmental effects associated with ozone and particulate matter (PM) emissions.

In addition, the policy options can help reduce the impact from air toxics on people who operate, or are otherwise in close proximity to these engines. Air toxics include: benzene, 1,3-Butadiene, formaldehyde, acrolein, polycyclic organic matter, and naphthalene, all of which pose a significant cancer risk when breathed in as well as having other negative health effects.[6] Finally, the policy options may reduce noise (particularly from two stroke engines) as well as reducing water pollution. However, these and other beneficial effects, such as reduce water and noise pollution, that could result from applying the emissions restrictions are not quantified in this study. This is due to data limitations and justified by the fact that the avoided health costs and lost income from reduced exposure to air

[6] EPA 2007, Control of Emissions from Non-road Spark-Ignition Engines and Equipment; Proposed Rule, May 18, 2007, Federal Register, pp 28110-28112

pollution from hydrocarbons, nitrogen oxides and particulate matter alone are more than sufficient to justify the policy case for intervention.

The following chapter of this report sets out the definition of non-road engines employed in this study, explains the proposed emissions limits, discusses the pollutants emitted from non-road engines and outlines the current status of non-road engines and emissions control in Australia.

Chapter 3 sets out MMA's approach and describes the models used to undertake the analysis.

Chapter 4 sets out the results of the cost-benefit analysis.

2 BACKGROUND CONCEPTS

2.1 Definition of non-road engines

The engines included in this study were selected based on the rankings of non-road emissions identified in the report *Management options for-non-road engine emissions in urban areas* (PAE 2005). The report found that engines used in the lawn and garden sector, commercial marine sector and recreational marine sector ranked highest in both the quantity and toxicity of emissions impacted upon urban areas. To align with international emission standards for non-road engines (see section 2.6), commercial marine engines which are not covered by these standards, were excluded from the analysis. Accordingly the non-road engines included in this study were as follows:

1. Marine spark ignition engines: - outboard engines and powered personal watercraft.[7]
2. Small non-road engines: - any engine equal or less than 19 kilowatts. Uses for small non-road engines included, but was not limited to, applications such as lawn mowers, weed trimmers, chain saws, generators and pumps.

Moreover, due to emissions and sales data limitations for small non-road engines in Australia, the present study only quantifies the benefits of regulating emissions from specific gardening equipment, namely lawn mowers, brushcutters, hedge trimmers and hand held blowers. Given that other types of small non-road equipment have similar engines to those studied here, the benefits from regulation are likely to extend to these as well. Furthermore, again due to data limitations, only the effects of implementing US Phase 2 standards were considered, ignoring the effects of Phase 3 regulations scheduled for introduction in 2011/12. The failure to include them in this study is likely to significantly under-estimate the effects from regulation.

2.2 Policy options, scenarios and associated emission limits

The three policy options under consideration are: a voluntary industry agreement, a National Environmental Protection Measure and Commonwealth regulation.

The voluntary industry agreement option was specified in the request for tender as covering only the marine outboard sector, with an aim to reduce the sales of higher emitting engines to 15% of total new engine sales by 2012. In this context, higher emitting engines are those that achieve zero or one star under the Outboard Engine Distributor Association's (OEDA) Voluntary Emissions Labelling Scheme (VELS). Two scenarios were

[7] Using the US EPA definitions, outboard engines are marine spark ignition engines that, when properly mounted on a marine vessel in the position to operate, houses the engine and drive unit external to the hull of the marine vessel. Personal watercraft engines (PWC) are marine spark ignition engines that do not meet the definition of outboard engine, inboard engine, or sterndrive engine, except that the Administrator in his or her discretion may classify a PWC as an inboard or sterndrive engine if it is comparable in technology and emissions to an inboard or sterndrive. See, http://www.epa.gov/otaq/regs/nonroad/marinesi-equipld/a1998a-f.pdf

evaluated. Scenario IA-1 achieves full compliance by 2012 and Scenario IA-2 achieves full compliance by 2020 (i.e. higher emitting engine sales exceed 15% of total new engine sales until 2020).

The emission limits proposed for the NEPM and Commonwealth regulation are identical and involve adopting the relevant US standards in Australia. The US emissions standards are phased (in the gardening equipment sector, the next more stringent standard is expected in 2011/2012, and for the marine sector, in 2009). Industry has expressed support for a fast tracked introduction of standards in Australia. If administratively possible, a faster introduction provides higher benefits than a later introduction of standards because each non-compliant engine sold has net costs associated with it. This study assesses a number of scenarios involving different pathways to the adoption of the US standards to provide decision makers with an estimate of the benefits of expediting regulation. As shown in Table 2-1, the scenarios start in 2010 or 2012 and either directly adopt the US standards (the non-phased scenarios), or adopt US standards with a lag (the phased scenarios).

Table 2-1 Four NEPM and Commonwealth regulation scenarios

	Gardening		Marine	
	US Phase 2	US Phase 3 (from 2011/12)	US 2006 standard	US 2009 standard
1) Phased 2012 start	2012	2016	2012	2014
2) Non-phased 2012 start	n/a	2012	n/a	2012
3) Phased 2010 start	2010	2014	2010	2012
4) Non-phased 2010 start	2010	2011/2012	n/a	2010

As summarised in Table 2-2 below, outboard engine scenarios OB-1 to OB-4 and personal watercraft scenarios PWC-1 to PWC-4 follow the standards introduction schedule reported in Table 2-1 for the Marine sector. However, due to the data limitations discussed later in section 3.4, it was not possible to ascertain which gardening equipment engines comply with the Phase 3 restrictions. It was therefore not possible to distinguish the phased and non-phased scenarios for the gardening equipment sector which resulted in two scenarios being analysed: scenario Grd-1, for the 2012 start dates (corresponding to items 1) and 2) in Table 2-1), and scenario Grd-2, for the 2010 start dates (corresponding to items 3) and 4) in Table 2-1).

Table 2-2 Policy scenarios modelled

	Name	Scenario description
Commonwealth regulation scenarios	OB-1	US 2006 outboard emission standards implemented in Australia in 2012, followed by US 2009 standards in 2014.
	OB-2	US 2009 outboard engine emission standards implemented in Australia in 2012.
	OB-3	US 2006 outboard emission standards implemented in Australia in 2010, followed by US 2009 standards in 2012.

	Name	Scenario description
	OB-4	US 2009 outboard engine emission standards implemented in Australia in 2010.
	PWC-1	US 2006 PWC emission standards implemented in Australia in 2012, followed by US 2009 standards in 2014.
	PWC-2	US 2009 PWC emission standards implemented in Australia in 2012.
	PWC-3	US 2006 PWC emission standards implemented in Australia in 2010, followed by US 2009 standards in 2012.
	PWC-4	US 2009 PWC emission standards implemented in Australia in 2010.
	Grd-1[8]	US Phase 2 gardening equipment emissions limits implemented in Australia in 2012.
	Grd-2[8]	US Phase 2 gardening equipment emissions limits implemented in Australia in 2010.
Industry agreement scenarios	IA-1	Sales of zero or one star engines under the Outboard Engine Distributor Association's (OEDA) Voluntary Emissions Labelling Scheme limited to 15% of total sales by 2012.
	IA-2	Sales of zero or one star engines under the Outboard Engine Distributor Association's (OEDA) Voluntary Emissions Labelling Scheme limited to 15% of total sales by 2020.
NEPM scenarios	The NEPM scenarios are identical to the Commonwealth regulation scenarios, except for the likely lag in implementation of the Standard. To account for these effects, the NEPM policy scenarios (NEPM OB-1 to 4, NEPM PWC-1 to 4 and NEPM Grd-1-4) are discounted by 10% to account for the likely additional time needed for all States and Territories to implement legislation as compared to the respective Commonwealth policy scenarios.	

Note: Gardening scenarios (Grd)

- Due to data limitations, the effect of Phase 3 regulation was not considered.
- Only the effect on lawn mowers, trimmers, hand held blowers and brushcutters were considered.

2.2.1 Voluntary Emissions labelling Scheme

The Outboard Engine Distributor Association (OEDA), whose members sell about 98% of all outboard engines in Australia, developed a labelling scheme that was launched at the Brisbane Boat Show in September 2006, and was implemented on 1 January 2007.

The labelling scheme is largely based on Californian Air Resources Board (CARB) emission standards. The Californian standards are considerably more stringent than those that apply to the rest of the USA: CARB's 2001 exhaust emission standards are equivalent to US EPA 2006 standard; CARB's 2004 exhaust emission standards are 20% less than the US EPA 2006 standard; and, CARB's 2008 exhaust emission standards are 65% less than US EPA 2006 standard.

[8] For gardening equipment, only avoided emissions from lawn mowers, hedge trimmers, brush cutters and hand held blowers were assessed. Furthermore, due to data limitations, only the effects of implementing US Phase 2 standards were considered, ignoring the effects of Phase 3 regulations scheduled for introduction in 2011/12.

VELS includes a 'No Star' high emission label which is set at a level similar to the US EPA 1999 standard for outboards less than 4.3kW. It is intended that the Star rating emission limits will be periodically reviewed to ensure that their relevance and usefulness is maintained. More details of the labelling scheme are provided in Table 2-3.

Table 2-3 OEDA VELS labels

OEDA Australian Label	OEDA Emissions Limit HC + NOx g/kW/hr	Comparison with CARB star rating HC + NOx g/kW/hr	Comparison with US EPA Limits HC + NOx g/kW/hr
	> 250	None	None
	64.8 – 250[9]	1 star = 64.8 - 81	For P < 4.3 KW EPA 1999< 253 EPA 2006 < 81
	30 – 64.8[9]	2 stars = 30 – 64.8	
	5 – 30[9]	3 stars < 30	
	< 5[9]	4 stars < 5 Note: no current outboard engine can meet this limit.	

[9] These limits are indicative only and have identical specifications to CARB 2, 3 and 4 star limits which have lower emission limits (kW/hr) as engine power increases.

2.2.2 Applicable US emissions standards

For the gardening equipment sector, the USA has introduced phased standards with progressively tighter limits. The currently applicable standard is Phase 2, and Phase 3 limits are expected in 2011/12. Table 2-4 presents these limits. Due to data limitations, the analysis provided in this paper only considers the effect of introducing Phase 2 emissions limits in Australia for the gardening equipment sector.

Table 2-4 US garden equipment emission limits

		Phase 2			Phase 3	
Engine class	**Sub-class**	**HC+NOx (g/kWh)**	**NMHC+NOx (g/kWh)**	**CO (g/kWh)**	**HC+NOx (g/kWh)**	**CO (g/kWh)**
Non-Handheld						
Class I	<66cc	50	-	610	eliminated as a sub class	
	66cc to < 100cc	40	37	610	eliminated as a sub class	
	100cc to < 225cc	16.1	14.8	610	eliminated as a sub class	
	<80cc	These sub classes do not commence until 2016			As per relevant handheld limit	
	80cc to <225cc				10.0	610
Class II	≥ 225cc	12.1	11.3	610	8.0	610
Handheld						
Class III	<20cc	50	-	805	50	805
Class IV	20cc to <50cc	50	-	805	50	805
Class V	≥ 50cc	72	-	603	72	603

The current and the proposed 2009 emission limits for marine outboards and PWC are shown in Table 2-5.

Table 2-5 US marine engine emission limits

	US 2006 standard	US 2009 standard	
Power	HC + NOx (g/kWh)	HC + NOx (g/kWh)	CO (g/kWh)
Power < 4.3 kW	81	-	-
Power ≥ 4.3 kW	0.250 * (151 + 557 /P0.9) +6.00	-	-
Power ≤ 40 kW	-	28 – 0.3 x P	500 – 5 x P
P ower > 40 kW	-	16	300

2.2.3 Averaging, banking and trading provisions

The US regulations make provision for averaging, banking and trading (ABT). That is, producers can average emissions across product families within their product lines, they can use credits accrued in one year for engines that exceed standards to offset shortfalls in subsequent years and manufacturers can trade credits for engines that outperform the standards for ones that fall short amongst each other.

The advantage of these provisions is that they allow more flexibility in the market by not banning high emitting engines outright, so long as other engines outperform the standards set. For example, if some special applications require engine characteristics that are not present to the same extent in cleaner engines (for example, some argue that old style two stroke engines are simpler and therefore more reliable and hence more desirable in remote applications) the ABT provisions make the continued sale of such engines possible.

However, ABT effectively reduces the stringency of the standards set by allowing the average of engines sold to meet the standard, rather than for the standard to provide an upper bound on emissions. That is, so long as some engines produce less emissions than required by the standard regardless of ABT, then allowing ABT increases the average emissions intensity of engines sold into the market.

That said, proponents of ABT point out that the fact that credits can be obtained for better performing engines gives an incentive for manufacturers to produce engines that produce less emissions than required by the standard rather than only to meet it. To the extent that this incentive does deliver faster technological development, it can allow authorities to tighten standards faster and thus dynamically reduce average emissions from engines sold into the market. A counter to this argument is that the ABT provisions are too technology dependent and do not allow innovations that may save much more emissions than the covered engine types (e.g. electric engines), thereby inefficiently distorting the technology development pathway in favour of combustion engines.

The overall effect of ABT on average emissions in the long run is unclear. For Australian regulations the bigger problem is how to deal with the provisions as they exist in the USA. If, for example, regulations are formulated to allow any engine that can be sold in the USA to be sold in Australia, there is a danger that a higher proportion of high emitting engines could be sold here as this would not have any effect on manufacturers' average emissions for certification purposes. At the extreme, it would be possible for manufacturers to use the ABT provisions to sell a very small number of high emitting engines in the USA, thereby incurring only very small additional credit requirements, and then selling large numbers of such engines here in Australia. A solution to this problem may be for Australian regulations to have the same compliance requirements as in the USA but without ABT. For instance, the regulations could accept US testing results to ascertain compliance with Australian regulations but not automatically allow engines that can be sold in the USA to be accepted for sale in Australia.

MMA cannot recommend a specific course of action in respect of ABT without further analysis than is possible within the scope of this paper. However, for the purposes of the modelling undertaken in this study, it is assumed that Australia will only allow engines to be sold that meet or exceed the emissions standards, and that no allowance will be made for ABT.

2.3 Pollutants from non-road engines

Pollutants generated through combustion in non-road engines include nitrogen oxides (NOx), volatile organic compounds (VOC), carbon monoxide (CO), carbon dioxide (CO_2) and particulate matter (PM). These compounds include precursors to the formation of ozone in our major cities, as well as direct contributors to haze and greenhouse gases. In addition, PM and air toxic pollutants emitted by non-road engines can impact on humans, animals and plant life.

Although air quality in our cities is relatively good, air quality standards for ozone and/or PM are sometimes exceeded[10]. The contribution of non-road engines used for lawn mowing and recreational boating to total annual emissions in selected airsheds are shown in Table 2-6 and Table 2.7. These data show that lawn mowing contributes about 0.03% to 1.1% of NOx, between 2.4% and 3.2% of VOC, 0.17% to 0.35% of PM10 and between 1.2% and 3.2% of CO on an annual basis, and recreational boating exhibits similar contributions.

Table 2-6 Summary of Annual Emissions from Domestic Lawn Mowing (% Contribution to total Anthropogenic Emissions)[11]

Inventory	CO	NOx	PM	Total VOCs
GMR[a]	3.2%	0.06%	0.33%	3.2%
MAQS[b]	1.2%	0.03%	0.17%	2.5%
SEQ[c]	2.0%	0.06%	0.35%	2.7%
Port Phillip[d]	2.4%	1.1%	0.24%	2.4%

Sources: [a] New South Wales Greater Metropolitan Region (NSWGMR) Emissions Inventory
[b] Metropolitan Air Quality Study (MAQS) Air Emissions Inventory
[c] South East Queensland (SEQ) Air Emissions Inventory
[d] Port Phillip Air Emissions Inventory.

Table 2-7 Summary of Annual Emissions from Recreational Boating (% Contribution to total Anthropogenic Emissions) [12]

Inventory	CO	NOx	PM	Total VOCs
GMR[a]	0.75%	0.059%	0.31%	2.1%
MAQS[b]	1.2%	0.046%	Not provided	2.3%
SEQ[c]	3.1%	1.6%	0.28%	3.1%
Port Phillip[d]	0.43%	0.22%	0.015%	0.52%

Sources: [a] New South Wales Greater Metropolitan Region (NSWGMR) Emissions Inventory
[b] Metropolitan Air Quality Study (MAQS) Air Emissions Inventory
[c] South East Queensland (SEQ) Air Emissions Inventory
[d] Port Phillip Air Emissions Inventory

The annual contributions to airshed emissions may appear small. However, emissions from these sources are highly skewed towards weekend days during summer, when

10 Ozone (O_3) is a key component of photochemical smog and is formed from complex chemical reactions of NOx, CO, and VOC in the lower atmosphere. These reactions are catalysed by ultraviolet radiation.

11 PAE 2007.

12 PAE 2007.

ozone and/or particulate matter air quality standards are most likely to be exceeded. Also, the concentration of these emissions on a relatively few days during the warmer months can result in these sources being major contributors to photochemical smog formation on particular days (PAE 2007). That said, due to data limitations the cost benefit analysis in this paper does not take into account these effects and relies on the average effect of the gases and combustion related PM emissions instead, thereby providing a lower bound on the benefits from the introduction of emissions controls.

2.4 Controlling combustion emissions

Four fundamental techniques may be used for the control of combustion emissions:

- the combustion process can be controlled to reduce the quantities of pollutants formed. For example, air levels can be controlled to control flame temperature and reduce the production of NOx.
- pollutants can be removed from the flue gas, such as through the use of catalytic converters or particle filters in the gas stream.
- the level of activity producing emissions can be reduced, such as by reducing lawn area or increasing to the average length of grass, or applying stricter regulation to recreational boating.
- a basic change in technology can take place, for example a change from petrol to electric lawn mowing, or petrol to electric boats.

The proposed policy options do not prescribe any particular method for controlling emissions from non-road engines but rather require engines sold into the Australian market to achieve minimum emissions standards. Thus, they leave it to manufacturers to choose the most efficient way of achieving emissions reductions from the engines they sell. The policy options do not target activity level reduction or changes in technology and only affect these indirectly by removing some lower-cost high-emissions engines from the market. This can increase the cost of the activity and thereby reduce activity levels and it can also enhance the competitiveness of alternative, lower emissions technologies.

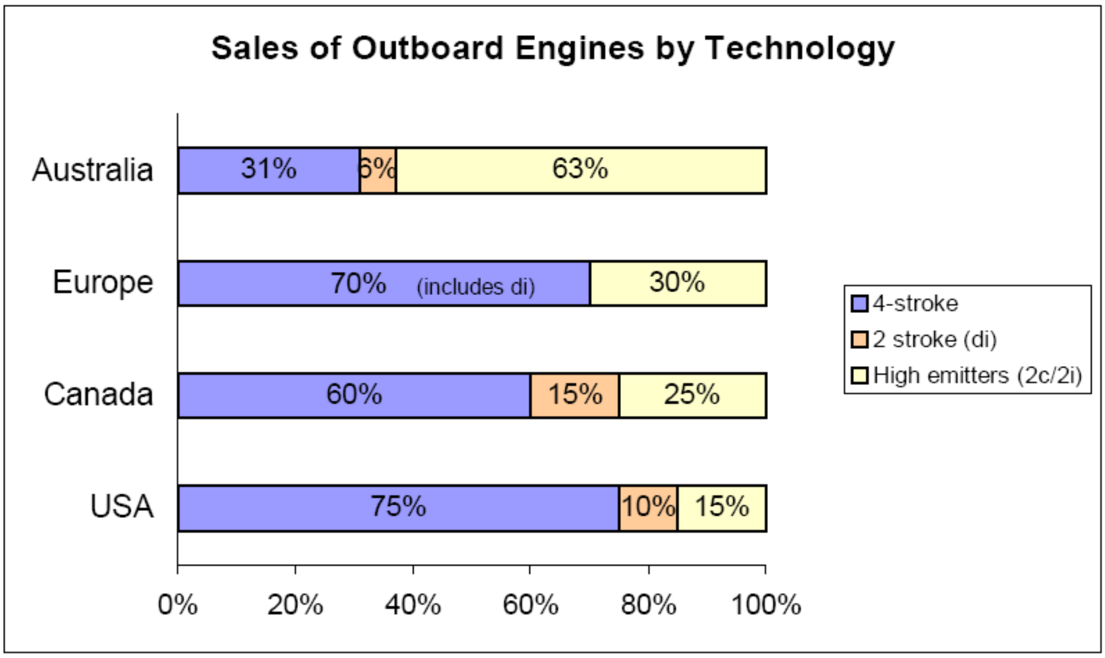
2.5 Current status of non-road engine emissions control in Australia

There are currently no standards or regulations applicable to air pollutant emissions from non-road engines in Australia. However, the outboard industry has developed a voluntary emissions labelling scheme (VELS) that commenced in 2007.

Most non-road engines sold in Australia are imported, and as such, may be models destined for countries that already have regulations to limit emissions (the USA and Europe in particular). Many do comply with emission standards applicable to the country of origin or other regulated markets. However, this is not the case for all engines and many engines sold in Australia are highly polluting variants.

During 2005, only 31% of outboard engine sales in Australia were of the lower emission four stroke engines as shown in Figure 2-1. This is significantly less than the percentage sold in Europe, the USA or Canada.

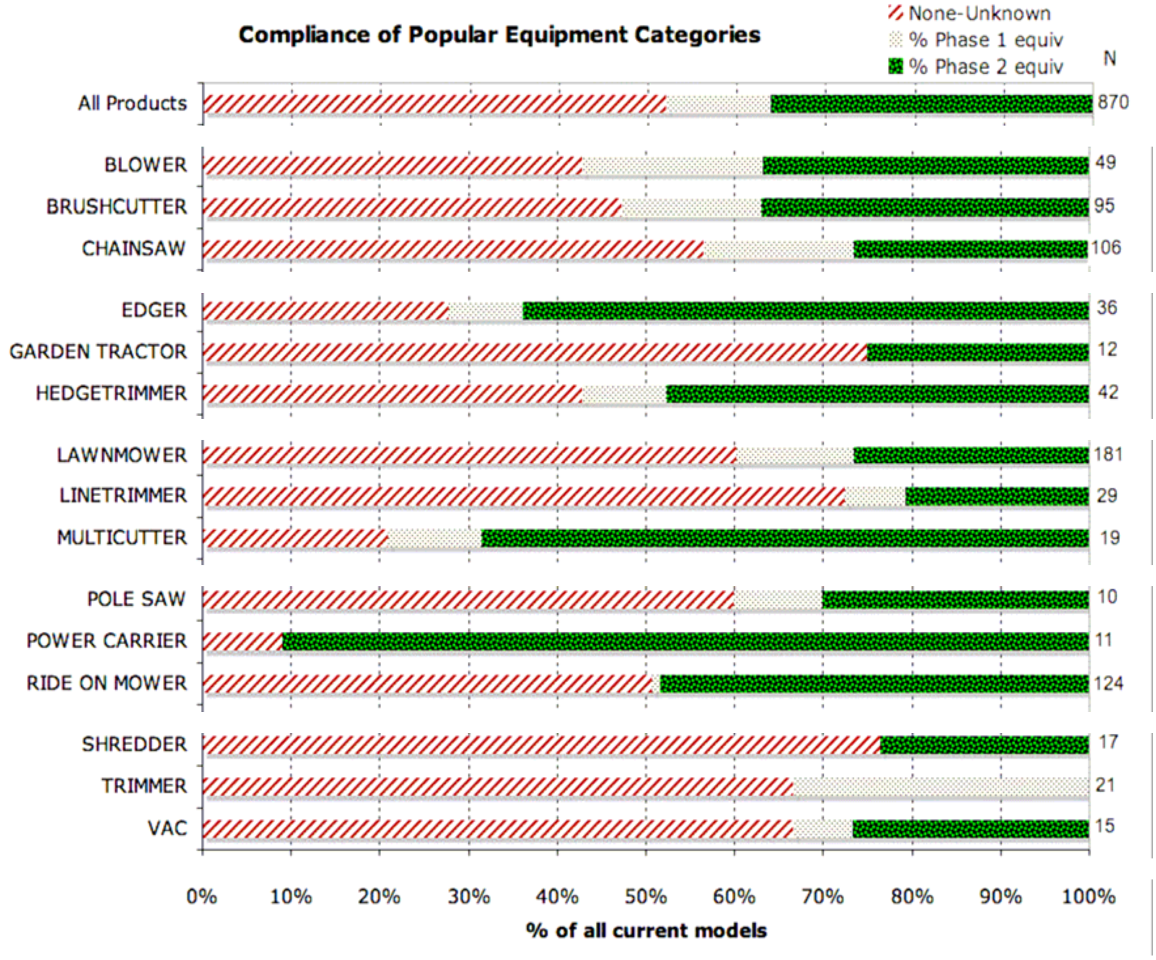
Figure 2-1 Sales of outboard by technology, 2005



Source: Comparative Assessment of the Environmental Performance of Small Engines - Marine Outboards and Personal Watercraft, Department of the Environment and Water Resources, February 2007.

For outdoor equipment the breakdown of two and four strokes does not capture the emissions picture as well as for outboard motors. However, many outdoor gardening equipment engines fail to comply with the Phase 2 emissions standards currently in force in the USA, which indicates that emissions from engines in this sector are also likely to be much higher than in countries where emissions restrictions apply. Figure 2-2 shows the extent of compliance of selected outdoor equipment categories with US EPA phase 1 and 2 emissions standards of engines on the Australian market in 2006, based on an industry survey conducted by Environment Link and Vehicle Design and Research P/L for their report to DEWR (DEWR 2007).

Figure 2-2 Compliance of outdoor gardening equipment with US EPA phase 1 and 2



Source: Comparative Assessment of the Environmental Performance of Small Engines – Outdoor Garden Equipment, Department of the Environment and Water Resources, February 2007.

2.6 The importance of overseas regulations

The overwhelming majority of non-road engine equipment sold in Australia is imported from overseas markets. Due to this fact, it is highly desirable that any regulation of the emissions from these engines be consistent with those in force in the larger global markets for this equipment. The key markets of importance in terms of mobile non-road engine regulation are the USA and Europe. The regulations in Europe and the USA are essentially identical in terms of the limits imposed on hydrocarbon, nitrous oxide and carbon monoxide emissions. Given the relatively small size of the Australian market, requiring that specific engine models be developed, certified and imported into Australia to meet emission requirements inconsistent with those of North America or Europe would be highly inefficient and result in significantly higher compliance costs. For the purposes of this analysis the US emissions limits are used.

3 APPROACH AND MODEL DESCRIPTION

Overview

Cost benefit analyses of the options detailed in section 3.1 were conducted by developing and perturbing a model of the stock of engines for sale and in use in Australia. A heuristic (but precise) description of the model is given in Section 3.2; The implementation of the model differs in the order in which the calculations described are performed, but is mathematically equivalent. A more detailed description of the model used for marine engines model is given in Section 3.3, and for engines used in gardening equipment is given in Section 3.4.

A Business as Usual (BAU) scenario was developed and used as a benchmark against which the policy options were compared. Each policy option is modelled as a perturbation of the BAU scenario; specifically, the stock of engines available for sale in each year is changed. This in turn changes the numbers of different types of engines operating in the economy and therefore the costs and emissions associated with them in each year relative to the BAU case.

The scenarios modelled are described in detail in Section 3.1.

3.1 Scenarios for implementing the emission limits

3.1.1 Business as usual (BAU)

Under this scenario, emissions from non-road engines continue to be uncontrolled in Australia. This provides the baseline against which the other scenarios are compared.

3.1.2 Voluntary Industry agreement

This scenario involves a voluntary agreement within the marine outboard sector to reduce the sales of higher emitting engines to 15% of total new engine sales by 2012. In this context, higher emitting engines are defined as those that achieve zero or one star rating under the Outboard Engine Distributor Association's (OEDA) voluntary emissions labelling scheme (VELS).

This policy option is limited to the outboard marine engine sector and does not extend to non-road engines more generally. The reason is that: "… it is highly unlikely that all the companies in the garden equipment industry would engage in, or commit to, a voluntary program to reduce their products' exhaust emissions. It is therefore clear that the only feasible path to reduce emissions from these small engines is through regulation." (DEWR 2007a, p44).

Scenario IA-1 assumes full compliance and models a linear decrease in the sale of high emitting engines to 15% of market share by 2012. Scenario IA-2 defers compliance and decreases the sale of high emitting engines to 15% by 2020.

3.1.3 National Environment Protection Measure

Under this option, a NEPM would be developed under the *National Environment Protection Council Act 1994* to restrict emissions from non-road engines using the US standards reported in Table 2-4 on page 16 (gardening equipment limits) and Table 2-5 on page 16 (marine engine emissions limits). This NEPM would apply to new engines being sold into the market. To offer national coverage, each State and Territory would need to adopt NEPM provisions in their own jurisdiction, under their own legislation. Thus, engine suppliers may need to deal with more than one regulatory agency, given the national nature of the market.

The difficulty in implementing a NEPM, and the need to adopt regulations in each of the states and territories could take longer than if restrictions were applied directly through Commonwealth regulation, and may therefore create additional delays. Various stakeholders commented that this may be the case. However, the potential for delay was not modelled separately for this report because the scenario runs have different implementation timetables (see Table 2-1 on page 13) and therefore, give an indication of the cost of delay. To the extent that the NEPM regulation process is slower than the Commonwealth regulation process, this would increase the estimated additional benefit from implementing Commonwealth regulation rather than a NEPM. To account for the likely lag in the introduction of effective legislation in each state and territory, as compared with Commonwealth regulation, we discounted the net benefits from using the NEPM option by 10%. This corresponds to a delay of about one to two years – the reduction in NPV from a two year delay amounts to 15% as can be seen by comparing scenarios 1 and 3 or scenarios 2 and 4 in Table 0-2 .

3.1.4 Commonwealth regulation

The Commonwealth regulation option would require the enactment of a new piece of legislation. Like a NEPM, Commonwealth regulation would apply to all new engines being sold into the Australian market and would restrict emissions from non-road engines using the US standards reported in Table 2-4 on page 16 (gardening equipment limits) and Table 2-5 on page 16 (marine engine emissions limits).

The Commonwealth regulation scenario is identical to the NEPM scenario in terms of the equipment fleet and the resulting emissions (except for the 10% discount factor applied to the NEPM, to account for the potential implementation delay, as discussed in Section 3.1.3).

3.2 Description of modelling method

Due to differences in the data that was available, different models were used for marine engines and gardening equipment. Both models were based on projections of future and historic sales of engines but differed in the way the stock and sales of engines were projected. Details of the model used for marine engines are given in section 3.3, and details of the model used for engines used in gardening equipment are given in section

3.4. Although many of the mathematical details of the two models are identical, they are presented in sections 3.3 and 3.4 so the less technical reader can focus on the, 'heuristics', (i.e. the set of rule based techniques, assumptions and approximations) employed to define the often incomplete sources of empirical and historical data used in the model. These heuristics are presented in the current section.

Each scenario is modelled in the following steps.

1. **Estimate the sales of engines of each type in each year.** The taxonomies of engine types differ between the marine and gardening equipment models and are described in detail in the respective sections below. In both models, the sales are based on historic sales figures and are for- and back-casted based on population levels, but the data available and hence methods used are quite different. Sales are estimated for the years 1990 to 2030. The reason for including sales prior to 2009 is given in the next step.

2. **Estimate the number and age profile of the stock of engines in service in each year.** The stock of engines in a given year is the sum of sales in that year and engines sold in previous years that have not yet been scrapped. A 'scrapping' function is used to determine the proportion of the stock sold in each previous year remains in a given year. The scrapping function used for a given engine is based on the type of the engine.[13] Applying this to the sales of engines in each year, gives the number and age profile of each engine type in each year. This method 'accumulates' engines sold in the current and all previous year to the current year. This is why we started sales in 1990 – so we had a 'representative' stock of engines (in terms of types and age distribution) in use in 2009 and beyond. The age profile of the engines is important, as the emissions intensity of an engine is dependent on its age (engines tend to degrade and become more polluting as they age). This is explained further in the following step. A mathematical description of the method used in the stock calculation is given in Section 3.2.1.

3. **For each year, estimate (units shown in square brackets, dollar amounts are nominal[14]):**
   a) the value of sales [2008 $AU] – based on base price and inflation,
   b) the emissions [tonnes]:
   - Particulate Matter (PM) – based on emission factor,
   - Nitrous Oxides (NOx) – direct measurement,
   - Hydrocarbons (HC) – direct measurement,
   - Carbon Monoxide (CO) – direct measurement, and

   c) the amount of fuel consumed [litres] – fuel consumption factor, and
   d) servicing costs [2008 $AU] – based on expert opinions.

---

[13] In the case In the case of gardenning equipment, the type of user – commercial or domestic - is also taken into account. Engines used by commercial users have shorter life spans compared to domestic users as they are used more intensively.
[14] Nominal dollars are the *actual* dollars that need to be exchanged to make a purchase.

Once estimates of the number and age profile of the engines in service in a given year are known, the emissions arising from usage of these engines can be determined. The emissions from and fuel consumed by a given engine in a given year are calculated based on its age, capacity (displaced volume of the cylinder(s)), type, estimates of its annual usage and the average load under which it is operated. Emissions and fuel consumption are calculated using "emission factors", "fuel consumption factors", "deterioration factors" and for HC and NOx, engine specific emissions information.

An emission factor gives the emissions of a new engine of a specified type in *grams per kilowatt hour*. A fuel consumption factor gives the fuel consumption of a new engine of a specified type in *litres per kilowatt hour*. A deterioration factor gives the proportional increase in the emissions intensity or fuel consumption for a given engine of a given age relative to its emissions intensity or fuel consumption when it was new.

All factors were obtained from (US EPA 2005a) and (US EPA 2005b).

The total emissions arising from the entire stock of engines in use in a given year is the aggregate of the emissions from each individual engine. A description of the mathematics used in the emissions calculations is given in Section 3.2.2.

4. **For each year, estimate the costs and benefits arising from the use of the stock of engines.** Once the quantities listed in step 3 have been estimated, the nominal costs and benefits arising in that year can be calculated. This involves the conversion of non-dollar quantities to nominal dollars.[15] These costs have been calculated from various studies on the health related costs of emissions and are discussed in Section 3.5. The studies report health costs in dollars per tonne, so the conversion is done by multiplying the emissions estimates from step 3 by the relevant factor. Note that the results reported in the different studies take account of health effects in different ways, some for instance using PM as a proxy for all emissions. This methodology has been respected in our calculations; i.e. if the study only used PM, then we only use our estimates of PM emissions and the other pollutants are ignored.

5. **Discount the annual costs back to 2008.** Once the nominal costs have been calculated we have a time series for each of the costs listed in step 3 above. These are discounted using a nominal interest rate of seven per cent to obtain the Net Present Value (NPV) of the costs in 2008. This discount rate is that same as that used by the US EPA for its regulatory impact analysis of standards for small engines (US EPA 2007, p 7.3).

6. **Calculate the costs and benefits of a given regulation.** Once the costs are discounted back to the same period, the results for different scenarios, including the BAU, can be compared simply by differencing. It should be noted that, in this context, a cost is

[15] CO_2 has not been included in the costings, as it has no direct health effects and it did not seem appropriate to assume a carbon price as this would complicate interpretation of the results. Including CO_2 would increase the costs of each sceenario, and since 2 stroke engines generally use more petrol than 4 stroke engines, would have increased the benefits accruing to regulation.

defined as any difference between the BAU and the scenario being considered which is negative, and a benefit is any difference which is positive. Costs and benefits can be considered for individual components (e.g. petrol) or on the totals. If we consider, say, petrol, we can calculate the costs/benefits to expenditure on petrol as:

(*NPV of petrol consumed under BAU) – (NPV of petrol consumed under scenario X)*.

Similarly, the total costs/benefits of the regulations modelled by scenario *X* are:

(*NPV of total costs under BAU) – (NPV of total costs under scenario X)*.

For all scenarios other than the BAU, the costs of regulation should be included in the total costs. These would include, for example, the cost of checking engines for compliance and the costs involved with implementing the regulations. Technically, intangible costs, such as a reduction in the pleasure derived from using equipment[16], or the emotional suffering caused by severe illness or death caused by air pollution should also be included. However, such calculations have been excluded from this analysis due to their subjective nature. This is discussed further in section 3.5.

To ensure the stock has time to turn over and to take into account time lagged benefits, the sales in each scenario were run to 2030. However, the model tracks emissions and costs up until 2050. If this is not done, the higher initial purchase costs of cleaner engines still in service after 2030 would increase the costs of the policy options without a commensurate decrease in costs related to emissions reductions or fuel savings accruing. This would bias the results against intervention. For example, when compared to a two stroke outboard engine sold in 2029, a four stroke would incur the full upfront purchase price differential, but only one year's worth of emissions reductions and fuel savings would be accounted for, if we did not track emissions and costs through to 2050. Truncating the benefits in this way would inappropriately reduce the net present value of the policy intervention and bias the results against intervention.

The various scenarios are modelled as changes to the stocks of engines available for sale under the BAU in each year. This is the only aspect of the market affected by any of the regulations modelled in this study. The change in stocks is effected in step 1 of the modelling as described above, since, as described in step 2 above, the stock available in each year is fully determined by sales in that and previous years. A description of how this is achieved is given in section 3.2.3.

Changes in purchasing patterns are reflected by incorporating demand side elasticities as described in section 3.4.4. It has been assumed that, since the Australian market is small compared to the global market, Australia is a price taker and hence supply side elasticities have been ignored (i.e. regulation in Australia is not going to affect the production cost and supply price of engines).

[16] Such reductions would occur if, for example, regulation increases prices and hence reduces usage.

3.2.1 Stock calculations

The Scrapping functions were based on a similar methodology to that described in the United States Environment Protection Agency non-road model (US EPA 2005); that is, the life of an engine is specified by a cumulative normal distribution with a mean and variance specific to the engine being considered. See Box 1 for a mathematical description of the stock calculations.

Box 1 Calculation of stock in a given year

Let s_{ky} denote sales of new engines of type *k* in year *y*; μ_v denote the mean 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:

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

3.2.2 Emissions calculations

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 Box 2. This calculation includes the proportion of the average full load of operation of the engine. The calculation is conceptually the same for gardening equipment but is complicated slightly due to the structure of that model. These complications are described in section 3.4.5.

The model also takes into account that engines deteriorate and produce more emissions as they age. The rates of degradation are based on the US EPA non-road model (US EPA 2005b)[17].

Box 2 Calculation of total emissions in a given year

Let z_{k0} denote the zero-hour emissions from a given motor[18], h_{ky} denote the number of hours a motor of type *k* is run in year *y*, l_k denote the average proportion of their maximal output that the motors of type *k* are operated at, A_{pk} be the proportion of z_{k0} by which an engines emissions will increase by the time it reaches its median life, and v_k denote the technology of engines of type *k*. *b* is set to 0.75 for all engines and emission types. The emissions of type *p* in year *y* from a motor of type *k*, ${}_p e_{ky}$, are then:

17 We used the same average proportional increases in the level of emissions of engine types by their median lifetime as those used in the US EPA model (the 'A' parameter). However, we used only one of the two parameters that determine the rate at which engines deteriorate in the US EPA model, namely 0.75 (the 'b' parameter).

18 The zero hour emissions are the emissions produced by a motor when it is brand new.

$$
{}_p e_{ky} = z_{k0}\left[1 + A_{pk}\left(l_k \sum_{j<y} h_{kj} \Big/ \mu_{v_k}\right)^b\right] \text{if } l_k \sum_{j<y} h_{kj} \Big/ \mu_{v_k} < 1,
$$
$$
= z_{k0}\left(1 + A_{pk}\right), \text{otherwise}
$$

Letting K denote the set of engines on the stock list, the total emissions of type p in year y are:

$$
\sum_{k \in K}\left\{s_{ky} z_{k0} + \sum_{i<y} s_{ki}\, {}_p e_{ki}\left[1 - \Phi\left(y - i; \mu_{v_k}, 3.33\right)\right]\right\}
$$

3.2.3 Modelling of policy options

The policy options considered in this report, as described in sections 0 and 3.2 involve either the reduction or the removal of high emissions engines from the market, depending on the option modelled. The model reflects this by reducing or removing sales of engines that do not conform to the standards set. The total sales were calculated based on the demand structure under the business as usual scenario and, following (US EPA, 2007), were then adjusted using a demand elasticity based on the equipment type.

The distribution of sales across remaining engines differs between the marine and gardening equipment models due to the differences in structure of those models. The specifics of the calculations are given in sections 3.3.5 and 3.4.4.

The calculation of sales in a given year under a given regulation is described mathematically in Box 3. Once the sales of engines in a given year are determined, the resulting emissions were calculated as per Section 3.2.2.

Box 3 Calculation of sales in a given year under the policy scenarios

Let $p_{a,b}$ denote the probability that engine a is replaced by engine b, h_c denote the power of an engine of type c and $\varphi(x; \mu, \sigma)$ denote a normal density with mean μ and standard deviation σ. Then:

$$
p_{ay,by} \propto \varphi\left(h_b; h_a, kh_a\right),
$$

where k is a constant. Now let K_{ry} denote the set of engines that are removed by the regulations in year y and K_{ly} be the set of those that remain. The increase in sales of engines of type k_1, $\Delta s_{k_0 y, k_1 y}$, due to the removal of engines of type k_0 is hence modelled as:

$$
\Delta s_{k_0 y, k_1 y} = \tilde{S}_y \frac{p_{k_0 y, k_1 y}}{\sum_{i \in K_l} p_{k_0 y, iy}},
$$

where $\tilde{S}_y = \mathrm{f}(e) S_y = \mathrm{f}(e) \sum_{i \in K_r} s_{iy}$ is the sales of engines which replace those no longer available due to regulation, taking into account the elasticity of demand, e.

The total change in sales of engines of type k_1 is then:

$$\Delta s_{k_1 y} = \tilde{S}_y \sum_{i \in K_r} \Delta s_{iy,k_1 y}.$$

To account for the elasticity of demand let $P_y = \sum_{k \in K_r} s_{ky} p_{ky}$ where p_{ky} is the price of engine k in year y denote the expenditure on engines that are removed under regulation assuming business as usual sales in year y. Also let $\tilde{P}_y = \sum_{i \in K_l} p_{iy} \left(s_{iy} + \Delta s_{iy} \right)$ with $f(e) = 1$ be the expenditure on engines under regulation assuming business as usual sales levels. Using the usual approximation for e:

$$e = \frac{\left| \tilde{S}_y - S_y \right|}{S_y + \tilde{S}_y} \Bigg/ R$$

where $R = \left| \tilde{P}_y - P_y \right| \Big/ P_y + \tilde{P}_y$, we then have:

$$\begin{aligned} f(e) &= \frac{R+e}{|R-e|} \text{ if } \tilde{P}_y < P_y \\ &= 1 \text{ if } \tilde{P}_y = P_y \\ &= \frac{|R-e|}{R+e} \text{ if } \tilde{P}_y > P_y \end{aligned}$$

3.3 Marine emissions model

This section discusses the data underlying the marine emissions model, the method used for estimating sales, how the stock-list was prepared, the method used for calculating stocks, the method for estimating emissions and how the policy options were modelled.

3.3.1 Data

The following data on the marine engine market was used as the input into the model:

- historic sales in the years 1998 to 2007, categorised by technology (two stroke carburetted, two stroke injected and four stroke) (DEWR 2007a)
- sales of engines in 2005 and 2007, categorised by technology (two stroke carburetted, two stroke injected and direct injected, and 4 stroke carburetted), and by horse power ((0, < 10), (10, < 26), (26, < 51), (51, < 90), (91, < 151), (151, ∞) (DEWR 2007a)
- the proportion of stock in 2005, belonging to each technology type (two stroke carburetted, two stroke injected, two stroke direct-injected, four stroke carburetted and four stroke injected) (DEWR 2007a)
- estimated annual hours of usage by technology type (two stroke petrol, four stroke petrol, diesel, and personal water craft) (PAE 2007)

- fuel consumption in litres per kilowatt hour, by technology type (two stroke carburetted, two stroke injected, two stroke direct-injected, four stroke carburetted and four stroke injected) and by power ((0, < 2.23), (2.23, < 4.5), (4.5, < 8.2), (8.2, < 11.9), (11.9, < 18.7), (18.7, < 29.8), (29.8, < 37.3), (37.3, < 74.6), (74.6, < 130.6), (130.6, ∞)) (US EPA 2005a)
- PM_{10} particulate emissions per kilowatt hour by technology type (two stroke carburetted, two stroke injected, two stroke direct-injected, four stroke carburetted and four stroke injected) and by power ((0, < 2.23), (2.23, < 4.5), (4.5, < 8.2), (8.2, < 11.9), (11.9, < 18.7), (18.7, < 29.8), (29.8, < 37.3), (37.3, < 74.6), (74.6, < 130.6), (130.6, ∞)) (US EPA 2005a)
- engine emission deterioration factors for the various pollutants considered in this report (US EPA b)
- listings of various engines available on the market (Fooks 2008, DEWR 2008)
- historic and projected population levels (ABS, 2006a and 2006b).

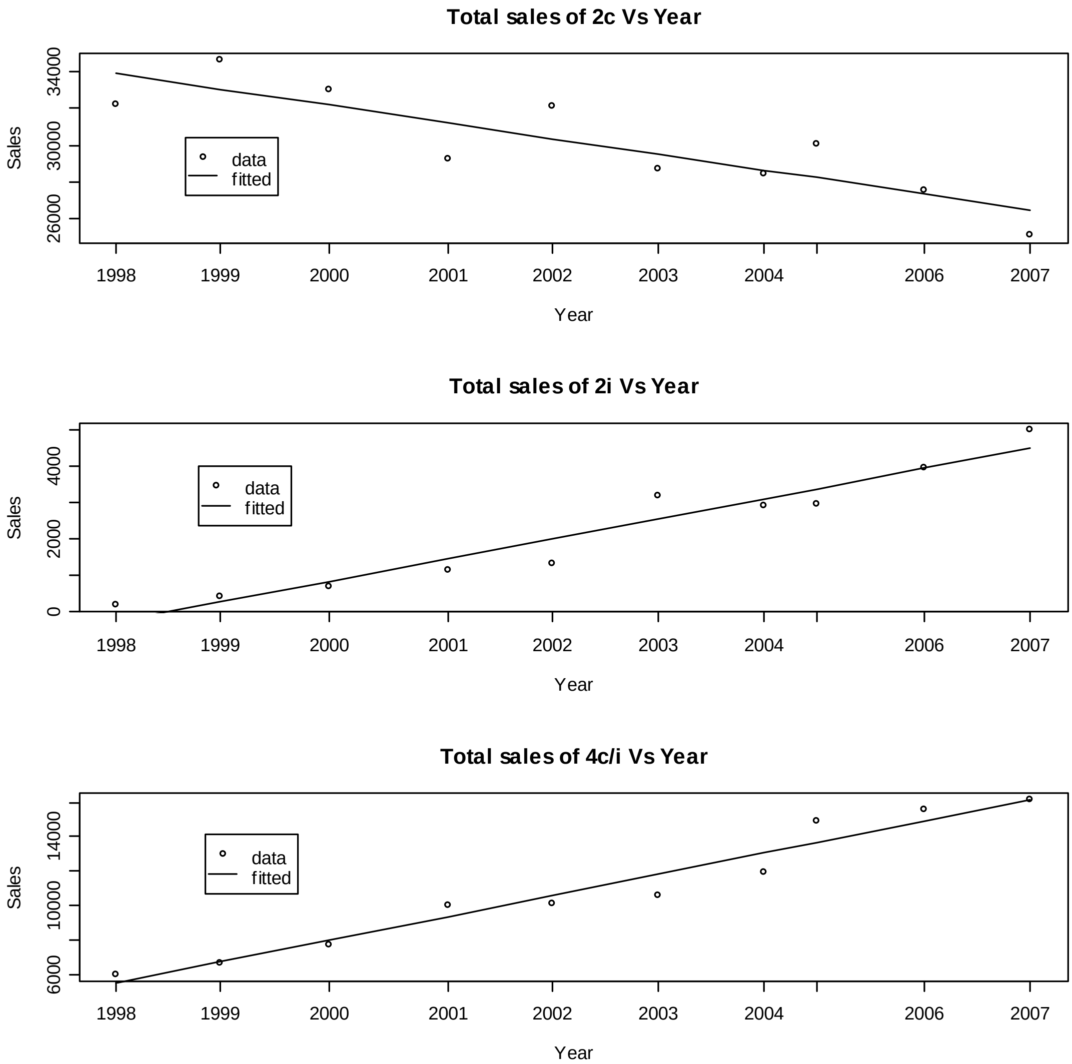
3.3.2 Sales Projections

Sales projections of outboard marine engines were based on linear extrapolation of the relationships between historic sales, and contemporary population levels. The data used is presented in Table 3-1 and the relationships are shown in Figure 3-1.

Table 3-1 Sales by engine type by year

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
2c	32,186	34,594	32,984	29,263	32,139	28,725	28,420	30,026	27,573	25,119
2i	190	432	683	1,139	1,319	3,192	2,931	2,959	3,974	4,989
4c/i	6,035	6,708	7,724	10,041	10,122	10,628	11,932	14,950	15,559	16,168

Figure 3-1 Relationships between sales and population levels[19]



When these relationships are extrapolated back to 1990, the projected sales of two stroke injected engines and four stroke engines become negative. Similarly, when extrapolated forward, the sales of two stroke carburetted engines become negative in 2047. These negative values were replaced by zeros and contemporary values for the remaining non-negative projections re-scaled so that total projected sales levels are preserved. This assumes that two stroke injected, two stroke direct injected and four stroke engines are still penetrating the market and hence causing substitution away from two stroke carburetted engines.

Projected sales were then pro-rated across power ranges using relative sales of each power in each technology class. Relative sales were calculated as the plain average proportion of sales calculated from the 2005 and 2007 sales data (DEWR, 2007), which is presented in Table 3-2. This implicitly assumes that the relative numbers of sales of engines in each

[19] The positions of the years on the x-axis reflect population levels in the corresponding year. For example there was less population growth between 2004 and 2005 than between 2005 and 2006 accoing to the ABS population statistics.

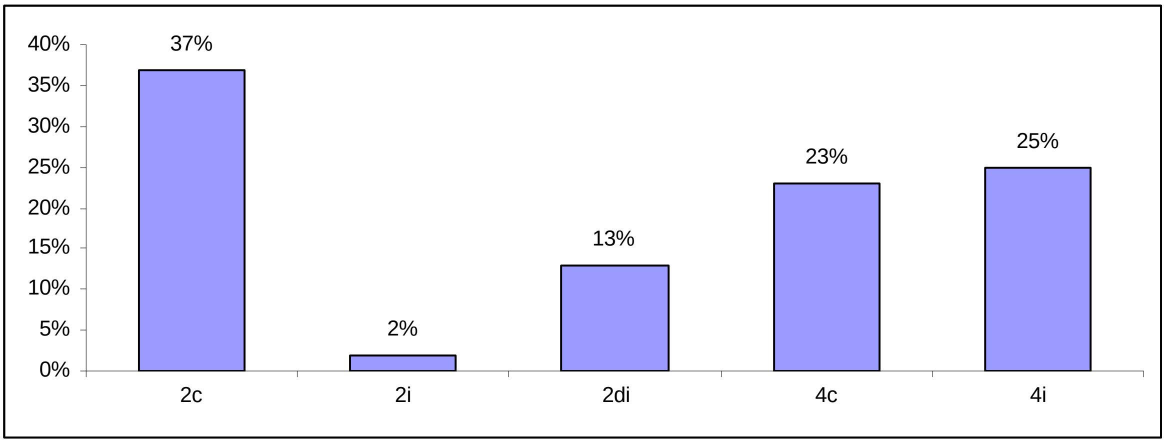
power class is constant through time. Ideally more detailed historical data would have been used to obtain trends in sub classes, but in the absence of such data this assumption had to be made.

Table 3-2 Sales by engine type and power range in 2005 and 2007

			Power range (hp)					
			0-10	11-25	26-50	51-90	91-150	>=151
Engine type	2005	2c	7,405	8,404	8,215	3,596	2,036	372
		2i/di	0	0	456	1,353	632	518
		4c	2,289	1,342	2,706	3,909	3,512	1,192
	2007	2c	6,823	8,057	7,217	2,071	742	209
		2i/di	0	0	526	1,831	1,842	790
		4c	2,664	1,340	2,946	4,144	3,511	1,563

The resulting projections were then further pro-rated across the full range of engine technologies (two stroke carburetted, two stroke injected, two stroke direct injected, four stroke carburetted and four stroke injected), using the relative proportion of each technology available in the market (see Figure 3-2). This assumes that sales of two stroke injected and two stroke direct injected engines are proportional to the number of models available within those classes, and that sales of four stroke carburetted and four stroke injected are proportional to the number of models available within those classes.

Figure 3-2 Proportion of engine on the market by type



Source: DEWR, 2007.

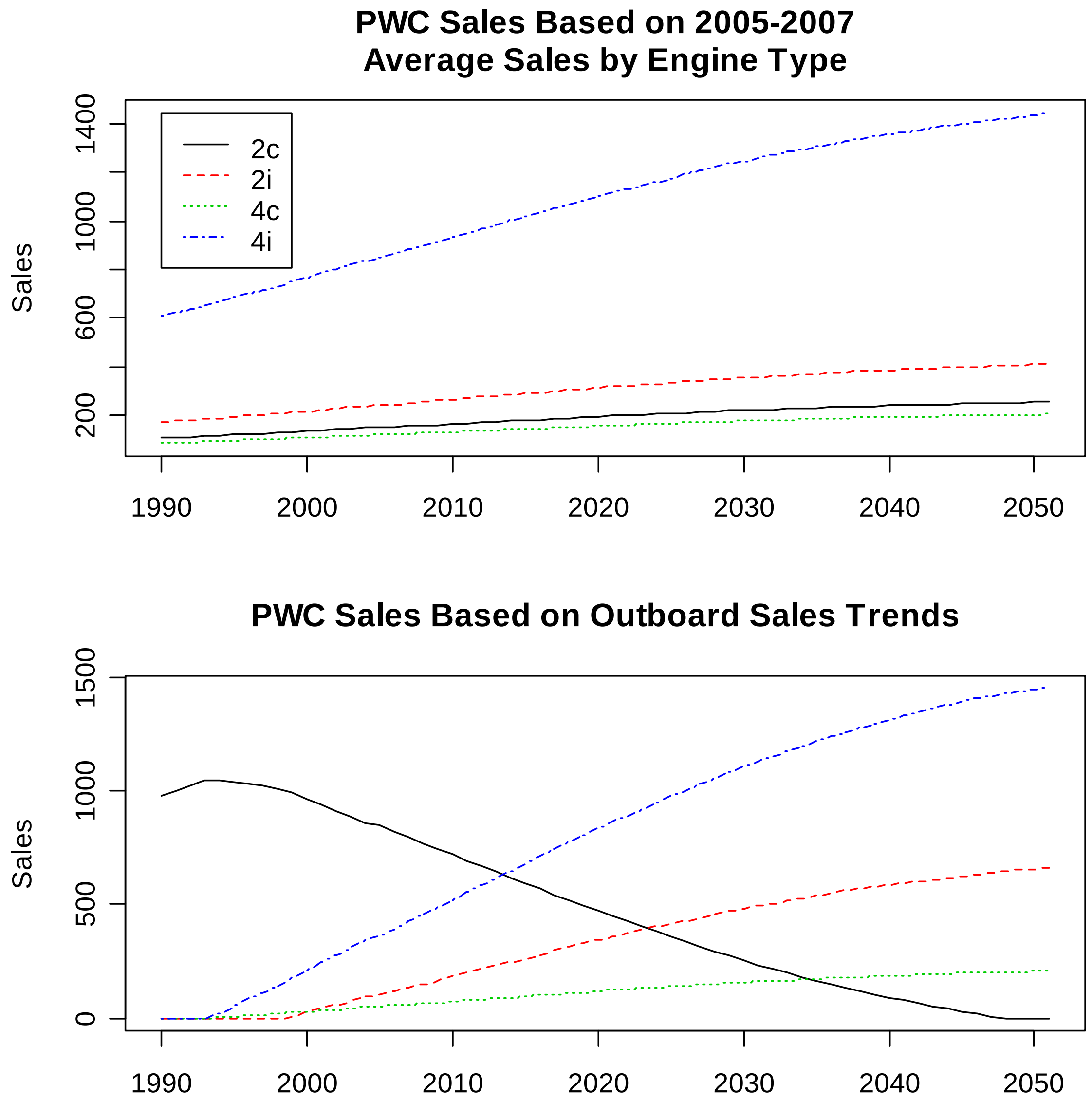
Finally, sales for individual stock items (DEWR 2008, Fooks 2008) were made by uniformly distributing projected sales for a given technology and power range across all items listed for that technology and power range.

Although information on the relative sales of personal water craft by engine type was available for the years 2005, 2006 and 2007, this was considered inadequate for the development of a prediction model, as no trends were present in these limited data. Furthermore, simply taking the average of these proportions would result in the sales trends shown in Figure 3-3, which predicts increasing sales of personal water craft of all engine types. This seemed unreasonable given the trends observed amongst outboard engines. Therefore, sales predictions were based on the relative sales of different engine types observed amongst outboard motors. This reduced the pollution under the BAU scenario and is hence conservative. Sales of personal water craft were projected as three percent of total outboard engine sales as shown in Figure 3-3[20]. Sales have been pro-rated by technology but not by power, as no suitable data was available[21].

20 The increasing sales of carburetted two strokes at the beginning of the series is due to the adjustment made for negative sales figures as described above. Total outboard engine sales were based on DEWR 2007.

21 Sales by technology type were pro rated using figures from DEWR 2008.

Figure 3-3 Comparison of Projection methods



3.3.3 Preparation of the stock list

Both the stock lists used (Fooks 2008, DEWR 2008) contained missing values for some variables in some of the stock. For the outboard motors, recommended retail price, HC, CO and NOx were imputed based on the power and technology of the engine concerned. These relationships are shown in Figure 3-4 and Figure 3-5. Note that the relationships between power and both HC and NOx for the two stroke injected engines are produced by randomly selecting a non-missing value from another engine. Hence, the relationship shown for two stroke injected engines is indicative only of the imputations that might be made for a given power. This approach was chosen because the relationships for these variables tended to the extremes, as is shown in Figure 3-5.

Three models (Yamaha VX Deluxe, Yamaha VX Sport and Yamaha VX700) were removed from the personal water craft stock list where the HC, NOx and CO values were missing and there were an insufficient number of models to impute values reliably. Once these values were removed, recommended retail price was the only variable with missing values and was imputed based on the power of the craft only, as there were insufficient models to include the technology in the calculation.

Figure 3-4 Relationships between recommended retail price and power used for imputation of retail price in outboard engine stock list

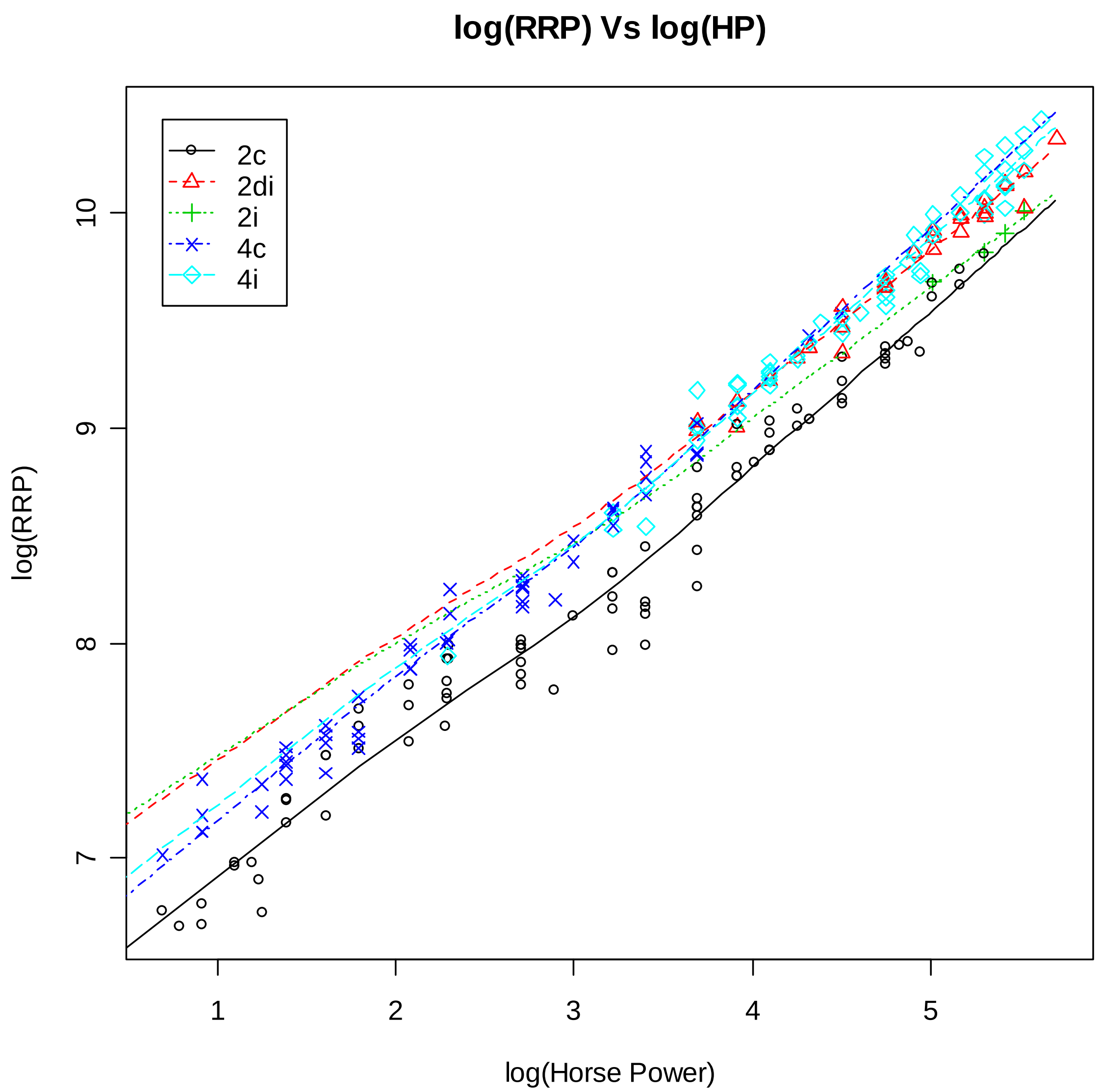


Figure 3-5 Relationships between various pollutants and power used for imputation on outboard engine stock list

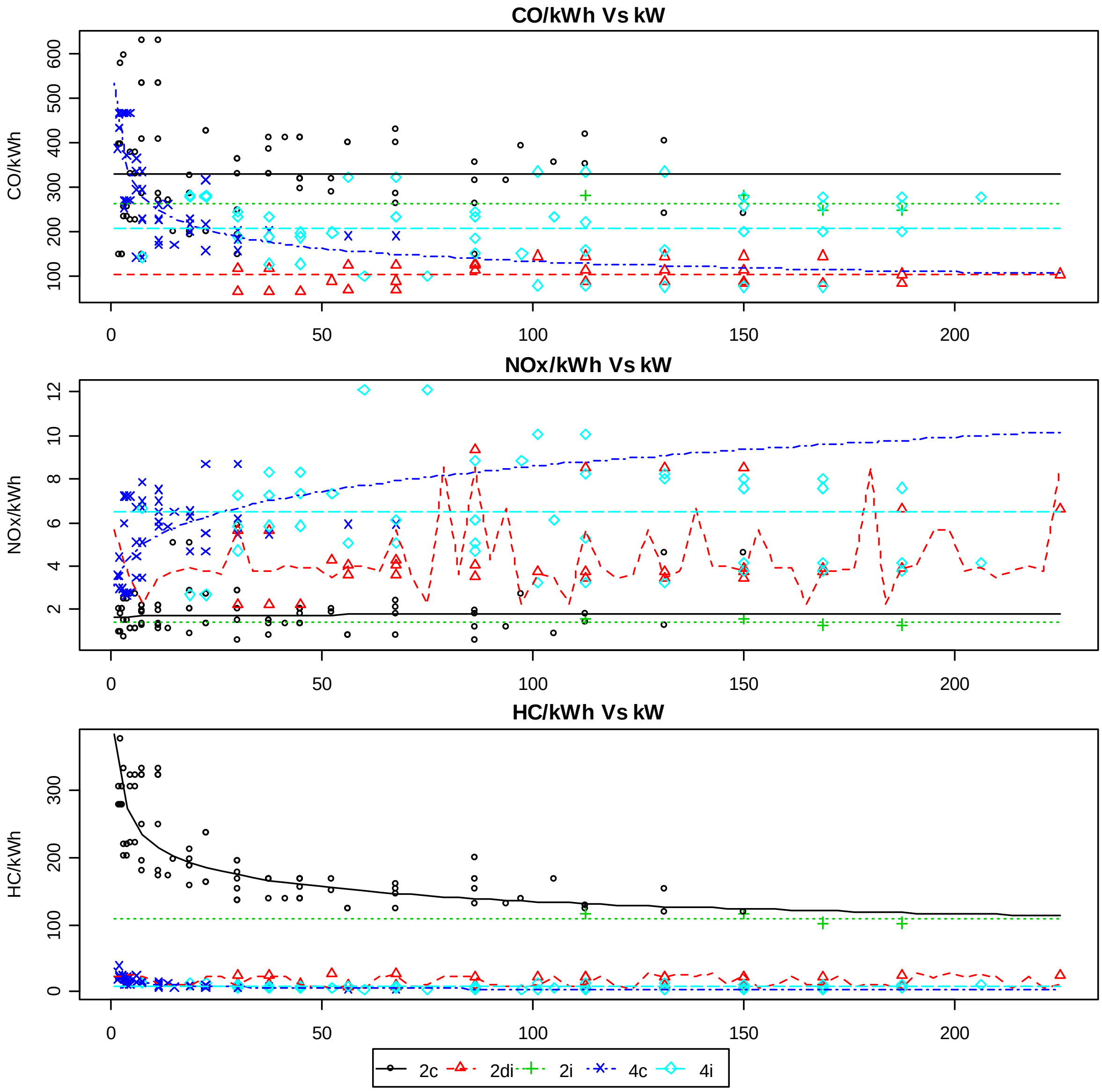
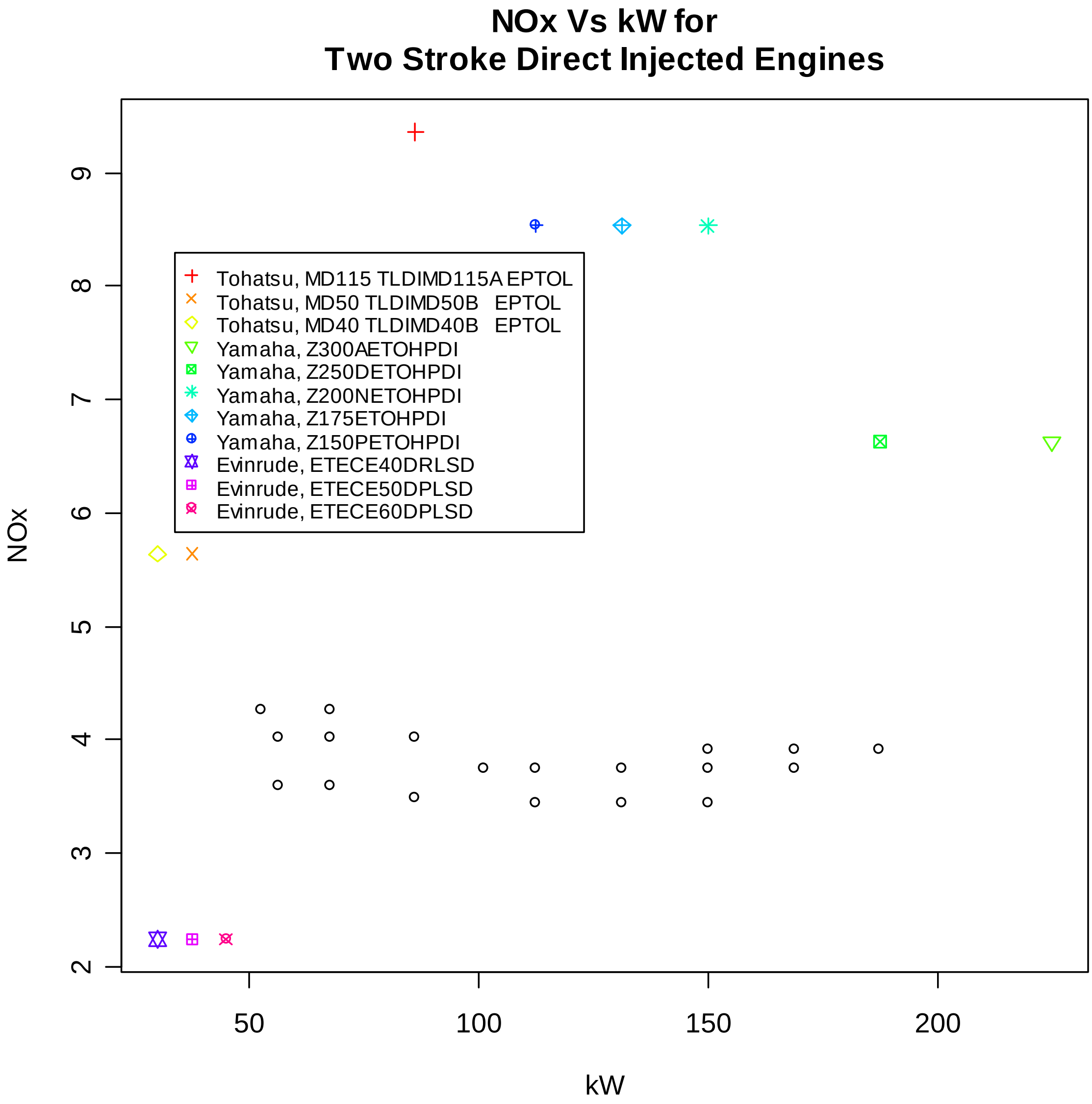


Figure 3-6 Relationship between NOx (g/kWh) and power (kW) for two stroke direct injected engines



Fuel consumption and PM_{10} particulate emissions factors were then calculated for each engine using smoothed estimates from (US EPA 2005) as shown in Figure 3-7 and Figure 3-8 respectively. The raw data is shown in tables Table 3-3 and Table 3-4.

Figure 3-7 Relationship between fuel consumption and power

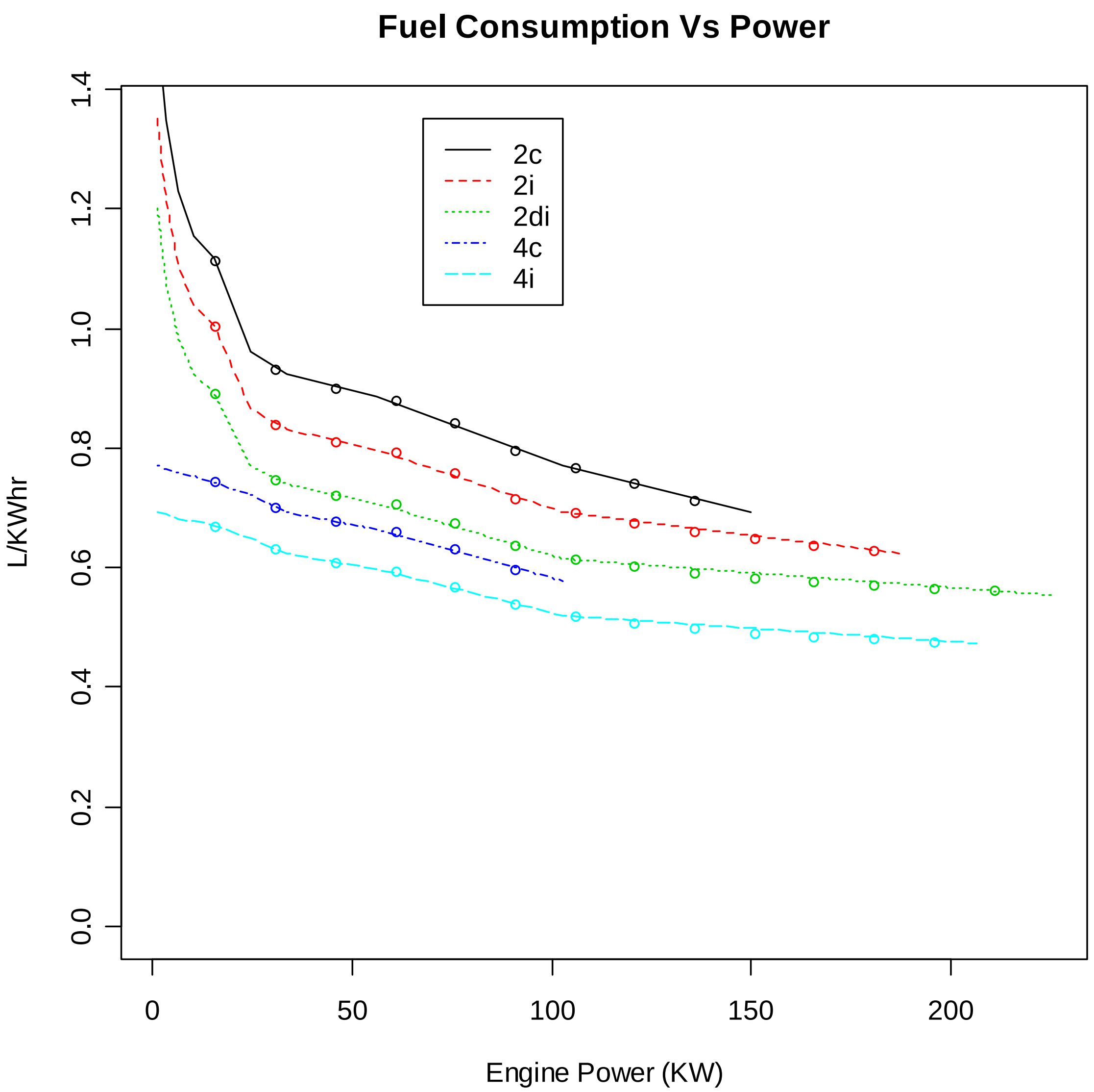


Figure 3-8 Relationship between PM_{10} emissions and power

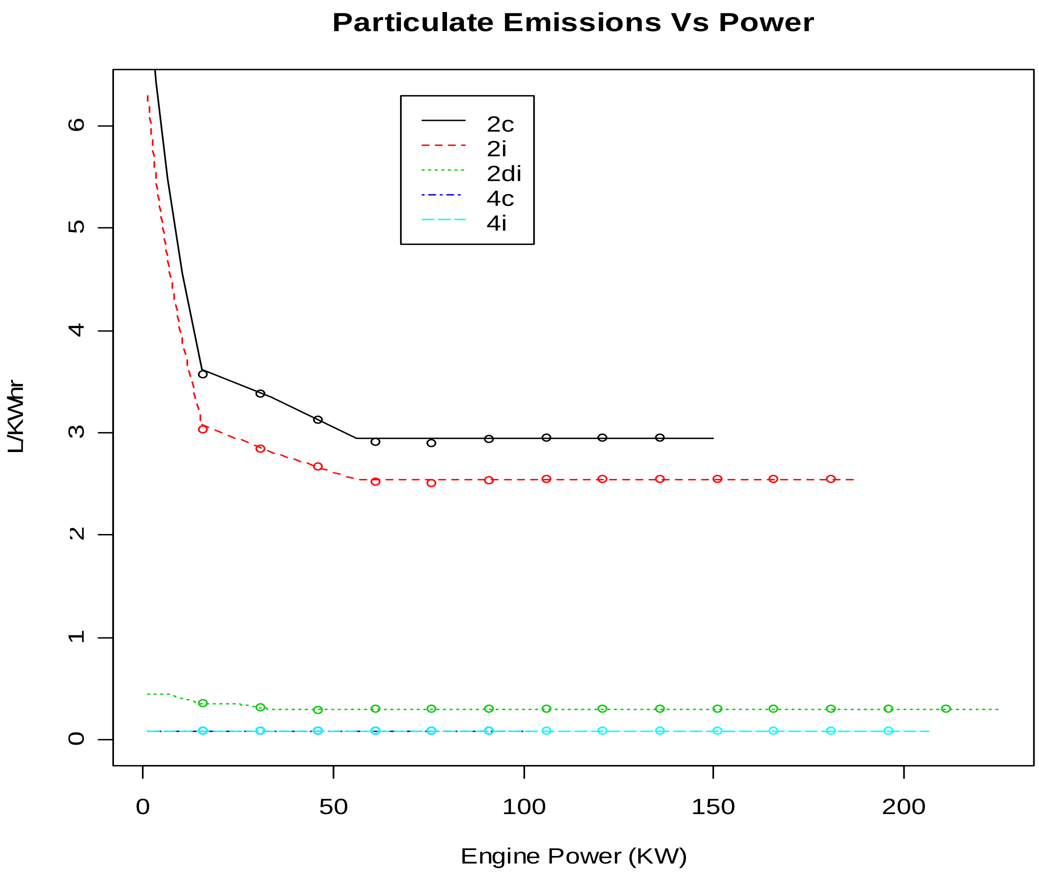


Table 3-3 Fuel consumption (L/kWh) for engine type and power range

		Engine type				
		2c	2i	2di	4c	4i
Power range (kW)	0-2.23	1.50	1.35	1.20	0.77	0.69
	2.23-4.5	1.35	1.21	1.08	0.77	0.69
	4.5-8.2	1.23	1.11	0.99	0.76	0.68
	8.2-11.9	1.15	1.04	0.92	0.76	0.68
	11.9-18.7	1.12	1.00	0.89	0.75	0.67
	18.7-29.8	0.96	0.87	0.77	0.73	0.65
	29.8-37.3	0.92	0.83	0.74	0.70	0.62
	37.3-74.6	0.89	0.80	0.71	0.67	0.60
	74.6-130.55	0.77	0.69	0.62	0.58	0.52
	>=130.6	0.69	0.62	0.56	0.55	0.47

Table 3-4 PM_{10} emissions for (g/kWh) for engine type and power range

		Engine type				
		2c	**2i**	**2di**	**4c**	**4i**
Power range (kW)	**0-2.23**	7.37	6.30	0.44	0.08	0.08
	2.23-4.5	6.43	5.49	0.44	0.08	0.08
	4.5-8.2	5.49	4.69	0.44	0.08	0.08
	8.2-11.9	4.56	3.89	0.40	0.08	0.08
	11.9-18.7	3.62	3.08	0.35	0.08	0.08
	18.7-29.8	3.48	2.95	0.35	0.08	0.08
	29.8-37.3	3.35	2.81	0.29	0.08	0.08
	37.3-74.6	2.95	2.55	0.29	0.08	0.08
	74.6-130.55	2.95	2.55	0.29	0.08	0.08
	>=130.6	2.95	2.55	0.29	0.08	0.08

3.3.4 Stock calculations

The scrapping function used for marine engines is based on a cumulative normal distribution with a mean of 10 years and a standard deviation of 3.33 years.[22]

It is generally accepted that four stroke engines last longer than two stroke engines. However, if different engine lifetimes are used in the model, then an artificial accumulation of engines occurs as four stroke engines are substituted for two strokes resulting in unrealistic stock numbers. To remove this effect while retaining differing lifetimes, it would be necessary to know what proportions of engines are new purchases or replacements for scrapped engines. Data enabling this was unavailable. The scrapping rates were therefore assumed to be equal across the engine types. This has led to a slight under estimation of the net benefits from substitution to four strokes, since fewer engines need to be purchased than is reflected in the model.

3.3.5 Modelling of policy options

Following (US EPA, 2007), the sales under a given scenario were adjusted using a demand elasticity of two for both outboard engines and personal water craft.

The total sales were then distributed across engines that remain available after the removal of high emissions engines, as a function of power output. In other words, replacements

[22] This was chosen based on the based on the quantiles of a normal distribution, only 2.5% of motors will fail in the first year.

for the engines that are no longer available after the introduction of each policy scenario were chosen from the remaining engines in proportion to the similarity of their power rating.

Outboard motors were assumed to run, on average, at 30% of their maximal power output, personal water craft were assumed to run at 70% of their maximal load.

3.3.6 Service costs

Service costs were estimated based on consultation with industry experts. These are represented in the model as linear functions of engine power (HP), depending on whether the engine is two or four stroke. The parameters of these functions are shown in Table 3-5.

Table 3-5 Parameters of service cost functions

	Intercept	Slope
Two stroke	200	2.5
Four stroke	250	2.9

Once the emissions, service costs and expenditure on new engines were calculated, they were costed, inflation adjusted and discounted at a rate of seven per cent per year.

3.4 Gardening equipment emissions model

The model used for gardening equipment is fundamentally the same as that described above for marine engines. However, matching the engines available in Australia (DEWR, 2008) against the emissions test data used by the US EPA[23] proved to be very difficult and hence the stock list comprises representative engines for each class and usage. Estimates of the proportion of each representative engine which comply with the various phases of regulation are provided in (DEWR, 2007b) and were used in the emissions calculations. The equipment classes included in this analysis were: walk behind lawn mowers, brushcutters, hand held blowers and hedge trimmers. This notably excludes chainsaws, ride-on mowers and wheeled blowers. Chainsaws and ride-on lawn mowers have been excluded, as neither a list of models available in Australia, nor estimates of the proportion of available stock that would qualify under the various phases of regulation, were available. Ride-on mowers are generally powered by larger four stroke engines and most would qualify for sale under the policy options investigated herein. Their exclusion is unlikely to make a significant difference to the results. Wheeled blowers were excluded as these are generally more expensive, specialised pieces of equipment that have relatively low sales and are powered by similar engines to good quality lawn mowers. Most can be assumed to qualify for sale under all phases of regulation investigated herein and their exclusion is unlikely to have made a significant difference to the results. Other small engine types like portable generators were excluded as no data on emissions or models available in Australia could be sourced. As this analysis was based on absolute numbers of

[23] http://www.epa.gov/oms/certdata.htm#smallsi

engines, the exclusion of these equipment classes will underestimate the benefits from regulation.

The original project plan involved the assessment of a tiered adoption of the US EPA phase 2 and 3 emission standards for gardening equipment. However, no data was available on what proportion of existing engines in Australia would comply with US EPA phase 3 standards. Since we could not effectively match the engines on the US EPA testing database (which contains HC and NOx test results), it was not possible to determine directly which engines would comply with phase 3 emissions standards via analysis of the test emissions.

3.4.1 Data

The following data was sourced on the gardening equipment market:

- Historic sales in the years 2002 and 2005/06 (DEWR 2007b). The latter has been assumed to occur in 2006 when estimating sales.
- Sales of engines in 2005 and 2007 categorised by technology (two stroke carburetted, two stroke injected and direct injected, and 4 stroke carburetted) and by horse power {(0, 10], (10, 26], (26, 51], (51, 90], (91, 151], (151, ∞)} (DEWR 2007b).
- The proportion of stock belonging to each technology type (two stroke carburetted, two stroke injected, two stroke direct-injected, four stroke carburetted and four stroke injected) (DEWR 2007b).
- Estimated annual hours of usage, by technology (DEWR 2007b).
- Fuel consumption in litres per kilowatt hour, by technology type (two stroke carburetted, two stroke injected, two stroke direct-injected, four stroke carburetted and four stroke injected) and by power {(0,2.23], (2.23, 4.5], (4.5, 8.2], (8.2, 11.9], (11.9, 18.7], (18.7, 29.8], (29.8, 37.3], (37.3, 74.6], (74.6, 130.6], (130.6, ∞)} (USEPA 2005a).
- PM10 particulate emissions per kilowatt hour by technology type {two stroke carburetted, two stroke injected, two stroke direct-injected, four stroke carburetted and four stroke injected} and by power {(0,2.23], (2.23, 4.5], (4.5, 8.2], (8.2, 11.9], (11.9, 18.7], (18.7, 29.8], (29.8, 37.3], (37.3, 74.6], (74.6, 130.6], (130.6, ∞)} (USEPA 2005a),
- Listings of various engines available on the market (DEWR 2008).
- Historic and projected population levels (ABS, 2006)

3.4.2 Sales projections

Sales projections of gardening equipment by equipment class were based on linear extrapolation of the relationship between sales of engines in 2002 and 2005/06, and contemporary population levels. Since there are only two years of data, and it can reasonably be assumed that demand for gardening equipment will be directly proportional to population levels, regression through the origin has been used to develop this relationship. Sales for 2005/06 have been assumed to occur in 2006, which will slightly underestimate sales, and hence the benefits from intervention, as it reduces annual sales figures and hence the number of engines. The sales figures for 2002 and 2005/06 are shown in Table 3-6.

Table 3-6 Sales of garden equipment (,000s) by category in 2002 and 2005/06

	2002	2005/06
Lawn mower	246	424
Brushcutter	192	339
Blower	50	109
Trimmer	220	40

The projected sales by equipment class were then pro-rated between commercial and domestic users, using the estimated proportions from the DEWR report (DEWR, 2005b). These proportions are shown in Table 3-7. Projected sales were then further pro-rated across engine type and capacity class using the estimated proportions of each from the DEWR report (DEWR, 2005b).

Table 3-7 Proportion of total purchases made by commercial operators of gardening equipment by category

	%
Lawn mower	0.025
Brushcutter	0.037
Blower	0.037
Trimmer	0.037

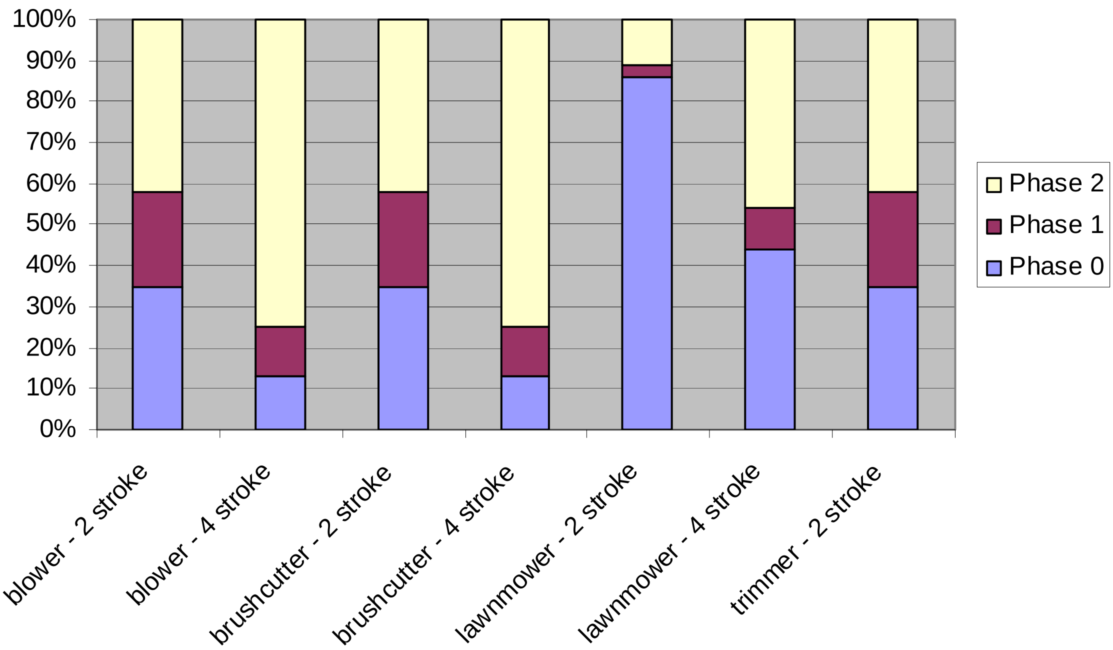
3.4.3 Preparation of the stock list

The stock list was developed from the DEWR report (DEWR, 2008). This data did not contain information on HC or NOx emissions for individual engines, which made it impossible to directly determine which engines would qualify for sale under the various interventions. Further, most fields contained numerous missing values, most importantly: recommended retail prices, engine capacity and technology class. This made the imputation of missing values impractical. Matching was attempted against US EPA emissions testing data, but only a relatively small number of engines could be matched. For these reasons, a list of representative engines was developed for each of the sales categories described above. Firstly, engines with missing values for the recommended retail price, engine capacity or engine type were removed from the list. Secondly, the power rating for engines where the power rating was missing was imputed based on the average of all engines of the same equipment class, engine type and capacity class. One representative engine for each equipment class, engine type and capacity class was created for commercial users and domestic users respectively using the average power, average recommended retail price and average capacity for each combination of capacity class, equipment class and technology type.

3.4.4 Stock calculations

The sales of each representative engine in a given year was adjusted according to the proportion of those engines, by equipment class and engine type, which conform to the regulations in place in that year, as reported in DEWR 2005b. The proportions used are presented in Figure 3-9. This adjustment process is best described by a hypothetical example which is presented in Box 4. The demand elasticities used in the gardening equipment model are those used by the US EPA, and are presented in Table 3-8.

Figure 3-9 Proportion of engines conforming to phase 1 and phase 2 regulations (phase 0 indicating no compliance with either phase 1 or 2)



Box 4 Hypothetical example of sales adjustment induced by regulation

Assume the sales of two and four stroke lawn mowers to domestic users in a given year under no regulation are 100 and 500 units respectively. Assume also that the proportion of two stroke and four stroke lawn mowers that conform to *only* phase one regulations are 10% and 30% respectively, and the proportion of two stroke and four stroke lawn mowers that conform to phase two regulations (and hence also phase one regulations) are 2% and 15% respectively. If we then apply phase one regulations in that year, the sales of two stroke lawn mowers becomes (approximately):[24]

[24] The calculation is complicated by the inclusion of the elasticity of demand. See Box 3 for details.

$$\frac{100(100+500)(10+2)}{100(10+2)+500(30+15)} \approx 30.4,$$

and the sales of four stroke lawn mowers becomes:

$$\frac{500(100+500)(30+15)}{100(10+2)+500(30+15)} \approx 569.6.$$

Table 3-8 Demand elasticities used in the gardening model

	Elasticity
Lawnmower	0.2
Trimmer	1.9
Brushcutter	1.9
Blower	1.9

3.4.5 Emissions calculations

The emissions calculations in the gardening model must reflect the mix of engines sold in a given year that conform to the regulations in place in that year. The details of the calculation are very similar to those presented in Section 3.2.2 with the slight complication that the emissions from a representative engine must reflect the proportions of engines of that type that conform to the various phases of regulation[25]. The usage hour data used from the DEWR report (DEWR, 2005b), are shown in Table 3-9 and the details of the emissions calculations are given in Box 5. The load factors used for the various equipment classes are shown in Table 3-10 and are also from the DEWR report (DEWR, 2005b).

Table 3-9 Annual usage hours by equipment class

	Domestic	Commercial
Lawn mowers	22.50	320.00
Blowers	10.50	231.50
Trimmers	10.00	222.50
Brushcutters	10	215.00

Table 3-10 Load factors by equipment class

	Load factor
Lawn mowers	0.33
Trimmers	0.91
Brushcutters	0.91
Blowers	0.94

25 This is only relevant through the years when the regulations are being phased in. Once they are phased in, then all engines have the same emissions profile.

Box 5 Emissions calculations for gardening equipment

For a particular engine type which conforms to a given phase, we have from Box 2:

$$_{p}e_{ky} = z_{k0}\left[1 + A_{pk}\left(l_k \sum_{j<y} h_{kj} \Big/ \mu_{v_k}\right)^b\right].$$

In the gardening model we have the slight complication that different proportions of a given engine conform to the different regulations, and these are allowed to have different emissions characteristics. The analogous relation is:

$$_{p}e_{kyt} = \sum_{i=0}^{2} \alpha_{k,it} z_{k0,it}\left[1 + A_{pk,it}\left(l_k \sum_{j<y} h_{kj} \Big/ \mu_{v_k}\right)^b\right],$$

where $\alpha_{k,it}$ is the proportion of engines of type *k* that qualify under regulation scheme *i* (zero corresponding to no regulation) and $A_{pk,it}$ and $z_{k0,it}$ are specific to regulation scheme *i* in year *t*. Total emissions are then calculated as per Box 2.

3.5 Benefits of avoided emissions

The estimation of the health and environmental damages associated with air pollution are subject to high levels of uncertainty, as many of the impacts are indirect and often intangible. The dominant factors affecting published estimates of the impacts of air pollution from combustion engines are health related. Epidemiological studies linking air pollution to health outcomes are generally based on linking pollution levels to health statistics. The health outcomes are then evaluated by accounting for direct health costs, estimating the value of life years lost and the value of a mean statistical life.

Such estimates tend to be conservative in the sense that they rely mainly on the direct health costs and income lost, but only partially attempt to estimate pain and suffering, if at all. Furthermore, our use of such studies limits the set of emissions included, for example, excluding all the toxic substances emitted (due to data limitations) and do not value most environmental impacts.

The estimates presented in this section are therefore very conservative and yet, given the high emissions nature of carburetted two stroke engines relative to four stroke engines, the net benefits from introducing emissions constraints are large.

The main studies relied on in this paper are the Victoria Transport Policy Institute (VTPI 2005), the European Commission's air pollution damage estimates (EC 2005) and estimates imputed from the Bureau of Transport and Regional Economics health costs of motor vehicle emissions estimates (BTRE 2005 and 2003).

As described in the modelling sections, the data we used reports hydrocarbon (HC) emissions and not volatile organic compounds (VOC), but the studies reported here use VOC. To convert from HCs to VOCs we used a conversion factor of 1, in other words we use HCs and VOCs interchangeably. According to the US EPA, the conversion factor for non-road engines is 1.034 for two strokes and 0.933 for four strokes, but this is based on very sparse data. Using VOCs and HCs interchangeably therefore provides a conservative estimate.

The Bureau of Transport and Regional Economics (BTRE) quantified the health impacts of transport emissions in Australia. Following Kunzli et al (2000) and Fisher et al (2002), they used PM_{10} emissions as a surrogate for all air pollution related health impacts. Using their estimate of health damages from motor vehicle related air pollution for Australian capital cities (BTRE 2005, p100) and the BTREs estimate of PM_{10} emissions in Australian capital cities (BTRE 2003, p125), the implied health cost per ton of PM_{10} emissions as a surrogate for air pollution from motor vehicle emissions in today's dollars is between $136,000 and $324,000, with a best estimate of $230,000 per ton of combustion-related PM_{10}.[26] The large range reflects uncertainty about motor vehicle related particle emissions, and the value of life years lost, and the median value of a statistical life. This analysis only considers health related damages from a subset of combustion emissions in motor vehicles, and omits some harmful gases as well as environmental harm, including to crops and equipment. The BTRE's estimates are therefore likely to be conservative.

The European Commission funded a major study to provide estimates of the damages per tonne emission of $PM_{2.5}$, NH_3, SO_2, NOx and VOCs from each EU25 member state (excluding Cyprus) and surrounding seas to update previous estimates and to inform its Clean Air for Europe (CAFE) program (EC 2005). The range provided takes account of variation in the method used to value mortality, reflecting the use of the median and mean estimates of the value of a life year (VOLY) from NewExt (2004) (€50,000 and €120,000 respectively in 2000 €), and the use of the median and mean estimates of the value of statistical life (VSL), also from NewExt (€980,000 and €2,000,000 respectively). The range is shown in Table 3-11 and also includes sensitivity to the effects quantified and to the use of a zero cut-point for assessment of ozone impacts. Again, the study omits a number of gases emitted from combustion engines and, aside from some agricultural impacts from the emissions of sulphur oxides (not used in our study), quantifies mainly health effects and produces figures that are therefore conservative.

We added a composite medium case to the estimates provided by the EC, averaging across the low sea case and the high land case for our central estimate. This is reasonable for Australia because the population density is lower than in most of Europe and this provides a conservative estimate of emissions on land and in estuaries. We used this composite medium case for our best estimate of the net benefits from the policy options.

[26] The method used to derive this estimate is identical to that used by The Center for International Economics to quantify the air pollution costs of transport in Sydney . Their estimate in 2005 dollars was $257,000 per ton of PM_{10} for Sydney only.Our estimate extends to all capital cities of Austrlia and adjusts for inflation to 2008.

Table 3-11 European Commission pollution costs per tonne (2008 AU$)

	NOx	HC	$PM_{2.5}$
EC land - high	22,497	5,249	140,608
EC land - low	8,249	1,781	48,744
Best estimate (EC composite)	**13,592**	**3,356**	**82,490**
EC sea - high	12,936	4,312	67,492
EC sea - low	4,686	1,462	24,372

A third set of air pollution damage estimates used in this paper comes from the Victoria Transport Policy Institute's studies. This study reviewed a number of air pollution cost estimates to arrive at their own, including work done by the US EPA. As can be seen in Table 3-12, their estimate of the cost of particle pollution is much lower than the estimate reported in the European Commission study. However, their estimate of the damage of hydocarbons is much higher and, in contrast to the EC study, they did quantify the effects of carbon monoxide. Overall, these differences mean that the damage estimates from non-road engine emissions using the VTPI numbers are substantially higher then those using the EC study.

Table 3-12 Victoria Transport Policy Institute pollution costs per tonne (2008 AU$)

	NOx	HC	CO	PM_{10}
VTPI - high	19,510	18,244	550	11,940
VTPI - medium	14,182	11,341	550	9,352
VTPI - low	8,854	4,438	550	6,765

All of the studies we have drawn upon in this paper exclude "upstream" emissions that occur during fuel production and distribution, as well as quantifying mainly the monetary health effects and excluding most environmental and social effects. As the studies report themselves, they all only quantify a subset of likely costs and are therefore to be interpreted as conservative estimates of the likely actual costs of air pollution per ton of pollutants emitted. Our estimate of the cost of air pollution from non-road engines is even more conservative as it only accounts for a subset of air pollutants. For example, due to data limitations, we ignored the effects of air toxics and, given the EC study does not quantify carbon monoxide or PM_{10} ($PM_{2.5}$ being a subset of PM_{10}), our best estimate also ignores the harmful effects from CO and of particles between $PM_{2.5}$ and PM_{10}.

Table 3-13 summarises the cost per tonne for the pollutants considered in this study. This highlights the large variation in per tonne cost estimates among studies. The overall conclusions were not affected, however, since even the lowest per tonne cost estimates provided large net present value benefits from all of the policy options modelled.

Table 3-13 Pollution costs per tonne (2008 AU$)

	NOx	HC	CO	$PM_{2.5}$	PM_{10}
BTRE high	PM_{10} used as a surrogate for all air pollutants in BTRE study				324,000
BTRE medium					229,738
BTRE low					136,068
EC land - high	22,497	5,249	Not estimated	140,608	Not estimated
EC land - low	8,249	1,781		48,744	
Best Estimate (EC composite)	**13,592**	**3,356**		**82,490**	
EC sea - high	12,936	4,312		67,492	
EC sea - low	4,686	1,462		24,372	
VTPI - high	19,510	18,244	550	$PM_{2.5}$ is a subset of PM_{10}	11,940
VTPI - medium	14,182	11,341	550		9,352
VTPI - low	8,854	4,438	550		6,765

4 RESULTS

This chapter reports the results of the cost benefit analysis, beginning with the aggregated results from all sectors considered in this paper (marine outboard engines, personal watercraft and selected gardening equipment, namely, lawn mowers, brushcutters, trimmers and hand held blowers). This is followed by a discussion of each sector separately (section 4.1 to 4.3).

Section 4.4 provides a discussion of results in terms of the air emission externalities associated with representative single engines from each sector, rather than the aggregate NPV benefits discussed previously in this document.

Table 4-1 provides a summary of the scenarios modelled and discussed in this chapter. To obtain the NPV of the policy options, as a whole, the net present values of the estimated benefits for each sector are added together.

Table 4-1 Policy scenarios modelled

	Name	Scenario description
Commonwealth regulation scenarios	OB-1	US 2006 outboard emission standards implemented in Australia in 2012, followed by US 2009 standards in 2014.
	OB-2	US 2009 outboard engine emission standards implemented in Australia in 2012.
	OB-3	US 2006 outboard emission standards implemented in Australia in 2010, followed by US 2009 standards in 2012.
	OB-4	US 2009 outboard engine emission standards implemented in Australia in 2010.
	PWC-1	US 2006 PWC emission standards implemented in Australia in 2012, followed by US 2009 standards in 2014.
	PWC-2	US 2009 PWC emission standards implemented in Australia in 2012.
	PWC-3	US 2006 PWC emission standards implemented in Australia in 2010, followed by US 2009 standards in 2012.
	PWC-4	US 2009 PWC emission standards implemented in Australia in 2010.
	Grd-1[27]	US Phase 2 gardening equipment emissions limits implemented in Australia in 2012.
	Grd-2[28]	US Phase 2 gardening equipment emissions limits implemented in Australia in 2010.
Industry agreement scenarios	IA-1	Sales of zero or one star engines under the Outboard Engine Distributor Association's (OEDA) Voluntary Emissions Labelling Scheme limited to 15% of total sales by 2012.

27 For gardening equipment, only avoided emissions from lawn mowers, hedge trimmers, brush cutters and hand held blowers were assessed. Furthermore, due to data limitations, only the effects of implementing US Phase 2 standards were considered, ignoring the effects of Phase 3 regulations scheduled for introduction in 2011/12.

28 See footnote 24 above.

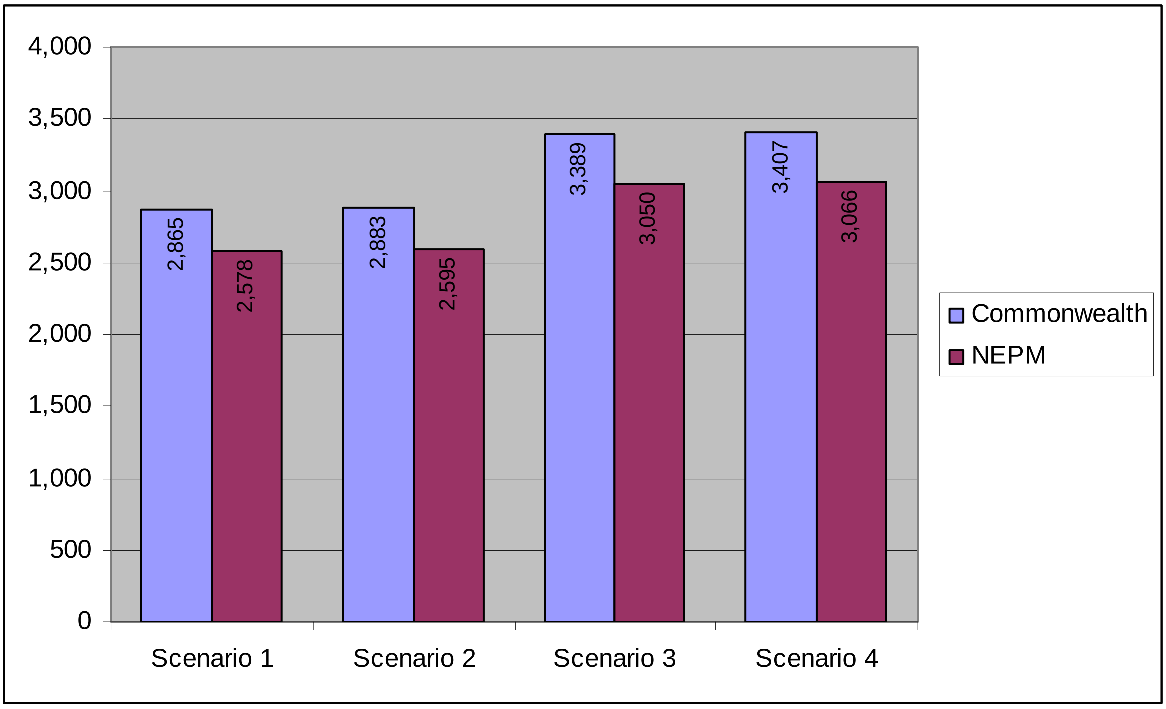
	Name	Scenario description
	IA-2	Sales of zero or one star engines under the Outboard Engine Distributor Association's (OEDA) Voluntary Emissions Labelling Scheme limited to 15% of total sales by 2020.
NEPM scenarios	The NEPM scenarios are identical to the Commonwealth regulation scenarios, except for the likely lag in implementation of the Standard. To account for these effects, the NEPM policy scenarios (NEPM OB-1 to 4, NEPM PWC-1 to 4 and NEPM Grd-1-4) are discounted by 10% to account for the likely additional time needed for all States and Territories to implement legislation as compared to the respective Commonwealth policy scenarios.	

Table 4-2 presents the benefits under the scenarios modelled herein as valued under the cost models described in section 3.5. Figure 4-1 shows the net present value of benefits from the Commonwealth regulations and NEPM policy options valued under the best estimate (EC composite). Scenario 1 is the sum of scenarios OB-1, PWC-1 and Grd-1; scenario 2 is the sum of scenarios OB-2, PWC-2 and Grd-1; scenario 3 is the sum of scenarios OB-3, PWC-3 and Grd-2; and Scenario 4 is the sum of scenarios OB-4, PWC-4 and Grd-2.

Table 4-2 NPV of Commonwealth regulation policy options (sum of scenarios OB-1 to 4, PWC-1 to 4 and Grd-1 and 2) under different pollution cost assumptions ($million, 2008)

	Scenario 1 (OB-1 + PWC-1 + Grd-1)	Scenario 2 (OB-2 + PWC-2 + Grd-1)	Scenario 3 (OB-3 + PWC-3 + Grd-2)	Scenario 4 (OB-4 + PWC-4 + Grd-4)
EC land - high	3,906	4,036	4,509	4,638
EC land - low	2,081	2,142	2,420	2,481
Best estimate (EC composite)	**2,865**	**2,956**	**3,316**	**3,407**
EC sea - high	3,134	3,237	3,622	3,724
EC sea - low	1,823	1,875	2,123	2,175
BTRE - high	3,294	3,381	3,835	3,922
BTRE - medium	2,666	2,736	3,109	3,178
BTRE - low	2,043	2,094	2,388	2,439
VTPI - high	8,020	8,329	9,181	9,488
VTPI - medium	5,423	5,625	6,222	6,423
VTPI - low	2,825	2,920	3,263	3,357

Figure 4-1 Net present value of benefits from the Commonwealth regulation and NEPM policy options, scenarios 1 to 4 (2008 AU$ million)



It is immediately apparent from Table 4-2 and Figure 4-1 that implementing emissions restrictions in 2012 (Scenarios 1 and 2) provides significantly less net benefits that implementing the restrictions two years earlier (Scenarios 3 and 4). This is the case because every non-compliant engine sold prior to the introduction of emissions limits gives rise to significant air pollution externalities and such externalities are avoided for each year that the restrictions apply.

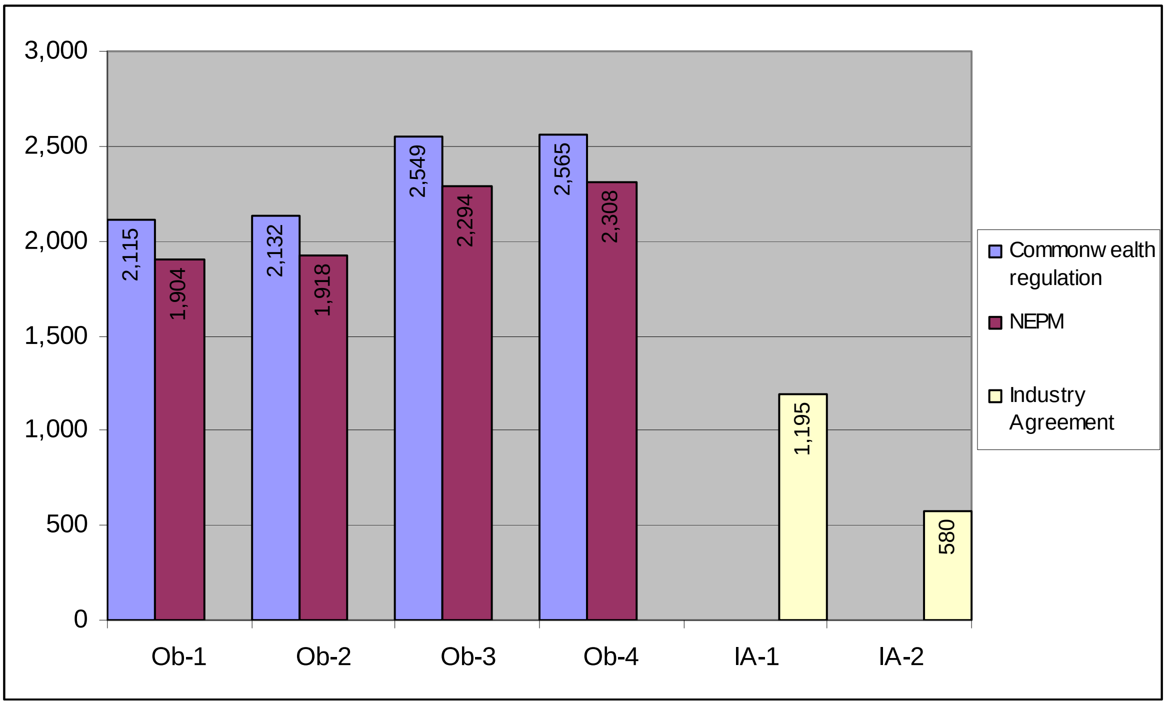
Figure 4-1 also illustrates the benefits from not phasing the introduction of emissions constraints albeit only just (Scenarios 1 and 3 are phased and Scenarios 2 and 4 are not), The non-phased approaches only provide under $20 million additional benefits in NPV terms, when compared to the phased ones.

4.1 Outboard engines

This section reports the results of our modelling for outboard engines. The net present value (NPV) benefits from the Commonwealth regulation and NEPM policy options (Scenarios OB-1 to OB-4), as well as from the Industry agreement policy options (Scenarios IA-1 and IA-2) are shown in Figure 4-2.

Sections 4.1.1 to 4.1.4 below, present our results for each of the OB-1 to OB-4 scenarios, and Sections 4.1.5 and 4.1.6 present results for scenarios 1A-1 and 1A-2. For each of the scenarios we provide graphs showing the service costs and expenditure for outboard engines over the years to 2030, from both the business as usual scenario and the regulated scenarios. Fuel consumption and emissions for outboard engines are also reported for each of the scenarios modelled. Please note that the NEPM scenarios are identical to the Commonwealth regulation scenarios except for an applied discount of 10% to account for the likely delay in effective implementation under the NEPM option.

Figure 4-2 NPV of benefits from outboard engine emissions restrictions, scenarios OB-1 to OB-4, NEPM OB-1 to NEPM OB-4 and IA-1 and IA-2 (2008 AU$ million)



4.1.1 Scenario OB-1

Figure 4-3 Outboard engines service costs and expenditure, scenario OB-1

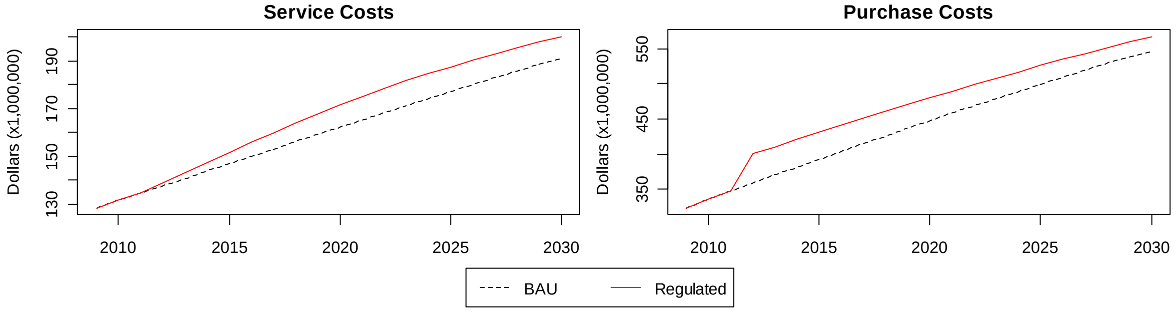
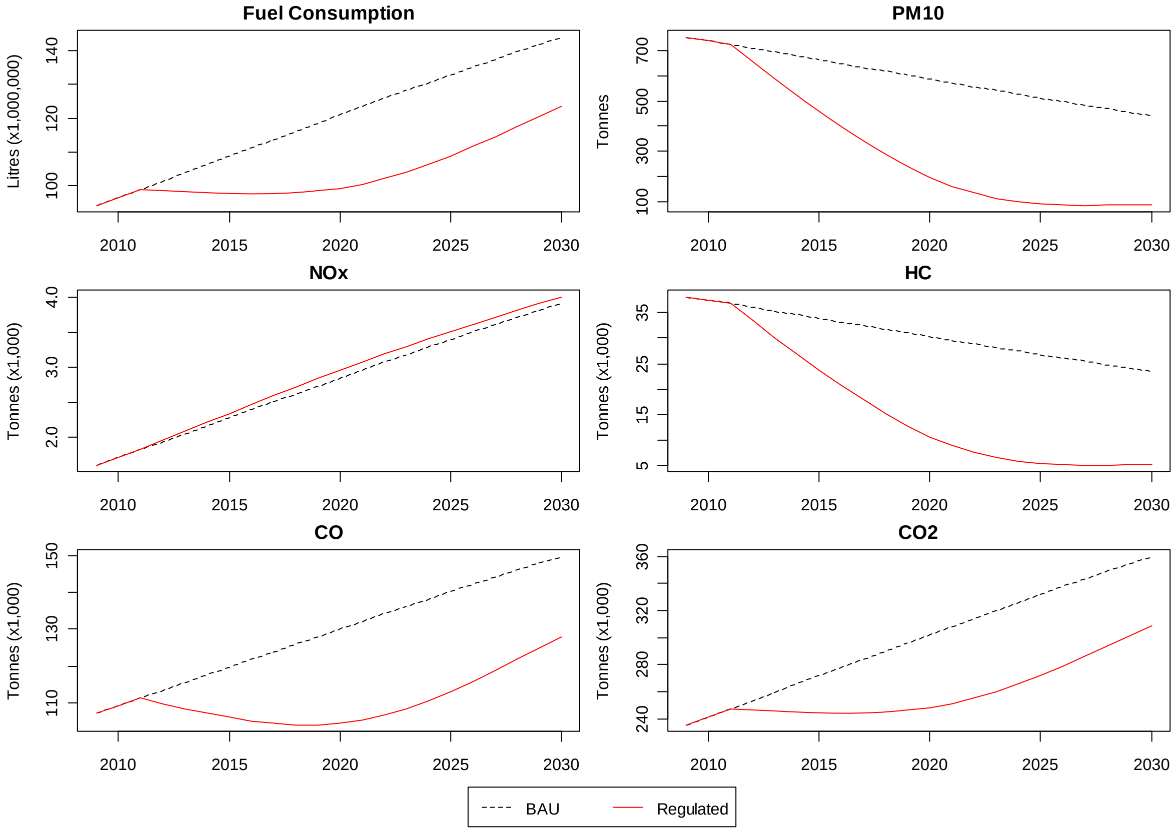


Figure 4-4 Outboard engines fuel consumption and emissions, scenario OB-1



4.1.2 Scenario OB-2

Figure 4-5 Outboard engines service costs and expenditure, scenario OB-2

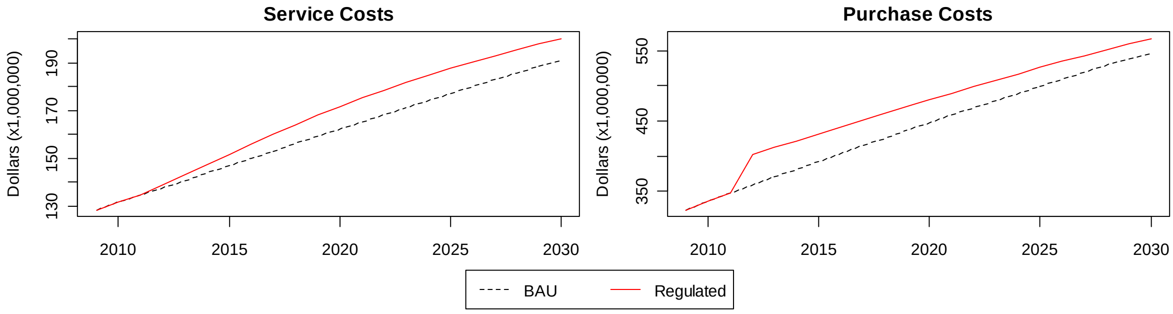
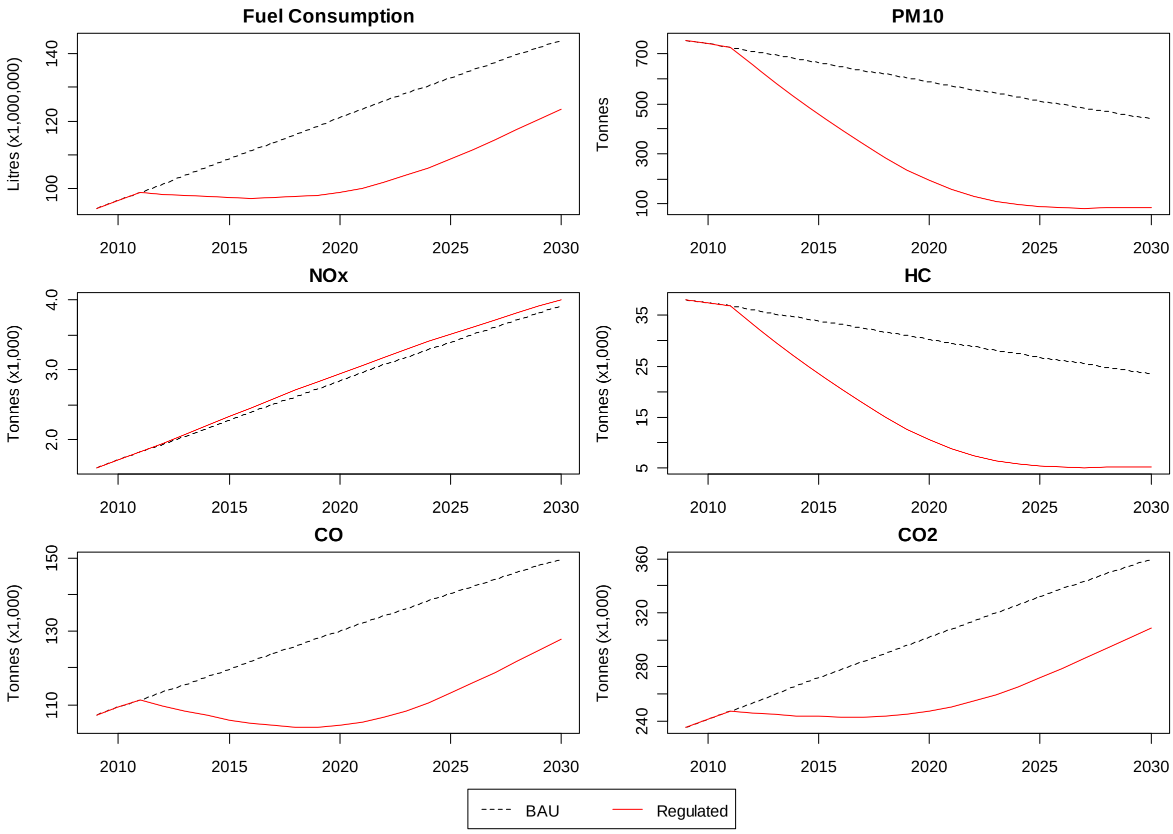


Figure 4-6 Outboard engines fuel consumption and emissions, scenario OB-2



4.1.3 Scenario OB-3

Figure 4-7 Outboard engines service costs and expenditure, scenario OB-3

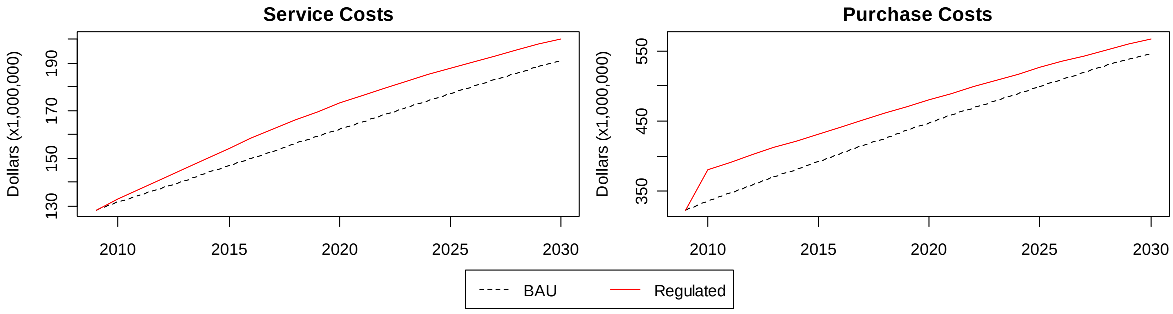
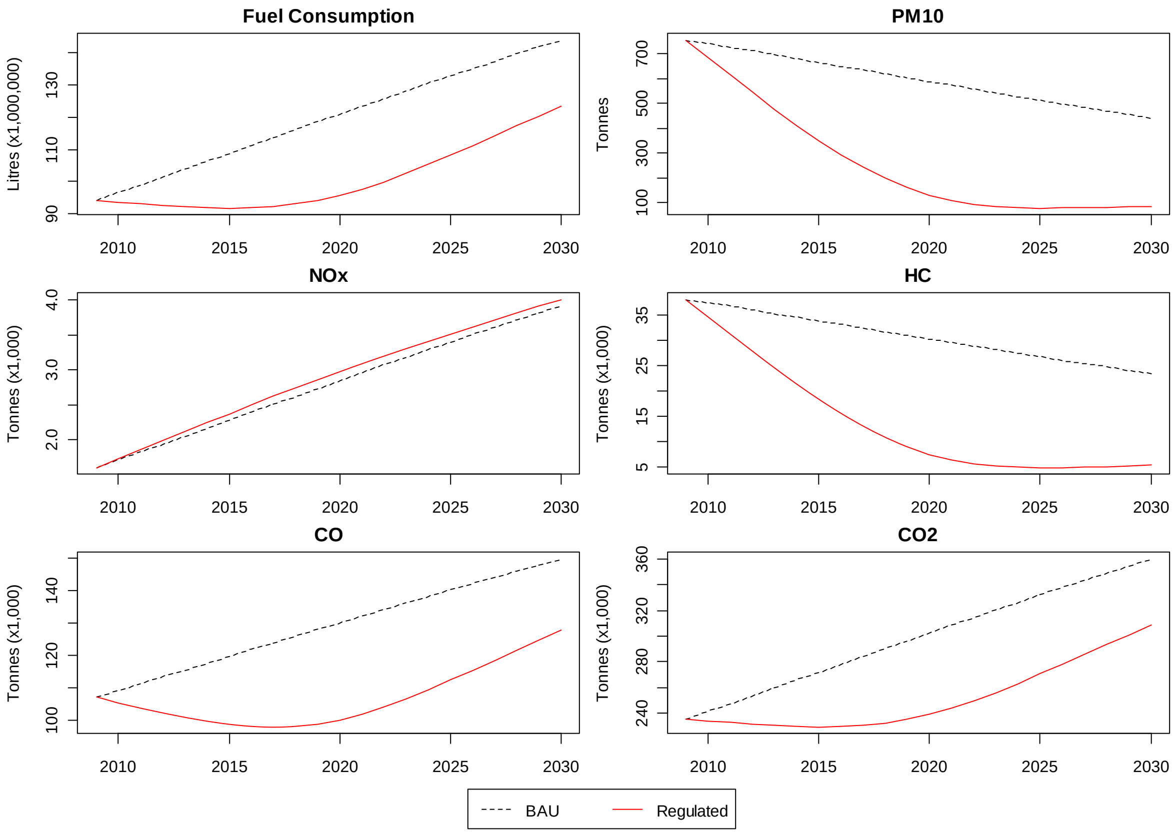


Figure 4-8 Outboard engines fuel consumption and emissions, scenario OB-3



4.1.4 Scenario OB-4

Figure 4-9 Outboard engines service costs and expenditure, scenario OB-4

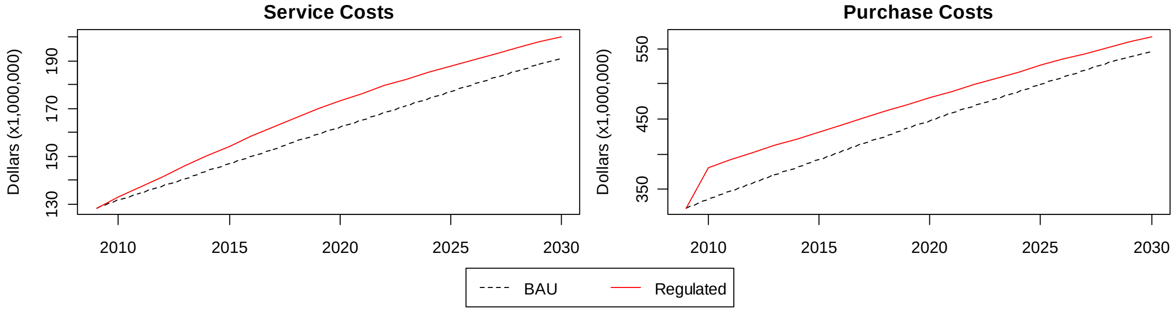
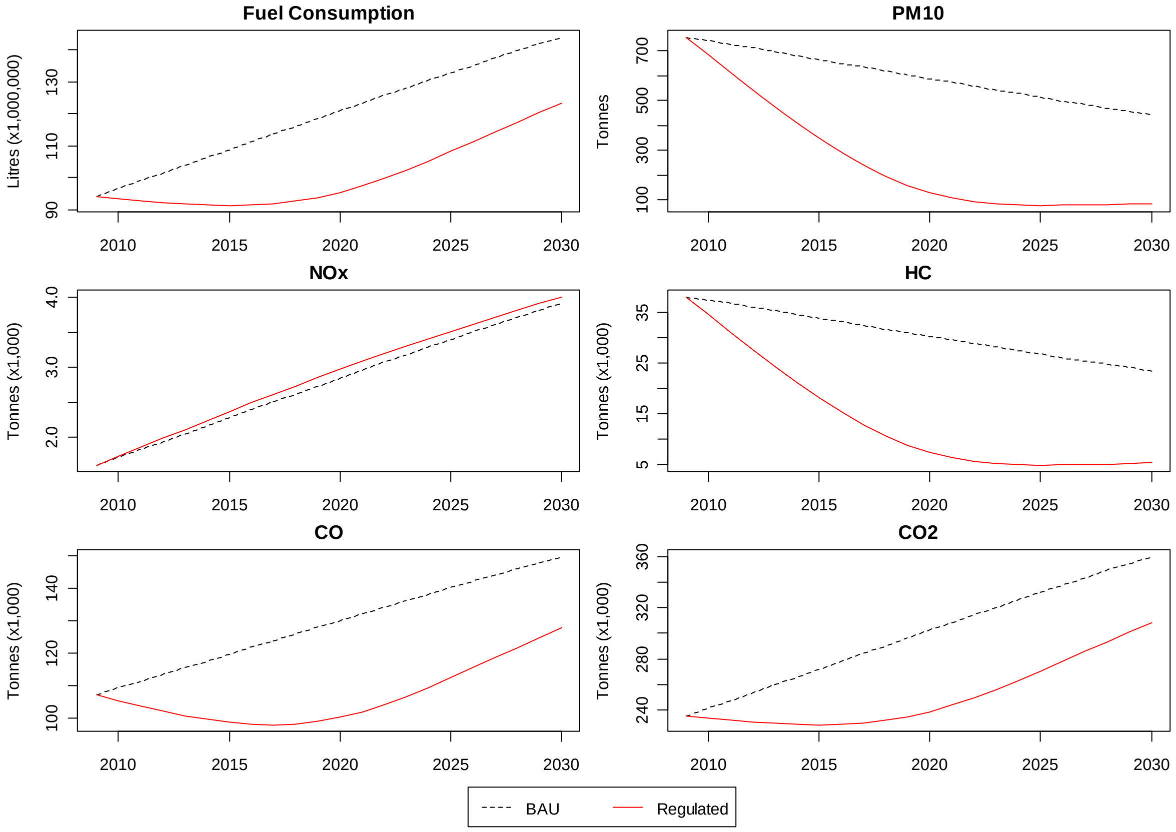


Figure 4-10 Outboard engines fuel consumption and emissions, scenario OB-4



4.1.5 Scenario IA-1

Figure 4-11 Outboard engines service costs and expenditure, scenario IA-1 (2008 AU$)

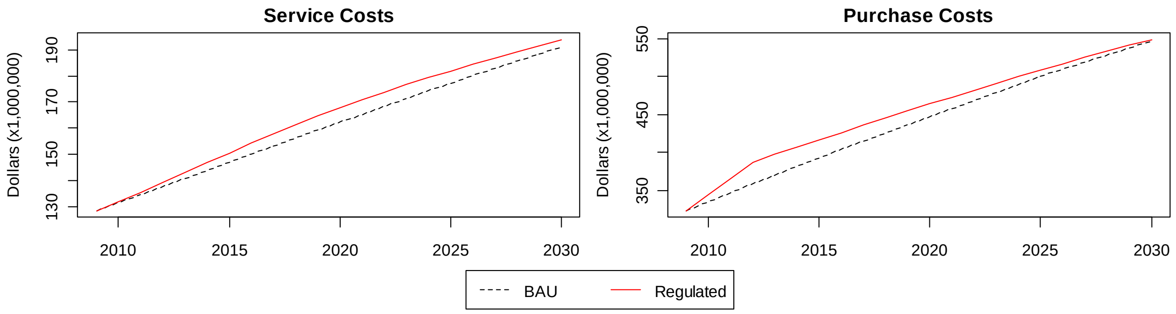
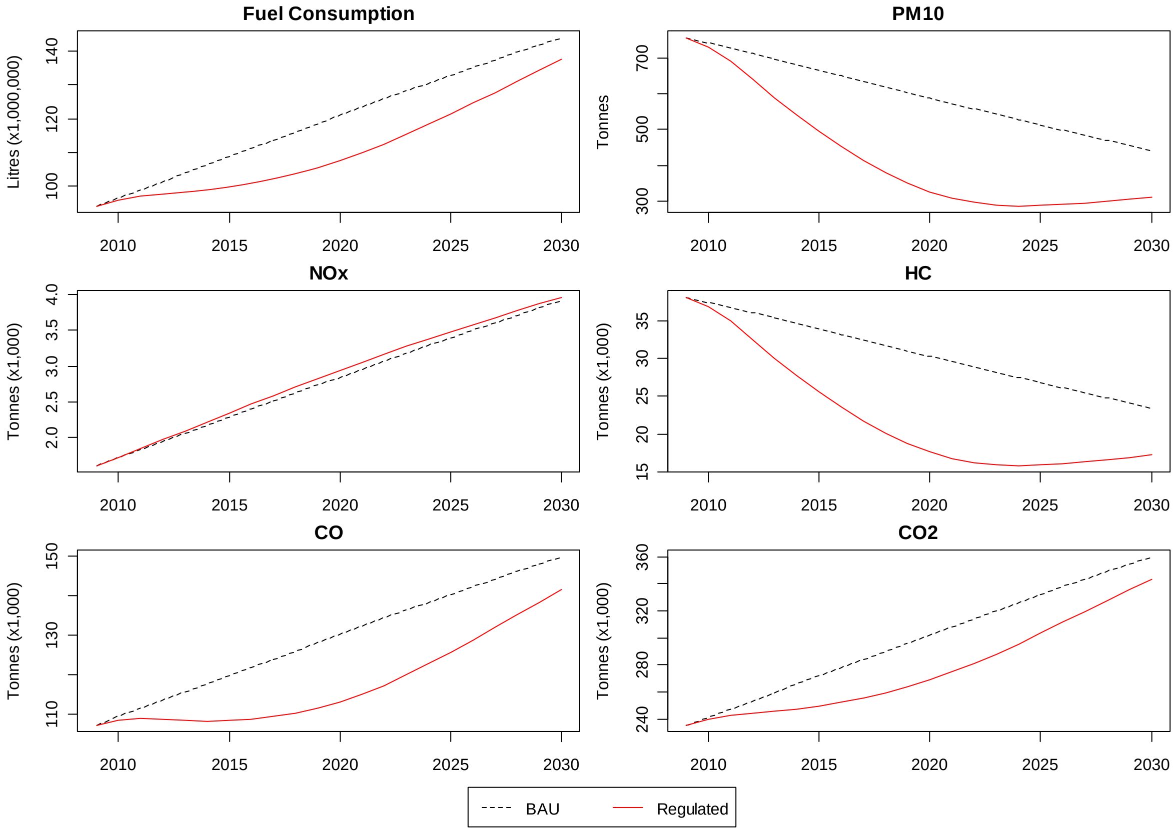


Figure 4-12 Outboard engines fuel consumption and emissions, scenario IA-1



4.1.6 Scenario IA-2

Figure 4-13 Outboard engines service costs and expenditure, scenario IA-2 (2008 AU$)

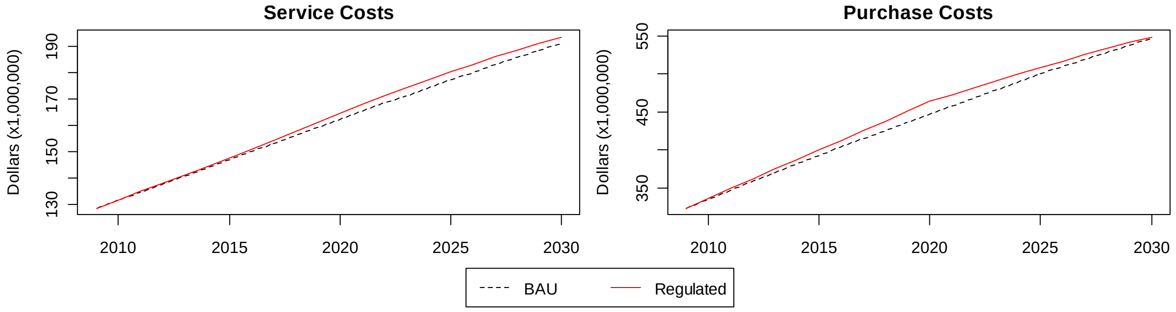
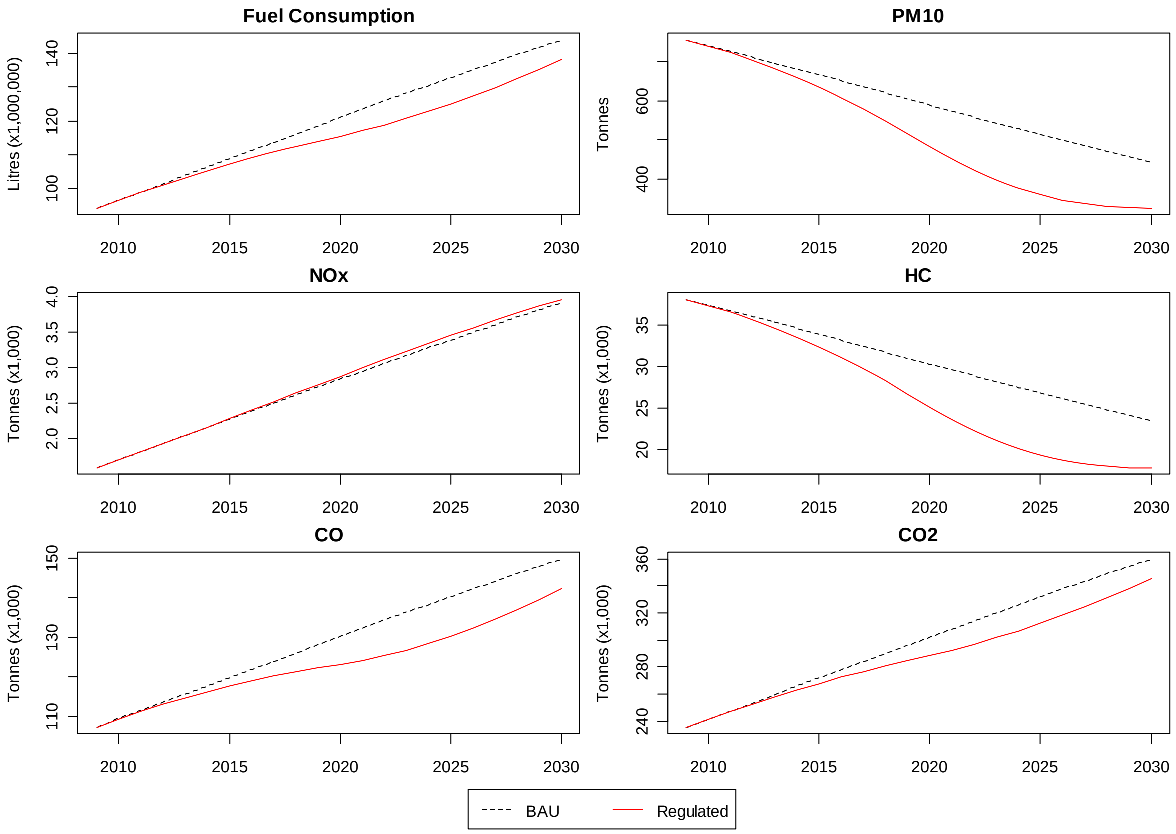


Figure 4-14 Outboard engines fuel consumption and emissions, scenario IA-2

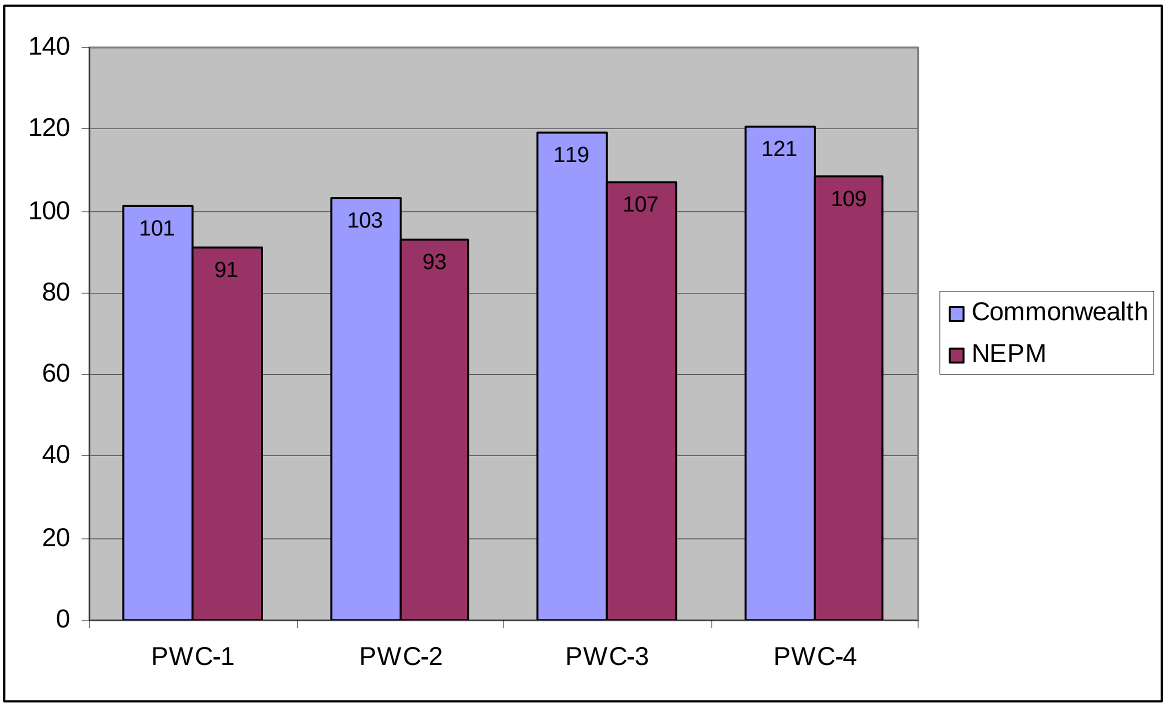


4.2 Personal Watercraft

This section reports the results of our modelling for personal watercraft emissions restrictions. The net present value (NPV) benefits from the Commonwealth regulation and NEPM policy options (Scenarios PWC-1 to PWC-4), are shown in Figure 4-15.

Sections 4.2.1 to 4.2.4 below, present our results for each of the PWC-1 to PWC-4 scenarios. For each of the scenarios we provide graphs showing the service costs and expenditure of personal watercraft (PWC) over the years to 2030, from the business as usual and the regulated scenarios. Fuel consumption and emissions for PWC are also reported for each of the scenarios modelled. Please note that the NEPM scenarios are identical to the Commonwealth regulation scenarios except for an applied discount of 10% to account for the likely delay in effective implementation under the NEPM option.

Figure 4-15 NPV of benefits from PWC emissions restrictions, scenarios PWC-1 to PWC-4, NEPM PWC-1 to NEPM PWC-4 (2008 AU$ million)



4.2.1 Scenario PWC-1

Figure 4-16 PWC engines service costs and expenditure, scenario PWC-1 (2008 AU$)

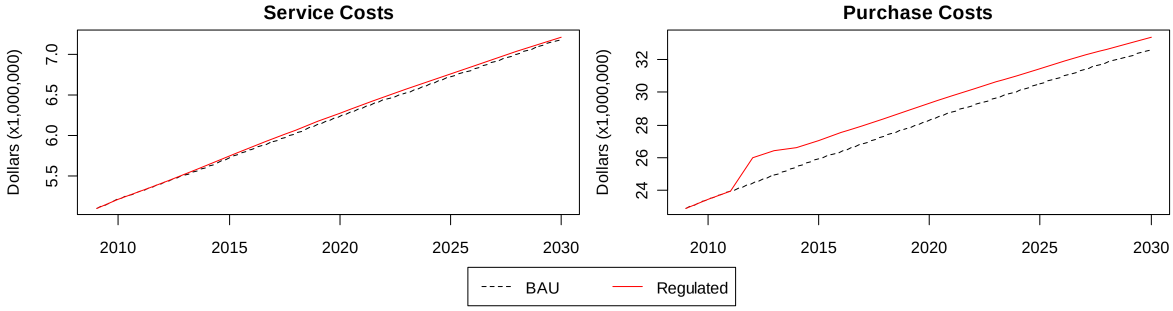
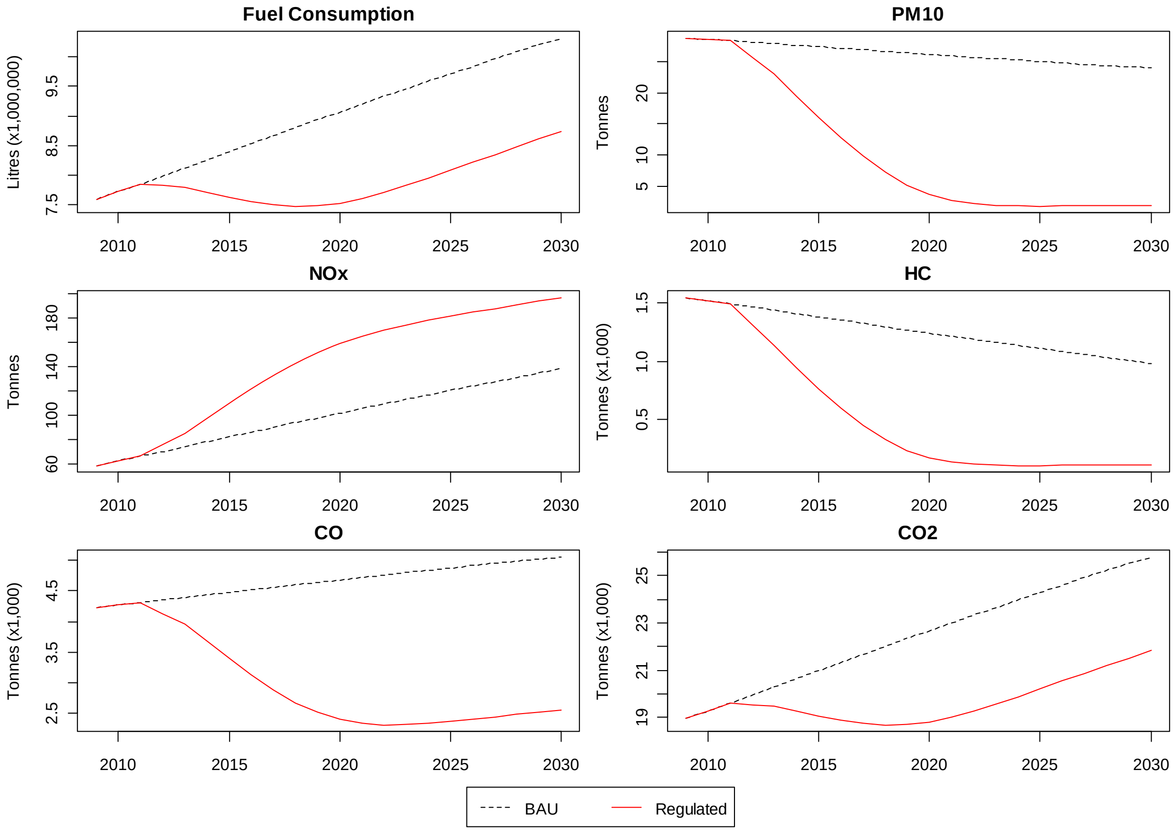


Figure 4-17 PWC engines fuel consumption and emissions, scenario PWC-1



4.2.2 Scenario PWC-2

Figure 4-18 PWC engines service costs and expenditure, scenario PWC-2 (2008 AU$)

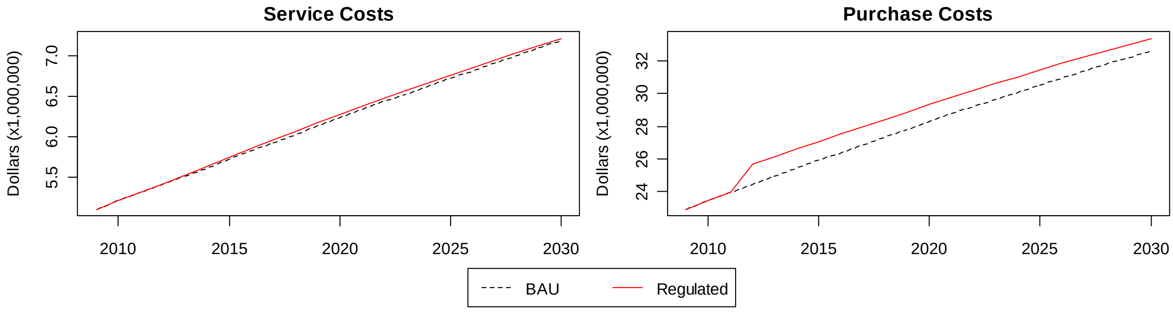
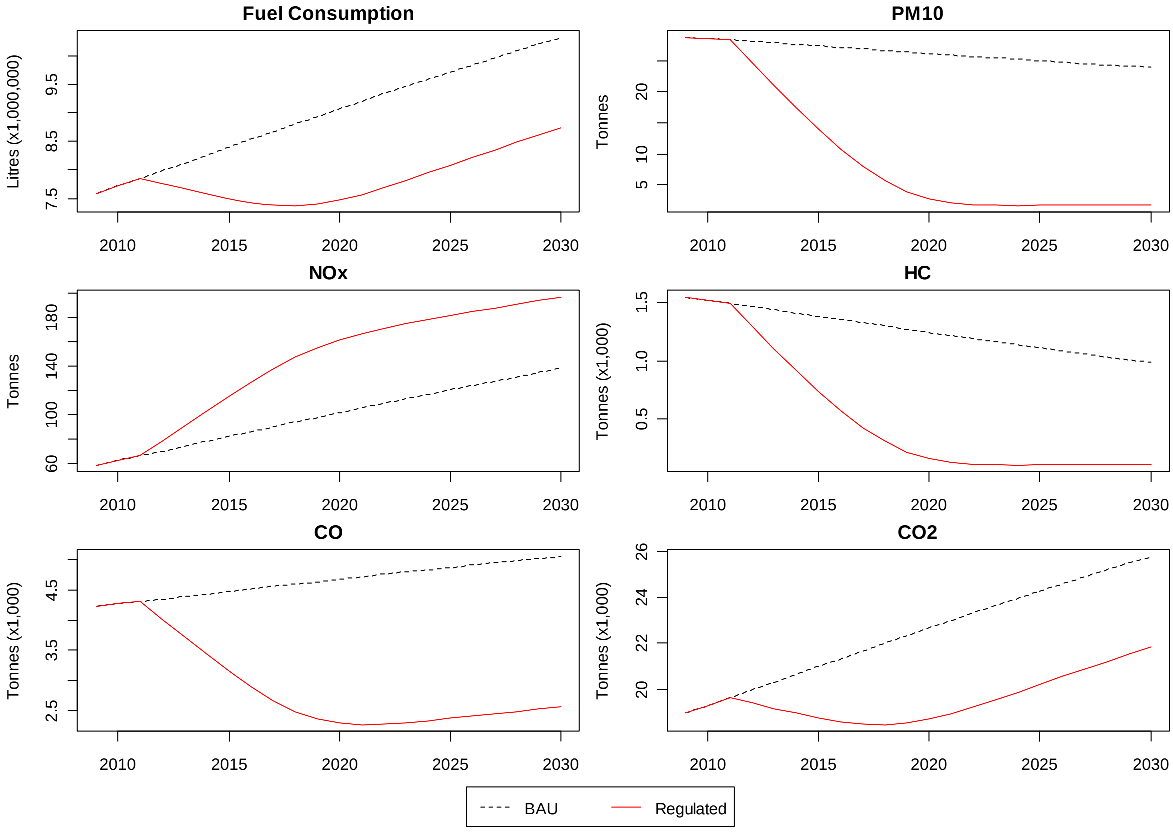


Figure 4-19 PWC engines fuel consumption and emissions, scenario PWC-2



4.2.3 Scenario PWC-3

Figure 4-20 PWC engines service costs and expenditure, scenario PWC-3 (2008 AU$)

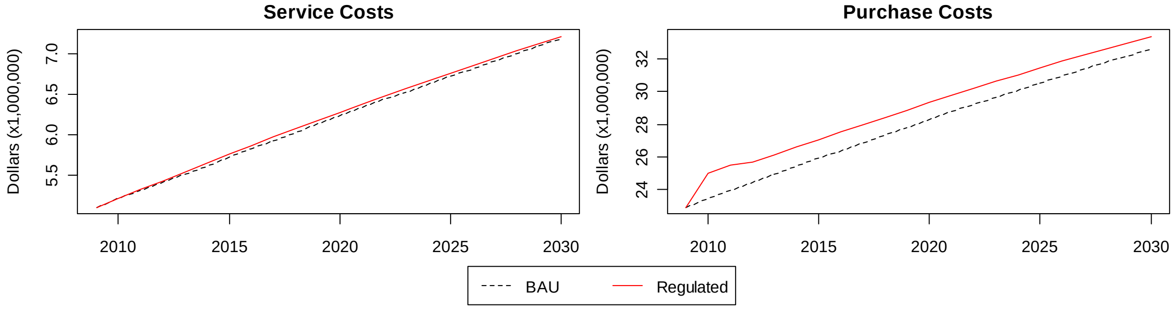
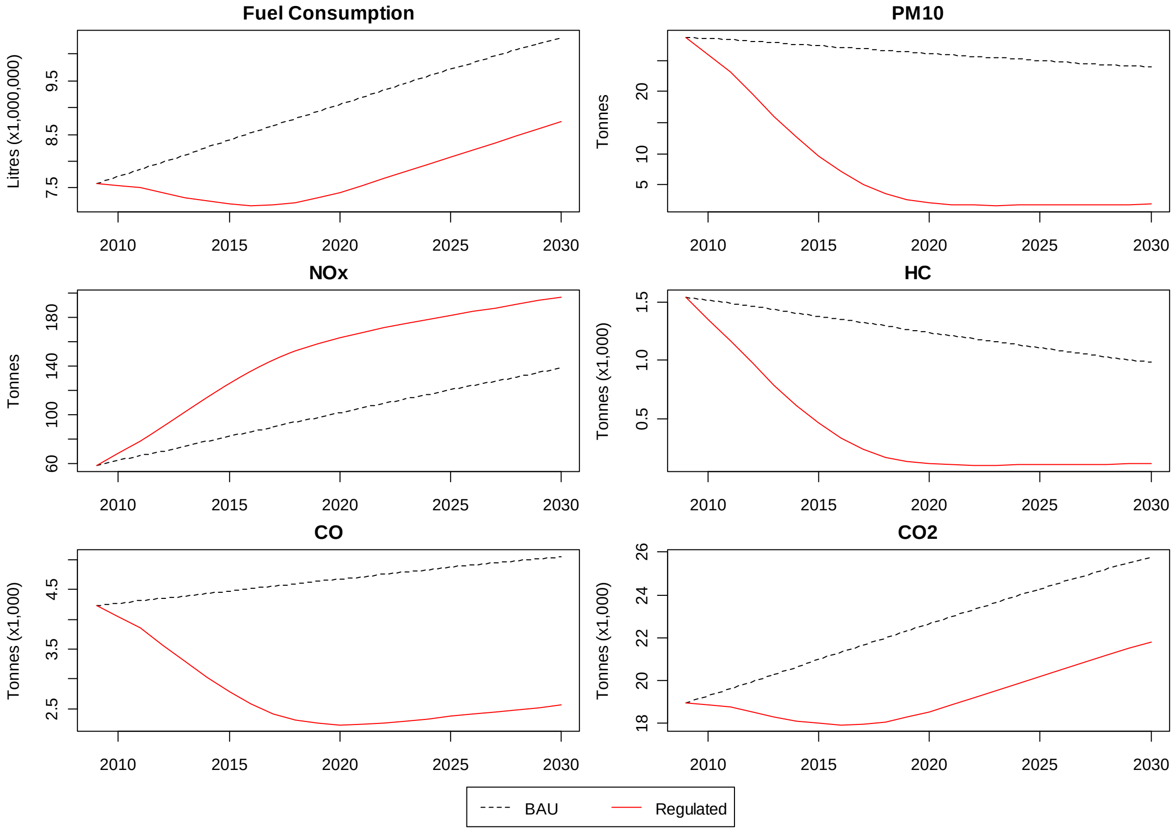


Figure 4-21 PWC engines fuel consumption and emissions, scenario PWC-3



4.2.4 Scenario PWC-4

Figure 4-22 PWC engines service costs and expenditure, scenario PWC-4 (2008 AU$)

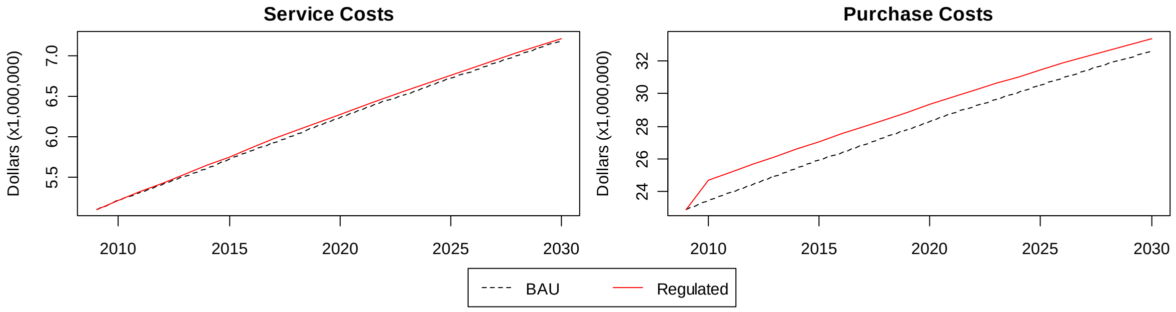
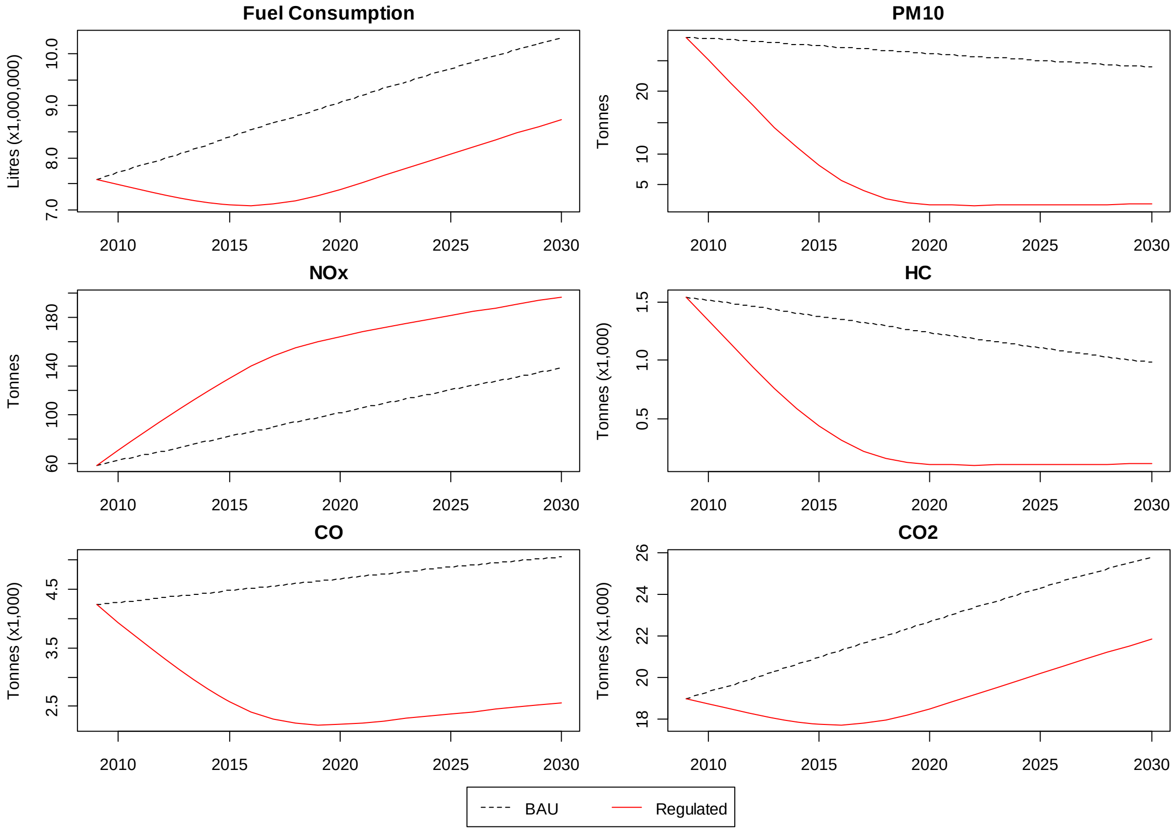


Figure 4-23 PWC engines fuel consumption and emissions, scenario PWC-4

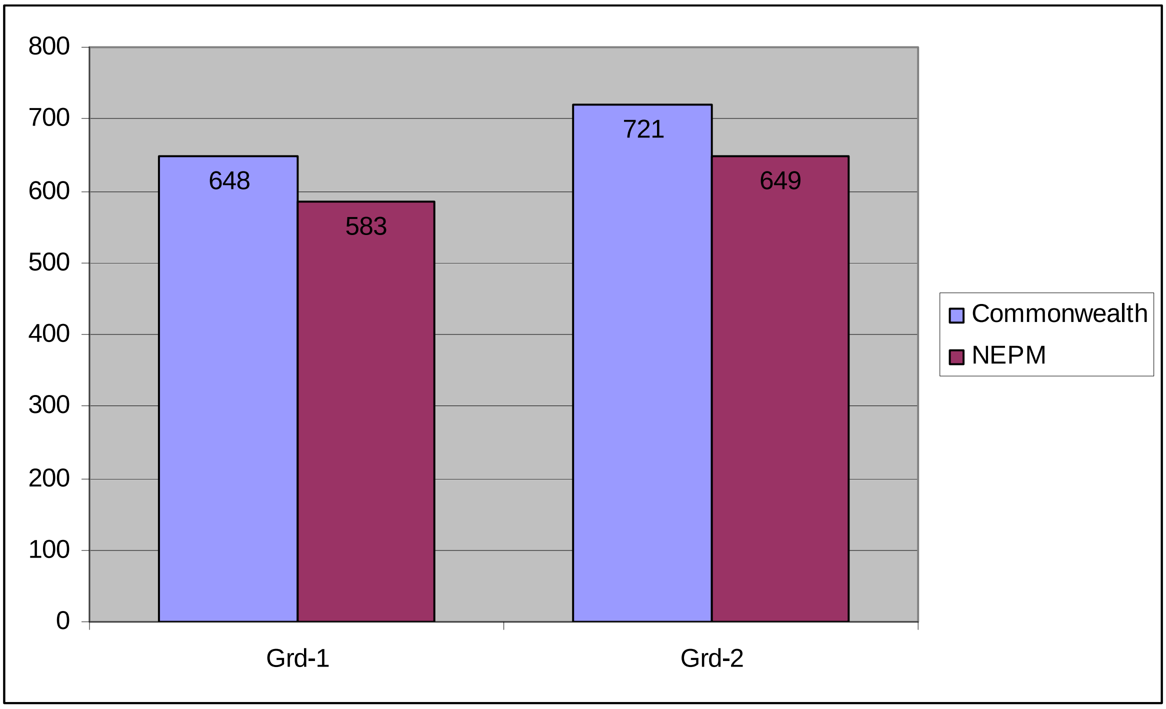


4.3 Gardening equipment

This section reports the results of our modelling for gardening equipment emissions restrictions. The net present value (NPV) benefits from the Commonwealth regulation and NEPM policy options (Scenarios Grd-1 and Grd-2), are shown in Figure 4-24.

Sections 4.3.1 and 4.3.2 below, present our results for the Grd-1 and Grd-2 scenarios respectively. For each of the scenarios we provide graphs showing the gardening equipment sector (lawn mowers, trimmer, brushcutters and hand held blowers only) service costs and expenditure over the years to 2030, from the business as usual scenario and the regulated scenarios. Gardening equipment fuel consumption and emissions are also reported for each of the scenarios modelled. Please note that the NEPM scenarios are identical to the Commonwealth regulation scenarios except for an applied discount of 10% to account for the likely delay in effective implementation under the NEPM option.

Figure 4-24 NPV of benefits from gardening equipment emissions restrictions, scenarios Grd-1 and Grd-2 (2008 AU$ million)



4.3.1 Scenario Grd-1

Figure 4-25 Gardening equipment engines service costs and expenditure, scenario Grd-1 (2008 AU$)

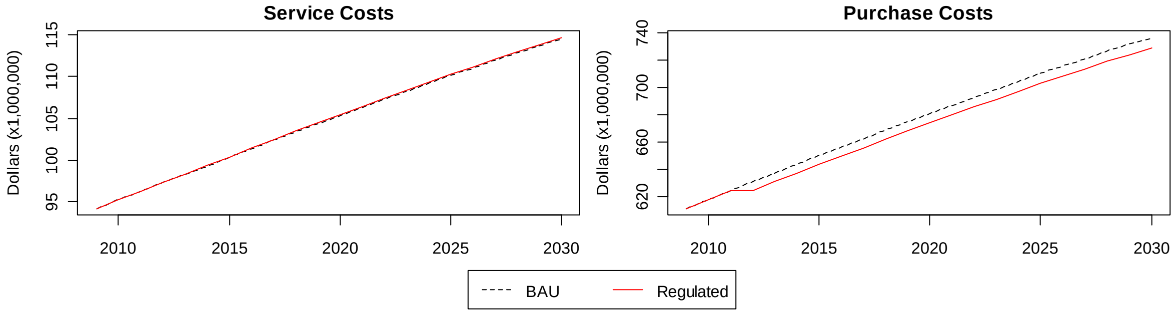
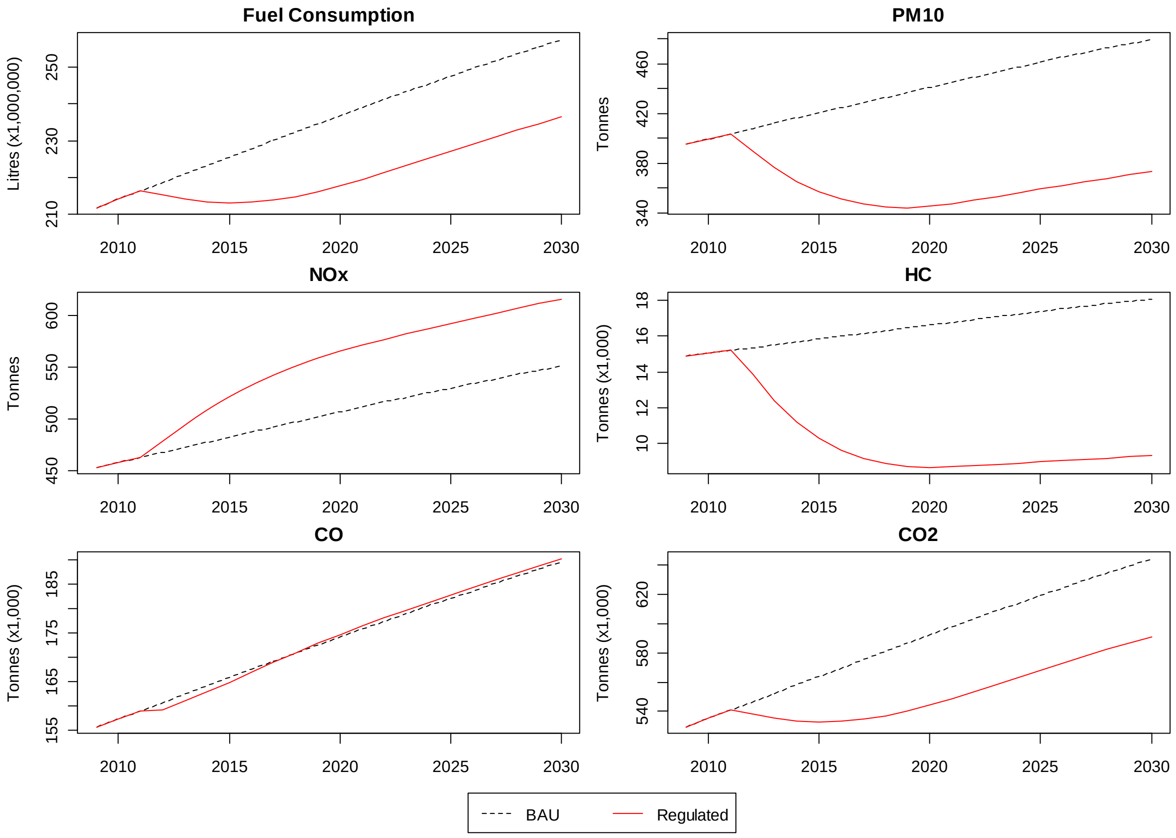


Figure 4-26 Gardening equipment engines fuel consumption and emissions, scenario Grd-1



4.3.2 Scenario Grd-2

Figure 4-27 Gardening equipment engines service costs and expenditure, scenario Grd-2 (2008 AU$)

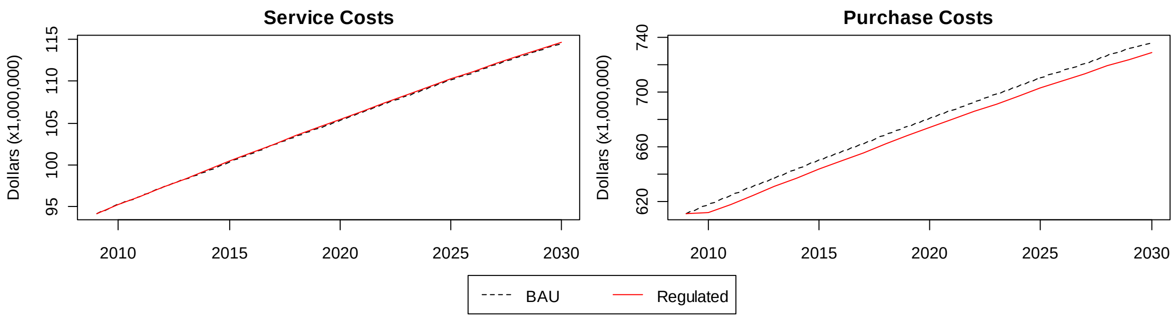
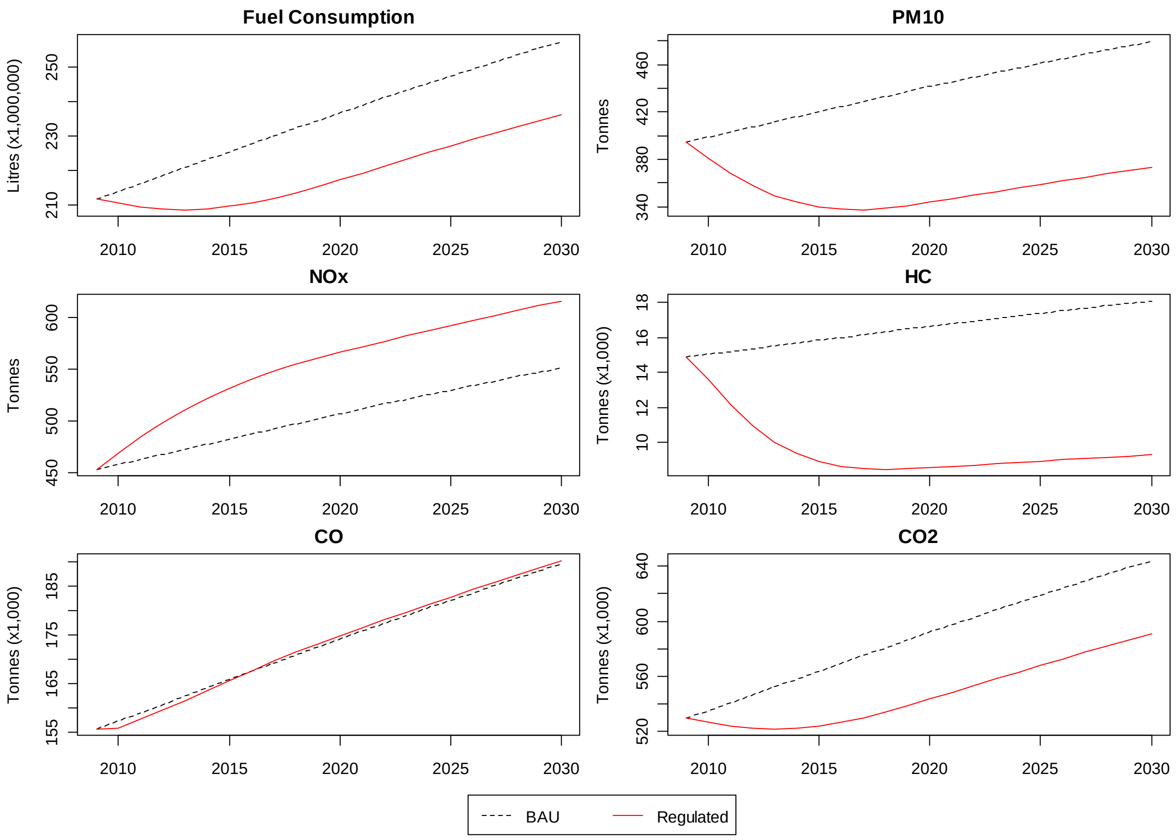


Figure 4-28 Gardening equipment engines fuel consumption and emissions, scenario Grd-2



4.4 Representative single engine analysis

The estimates provided throughout this report are aggregated at the level of sectors (marine outboard, personal watercraft and gardening equipment). While this provides an indication of the externalities that must be associated with each engine sold and used, it does not provide a direct estimate of the magnitude of externalities associated with single engines. This section aims to fill this gap.

To provide an overview of the single engine externalities, the analysis is undertaken on the basis of a 'representative' single engine for each of the marine sectors (outboard motors and personal watercraft) as well as for the gardening equipment sectors modelled (lawn mowers, brushcutters, trimmers and hand held blowers).

4.4.1 Marine sector representative single engine analysis

For the marine sectors, the representative non-compliant engine is constructed using the average emissions from all non-compliant engines in the pool of engines present in our dataset. Similarly, the compliant representative engine is constructed using the average emissions from all compliant engines in the same dataset. The externality associated with emissions from each of the compliant and non-compliant engines are reported in Table 4-3 for outboards and in Table 4-4 for personal watercraft. These tables also provide a column estimating the social cost of equipment (the recommended retail price plus the NPV of the air pollution costs for the different air pollution estimates reported in Section 3.5).

Table 4-3 Net present value of externality associated with lifetime emissions from representative compliant and non-compliant outboard engines, (2008 AU$)

	Non-compliant with any US standard (rrp $7,952)		Compliant with 2009 US standard (rrp $11,010)	
Study	**Externality**	**rrp+ext**	**Externality**	**rrp+ext**
EC composite	11,010	18,962	1,889	12,899
EC land -high	14,846	22,798	2,607	13,617
EC land - low	5,092	13,044	933	11,944
EC sea - high	10,402	18,354	1,652	12,662
EC sea - low	3,587	11,539	585	11,595
BTRE - high	11,869	19,821	469	11,480
BTRE - medium	8,416	16,368	333	11,343
BTRE - low	4,985	12,937	197	11,207
VTPI - high	33,711	41,663	3,919	14,929
VTPI - medium	21,092	29,044	2,597	13,607
VTPI - low	8,472	16,424	1,275	12,285

Table 4-4 Net present value of externality associated with lifetime emissions from representative compliant and non-compliant PWCs, (2008 AU$)

	Non-compliant (rrp $16,275)		Compliant (rrp $16,765)	
Study	**Externality**	**rrp+ext**	**Externality**	**rrp+ext**
EC composite	10,720	26,995	3,644	20,408
EC land -high	14,555	30,829	5,104	21,869
EC land - low	5,039	21,314	1,852	18,617
EC sea - high	9,923	26,198	3,041	19,806
EC sea - low	3,443	19,717	1,092	17,856
BTRE - high	10,241	26,515	617	17,382
BTRE - medium	7,261	23,536	438	17,202
BTRE - low	4,301	20,575	259	17,024
VTPI - high	30,015	46,289	5,609	22,374
VTPI - medium	18,955	35,230	3,886	20,650
VTPI - low	7,895	24,170	2,163	18,927

What is striking about this single engine representation is how high the externalities from non-compliant engines are. Using our best estimate the difference in externality between the compliant and non-compliant engines is over $9,000 per outboard engine and nearly $7,000 per personal watercraft.[29] This is highly significant because the average compliant outboard engines only cost around $3,000 more than the non-compliant ones and there is very little difference in the price of PWCs. This means that when externalities are accounted for, the social cost of non-compliant outboard engines exceeds that of compliant engines by over $6,000 but the private cost is $3000 less. This provides a highly distorted price signal to the outboard engine market and encourages socially inefficient market outcomes. Similarly, the social cost of non-compliant PWC is about $6,500 higher than the social cost of compliant PWCs but the private cost is $500 lower for non-compliant engines. Again, this provides a massive distortion in favour of non-compliant engines in the PWC market.

Even for the compliant engines, the externality is around 15 per cent of the recommended retail price of outboard engines and PWCs. Thus, while emissions restrictions significantly ameliorate the situation, market prices remain sizeably distorted from a social perspective, even after the adoption of emissions restrictions. To ensure economic efficiency the first best solution would be to impose an externality charge. If externalities were able to be measured accurately and appropriate externality charges imposed, there would be no need for emissions restrictions. However, given that the externalities are extremely difficult to estimate and that a conservative approach to estimating them tends

---

29 It is important to bear in mind that the estimated externalities are conservative in that they only account for direct health costs and forgone income from any loss of life associated with three pollutants (PM_{10}, NOx and HC), see Section 3.5)

to be chosen, a minimum standard can exclude the worst polluting engines, while a pollution charge could help reduce distortions in the remaining market.

4.4.2 Gardening equipment representative single engine analysis

The gardening sector single engine analysis is somewhat different to the analysis undertaken for the marine sectors above. This is because, due to data limitations, we were unable to estimate emissions for compliant and non-compliant engines separately. Instead we relied on average emissions from all engines (compliant and non-compliant ones) without regulation and compared that to the average emissions from engines that comply with phase 2 emissions restrictions. Thus rather than providing the externalities associated with non-compliant engines and compare these with emissions from compliant engines – as was done in the previous section for marine engines – we compare average externalities under no regulation versus average emissions with phase 2 regulation.

Table 4-5 NPV of externality associated with lifetime emissions from average gardening equipment under no regulation and under Phase 2 regulations, (2008 AU$)

			Average engine under no emissions standard		Average engine under US Phase 2 regulation	
Study		Recommended retail price	Externality	Percent of rrp	Externality	Percent of rrp
EC composite	Lawn mower	786	406	52%	318	40%
	Brushcutter	567	163	29%	84	15%
	Trimmer	737	272	37%	129	18%
	Blower	526	314	60%	181	34%
EC land -high	Lawn mower	786	660	84%	523	67%
	Brushcutter	567	264	47%	140	25%
	Trimmer	737	441	60%	218	30%
	Blower	526	511	97%	302	57%
EC land - low	Lawn mower	786	226	29%	181	23%
	Brushcutter	567	91	16%	48	9%
	Trimmer	737	151	20%	75	10%
	Blower	526	175	33%	104	20%
EC sea - high	Lawn mower	786	440	56%	321	41%
	Brushcutter	567	180	32%	78	14%
	Trimmer	737	298	40%	115	16%
	Blower	526	338	64%	167	32%
EC ses - low	Lawn mower	786	152	19%	112	14%
	Brushcutter	567	62	11%	28	5%
	Trimmer	737	103	14%	41	6%
	Blower	526	117	22%	59	11%
VTPI - high	Lawn mower	786	1,275	162%	732	93%
	Brushcutter	567	550	97%	120	21%
	Trimmer	737	899	122%	122	17%
	Blower	526	967	184%	241	46%
VTPI - medium	Lawn mower	786	798	101%	463	59%
	Brushcutter	567	344	61%	76	13%

	Trimmer	737	562	76%	79	11%
	Blower	526	606	115%	154	29%
VTPI - low	Lawn mower	786	321	41%	194	25%
	Brushcutter	567	138	24%	33	6%
	Trimmer	737	225	31%	36	5%
	Blower	526	244	46%	67	13%

For the gardening sector analysis, no data was available on the recommended retail price difference between unregulated and phase 2 compliant engines, since the source for average emissions did not specify the engine makes and models. However, using a stock list provided by DEWHA, it appeared that the compliant engines were of approximately the same cost (or indeed slightly cheaper!). We have therefore assumed that the average recommended retail price is equal for the average unregulated and the average non compliant engines at $786 for lawnmowers, $567 for brushcutters, $737 for trimmers and $526 for blowers.

Using the EC composite to quantify the health costs associated with air pollution, the externalities associated with the average phase 2 compliant engines are approximately half those of the average unregulated engines for brushcutters, trimmers and blowers and about 20% less for lawnmowers (Table 4-5). Phase 3 emissions restrictions can be expected to reduce emissions further but this was not possible to model in this report given the lack of engine specific emissions data for the gardening equipment stock in Australia.

As was the case for the marine engine single engine analysis in the previous section, this analysis highlights the benefits of regulation in terms of reducing the social cost of operating non compliant engines but it also highlights that compliant engines still give rise to substantial external health costs, ranging from 15% to 40% of the recommended retail price under current US phase 2 regulation. This reinforces the finding in the previous section that minimum standards can truncate the worst polluting engines and are therefore necessary, a pollution charge is necessary if distortions in the remaining portion of the market are to be removed.

5 CONCLUSION

The net present value of benefits accounted for in this paper is more than sufficient (by a large margin) to justify the introduction of emissions standards equivalent to those both in force and proposed in the USA. This conclusion holds despite the fact that the analysis undertaken is extremely conservative by taking into account:

- Only the health impacts of avoided emissions of nitrogen oxides, hydrocarbons and particulate matter. Benefits from all other avoided emissions are ignored.
- Only direct health costs and lost income are considered. They ignore non-monetary losses in welfare associated with illness and the loss of life.
- Other water and noise pollution related damages are ignored.
- At every point where an assumption had to be made in the modelling, the assumption that would result in the least reduction from the BAU case was chosen.

For the small non-road engines, the estimated benefits from regulation are further reduced due to data limitations. In the small-non road engine sector, only a subset of gardening equipment (namely lawn mowers, trimmers, hand held blowers and brushcutters) has been taken into account, significantly underestimating the number of engines sold and in use. Furthermore, only the benefits from adopting Phase 2 emissions standards was taken into account for the gardening equipment sector, ignoring benefits from the adoption of Phase 3 standards. The effect of including the phase 3 standards has the potential to double the figure arrived at in this analysis.[30]

The justification for providing very conservative estimates of the benefits from adopting US emissions standards is that it leaves the conclusion beyond doubt – adopting US emissions standards for small non-road, outboard and PWC engines is likely to provide billions of dollars of net benefits to the community.

Bearing in mind that enacting and implementing legislation takes time, the earlier the limits can be implemented, the greater the benefits that will be realised. Our estimates suggest that bringing forward the start date of regulation by two years can provide additional NPV benefits of over $500 million. Indeed, the earlier the start date the higher the NPV benefits because each non compliant engine sold prior to regulation has more costs than benefits associated with it. The implementation of legislation is subject to statutory processes, so it cannot be introduced instantaneously but our estimates show that there are significant benefits from acting as quickly as possible.

The analysis also shows that there are benefits from the 'non-phased' approaches, where US standards are applied in Australia without a lag between the introduction of more

[30] US EPA estimated that a move from Phase 2 to Phase 3 emission standards would provide net benefits of about $1.3 billion *per year* by 2030 (in 2005 US$). Adjusting for the higher population in the USA, this same move is likely to provide in the order of AU$90 million *per year* by 2030 in Australia.

stringent standards in the US and their adoption in Australia. Our estimates suggest additional gains from non-phased approaches of in the order of $20 million in NPV terms. However, this is likely to under estimate the benefits from adopting US emissions limits as soon as they are adopted in the US because our modelling ignored the move to US Phase 3 emissions restrictions for the gardening equipment sector and because there is a risk that a phased approach may invite producers to 'dump' engines that comply with current US emissions standards but not with new ones in the period when Australian standards lag behind the US ones.

Of the three policy options suggested, the Commonwealth Government regulation option stands out as the preferred option as it gives rise to around $300 million of additional NPV as compared to the NEPM option (this does not take into account the higher scheme implementation and administration costs from the NEPM option and is based on a conservative estimate of the likely delay, one to two years, in implementing legislation in all States and Territories as compared to the Commonwealth implementing it). The Commonwealth regulation option also offers in the order of one to two billion dollars of additional benefits from restricting emissions in the marine outboard sector when compared to the industry agreement.

The voluntary industry agreement is the least effective of the three policy options, largely because it provides less stringent standards by still allowing outboard engines to be sold that are not compliant with US standards. Industry has also indicated that it will not be enforceable since importers could simply ignore any industry standards. Indeed, even if the analysis results had shown larger net benefits from the industry agreement option, strong doubts about the merits of its implementation would have remained. Significant parts of the outboard industry do not consider it to be a viable option, and an industry agreement will only work if it receives strong support from industry.

The National Environment Protection Measure option is formulated to achieve the same standards as the Commonwealth regulation option. However, it suffers from requiring legislation to be implemented in each state and territory, thereby adding to the implementation cost. Under this option, greater compliance costs are also imposed on industry which has to operate across jurisdictions and comply with different jurisdictional requirements.

Furthermore, implementing the legislation through a NEPM may delay the starting date for emissions restrictions. Mutual Recognition Agreement (MRA) legislation allows goods sold legally in one state or territory to be sold in any other state or territory. Accordingly, the start date for all jurisdictions will be determined by the last jurisdiction to implement the NEPM. In making the NEPM, jurisdictions can set an implementation deadline that all agree to meet. While a deadline provides an effective implementation date, the agreed length of time for the deadline may be influenced, and hence delayed, by states or territories with less of a perceived need to act, or by the different processes for enacting legislation in the respective jurisdictions.

Overall, MMA concludes that of the policy options considered in this analysis, adopting the US emissions limits in Australia through Commonwealth regulation, as soon as practicable and without phasing is likely to yield the greatest net benefits.

6 REFERENCES

ABS 2006a, *Australian Bureau of Statistics, Population Projections for Australia,* Cat. No. 3222.0.

ABS 2006b, *Australian Bureau of Statistics,* Cat. No. 3105.0.65.001, Table 1: Australian Historical Population Statistics.

BTRE 2003, *Urban Pollutant Emissions from Motor Vehicles*: Australian Trends to 2020.

BTRE 2005, *Health impacts of transport emissions in Australia*: Economic costs, BTRE working paper 63.

DEWR 2007a, *Department of the Environment and Water Resources, Comparative Assessment of the Environmental Performance of Small Engines*: Marine Outboards and Personal Watercraft.

DEWR 2007b, *Department of the Environment and Water Resources*, *Comparative Assessment of the Environmental Performance of Small Engines:* Outdoor Garden Equipment.

EC 2005, *Damages per tonne emission of PM2.5, NH3, SO2, NOx and VOCs from each EU25 Member State (excluding Cyprus) and surrounding seas*, Service Contract for carrying out cost-benefit analysis of air quality related issues, in particular in the clean air for Europe (CAFE) programme.

Environment Australia 2004, *NPI Definition for Volatile Organic Compounds* - Version 2.4 - 23 March 2004. Source: http://www.npi.gov.au/handbooks/pubs/voc.pdf

Fisher GW, Rolfe KA, Kjellstrom T, Woodward A, Hales S, Sturman AP, Kingham S, Petersen J, Shrestha R, King D 2002, *Health effects due to motor vehicle air pollution in New Zealand, a report submitted to the Ministry of Transport,* Wellington, New Zealand.

Guenther et al. 1995, *A global model of natural volatile organic compound emissions*, *J. Geophys. Res.*, 100:8873-8892, Guenther, A., C. N. Hewitt, D. Erickson, R. Fall, C. Geron, T. Graedel, P. Harley, L. Klinger, M. Lerdau, W. A. McKay, T. Pierce, B. Scholes, R. Steinbrecher, R. Tallamraju, J. Taylor, and P. Zimmerman. US EPA 2004, 40 CFR Part 51 Section 51.100 Definitions, Effective as of December 29, 2004 *(based on final rules to date)*

Künzli N, Kaiser R, Medina S, Studnicka M, Chanel O, Filliger P, Herry M, Horak F Jr, Puybonnieux-Texier V, Quenel P, Schneider J, Seethaler R, Vergnaud JC, Sommer H 2000, 'Public health impact of outdoor and traffic related air pollution: a European assessment', *The Lancet*, vol. 356, pp. 795–801.

PAE 2005, *Management options for non-road engine emissions in urban areas*. Unpublished report to the Department of the Environment and Water Resources.

PAE 2007, *Non-Road Engine Emissions Inventory Source Contribution Review, Department of the Environment and Water Resources.*

US EPA 1995, AP-42, Fifth Edition, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Point and Area.* Source: http://www.epa.gov/ttn/chief/ap42/index.html

US EPA 2005a, *United States Environmental Protection Agency*, *Exhaust Emission Factors for Non-road Engine Modelling*: Spark-Ignition.

US EPA 2005b, *United States Environmental Protection Agency, Non-road Spark Ignition Engine Emission Deterioration Factors*.

US EPA 2007, *United States Environmental Protection Agency, Control of Emissions from Marine SI and Small SI Engines*, Vessels, and Equipment: Draft Regulatory Impact Analysis.

VTPI 2006, *Transportation Cost Benefit Analysis*, chapter 5.1, air pollution. Source: http://www.vtpi.org/tca/

Yienger et al. 1995, *Empirical model of global soil-biogenic NO_X emissions*, J. Geophys. Res., 100, D6, 11447-11464, Yienger J. J. and H. Levy II.