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Policies to Reduce Harmful Emissions from Vehicles: *Costs and Benefits*

Prepared for

Ministry of Transport

economics | research | forecasting | public policy

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Policy Summary

Background

This report examines the costs and benefits of a small number of policy instruments that can reduce the health effects of particulate emissions from vehicles. It focuses on the most problematic locations and sources of pollution: fine particulates (PM_{10})[1] from diesel vehicles in Auckland.

A larger number of policy options were examined qualitatively (emission standards, emission charges, low emission zones, road pricing, emissions testing, fuel switching and increases in fuel and road user charges), but the detailed analysis was limited to Low Emission Zones (LEZs), regional emissions testing and road pricing.

Approach

Estimates of Costs

The estimated costs of policies include:

- The costs to government of developing and introducing the policy, including legislation;
- The technical requirements, eg the costs for enforcing an LEZ or of vehicle testing, including up-front and on-going costs;
- The costs of the responses by vehicle owners, including the purchase of new vehicles, fitting of retrofit technologies or vehicle repairs.

Estimates of Benefits

(a) Health Outcomes

The following effects were included in the analysis:

- Premature mortality or years of life lost
    - For adults, all ethnicities; and
    - For babies, all ethnicities.
- Morbidity or ill health
    - Respiratory hospital admissions;
    - Cardiac hospital admissions; and
    - Restricted activity days.

(b) Exposure-Response Relationships

The number of avoided cases for each health outcome was calculated from changes in PM_{10} concentrations using the exposure-response relationships as used in the updated

[1] The majority of epidemiological studies to date link adverse health effects with PM10, and it is regarded as the best available summary indicator of air pollution exposure in New Zealand.

Health and Air Pollution in New Zealand study (HAPiNZ update – see Table PS1), combined with data on current rates of mortality at different ages. Because we did not have baseline data for Auckland on hospital admissions, we estimated the impacts on cardiac and respiratory hospital admissions plus restricted activity days using the ratios between these cases and mortality impacts as estimated in the HAPiNZ update study for the Auckland urban airshed (Table PS2).

Table PS1 Exposure Response Functions used in this study

Health Outcome	Exposure Response Functions (Relative risks per 10μg/m³ PM_{10})
1 Premature mortality, all adults, all ethnicities	**1.07**
2 Premature mortality, babies, all ethnicities	**1.05**

Source: Kuschel G *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report

Table PS2 Ratios of cases used to estimate morbidity impacts of cases

Impact	Ratio
Premature mortality (adults)	1
Cardiac admissions (all)	0.222
Respiratory admissions (all)	0.456
Restricted activity days (RADs)	1,705

In addition to impacts on premature mortality (measured using Value of Statistical Life or VoSL), we include an analysis of the effects measured as life years gained (measured using value of life years or VoLY). We use a relatively simple approach that has been used in overseas studies that multiplies the age-specific mortality gain by the expected life expectancy for each age and sex. The values used in analysis are those shown in Table PS3.

Table PS3 Values used in analysis

Factor		Value
Mortality	VoLY	$25,000
	Value of Statistical Life (VoSL)[1]	$3,948,300
Morbidity	Cardiac admission	$6,810
	Respiratory Admission	$4,864
	Restricted activity day	$66

[1] These are not additive to the VoLY-based values

Results and Conclusions

In Table PS4 we show the overall results using our base assumptions (including VoLY-based benefit valuation) and the same assumptions as used in the updated HAPiNZ study. This includes:

- Mortality benefits measured using VoSL;
- No lagged benefits.

Using the HAPiNZ assumptions there are positive net benefits from two Auckland urban airshed LEZ options, plus testing and road pricing, whereas using the base case assumptions (including VoLY), all options have net costs.

Table PS5 Net Present Value of Policy Options – Base Case and HAPiNZ Assumptions (PV - $million)

	CBD & Port		Auckland	
Policy Scenario	**Base Case (VoLY)**	**HAPiNZ (VoSL)**	**Base Case (VoLY)**	**HAPiNZ (VoSL)**
LEZ				
1 Euro II HCV	-$18	-$18	-$63	-$20
2 Euro III HCV	-$26	-$26	-$99	-$6
3 Euro IV HCV	-$39	-$36	-$157	**$33**
4 Euro 2/II LCV&HCV	-$27	-$26	-$79	**$18**
5 Euro 3/III LCV&HCV	-$42	-$41	-$132	-$22
6 Euro 2/II All diesel	-$44	-$43	-$117	-$18
7 Euro 3/III All diesel	-$72	-$70	-$187	-$9
Emissions Testing			-$42	**$91**
Road Pricing			-$9	**$1**

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

The Importance of Assumptions on Benefit Valuation

The analysis suggests that the policy options examined offer positive net benefits only when the benefits are measured using VoSL. The choice of benefit valuation methodology is hugely important.

HAPiNZ used VoSL and we have included results that are consistent with HAPiNZ, but we suggest that there are reasons for changing these assumptions, particularly for policy studies addressing the impacts of **changes** in concentrations rather than the impacts of **absolute** levels. We have included two significant modifications to the HAPiNZ approach that are consistent with approaches being adopted internationally. These are:

- the inclusion of a cessation lag (lagged benefit values), in recognition that the major effects are on chronic mortality and that repairs to health will not happen instantaneously with reductions in concentrations, but rather will emerge over time after living in lower concentrations for several years; and

- the use of changes in life years, valued using VoLY as the primary measure of mortality effect.[2] This is more consistent with the nature of the effect.

[2] A VoLY can be calculated from the VoSL and this results in relatively high benefit values, but we have more confidence in values from studies that have derived VoLYs directly through survey techniques. There is a need for more work on these values in a New Zealand context.

Policy Choices

The analysis suggests that the net benefits (or costs) of the policy options examined to limit emissions in Auckland are highly uncertain. The results depend critically on some key assumptions, particularly the benefit valuation assumptions as discussed above.

LEZs

The costs of LEZs depend on whether the requirements can be met using retrofit technologies or if vehicle owners face the higher costs of vehicle replacement.

There is the potential for positive net benefits for two Auckland urban airshed LEZs, however these options could have very significant net costs if VoLY-based benefit valuation is used. Restricting an LEZ to the CBD & port only has lower risks of high costs. We would not recommend any LEZ is adopted, but if one is experimented with, then minimising costs through focusing on a smaller area and older vehicles (Euro II standard) would be preferable.

Emissions Testing

The costs of emissions testing depend on the costs of the test itself and the number of vehicles that would need to be replaced rather than repaired (because of emission requirements). The benefits are based on vehicles being maintained in a way that would reduce emissions to levels achieved at manufacture, avoiding the deterioration that occurs in the absence of regular servicing and maintenance.

Emissions testing has positive net benefit using a VoSL-based benefit valuation approach. But, even if all other assumptions were favourable there are net costs under VoLY-based benefit valuation assumptions.

Road Charging

Road charging to address congestion has very small positive net benefits when VoSL is used and other favourable assumptions are adopted, such as no benefit lag, but it has net costs using VoLY.

Overall Conclusions

No policy option provides certainty of positive net benefits.

Across the suite of policy options examined the analysis provides insufficient confidence in any of them for positive policy recommendations to be made.

Summary

Background

This report examines the costs and benefits of a small number of policy instruments that can reduce the health effects of particulate emissions from vehicles.

Because these health effects are proportional both to ambient concentrations and the size and vulnerability[3] of the exposed population, the greatest effects of policy are obtained by focussing on areas with higher population densities and higher concentrations of pollutants. Consistent with this, the focus of policy analysis in this study is on the most problematic sources, defined with respect to:

- Location – the main concern is with Auckland;[4]
- Pollutants – fine particulates;[5] and
- Vehicle type – diesel vehicles.[6]

Approach and Key Assumptions

Initial Review of Options

The policy options that were examined qualitatively were emission standards, emission charges, low emission zones, road pricing, emissions testing, fuel switching and increases in fuel and road user charges. To limit the number for more detailed analysis, the focus was restricted to those with most potential for being specified geographically so that they can be introduced in Auckland alone. The main policies with this potential are Low Emission Zones (LEZs), regional emissions testing and road pricing.

The review of international experience with these policies suggests that:

- **LEZs'** effectiveness in limiting air pollution varies with the stringency of the requirements set and the costs are influenced significantly by whether ineligible vehicles can comply using retrofit technologies or if they need to be replaced.

- **Regional emissions testing** with regional emission standards can provide incentives for vehicle maintenance which can arrest the deterioration of engine performance and the increase in emissions with vehicle age that otherwise occurs. The costs include those of the test itself and the responses, which will be a mix of vehicle repair and replacement.

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[3] Lower socioeconomic and susceptible groups with pre-existing lung or heart disease, as well as elderly people and children, are particularly vulnerable

[4] This geographic limitation was defined in the scope for this study provided by MoT and reflecting the results of the HAPiNZ update (Kuschel et al 2012a)

[5] See discussion on page ii (*Pollutants of Interest)*

[6] This vehicle limitation was defined in the scope for this study provided by MoT and reflecting the results of the HAPiNZ update (Kuschel et al 2012a)

- **Road pricing** can have a similar effect to an LEZ if charges vary with emissions. Generalised road pricing, eg charges for access to the Auckland central area, can reduce emission through reducing vehicle kilometres travelled (VKT) and is likely to target older more polluting vehicles because users would be expected to be more responsive to price.

Other policies that can be used but have less potential for geographical-specification include emission standards (currently applying to vehicle entry to the fleet), emission charges (on vehicle licencing/purchase), encouragement of alternative fuels and increases in fuel charges or RUCs. We have not considered these further in this study.

Base Year

The base year for the analysis is 2016, the earliest time any policy might be introduced. We use VKT and emission projections for this year. The exposed population is based on the 2013 census data for individual area units; we do not scale up the population to 2016 as the major health effects are on those who have had long-term exposure so there will be limited impact on those who have moved to Auckland since 2013.

Spatial Boundaries

We used different spatial boundaries for the individual policy measures (Table S1). For the LEZ options, these are to test if there are economies of scale, given some fixed costs. Emissions testing is applied to the region as a whole as a natural boundary for such a policy, although the effects are estimated for the urban airshed. The road pricing analysis is based on existing proposals for a congestion scheme in central Auckland.

Table S1 Geographical areas used in policy analysis

Policy Option	Geographical area
LEZ – CBD and port	Five census area units (CAUs): Auckland Central East, Auckland Central West, Harbourside, Newton and Grafton West
LEZ – Auckland	Auckland urban airshed – the main urban areas of Auckland excluding the rural and coastal towns
Emissions testing	Auckland urban airshed
Road pricing	Central Auckland: includes the CBD & port area plus a further 32 census area units that make up the congestion scheme area

Annex 3 has a more detailed description and full list of census area units (CAUs).

Pollutants of Interest

The analysis is based on fine particulates (PM_{10}) emissions because the majority of epidemiological studies to date link adverse health effects with PM_{10}, and it is regarded as the best available summary indicator of air pollution exposure in New Zealand. While research shows that many of the main health effects attributable to particulates are more likely to be associated with the finer fraction of PM_{10}, such as $PM_{2.5}$, the lack of monitoring data in New Zealand and relevant exposure-response functions makes it difficult to quantify the impacts of smaller fractions robustly. The assessment is therefore based on PM_{10} as used in the HAPiNZ Update 2012.[7]

Other pollutants that have health effects include nitrogen dioxide (NO_2), carbon monoxide (CO) and benzene. However, other analysts have noted that there are insufficient national NO_2 data currently to assess exposure in New Zealand, that there is a risk of double-counting the impacts of CO with the mortality effects of PM_{10} and that benzene is at low levels and has low risks.[8] Not assessing changes in NO_2 exposure does not necessarily mean that the health effects are underestimated in this study, because some of the effects of changes in NO_2 emissions will already be included in the exposure-response relationships for PM_{10}.

Fleet and Emissions Estimates

We use the latest version of the Vehicle Emissions Prediction Model (VEPM 5.1) to predict changes in concentrations. VEPM has been developed by the NZ Transport Agency and Auckland Council to predict emissions from vehicles in the New Zealand fleet under typical road, traffic and operating conditions.[9] We run the Auckland-specific fleet profiles generated from the Auckland Regional Transport Model ART3[10] to derive emission factors for the 2016 base year and for each of the specific policy scenarios. To achieve this, vehicle kilometres travelled (VKT) data generated from the ART3 model were extracted for each CAU to be assessed. The HAPiNZ health effects model[11] was then used to derive annual average PM_{10} concentrations for each CAU in $\mu g/m^3$. The results generated for each scenario are compared with the 2016 base case model for the relevant geographical area (Table S1 above).

The CAU-based assessment method is based on overall population exposure and aggregate effects. This approach may under-estimate the potential benefits of the emissions reduction scenarios where there is a higher population density and higher pollution levels near to roads.

Estimates of Costs

The estimated costs of policies include:

- The costs to government of developing and introducing the policy, including legislation;
- The technical requirements, eg the costs for enforcing an LEZ or of vehicle testing, including up-front and on-going costs;

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[7] Kuschel G et al (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report

[8] Kuschel *et al* (op cit)

[9] http://air.nzta.govt.nz/vehicle-emissions-prediction-model

[10] Auckland Regional Council (2009) Auckland Regional Transport Model Version 3. Auckland Regional Council, July 2009.

[11] Available at www.hapinz.org.nz/

- The costs of the responses by vehicle owners, including the purchase of new vehicles, fitting of retrofit technologies or vehicle repairs.

Estimates of Benefits

(c) Health Outcomes

The following effects were included in the analysis:

- Premature mortality or years of life lost
    - For adults, all ethnicities; and
    - For babies, all ethnicities.

- Morbidity or ill health
    - Respiratory hospital admissions;
    - Cardiac hospital admissions; and
    - Restricted activity days.

(d) Exposure-Response Relationships

The number of avoided cases for each health outcome was calculated from changes in PM_{10} concentrations using the exposure-response relationships as used in the HAPiNZ update (see Table S2), combined with data on current rates of mortality at different ages. Because we did not have baseline data for Auckland on hospital admissions, we estimated the impacts on cardiac and respiratory hospital admissions plus restricted activity days using the ratios between these cases and mortality impacts as estimated in the HAPiNZ update study for the Auckland urban airshed (Table S3).

Table S2 Exposure Response Functions used in this study

Health Outcome	Exposure Response Functions (Relative risks per 10µg/m^3 PM_{10})
1 Premature mortality, all adults, all ethnicities	**1.07**
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Source: Kuschel G *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report

Table S3 Ratios of cases used to estimate morbidity impacts of cases

Impact	Ratio
Premature mortality (adults)	1
Cardiac admissions (all)	0.222
Respiratory admissions (all)	0.456
Restricted activity days (RADs)	1,705

In the literature, different formulae and starting points have been used to relate the exposure-response functions (eg those in Tables S2 and S3) to changes in concentrations. For example, the HAPiNZ update applies the response functions to the estimated mortality rates with zero pollution, whereas other studies apply these functions to mortality rates based on existing pollution levels. As explained in more detail in Section 4.2.2, we have used an approach that is a compromise between these two broad approaches, rather than seeking to identify what might be the theoretically correct approach.

In addition to impacts on premature mortality, we include an analysis of the effects measured as life years gained. We use a relatively simple approach that has been used in overseas studies that multiplies the age-specific mortality gain by the expected life expectancy for each age and sex.

(e) Approach to Valuing Mortality Effects

We review the literature on mortality impacts of particulates, noting the wide number of studies and government reports that either recommend the use of changes in life years (and valuation using value of life years or VoLY), rather than premature mortality (measured using Value of Statistical Life or VoSL), or that recommend presentation of results using both metrics. The approach reflects the way in which mortality impacts are characterised:

- the VoLY approach assumes that the mortality impact is an extension to life expectancy. Life is extended at the end of life, possibly many years in the future;
- the VoSL approach assumes that the mortality effect can be characterised as a reduction in the risk of death for people of all ages.

Consistent with international practice, particularly in the UK and studies for the European Commission, our preference is to use VoLY but to include results using VoSL. The monetary values used for individual cases in this analysis are shown in Table S4. The VoLY value is taken from international literature that has assessed willingness to pay (WTP) for life extension; the value chosen ($25,000) is at the high end of the range of results from WTP studies. In sensitivity analysis we test a low VoLY ($5,000), a high value ($199,000) that is derived from the VoSL and a value of $44,000 that is a maximum value on the assumption that VoLY must be constrained by income. These values are highly uncertain and there is a clear need for research in New Zealand to address this uncertainty through deriving willingness-to-pay based values.

Table S4 Values used in analysis

Factor		Value
Mortality	VoLY	$25,000
	Value of Statistical Life (VoSL)[1]	$3,948,300
Morbidity	Cardiac admission	$6,810
	Respiratory Admission	$4,864
	Restricted activity day	$66

[1] These are not additive to the VoLY-based values

(f) Benefit Lags

In the base case we assume that the benefits of reduced emissions do not arise immediately. Because of the importance of long-term exposure to total mortality effects, the full benefits will only be realised after a long period of exposure to reduced concentrations. We use a standard approach used in international policy studies based on assumptions developed by the US EPA; it assumes that following a reduction in emissions 30% of the predicted reductions in health effects occur in the first year, 50% is spread equally (12.5% per year) across years 2 through 5 and the remaining 20% spread equally over years 6 through 20. In sensitivity analysis we assume no lag and 30-year lag in which the mortality reductions are spread equally over 30 years, with 3.3% of the estimated benefit in each year.

Overall Cost Benefit Comparison

Timing of Analysis and Discount Rate

The major effects of analysis are as a result of vehicles being replaced with newer vehicles. This is bringing forward in time what would happen anyway as vehicles are replaced (normal fleet turnover). It means that there are time constraints to any policy benefits. We use five year turnovers in our base case, which, according to NZ industry sources, is the usual timescale over which heavy commercial vehicles are replaced.

To compare the costs and benefits over time we discount future values using a standard 8% discount rate as recommended by Treasury for policy analysis. We use 5% in sensitivity analysis.

Where lagged benefits are used, we analyse these separately, eg we discount the proportion of benefits in each future year to derive ratios that are used as multipliers with the benefit values: 0.80 (EPA approach) and 0.41 (30-year lag) using an 8% discount rate.

Low Emission Zones

The first policy options examined are Low Emission Zones (LEZs). They define geographical areas from which vehicles are excluded if they do not meet specified emission rates or standards. We examine two possible areas:

- The Auckland urban air-shed; and
- The CBD and Port where there are high levels of emissions.

Seven separate options are examined relating to the vehicles excluded (Table S5).

Table S5 LEZ Scenarios

Euro Standard	HCV only	HCV & LCV	All diesels
Euro 2/II	1	4	6
Euro 3/III	2	5	7
Euro IV	3		

- Scenario 1-3 apply to heavy commercial vehicles (HCVs) only and exclude, respectively, vehicles that do not meet Euro II, III and IV standards for particulate emissions.

- Scenarios 4 and 5 apply to light commercial vehicles (LCVs) also and include Euro II and III standards

- Scenarios 6 and 7 apply to all diesel vehicles including light passenger vehicles (LPVs).

The standards can be met through changing vehicles or through retrofitting technologies such as Diesel Oxidation Catalysts (DOCs), where they are expected to lead to sufficient emission reductions.

Table S6 summarises the estimated costs and benefits for a CBD & Port LEZ as the present value (PV) discounted over five years using an 8% discount rate and lagged benefits. The operator costs included costs for vehicle replacement or for retrofits, the choice depending on whether retrofits would achieve the required standards. Even using the VoSL-based benefit valuation, none of the options have positive net benefits.

Table S6 Summary of Cost, Benefits and Net Benefits – CBD & Port LEZ (Present Value – $million)

LEZ option:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Vehicle types	HCV	HCV	HCV	LCV/HCV	LCV/HCV	All diesel	All diesel
Euro standard	II	III	IV	2/II	3/III	2/II	3/III
Costs							
Equipment	$6.0	$6.0	$6.0	$6.0	$6.0	$6.0	$6.0
Government	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5
Operator (retrofit)	$12.0	$19.7	$32.8	$20.2	$35.5	$37.4	$65.3
Total costs	$18.5	$26.2	$39.3	$26.6	$42.0	$43.9	$71.8
Benefits							
VoLY	$0.1	$0.1	$0.4	$0.1	$0.1	$0.1	$0.3
VoSL	$0.4	$0.5	$2.6	$0.5	$0.7	$0.5	$1.6
Net Benefits							
VoLY	-$18.4	-$26.1	-$38.8	-$26.6	-$41.9	-$43.8	-$71.5
VoSL	-$18.1	-$25.7	-$36.6	-$26.1	-$41.3	-$43.4	-$70.2

The Auckland urban airshed LEZ results are shown in Table S7. The benefits are closer in magnitude to the costs, but costs exceed the benefits in all scenarios unless a VoSL-based approach to benefit valuation is used where there are positive net benefits for two options: 3 and 4 (highlighted in Table S7).

Table S7 Summary of Cost, Benefits and Net Benefits – Auckland urban airshed LEZ (PV – $million)

LEZ option:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Vehicle types	HCV	HCV	HCV	LCV/HCV	LCV/HCV	All diesel	All diesel
Euro standard	II	III	IV	2/II	3/III	2/II	3/III
Costs							
Equipment	$9.0	$9.0	$9.0	$9.0	$9.0	$9.0	$9.0
Government	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5
Operator (retrofit)	$57.5	$94.6	$157.3	$74.7	$127.7	$112.2	$186.6
Total costs	$67.0	$104.1	$166.8	$84.2	$137.2	$121.7	$196.1
Benefits							
VoLY	$4.3	$4.6	$9.4	$4.8	$5.4	$4.9	$8.8
VoSL	$37.7	$97.9	$199.1	$101.8	$115.3	$103.5	$186.3
Net Benefits							
VoLY	-$62.7	-$99.5	-$157.4	-$79.4	-$131.7	-$116.9	-$187.3
VoSL	-$29.3	-$6.2	**$32.4**	**$17.6**	-$21.9	-$18.2	-$9.8

Emissions Testing

Emissions testing has been examined on the assumption that all diesel vehicles in Auckland would have an emissions test as part of their Warrant of Fitness (WoF) or Certificate of Fitness (CoF) inspection. We have modelled the emission results for the Auckland urban airshed.

VEPM5.1 includes a default factor that accounts for degradation of vehicles (except Euro 6/VI) over time. This degradation factor accounts for the assumption that exhaust emissions will increase with increasing vehicle age and mileage. With the introduction of regional in-service standards, through vehicle testing inspections, the high emitters would be identified and be required to undertake maintenance or repair to restore vehicle emissions to the required standard for that vehicle. For analysis of the with-testing option we remove the degradation factor.

Table S8 summarises the net benefits of an emission testing regime. The results are shown for the present value (PV) of costs and benefits over a five year project discounted at 8%. Testing is found to have positive net benefits only if using VoSL for benefit valuation.

Table S8 Cost, Benefits and Net Benefits of Emissions Testing (PV – $ million)

Element		Value
Costs	Testing	$22.6
	Servicing	$12.1
	Repair	$2.0
	Replacement vehicles	$17.1
	Government	$2.0
	Total costs	$55.8
Benefits	VoLY	$13.5
	VoSL	$146.2
Net Benefits	VoLY	-$42.3
	VoSL	$90.3

Road Pricing

The road pricing option examines the air quality benefits of introducing road pricing for congestion purposes. The assumptions are derived from the 2008 MoT *Auckland Road Pricing Study*.[12] Road pricing would apply to a central Auckland area including the CBD & Port and a wider area beyond. Road pricing is estimated to result in an approximate 10% reduction in traffic, an approximate 5% increase in public transportation service requirements and to result in an average reduction in PM_{10} concentration of 0.20$\mu g/m^3$ across the central Auckland area.

The costs and benefits of road pricing are presented in Table S9. This includes only the equipment (technical) and government costs of road pricing. It is assumed that, because road pricing is correcting a congestion externality,[13] the other cost elements (the response to pricing itself), will have lower costs than paying the congestion charge itself,

[12] Ministry of Transport (2008) Auckland Road Pricing Study 2008 Report no: WL00062-1

[13] We assume that the congestion charge is based on the estimated cost of congestion.

and will result in benefits that are equal in value to the congestion charge (the avoided costs of congestion). The costs and benefits are present values over five years.

Table S9 Cost, Benefits and Net Benefits of Road Pricing – present value ($ million)

Element		Value
Costs	Equipment	$10.00
	Government	$0.50
	Total costs	**$10.50**
Benefits	VoLY	$1.1
	VoSL	$8.9
Net Benefits	VoLY	-$9.4
	VoSL	-$1.6

Road pricing does not yield positive net benefits under either VoLY or VoSL-based benefit valuation.

Summary Results

In Table S10 we show the results using our base assumptions (including VoLY-based benefit valuation) and the same assumptions as used in the updated HAPiNZ study. This includes:

- Mortality benefits measured using VoSL;
- No lagged benefits.

These HAPiNZ values provide a basis for comparison of results with previous studies. There are positive net benefits from two Auckland urban airshed LEZ options, plus testing and road pricing, whereas using VoLY all options have net costs.

Table S10 Net Present Value of Policy Options – Base Case and HAPiNZ Assumptions (PV - $million)

	CBD & Port		Auckland	
Policy Scenario	**Base Case (VoLY)**	**HAPiNZ (VoSL)**	**Base Case (VoLY)**	**HAPiNZ (VoSL)**
LEZ				
1 Euro II HCV	-$18	-$18	-$63	-$20
2 Euro III HCV	-$26	-$26	-$99	-$6
3 Euro IV HCV	-$39	-$36	-$157	**$33**
4 Euro 2/II LCV&HCV	-$27	-$26	-$79	**$18**
5 Euro 3/III LCV&HCV	-$42	-$41	-$132	-$22
6 Euro 2/II All diesel	-$44	-$43	-$117	-$18
7 Euro 3/III All diesel	-$72	-$70	-$187	-$9
Emissions Testing			-$42	**$91**
Road Pricing			-$9	**$1**

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

Sensitivity Analysis

Sensitivity analysis is undertaken on a number of key assumptions and the overall results are shown as the maximum percentage differences (in absolute terms)[14] from the base case assumptions in Table S11.

Table S11 Maximum Impact of Assumptions on Net Benefits (% difference from base case with VoLY)

Assumptions		LEZ	Testing	Road Pricing
Benefit valuation	Low VoLY ($5,000)	4%	18%	7%
	High VoLY ($199,000)	41%	217%	62%
	VoSL	122%	313%	83%
Confidence intervals	Sensitivity (high)[1]	3%	14%	5%
	Sensitivity (low)[2]	3%	18%	7%
Discount rate	5%	27%	8%	3%
Lagged benefits	No lag	2%	8%	3%
	30-yr lag	3%	16%	6%
Region-wide benefits	Region-wide benefits from CBD LEZ	6%		
Costs	Low costs	51%	67%	53%
	High costs	51%	67%	53%

[1] Premature mortality risk rate = 1.10/1.08 per 10μg/m³ for adults/babies; [2] 1.03/1.02 per 10μg/m³

The base case assumptions are:

- Mortality benefits measured using VoLY;
- EPA assumptions for lagged benefits;
- 8% discount rate;
- Costs and benefits calculated over five years.

The most significant assumptions are for the approach to benefit valuation, and especially if a VoSL-based approach is used rather than using VoLY. Other significant assumptions are those relating to the discount rate employed and the level of costs. We vary costs to take account of factors that include the ratio between vehicles and VKT, the costs of testing and the costs of the road pricing system.

Conclusions

The Importance of Assumptions on Benefit Valuation

The analysis suggests that the policy options examined offer positive net benefits only when the benefits are measured using VoSL. The choice of benefit valuation methodology is hugely important.

HAPiNZ used VoSL and we have included results that are consistent with HAPiNZ, but we suggest that there are reasons for changing these assumptions, particularly for policy studies addressing the impacts of **changes** in concentrations rather than the impacts of **absolute** levels. We have included two significant modifications to the HAPiNZ approach that are consistent with approaches being adopted internationally. These are:

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[14] We ignore whether the change is positive or negative but concentrate only on how large the effect is

- the inclusion of a cessation lag (lagged benefit values), in recognition that the major effects are on chronic mortality and that repairs to health will not happen instantaneously with reductions in concentrations; and

- the use of changes in life years, valued using VoLY as the primary measure of mortality effect. This is more consistent with the nature of the effect.

The other significant difference relates to the monetary values used. The VoSL we have adopted uses the same source as used in HAPiNZ. A VoLY can be calculated from the VoSL and this results in relatively high benefit values, but we have more confidence in values from studies that have derived VoLYs directly through survey techniques. There is a need for more work on these values in a New Zealand context.

Policy Choices

The analysis suggests that the net benefits (or costs) of the policy options examined to limit emissions in Auckland are highly uncertain. The results depend critically on some key assumptions, particularly the benefit valuation assumptions as discussed above.

- If VoSL-based benefit valuation is used, the analysis suggests that emissions testing has positive net benefits, as do certain Auckland urban airshed-wide LEZs, particularly a Euro IV-based LEZ targeted at HCVs and a less stringent (Euro 2/II) version that targets LCVs and HCVs and could be met using retrofit technologies. The common element is the HCV focus.

- In contrast, using the preferred VoLY-based analysis, all options have net costs. A LEZ focussed on HCVs and imposing a Euro II requirement is the best LEZ option (lowest net costs) for the CBD & Port and Auckland urban airshed, although we note that it is the worst option for the Auckland urban airshed if using VoSL-based analysis. The next best LEZ options are Option 2 (Euro III HCV) and Option 4 (Euro 2/II LCV & HCV). This suggests that those focussed on the oldest and most-polluting vehicles (HCVs) are best, largely because of the lower costs.

LEZs

The costs of LEZs depend on whether the requirements can be met using retrofit technologies or if vehicle owners face the higher costs of vehicle replacement.

There is a risk in concluding that an Auckland urban airshed LEZ would be better than a CBD LEZ on the basis of the potential for positive net benefits. The benefits are highly uncertain and, if they are closer to the VoLY-based values, then the Auckland urban airshed LEZ would result in much higher net costs than a CBD & port LEZ, eg LEZ option 3 for the Auckland urban airshed ranges in value from positive $32 million (VoSL) to negative $157 million (VoLY), but for the CBD & port has net costs of less than $40 million.

We would not recommend any LEZ is adopted, but if one is experimented with, then minimising costs through focusing on a smaller area and older vehicles (Euro II standard) would be preferable.

Emissions Testing

The emissions testing analysis has not examined the emissions testing options in any detail. The costs depend on the costs of the test itself (which would cover equipment and labour costs) and the number of vehicles that would need to be replaced rather than repaired (because of emission requirements). The benefits are based on vehicles being maintained in a way that would reduce emissions to levels achieved at manufacture, avoiding the deterioration that occurs in the absence of regular servicing and maintenance.

Emissions testing is ideal where the test costs are low and it provides incentives for vehicle maintenance, which if undertaken, avoids the need for vehicle replacement and/or costly repairs. However, the risk of facing these high costs provides the incentive for maintenance.

Emissions testing has positive net benefit using a VoSL-based benefit valuation approach. But, even if all other assumptions were favourable there are net costs under VoLY-based benefit valuation assumptions

Road Charging

The analysis suggests that road charging to address congestion only has positive net benefits when VoSL is used and other favourable assumptions are adopted, such as no benefit lag. However, we do not consider all costs and benefits of this option[15] and there may be net benefits from congestion reduction that would tip this from negative to positive.

Overall Conclusions

No policy option provides certainty of positive net benefits.

Across the suite of policy options examined the analysis provides insufficient confidence in any of them for positive policy recommendations to be made.

[15] We assume that the level of charge is set at a level that corrects for external costs of congestion (the costs imposed on other drives), so that any response to this charge would be economically efficient (benefits would exceed the costs). However, the benefits still need to exceed the costs of implementing this price instrument, including the technical and government costs.

Glossary

ANPR	Automatic Number Plate Recognition
ART model	Auckland Regional Transport model
CAAA	Clean Air Act Amendments (US)
CAFE	Clean Air for Europe - a long-term strategy to tackle air pollution and protect against its effects on human health and the environment
CAU	Census Area Unit
CBA	Cost Benefit Analysis
CBD	Central Business District
CDPF	Catalysed Diesel Particulate Filter
CITA	International Motor Vehicle Inspection Committee
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CoF	Certificate of Fitness
COMEAP	Committee on the Medical Effects of Air Pollution - an expert committee to advise the UK government on all matters concerning the health effects of air pollutants
COPD	Chronic Obstructive Pulmonary Disease
Defra	Department for Environment, Food & Rural Affairs (UK)
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particle Filter
EF	Emission Factor
EPA	Environmental Protection Agency (US)
FTL/AUL	Fuel Technology Limited & Auckland Uniservices Limited
GNS Science	Trading name of the Institute of Geological and Nuclear Sciences Ltd
HALY	Health-adjusted life year (equivalent to a QALY)
HAPiNZ	Health and Air Pollution in New Zealand
HCV	Heavy Commercial Vehicle
HES	Health Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis, an advisory council to the US EPA on public health, economy, and environment.
HGV	Heavy Goods Vehicle (UK equivalent to HCV)
LCV	Light Commercial Vehicle
LEZ	Low Emission Zone
LGV	Light Goods Vehicle (UK equivalent to LCV)
LPV	Light Passenger Vehicle
MES	Milan Ecopass Scheme
MfE	Ministry for the Environment
MoT	Ministry of Transport

NESAQ	National Environmental Standard for Air Quality
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides including NO and NO_2
NPV	Net Present Value = the sum of discounted benefits minus the sum of discounted costs
NZIER	New Zealand Institute for Economic Research
NZTA	New Zealand Transport Agency
OBD	On-Board Diagnostics
OMB	Office of Management & Budget
PHARMAC	Pharmaceutical Management Agency
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter less than 2.5 μm in diameter
PM_{10}	Particulate matter less than 10 μm in diameter
PMT	Payment – an Excel function that calculates an equal annual payment (an annuity) over a given time period for which the discounted sum will equal a present value
PTI	Periodic Technical Inspection
PV	Present Value = discounted sum of future costs or benefits
QALY	Quality-adjusted life year (a life year in perfect health)
RAD	Restricted Activity Day
RPC	Reduced Pollution Certificate –can be obtained in the UK if a vehicle has been modified (retrofit technology to reduce emissions)
RR	Relative Risk
RUC	Road User Charge – a per kilometre charge paid by users of diesel vehicles
SAB	Science Advisory Board (US)
SCR	Selective Catalytic Reduction
TEDDIE	TEst(D)DIEsel
TfL	Transport for London
μg	microgram, one millionth of a gram
ULEZ	Ultra Low Emission Zone
UNEP	United Nations Environment Programme
VEPM	Vehicle Emissions Prediction Model
VKT	Vehicle Kilometres Travelled
VoLY	Value of a Life Year
VoSL (or VSL)	Value of a Statistical Life
VSLY	Value per statistical life year
WHO	World Health Organisation
WoF	Warrant of Fitness
WTP	Willingness to pay

1 Introduction

1.1 Background

The Ministry of Transport (MoT) is establishing a programme of work that co-ordinates initiatives to improve the quality of New Zealand's vehicle fleet. One area of focus is improvement of air quality outcomes and there is a research interest in identifying potentially cost-effective policies to reduce emissions from vehicles in the fleet.

Because these health effects are proportional both to ambient concentrations and the size and vulnerability[16] of the exposed population, the greatest effects of policy are obtained by focussing on areas with higher population densities and higher concentrations of pollutants. Consistent with this, the focus of policy analysis in this study is on the most problematic sources, defined with respect to:

- Location – the main concern is with Auckland;[17]
- Pollutants – fine particulates;[18] and
- Vehicle type – diesel vehicles.[19]

The project aims to identify a number of options that have been successful in reducing air pollution from vehicles in designated urban areas elsewhere, and then assessing their likely costs and benefits in a New Zealand context, specifically in Auckland.

1.2 The Sources and Incidence of Air Pollution Problems

Air pollution is problematic because of its impacts on human health and the environment. There have been a number of studies that have assessed the overall impacts of in New Zealand, particularly the Health and Air Pollution in New Zealand (HAPiNZ) study, initially undertaken in 2007[20] but recently updated to take account of new data and understanding of health effects.[21] The results of the HAPiNZ studies have been used as inputs to a national cost benefit analysis of air quality standards.[22] In New Zealand, as elsewhere, economic analyses have suggested that the adverse impacts are dominated by the health effects, particularly the impacts on premature deaths.

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[16] Lower socioeconomic and susceptible groups with pre-existing lung or heart disease, as well as elderly people and children, are particularly vulnerable

[17] This geographic limitation was defined in the scope for this study provided by MoT and reflecting the results of the HAPiNZ update (Kuschel et al 2012a)

[18] See discussion on page ii (*Pollutants of Interest)*

[19] This vehicle limitation was defined in the scope for this study provided by MoT and reflecting the results of the HAPiNZ update (Kuschel et al 2012a)

[20] Fisher G, Kjellstrom T, Kingham S, Hales S & Shrestha R (2007). Health and Air Pollution in New Zealand: Main Report, A Research Project Funded by: Health Research Council of New Zealand, Ministry for the Environment and Ministry of Transport.

[21] Kuschel G, Metcalfe J, Wilton E, Guria J, Hales S, Rolfe K and Woodward A (2012) Updated Health and Air Pollution in New Zealand Study Volume 1: Summary Report. Prepared for Health Research Council of New Zealand, Ministry of Transport, Ministry for the Environment and New Zealand Transport Agency.

[22] NZIER (2009) The value of air quality standards. Review and update of cost benefit analysis of National Environmental Standards on air quality Report to Ministry for the Environment

1.2.1 Key Pollutants

Air pollution is the result of a complex mixture of contaminants and particles, but the majority of epidemiological studies to date link PM_{10} with adverse health effects, and it is regarded as the best available summary indicator of air pollution exposure in New Zealand. While research shows that many of the main health effects attributable to particulates are more likely to be associated with the finer fraction of PM_{10}, such as $PM_{2.5}$, the lack of monitoring data and relevant exposure-response functions makes it difficult to robustly quantify the impacts of smaller fractions such as $PM_{2.5}$ currently in New Zealand. The assessment is therefore based on PM_{10} as used in the HAPiNZ Update 2012.[23]

Additional pollutants of concern include nitrogen dioxide (NO_2), carbon monoxide (CO) and benzene. However, Kuschel *et al* noted that there were insufficient NO_2 data to assess exposure in New Zealand, that there is a risk of double-counting the impacts of CO with the mortality effects of PM_{10} and that benzene is at low levels and has low risks.

For PM_{10} the most recent NZ analysis assumes linear (in percentage terms), no threshold exposure-response functions in which health effects are detectable at any concentration above zero and that the increase in the effect is proportional to the increase in concentration.

Estimates of exposure have been based on measurements of concentrations coupled with predictive models using vehicle kilometres travelled (VKT) per census area unit (CAU) and emission factors for individual vehicles.

The exposure modelling approach used in this study is explained in Section 4.2 and Annex 3.

1.2.2 Emissions Sources

The 2012 update to the HAPiNZ study estimates that, of the total social costs attributable to air pollution (estimated to total $4.28 billion per year), 56% is attributable to domestic fires and 22% to motor vehicles, with the remainder split between open burning (12%) and industry (10%).[24] There are regional and local differences. In Auckland emissions are dominated by motor vehicles, particularly in the CBD. For the Auckland region, 43% of the anthropogenic effects (measured as social cost) are attributable to motor vehicles and 38% to domestic fires; in former Auckland city, 49% is attributable to motor vehicles.

Within Auckland (and other locations), and reflecting the importance of transport sources, air pollution problems are particularly concentrated in certain transport corridors.[25]

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[23] Kuschel G et al (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report

[24] Kuschel *et al* (op cit)

[25] Auckland Regional Council (2010) State of the Auckland Region report 2009. Chapter 4.1 Air

1.3 Policies to Limit Emission Effects

The RFP for this research notes that the objective of the work is to identify cost-effective policies to reduce vehicle emissions (especially fine particulates and oxides of nitrogen (NOx)) in the Auckland Region. The research is to focus on emissions from diesel vehicles, but considers air pollution from non-tail pipe sources (eg tyres, brakes, etc) where this is relevant and included in the emissions modelling.[26] Policy options to be considered should include:

- emissions testing;
- low emissions zones;
- low emission fuels; and
- retrofits of emissions reduction technologies.

Table 1 sets out three separate objectives for classifying the available policy options. Each option can result in a reduction in the impacts of emissions by reducing the emission produced per vehicle, by shifting the vehicles away from people or by reducing VKT and thus emission rates.

Table 1 Classification of Policy Options

Objective	All vehicles	Specific locations
Improve emission rates per vehicle	• Emission standards • Emission charges • Information/testing • Fuel switching measures	• Low emission zones • Entry charges (emission-related)
Shift vehicles and emissions		• Low emission zones • Entry charges (emission-related)
Reduce VKT	• Fuel charges/road user charge (RUC) increases • Emission charges	

Policy to improve the emission rates per vehicle include:

- emission standards, as currently applied in New Zealand. These require vehicles first entering the market to meet minimum recognised international emission standards;

- emissions charges provide incentives for lower emission vehicles by increasing the costs of purchasing or using higher emissions vehicles;

- information systems or requirements to pass in-service testing can be used to provide information to vehicle owners relating to their emissions that might provide incentives to improve them, or can be combined with emission standards or rules for vehicles in use (rather than just first entry). Testing might also be used alongside charge systems;

[26] Particulate emissions from brake and tyre wear are included in the Vehicle Emissions Prediction Model (VEPM) used in this study and are thus built into the results.

- fuel switching measures could be used to encourage shifts towards less emissions-intensive fuels.

Emission rates per vehicle can also be encouraged in specific locations by policies such as:

- Low Emission Zones (LEZs) that restrict entry to some locations based on the vehicle type and/or emission rates or standards the vehicle was manufactured to. For example, LEZs have been used to restrict entry of heavy goods vehicles (HGVs) from urban centres in many parts of Europe. They have also applied to ports, such as the ports of Los Angeles;[27]

- entry charges can function in a similar way to LEZs by charging for entry based on the emission profile of the vehicle.

Measures have the potential to shift vehicles away from people, eg away from high density areas or where particularly vulnerable people live, eg schools, hospitals etc. Measures include LEZs and emission charges that also incentivise a shift towards lower emission vehicles.

Reductions in VKT occur where there is an increased cost for each additional VKT. This applies particularly to measures that would affect fuel prices or per kilometre road user charges (RUCs). This could include increased fuel taxes or carbon charges.

We use this spectrum of charges as a way to organise the discussion of options.

1.4 Policy Options

The objective is to identify potentially cost-effective policies that might be used to tackle air pollution in specific areas and for specific vehicles. The main criterion used to isolate policies for further analysis is their potential for being specified geographically. The main such policies employed elsewhere are low emission zones (LEZs), regional emissions testing of vehicles to a specific local standard, eg as part of in-service inspection,[28] and road pricing.

Thus the suggested options for more detailed analysis and modelling are the following:

- Low Emission Zones, including
  - all of Auckland;
  - a smaller part, eg CBD and port or transport corridors (major roads);

[27] The ports of Los Angeles and Long Beach have established a progressive ban on polluting trucks. From October 1 2008 all pre-1989 trucks were banned from entering the Port; from January 1, 2010, 1989-1993 trucks were banned and 1994-2003 trucks that had not been retrofitted; from January 1 2012, all trucks that did not meet the 2007 Federal Clean Truck Emissions Standards were banned from the ports. www.portoflosangeles.org/ctp/idx_ctp.asp

[28] Warrant of Fitness (WoF) or Certificate of Fitness (CoF)

- Road pricing for the central Auckland congestion zone;

- Vehicle testing with regional in-service standards.

The reasoning behind this is set out in Section 3 below, particularly Section 3.8.

1.5 Structure of Report

The report is structured as follows:

- Section 2 provides background on the vehicle fleet in Auckland and recent trends in emissions. It provides additional material to set the scene for the analysis;

- Section 3 discusses the available policy options and outlines and related international experience. It recommends a limited set for detailed analysis;

- Sections 4 and 5 set out methodological issues and data used in the analysis of costs and benefits. Further detail is provided on the benefit analysis methodologies in Annex 4;

- Sections 6 to 8 provide the analysis of the individual policies: low emission zones (LEZs, emissions testing and road pricing, including the results under the base case assumptions);

- Section 9 summarises the analysis across all options and conducts sensitivity analysis relating to key assumptions. It provides conclusions relating to analysis and policy.

- Four Annexes are provided that include:
    - additional detail relating to LEZs used internationally (Annex 1);
    - the impacts of different assumptions on vehicle costs (Annex 2);
    - the methodologies used in assessing emission impacts (Annex 3); and
    - benefit valuation techniques (Annex 4).

2 Auckland Context

In this Section we provide background material that sets the scene for the analysis. It includes information on emission and concentrations of pollutants in Auckland, the importance of vehicles relative to other sources, the factors influencing vehicle emissions and how they vary over time and space within Auckland.

It provides background for the focus on Auckland, on particulate emissions and the geographical scope of policy interventions.

2.1 Ambient air concentrations of key contaminants in Auckland

2.1.1 Auckland Council continuous monitoring network

Auckland Council owns an extensive continuous air quality monitoring network in the Auckland region. The pollutants that are key indicators of transport-related emissions are particulate matter (PM_{10} and $PM_{2.5}$) and nitrogen dioxide (NO_2). The relevant ambient air quality guidelines and standards for assessment of air quality in New Zealand are summarised in Table 2

Table 2 Air quality guidelines and standards

Contaminant	1-hour average	24-hour average	Annual average
PM_{10}	N/A	50 µg/m^3 Note 1	20 µg/m^3
$PM_{2.5}$	N/A	25 µg/m^3 Note 2	10 µg/m^3 Note 2
NO_2	200 µg/m^3 Note 1	100 µg/m^3	40 µg/m^3 Note 2

Note 1: Also the National Environmental Standard for Air Quality (NESAQ), with an allowance for 1 exceedance in a 12-month period for PM_{10} and 9 exceedances in a 12-month period for NO_2
Note 2: Values are from the proposed Auckland Unitary Plan Auckland Ambient Air Quality Standards (AAAQS)

Historically carbon monoxide (CO) has been used as an indicator of traffic emissions. However, due to improvements to vehicle emissions systems, motor vehicle discharges of CO are low, and difficult to differentiate from other combustion sources. Therefore, CO is no longer considered useful as an indicator pollutant.

The Auckland Council monitoring sites are representative of different environments and of likely source contributions. There are two "peak" monitoring sites, which are indicative of worst case air concentrations in Auckland, but not necessarily representative of urban air that people would be exposed to over long periods of time:

- Khyber Pass Road in Newmarket, which is representative of conditions at a busy intersection.

- Queen Street in the CBD, which is located within a street canyon, prone to slow moving traffic and a main bus route.

The Auckland Council has also identified three "roadside" monitoring sites, which are considered to be broadly representative of air quality at traffic-affected sites.[29] These sites are:

- Gavin Street in Penrose, which is located 106m northeast of the Southern Motorway and will also have influences from industrial and residential sources (PM_{10}, $PM_{2.5}$, NO_2).

- Westlake Girls College in Takapuna (PM_{10}, $PM_{2.5}$, NO_2), which is located 60m east of the Northern Motorway and 30m south of Wairau Rd. This site will also have influences from industrial and residential sources.

- Bell Reserve in Pakuranga (PM_{10}), which is located 7.5m from Pakuranga Highway and will also have influences from residential sources.

The air quality monitoring data presented in the following subsections are based on data provided by the Auckland Council.

Long term (annual) average concentrations

Annual average PM_{10} and $PM_{2.5}$ concentrations have decreased around the Auckland region since the mid-1990s but appear now to be stabilising. here have been no exceedances of either the PM_{10} (20 μg/m^3) or $PM_{2.5}$ (10 μg/m^3) guidelines since 2010 with the exception of the beta gauge monitor at peak monitoring site Khyber Pass Road[30]. Between 2003 and 2013, of the more than 15 sites monitored for PM_{10}, only Khyber Pass Road (2006 to 2009, 2013), Queen Street (2007) and Penrose (2006) exceeded the annual PM_{10} guideline.

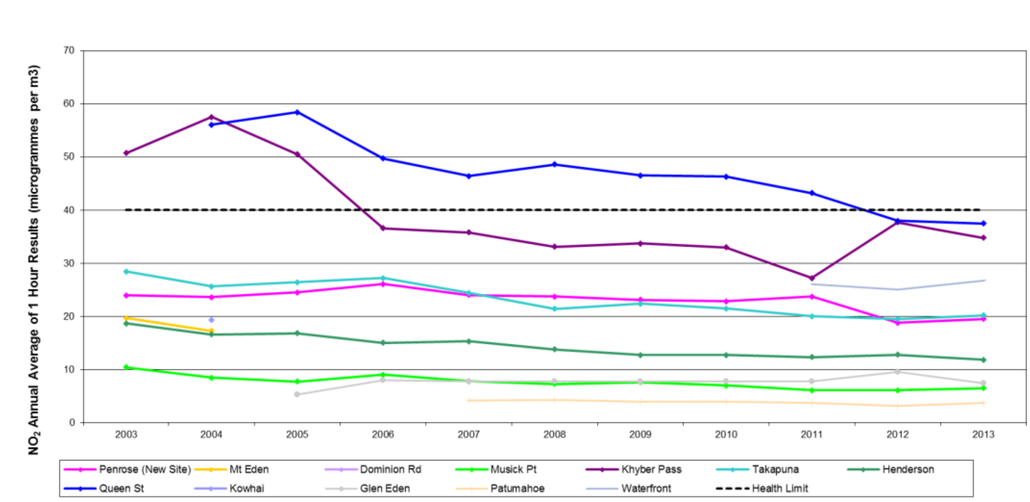
There are fewer monitoring sites for $PM_{2.5}$ (only 6 sites have more than 5 years monitoring data in the 2003 to 2013 period). The sites at Khyber Pass Road and Queen Street exceeded the WHO annual average $PM_{2.5}$ guideline in 2004 and 2004 to 2008, respectively. The data suggest that $PM_{2.5}$ levels have stabilised, with recent (2011 to 2013) annual average concentrations at the urban monitoring sites between 6.5 and 7.8 μg/m^3.

There are 8 air quality monitoring sites with more than 5 years of data for nitrogen dioxide over the period 2003 to 2013. The annual average NO_2 concentrations show similar trends to PM_{10} and $PM_{2.5}$ of generally decreasing concentrations since the mid-1990s, as shown in Figure 1. This is particularly the case at the peak roadside monitoring sites at Khyber Pass Road and Queen Street, which are the only two sites that have exceeded the WHO annual NO_2 guideline of 40 μg/m^3 between 2003 and 2013.

[29] Use of Background Air Quality Data in Resource Consent Applications. Emission Impossible Ltd. Prepared for Auckland Council. July 2014

[30] In 2013, the beta gauge monitor at Khyber Pass recorded 21 μg/m^3 (annual average) PM_{10} and the co-located Partisol recorded 16 μg/m^3 (annual average).

Figure 1 Auckland Council annual average NO_2 concentrations

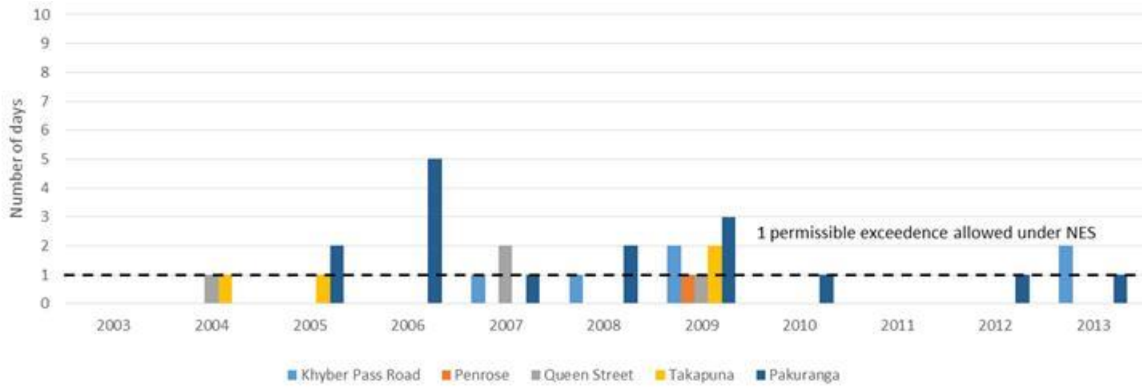


Source: Auckland Council

Short term (hourly or daily) averages

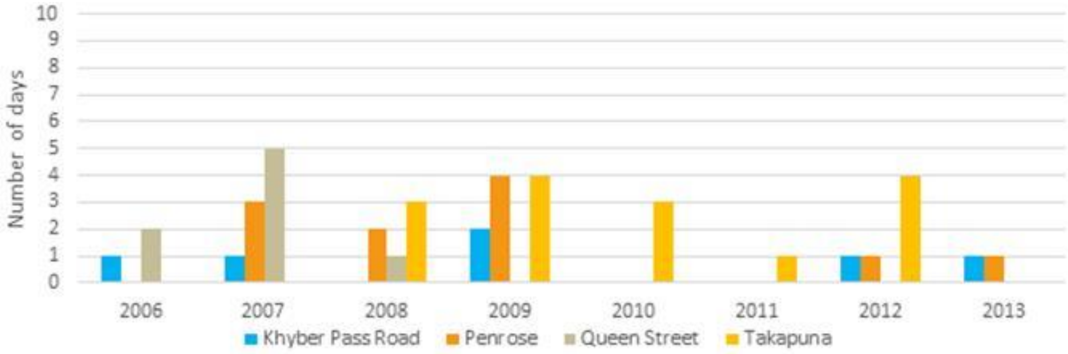
There are a number of locations in Auckland that have exceeded the 24-hour average guidelines for PM_{10} and $PM_{2.5}$ between 2003 and 2013. These sites include a mix of urban and rural areas around Auckland, which are not principally affected by traffic. The number of days exceeding the 24-hour average PM_{10} and $PM_{2.5}$ air quality guidelines at each of the peak and roadside sites are shown in Figure 2 and Figure 3 respectively. The $PM_{2.5}$ data are shown from 2006 as only Khyber Pass and Queen Street were operating prior to this.

Figure 2 Days exceeding the PM10 24-hr air quality standard



Source: Auckland Council

Figure 3 Days exceeding the $PM_{2.5}$ air quality guideline

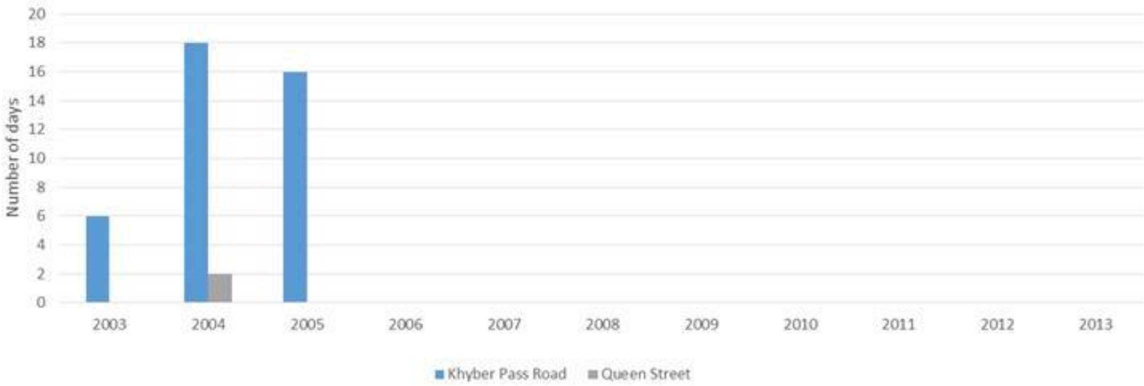


Source: Auckland Council

Only the two peak monitoring sites of Khyber Pass Road and Queen Street have exceeded 24-hour NO_2 air quality guideline of 100 μg/m³ in the 2003 to 2013 period.

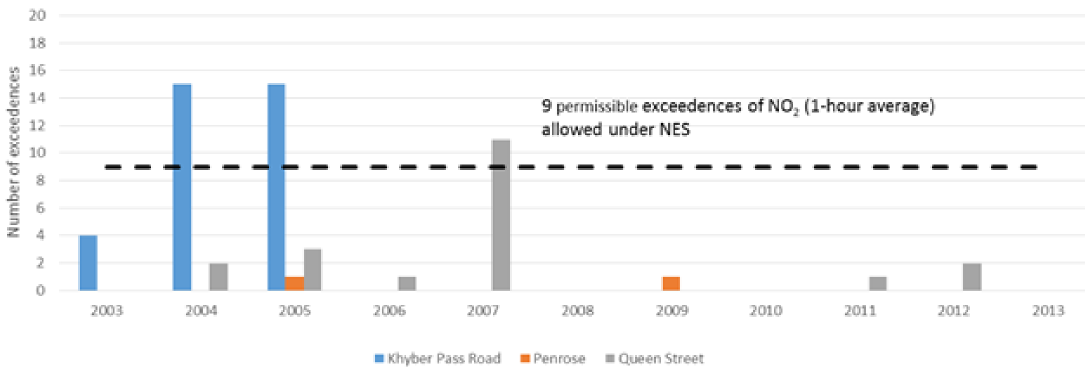
The 1-hr National Environmental Standard for Air Quality (NESAQ) for NO_2 is 200 μg/m³, with an allowance for 9 exceedances in a twelve month period. The number of hours exceeding the standard at each of the peak and roadside sites is shown in Figure 5. Taking into account the "permissible exceedances" air quality has complied with the NESAQ since between 2010 and 2013.

Figure 4 Days exceeding the NO_2 24-hour air quality guideline



Source: Auckland Council

Figure 5 Hours exceeding the NO_2 1-hour air quality standard



Source: Auckland Council

2.1.2 Passive monitoring network

The New Zealand Transport Agency (NZTA) maintains an extensive passive NO_2 monitoring network across the Auckland region. Monthly passive samples are taken at positions representative of state highways, local roads and a number of background sites (low traffic areas). Passive monitoring allows for a larger number of sites in comparison to continuous monitoring due to the relatively low cost. However, passive monitoring is less accurate and has a lower resolution (eg it does not show diurnal variations). Monitoring between 2007 and 2013 shows annual average concentrations throughout Auckland lie in the range between 10 and 46.5 $\mu g/m^3$.

Due to the long sampling length (1-month), assessment against long-term NO_2 guidelines, such as the WHO annual 40 $\mu g/m^3$, is most appropriate. Passive monitoring between 2007 and 2013 indicated four sites that exceeded the WHO annual NO_2 guideline:

- George Bolt Dr & Kirkbride Rd Intersection (Mangere);
- Canada Street Interchange (Newton);
- New North Rd & Mt Albert Rd Intersection (Mt Albert); and
- Great North Rd & Rata St Intersection (New Lynn).

The above four sites are all located near major road intersections (or interchanges in the case of Canada St) with roads of four lanes or greater in each direction.

2.2 Relative contribution of motor vehicle emissions to air pollution

2.2.1 Auckland emissions inventory

The most recent *Auckland Air Emissions Inventory* was prepared for the 2006 base year[31]. The 2006 annual estimates of the total anthropogenic emissions across the entire Auckland region are approximately:

- 3,170 t/yr PM_{10} (38% transport; 47% domestic; 15% industry)
- 3,000 t/yr $PM_{2.5}$ (39% transport; 50% domestic; 11% industry)
- 20,800 t/yr NO_x (79% transport; 16% industry; 4% biogenic)

On a regional basis, motor vehicle emissions (within the transport sector) are the second largest source of anthropogenic particulate emissions and the largest source of NO_x emissions.

2.2.2 Source apportionment of particulate matter

A source apportionment study was carried out by GNS Science in 2007 over 5 sites in the Auckland region to identify the primary sources of coarse (PM_{10}) and fine ($PM_{2.5}$) particulate matter in ambient air samples.[32] The monitoring sites investigated were

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[31] Xie, S., Sridhar, S and Metcalfe, J (2014). Auckland air emissions inventory 2006. Auckland Council technical report, TR2014/015

[32] Davy, P., Trompetter, B., Markwitz, A. (2007). Source apportionment of airborne particles in the Auckland region. Prepared by GNS Science Consultancy for Auckland Regional Council. Report 2007/314

Kingsland (PM_{10} & $PM_{2.5}$), Takapuna (PM_{10}), Queen Street (PM_{10} & $PM_{2.5}$), Khyber Pass Road (PM_{10} & $PM_{2.5}$) and Penrose ($PM_{2.5}$).[33]

The purpose of the study was to determine the relative contribution of different sources of particulate matter at the different locations. Common sources of particulate matter that were considered in the study were vehicle emissions, biomass burning, marine aerosols, secondary sulphates and soils.

The study showed that there was a large seasonal variation in source contributions at all sites, reflecting an increase in biomass burning over winter months and an increase in marine aerosols and crustal matter over summer months. Motor vehicle contribution showed some minor seasonal variation with higher contributions in the winter months. This is likely to reflect seasonal differences in dispersion characteristics, rather than emissions. The results are summarised in Table 3.

2.3 Factors influencing motor vehicle emissions

2.3.1 Relative contributions of different vehicle/fuel types

The Auckland Council has recently published an updated motor vehicle emissions inventory for 2011 for the Auckland region.[34] The inventory used data from the Vehicle Emission Prediction Model version 5.1 (VEPM5.1) and traffic data from the Auckland regional transport model version 3 (ART3) (except for the 2001 estimates used for trend analysis, which were based on data provided by the Ministry of Transport).

The fleet profile was taken from VEPM5.1 but was adjusted for the Auckland region, which has a higher proportion of total vehicle kilometres travelled (VKT) for light and heavy commercial vehicles compared to the national fleet average. The Auckland fleet profile for the base years considered is shown in Table 4.

The key findings of the inventory (for the 2011 year) were:

- Although diesel vehicle technology has improved significantly, diesel vehicles still contribute disproportionately to PM_{10} and NOx emissions. Diesel exhaust is the primary contributor to both PM_{10} (72%) and NOx (55%) vehicle emissions, despite diesel vehicles making up only 26% of the VKT;
- Diesel light commercial vehicles account for 28% of PM_{10} vehicle emissions and 13% of NOx vehicle emissions (while only making up 12% of VKT);
- Diesel heavy commercial vehicles (including buses) account for 25% of PM_{10} vehicle emissions and 35% of NOx vehicle emissions (while only making up 6% of VKT); and
- Petrol cars are a significant source of NOx emissions (45%); however, their contribution is disproportionately low when compared to the VKT (74%).

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[33] We understand that there has been an update to this study, not currently in the public domain

[34] Sridhar, S., Metcalfe, J and Wickham, L (2014). Auckland motor vehicle emissions inventory. Prepared by Emission Impossible Ltd for Auckland Council. Auckland Council technical report, TR2014/029

Table 3 Summary of source apportionment study findings

Monitoring site	Overall average	Peak days
Queen Street	Motor vehicle emissions were the primary source of both PM_{10} and $PM_{2.5}$ (38% and 41%, respectively).	On peak $PM_{2.5}$ days, the contribution from motor vehicle emissions was relatively constant (6 to 9 µg/m^3). Peak $PM_{2.5}$ concentrations (over 20 µg/m^3) were largely due to emissions from domestic solid fuel fires. PM_{10} source contributions were found to be similar to $PM_{2.5}$ sources, with combustion sources and marine aerosol responsible for peak PM_{10} concentrations.
Khyber Pass Road	Motor vehicle emissions were the primary source of both PM_{10} and $PM_{2.5}$ (46% and 49%, respectively).	Biomass burning sources were found to have a significant impact on particle concentrations at the monitoring site during cold calm days in winter
Kingsland	Biomass burning was the primary source of both PM_{10} and $PM_{2.5}$. Motor vehicles contributed 7% and 26 to 35% to average PM_{10} and $PM_{2.5}$, respectively.	Biomass burning was the primary source of peak $PM_{2.5}$ concentrations during the winter.
Takapuna	Biomass burning (32%) and marine aerosols (36%) were the main contributors to PM_{10} with motor vehicles being a relatively minor source (14%)	Biomass burning (60 % to 70 %) was the primary source of PM_{10} during peak winter days with substantial contributions from motor vehicle emissions (15 to 20 %). During summer, peak PM_{10} concentrations are most likely due to marine aerosol with minor contributions from crustal matter.
Penrose	Biomass burning (36 %) and motor vehicle emissions (28%) were the most significant contributors to $PM_{2.5}$ concentrations.	Biomass burning, most likely due to emissions from domestic solid fuel fires, was found to be responsible for peak $PM_{2.5}$ concentrations.

Table 4 Auckland vehicle fleet profile

		% of total VKT		
Vehicle type	**Fuel**	**2001**	**2006**	**2011**
Car	Petrol	72.9%	70.8%	70.3%
Light commercial	Petrol	5.9%	4.2%	3.6%
Hybrid & Electric	Petrol	0.0%	0.07%	0.3%
Car	Diesel	7.0%	8.1%	7.6%
Light commercial	Diesel	7.8%	9.7%	11.5%
Bus	Diesel	0.5%	0.6%	0.6%
Heavy	Diesel	5.9%	6.6%	6.1%
Total petrol (% of VKT)		79%	75%	74%
Total diesel (% of VKT)		21%	25%	26%

Source: Sridhar, *et al*, 2014

Trends identified in the emissions inventory were:

- Although there was a 16% increase in VKT between 2001 and 2011, NOx emissions are estimated to have decreased by 30% and PM_{10} emissions by 23% over this period; and
- The relative contribution of petrol cars to NOx emissions is expected to reduce over time due to improved emissions control. Consequently, diesel cars and

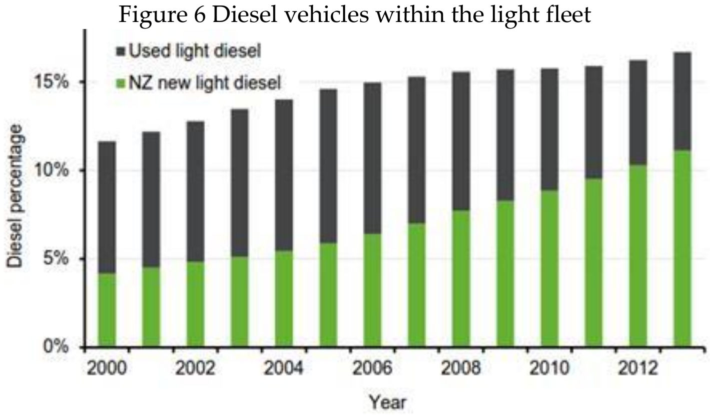
diesel light commercial vehicles are increasing in importance with respect to total NOx emissions from motor vehicles.

2.3.2 Trends in fleet composition

The relative contributions of different vehicle and fuel types, as described in Section 2.3.1, need to be considered in the context of the trends in the vehicle fleet composition. The following paragraphs summarise the key trends in the New Zealand fleet composition based on MoT Annual fleet statistics for 2013[35]:

As shown in Figure 6, the proportion of the fleet that is diesel-powered is increasing. For light vehicles, the proportion grew from 11.7% in 2000 to 16.7% in 2013, most of which are commercial vehicles. Light diesel vehicles continue to travel further on average each year than light petrol vehicles. A high proportion of new vehicles entering the light commercial fleet are diesel powered.

Figure 6 Diesel vehicles within the light fleet

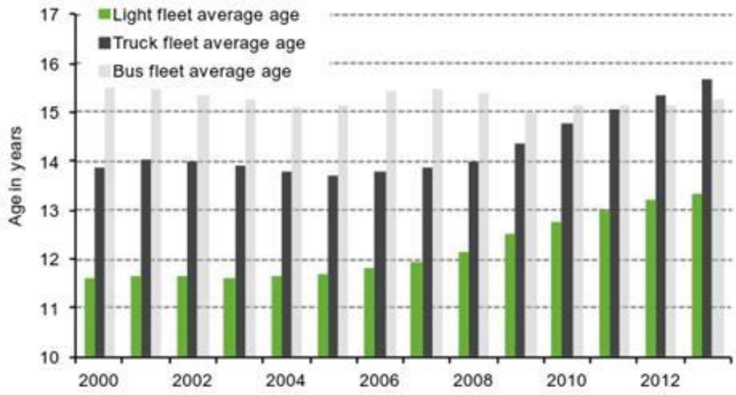


Source: MoT 2014

The average age of the light vehicle fleet, including passenger vehicles and light commercials (13 years), and the truck fleet (16 years) have been increasing in recent years (refer Figure 7). The average age of the bus fleet (15 years) has dropped slightly in recent years in response to increased new vehicle purchasing, although it remains relatively high. Emissions from older vehicles generally will be higher than newer vehicles of equivalent fuel type and servicing.

[35] Ministry of Transport Annual Fleet Statistics 2013 –August 2014 release http://www.transport.govt.nz/assets/Uploads/Research/Documents/New-Zealand-Vehicle-fleet-stats-final-2013.pdf

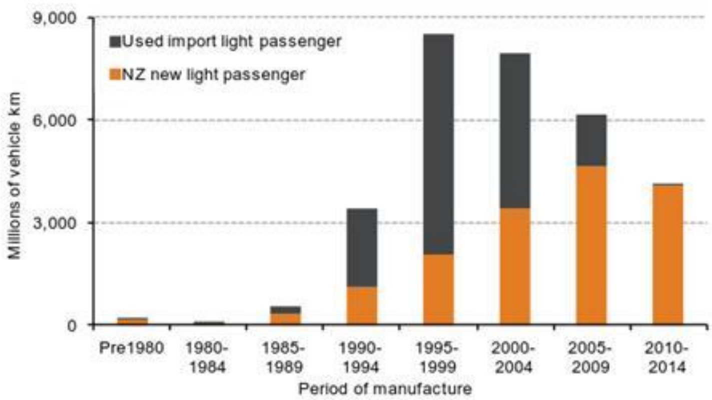
Figure 7 Fleet average age



Source: MoT 2014

There is a clear relationship between vehicle age and travel with older vehicles not being driven as far each year. However, a substantial proportion of travel is still done by light used imported vehicles manufactured during the 1990s. Light commercial vehicles are generally driven further each year than passenger vehicles until they reach an age of about 15 years, after which the annual distances are similar.

Figure 8 Light passenger fleet travel in 2013



Source: MoT 2014

There is an increasing trend in VKT despite the vehicle fleet size having remained relatively stable in recent years (2007 to 2012). In addition, the size of the fleet is projected to grow in future[36]; this growth is expected to include an increased uptake in diesel and hybrid and electric vehicles, but reduction in the number of petrol vehicles. This has implications for increased VKT and vehicle emissions, particularly from the diesel proportion of the fleet.

2.3.3 Cold start journeys

When a vehicle is started and operated from cold (ambient temperature), the emissions will be higher than when the engine and catalyst (if equipped) are operating under hot (normal operating) temperature. These higher emissions are due to a range of factors including fuel enrichment, higher friction, lower efficiency of combustion and lack of

[36] Ministry of Transport (2008b) Vehicle Fleet Emission Model

catalytic conversion (if applicable). The speed at which a vehicle engine cools after parking is dependent on variables such as wind speed, ambient temperature and engine size.

Standard emission models like VEPM5.1 include adjustment factors to allow for a percentage of the VKTs to be under cold start conditions. The percentage of cold start emissions is calculated from the average trip length, which can be changed by the model user. A shorter average trip length will result in higher average emissions because the proportion of the trip in cold start conditions is higher.

Heavy duty vehicles are mostly used for commercial purposes, which generally means longer trip distances and maximum utilisation. Therefore, the fraction of trip length affected by cold start operation is assumed to be zero.

2.4 Temporal and spatial characteristics of vehicle emissions

2.4.1 Introduction

In urban areas, the variable temporal and spatial nature of vehicle emissions and complex dispersion patterns due to the influence of urban form, result in localised pollution hotspots and strong horizontal and vertical pollutant concentration gradients. Temporal variations occur with changes in vehicle patterns diurnally and seasonally, while spatial variations include the linear nature of traffic corridors, the fleet emissions profile on different routes, the presence of intersections and buildings, and drop off in pollutant concentrations with increasing distance from road emission sources.

2.4.2 Diurnal patterns

Temporal variations in vehicle emissions occur through diurnal and seasonal variations in traffic flows. These variations can particularly be seen in monitored roadside pollutant concentration data. Diurnal profiles for the Auckland Council roadside and peak NO_2 monitoring sites (as shown in Figure 9) show concentrations are lowest overnight and peak concentrations typically mirror the two traffic flow peaks associated with morning and evening rush hours.

2.4.3 Reduction in pollutant concentrations with distance

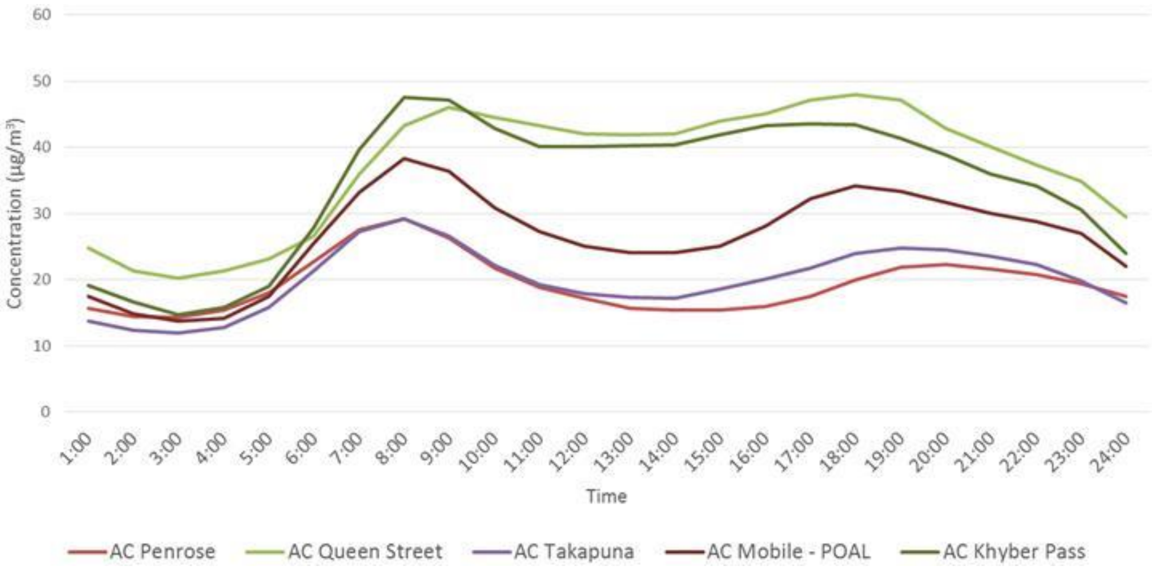
There is a strong horizontal gradient in pollutant concentrations with increasing distance from the road network due to dispersion of emissions.

An Auckland Study[37] which investigated the decline of NO_2 concentrations away from roadsides of motorways, through the review of passive diffusion tubes survey results, showed that, downwind of the prevailing wind, there is a general downward trend of NO_2 concentrations with increasing distances from the roadside. On average, concentrations are higher on the downwind side of the motorway and the contributions from the motorway can remain elevated up to at least 300 m away from the roadside.

[37] Auckland Regional Council (2007) Technical Publication No. 346 Nitrogen Dioxide in air in the Auckland Region: Passive Sampling Results.

A UK study,[38] which reviewed the results of numerous monitoring campaigns for NO_2 concentrations at differing distances from roads, showed a linear reduction in the influence of the road with the natural logarithm of distance from the kerb at distances between 10cm from the kerb and 140m from the kerb. In other words, NO_2 concentrations were found to reduce rapidly with increasing distance from the road. This relationship is expected to be similar for fine particles, which essentially behave like gases. The study showed that beyond 50m from the road, concentrations start to approach background levels and at 100m or more from the road, the difference between the total concentration and the background concentration become close to zero. From 50m of the roadside the reductions in measured concentrations are extremely small. The influence of vehicle emissions on pollutant concentrations therefore tends to be localised.

Figure 9 Diurnal profile for Auckland peak and roadside NO_2 sites (based on 2013 data)



Source: Auckland Council

2.4.4 Building effects

Street canyons are created where buildings occur on both sides of the road. The buildings cause the formation of vortices and recirculation of air flow that can trap pollutants and restrict dispersion. Street canyons tend to occur in narrow streets where the height of buildings on both sides of the road is greater than the road width. However, the presence of buildings along broader streets may also affect pollutant concentrations. This becomes an increasing issue in urban areas where new development increases the density and height of buildings along roadsides and results in a restriction of the dispersion of pollutants.

Locations on the windward side of a canyon can experience greater dispersion and ventilation leading to lower pollutant levels. However, pollutants can become trapped on the leeward side of a canyon, particularly when wind directions are perpendicular to

[38] Laxen, D. and Marner, B. (2008) NO_2 Concentrations and Distance from Roads. Air Quality Consultants Ltd.

the orientation of the street. Wind flows can vary, or even reverse, over short time periods, highlighting the level of complexity of dispersion in these circumstances.

Monitoring studies within street canyons commonly measure significantly different concentrations at different locations and heights within the canyon, and on each side of the canyon. Monitoring studies on both sides of street canyons also have shown that background concentrations influence pollutant levels within street canyons as the air mass at rooftop level moves into the canyon, leading to increased ventilation and "flushing out" of polluted air. Similarly, gaps between buildings may allow increased wind flows to enter the canyon thus re-circulating pollutants away from the junctions, but causing increased concentrations further away. However, the opposite effect may occur if the gap is at junction, where road traffic emissions are carried into the canyon, resulting in higher concentrations.

Auckland Council's Queen Street monitoring site in the CBD, is an example of where street canyon effects are likely to be a contributing factor to elevated pollutant concentrations.

2.4.5 Freight and public transport corridors

Given the disproportionate contribution of PM and NO_X emissions from diesel heavy commercial vehicle exhausts, freight and public transport corridors tend to experience higher corridor emissions compared with other roads with a lesser proportion of heavy vehicles in the fleet profile. The effect of these higher emissions on pollutant concentrations experienced by sensitive receptors will depend on a number of factors, including overall traffic volumes along the corridors, building and meteorological effects and proximity of sensitive receptors to the roadside.

Auckland Council's Queen Street monitoring site is located within a street canyon, prone to slow moving traffic and on a main bus route. Measured pollutant concentrations at this location are one of the highest of the automatic monitoring network (refer Section 2.1.1). However, this location is in an area of short-term exposure and not necessarily representative of urban air that people would be exposed to over long periods of time.

2.4.6 Influence of signalised intersections

Intersections are recognised as localised emission hotspots due to the cycle of vehicles decelerating, idling and accelerating. These effects can be seen in the continuous air quality monitoring data at Khyber Pass Road and the NZTA passive sampling sites at intersections (refer Section 2.1.2). Internationally, measures to reduce the localised air quality impact of signalised intersections include optimising light phasing to minimise queuing and replacement of signalised intersections with roundabouts or flyovers.

A report has recently been prepared for the Auckland Council that investigated the effects of motor vehicle emissions on PM_{10}, $PM_{2.5}$ and NOx concentrations in the vicinity of signalised intersections.[39] The intersection of Balmoral and Dominion Roads was selected as an example of a typical busy arterial intersection. The effects of motor vehicle emissions at this intersection, using actual traffic data, were investigated using dispersion modelling. The modelling study found that concentrations of air pollutants were predicted to be elevated in the vicinity of congested intersections compared to levels of pollutants measured near free-flowing traffic. Peak pollutant levels were predicted to occur within the first 20m from the intersection and the relative effect decreases with distance. The predicted pollutant levels were still higher than under free-flowing conditions at a distance of over 100m from the intersection (however the differences were less than 20% at this distance).

The University of Auckland undertook a study in 2009[40] which looked at spatial and temporal variability in pollutant concentrations at a complex signalised intersection (Symonds Street/Wellesley Street intersection in Auckland). This study showed how pollutant concentrations vary considerably in time and space around a complex intersection and that pollutant concentrations are not always dependent on proximity to the pollutant source. Local geometry and meteorology played an important role in determining local concentrations. Concentrations were found to be highest in Symonds Street associated with parallel flows, which was attributed to a combination of complex flow patterns resulting from the presence of trees in the street canyon and local advection influence local concentrations.

The standard motor vehicle emission models, like VEPM5.1, rely on average speed data and are not able to simulate the micro-scale emissions from signalised intersections.

2.5 Conclusions

In relation to identification of options to reduce the effects of motor vehicle particulate emissions, the above analysis indicates that:

- The main pollutants of interest related to motor vehicle emissions are particulates and NO_2;;

- With diesel vehicles, particularly heavy commercial vehicles, contributing disproportionately to PM_{10} and NOx emissions, targeting this segment of the fleet for emission controls could have significant benefits, e.g. a low emission zone (LEZ) or vehicle testing regime targeting heavy diesel vehicles;

- The localised (spatial and temporal) nature of pollutant concentrations from vehicle emissions indicates that targeted action to address pollution hotspots (particularly where there is relevant exposure) could have the greatest benefits, eg using a small area or corridor LEZ; and

- Urban form has a significant effect on pollutant concentration gradients and therefore land use planning and urban design have a significant role in reducing

[39] Noonan, M. Childcare Assessment Guidance Dispersion Modelling. Prepared by Beca Ltd for Auckland Council. 2014

[40] Salmond *et al* (2009) 3- Dimensional spatio-temporal variability in air quality at a road intersection

the effects of vehicle emissions in urban areas eg in preventing formation of street canyons and avoiding relevant exposure at busy roadside and intersections.

3 Review of Policy Options

In this section we discuss a number of policy options that have been used in other countries to address air pollution. We examine how they operate and the extent to which they are potential options for regional application in New Zealand. We consider the following options in turn below.

- Emission standards
- Emission charges
- Low emission zones
- Road pricing measures
- Emissions testing
- Fuel switching
- Fuel charges & RUC increases

3.1 Vehicle Exhaust Emission Standards

Requiring vehicles to meet exhaust emission standards aims to reduce the level of emissions produced by vehicles entering the fleet. Vehicle emission standards have been set in New Zealand to apply to vehicles imported (or first registered) new or used.[41] In general, emission standards do not restrict use of vehicles once they have entered New Zealand, apart from the requirement not to modify a vehicle such that it would not pass the emissions test required on first import, and a *visible smoke test*; these requirements are set out in Sections 3.2 and 4, respectively, of the Land Transport Rule: Vehicle Exhaust Emissions 2007.

The Rule requires that vehicles entering the New Zealand fleet meet a recognised international standard, eg Japanese, European, Australian or US.[42] Emission standards could be modified to apply the same standard to used imported vehicles to those currently applying to new vehicles, ie Euro 5/Japan 09,[43] which would limit imports to post-2009 vehicles.

In this section we discuss international analyses of requiring emission standards. In later sections we examine the potential for requiring vehicles in use to meet emission requirements for LEZs, which are effectively localised emission standards, and the inclusion of vehicle testing in Warrant of Fitness checks.

3.1.1 NZ Impacts

In contrast to LEZs and other geographically-specified policies, emission standards for imported vehicles apply to all vehicles wherever they are driven. However, the effects

[41] Exceptions are provided under some circumstances where the vehicle is more than 20 years old, is a 'special interest' vehicle or for immigrants bringing a passenger vehicle (or some other limited types) to New Zealand.

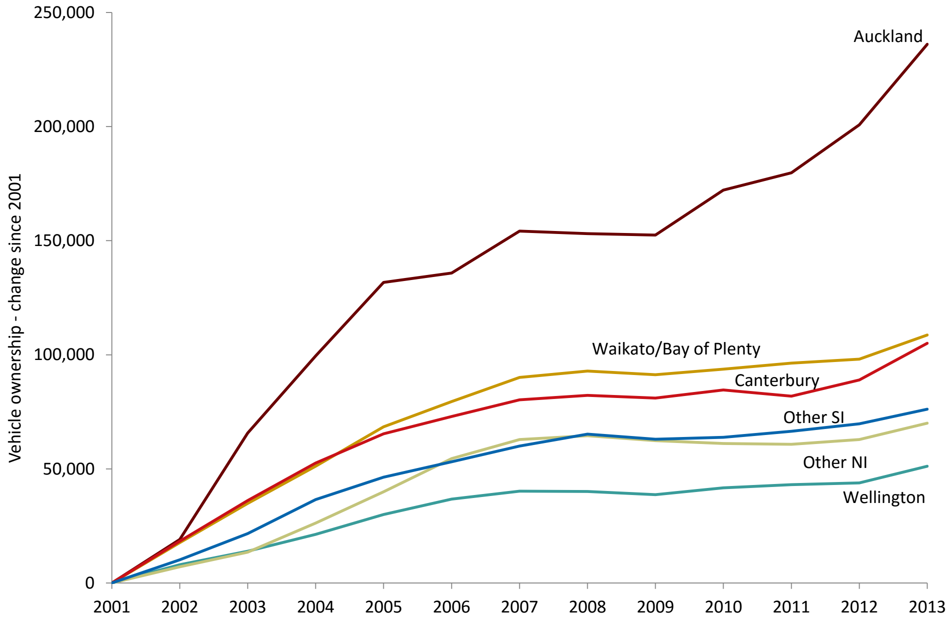
[42] http://vehicleinspection.nzta.govt.nz/virms/entry-certification/i-and-c/exhaust/exhaust-emissions#up

[43] Japan 09 for petrol applies to gasoline direct injection engines and this is used only in a few models by one manufacturer (Mitsubishi), meaning emissions standards cannot be effectively tightened for light petrol vehicles ex Japan (Iain McGlinchy, MoT pers comm).

and potential benefits will be somewhat weighted towards the major urban centres because:

- that is where the majority of fleet growth occurs (Figure 10)[44] such that there will be an expected larger effect of emission standards;
- the higher rate of growth is also reflected in the average age of the fleet. This is lowest in Auckland and Wellington, and highest in the South Island regions (Figure 11).

Figure 10 Growth in vehicle fleet since 2001 by region



Source: Ministry of Transport The New Zealand 2013 Vehicle Fleet: Data Spreadsheet; Covec analysis

Previous analyses of emission standard policies have suggested the potential downsides. By effectively restricting vehicle importers to the purchase of later model vehicles (that meet minimum recognised standards), average import prices will tend to rise. The market response was expected to include the import of newer vehicles, and potentially a shift towards retaining vehicles for longer, ie an aging fleet.[45] Because of the potential for an aging fleet, it was suggested that programmes to tackle vehicles at the other end of the market, eg scrappage programmes, might usefully complement these standards.[46]

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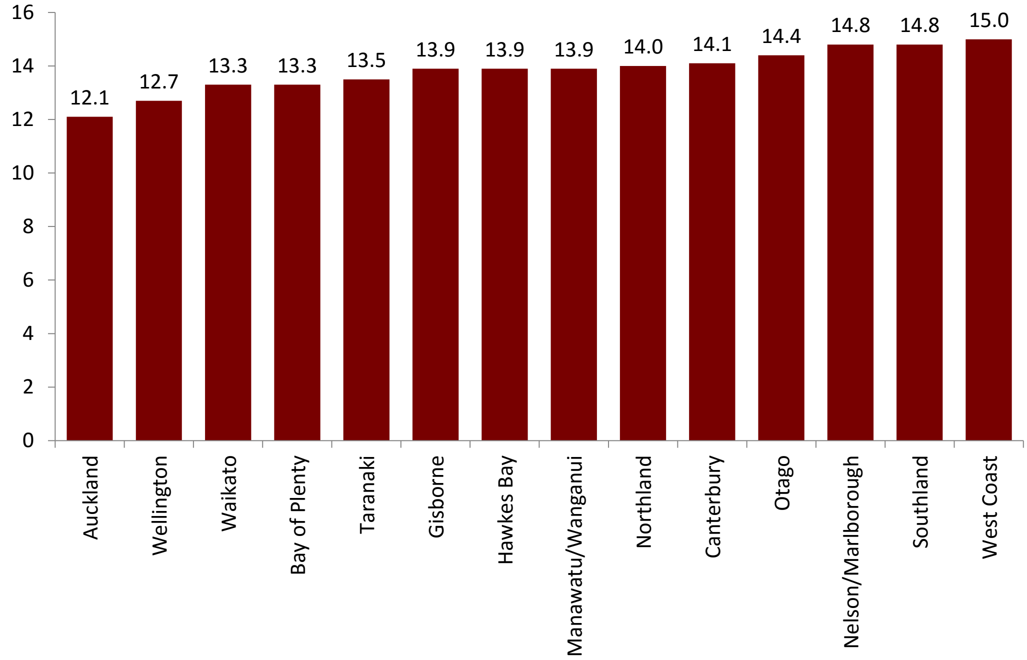
[44] Note, this will include some effect of people moving to Auckland with their vehicles from elsewhere in New Zealand

[45] Covec (2006) Socio-economic impacts of emissions standards on used imported vehicles. Report to Ministry of Transport

[46] Covec (2007) Update and Extension of Vehicle Emissions Modelling. Final Report to Ministry of Transport.

Figure 11 Average Age of Vehicle Fleet by Region (as of 2013)



Source: Ministry of Transport. Transport volume : Fleet information (www.transport.govt.nz/ourwork/tmif/transport-volume/tv006/)

International studies have suggested that such programmes can be successful,[47] but the cost-effectiveness at reducing emissions is limited because older (low value) vehicles targeted by scrappage programmes are likely to be driven little. For example, a review of trials with scrappage schemes in Auckland, Wellington and Christchurch concluded that there were "*limited social and environmental benefits from the early retirement of vehicles during the trials*", that "*the scrapped vehicles would have been scrapped soon regardless of the trials*", on average the replacement vehicles "*were around 12 years old, … have larger engines and are driven further than older vehicles and so fuel savings were unlikely*" and although "*scrapped vehicles were likely to have limited emissions controls (such as exhaust catalytic converters) …[they] generally did not travel far.*"[48] In addition, prior to the introduction of exhaust emission standards there is little relationship between emissions and vehicle age (apart from the introduction of control technologies/catalytic convertors).[49]

The evidence for the actual (rather than predicted) impacts of NZ emission standards (introduced in January 2008) on the vehicle fleet is somewhat unclear. The average age of the vehicle fleet has increased over time (Table 5), but this will reflect factors that include the very large number of mid-1990s vehicles that were imported in the early 2000s (Figure 12) and improved vehicle longevity, ie vehicles are built better and last longer anyway. The average age of used light petrol vehicles entering the fleet has not changed with the introduction of vehicle exhaust emission standards (Figure 13),

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[47] IHS Global Insight (2010) Assessment of the Effectiveness of Scrapping Schemes for Vehicles. Economic, Environmental, and Safety Impacts. Prepared for: European Commission DG Enterprise and Industry Automotive Industry

[48] Ministry of Transport (2009) A vehicle scrappage trial for Christchurch and Wellington: May 2009

[49] I McGlinchy, personal communication

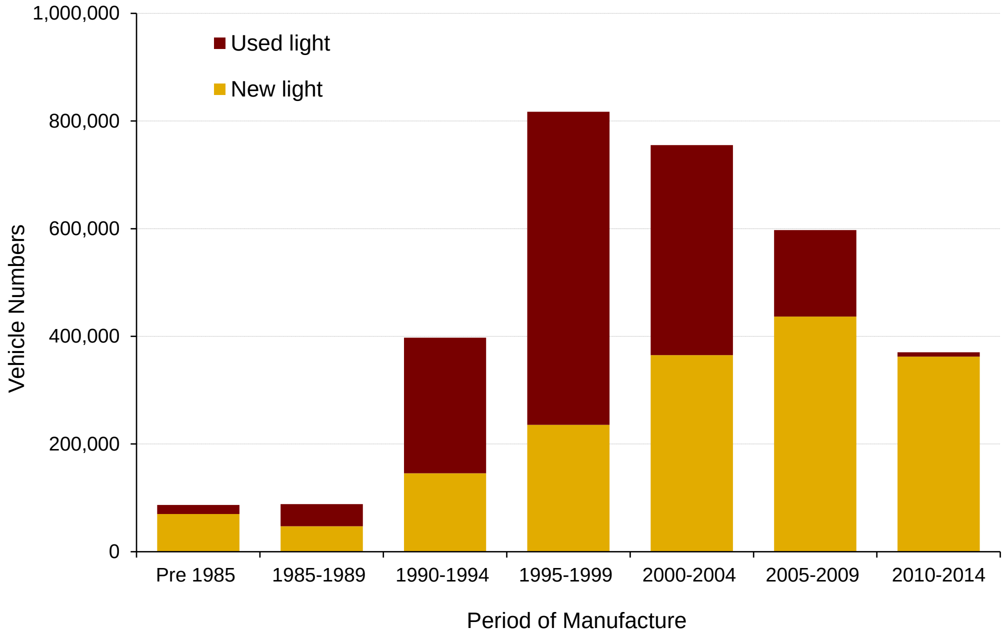
despite the expectation of a change to newer vehicles (as noted above); it may be that the emission standards have largely reinforced existing trends. However, there has been a general decrease in the average of age of imports of used trucks and light diesel vehicles since the introduction of standards in 2008For used light diesels the impact was delayed until the tighter standard (from Japan 02/04 to Japan 05) commenced in January 2009.

Table 5 Average age of fleet in different vehicle categories

Period	Light Private	Light Commercial	Heavy Commercial	Bus	Other
2000	11.57	11.97	13.87	15.50	17.63
2001	11.60	11.98	14.01	15.49	17.64
2002	11.60	11.93	13.99	15.37	17.17
2003	11.59	11.86	13.91	15.25	16.77
2004	11.63	11.75	13.79	15.08	16.62
2005	11.71	11.63	13.71	15.15	16.31
2006	11.84	11.61	13.79	15.41	16.50
2007	12.02	11.55	13.88	15.46	16.53
2008	12.22	11.56	14.00	15.37	16.49
2009	12.59	11.85	14.38	14.96	16.62
2010	12.88	12.05	14.78	15.13	17.05
2011	13.15	12.16	15.04	15.16	17.20
2012	13.35	12.23	15.35	15.13	17.48
2013	13.53	12.21	15.67	15.27	17.77

Source: Ministry of Transport The New Zealand 2013 Vehicle Fleet: Data Spreadsheet

Figure 12 Period of manufacture of light fleet



Source: Ministry of Transport The New Zealand 2013 Vehicle Fleet: Data Spreadsheet

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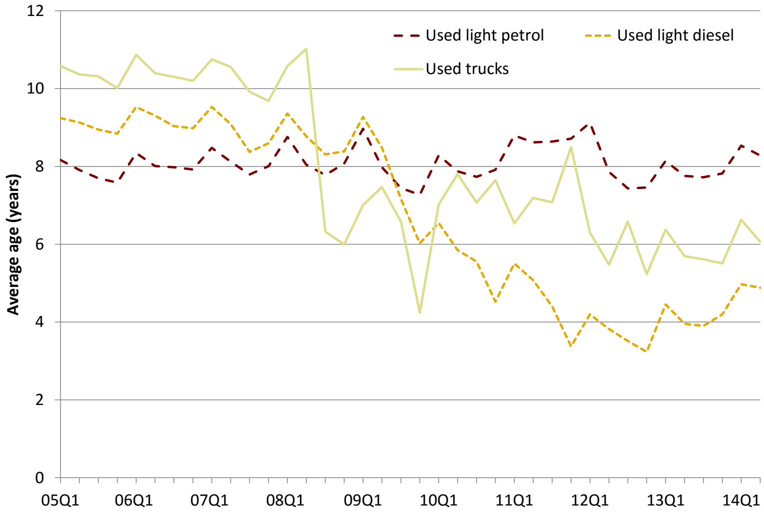
Figure 13 Average age of vehicle imports



Source: Ministry of Transport. The NZ Vehicle Fleet : Quarterly Update Jun 2014

Vehicle emissions under actual operating conditions may be different from that expected based on certification standards. Typically, vehicle emission models, including VEPM, apply corrections based on extensive testing databases to account for differences from the certification standard and for degradation in performance with vehicle age.

3.1.2 International Studies

International studies that have considered the costs and benefits of emission standards on fleet entry have tended to suggest significant net benefits as a result. UK[50] and German[51] studies suggest that emission standards are some of the most cost-effective measures aimed at reducing emissions.

In the UK cost benefit analysis, emission reductions were analysed that went beyond Euro 4 for light duty vehicles (from 2010) and Euro V for heavy duty vehicles (from 2013). It was assumed that tighter standards were met using emission reduction technologies that need to be fitted at manufacture.[52]

In this report we do not examine the effects of emission standards per se. This is both because:

- the interest is in policies that can be introduced for specific geographic areas, rather than nationwide, and measures such as LEZs are equivalent to locally-specified emission standards; and

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[50] Defra *et al* (2007) An Economic Analysis to inform the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits

[51] Sadler Consultants (2010) Low Emission Zones in Europe. Report for the UK Department of Transport

[52] See Defra (op cit), pp103, 108, 113

- there is little scope for tightening import standards beyond those that exist currently as stringent emission standards are already required.

3.2 Emission Charges

Emission charges would provide incentives for purchasing lower emission vehicles because of the higher operating costs of higher-emitting vehicles. Emissions charges could operate as differential acquisition fees or differential annual registration fees. Other forms of charges, eg road charges or fuel charges are discussed below.

Vehicle charges that vary with emissions have typically been introduced to address CO_2 emissions. In theory charges could be used to incentivise purchases of vehicles with low emissions of other pollutants. If targeted at particulates this would mean higher charges for diesel vehicles than for petrol vehicles (see Table 6).

Table 6 Relative emissions (per VKT) by vehicle type (2011) – including exhaust plus brake & tyre emissions

Vehicle type	CO_2 (g/km)	NOx (g/km)	PM10 (g/km)
Petrol car	217.9	0.443	0.015
Diesel car	224.6	0.696	0.162
Petrol LGV	270.9	0.649	0.014
Diesel LGV	270.3	0.828	0.120
Diesel HGV	639.4	4.207	0.199

Source: Estimated from Table A-3 in Sridhar S, Metcalfe J and Wickham L (2014). Auckland motor vehicle emissions inventory. Prepared by Emission Impossible Ltd for Auckland Council. Auckland Council Technical report, TR2014/029

Emission charges would ideally be set at a level that reflected the costs of emissions from each vehicle type. To be most economically efficient, ie to provide incentives for emission reduction at least cost, this would need to reflect the expected emission costs over the lifetime of the vehicle (if on acquisition) or per year (if an annual licence fee). However, because these costs are likely to vary significantly by location (costs are low if emissions are away from people), this approach will not be highly efficient. It is more suitable for addressing CO_2 emissions than local pollutants.

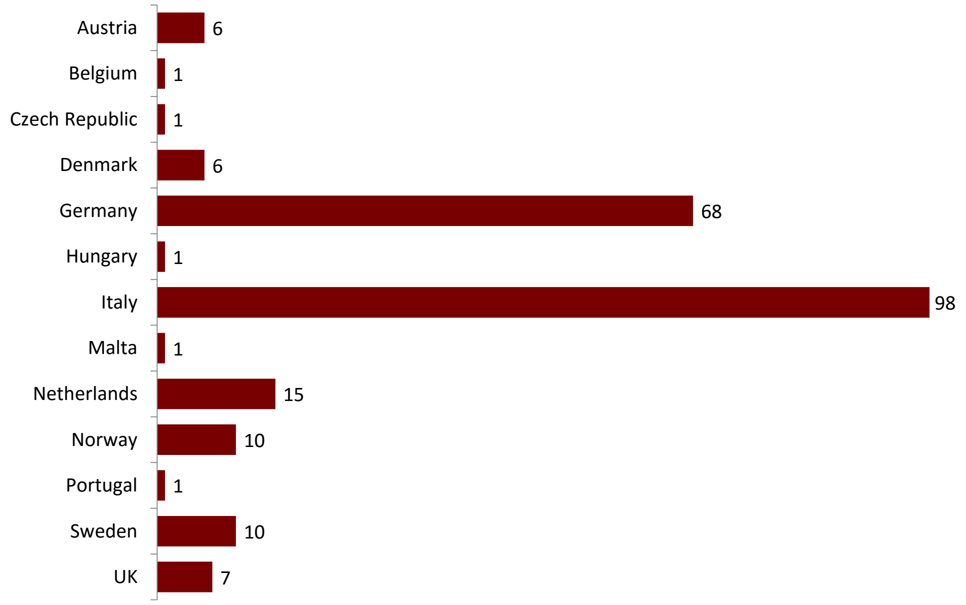
3.3 Low Emission Zones

3.3.1 Description

Low Emission Zones (LEZs) are "*areas or roads where the most polluting vehicles are restricted from entering. This means that vehicles are banned, or in some cases charged, if they enter the LEZ when their emissions are over a set level.*"[53] They might be characterised as "in-service emission standards" that apply to vehicles in use and not just to imports during entry certification. There are around 225 LEZs in operation, or planned, in 13 European countries (Figure 14). Examples are provided in Annex 1.

[53] http://urbanaccessregulations.eu/low-emission-zones-main

Figure 14 LEZs in Europe (current and planned)



Source: http://urbanaccessregulations.eu/lez-quick-guide

The London LEZ is identified as a charge-based system rather than a restriction, as no vehicles are restricted; they are simply made to pay (high) entrance fees that are designed to discourage entry.

Approaches to LEZs differ in the extent to which they either:

(1) make broad generalisations about which vehicles are most polluting, eg heavy duty goods vehicles are restricted, or

(2) are more targeted, eg using vehicle-specific emission rates and/or whether they have a catalytic converter (which is recorded with the vehicle data).

Most of the LEZs in Europe affect heavy-goods vehicles (HGVs) only;[54] however, also including light duty vehicles gives greater impact.[55] Apart from some Italian examples, typically LEZs are in force 24 hours a day, 365 days a year.[56]

Some examples are given in Table 7. The LEZs vary with:[57]

- approach – charge (Milan, London) vs restrictions (Sweden, Netherlands, Germany); and
- target – broad categories (Sweden) vs more targeted approaches (Germany)
-

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[54] Heavy duty vehicles (HDVs) in the UK

[55] Sadler Consultants (2010) Low Emission Zones in Europe. Report for the UK Department for Transport

[56] http://urbanaccessregulations.eu/low-emission-zones-main

[57] Defra (2009) Local Air Quality Management Practice Guidance 2. Practice guidance to Local Authorities on Low Emissions Zones.

Table 7 Examples of LEZs

Vehicle Type	LEZ	Current Emissions standard 2014	Future Emissions standard[1]
Trucks only	Netherlands	Euro IV	
	Motorway A12, Austria	Euro II/III	
	Austria regional	Euro I - III	Euro III
	Mont Blanc Tunnel, FR/IT	Euro III	
	Prague, CZ	Euro II	
	Budapest, Hungary	Differential parking charges	
Heavy duty vehicles	London, UK	Euro IV (PM)	
	Denmark	Fit Filter if less than Euro IV	
	Sweden	8 years old / Euro III	
Vehicles with 4+ wheels	Germany	Euro 3/III-4/IV (PM) & Euro 1/I Petrol	Euro 4/IV (PM) & Euro 1/I Petrol
	Lisbon, Portugal	Euro 1/I or Euro 2/II	Planned: Euro 3/III all
	Greece, Athens	Euro 1/I Euro 4/IV	
	Netherlands		Utrecht from 1/1/2015.
All vehicles	Italy	Euro 1-4/I-IV ; no 2-stroke motorcycles	Euro 2-4/II-IV; no 2-stroke motorcycles
Local buses under agreements	Norwich, UK	Euro III (NOx)	
	Oxford, Brighton, UK	Euro V	
Vans	London, UK	Euro 3 (PM)	
	Germany	Euro 2-4 (PM) & Euro 1 Petrol	Euro 3-4 (PM) & Euro 1 Petrol
	Italy	Euro 1-4 / no 2-stroke motorcycles	Euro 2-4 / no 2-stroke motorcycle
	Netherlands		Utrecht from 1/1/2015.

[1] These are the emission standards expected to be adopted in the future for these LEZs
Source: modified from http://urbanaccessregulations.eu/overview-of-lezs

3.3.2 Components

The individual components of LEZs include:[58]

- the vehicles to be affected;
- the emissions standard to be required;
- whether sticker or database identification (camera enforcement), and whether vehicle operators need to register;
- enforcement methods and penalties;
- the main exemptions;
- that the LEZs are in permanent operation

All LEZs except those in Sweden, Norway and the Austrian motorway allow retrofitting of diesel particulate filters (DPFs) to meet the PM standard. That means if a vehicle does not meet the required standard (eg, because of the age of manufacture), the owner can choose to retrofit a DPF.[59]

[58] Sadler Consultants (op cit)
[59] Sadler Consultants (op cit)

3.3.3 Evaluation

The magnitude of the air quality impact of the LEZ depends on the emissions standard set.[60] Most LEZs have two phases, phase 1 with a less stringent standard to enable start-up, phase 2 expecting to have more impact.

Qualitative

Defra reports on the expected effects of the LEZ in qualitative terms. It notes a number of factors that are significant determinants of costs: [61]

- **the number of vehicles** because in broad terms, the size of the UK fleet rises in number from bus/coach, heavy commercial, light commercial, to passenger cars, so a scheme that includes only heavy vehicles will tend to cost less than one that only includes passenger cars, all other things being equal;

- **the size of the area**, eg because of the number of entry points;

- **level of technology used** – schemes that use technologies such as tags, smart cards or Automatic Number Plate Recognition (ANPR) cameras will have higher set-up costs than paper or sticker-based schemes.[62] These costs need to be compared with the effectiveness of the different options.

Quantitative

A review of the experience with LEZs by Sadler Consultants notes the effects both in terms of monitoring data and from emissions modelling. The monitoring data suggest reductions in annual average PM_{10} and NO_2 concentrations of zero to 12%; these were generally greater than the modelled effects. However, there were a number of other circumstances that would have affected results including differences in weather conditions and changes in levels of other activities, eg building work.

An economic analysis of the UK's Air Quality Strategy included an analysis of a number of LEZ options.[63] The initial London LEZ feasibility study,[64] found that benefits are highest in year 1 and fall over time because of the turnover of the fleet (vehicles improving in emission levels over time). The effects were estimated by measuring emission reductions and applying a relevant cost per tonne damage cost estimate.

The analysis suggested that the benefits would apply beyond London because of a cleaner fleet operating. As 30% of all trucks and 50% of buses (coaches) in the UK enter London an LEZ for London would result in cleaner vehicles being used more widely.

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[60] Sadler Consultants (2010) Low Emission Zones in Europe. Report for the UK Department for Transport

[61] Defra (2009) Local Air Quality Management Practice Guidance 2 Practice Guidance to Local Authorities on Low Emissions Zones, p25.

[62] Sticker-based schemes require vehicles to have the appropriate sticker on their windscreen (eg the red, yellow or green stickers of the German schemes). These are readily identified manually.

[63] Defra *et al* (2007) An Economic Analysis to inform the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits

[64] Watkiss P *et al* (2003) London Low Emission Zone Feasibility Study. Phase II. Final Report to the London Low Emissions Zone Steering Group. AEA Technology.

The study also noted that pre-Euro and Euro I vehicles are noisier so the measure would have reductions in noise also.

The estimated costs included those for implementing and operating the scheme. Manual and automatic schemes were considered. The total costs depend particularly on the response of operators with non-compliant vehicles (pre-Euro, Euro I and Euro 2/II vehicles) – replacing vehicles, re-engining, fitting abatement equipment (particulate filters for PM or SCR for NOx) etc.

Overall the net benefits were estimated to be negative, ie costs exceed the benefits.

3.4 Road Pricing

Road pricing schemes can operate in an undifferentiated way, ie costs for entry regardless of vehicle, or can be differentiated by vehicle type.

3.4.1 Un-Differentiated Prices

In the UK, a national road pricing scheme was evaluated using evidence from a separate road pricing feasibility study.[65] The scenarios examined included charges that differed with levels of congestion, road type, and area type (eg urban/rural). The assessment assumed charge levels equal to marginal social costs (based on estimates of damage) within a maximum of 10 charge bands; it was capped at 80pence/km (NZ $1.60/km). Air quality benefits represented a small proportion of the total benefits, with reductions in congestion valued more highly in total. The measure was estimated to save 196,000-374,000 life years from particulate matter reduction over 2010-14 and to reduce CO_2 emissions by 1.5 million tonnes.

The analysis suggests that such a measure would not be a primary policy tool for addressing air pollutants.

3.4.2 Differentiated Prices

Milan

Milan combines an LEZ with a congestion charge, and as a result the effects include a reduction in the number of vehicles entering the zone, in addition to a change in the vehicle fleet. The focus of the Milan Ecopass Scheme (MES) was to improve air quality.

The MES was introduced in 2008 for entry to an 8 km^2 area in the city centre. The charge varies based on a number of factors, primarily with the Euro emission standard of the vehicles entering the area and the frequency of entry (see Table 8). The MES operates via an automatic-number-plate-recognition (ANPR) technology, previously tested in London, and Stockholm.

[65] Department for Transport (2004) Feasibility study of road pricing in the UK – Full Report

Table 8 Milan Ecopass tariffs

Class	Definition	Daily charge (€)	Yearly pass
I	LPG, methane, electric, hybrids	Free	Free
II	Petrol: Euro 3,4 or higher; Diesel: Euro 4 without PF; Cars & freight: Euro 4 with PF	Free	Free
III	Petrol: Euro 1 & 2	€2	€50
IV	Petrol: Euro 0; Diesel cars: Euro 1-3; Diesel goods vehicles: Euro 3; Diesel buses: Euro 4 & 5	€5	€125
V	Diesel cars: 0; Goods vehicles: Euro 0-2; Diesel buses: Euro 0-3	€10	€250

Source: Rotaris L, Danielis R, Marcucci E and Massiani J (2009) The urban road pricing scheme to curb pollution in Milan: a preliminary assessment. Università di Trieste, Dipartimento di Economia e Scienze Statistiche Working Paper n. 122

As a result of the scheme, average annual PM_{10} concentrations are estimated to have fallen from 51-53μg/m^3 in 2008-07 to 40-44μg/m^3 in 2008-10. Overall the MES is estimated to have had positive net economic benefits.[66]

Netherlands

The Netherlands Ministry of Housing, Spatial Planning and the Environment (VROM) has considered the impact on particle emissions of varying a kilometre-based road charge according to whether or not vehicles are fitted with a particle filter.[67] The scheme was conceptualised as a penalty/discount system, with diesel cars lacking an ex-works particle filter subject to a penalty of 2.5 Euro cents on top of the standard kilometre tariff and other vehicles being eligible for a discount. The level of this discount was designed such that the kilometre charge remains cost-neutral for motorists. It was projected to result in a reduction in PM_{10} emissions of between 0.01 and 0.06 kt in 2020, or 1 to 7% of the total particulate emissions of passenger cars, and a similar percentage reduction in $PM_{2.5}$ emissions.

3.5 Emissions Testing

Emissions testing measures would introduce requirements for an emissions test as part of the Warrant of Fitness (WoF) or Certificate of Fitness (CoF) for diesel vehicles, with a requirement for those vehicles that fail the test to take steps to come into compliance. Typically an emissions screening programme has the following elements:[68]

- performance limits, including their stringency and banding (different standards for different vehicle classes/characteristics);

[66] Danielis R, Rotaris L, Marcucci E and Massiani J An economic, environmental and transport evaluation of the Ecopass scheme in Milan: three years later. Available at: http://www2.units.it/danielis/wp/Ecopass%20-%203%20years%20later,%20finale.pdf

[67] www.cedelft.eu/publicatie/the_impact_of_particle-filter_differentiation_of_the_kilometre_charge_on_pm10_emissions_/1003

[68] Ministry of Transport (2004) New Zealand Vehicle Emissions Screening Programme. Discussion Document.

- network requirements – whether test facilities are centralised or de-centralised, with the approach generally reflecting the complexity of test procedure;
- test type requirements – visual checks, idle tests, dynamometer tests, On-Board Diagnostics (OBD) etc;
- vehicle coverage – which classes of vehicle are included; and
- frequency of test requirements.

An alternative approach would use remote sensing of vehicles to identify potential gross emitters and then only request those vehicles to present themselves for a full emissions test. This would be expected to have lower costs and benefits than the option examined here.

3.5.1 Expected Effects

Previously it has been suggested that older vehicles have higher emission rates and that emission tests would be expected to increase the likelihood of repair or scrappage requirement for older vehicles.[69] This effect is reduced if the emission test differs with the age of the vehicle, ie if it is testing whether the vehicle is performing at the standard to which it was manufactured. However, as with other vehicle engine problems, the older the vehicle the more likely that there is some kind of failure that results in higher emissions than at original manufacture. This is observed in percentage failure rates for emissions testing.[70] Thus, older vehicles are more likely to fail tests and, all other things equal, this leads in turn to reduced demand for older vehicles and increased demand for newer vehicles.

If vehicle repairs can be used to make a vehicle compliant, the impacts of the policy will be muted by the dynamic effect on the vehicle market: increased costs of repair for older vehicles would be expected to be compensated for (from the buyer's perspective) by reduced vehicle price such that the full cost of purchasing older vehicles may not change.

3.5.2 TEDDIE

The TEDDIE (TEst(D)DIEsel) project was coordinated by the International Motor Vehicle Inspection Committee (CITA) and jointly funded by its members and the European Commission. It set out to investigate cost-effective equipment and procedures

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[69] Covec (2005) Vehicle Fleet Emission Screening Programme Social and Economic Impact Assessment Phase I. Final Report to MoT.

[70] Thomas WD (2014) Which Vehicles have a Higher Probability of Failing a California Smog Check Inspection Primarily Consisting of a Diagnostic Scan of the Vehicle's on-Board Computer System? A Thesis Presented to the faculty of the Department of Public Policy and Administration California State University, Sacramento Submitted in partial satisfaction of the requirements for the degree of master of Public Policy and Administration; Wenzel T, Ross M and Sawyer R (1997) Analysis of Emissions Deterioration of in-use Vehicles, using Arizona IM240 data. Presented at the Society of Automotive Engineering Government/Industry Meeting Washington, DC May 5-7, 1997; www.abqjournal.com/380116/news/what-are-the-emissions-failure-rates-for-cars-of-various-ages.html; www.cga.ct.gov/PRI/archives/1999veconsultant.htm

for measuring emissions of nitric oxide (NO), nitrogen dioxide (NO_2) and particulate matter (PM) during the periodic technical inspection (PTI) of diesel road vehicles in the European Union (EU).[71]

Currently the PTI measures the opacity of diesel exhaust during a so-called 'free acceleration' test. The limits are vehicle-specific, and stated as 'plate' values on the vehicle. The TEDDIE programme has investigated alternative test procedures. The research concluded that the combination of the free acceleration test and new instruments measuring PM in mg/m^3 (instruments using the laser light scattering principle and one 'escaping current' sensor) represents a viable option for the future PTI emission testing of cars, but that further evaluation is needed for heavy-duty vehicles. The measurement of NOx emissions (or the NO_2/NOx ratio) and the use of OBD during PTI emission tests require further investigation in field tests.

A cost benefit analysis (CBA) has been undertaken of the measure but it is flawed. It argues, for example that "*counting the repair costs is economically incorrect. … spending money on repairs leads to benefits for the repair industry. So repairing is, in the general economic sense, only a shift of money from the consumer (car owner) to the car repair centre and automotive industry.*"[72] This assumes that all payments to repairers are pure profit rather than compensating repairers for the opportunity costs of allocating labour and other resources to repair activities. Only the costs of the test equipment were taken into account.[73]

Some simple assumptions were made, eg that 10% of the inspected vehicles would have exhaust defects that could be only detected by the new roadworthiness emission test and that the detected defects would be completely repaired so that the emissions of vehicles would return to their design levels.

The analysis suggested that the benefits in terms of emissions savings would be equivalent to €20/vehicle tested. They compared this to the costs of the test equipment (annual costs of €22 – 92 million or €0.53 – 2.14 per vehicle tested) to suggest very significant net benefits. However, given the assumed 10% of vehicles failing, average repair costs of over €183-200/vehicle would mean that the policy had a net cost.

3.6 Fuel Switching

Some fuel switching measures might be used to achieve reduction in particulate emissions, eg biofuels encouragement. The New Zealand government introduced the 2007 Biofuels Bill which set a future mandatory biofuels sales target but this was later repealed by amendments to the Energy (Fuels, Levies, and References) Act 1989 at the end of 2008. The requirements under the original Bill were similar in form to obligations

[71] Boulter P *et al* (2011) TEDDIE A new roadworthiness emission test for diesel vehicles involving NO, NO_2 and PM measurements. Final Report. European Commission, DG-MOVE Contract: MOVE/MAR/2010/D3/59-1/S12.583229/TEDDIE

[72] Ibid, p83

[73] They also argued that because vehicle owners had a legal requirement to make their vehicles roadworthy the costs to do so, even if they only happened as a result of the test procedure being introduced, should not be counted. However, they counted the benefits of making vehicles roadworthy.

introduced in other countries, such as the UK Renewable Transport Fuel Obligation (RTFO).

Kuschel notes studies for Auckland Regional Council that had found emission reductions for PM and other pollutants from biodiesel blends in buses compared with 50ppm sulphur diesel.[74] In field tests she found reductions in smoke density of 3-50% (95% confidence level). Similarly, the US EPA suggests that there can be significant reductions in particulate emissions with biodiesel.[75] Some international analyses have suggested that although biofuels have slightly lower emission rates for particulates than conventional fuels, they can have higher emission rates for NOx;[76] they are primarily aimed at reducing CO_2 emissions.

Others have noted the benefits of using biodiesel in an emulsion, eg "a 6.5% (by mass) water content in the emulsified B20 biodiesel fuel effectively 'neutralized' any NOx emissions increases previously witnessed with regular B20 biodiesel fuel use in diesel engines" and that "emulsion technology significantly reduced particulate matter (PM) emissions on the order of 42% as compared to the levels witnessed with ULSD fuel."[77]

Some consideration of biodiesel, including in regional fuel markets, may be worthwhile, particularly in emulsion form. However, we have not considered it further in this study, particularly given the uncertainty over the effects.

3.7 Fuel charges & RUC increases

Fuel charges and increases in road user charges (RUCs) might be used to tackle PM emissions.

A study of the effectiveness of a road tax (based on vehicle miles travelled) in the US found that a tax of $0.003 per passenger car mile (NZ0.2c/km)[78] and $0.01 per light-duty truck mile (NZ0.8c/km) (resulting in a mean annual tax burden of US$128 per household in the first year) would reduce annual particulate emissions by between 7% and 11%, depending on the degree of heterogeneity in household driving behaviour. Doubling the tax rates would result in reductions in PM_{10} emissions of between 12% and 23%.[79]

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[74] Kuschel G (2014) Investigations into Reducing Emissions from Heavy Duty Diesel Vehicles in Auckland – a Summary Report. Auckland Council Technical Report 2014/018.
[75] Miller AC (2008) Characterizing Emissions from the Combustion of Biofuels. US EPA/600/R-08/069.
[76] Covec (2006) Enabling Biofuels: Biofuel Economics. Report to Ministry of Transport. This built particularly on emission factors in: Beer T, Grant T, Morgan G, Lapszewicz J, Anyon P, Edwards J, Nelson P, Watson H and & Williams D (2001) Comparison of Transport Fuels Final Report (EV45A/2/F3C) to the Australian Greenhouse Office on the Stage 2 study of Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles
[77] Grimes P, Hagstrand W, Psaila A, Seth J and Waldron J (2011) Emulsified Biodiesel Fuel Effects on Regulated Emissions. DieselNet Technical Report (www.dieselnet.com/papers/1112grimes.pdf)
[78] At $10/t CO_2 a carbon price would have an impact on a vehicle with an average fuel efficiency of 10litres/100km of approximately 0.23c/km (0.27c/km for diesel) – see Covec (2011) Impacts of the NZ ETS: Actual vs Expected Effects. Report to MfE.
[79] Larsen J and Caplan AJ (2009) "Estimating the Effectiveness of a Vehicle Miles Traveled Tax in Reducing Particulate Matter Emissions." Journal of Environmental Planning and Management, 52(3), 315-344.

These instruments have not been considered further in this study because of the focus on geographically-specified interventions. Price instruments have been addressed in the form of road pricing.

3.8 Summary

A summary of the review is given in Table 9. It suggests the following:

- The main policies with potential for being used in a geographically-confined area are LEZs, road pricing and regional emissions testing.
    - **LEZs**' effectiveness varies with the stringency of the requirements set and the costs appear to be related significantly to whether the requirements can be met using retrofit technologies or if they force vehicle replacement.
    - **Emissions testing** with regional emission standards can provide incentives for vehicle maintenance which can slow the deterioration of engine performance and the increase in emissions with vehicle age. The costs include those of the test itself and the responses, which will be a mix of vehicle repair and replacement.
    - **Road pricing** can have a similar effect to an LEZ if specified such that charges vary with emissions. Generalised road pricing can reduce emissions through reducing overall VKT and is likely to target older more polluting vehicles because users would be expected to be more responsive to price.
- Other policies that can be used but have lesser potential for geographical-specification include emission standards, emission charges (on vehicle licencing/purchase), encouragement of alternative fuels and increases in fuel charges or RUCs. We have not considered these further in this study.

In this study we analyse the potential impacts of the three main policy options that can be used in a geographically-limited areas.

Table 9 Summary of Policy Option Review

Policy Option	Primary Target	Geographically limited	Potential effectiveness	Main cost factors	Risks
Emission standards	Emissions	No	Little scope for tighter international-based standards on new vehicles but standards for used vehicles could be increased. Effectiveness would vary with stringency and is proportional to costs	Higher costs if standards result in significant change in vehicle purchases. May be limited through allowing retrofits	Increase in costs for new vehicles may lead to extension of life of existing vehicles, although little evidence of this historically
Emission charges	Emissions	No	Limited effectiveness. More suited to CO_2	Higher costs if it results in significant change in vehicle purchases. May be limited through allowing retrofits	Increase in costs for new vehicles may lead to extension of life of existing vehicles as cost of change increases
Low emission zones (LEZ)	Emissions	Yes	Varies with standards set and is proportional to costs	Higher costs if it results in significant change in vehicle purchases (rather than shifting location of existing vehicles). May be limited through allowing retrofits	High costs from vehicle replacements. CBAs suggest limited to negative net benefits
Road pricing	VKT or emissions	Yes	Generalised road pricing can shift VKT and thus reduce emissions. Road pricing that varies with emission rates can be more targeted and effective.	Pricing (rather than outright bans) can limit costs for currently non-compliant vehicles. Given the option, this approach will always be lower cost than a "straight" LEZ	
Testing	Emissions	Yes	Depends on market response. Failing vehicles may be outside of main urban areas.	Costs will be proportional to level of standard set	Increase in repair costs can result in higher costs for lower income households
Fuel switching	Emissions	Possibly for sales (but cannot exclude vehicles filled elsewhere)	Evidence is mixed but new emulsion fuels may be effective	Varies with percentage requirements (eg biofuel obligation)	Potentially negative effects (eg higher NOx) Political and other risks over biofuel sources
Fuel charges/RUCs	Fuel consumption, VKT	Limited potential	Reduced VKT reduces all emissions but may not be well targeted. High emission areas may have high demand for transport activity	Elasticity of demand for transport.	Main impacts are in areas with little current air pollution impact

4 Benefit Valuation

In this section we set out how we have measured the benefits of reductions in air pollution associated with the individual policies. There is more detail in Annex 4. To be consistent with previous studies we have started with the approach used in the 2012 HAPiNZ study update[80] and we include results that are consistent with and can be compared to the results from that analysis. However, we make some changes in our base case to reflect:

- the concern of this study with measuring the impacts of **marginal** changes in concentrations in response to policy rather than the effects of the **absolute** values. This means we include lagged benefits because all the health effects will not be felt immediately after concentrations are reduced because of the health damage already experienced by people from living with elevated pollution levels; and

- the emerging international approach, particularly in the EU of presenting results in the form of life years lost rather than premature deaths as a potentially more accurate characterisation of the effect.

The arguments relating to these issues are discussed in more detail in Annex 4 and we summarise our approach in Section 4.2.

4.1 Impact Priorities

4.1.1 Health Effects

The adverse effects of air pollution include:

- human health effects;
- reduced visibility and discolouration of air; and
- nuisance and amenity effects, including dust, smoke, materials damage and odour.

A number of economic studies in the late 1990s and early 2000s, particularly in Europe, estimated the relative costs of the different effects, concluding that the most significant impacts are on human health.[81] More recently this has been confirmed in the European Commission's Handbook on External Costs of Transport.[82] In New Zealand, the Ministry of Transport examined the full range of external effects of transport in its land transport pricing study in the mid-90s, suggesting that the damage costs of air pollution

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[80] Kuschel G *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report & Volume 2 Technical Report

[81] See for example ExternE studies, eg Rabl A & Spadaro J *et al* (2004) Externalities of Energy: Extension of accounting framework and Policy Applications. Final Technical Report ENG1-CT2002-00609; Hohmeyer O (1998) The social costs of energy consumption. Springer Verlag. Berlin.

[82] Ricardo-AEA (2014) Update of the Handbook on External Costs of Transport. Report for the European Commission: DG MOVE Ricardo-AEA/R/ ED57769

were dominated by health effects, especially mortality caused by particulates.[83] Jakob *et al* compared health costs of air pollution in Auckland to those of damage to agriculture and forests; these other costs were only 0.002% of the total air pollution costs.[84] Other studies internationally and in New Zealand, have not questioned this hierarchy of effects but have concentrated on health effects.

This study follows this pattern and examines only the impacts of policy on health effects of air pollution.

4.1.2 Pollutants

Epidemiological studies usually report the adverse associations between one or more pollutants and health. Pollutants such as particulate matter (PM), NO_2 (nitrogen dioxide) and carbon monoxide (CO) are often strongly correlated and occur as components of a pollution mix. NO_2 is increasingly being recognised as an important pollutant in its own right, including through impacts on human health, and consistent with WHO recommendations,[85] NZTA has recommended that NO_2 is used as an indicator of pollution levels as a proxy for all motor vehicle pollutants.[86] However, there is a close correlation between NO_2 and particle emission levels.[87]

The extent of correlation between pollutants makes it difficult to accurately determine the independent effects of individual pollutants.[88] WHO suggests that current available evidence does not allow discernment of the pollutants or pollutant combinations that are related to different adverse health outcomes (partly because of the vulnerability of populations).[89] Health effects of air pollution can be correlated with particulate concentrations, even if these relationships reflect the effects of particulates and other pollutants.

One potential difficulty with particulates as a measure is that small particulates, measured as PM_{10}, have a wide range of sources, including natural (eg sea spray) sources. Very small particles ($PM_{2.5}$) or even ultra-fine particles ($PM_{0.1}$) are more likely to be the result of human activity. However, the lack of monitoring data and relevant exposure-response functions makes it difficult to robustly quantify the impacts of smaller fractions such as $PM_{2.5}$ currently in New Zealand. In addition, until recently, much of the epidemiological work used in impact analysis has identified relationships

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[83] Ministry of Transport (1996) Land Transport Pricing Study: Environmental Externalities. Discussion Paper.

[84] Jakob A, Craig JL and Fisher G (2006) Transport Cost Analysis: a case study of the total costs of private and public transport in Auckland. *Environmental Science and Policy* 9(1): 55-66

[85] World Health Organization (2006) WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005 Summary of risk assessment.

[86] NZ Transport Agency (2011). Ambient air quality (nitrogen dioxide) monitoring network report 2007-2009

[87] World Health Organization (2013) Review of evidence on health aspects of air pollution – REVIHAAP Project Technical Report. WHO Regional Office for Europe.

[88] Department of Environment and Conservation (NSW) (2014) Air Pollution Economics Health Costs of Air Pollution in the Greater Sydney Metropolitan Region

[89] World Health Organization (op cit)

between PM_{10} and health, rather than with finer particulates. It is regarded as the best available summary indicator of air pollution exposure in New Zealand.

The assessment is therefore based on PM_{10} as used in the HAPiNZ Update 2012.[90]

4.2 Our Approach

We analyse benefits in this study using the following approach.

4.2.1 Emissions Estimates

We use VEPM 5.1 to run the Auckland-specific fleet profiles generated from the Auckland Regional Transport Model ART3 to derive emission factors for the 2016 base year and for each of the specific policy scenarios. To achieve this, VKT data generated from the ART3 model (as individual road links) was extracted for each census area unit (CAU) to be assessed.

VKT data for the 2016 model period (separated into vehicles travelling slower or faster than 80 km/h) were entered into the HAPiNZ exposure model for each CAU. Emission factors for each scenario generated using VEPM 5.1 were also entered into the HAPiNZ exposure model. The HAPiNZ model was then used to derive annual average PM_{10} concentrations for each CAU in $\mu g/m^3$. The results generated for each scenario are compared with the 2016 base case model for the geographical extent relevant to each of the policy options.

Key limitations of the approach have been identified as:

- We use the HAPiNZ update exposure model, which was prepared in 2006 using source apportionment data (either measured or calculated) including emission sources from motor vehicles, domestic heating, outdoor burning, natural sources and industrial contributions. This assessment adopts a base year of 2016 to generate updated motor vehicle emission estimates. However it makes the assumption for overall annual PM_{10} concentrations at each CAU that outputs from all other sources (excluding motor vehicles) have remained static since 2006. Keeping all other sources static does not matter for the measure of impacts because our interest is in the **change** in emissions and concentrations rather than the **absolute** effect.

- The main pollutants of interest from motor vehicle emissions are particulates and nitrogen dioxide (NO_2), so these should be the focus of the potential options. However, the HAPiNZ model is based only on PM_{10} exposure, as there are insufficient NO_2 data to assess exposure in New Zealand, and the effects of changes in NO_2 will already be included, to some extent at least, in exposure-response relationships relating to PM.

[90] Kuschel G et al (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report

- A low emission zone for specific corridors (major roads) was considered as a policy option for detailed assessment. While this option would provide benefits of targeting local pollution hotspots, the modelling approach required was outside the scope of this assessment. This is discussed further in Annex 3.

A full methodology for calculation of PM_{10} concentration per CAU for the identified policy scenarios is provided in Annex 3.

4.2.2 Exposure-Response Relationships

We use the exposure-response relationships as used in the HAPiNZ update, although we do not analyse impacts on Māori or any other population sub-groups separately. The reduced number of coefficients (from Table 75 in Annex 4) are shown in Table 10; these are used with annual average concentration changes. We use the range of values (95% confidence intervals) in sensitivity analysis.

Table 10 Exposure Response Functions used in this study

Health Outcome	Exposure Response Functions (Relative risks per 1μg/m^3 PM_{10})
1 Premature mortality, all adults, all ethnicities	**1.007** (1.003 – 1.010)
2 Premature mortality, babies, all ethnicities	**1.005** (1.002 – 1.008)

Values in brackets are 95% confidence intervals
Source: Adapted from Kuschel G *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report.

For morbidity effects we do not have data on Auckland hospital admissions. Rather we assume the same ratio between premature mortality estimates and morbidity effects as estimated for Auckland using the updated HAPiNZ model (Table 11), eg we assume 1,705 reduced activity days (RADs) per premature mortality.

Table 11 Impacts of PM_{10} from transport and ratio of cases in the Auckland Urban Airshed in 2006

Impact	Cases	Ratio
Premature mortality (adults)	121.1	1
Premature mortality (babies)	0.6	na
Cardiac admissions (all)	26.9	0.222
Respiratory admissions (all)	55.2	0.456
Restricted activity days (RADs)	206,483	1,705

Note: na = not applicable; we use the response functions in Table 10 for babies
Source: Base Case Outputs Table in: Kuschel *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Health Effects Model. Available at:
www.hapinz.org.nz/HAPINZ%20Update_Health%20Effects%20Model.xlsx

The number of premature deaths is calculated using a formula that is consistent with that used in the HAPiNZ update study.[91]

[91] Kuschel G *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report

HAPiNZ starts by asserting that:

$$Cases_{Total} = Cases_{Base} + Cases_{AP} \quad (1)$$

Where: $Cases_{Total}$ = the total number of cases observed in the population of interest
$Cases_{AP}$ = the number of extra cases that arise due to exposure to air pollution
$Cases_{Base}$ = the total number of cases in the population of interest in the absence of air pollution

In HAPiNZ it is assumed that the effects are linear and directly proportional to exposure, and that:

$$Cases_{AP} = Cases_{Base} \times (RR - 1) \times E \quad (2)$$

Where: RR = the relative risk per unit of pollution (see Table 11)
E = the exposure for the population of interest in $\mu g/m^3$

This formula might imply that exposure-response functions (as in Table 11) are always starting from a base with zero particulate concentrations and that percentage changes in cases (mortality and morbidity) are from this theoretical base level. However, the literature suggests that the exposure-response relationships are relative to current concentrations (and mortality/morbidity rates). For example, Hales et al,[92] in the study used to derive the relationships used in the HAPiNZ update, note that "*the odds of all-cause mortality in adults … increased by 7% per 10 $\mu g/m^3$ increase in average PM_{10} exposure*" (emphasis added), consistent with their analysis of the mortality rates in locations with different, but non-zero, concentrations. COMEAP (2010) uses the published coefficients[93] applied to a 1$\mu g/m^3$ decrease in annual average $PM_{2.5}$.[94] The decrease is, by definition, from some non-zero concentration; current concentrations are used. The US EPA's expert elicitation takes the same approach.[95]

This assumption matters because the percentage is either of a lower (number of cases with no air pollution) or higher (cases with air pollution) number.

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[92] Hales S, Blakely T, Woodward A. (2010). Air pollution and mortality in New Zealand: cohort study, Journal of Epidemiology and Community Health. doi:10.1136/jech.2010.112490

[93] 1.06 change in all-cause mortality hazard per 10 $\mu g/m^3$ $PM_{2.5}$ (annual average concentration)

[94] In COMEAP (2010) the equation for scaling is based on multiplicative scaling of the relative risk, ie 1.06 for all-cause mortality for a concentration increase of 10 $\mu g/m^3$ $PM_{2.5}$, but if the change in population weighted-mean concentration is $-x$ $\mu g/m^3$ (with a negative sign for reductions in concentration), then the new relative risk is calculated as $1.06^{-x/10}$. But they suggest that, for convenience, people may simply scale the coefficient on a linear basis (eg the percentage change in mortality rates would be halved for a 5 $\mu g/m^3$ change) and that this is a reasonable approximation in many circumstances but the methods diverge increasingly when using larger coefficients (eg 12%) and large concentration changes (eg elimination of anthropogenic pollution). We use this simplifying method.

[95] Industrial Economics (2006) Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between PM2.5 Exposure and Mortality. prepared for: Office of Air Quality Planning and Standards, US Environmental Protection Agency

In this study we use an approach that is consistent with this health and policy literature, while attempting to show consistency with HAPiNZ.

Firstly, we note that equation (2) above also means that:

$$Cases_{Total} = Cases_{Base} \times (1 + (RR - 1) \times E) \quad (3)$$

And that:

$$Cases_{Base} = \frac{Cases_{Total}}{(1 + (RR - 1) \times E)} \quad (4)$$

Taking the calculation as starting from the current concentration and number of cases, we might assume that:

$$Cases_{PS} = \frac{Cases_{Total}}{(1 + (RR - 1) \times \Delta E)} \quad (5)$$

Where: $\Delta Cases_{PS}$ = the total number of cases observed in the policy scenario, ie following reduction in concentrations

ΔE = the change in exposure as a result of policy

This produces results consistent with HAPiNZ if we assume that some theoretical policy removes all particulate emissions. However, it produces a larger estimate of effects if a small marginal change in concentrations is estimated because the percentage change is relative to the current number of cases.

We use formula (5) to estimate the number of premature deaths in our policy scenarios and the effects of policy as:

$$Cases_{PE} = Cases_{Total} - Cases_{PS} \quad (6)$$

Where: $Cases_{PE}$ = The change in the number of cases as a policy effect.

Reflecting the emerging international consensus on the use of life years lost as the primary measure of effects, we estimate the reduction in life years lost (life years gained) using the simple approach suggested by the UK Committee on the Medical Effects of Air Pollution (COMEAP).[96] To do so, the estimate of effects on premature mortality is undertaken for every year (or all 30 and above, plus under one years old). The life years gained at each age are multiplied by the life expectancy at that age. We undertake the analysis separately for males and females. The approach is illustrated in Table 12 using data for males in the Auckland urban airshed and a 0.2 μg/m^3 change in PM_{10} concentration. The number of life years gained is summed across all years.

[96] COMEAP (2010) The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom. A report by the Committee on the Medical Effects of Air Pollutants

Table 12 Estimation of Life years gained – males (Auckland urban airshed) – 0.2μg/m³ change in annual average PM_{10} concentration

Age	2013 Population	Life expectancy	Probability of death in age group	Deaths	Deaths saved	Life years gained
0 Years	9,276	79.40	0.0050	46.6	0.046	3.680
30-34	39,840	48.78	0.0008	30.1	0.043	2.079
35-39	39,114	43.98	0.0010	38.0	0.053	2.337
40-44	41,400	39.22	0.0015	62.4	0.087	3.416
45-49	40,419	34.56	0.0021	84.7	0.118	4.078
50-54	36,297	30.00	0.0033	121.0	0.169	5.057
55-59	30,042	25.58	0.0052	156.5	0.218	5.579
60-64	26,385	21.36	0.0077	205.2	0.286	6.110
65-69	19,350	17.34	0.0128	251.3	0.350	6.069
70-74	14,541	13.64	0.0211	313.6	0.436	5.949
75-79	9,759	10.44	0.0369	373.7	0.519	5.424
80-84	6,855	7.82	0.0621	454.7	0.631	4.936
85+	4,446	3.50	0.1266	645.1	0.895	3.132
Total 30+	308,448			2,736	3.8	54

To undertake this analysis:

- Population data are taken from the latest (2013) census data for each area unit included in the study area (the data in Table 12 are for males in the Auckland urban airshed);
- Life expectancy at each age group is taken from the Statistics NZ's Auckland Region Abridged Life Table, 2005–07, the latest dates for which sub-National data are available (these were modified to produce life expectations for the mid-point of the age category- see Annex 4, Section A4.5);
- Probability of death in age group uses Auckland mortality data averaged over 2009-2011.[97] It is the number of deaths in each age group divided by the population in that age group (prior to those deaths);
- Deaths within the individual study areas (CBD & Port, central area, Auckland urban airshed – see Sections 6-8 and Annex 3) are estimated using the population and the probability of death. ;
- Deaths saved are estimated using formula 5 and 6 above; and
- Life years gained is estimated as the deaths saved times the expected life expectancy for each age group.

We present results using the impact on life years, but provide results as changes in attributed (premature) deaths also.

[97] www.health.govt.nz/nz-health-statistics/health-statistics-and-data-sets/mortality-data-and-stats

We note that the ratio of life years gained to deaths saved in Table 12 (14.3) is similar to ratios found in international studies. As noted in Annex 4, COMEAP notes across a number of different coefficients (change in mortality per unit change in PM concentration) that the estimated life years lost (or gained) were 11.8 – 12.2 times the estimated number of attributable deaths amongst adults (30 years and above).[98]

4.2.3 Lagged Benefits

Lagged benefits have been used in policy studies in the US and Europe for a number of years to reflect the fact that reductions in emissions and concentrations will not result in all the health benefits being obtained immediately. Because people are "frail" as a result of living in elevated concentrations of pollutants, they will still be vulnerable to some effects and repair to historical damage will take some time. We use the US EPA lag model as the primary assumption, with sensitivity analysis using: no lag and 30-year lag. The assumptions are:

- EPA: 30% of the reductions in health effects occur in the first year, 50% spread equally (12.5% per year) across years 2 through 5 and the remaining 20% spread equally over years 6 through 20;
- No lag: 100% of the mortality reductions occur immediately after emission reduction;
- 30-year lag: the mortality reductions are spread equally over 30 years, with 3.3% of the benefit in each year.

These and alternative lag structures are illustrated in Figure 30 in Annex 4 (page 118).

4.2.4 Valuation

We use the values in Table 13 in the analysis. The Value of a Statistical Life (VoSL) is taken from the most recent traffic accident values.[99] The Values of a Life Year (VoLYs) include a high value ($199,000) that is derived by converting the VoSL into a discounted stream of annual life year values over the remaining lifetime of the subject. This is simple to do but has less theoretical validity than those derived directly using surveys. International studies have identified a range of values for willingness to pay for future life extensions and the literature was reviewed in the context of the cost benefit analysis of the UK's air quality strategy.[100] We have taken the UK raw values based on annual willingness to pay (WTP) for life extensions of 1 to 6 months at the end of life. These are discounted at 4% over 40 years, reflecting the assumptions used for the VoSL-based calculation of VoLY (see above). These values may over-estimate VoLY as they are estimates for life extension in perfect health; with small changes in concentrations of air pollutants life extensions may be in less than perfect health. We use a base value of $25,000 which is close to the top of the range of values used in the UK based on WTP studies, and a low value of $5,000. The detailed discussion is provided in Annex 4.

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[98] COMEAP (2010) – using data on p67

[99] Ministry of Transport (2014) Social cost of road crashes and injuries 2014 update.

[100] Defra et al (2007) An Economic Analysis to inform the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits

Table 13 Values used in analysis

Factor		Low	Base Case	High
Mortality	VoLY	$5,000	$25,000	$199,000
	Value of Statistical Life (VoSL)[1]		$3,948,300	
Morbidity	Cardiac admission		$6,810	
	Respiratory Admission		$4,864	
	Restricted activity day		$66	

[1] These are not additive to the VoLY-based values

Morbidity values are taken from the updated HAPiNZ, inflated using the Producer Price Index for *Professional and Administrative Services*.[101] Given the relatively low impact of morbidity values on the total, we do not conduct sensitivity analysis on these values; sensitivity analysis is conducted on a number of other variables.

The full range of factors and differences from the HAPiNZ update are noted in Table 14. Note we include results using HAPiNZ assumptions also.

Table 14 Factors used in analysis

Factor	This study	HAPiNZ update
Premature mortality – all adults, all ethnicities	1.07 per 10 μg/m^3 PM_{10}	1.07 per 10 μg/m^3 PM_{10}
Life years lost (adults)	Premature mortality times life expectancy	Not included
Premature mortality – babies	1.05 per 10 μg/m^3 PM_{10}	1.05 per 10 μg/m^3 PM_{10}
Life years lost (babies)	Premature mortality times life expectancy	Not included
Cardiac admissions	0.222 cases/adult premature mortality	1.01 per 10 μg/m^3 PM_{10}
Respiratory admissions	0.456 cases/adult premature mortality	1.02 per 10 μg/m^3 PM_{10}
Restricted activity days	1,705 cases/adult premature mortality	0.9 per person per 10 μg/m^3 PM_{10}
Cessation lag	EPA assumptions; no-lag & 30-yr lag	No lag
Mortality valuation	VoLY & VoSL	VoSL only

[101] Statistics NZ. Index = 993 in June 2010 and 1065 in December 2014 (7.3% increase)

5 Cost Analysis

5.1 Approach

The costs of policies will include a number of elements. These include:

- The costs to government of introducing the policy, including the costs of legislation;
- The technical requirements for introducing the policy, eg the costs for enforcing an LEZ or of vehicle testing;
- The costs of the responses by vehicle owners, including the purchase of new vehicles.

In this section we summarise the main data that will be used in the analysis of a number of policies. Specifically this includes the number of vehicles in Auckland, by type and the costs of upgrading vehicles.

5.2 Fleet Numbers

Table 15 shows the number of vehicles that are in Auckland. These data are compiled on the basis of WoF/CoF inspection location rather than the owner address, to avoid the problem of vehicles being registered by a company Head Office rather than their location of use. We use these to derive the number of vehicles that might be affected by the policies.

Table 15 Vehicle numbers in the Auckland region

Vehicle type	Total	Diesel	Diesel as % of total
Light passenger vehicle	905,566	60,907	7%
Light commercial vehicle	87,462	57,193	65%
Heavy goods vehicle	26,377	25,831	98%
Bus	2,193	2,119	97%
Total	1,021,598	146,050	14%

Source: Ministry of Transport.

In addition to numbers of vehicles in Auckland, there are available data on VKT and traffic counts. However, neither of these provide information on the number of vehicles that are driving in specific locations. Traffic counts can be used to derive the number of trips but cannot distinguish between many vehicles making single trips and one vehicle making many trips. National average VKT per vehicle might be used also, although it is highly unlikely to be representative of vehicle behaviour in Auckland. Given this uncertainty we make some simple assumptions based on the number of vehicles in Table 15.

For analysis of the vehicles entering the CBD and port area and affected by an LEZ established there, we assume the percentage of vehicles affected is as shown in Table 16. For most vehicles only 25% are assumed to enter the CBD & port area as many people and businesses conduct their activities in other parts of Auckland.[102] Many bus routes go into the centre of town or companies operate in a way that allows them to shift vehicles around when required, so they are likely to be more affected by CBD regulations.

Table 16 Proportion of vehicles affected by geographical policies – central assumption (and range)

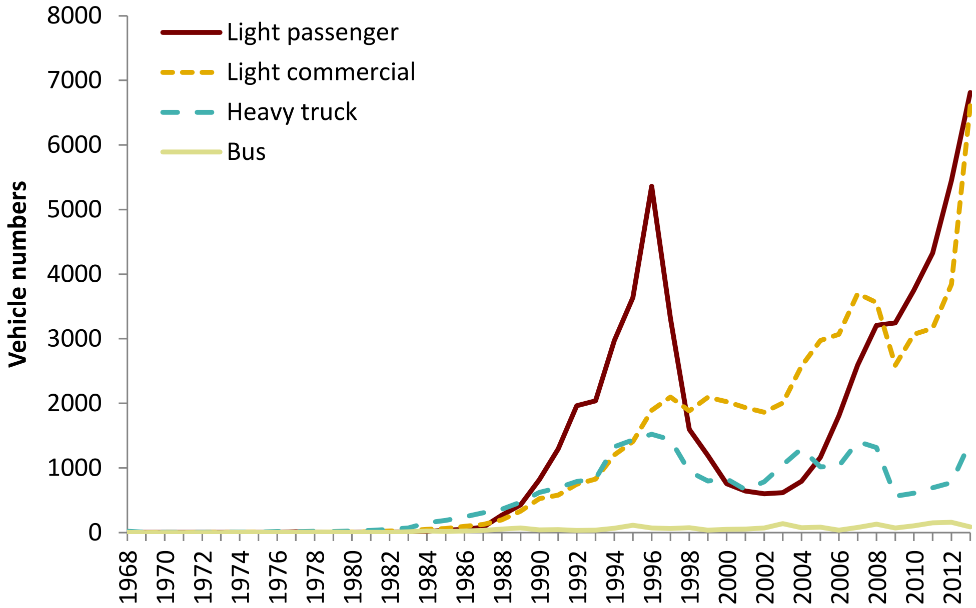
Vehicle type	% entering CBD	% in Auckland
Light passenger vehicle	25% (10 – 40%)	120% (100 – 150%)
Light commercial vehicle	25% (10 – 40%)	100% (90 – 125%)
Heavy goods vehicle	25% (10 – 40%)	120% (100 – 150%)
Bus	75% (50 – 90%)	100% (90 – 125%)

The number of vehicles affected by regulations targeting Auckland as a whole will be more than 100% of vehicles that are based in Auckland as it will also affect visitors (light passenger vehicles) and those conducting business in Auckland, including those delivering to or collecting from the port.

5.3 Vehicle Ages

Vehicle age determines which vehicles will be affected by regulations. Figure 15 shows the number of vehicles in these different categories by year of manufacture. There are increasing numbers of new vehicles for light passenger and commercial vehicles, suggesting that more are being purchased over time. For heavy vehicles there has been a growth in demand since a low in 2009 following the global recession, but over the longer run numbers are relatively constant, suggesting that there is no significant growth in demand in comparison with other vehicle types.

Figure 15 Number of Auckland vehicles by year of manufacture

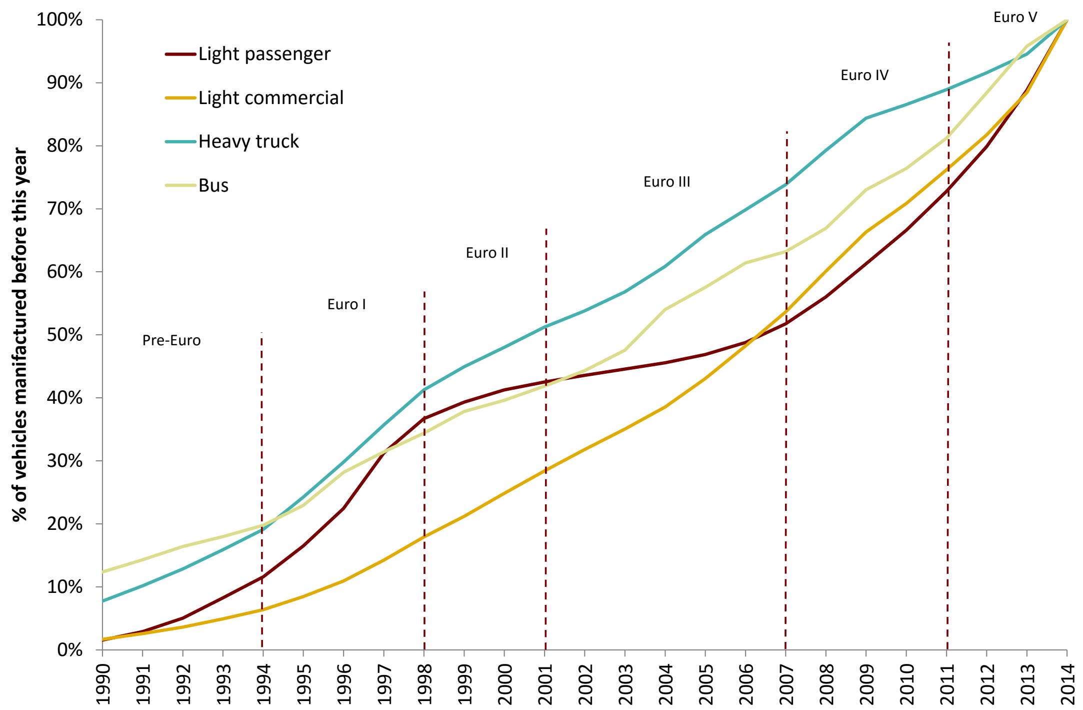


Source: MoT

[102] This simple approach was discussed with Auckland Council transport modellers as the most appropriate for this study

In Figure 16 we show the cumulative percentage of vehicles that are manufactured prior to the time of introduction of successive Euro standards. This is a relatively simple way of classifying the vehicles and does not take account of whether they are manufactured in Japan (and thus subject to different standards), in Europe or elsewhere. Nevertheless, it provides a reasonable picture of the distribution.

Figure 16 Percentage of vehicles by year of manufacture and Euro Class (Diesels in Auckland)



Source: MoT

Using the ages of the fleet we estimate the proportion of the fleet in different age and Euro categories (Table 17). We then calculate the weighted average age of the fleet in each category. This provides the basis for estimating the number of vehicles that need to be replaced to meet specific standards.

Table 17 Fleet Profiles

	Light passenger	Light commercial	Heavy truck	Bus
Percentage of fleet				
Pre-Euro	11.6%	6.4%	19.1%	19.8%
Euro 1/I	25.1%	11.5%	22.1%	14.6%
Euro 2/II	5.8%	10.5%	10.0%	7.5%
Euro 3/III	9.2%	25.2%	22.6%	21.3%
Euro 4/IV	21.0%	22.6%	15.1%	18.0%
Euro 5/V	27.2%	23.8%	11.1%	18.8%

5.4 Vehicle Replacement Costs

The costs of replacing vehicles are estimated from data collected on new and used vehicle prices from a number of dealer websites. The data used are list prices, subsequently checked with a number of companies to ensure that they are producing sensible results. The idea is to provide broad guidance on prices, although there will be significant variation in individual categories. The resulting price assumptions are shown in Table 18; we start with a new vehicle price, reduce this by 20% in the first year[103] and then by a fixed percentage each year thereafter.[104] We combine these with the number of vehicles of each age to estimate a weighted average price per Euro category; for heavy vehicles this combines all vehicle weights.

Table 18 Vehicle price assumptions (2015 dollar values)

Vehicle	Start price ($k)	Year 1/ Annual price reduction	V	IV	III	II	I	pre
LPV	$40	20/10%	28,800	18,896	11,158	6,589	4,803	2,836
LCV	$50	20/7.5%	37,000	25,056	18,343	12,422	9,831	6,158
3.5 - 7.5 t	$60	20/7.5%						
7.5 - 12 t	$80	20/5%						
12 - 15 t	$110	20/5%			weighted averages			
15 - 20 t	$150	20/5%	100,922	76,317	61,135	46,425	39,397	26,932
20 - 25 t	$250	20/5%						
25 - 30 t	$275	20/5%						
> 30 t	$300	20/5%						
Bus	$380	20/5%	274,360	235,229	172,915	140,841	114,715	80,110

5.5 Retrofit Technologies

A number of technologies are available that can be retrofitted to vehicles to reduce emissions.[105] Diesel Oxidation Catalysts (DOCs) are the most common retrofit technology available for diesel emissions control; estimates suggest that possible exhaust particulate matter emission reductions are in the order of 20-50%.[106]

For individual vehicle categories (vehicle type and Euro class) we estimate whether a DOC might be a feasible option for reducing emissions to meet the required standard. Table 19 shows the weighted average (based on vehicle numbers) emission factors included in VEPM for the Auckland fleet and a speed of 40km/hr. It also shows the reduction in emissions that would result from changing vehicle to one in a higher Euro class, as might be required by policy. This change in emissions is the required emission reduction. We estimate whether the retrofit technology can achieve it.

It suggests that, assuming a 20-50% reduction in exhaust particulate matter emissions through retrofitting a DOC:

- Pre-Euro vehicles cannot be retrofitted to meet any standard;

[103] This was recommended by a number of vehicle dealers spoken to for this study
[104] These do not include the full prices for specialist vehicles, such as rubbish trucks or refrigerated trucks. We assume that the additional costs for these are the same regardless of the age of the truck itself.
[105] Kuschel G (2014) Investigations into Reducing Emissions from Heavy Duty Diesel Vehicles in Auckland – a Summary Report. Auckland Council Technical Report 2014/018
[106] www.unep.org/tnt-unep/toolkit/Actions/Tool11/Facts.html

- Euro I LCVs and HCVs (and possibly cars) can be retrofitted to meet Euro II standards;
- Euro I HCVs can be retrofitted to meet Euro III standards;
- Euro II cars and HCVs can be retrofitted to meet Euro III standards;
- No Euro III vehicles cannot be retrofitted to meet higher standards; and
- Euro IV HCVs can be retrofitted to meet Euro V standards.

This is summarised in Table 20. For the different vehicle categories, whether retrofit technologies have the potential to achieve a level of emission reduction equivalent to changing vehicle to a higher emission standard. This is used as the basis for estimating the costs of policies that set standards on the basis of Euro classes, eg for entry into a LEZ.

Table 19 VEPM Emission factors for diesel vehicles and the estimated emission reduction requirements associated with a higher required emission standard

Euro Standard		LPVs	LCVs	HCVs
		(Weighted) average emission factors (g PM_{10}/km)		
Pre-Euro		0.404	0.641	0.795
I		0.142	0.237	0.268
II		0.093	0.244	0.244
III		0.075	0.119	0.248
IV		0.040	0.072	0.047
V		0.001	0.001	0.047
From	**To**	**% change in PM_{10} emissions required**		
Pre	I	65%	63%	66%
I	II	35%	-3%	9%
II	III	20%	51%	-2%
III	IV	47%	40%	81%
IV	V	98%	99%	-1%
Pre	II	77%	62%	69%
I	III	48%	50%	7%
II	IV	57%	71%	81%
III	V	99%	99%	81%

Source: Emission factors from VEPM5.1

Table 20 Retrofit potentials

	Cars	LCVs	HCVs
Pre-Euro	No	No	No
I	?	Yes	Yes
II	Yes	No	Yes
III	No	?	No
IV	No	No	Yes

Costs for retrofit technologies were included in the cost benefit analysis of the UK Air Quality Strategy; in 2005 prices these were approximately £200 for diesel cars (NZ$640 in current prices),[107] £300 for light commercial vehicles (NZ$960) and £430-2,600 for

[107] We convert to NZ$ values using a mid-2005 exchange rate £1:NZ$2.5778 (oanda.com) and inflate to December 2014 prices ($1:$1.24)

heavy vehicles (NZ$1,375-$8,300), but these were for fitting at manufacture. Costs for similar technologies would be expected to be higher in New Zealand because of the high percentage that second hand imports, rather than new vehicles, are of vehicles first entering the fleet, and the potentially higher costs of retrofitting technologies rather than fitting at manufacture.

The US EPA estimates costs for emission control technologies as shown in Table 21 (for 2007). Costs of DOCs are estimated by UNEP to be US$600 - $2,000 each.[108]

Table 21 Emission control technology prices

Technology	2007 US$ price	Current NZ$ price
Diesel oxidation catalyst (DOC)	US$425 - $2,000	$644 - $3,030
Catalysed diesel particulate filter (CDPF)	US$3,000 - $10,000	$4,545 - $15,149
Selective catalytic reduction (SCR)	US$12,000 - $20,000	$18,179 – $30,298

Source: US EPA Office of Transportation and Air Quality (2007) Diesel Retrofit Technology. An Analysis of the Cost-Effectiveness of Reducing Particulate Matter and Nitrogen Oxides Emissions from Heavy-Duty Nonroad Diesel Engines through Retrofits.
We inflate 2007 US$ to 2015 US dollar values using a US producer price index for transportation equipment (http://download.bls.gov/pub/time.series/pc/pc.data.22.TransportationEquipment) and convert to NZ$ values using an exchange rate of NZ$1:US$0.75

Taking these various estimates together, and including fitting costs and high costs in New Zealand because of the smaller market size, we assume the costs shown in Table 22.

Table 22 Cost assumptions for DOCs in New Zealand (2015 $ values)

Vehicle type	Costs
Light passenger	$1,000
Light commercial	$1,500
Heavy vehicles and buses	$3,000

[108] www.unep.org/tnt-unep/toolkit/Actions/Tool11/Facts.html

6 Low Emission Zones

6.1 Approach

Low Emission Zones (LEZs) define geographical areas from which vehicles are excluded if they do not meet specified emission rates. We examine two possible areas:

- The CBD and Port; and
- The Auckland urban airshed.

We considered a corridor LEZ, eg an LEZ for a specific road. However, we have not taken this further in analysis. This is partly because of the modelling constraints: we have been limited to considering impacts at the CAU level. However, it is also because of the considerable uncertainties surrounding the effects: because PM_{10} does not have a threshold in effects, and because a corridor LEZ is expected only to shift traffic rather than resulting in a change in vehicle type or retrofits, a corridor LEZ will only be effective if the traffic is shifted to less populated areas. We are unable to model this.

The CBD and port is defined by the following census area units (CAUs): Auckland Central East, Auckland Central West, Harbourside, Newton and Grafton West. It is shown in Figure 17 alongside the Central area used for the road pricing option (see below).

Figure 17 Spatial Extent of CBD & Port and Central area (Congestion scheme)

Source: Aerial source from Auckland Council GIS website

The Auckland urban airshed is shown in Figure 28 and Table 70.

The vehicles that would be restricted would be limited to diesels. We examine the implications of setting the emission standards at different levels and for different vehicles. These are shown in Table 23.

Table 23 LEZ Scenarios

Euro Standard	HCV only	HCV & LCV	All diesels
Euro II	1	4	6
Euro III	2	5	7
Euro IV	3		

6.2 Costs

The elements of costs are:

- The compliance, monitoring and enforcement system;
- The costs for operators of changing vehicles or retrofits; and
- The government administration costs.

6.2.1 Compliance, Monitoring and Enforcement

There are different ways to implement the LEZ in practice. This includes:

- Automatic Number Plate Recognition (ANPR) systems, such as used in London; and
- paper or sticker-based schemes, such as used in Berlin.

Automatic Number Plate Recognition

ANPR systems require:

- a database of every vehicle that would identify whether they were eligible to enter the LEZ;
- a camera system that identified the vehicles that entered the zone and extracted a list of number plates;
- a check of those number plates against the database of eligible vehicles;
- an enforcement system that targeted those that were in breach of the requirements.

There are other examples of ANPR systems in New Zealand.

- The Police use mobile ANPR systems attached to vehicles that can scan up to 3,000 plates per hour. The ANPR system "*scans the number plates of passing vehicles and feeds the information to a computer inside the vehicle. The system instantly checks the details against information already held by Police about vehicles of interest, and if found, it alerts the officer for follow up.*"[109]

[109] NZ Police Press Release 1 August 2014 "*Technology helps get dangerous vehicles, high risk drivers and criminals off roads*". www.police.govt.nz/news/release/technology-helps-get-dangerous-vehicles-high-risk-drivers-and-criminals-roads

- A permanent ANPR system is set up for the Northern Gateway Toll Road. It checks the number plate against a database to identify the type of vehicle and the toll it needs to pay. This is then used to check whether the toll has been paid or if a toll payment notice needs to be sent.[110]

An analysis of the costs of implementing an LEZ in London suggested that use of fixed cameras would be very expensive; costs for London were estimated (in 2003) to be £8 million to set up and £6 per annum to operate (Table 24). Lower costs were possible with mobile (vehicle-based) cameras or manual enforcement (identifying vehicles via window stockers).

Table 24 Estimated costs of implementing London LEZ (2003 £ million)

	Heavy vehicles only				Light vans and heavy vehicles
	Manual enforcement	Mobile ANPR cameras	Fixed ANPR cameras	Mobile and fixed ANPR cameras	Mobile and fixed ANPR cameras
Start-up costs	£2.8	£6.4	£7.6	£9.3	£10.4
Annual operating costs	£3.9	£5.0	£5.8	£6.4	£7.0

Source: Watkiss P, Jones G and Kollamthodi S (2004) An Evaluation of the Air Quality Strategy Additional Analysis: Local Road Transport Measures. Final Report to Defra. AEA Technology

The system used by the police is most similar; it is a simple comparison of the number plate with a list of "vehicles of interest". The costs of the units are approximately $35,000-$40,000 each.[111] On the police systems, the data are transmitted to a database held in the vehicles, but alternative approaches would send the image to a centralised computer, either in raw form or automatically modified to protect privacy, while still providing the number plate data.

There would be a need for two or more units on each road that enters the LEZ (one in each direction), and more on roads with more than one lane.

We note a study for NZTA by AECOM of the potential costs of a system of point to point speed cameras (number plates photographed twice on the same road at a fixed distance apart) at three permanent sites;[112] they estimated capital costs of $1.1 million and recurring costs of $0.85 million per year. The recurring costs included communications and data transfer costs, operation and maintenance costs, and infringement processing costs. It is not clear from their analysis how many cameras were required; the assumption was that the cameras were mounted on a gantry above state highways.

[110] http://www.tollroad.govt.nz/About/How
[111] NZ Police (op cit)
[112] Lynch M, White M and Napier R (2011) Investigation into the use of point-to-point speed cameras. NZ Transport Agency research report 465

Table 25 LEZ Implementation cost assumptions

LEZ	Roads entering	Capital costs	Annual operating costs
CBD & Port	20	$2 million	$1 million
Auckland urban airshed	25	$3 million	$1.5 million

6.2.2 Operator Response

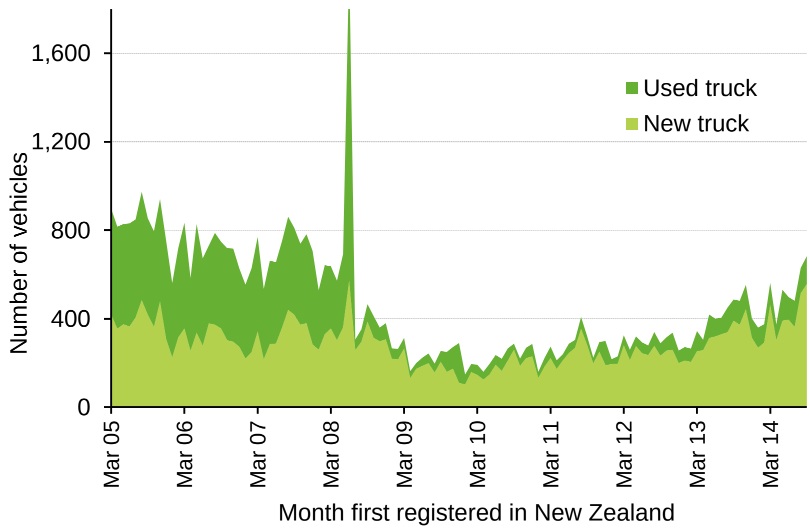
There are three main options in terms of response:

- Moving vehicles around within the fleet so that older vehicles are operated outside of Auckland;
- Vehicle replacement; and
- Retrofit technologies.

There will also be the option that the costs of vehicle replacement are too high for some operators such that the truck owner exits the industry. In this case it would be expected that the net costs to the community will be less than the additional costs of the replacement vehicle. This is because the business surplus from which the additional costs would otherwise have been funded will be small, and the surplus would have been the main economic contribution of the business. This assumes that all costs, including owner-operator salaries, reflect opportunity costs, ie they reflect the value of the resources in some other activity.

The option of moving older, more polluting vehicles to another location will be an option for larger operators only, and these tend to purchase new vehicles that will not require relocation. The majority of imports of trucks are new, which is a change since the introduction of the Land Transport Emission Rule in 2008 (Figure 18). New imports comprised 79% of new registrations in the year to September 2014, compared to 50% in the year to May 2008 (prior to the June 2008 spike).

Figure 18 Heavy vehicle imports to New Zealand (monthly registrations)



Source: Ministry of Transport Quarterly Fleet Statistics Spreadsheet July to Sept 2014 update

The review of the London scheme suggested that large fleet operators replaced their vehicles every 5-6 years, but smaller fleet operators did so less frequently. Those with specialist bodies (cement trucks, rubbish trucks etc) have much longer replacement cycles. There are similar rates of truck replacement in New Zealand,[113] suggesting that larger operators will be purchasing new vehicles and by 2016 most will have vehicles that are Euro V (there oldest vehicles will be manufactured in 2011).

The older vehicles that will be excluded from the LEZ are more likely to be owned by owner-operators. These firms have few options apart from changing their business model or purchasing new vehicles and using retrofit technologies (for Euro I or II vehicles). We examine these costs through the costs of newer vehicles and retrofits.

Changing Vehicles

We estimate costs for changing vehicles by taking the percentage of vehicles that enter the zones from Table 16. We assume the percentages are the same across all age categories, so we estimate numbers of vehicles affected using the fleet data (see Figure 15). We then combine this with the average price of vehicles in the fleet (Table 18).

For the different scenarios we assume that vehicle owners replace their vehicles with the lowest cost vehicle they can, eg if the entry standard is set at Euro III, owners of pre-Euro, Euro I and Euro II vehicles replace their vehicles with Euro III vehicles. The costs are estimated as the difference in costs. This is a conservative assessment and does not include any estimates for changes in prices in response to demand changes. For example, Scenario 1 introduces a restriction on heavy commercial vehicles (HCVs) at the Euro II level. A CBD LEZ is assumed to affect 25% of HCVs in Auckland, this will include 1,234 Pre-Euros and 1,430 Euro I vehicles, a total of 2,665 which we assume will replaced by Euro II vehicles (Table 26). We assume that the vehicles that need to be replaced can be sold at their market price and the replacement vehicles will cost the market price (Table 18); thus there is a saving equal to the market price of the existing fleet and a cost equal to the purchase price of the replacement Euro II vehicles. The total cost is estimated at $34 million.

These costs are a one-off cost but they are also just a cost brought forward. Vehicle owners would need to replace their vehicles at some stage anyway. This both reduces the costs and sets a limit on the benefits achieved also. For analysis we assume that the costs are brought forward by five years consistent with the industry figures discussed above. Thus the total costs are analysed as the net costs minus the discounted value of these net costs in five years' time. So a cost of $34 million is avoiding a discounted cost of $23 million in the future (at an 8% discount rate), making a net cost of $11 million.

[113] Ken Shirley, Road Transport Forum, personal communication

Table 26 Impacts of CBD LEZ under Scenario 1 (medium assumptions)

Euro Class	Vehicles	Affected	No. affected or required	Price	Cost
Pre-Euro	4,937	25%	1,234	26,932	-$33,240,735
Euro I	5,721	25%	1,430	39,397	-$56,347,828
Euro II			2,665	46,425	$123,700,060
Total					$34,111,498

The results across all scenarios for a CBD & Port LEZ are shown in Table 27 for medium assumptions (Table 16) and for the Auckland LEZ in Table 28; results for low and high assumptions are provided in Annex 2.

Table 27 Costs of CBD & Port LEZ – Vehicle upgrade (medium assumptions) ($ million)

Scenario	LPVs	LCVs	HCVs	Bus	Total
% of vehicles entering LEZ:	25%	25%	25%	75%	
1 Euro II HCV	-	-	11	-	11
2 Euro III HCV	-	-	36	-	36
3 Euro IV HCV	-	-	88	-	88
4 Euro II HCV&LCV	-	3	11	-	14
5 Euro III HCV&LCV	-	17	36	-	53
6 Euro II All diesel	4	3	11	8	26
7 Euro III All diesel	16	17	36	20	89

Table 28 Costs of Auckland urban airshed LEZ – Vehicle upgrade ($ million)

Scenario	LPVs	LCVs	HCVs	Bus	Total
% of vehicles entering LEZ	120%	100%	120%	100%	
1 Euro II HCV	-	-	52	-	52
2 Euro III HCV	-	-	173	-	173
3 Euro IV HCV	-	-	420	-	420
4 Euro II HCV&LCV	-	13	52	-	65
5 Euro III HCV&LCV	-	67	173	-	240
6 Euro II All diesel	21	13	52	11	96
7 Euro III All diesel	75	67	173	27	342

These costs are all one-off costs and need to be compared with the present value of annualised benefits.

Retrofit Technologies

If retrofit technologies are available costs fall significantly. Assuming that all Euro I and II vehicles can be retrofitted, whereas other vehicles must be replaced, the costs are estimated for the CBD & Port and Auckland LEZs in Table 29 and Table 30 respectively.

Table 29 Costs of CBD & Port LEZ – Retrofit Euro I & II ($ million)

Scenario	LPVs	LCVs	HCVs	Bus	Total
% of vehicles entering LEZ	25%	25%	25%	75%	
1 Euro II HCV	-	-	12	-	12
2 Euro III HCV	-	-	20	-	20
3 Euro IV HCV	-	-	33	-	33
4 Euro II HCV&LCV	-	8	12	-	20
5 Euro III HCV&LCV	-	16	20	-	36
6 Euro II All diesel	10	8	12	7	37
7 Euro III All diesel	19	16	20	10	65

Table 30 Costs of Auckland LEZ – Retrofit Euro I & II ($ million)

Scenario	LPVs	LCVs	HCVs	Bus	Total
% of vehicles entering LEZ	120%	100%	120%	100%	
1 Euro II HCV	-	-	57	-	57
2 Euro III HCV	-	-	95	-	95
3 Euro IV HCV	-	-	157	-	157
4 Euro II HCV&LCV	-	17	57	-	75
5 Euro III HCV&LCV	-	33	95	-	128
6 Euro II All diesel	29	17	57	9	112
7 Euro III All diesel	45	33	95	14	187

6.2.3 Government Administration

The costs to government are expected to be small in comparison with the other cost elements. Costs will include those associated with policy development and drafting legislation, communication and consultation costs, plus technical support. We assume $500,000 for all scenarios.

6.3 Benefits

The benefits associated with the LEZs was calculated by estimating the change in PM_{10} concentrations in each census area unit (CAU) included in the LEZ (see lists in Table 70 in Annex 3). We estimate the population-weighted change in concentrations for the different areas (Table 31).

Table 31 Impacts of LEZs on reduction in PM_{10} concentrations ($\mu g/m^3$)

Scenario	CBD & Port	Rest of Auckland	Auckland urban airshed
1 Euro II HCV	0.099	0.072	0.073
2 Euro III HCV	0.130	0.077	0.078
3 Euro IV HCV	0.673	0.153	0.166
4 Euro II HCV&LCV	0.131	0.080	0.081
5 Euro III HCV&LCV	0.185	0.090	0.092
6 Euro II All diesel	0.137	0.081	0.082
7 Euro III All diesel	0.411	0.145	0.151

In Table 32 we show the impacts on health effects under the different scenarios for the CBD & Port LEZ, and in Table 33 for an Auckland urban airshed LEZ. The CBD results may underestimate the effect as the (lower emissions) vehicles that enter the CBD will also be travelling in the rest of Auckland, thus reducing emissions there also. The extent of this effect depends on whether vehicles that now enter the CBD have been replaced by vehicles that now travel in the rest of Auckland. This makes these effects highly uncertain. However, the health effects of an LEZ in the CBD & Port range from 2% to 5% of those for the Auckland urban airshed (based on life years gained), such that, if the CBD LEZ resulted in only a small percentage of the Auckland wide benefits, it could easily exceed the current measured benefits for a CBD LEZ.

Table 32 Impacts of concentration changes on Health effects (CBD & Port LEZ) (reductions in cases)

Scenario:	1 Euro II HCV	2 Euro III HCV	3 Euro IV HCV	4 Euro II HCV&LCV	5 Euro III HCV&LCV	6 Euro II All diesel	7 Euro III All diesel
Attributed deaths (adults)	0.030	0.038	0.200	0.039	0.055	0.041	0.122
Life years gained (adults)	0.631	0.822	4.268	0.831	1.174	0.867	2.607
Attributed deaths (babies)	0.000	0.001	0.003	0.001	0.001	0.001	0.002
Life years gained (babies)	0.020	0.026	0.135	0.026	0.037	0.027	0.082
Cardiac admissions (all)	0.007	0.009	0.044	0.009	0.012	0.009	0.027
Respiratory admissions (all)	0.013	0.018	0.091	0.018	0.025	0.018	0.056
Restricted activity days	50.3	65.6	340.6	66.3	93.7	69.2	208.0

Table 33 Impacts of concentration changes on Health effects (Auckland urban airshed LEZ) (reductions in cases)

Scenario:	1 Euro II HCV	2 Euro III HCV	3 Euro IV HCV	4 Euro II HCV&LCV	5 Euro III HCV&LCV	6 Euro II All diesel	7 Euro III All diesel
Attributed deaths (adults)	2.9	3.1	6.2	3.2	3.6	3.2	5.8
Life years gained (adults)	37.9	40.5	83.4	42.1	47.8	42.8	77.5
Attributed deaths (babies)	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Life years gained (babies)	2.6	2.8	5.6	2.9	3.3	2.9	5.3
Cardiac admissions (all)	0.6	0.7	1.4	0.7	0.8	0.7	1.3
Respiratory admissions (all)	1.3	1.4	2.8	1.5	1.6	1.5	2.7
Restricted activity days	4,905	5,231	10,643	5,440	6,160	5,534	9,958

The monetary value of these benefits is given in Table 34. The benefits vary from $15,700 ($97,300 using VoSL) for Scenario 1 to $106,500 ($658,600) for Scenario 3. Note, as discussed above these benefits do not include those associated with the effects of the

CBD & port LEZ on vehicles in the rest of Auckland. We explore this in sensitivity analysis.

Table 34 Benefit valuation - CBD & Port LEZ ($'000 per annum)

	1 Euro II HCV	2 Euro III HCV	3 Euro IV HCV	4 Euro II HCV&LCV	5 Euro III HCV&LCV	6 Euro II All diesel	7 Euro III All diesel
Life years gained (adults)	$12.6	$16.4	$85.1	$16.6	$23.4	$17.3	$52.0
Life years gained (babies)	$0.4	$0.5	$2.7	$0.5	$0.7	$0.5	$1.6
Cardiac admissions (all)	$0.0	$0.0	$0.2	$0.0	$0.1	$0.0	$0.1
Respiratory admissions (all)	$0.1	$0.1	$0.4	$0.1	$0.1	$0.1	$0.2
Restricted activity days	$2.7	$3.5	$18.1	$3.5	$5.0	$3.7	$11.0
Total (VoLY)	**$15.7**	**$20.5**	**$106.5**	**$20.7**	**$29.3**	**$21.6**	**$65.0**
Total (VoSL)	**$97.3**	**$126.8**	**$658.6**	**$128.2**	**$181.1**	**$133.8**	**$402.2**

These results are all in annual benefits; they will continue for so long as the policy scenario is assumed to be different from the baseline (no intervention scenario). In the discussion of costs above we suggested that the costs of new vehicles consisted of bringing forward the timing of investment rather than an absolute cost. We assumed that the regulations resulted in costs being brought forward by five years; we assume the same impact on benefits, ie that they last for five years. The discounted future values are included in the *Net Benefits* Section below. Table 35 has the same results for the Auckland urban airshed LEZ.

Table 35 Benefit valuation – Auckland urban airshed LEZ ($'000 per annum)

	1 Euro II HCV	2 Euro III HCV	3 Euro IV HCV	4 Euro II HCV&LCV	5 Euro III HCV&LCV	6 Euro II All diesel	7 Euro III All diesel
Life years gained (adults)	$757	$808	$1,664	$840	$953	$855	$1,546
Life years gained (babies)	$52	$55	$112	$57	$65	$58	$105
Cardiac admissions (all)	$3	$4	$8	$4	$4	$4	$7
Respiratory admissions (all)	$5	$5	$11	$6	$6	$6	$10
Restricted activity days	$260	$278	$565	$289	$327	$294	$528
Total (VoLY)	**$1,077**	**$1,150**	**$2,359**	**$1,196**	**$1,356**	**$1,216**	**$2,197**
Total (VoSL)	**$9,434**	**$24,511**	**$49,872**	**$25,491**	**$28,866**	**$25,932**	**$46,664**

6.4 Net Benefits

Table 36 summarises the results over five years with an 8% discount rate. Costs exceed benefits for all options. Increasing the time of analysis to ten years increases costs more than the benefits. Even using the VoSL-based benefit calculation, the benefits increase by $2 million in Scenario 3 but the costs by $21 million (under the retrofit option).

Table 36 Summary of Cost, Benefits and Net Benefits – CBD & Port LEZ ($ million)

LEZ option:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Vehicle types	HCV	HCV	HCV	LCV/HCV	LCV/HCV	All diesel	All diesel
Euro standard	II	III	IV	2/II	3/III	2/II	3/III
Costs							
Equipment	$6.0	$6.0	$6.0	$6.0	$6.0	$6.0	$6.0
Government	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5
Operator (retrofit)[1]	$12.0	$19.7	$32.8	$20.2	$35.5	$37.4	$65.3
Total costs	$18.5	$26.2	$39.3	$26.6	$42.0	$43.9	$71.8
Benefits							
VoLY	$0.1	$0.1	$0.4	$0.1	$0.1	$0.1	$0.3
VoSL	$0.4	$0.5	$2.6	$0.5	$0.7	$0.5	$1.6
Net Benefits							
VoLY	-$18.4	-$26.1	-$38.8	-$26.6	-$41.9	-$43.8	-$71.5
VoSL	-$18.1	-$25.7	-$36.6	-$26.1	-$41.3	-$43.4	-$70.2

Note: [1] Retrofit technologies are used where possible

The Auckland urban airshed LEZ results are shown in Table 37. The benefits are closer in magnitude to the costs, but costs exceed the benefits in all scenarios unless VoSL-based benefit valuation is used (4 out of 7 scenarios have positive net benefits).

Table 37 Summary of Cost, Benefits and Net Benefits – Auckland urban airshed LEZ ($ million)

LEZ option:	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Vehicle types	HCV	HCV	HCV	LCV/HCV	LCV/HCV	All diesel	All diesel
Euro standard	II	III	IV	2/II	3/III	2/II	3/III
Costs							
Equipment	$9.0	$9.0	$9.0	$9.0	$9.0	$9.0	$9.0
Government	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5
Operator (retrofit)[1]	$57.5	$94.6	$157.3	$74.7	$127.7	$112.2	$186.6
Total costs	$67.0	$104.1	$166.8	$84.2	$137.2	$121.7	$196.1
Benefits							
VoLY	$4.3	$4.6	$9.4	$4.8	$5.4	$4.9	$8.8
VoSL	$37.7	$97.9	$199.1	$101.8	$115.3	$103.5	$186.3
Net Benefits							
VoLY	-$62.7	-$99.5	-$157.4	-$79.4	-$131.7	-$116.9	-$187.3
VoSL	-$29.3	-$6.2	**$32.4**	**$17.6**	-$21.9	-$18.2	-$9.8

Note: [1] Retrofit technologies are used where possible

There is a risk in concluding that an Auckland urban airshed LEZ would be better than a CBD LEZ on the basis of the potential for positive net benefits. The benefits are highly uncertain and, if they are closer to the VoLY-based values, then the Auckland urban airshed LEZ would result in much higher net costs.

Within the LEZ options, the ranking of options suggests that one focussed on HCVs and imposing a Euro II requirement is the best option (lowest net costs), although we note that it is the worst option for the Auckland urban airshed and VoSL-based analysis. The next best options are Option 2 (Euro III HCV) and Option 4 (Euro II HCV & LCV). This suggests that those focussed on the oldest and most-polluting vehicles are the best options, largely because of the lower costs.

7 Emissions Testing

7.1 Approach

The emissions testing option is assumed to apply to all vehicles in the Auckland region. It has been examined on the assumption that all vehicles would be required to have an emissions test as part of their Warrant of Fitness (WoF) or Certificate of Fitness (CoF).[114]

The impacts have been modelled on the basis of the population in the Auckland urban airshed as used in the LEZ option above.

The various options for testing and test facilities were examined by Fuel Technology Limited & Auckland Uniservices (FTL-AUL) in a trial of emissions testing from 2004.[115] More recently this has been examined by Gerda Kuschel for Auckland Council.[116]

In this report we do not discuss the options in any detail. Rather we use the assumption that snap acceleration testing is used; it is widely discussed in these previous publications and we do not update this here. We assume that a testing requirement tied to the WoF/CoF could result in improvements to vehicle performance through vehicles having more regular servicing. This would result in less deterioration of performance and emissions.

VEPM5.1 includes a default factor that accounts for degradation of diesel vehicles (except Euro VI) over time. This degradation factor therefore assumes that diesel vehicle exhaust emissions will increase with increasing vehicle age and mileage. With the introduction of regional in-service standards, through vehicle testing inspections, the high emitters would be identified and be required to undertake maintenance to restore vehicle emissions to the required standard for that vehicle.

For the vehicle testing scenario, the 2016 base case for the identified assessment areas has been run through VEPM 5.1 with the degradation factors not included. This scenario assumes diesel vehicles would be maintained and brought back to their required emission standard and that the change in VKT as a result of vehicles being retired because they cannot meet the regional standard is negligible.

7.2 Costs

The cost components include:

- the costs of the test facilities; and
- the costs for vehicles that will include:
  - More frequent servicing to avoid test failures;

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[114] Warrant of Fitness (WoF) applies to cars and all vehicles less than 3,500 kg in weight.

[115] Campbell A, Gething J, Raine R, Elder S and Jones K (2006) Vehicle Emissions Pilot Project — Diesel Vehicles Project 1503257: CEL. Fuel Technology Limited & Auckland Uniservices Limited. Prepared for Ministry of Transport.

[116] Kuschel G (2014) Investigations into Reducing Emissions from Heavy Duty Diesel Vehicles in Auckland – a Summary Report. Auckland Council Technical Report 2014/018

- Repairs for vehicles that fail;
- Replacement of vehicles that fail.

We examine these in turn below.

7.2.1 Test Facilities

Campbell *et al* estimated the capital and operating costs of a testing system and converted this into a cost per test of $20-$56 ($24-$66 in 2014 values), with a weighted average of $33 ($39 in 2014 dollars).[117]

7.2.2 Vehicle Costs

Servicing Costs

Servicing costs might increase for older vehicles that would be at risk of failure. The extent to which this would affect vehicles depends on current service frequency and perceptions of the effectiveness of servicing. Service costs for diesel vehicles are estimated to be in the region of $210 - $260.[118] Costs would be expected to be higher for heavy vehicles.

There will be some additional costs involved for the time taken to deliver and pick-up the vehicle plus any associated repairs. However, service costs will be off-set by lower costs because mechanical problems will be detected and fixed before they arise, and the vehicle will be running more efficiently with lower expected fuel costs.

Repair Costs

Repair costs were examined by FTL-AUL in the 2006 trial of emissions testing.[119] It estimated costs for diesel vehicles that ranged from $150 - $1,200 for light vehicles and $150 - $2,000 for heavy vehicles, which we assume to be exclusive of GST,[120] and $522 as an average ($600 including GST). For this analysis we exclude GST as it is not a cost to the nation; it is just a transfer from the vehicle owner, via the tester, to the Government. We use the average figure and inflate this to $615 (rounded up) in December 2014 prices and a range rounded to $275 - $2350.

Vehicle Replacement Costs

Some vehicles that fail to meet standards will need to be replaced. We take a mid-point (Euro IV vehicle) as the type of vehicle that is purchased. As with the analysis for LEZs we assume that the cost of vehicles brings forward a replacement vehicle rather than being an absolute cost. We use five years and an 8% discount rate.

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[117] We use the produce price index (output basis) for Retail. The "motor vehicle & parts, and fuel retailing" index was not calculated in 2006. The index results in an estimated 17.6% increase in prices in nominal terms.

[118] Based on on-line advertised prices (excl GST) for commercial diesel vehicles from AA, Pit Stop and Mobile Vehicle Tuning & Servicing Ltd

[119] Campbell *et al* (op cit)

[120] This is stated on p57 of the report where GST is not mentioned. GST-inclusive prices are noted on p52 where repair costs are said to be up to "over $2,000 (GST inclusive) for some heavy vehicles" [emphasis added]. We assume that $2,000 as a high cost estimate is GST exclusive as GST-inclusive costs can be over this amount.

Total Costs

We assume the following costs for analysis (Table 38). This includes the costs for testing, which will apply to all vehicle types. Although pre-Euro vehicles have no standard against which to test, if they are not included there would be an incentive towards obtaining pre-Euro vehicles. Servicing costs apply to a certain percentage of vehicles; the number represents the percentage of the fleet in the individual categories (Pre-Euro LPVs etc) that are not currently serviced regularly but would be following the introduction of the testing requirement. Repair costs apply to a percentage of these additionally serviced vehicles; another percentage of those additional vehicles serviced are replaced.

Table 38 Servicing cost assumptions

Cost element	LPVs	LCVs	HCVs	Buses
Testing cost	$40	$40	$60	$60
Servicing cost	$250	$250	$400	$400
Servicing (% increase)				
Pre-Euro	20%	15%	10%	10%
Euro I	20%	15%	10%	10%
Euro II	15%	10%	5%	5%
Euro III	10%	5%	2.5%	2.5%
Euro IV	5%	2.5%	1%	1%
Euro V	2.5%			
Repair cost	$300	$500	$1,000	$1,000
Repair percentage of serviced	10%	10%	10%	10%
Vehicle replacement (% of serviced)	5%	5%	2.5%	2.5%

Table 39 Total annual costs of testing regime

	LPVs	LCVs	HCVs	Buses	Total
Testing	$2,153,600	$2,142,040	$1,253,640	$102,000	$5,651,280
Servicing					
Pre-Euro	$353,350	$136,575	$197,480	$16,760	$704,165
Euro I	$764,050	$247,463	$228,840	$12,400	$1,252,753
Euro II	$132,938	$150,100	$51,480	$3,160	$337,678
Euro III	$140,650	$180,263	$58,370	$4,520	$383,803
Euro IV	$160,013	$80,738	$15,576	$1,528	$257,854
Euro V	$103,669	$0	$0	$0	$103,669
Total	$1,654,669	$795,138	$551,746	$38,368	$3,039,920
Repair	$198,560	$159,028	$137,937	$9,592	$505,116
Replacement cost ($/vehicle)	$6,036	$8,003	$24,377	$75,136	
Replacement cost	$1,997,383	$1,272,742	$840,615	$180,177	$4,290,917
Benefit					
Total cost	**$6,004,212**	**$4,368,947**	**$2,783,938**	**$330,137**	**$13,487,233**

In sensitivity analysis (see Section 9.7), we vary the assumptions made about the percentage of vehicles that need to be replaced (final line in Table 38): 0% in the low case and double the values in Table 38 in the high case. We also vary the costs of testing by 50% in either direction.

7.3 Benefits

The calculated benefits for the emissions testing option are greater than those for an LEZ. It is estimated to result in an overall average change in PM_{10} concentration of 0.24µg/m³ across the Auckland urban airshed.

Table 40 Health impacts of Emissions testing

Health impact	Number
Attributed deaths (adults)	9.0
Life years gained (adults)	119.8
Attributed deaths (babies)	0.1
Life years gained (babies)	8.0
Cardiac admissions (all)	2.0
Respiratory admissions (all)	4.1
Restricted activity days	15,276

The benefits are calculated in Table 41. The central estimate is a benefit of $3.8 million, within a range of $1.6 million to $30 million (or $37 million using a VoSL-based approach).

Table 41 Benefits of vehicle testing ($'000 per annum)

Impact	Value
Life years gained (adults)	$2,390
Life years gained (babies)	$161
Cardiac admissions (all)	$11
Respiratory admissions (all)	$16
Restricted activity days	$810
Total (VoLY)	$3,387
Total (VoSL)	$36,611

7.4 Net Benefits

Table 42 summarises the net benefits of an emission testing regime. The results are shown for the present value (PV) of costs and benefits over a five year project discounted at 8%. Testing is found to have positive net benefits only under the high benefit assumptions using VoLY.

Table 42 Cost, Benefits and Net Benefits of Emissions Testing – present value ($ million)

Element		Value
Costs	Testing	$22.6
	Servicing	$12.1
	Repair	$2.0
	Replacement vehicles	$17.1
	Government	$2.0
	Total costs	$55.8
Benefits	VoLY	$13.5
	VoSL	$146.2
Net Benefits	VoLY	-$42.3
	VoSL	$90.3

In analysis of this and other policy measures we project the impacts forward over five years, however we have not updated the exposed population numbers. To do so risks over-estimating the benefits as it assumes that new residents had historical exposure equivalent to the existing population. In addition, costs would need to change in addition to benefits, but in a way that is less easily modelled. It is also clear that these small changes to the assumptions are likely to have little material impact on the results.

In addition to the uncertainty over benefit assessment, reflecting the potential for preventing deterioration in addition to the uncertainty over valuation approach, the key factors that determine costs include the costs of testing and the number of vehicles that will need to be replaced because they fail to meet tests.

Under our base assumptions the costs are significantly higher than the benefits.

8 Road Pricing

8.1 Approach

The road pricing scenario was derived from the 2008 MoT Auckland Road Pricing Study (Report no: WL00062-1). It applies to a central Auckland area including the CBD & Port (Figure 17 and Table 70 in Annex 3) and is estimated to result in an approximate 10% reduction in traffic and approximate 5% increase in public transportation service requirements. VKT data for each CAU was reduced by 10% to account for the approximate 10% reduction in traffic prior to input into the HAPiNZ model. The fleet profile entered into VEPM 5.1 was adjusted to reflect a 5% increase in buses.

8.2 Costs

The scheme can be described as correcting a current externality by placing a charge on congestion. If the level of charge is correct the resulting impact is correcting regional outcomes to a level that is more optimal than current. As such, change in activity levels in the region would be welfare improving.

However, this ignores the costs of implementing the scheme, including the camera and computer system requirements. For simplicity we base our cost estimates on the costs for an LEZ. We assume a slightly higher total cost for the Auckland scheme: $10 million, versus $9 million for the LEZ (Table 37).

In sensitivity analysis we simply vary these costs by 50% in either direction.

8.3 Benefits

The calculated benefits for the emissions testing option are estimated to result in an overall average change in PM_{10} concentration of 0.20µg/m³ across the central Auckland area (Figure 17). The resulting health effects are shown in Table 43.

Table 43 Annual health impacts of Road Pricing

Health impact	Number
Attributed deaths (adults)	0.681
Life years gained (adults)	9.903
Attributed deaths (babies)	0.006
Life years gained (babies)	0.507
Cardiac admissions (all)	0.151
Respiratory admissions (all)	0.311
Restricted activity days	1,162

The benefits are calculated in Table 44. The central estimate (using VoLY) is a net benefit of $0.3 million, or $2.2 million using a VoSL-based approach.

Table 44 Benefits of road pricing ($'000 per annum)

Impact	Value
Life years gained (adults)	$198
Life years gained (babies)	$10
Cardiac admissions (all)	$1
Respiratory admissions (all)	$1
Restricted activity days	$62
Total (VoLY)	$271
Total (VoSL)	$2,230

8.4 Net Benefits

The estimated net benefits of road pricing are given in Table 45. Costs include equipment costs; the response to pricing itself is assumed to be welfare-improving and not a cost. The costs are present values over five years. Under the assumptions used, none of the benefit valuation options yields positive net benefits for road pricing.

Table 45 Cost, Benefits and Net Benefits of Road Pricing – present value ($ million)

Element		Value
Costs	Equipment	$10.00
	Government	$0.50
	Total costs	**$10.50**
Benefits	VoLY	$1.1
	VoSL	$8.9
Net Benefits	VoLY	-$9.4
	VoSL	-$1.6

This approach to analysis may over-estimate costs as there may be net benefits from road pricing that would offset these costs also, eg if the benefits from reduced congestion and reduced (and currently under-priced) CO_2 emissions[121] were greater than the costs from displaced and reduced activity. We proxy this in sensitivity analysis through the low cost option (50% of costs).

[121] This under-pricing reflects the current approach of charging 1 emission unit per 2 tonnes of CO_2-equivalent.

9 Summary, Sensitivity Analysis, Conclusions

9.1 Base Results – HAPiNZ Assumptions

The results for the HAPiNZ assumptions are shown in Table 46 in physical terms and in Table 47 in monetary terms.

Table 46 Impacts of Policy Options on Premature Deaths

	CBD & Port		Auckland	
	Adults	**Babies**	**Adults**	**Babies**
LEZ				
1 Euro II HCV	0.03	0.00	2.88	0.03
2 Euro III HCV	0.04	0.00	3.07	0.03
3 Euro IV HCV	0.20	0.00	6.24	0.07
4 Euro 2/II LCV&HCV	0.04	0.00	3.19	0.04
5 Euro 3/III LCV&HCV	0.05	0.00	3.61	0.04
6 Euro 2/II All diesel	0.04	0.00	3.25	0.04
7 Euro 3/III All diesel	0.12	0.00	5.84	0.07
Testing			8.96	0.10
Road Pricing			0.68	0.01

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

The assumptions used for monetary valuation include:

- Mortality benefits measured using VoSL;
- No cessation lag;
- 8% discount rate;
- Costs and benefits calculated over five years.

Table 47 Net Present Value of Policy Options - HAPiNZ Assumptions

	CBD & Port			Auckland		
	Costs	**Benefits**	**Net benefits**	**Costs**	**Benefits**	**Net benefits**
LEZ						
1 Euro II HCV	$18	$0	-$18	$67	$47	-$20
2 Euro III HCV	$26	$1	-$26	$104	$98	-$6
3 Euro IV HCV	$39	$3	-$36	$167	$200	**$33**
4 Euro 2/II LCV&HCV	$27	$1	-$26	$84	$102	**$18**
5 Euro 3/III LCV&HCV	$42	$1	-$41	$137	$116	-$22
6 Euro 2/II All diesel	$44	$1	-$43	$122	$104	-$18
7 Euro 3/III All diesel	$72	$2	-$70	$196	$187	-$9
Testing				$56	$147	**$91**
Road Pricing				$10	$11	**$1**

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

These values provide the basis for comparison of results with previous studies of the impacts of air pollution. However, the approach assumes instantaneous rather than lagged benefits, which are preferred for a marginal analysis such as this. It also uses a VoSL-based benefit valuation approach. Our preferred approach is VoLY-based.

Below we present the results using our preferred assumptions. In all results tables we highlight the positive net benefit results.

9.2 Mortality Characterisation

The overall results are shown in Table 48 using VoLY and VoSL-based assumptions. Unlike the HAPiNZ analysis, our base case analysis includes a cessation lag based on the EPA formula that distributes the benefits over 20 years: 30% in year 1, 50% spread evenly (12.5% per year) over years 2 to 5 with the 20% spread evenly over years 6 to 20. The VoLY analysis assumes a value of $25,000.

Table 48 Summary Results - PV of Net Benefits ($ million)

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$18	-$18	-$63	-$29
2 Euro III HCV	-$26	-$26	-$99	-$6
3 Euro IV HCV	-$39	-$37	-$157	**$32**
4 Euro 2/II LCV&HCV	-$27	-$26	-$79	**$18**
5 Euro 3/III LCV&HCV	-$42	-$41	-$132	-$22
6 Euro 2/II All diesel	-$44	-$43	-$117	-$18
7 Euro 3/III All diesel	-$72	-$70	-$187	-$10
Emissions Testing			-$42	**$90**
Road Pricing			-$9	-$2

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

It shows the impacts of different assumptions for benefit valuation, that are based on the way in which mortality impacts are characterised (see Table 80 on page 127):

- the VoLY approach assumes that the mortality impact is an extension to life expectancy; life is extended at the end of life, possibly many years in the future;
- the VoSL approach assumes that the mortality effect can be characterised as a reduction in the risk of death for people of all ages and the uncertainty of effect is such that it is the same for all ages.

Our preference is for the VoLY approach. Under these assumptions, none of the policy options examined results in positive net benefits. Under the VoSL approach, emissions testing and road pricing have positive net benefits.

In Table 49 we show the effects of varying the VoLY, given the uncertainty over this value. The analysis is undertaken for the wider Auckland areas, ie the Auckland urban airshed for the LEZ and testing options and the central region for road testing. The medium ($25,000) and low ($5,000) VoLYs are based on literature that has assessed the willingness to pay (WTP) for life extension. The high VoLY is really an alternative specification of the VoSL as it is an annualised estimate of the VoSL. The $44,000 VoLY assumes that VoLY is income constrained; this represents some maximum value. The high (VoSL-based) VoLY ($199,000) produces results that are closer to those based on VoSL and it includes a positive net benefit result for emissions testing.

Table 49 Summary Results - PV of Net Benefits ($ million) – alternative VoLY values

Policy Scenario	VoLY ($5k)	VoLY ($25k)	VoLY ($44k)	VoLY ($199k)
LEZ				
1 Euro II HCV	-$65	-$63	-$64	-$40
2 Euro III HCV	-$102	-$99	-$101	-$68
3 Euro IV HCV	-$163	-$157	-$160	-$94
4 Euro 2/II LCV&HCV	-$82	-$79	-$81	-$47
5 Euro 3/III LCV&HCV	-$135	-$132	-$133	-$95
6 Euro 2/II All diesel	-$120	-$117	-$118	-$84
7 Euro 3/III All diesel	-$192	-$187	-$190	-$128
Emissions Testing	-$50	-$42	-$46	**$49**
Road Pricing	-$10	-$9	-$10	-$4

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

9.3 95 % Confidence Intervals

Using the range of relative risk values based on 95% confidence intervals (see Table 10 on page 39), we estimate the impacts on the net benefits in Table 50 (low) and Table 51 (high). Under the low sensitivity assumptions there is a significant downward shift in net benefits, with only Auckland-wide testing using VoSL-based benefit valuation resulting in positive net benefits. Using high sensitivity (10%/8%), all but one LEZ options have positive net benefits under the VoSL-based benefit valuation approach, although not under the other assumptions.

Table 50 Summary Results - PV of Net Benefits ($ million) – Relative risks for mortality of 1.03 (adults) and 1.02 (babies)

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$18	-$18	-$66	-$59
2 Euro III HCV	-$26	-$26	-$103	-$62
3 Euro IV HCV	-$39	-$39	-$165	-$82
4 Euro 2/II LCV&HCV	-$27	-$27	-$83	-$41
5 Euro 3/III LCV&HCV	-$42	-$42	-$136	-$88
6 Euro 2/II All diesel	-$44	-$44	-$121	-$78
7 Euro 3/III All diesel	-$72	-$71	-$194	-$117
Emissions Testing			-$53	**$6**
Road Pricing			-$10	-$9

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

Table 51 Summary Results - PV of Net Benefits ($ million) – Relative risks for mortality of 1.10 (adults) and 1.08 (babies)

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$18	-$18	-$64	-$40
2 Euro III HCV	-$26	-$26	-$101	**$35**
3 Euro IV HCV	-$39	-$37	-$160	**$116**
4 Euro 2/II LCV&HCV	-$27	-$26	-$81	**$60**
5 Euro 3/III LCV&HCV	-$42	-$41	-$133	**$27**
6 Euro 2/II All diesel	-$44	-$44	-$118	**$25**
7 Euro 3/III All diesel	-$72	-$71	-$190	**$68**
Emissions Testing			-$46	**$151**
Road Pricing			-$10	-$4

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

9.4 Discount Rate

The results are undertaken with a discount rate of 8%, which is the Treasury suggested rate for policy analysis. If we use a lower rate of 5% that has been used for some recent policy analyses in the energy and transport sectors, the results are as shown in Table 52. The discount rate applies to the overall timing of results and to the impacts of the cessation lag assumptions.

At the lower discount rate all but one LEZ option for the Auckland urban airshed have positive net benefits if using a VoSL-based analysis.

Table 52 Summary Results - PV of Net Benefits ($ million) – 5% Discount Rate

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$16	-$16	-$51	-$12
2 Euro III HCV	-$22	-$22	-$78	**$22**
3 Euro IV HCV	-$31	-$28	-$115	**$90**
4 Euro 2/II LCV&HCV	-$24	-$24	-$65	**$40**
5 Euro 3/III LCV&HCV	-$38	-$37	-$106	**$13**
6 Euro 2/II All diesel	-$40	-$39	-$96	**$10**
7 Euro 3/III All diesel	-$64	-$63	-$150	**$42**
Emissions Testing			-$39	**$104**
Road Pricing			-$10	-$1

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

9.5 Lagged Benefits

The analysis has assumed a cessation lag in which the benefits do not arise immediately. This reflects the finding that most health effects are chronic as a result of living for a long time in elevated concentrations and the damage is not repaired immediately on reduction in pollution. The issue of cessation lag is discussed in Annex 4 from page 115.

We use the EPA lag model as the primary assumption, with sensitivity analysis using: no lag and 30-year lag. The assumptions are:

- EPA: 30% of the mortality reductions occur in the first year, 50% occur equally in years 2 through 5 and the remaining 20% occur equally over years 6 through 20;

- No lag: 100% of the mortality reductions occur immediately after emission reduction;

- 30-year lag: the mortality reductions are spread equally over 30 years, with 3.3% of the benefit in each year.

The no cessation lag results are given in Table 53 and the 30-yr cessation lag results in Table 54. It has the greatest impact on the highest benefit valuation methods, ie using VoSL. The 30-yr lag option shifts all the LEZ results to being negative, but there is little other significant effect.

The no cessation lag results using VoSL are equivalent to the HAPiNZ assumptions (Table 47).

Table 53 Summary Results - PV of Net Benefits ($ million) – No cessation lag

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$18	-$18	-$62	-$20
2 Euro III HCV	-$26	-$26	-$98	-$6
3 Euro IV HCV	-$39	-$36	-$155	**$33**
4 Euro 2/II LCV&HCV	-$27	-$26	-$78	**$18**
5 Euro 3/III LCV&HCV	-$42	-$41	-$130	-$22
6 Euro 2/II All diesel	-$44	-$43	-$116	-$18
7 Euro 3/III All diesel	-$71	-$70	-$185	-$9
Emissions Testing			-$39	**$91**
Road Pricing			-$9	**$1**

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

Table 54 Summary Results - PV of Net Benefits ($ million) – 30-yr cessation lag

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$18	-$18	-$65	-$48
2 Euro III HCV	-$26	-$26	-$102	-$7
3 Euro IV HCV	-$39	-$38	-$162	**$31**
4 Euro 2/II LCV&HCV	-$27	-$26	-$82	**$17**
5 Euro 3/III LCV&HCV	-$42	-$42	-$134	-$23
6 Euro 2/II All diesel	-$44	-$44	-$119	-$19
7 Euro 3/III All diesel	-$72	-$71	-$192	-$11
Emissions Testing			-$49	**$89**
Road Pricing			-$10	-$6

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

9.6 Region-Wide Benefits

The introduction of an LEZ for the CBD and port is likely to result in additional effects across the wider region because vehicles that travel in the CBD will also travel elsewhere in Auckland. We examine these effects by including a percentage of the wider Auckland effect as applying to the CBD & port LEZ; this would include both benefits and some costs (those for vehicle upgrading and/or retrofits).

Using an assumption that 25% of the benefits obtained across the rest of the Auckland urban airshed would also be obtained, and with no increase in costs, we show the results in Table 55. The Euro IV LEZ (Option 3) has positive net benefits, but only using the VoSL-based values.

Table 55 NPV ($ million) for CBD & Port LEZ including 25% of airshed benefits

LEZ	VOLY	VoSL
1 Euro II HCV	-$18	-$13
2 Euro III HCV	-$26	-$2
3 Euro IV HCV	-$38	**$12**
4 Euro 2/II LCV&HCV	-$26	-$1
5 Euro 3/III LCV&HCV	-$41	-$13
6 Euro 2/II All diesel	-$43	-$18
7 Euro 3/III All diesel	-$71	-$25

9.7 Cost Sensitivity

For LEZ, we vary the percentage of vehicles entering the CBD and Auckland. The modelling of emissions includes information on VKT but does not identify how many vehicles are responsible for those VKT. This we assess using assumptions, as set out in Table 16 on page 46. In Annex 2 we set out the implications for costs of the different assumptions and scenarios.

For the emissions testing option we:

- vary the costs of the test itself: 50% less in the low cost scenario and 50% more in the high scenario; and

- we vary the assumptions made about the percentage of vehicles that need to be replaced: 0% in the low case and double the values in Table 38 in the high case.

For road pricing we simply vary the costs by 50% downwards (low costs) or upwards (high costs).

We summarise the results to compare with Table 48 in Table 56 (low costs) and Table 57 (high costs).

Table 56 Summary Results - PV of Net Benefits ($ million) – Low Cost Assumptions

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$11	-$11	-$53	-$20
2 Euro III HCV	-$14	-$14	-$84	**$10**
3 Euro IV HCV	-$19	-$17	-$131	**$59**
4 Euro 2/II LCV&HCV	-$14	-$14	-$68	**$29**
5 Euro 3/III LCV&HCV	-$21	-$20	-$113	-$3
6 Euro 2/II All diesel	-$23	-$23	-$100	-$1
7 Euro 3/III All diesel	-$35	-$34	-$159	**$18**
Emissions Testing			-$14	**$119**
Road Pricing			-$4	**$3**

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

Table 57 Summary Results - PV of Net Benefits ($ million) – High Cost Assumptions

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$26	-$25	-$77	-$44
2 Euro III HCV	-$38	-$38	-$123	-$30
3 Euro IV HCV	-$58	-$56	-$197	-$7
4 Euro 2/II LCV&HCV	-$39	-$38	-$98	-$1
5 Euro 3/III LCV&HCV	-$63	-$63	-$164	-$54
6 Euro 2/II All diesel	-$64	-$63	-$145	-$46
7 Euro 3/III All diesel	-$107	-$105	-$234	-$56
Emissions Testing			-$71	**$62**
Road Pricing			-$14	-$7

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

Under the low cost assumptions four of the Auckland urban airshed LEZ options have positive net benefits, but only if the VoSL-based benefit valuation approach is used. Under the high cost assumptions all options have net costs. The road pricing option has positive net benefits under the low cost option.

9.8 Significant Assumptions

Table 58 summarises the assumptions and the maximum impacts on net benefits as a percentage change from the base values. The most significant assumptions are for the approach to benefit valuation. Other significant assumptions are those relating to the discount rate employed and the level of costs.

Table 58 Maximum Impact of Assumptions on Net Benefits

Assumptions		LEZ	Testing	Road Pricing
Benefit valuation	Low VoLY	4%	18%	7%
	High VoLY	41%	217%	62%
	VoSL	122%	313%	83%
Confidence intervals	Sensitivity (high)	3%	14%	5%
	Sensitivity (low)	3%	18%	7%
Discount rate	5% discount	27%	8%	3%
Lagged benefits	No lag	2%	8%	3%
	30-yr lag	3%	16%	6%
Region-wide benefits	Region-wide benefits from CBD LEZ	6%		
Costs	Low costs	51%	67%	53%
	High costs	51%	67%	53%

There are differences in the overall effects on the testing and road pricing options versus those for testing and road pricing. The discount rate, in particular has a more significant impact on the LEZ option.

Table 59 shows the results if we use all the most favourable assumptions. This includes:

- High sensitivity, ie 10% and 8% reduction in mortality for adults and babies respectively per 10μg/m^3 change in PM_{10};
- Low (5%) discount rate;
- No benefit lag;
- Inclusion of region-wide benefits of the CBD LEZ;
- Low costs.

Table 59 Summary Results - PV of Net Benefits ($ million) – High Benefit/Low Costs

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$8	**$8**	-$40	**$25**
2 Euro III HCV	-$11	**$26**	-$62	**$81**
3 Euro IV HCV	-$11	**$66**	-$88	**$202**
4 Euro 2/II LCV&HCV	-$11	**$27**	-$52	**$97**
5 Euro 3/III LCV&HCV	-$16	**$27**	-$87	**$82**
6 Euro 2/II All diesel	-$19	**$20**	-$79	**$73**
7 Euro 3/III All diesel	-$27	**$43**	-$120	**$152**
Emissions Testing			-$3	**$198**
Road Pricing			-$4	**$12**

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

The sensitivity of the overall result to the benefit valuation approach remains. All intervention options have positive net benefits if the VoSL approach is used and some do using the High (VoSL-based) VoLYs. But the medium VoLY does not result in any options with positive net benefits.

In Table 60 we minimise benefits and maximise costs.

Table 60 Summary Results - PV of Net Benefits ($ million) – Low Benefit/High Costs

	CBD & Port		Auckland	
Policy Scenario	**VoLY**	**VoSL**	**VoLY**	**VoSL**
LEZ				
1 Euro II HCV	-$26	-$26	-$80	-$73
2 Euro III HCV	-$38	-$38	-$127	-$86
3 Euro IV HCV	-$59	-$58	-$204	-$121
4 Euro 2/II LCV&HCV	-$39	-$39	-$102	-$59
5 Euro 3/III LCV&HCV	-$63	-$63	-$168	-$120
6 Euro 2/II All diesel	-$64	-$63	-$149	-$106
7 Euro 3/III All diesel	-$107	-$106	-$241	-$163
Emissions Testing			-$81	-$22
Road Pricing			-$15	-$14

Note: Auckland LEZ and emissions testing is for the Auckland urban airshed; road pricing is for central Auckland

This includes:

- Low sensitivity, ie 3% and 2
- 8% reduction in mortality for adults and babies respectively per 10μg/m^3 change in PM_{10};
- 8% discount rate;
- 30-year benefit lag;
- No region-wide benefits of the CBD LEZ;
- High costs.

All options have net costs.

9.9 Conclusions

9.9.1 The Importance of Assumptions on Benefit Valuation

The analysis suggests that the policy options examined offer positive net benefits only when the benefits are measured using VoSL. The choice of benefit valuation methodology is hugely important.

HAPiNZ used VoSL and we have included results that are consistent with HAPiNZ, but we suggest that there are reasons for changing these assumptions, particularly for policy studies addressing the impacts of **changes** in concentrations rather than the impacts of **absolute** levels. We have included two significant modifications to the HAPiNZ approach that are consistent with approaches being adopted internationally. These are:

- the inclusion of a cessation lag (lagged benefit values), in recognition that the major effects are on chronic mortality and that repairs to health will not happen instantaneously with reductions in concentrations; and

- the use of changes in life years, valued using VoLY as the primary measure of mortality effect. This is more consistent with the nature of the effect.

The other significant difference relates to the monetary values used. The VoSL we have adopted uses the same source as used in HAPiNZ. A VoLY can be calculated from the VoSL and this results in relatively high benefit values, but we have more confidence in values from studies that have derived VoLYs directly through survey techniques. There is a need for more work on these values in a New Zealand context.

9.9.2 Policy Choices

The analysis suggests that the net benefits (or costs) of the policy options examined to limit emissions in Auckland are highly uncertain. The results depend critically on some key assumptions, particularly the benefit valuation assumptions as discussed above.

- If VoSL-based benefit valuation is used, the analysis suggests that emissions testing has positive net benefits, as do certain Auckland urban airshed-wide LEZs, particularly a Euro IV-based LEZ targeted at HCVs and a less stringent (Euro 2/II) version that targets LCVs and HCVs and could be met using retrofit technologies.

- In contrast, using the preferred VoLY-based analysis, all options have net costs. An LEZ focussed on HCVs and imposing a Euro II requirement is the best LEZ option (lowest net costs), although we note that it is the worst option for the Auckland urban airshed and VoSL-based analysis. The next best LEZ options are Option 2 (Euro III HCV) and Option 4 (Euro 2/II LCV & HCV). This suggests that those focussed on the oldest and most-polluting vehicles are best, largely because of the lower costs.

LEZs

There is a risk in concluding that an Auckland urban airshed LEZ would be better than a CBD LEZ on the basis of the potential for positive net benefits. The benefits are highly uncertain, and if they are closer to the VoLY-based values then the Auckland urban airshed LEZ would result in much higher net costs than a CBD & port LEZ, eg LEZ option 3 ranges in value from positive $32 million (VoSL) to negative $157 million (VoLY) for the Auckland urban airshed, but for the CBD & port has net costs of less than $40 million (Table 48).

We would not recommend any LEZ is adopted, but if one is experimented with, then minimising costs through focusing on a smaller area and older vehicles (Euro II standard) would be preferable.

Emissions Testing

The emissions testing analysis has not examined the emissions testing options in any detail. The costs depend on the costs of the test itself and the number of vehicles that would need to be replaced rather than repaired. The benefits are based on vehicles being maintained in a way that would reduce emissions to levels achieved at manufacture, avoiding the deterioration that occurs in the absence of regular servicing and maintenance.

Emissions testing is ideal where the test costs are low and it provides incentives for vehicle maintenance in a way that avoids the need for vehicle replacement and/or costly repairs. However, the risk of facing these high costs provides the incentive for maintenance.

We found no assumptions that would yield positive net benefits for emissions testing, unless adopting the high VoSL-based benefit valuation approach. Even if all other assumptions were favourable (Table 59) there are net costs under VoLY-based benefit valuation assumptions.

Road Charging

The analysis suggests that road charging to address congestion only has positive net benefits when VoSL is adopted and other favourable assumptions, such as no benefit lag. However, we do not consider all costs and benefits of this option and there may be net benefits from congestion reduction that would tip this from negative to positive.

9.9.3 Overall Conclusions

No policy option provides certainty of positive net benefits.

Across the suite of policy options examined the analysis provides insufficient confidence in any of them for positive policy recommendations to be made.

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Annex 1: Examples of LEZs

A1.1 London

A1.1.1 Description

The London LEZ is one of the largest established. Established in 2008, it covers an area of 1,580 km^2, or most of greater London (Figure 19).[122] It restricts the entry of the most polluting diesel vehicles, including heavy-goods vehicles, buses, larger vans, and minibuses but does not apply to cars or motorcycles.

Figure 19 Area covered by London Low Emission Zone (shaded area)

Source: Transport for London (www.tfl.gov.uk/modes/driving/low-emission-zone)

The London LEZ has been introduced in phases as shown in Table 61. The first phases were all focussed on achieving specified standards relating to PM emissions.

Table 61 Phases of the London LEZ and PM requirements

Vehicle	Phase 1 Feb 2008	Phase 2 Jul 2008	Phase 3/4 Jan 2012[1]
HGVs (over 12 tonnes)	Euro 3		Euro 4
HGVs (3.5–12 tonnes), buses and coaches		Euro 3	Euro 4
Larger vans and minibuses (1.205-3.5 tonnes)			Euro 3
Motor caravans and ambulances (2.5–3.5 tonnes)			Euro 3

[1] Phase 3 extends the scheme to larger vans & minibuses plus caravans & ambulances; Phase 4 introduces tighter Euro 4 standards for the vehicles already in the scheme
Source: Greater London Authority Request for Mayoral Decision MD666

[122] Transport for London. Congestion Charging & Low Emission Zone Key Fact Sheet 01 April 2014 to 30 June 2014

Phase 5

The Mayor's Air Quality Strategy (MAQS) originally proposed to start Phase 5 in 2015 with a Euro 4 NOx requirement for larger diesel engine vehicles. However, this will now be restricted to Transport for London (TfL) buses.[123] The reasons given are because of the poor performance of Euro 4 and Euro 5 vehicles, which produce more NOx emissions than anticipated (especially in urban driving environments), that the government did not introduce a verification scheme for engine compliance, and because the majority of savings from LEZ Phase 5 could be gained from TfL buses. The new proposal will ensure that all TfL Buses meet at least a Euro 4 requirement for NOx by December 2015. This is estimated to save 600 tonnes (instead of 790 tonnes originally envisaged for LEZ Phase 5) and a maximum investment of £18m from TfL to accelerate the early uptake of Euro 6 within the TfL buses fleet. Retrofitting the remaining 900 Euro III buses was not cost effective as they only have two years on average remaining in service.

A1.1.2 Markings

The LEZ is marked by road signs at the entry points. In addition there are signs at strategic locations on roads outside the zone give advance warning to drivers that they are approaching the LEZ and within the zone, repeater signs are shown approximately every 5km reminding drivers that they are in the LEZ.[124]

A1.1.3 Compliance

Compliance is checked using fixed and mobile cameras which read the number plates of vehicles driven in the zone. These are compared with a register of vehicles that meet the LEZ emission standards.

Vehicles that do not meet the standards can drive inside the LEZ but they must pay a daily fee to do so. The fees are £100-200/day depending on the vehicle type, with penalty fees five times the fee (or 2.5 times if paid within 14 days) (Table 61).

Table 62 Emission Standards for the London LEZ

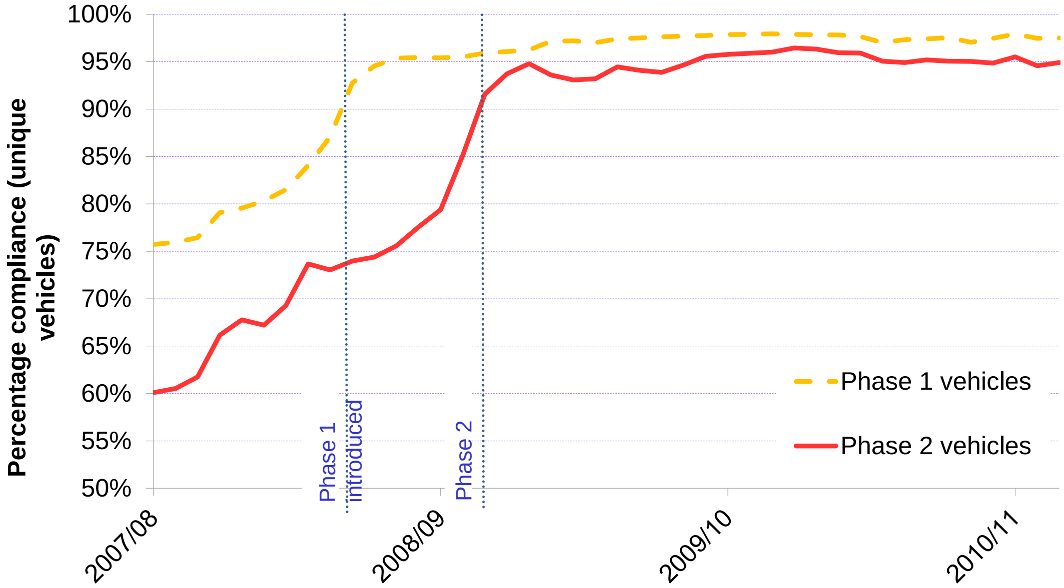
Vehicle type	Daily fee	Penalty charge (reduced amount if paid within 14 days)
HGVs (over 3.5 tonnes)	£200	£1,000 (£500)
Buses and coaches (over 5 tonnes)	£200	£1,000 (£500)
Minibuses and vans (1.205-3.5 tonnes)	£100	£500 (£250)
Motor caravans and ambulances (2.5–3.5 tonnes)	£100	£500 (£250)

Source: Transport for London (www.tfl.gov.uk/modes/driving/low-emission-zone)

Compliance rates are currently high, with compliance rates for Phase 3 over 99% and over 96% for Phase 4. Similarly high rates were found for earlier phases (Figure 20).

[123] Mayor of London (2014) Ultra Low Emission Zone Update to the London Assembly February 2014
[124] Freight Transport Association (2010) Greater London Low Emission Zone FTA Compliance Guide

Figure 20 London LEZ Compliance Rates



Source: Kennedy S (2011) London's Experience. Presentation to International Road Transport Union Workshop on "Traffic restrictions & low emission zones in Europe". Brussels March 2011.

A1.1.4 Impact Analysis

A study of the feasibility of a London LEZ, that included the costs and benefits,[125] was used as an input to a decision on whether to go ahead with implementing the LEZ. The study recommended that vehicles should meet an initial criterion of Euro 2 plus Reduced Pollution Certificate (RPC or equivalent)[126] in 2006/7 and that this be tightened to Euro 3 plus RPC (or equivalent) in 2010. It estimated that the recommended scheme would achieve a 23% reduction in total London PM_{10} emissions in 2010, a 43% reduction in the area of London exceeding the relevant PM_{10} air quality target in 2010, and a 19% reduction in the area of London exceeding the relevant NO_2 air quality target in 2010 (Table 63).

Table 63 Predicted air quality benefits of recommended LEZ (% change relative to baseline)

	Emission reduction			Reduction in areas exceeding targets		
Pollutant	**2007**	**2010 (A)**	**2010 (B)**	**2007**	**2010 (A)**	**2010 (B)**
NOx (NO_2)	1.5%	2.7%	3.8%	4.7%	12%	18.9%
PM_{10}	9.0%	19%	23%	0%*	32.6%**	42.9%**

* Targets expected to be met in the absence of the LEZ; ** Exceedance of the annual PM_{10} objective
2007 scheme only includes lorries, buses and coaches; in 2010: (A) includes lorries, buses and coaches and (B) includes lorries, buses, coaches, vans and taxis
Source: Watkiss P *et al* (2003) London Low Emission Zone Feasibility Study. Phase II. Final Report to the London Low Emissions Zone Steering Group. AEA Technology.

The study suggested that the benefits would be similar in size to the total costs of the scheme. The elements of costs and benefits are summarised in Table 64. The main costs

[125] Watkiss P *et al* (2003) London Low Emission Zone Feasibility Study. Phase II. Final Report to the London Low Emissions Zone Steering Group. AEA Technology.
[126] Retrofit technologies used to reduce emission rates

are the compliance costs for industry associated with changes in vehicles. These are presented in Table 64 as the present value of costs; these compare with the estimate benefits of the scheme

Table 64 Estimated costs and benefits of the recommended scheme

Element	One-off impacts or present value	Annual impacts
Set-up & operating costs	£6 – 10 million	£5 – 7 million
Industry costs (2007)	£64 – 135 million	
Industry costs (2010)	£121 – 367 million	
Health benefits (2007)	£100 million	
Health benefits (2010)	£122 million	

Source: Watkiss *et al* (op cit)

A later re-examination of the costs and benefits using updated data from European studies confirmed the overall conclusions, suggesting that the total costs of the scheme are probably broadly similar to the benefits and the upper range of cost estimates is potentially higher than the benefits.

Watkiss *et al* made a number of recommendations for the design of a LEZ, including that:

- the most appropriate area would be the whole of Greater London;
- the scheme start with lorries (trucks), buses and coaches, but that it be potentially extended in later years to include vans[127] and taxis.[128]
- that cars are not included in the scheme.

An initial baseline study was undertaken to assess the expected impacts of the LEZ at a 20m by 20m resolution.[129] This was used to plan a monitoring network and to estimate the expected effects. PM_{10} emissions were projected to decline by 2.6% in 2008 and by 6.6% by 2012, and NOx emissions were predicted to decline by 3.8% in 2008 and by 7.3% by 2012. The largest reductions in both pollutants were expected to occur along roadways.

A1.1.5 Results

Ellison notes that London's LEZ appears to have had a substantial effect on the composition of the vehicle fleet in London, with the proportion of non-compliant rigid and articulated vehicles dropping substantially more than in other areas of the UK during the same time period (see Figure 21). The greatest differences occurred in the year immediately before (increased switch to newer vehicles in anticipation of the LEZ) and immediately after the introduction of the LEZ with the replacement rate being sustained in the years since.

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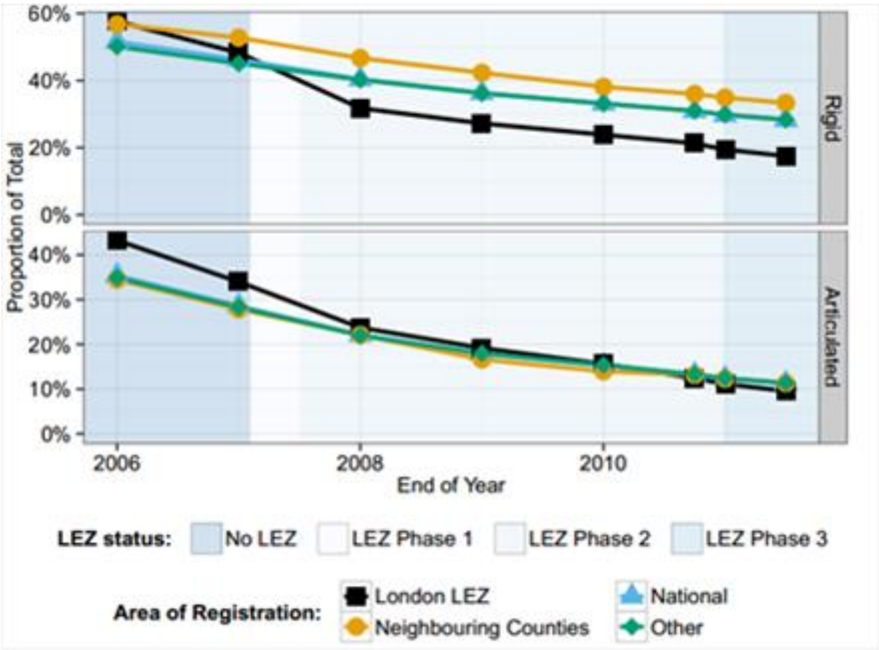
127 "subject to further investigation of the socio-economic effects of such a scheme on small companies/owner drivers"

128 It also suggested that taxis should be addressed earlier through the licensing process

129 Kelly F *et al* (2011) The London Low Emission Zone Baseline Study. Research Report 163 Health Effects Institute Boston, Massachusetts

Figure 21 Proportion of registered pre-Euro III rigid and articulated vehicles



Ellison RB (2014) Understanding Dynamic Responses to Mitigation Policies for Intra-urban Road Freight Emissions. A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy. Institute of Transport and Logistics Studies, the University of Sydney Business School.

Ellison also notes that air quality in London appears to have only improved marginally with reductions in concentrations of both NO_x and PM_{10}, noting that this is likely to be because of a substantial increase in the absolute number of vehicles entering the LEZ.

The Urban Access Regulations website reports the following ex-post results of the London LEZ: [130]

- Black Carbon has been estimated to have been reduced by 40-50%;
- NO_2: Average concentrations were reduced by 0.12 µg/m^3, peak concentration reductions up to 0.16 µg/m^3 on particularly polluted streets;
- PM_{10}: Average concentrations reduced 0.03 µg/m^3, peak concentration reductions up to 0.5 µg/m^3 on particularly polluted streets;
- Emissions of PM_{10} were reduced by 1.9% (28 tonnes);
- Emissions of NOx were reduced by 2.4% (26 tonnes).

A1.1.6 Ultra Low Emission Zone

Currently Transport for London is investigating options for an Ultra Low Emission Zone (ULEZ) for London that would aim to ensure all vehicles driving in the centre of the capital during working hours would be zero or low emission, and the feasibility of introducing such a scheme from 2020.[131]

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130 http://urbanaccessregulations.eu/low-emission-zones-main/impact-of-lezs

131 www.london.gov.uk/media/mayor-press-releases/2013/02/mayor-of-london-announces-game-changer-for-air-quality-in-the; Mayor of London (2014) Ultra Low Emission Zone Update to the London Assembly February 2014

A1.2 Berlin

A1.2.1 Description

Berlin introduced an LEZ in two stages covering a central city area of 85 km^2 inside a railway ring. Linked to a a German national vehicle labelling scheme, all diesel vehicles not meeting Euro 2 and petrol cars worse than Euro 1 were banned from the LEZ from January 2008. The criteria were tightened in January 2010 such that Euro 4, or retrofit with diesel particle filters (DPF), became mandatory for diesel vehicles, including passenger cars and commercial vehicles.

Figure 22 Berlin LEZ

Source: Lutz M (2009) The Low Emission Zone in Berlin – Results of a First Impact Assessment. Workshop on "NOx: Time for Compliance", Birmingham, Nov. 2009

Environmental criteria in Berlin's LEZ for all vehicles (passenger cars, LGVs and HGVs

Stage	Requirements
I (from 1.1.2008)	A red, yellow or green label on the window screen, ie at least pollution class 2 of the national labelling scheme. This corresponds as a minimum: • for Diesel-vehicles to Euro 2 or Euro 1 + particle filter • for petrol vehicles to Euro 1 with a catalytic converter
II (from 1.1.2010)	Need a green label, ie at least pollution class 4 of the national labelling scheme. This corresponds as a minimum • for Diesel-vehicles to Euro 4 or Euro 3 + particle filter • for petrol vehicles to Euro 1 with a catalytic converter

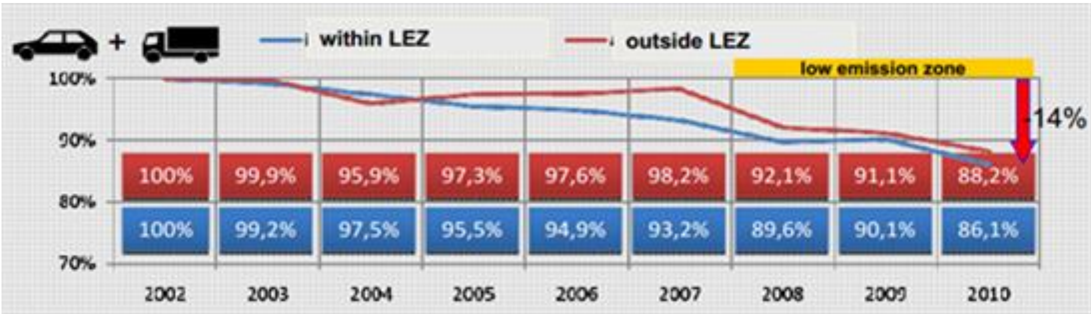
Source: Lutz M and Rauterberg-Wulff A (2010) Berlin's Low Emission Zone – top or flop? Results of an impact analysis after 2 years in force. 14th ETH Conference on Combustion Generated Particles.

A1.2.2 Impacts

The impacts were estimated after two years by combining measured concentrations at monitoring sites with traffic data inside and outside the LEZ and the emission characteristics of the registered vehicle fleet and of the vehicles on the roads. This was compared with predicted traffic levels (and emissions) to estimate the effects of the LEZ on traffic flows, emissions and air quality within and outside of the zone.[132]

The Berlin LEZ was estimated to have had no measurable impact on traffic flows. Lutz notes that initial concerns that traffic could be pushed into residential areas around the zone did not materialise. There was a decrease in traffic load (and emissions) but this was attributed to the peak in fuel prices in 2008 and of Berlin's transport policy to promote cleaner modes of transport.[133] Figure 23 illustrates the results.

Figure 23 Trend in traffic volumes 2002-2010 in Berlin 2002 = 100



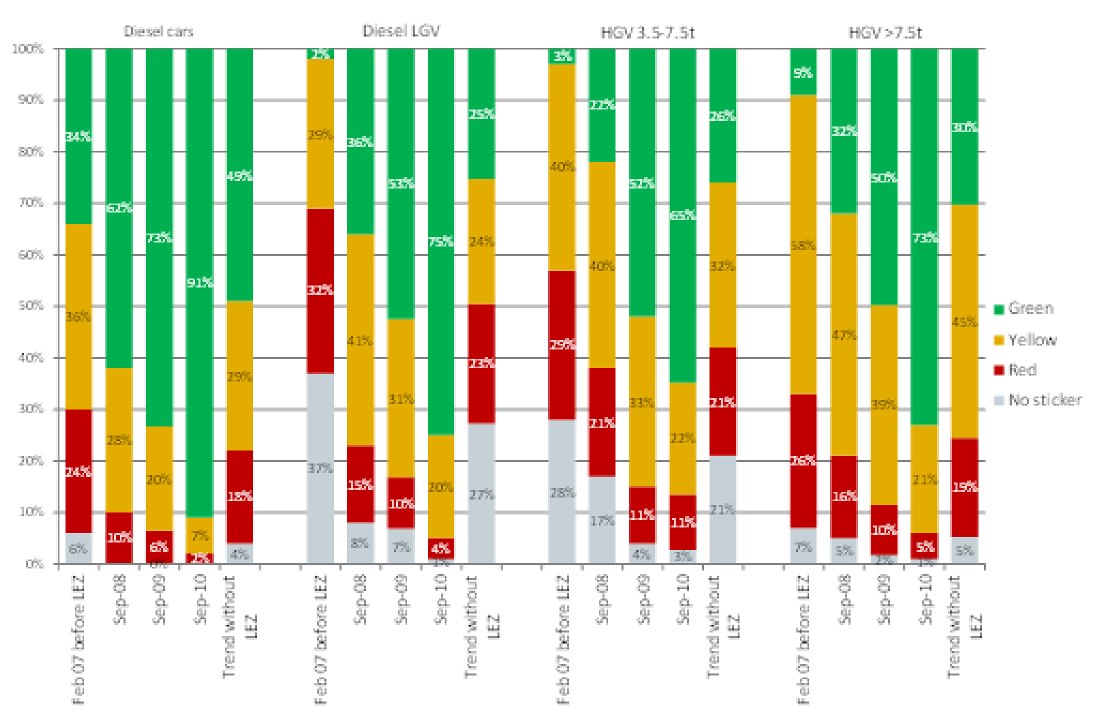
Source: Lutz M (2012) "*Abatement of PM and NO2 pollution in Berlin: The low emission zone and other measures*" Can Copenhagen learn anything from Germany/Berlin?

However, it was estimated that there was an increased turnover of the vehicle fleet towards cleaner vehicles in response to the LEZ. The results are shown in Figure 24. There is a significant shift towards Euro 4 (Green sticker vehicles) with 91% of diesel cars being at this level compared with business as usual expectations of only 49%; for other vehicle types the results are 75% (cf expected 25%) for diesel LGVs, 65% (cf 26%) for lighter HGVs and 73% (cf 30%) for heavier HGVs.

The results in emission terms are shown in Table 65. This compares the total emissions in 2010 against those expected in a no LEZ scenario, assuming a long-term average turn-over of the vehicle fleet. The analysis estimates that, as a result of the LEZ, exhaust particle emissions dropped by 58% or by 173 tonnes per annum in absolute terms. NOx emissions fell by 20% or more than 1,500 tpa.

[132] Source: Lutz M and Rauterberg-Wulff A (2010) Berlin's Low Emission Zone – top or flop? Results of an impact analysis after 2 years in force. 14th ETH Conference on Combustion Generated Particles.
[133] Lutz M (2009) The Low Emission Zone in Berlin – Results of a First Impact Assessment. Workshop on "NOx: Time for Compliance", Birmingham, Nov. 2009

Figure 24 Change of vehicle fleet composition on the road



Green = Euro 4; Yellow = Euro 3; Red = Euro 2

Source: Lutz M (2012) "*Abatement of PM and NO2 pollution in Berlin: The low emission zone and other measures*" Can Copenhagen learn anything from Germany/Berlin?

Table 65 Impact of the LEZ on exhaust emissions (2010) in tonnes

Pollutant		Whole fleet	Cars	LGV < 3.5t	HGV > 3.5t
NOx	No LEZ	7,627	4,199	843	2,548
	LEZ	6,110	3,118	650	2,123
	% reduction	20%	26%	23%	17%
PM	No LEZ	299	133	79	68
	LEZ	126	49	24	39
	% reduction	58%	63%	70%	43%

Source: Lutz M (2012) "*Abatement of PM and NO2 pollution in Berlin: The low emission zone and other measures*" Can Copenhagen learn anything from Germany/Berlin?

These results have been combined with an assumption of linear relationship between emissions and concentrations, coupled with estimates of source apportionment of $PM_{2.5}$ to estimate reductions in $MP_{2.5}$ concentrations.

A1.3 Munich

A1.3.1 Description

The LEZ in Munich covers 44 km², which accounts for 14 % of the whole city area and 32% of the city population (Figure 25).

Figure 25 Locations of the LÜB monitoring sites in Munich, Germany: Prinzregentenstrasse (●), Lothstrasse (■), Johanneskirchen (▲)

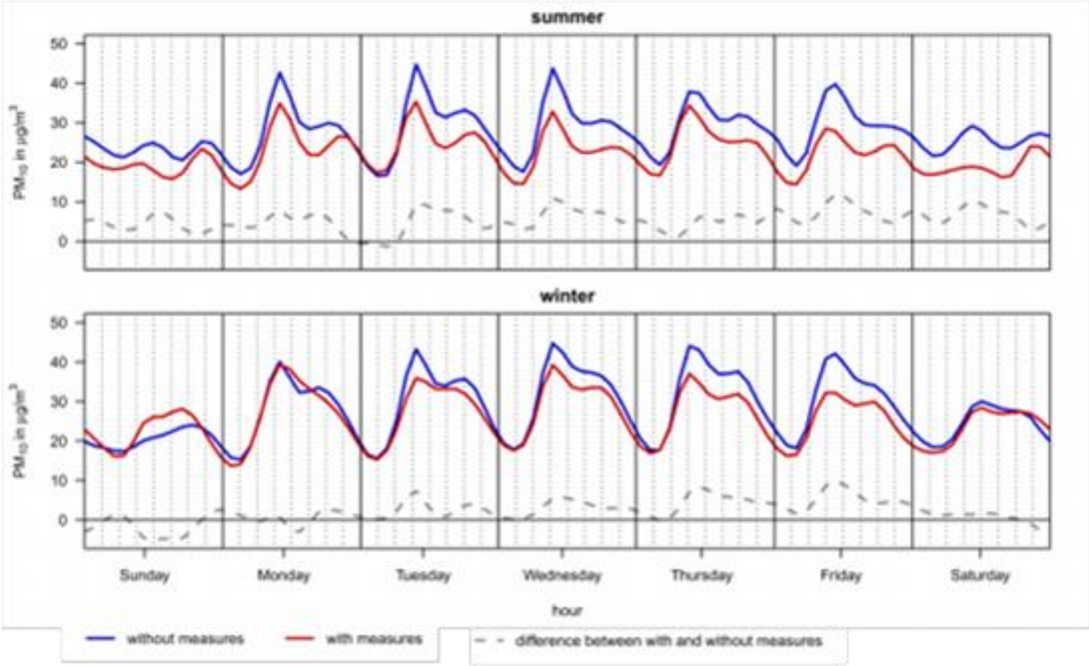
Source: Fensterer V, Küchenhoff H, Maier V, Wichmann H-E, Breitner S, Peters A, Gu J and Cyrys J (2014) Evaluation of the Impact of Low Emission Zone and Heavy Traffic Ban in Munich (Germany) on the Reduction of PM10 in Ambient Air. Int. J. Environ. Res. Public Health 2014, 11, 5094-5112; doi:10.3390/ijerph110505094

A1.3.2 Impacts

Fensterer *et al*[134] compared the PM_{10} concentrations prior to the implementation of the air quality measures (period 1) with those afterwards. They used data from two monitoring sites within the study area (an urban background monitoring site and a street site) plus one outside for comparison purposes. They measured the levels before and after the introduction of the LEZ and a number of other factors that might determine PM_{10} concentrations, including wind, background pollution and public holidays. The estimated reduction in PM_{10} concentration as a result of the LEZ was larger at a traffic monitoring site (13.0 %, 19.6 % in summer, and 6.8 % in winter) than the urban background (4.5 %, 5.7 % in summer, and 3.2 % in winter); the effect was most pronounced on Fridays and on the weekends in summer (Figure 26).

[134] Fensterer V, Küchenhoff H, Maier V, Wichmann H-E, Breitner S, Peters A, Gu J and Cyrys J (2014) Evaluation of the Impact of Low Emission Zone and Heavy Traffic Ban in Munich (Germany) on the Reduction of PM10 in Ambient Air. Int. J. Environ. Res. Public Health 2014, 11, 5094-5112; doi:10.3390/ijerph110505094

Figure 26 Modelled hourly concentrations of PM_{10} at the street site (Prinzregentenstrasse) adjusted for PM_{10} at the reference station, wind direction and public holidays



Source: Fensterer *et al* (op cit)

A1.4 Denmark

A report on expected costs in Odense (Denmark) gives establishment costs as around €60,000, annual enforcement as €17,000. Danish enforcement is focused primarily at the unloading points of the HGVs, with additional stopping of vehicles being combined with regular police activities (police are required to stop vehicles, but not enforce at unloading point).[135]

Costs of fitting DPF in Denmark for the first phase of the LEZs in 2008 (Euro 3 or DPF for HGVs), is estimated at €40m to fit DPFs and €2.5m in annual maintenance. For the second phase in 2010 (Euro 4 or DPF), it is €43m to fit and €2.6m annual maintenance. The DPF cost assumptions prior to LEZ implementation in Denmark are €5900 retrofit cost and €363 annual maintenance costs, although prices may have gone down with volume since.

The benefits are presented by Sadler in terms of reductions in health effects and premature deaths, which is not useful in the absence of information on the assumptions used to calculate these.

[135] Sadler Consultants (op cit)

Annex 2: Costs of Vehicle Measures

Table 66 Costs of CBD & Port LEZ – Vehicle upgrade ($ million)

Scenario	LPVs	LCVs	HCVs	Bus	Total
Medium					
% of vehicles entering LEZ	25%	25%	25%	75%	
1 Euro II HCV	-	-	11	-	11
2 Euro III HCV	-	-	36	-	36
3 Euro IV HCV	-	-	88	-	88
4 Euro II HCV&LCV	-	3	11	-	14
5 Euro III HCV&LCV	-	17	36	-	53
6 Euro II All diesel	4	3	11	8	26
7 Euro III All diesel	16	17	36	20	89
Low					
% of vehicles entering LEZ	10%	10%	10%	40%	
1 Euro II HCV	-	-	4	-	4
2 Euro III HCV	-	-	14	-	14
3 Euro IV HCV	-	-	35	-	35
4 Euro II HCV&LCV	-	1	4	-	6
5 Euro III HCV&LCV	-	7	14	-	21
6 Euro II All diesel	2	1	4	5	13
7 Euro III All diesel	6	7	14	13	41
High					
% of vehicles entering LEZ	50%	50%	50%	90%	
1 Euro II HCV	-	-	17	-	17
2 Euro III HCV	-	-	58	-	58
3 Euro IV HCV	-	-	140	-	140
4 Euro II HCV&LCV	-	5	17	-	23
5 Euro III HCV&LCV	-	27	58	-	84
6 Euro II All diesel	7	5	17	10	39
7 Euro III All diesel	25	27	58	24	134

Table 67 Costs of Auckland LEZ – Vehicle upgrade ($ million)

Scenario	LPVs	LCVs	HCVs	Bus	Total
Medium					
% of vehicles entering LEZ	120%	100%	120%	100%	
1 Euro II HCV	-	-	52	-	52
2 Euro III HCV	-	-	173	-	173
3 Euro IV HCV	-	-	420	-	420
4 Euro II HCV&LCV	-	13	52	-	65
5 Euro III HCV&LCV	-	67	173	-	240
6 Euro II All diesel	21	13	52	11	96
7 Euro III All diesel	75	67	173	27	342
Low					
% of vehicles entering LEZ	100%	90%	100%	90%	
1 Euro II HCV	-	-	44	-	44
2 Euro III HCV	-	-	144	-	144
3 Euro IV HCV	-	-	350	-	350
4 Euro II HCV&LCV	-	11	44	-	55
5 Euro III HCV&LCV	-	61	144	-	204
6 Euro II All diesel	17	11	44	10	82
7 Euro III All diesel	62	61	144	24	291
High					
% of vehicles entering LEZ	150%	125%	150%	125%	
1 Euro II HCV	-	-	65	-	65
2 Euro III HCV	-	-	216	-	216
3 Euro IV HCV	-	-	526	-	526
4 Euro II HCV&LCV	-	16	65	-	81
5 Euro III HCV&LCV	-	84	216	-	300
6 Euro II All diesel	26	16	65	13	120
7 Euro III All diesel	94	84	216	34	427

Table 68 Costs of CBD & Port LEZ – Retrofit technology ($ million)

Scenario	LPVs	LCVs	HCVs	Bus	Total
Medium					
% of vehicles entering LEZ	25%	25%	25%	75%	
1 Euro II HCV	-	-	12	-	12
2 Euro III HCV	-	-	20	-	20
3 Euro IV HCV	-	-	33	-	33
4 Euro II HCV&LCV	-	8	12	-	20
5 Euro III HCV&LCV	-	16	20	-	36
6 Euro II All diesel	10	8	12	7	37
7 Euro III All diesel	19	16	20	10	65
Low					
% of vehicles entering LEZ	10%	10%	10%	40%	
1 Euro II HCV	-	-	5	-	5
2 Euro III HCV	-	-	8	-	8
3 Euro IV HCV	-	-	13	-	13
4 Euro II HCV&LCV	-	3	5	-	8
5 Euro III HCV&LCV	-	6	8	-	14
6 Euro II All diesel	4	3	5	5	17
7 Euro III All diesel	8	6	8	7	29
High					
% of vehicles entering LEZ	50%	50%	50%	90%	
1 Euro II HCV	-	-	19	-	19
2 Euro III HCV	-	-	32	-	32
3 Euro IV HCV	-	-	52	-	52
4 Euro II HCV&LCV	-	13	19	-	32
5 Euro III HCV&LCV	-	25	32	-	57
6 Euro II All diesel	17	13	19	8	57
7 Euro III All diesel	31	25	32	12	100

Table 69 Costs of Auckland LEZ – Retrofit technology ($ million)

Scenario	LPVs	LCVs	HCVs	Bus	Total
Medium					
% of vehicles entering LEZ	120%	100%	120%	100%	
1 Euro II HCV	-	-	57	-	57
2 Euro III HCV	-	-	95	-	95
3 Euro IV HCV	-	-	157	-	157
4 Euro II HCV&LCV	-	17	57	-	75
5 Euro III HCV&LCV	-	33	95	-	128
6 Euro II All diesel	29	17	57	9	112
7 Euro III All diesel	45	33	95	14	187
Low					
% of vehicles entering LEZ	100%	90%	100%	90%	
1 Euro II HCV	-	-	48	-	48
2 Euro III HCV	-	-	79	-	79
3 Euro IV HCV	-	-	131	-	131
4 Euro II HCV&LCV	-	15	48	-	63
5 Euro III HCV&LCV	-	30	79	-	109
6 Euro II All diesel	24	15	48	8	95
7 Euro III All diesel	38	30	79	12	159
High					
% of vehicles entering LEZ	150%	125%	150%	125%	
1 Euro II HCV	-	-	72	-	72
2 Euro III HCV	-	-	118	-	118
3 Euro IV HCV	-	-	197	-	197
4 Euro II HCV&LCV	-	21	72	-	93
5 Euro III HCV&LCV	-	41	118	-	160
6 Euro II All diesel	36	21	72	11	140
7 Euro III All diesel	56	41	118	17	233

Annex 3: Methodology for Calculation of PM_{10} Concentration Changes per CAU

A3.1 Emissions estimates

This assessment uses the HAPiNZ (2012) update exposure model to evaluate the potential reductions in pollutant exposure for each of the policy options. The HAPiNZ model calculates population exposure and related social costs, spatially resolved by Census Area Unit (CAU).

The key data requirements for the HAPiNZ model, within each CAU, are:

- Vehicle fleet emission factors; and
- Vehicle Kilometres Travelled

Each of these are discussed in turn below.

A3.1.1 Vehicle fleet emission factors

Motor vehicle emissions estimates within the published HAPiNZ exposure model are based on fleet emission factors from the Vehicle Emission Prediction Model version 3.0 (VEPM 3.0). VEPM can be used to generate fleet emission factors for a selected fleet profile, comprising representative vehicle classes. Changes can be made to the fleet profile and percentage of Vehicle Kilometres Travelled (%VKT) for different vehicle classes (eg reducing the proportion of a particular type of vehicle).

VEPM can be used to generate fleet emission factors for a selected fleet profile, comprising representative vehicle classes. Changes can be made to the fleet profile and percentage of Vehicle Kilometres Travelled (%VKT) for different vehicle classes (eg, reducing the proportion of a particular type of vehicle).

The vehicle fleet emission factors for this assessment have been based on VEPM 5.1 as it provides updated emission factors that may better represent vehicle emissions for the 2016 base year. VEPM 5.1 was released in 2012 and incorporated the following improvements:

- Updated fleet profile data, including Euro V heavy commercial vehicles and Euro VI light commercial passenger vehicles, based on their implementation dates set by the Vehicle Exhaust Emission Rule;
- Latest international emission factors for all pollutants;
- The incorporation of size cut-off for particulate matter sourced from brake and tyre wear;
- The effect of variations in actual speed; and
- The effects of gradient.

The vehicle fleet profiles for this assessment were generated from the ART3 model VKT data for each of the specific areas and CAUs of interest, as outlined below. The area-specific fleet profiles were used for each defined scenario area to account for differing proportions of vehicle types present on roads within different CAUs (eg there are a higher proportion of buses and heavy vehicles in the Auckland Harbourside CAU within the CBD & Port area).

VEPM 5.1 was run with the Auckland-specific fleet profiles generated from the ART3 model to derive emission factors for the 2016 base year and for each of the specific policy scenarios. To achieve this, VKT data generated from the ART3 model (as individual road links) was extracted for each census area unit (CAU) to be assessed. As all roads are not completely contained within a CAU (eg some roads cross CAU boundaries) the VKT data for individual road links has been distributed proportionately across the relevant CAUs based on road length.

A3.1.2 Vehicle Kilometres Travelled

In the HAPiNZ exposure model, VKT data is required for each CAU with a breakdown of the VKTs at vehicle average speeds less than and greater than 80 km/hr. The motor vehicle particulate emission density within each CAU are generated as follows:

$$\text{Particulate emission density} = \frac{(VKT_{<80km/h} * EF_{<80km/h}) + (VKT_{>80km/h} * EF_{>80km/h})}{\text{CAU Area}}$$

Where:

- $VKT_{<80km/h}$ and $VKT_{>80km/h}$ are the total VKT for vehicles travelling slower than, and faster than, 80 km/h, respectively; and
- $EF_{<80km/h}$ and $EF_{>80km/h}$ are the emission factors for traffic travelling slower than, and faster than, 80 km/h, respectively.

A3.2 Exposure evaluation

As described above, the VKT data from the ART3 model for the 2016 model period (separated into vehicles travelling slower or faster than 80 km/h) was entered into the HAPiNZ exposure model for each CAU. Emission factors for each scenario were generated using VEPM 5.1 and also entered into the HAPiNZ exposure model. The HAPiNZ model was then used to derive annual average PM_{10} concentrations for each CAU in $\mu g/m^3$.

The results generated for each scenario are compared with the 2016 base case model for the geographical extent relevant to each of the policy options.

A3.3 Consideration of corridor LEZ

It has been highlighted in Section 2 of this report that localised air quality effects of transport emissions occur around highly trafficked intersections and busy road corridors. One of the policy options considered for detailed assessment was a low emission zone for specific corridors (major roads). While this option would provide benefits of targeting local pollution hotspots, the modelling approach required was outside the scope of this assessment.

In order to evaluate the impacts of a small LEZ, such as a corridor-based scenario, detailed traffic information would be required on the traffic diversion routes. It is likely that the emissions would simply be diverted to other routes, whether within the same

CAU or in another CAU. Because the assessment method is based on overall population exposure and aggregate effects, and because there are no thresholds for PM_{10} exposure, such detailed modelling would only be useful if the VKT are shifted to less densely populated areas (CAU) where there is less exposure. Otherwise there would be no change in aggregate effect.

For specific transport corridor LEZ modelling, an airshed modelling approach would be more appropriate, to resolve the localised effects.

A3.4 Spatial Extent of Policy Options

The assessment areas (as shown in Figure 27 and Figure 28 plus Table 70) include:

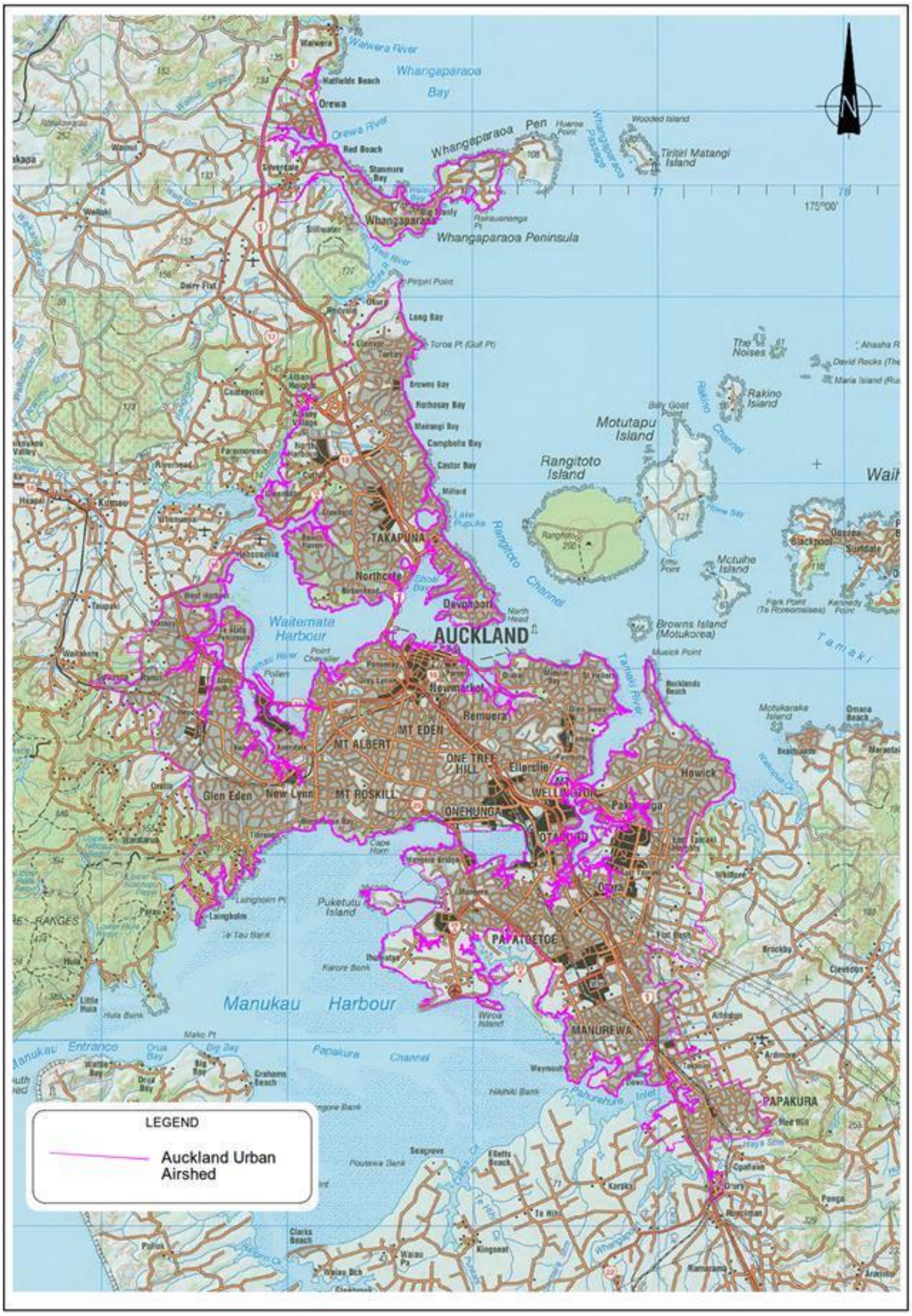
- Auckland CBD and Port area;
- Auckland central (congestion scheme area[136]); and
- Auckland Urban Airshed.

Figure 27 Spatial Extent of Policy Options: CBD & Port and Central area (Congestion scheme)

Source: Aerial source from Auckland Council GIS website

[136] As derived from MoT (2008a) Auckland Road Pricing Study 2008 Report no: WL00062-1

Figure 28 Spatial Extent of Policy Options: Auckland Urban Airshed



Source: Topomap sourced from Land Information NZ data (Crown copyright reserved).

Table 70 CAUs included in study regions

Port & CBD	Auckland Urban Airshed				
Auckland Central E	Hatfields Beach	Birkdale North	Waterview	Cockle Bay	Mangere Central
Auckland Central W	Orewa	Birkdale South	Point Chevalier West	Howick West	Mascot
Auckland H-side	Manly	Kauri Park	Point Chevalier East	Howick Central	Arahanga
Newton	Army Bay	Chelsea	Point Chevalier South	Otahuhu North	Viscount
Grafton West	Vipond	Birkenhead East	Epsom South	Fairburn	Mangere South
	Stanmore Bay West	Henderson North	Abbotts Park	Otahuhu East	Mangere East
Central area	Stanmore Bay East	Henderson South	Meadowbank North	Otahuhu West	Aorere
Freemans Bay	Wade Heads	Tangutu	Meadowbank South	Middlemore	Kohuora
Grafton East	Gulf Harbour	Woodglen	Orakei North	Papatoetoe West	Mangere Station
Westmere	Awaruku	Glen Eden East	Mission Bay	Papatoetoe North	Favona West
Herne Bay	Glamorgan	New Lynn North	Kohimarama West	Papatoetoe Central	Favona North
St Marys	Torbay	New Lynn South	Kohimarama East	Dingwall	Favona South
Ponsonby West	Waiake	Lynnmall	St Heliers	Papatoetoe East	Harania North
Ponsonby East	Browns Bay	Fruitvale	Glendowie	Puhinui	Harania West
Grey Lynn West	Oaktree	Rewarewa	Glen Innes North	Bucklands/Eastern Beaches	Harania East
Grey Lynn East	Rothesay Bay	Glendene North	Glen Innes West	Bleakhouse	Wiri
Surrey Crescent	Murrays Bay	Glendene South	Glen Innes East	Bucklands Beach South	Burbank
St Lukes North	Mairangi Bay	Kelston Central	Point England	Pigeon Mountain North	Homai West
Arch Hill	Campbells Bay	Sunnyvale	Sandringham West	Murvale	Rowandale
Eden Terrace	Castor Bay	Kaurilands	Sandringham East	Pigeon Mountain South	Homai East
Epsom North	Crown Hill	Crum Park	Mt Albert Central	Aberfeldy	Weymouth West
Epsom Central	Lake Pupuke	Titirangi South	Springleigh	Elsmore Park	Weymouth East
Parnell East	Westlake	Green Bay	Owairaka West	Half Moon Bay	Clendon North
Parnell West	Takapuna Central	Matipo	Owairaka East	Pakuranga North	Clendon South
Mt Hobson	Hauraki	Durham Green	Maungawhau	Sunnyhills	Hillpark
Remuera South	Seacliffe	Te Atatu Central	Mt Eden South	Pakuranga Central	Manurewa East
Remuera West	Bayswater	Edmonton	Three Kings	Edgewater	Manurewa Central
Waitaramoa	Kaipatiki	Wakeling	Royal Oak	Pakuranga East	Beaumont
Orakei South	Windy Ridge	Mcleod	Hillsborough West	Botany Downs	Leabank
Waiata	Glenfield Central	Konini	Hillsborough East	Maungamaungaroa	Wattle Farm
Newmarket	Glenfield North	Waima	Walmsley	Golfland	Papakura Central
Kingsland	Glendhu	Laingholm	Wesley	Millhouse	Papakura North
St Lukes	Witheford	Henderson West	Akarana	Burswood	Papakura South
Sandringham North	Target Road	Palm Heights	Lynfield North	Dannemora	Opaheke
Mt Eden North	Forrest Hill	McLaren Park	Lynfield South	Kilkenny	Rosehill
Sherbourne	Sunnynook	Starling Park	Waikowhai West	Shelly Park	Pahurehure
Balmoral	Monarch Park	Ranui Domain	Waikowhai East	Otara West	Papakura East
Mt Eden East	Sunnybrae	Ranui South	One Tree Hill Central	Otara North	Massey Park
Mt St John	Albany	Sturges North	One Tree Hill East	Otara East	Papakura North East
	Fairview	Kingdale	Penrose	Otara South	Red Hill
	Northcross	Fairdene	Onehunga North West	Ferguson	
	Unsworth Heights	Westgate	Onehunga North East	Flat Bush	
	Pinehill	Royal Road West	Onehunga South West	Donegal Park	
	Windsor Park	West Harbour	Onehunga South East	Ormiston	
	North Harbour West	Lucken Point	Oranga	Clover Park	
	North Harbour East	Royal Heights	Te Papapa	Redoubt North	
	Greenhithe	Waimumu North	Ellerslie North	Totara Heights	
	Narrow Neck	Waimumu South	Ellerslie South	Randwick Park	
	Mt Victoria	Roberton	Ferndale	Hyperion	
	Stanley Bay	Glenavon	Hamlin	Redoubt South	
	Ocean View	New Windsor	Mt Wellington South	Takanini North	
	Tuff Crater	Avondale South	Tamaki	Takanini South	
	Northcote South	Blockhouse Bay	Panmure Basin	Takanini West	
	Beachhaven North	Rosebank	Hingaia	Ambury	
	Beachhaven South	Avondale West	Mellons Bay	Mangere Bridge	

Note: Central Area includes CBD & Port; Auckland Urban Airshed includes Central Area

A3.5 Fleet Profiles for Policy Options

For each of the identified assessment areas, as shown in Table 71 and Table 72, Auckland-specific fleet profiles have been generated from the ART3 model VKT data to input into VEPM 5.1 to derive emission factors for the 2016 base year and for each of the specific policy scenarios.

It was noted that the CAUs within the CBD and Port area have a higher percentage of VKTs for Heavy Commercial Vehicles (HCV) and buses compared with the VEPM 5.1 default factors, and with other modelled areas in the region. This has potential implications for the effectiveness of policy options targeting HCV and bus emissions in this area.

Table 71 Auckland CBD & Port fleet profiles

			% of VKT (2016)					
				CBD & Port				
Vehicle type	**Weight category**	**Fuel type**	**VEPM 5.1 Default Factors**	**Auckland Harbour-side CAU**	**Auckland Central West CAU**	**Auckland Central East CAU**	**Newton CAU**	**Grafton West CAU**
	< 3.5 t	petrol	68.1	65.7	67.2	68.1	67.5	66.9
	< 3.5 t	diesel	8.3	8.0	8.2	8.3	8.3	8.2
Cars	< 3.5 t	hybrid	1.0	1.0	1.0	1.0	1.0	1.0
	< 3.5 t	petrol	2.7	2.6	2.7	2.7	2.7	2.7
	< 3.5 t	diesel	13.2	12.8	13.1	13.2	13.1	13.0
LCV	< 3.5 t	hybrid	0.2	0.2	0.2	0.2	0.2	0.2
	3.5 - 7.5 t	diesel	1.3	2.0	1.6	1.4	1.5	1.7
	7.5 - 12 t	diesel	0.7	1.1	0.8	0.7	0.8	0.9
	12 - 15 t	diesel	0.2	0.3	0.2	0.2	0.2	0.2
	15 - 20 t	diesel	0.3	0.3	0.2	0.2	0.2	0.2
	20 - 25 t	diesel	1.1	1.6	1.3	1.1	1.2	1.3
	25 - 30 t	diesel	1.0	1.6	1.2	1.0	1.2	1.3
HCV	> 30 t	diesel	1.2	1.9	1.5	1.2	1.4	1.6
Buses	> 3.5 t	diesel	0.6	0.9	0.7	0.6	0.7	0.8

Source: VEPM 5.1 and ART3 Model

Table 72 Auckland Central Area and Auckland Urban Airshed fleet profiles

Vehicle type	Weight category	Fuel type	Vehicle type	Weight category	Fuel type
	< 3.5 t	petrol	68.1	68.1	68.0
	< 3.5 t	diesel	8.3	8.3	8.3
Cars	< 3.5 t	hybrid	1.0	1.0	1.0
	< 3.5 t	petrol	2.7	2.7	2.7
	< 3.5 t	diesel	13.2	13.2	13.2
LCV	< 3.5 t	hybrid	0.2	0.2	0.2
	3.5 - 7.5 t	diesel	1.3	1.4	1.4
	7.5 - 12 t	diesel	0.7	0.7	0.7
	12 - 15 t	diesel	0.2	0.2	0.2
	15 - 20 t	diesel	0.3	0.2	0.2
	20 - 25 t	diesel	1.1	1.1	1.1
	25 - 30 t	diesel	1.0	1.1	1.1
HCV	> 30 t	diesel	1.2	1.2	1.3
Buses	> 3.5 t	diesel	0.6	0.6	0.6

Source: VEPM 5.1 and ART3 Model

Note 1: Auckland central area (congestion scheme) profile is used for CAU outside CBD & Port

Note 2: Auckland Urban Airshed profile is used for CAU outside CBD & Port and Auckland central area

A3.6 Assessment Scenarios

A3.6.1 Low Emission Zone

The modelled Low Emission Zone (LEZ) scenarios are summarised in Table 73. The LEZ scenarios were modelled for the introduction of minimum exhaust emission standards for diesel vehicles, as diesel vehicles contribute disproportionately to particulate emissions.

A 2016 base case for each geographical extent was generated, using the unique fleet profile for each geographical extent. Each base case was run at 40 km/h and 90 km/h in accordance with the HAPiNZ model methodology, which assumes that this is representative of emissions from vehicles travelling at <80 km/h and >80 km/h respectively.

The fleet profiles were modified to account for the changes to the fleet, assuming that vehicles which were not up to the LEZ standard would retire from the fleet and be replaced by a proportionate amount of vehicles that could meet the minimum standard. The models were then re-run for each scenario within VEPM to generate scenario-specific fleet emission factors. These emission factors were then entered into the HAPiNZ exposure model to determine PM_{10} concentration changes for each scenario.

Table 73 LEZ Policy Options Modelled

<table>
<tr><th>Vehicle categories</th><th>Euro Category (or equivalent) to be met</th><th>LEZ areas assessed</th></tr>
<tr><td>HCVs (3.5–>30 tonnes) and buses</td><td rowspan="3">Euro 2 (all),
Euro 3 (all), and
Euro 4 (HCVs & buses only)</td><td rowspan="3">CBD & Port,
Auckland central area (Congestion scheme),
and Auckland Urban Airshed</td></tr>
<tr><td>HCVs (3.5–>30 tonnes),buses and diesel LCVs (<3.5 tonnes)</td></tr>
<tr><td>All diesel vehicles</td></tr>
</table>

For each of the model scenarios, the proportion of the targeted vehicle fleet that would be affected are shown in Table 74.

Table 74 Percentage Vehicles Affected (By Category) for LEZ Scenarios

Area		Scenarios						
		Euro II HCVs	Euro III HCVs	Euro IV HCV's	Euro 2/II HCVs & LCVs	Euro III HCVs & LCVs	Euro 2/II All Diesel	Euro 3/III All Diesel
CBD & Port	Auckland Central East CAU	9.31%	18.73%	37.79%	4.14%	9.72%	4.08%	13.64%
	Auckland Central West CAU	9.32%	18.75%	37.82%	4.45%	10.26%	4.30%	13.86%
	Auckland Harbourside CAU	9.33%	18.77%	37.84%	4.94%	11.11%	4.67%	14.23%
	Auckland Newton CAU	9.32%	18.76%	37.83%	4.37%	10.12%	4.24%	13.81%
	Auckland Grafton West CAU	9.33%	18.77%	37.84%	4.56%	10.46%	4.39%	13.95%
Auckland central area (Congestion zone)		9.32%	18.77%	37.83%	4.24%	9.90%	4.15%	13.72%
Auckland Urban Airshed		9.28%	18.65%	37.63%	4.15%	9.72%	4.08%	13.64%

A3.6.2 Road pricing

The road pricing scenario was derived from the results of the 2008 MoT Auckland Road Pricing Study (Report no: WL00062-1), which predicts an approximate 10% reduction in traffic and approximate 5% increase in public transportation service requirements. VKT data for each CAU was reduced by 10% to account for the approximate 10% reduction in traffic prior to input into the HAPiNZ model. The fleet profile entered into VEPM 5.1 was adjusted to reflect a 5% increase in buses.

A3.6.3 Vehicle testing with regional in-service standards

VEPM5.1 includes a default factor that accounts for degradation of diesel vehicles (except Euro VI) over time. This degradation factor therefore assumes that diesel vehicle exhaust emissions will increase with increasing vehicle age and mileage. With the introduction of regional in-service standards, through vehicle testing inspections, the high emitters would be identified and be required to undertake maintenance to restore vehicle emissions to the required standard for that vehicle.

For the vehicle testing scenario, the 2016 base case for the identified assessment areas has been run through VEPM 5.1 with the degradation factors not included. This scenario assumes diesel vehicles would be maintained and brought back to their required emission standard and that the change in VKT as a result of vehicles being retired because they cannot meet the regional standard is negligible.

A3.7 Model approach limitations

A3.7.1 Fleet profiles

Seven different fleet profiles have been generated for the different geographical areas considered, as follows:

- five profiles generated at a CAU level for the CBD and Port area (Auckland Central East, Auckland Central West, Auckland Harbourside, Newton & Grafton West CAUs);
- one profile representing an approximate extent of the Auckland Central area (Congestion zone) (excluding VKT from CAU in the CBD and Port area); and
- one profile representative of the rest of the Auckland Urban Airshed (excluding VKT from the CBD & Port area and Auckland Central area, listed above).

The relatively high proportion of heavy diesel vehicles, with disproportionately high emissions, in the CBD and Port area means that there may be significant localised changes in air quality due to the policy options. Therefore, in this area, the fleet profiles were treated at a finer resolution (CAU level) compared to the other areas considered.

For the Auckland Central area and Auckland Urban Airshed, the fleet profiles have been averaged across a wider area. This makes the assumption that fleet profiles in each of the CAU contained within these areas are similar to that of the fleet profile of the overall area. Although this will not pick up localised differences, it is considered a reasonable assumption when comparing the similarities between the Auckland fleet profiles and the VEPM default.

A3.7.2 HAPiNZ model limitations

This assessment uses the HAPiNZ update exposure model, which was prepared in 2006 using source apportionment data (either measured or calculated) including emission sources from motor vehicles, domestic heating, outdoor burning, natural sources and industrial contributions. Data used to calculate the contributions from these sources has come from measured data, census data, resource consent information for industrial emissions, and from modelled results.

This assessment adopts a base year of 2016 to generate updated motor vehicle emission estimates. However it makes the assumption for overall annual PM_{10} concentrations at each CAU that outputs from all other sources (excluding motor vehicles) have remained static since 2006.

A3.7.3 Limitations of considering only PM_{10} exposure

Section 2 highlights that the main pollutants of interest from motor vehicle emissions are particulates and nitrogen dioxide (NO_2), so these should be the focus of the potential options. However, the HAPiNZ update exposure model is based only on PM_{10} exposure, as there are insufficient NO_2 data currently to assess exposure in New Zealand. There is also some uncertainty about the effects of exposure to low concentrations of nitrogen dioxide, and therefore it is not possible to quantify the benefits of reducing exposure to NO_2 below the guideline threshold levels.

It is recognised that the policy options targeted at diesel vehicles will have benefits in reducing concentrations of both PM_{10} and NO_2. Source apportionment results show vehicle emissions are a greater contributor to total NO_X emissions in the Auckland region than PM_{10}. Motor vehicle emissions also directly cause exceedances of short term air quality guidelines at peak sites. Therefore, an assessment based solely on PM_{10} will likely underestimate the potential benefits of the policy options when compared with NO_2.

Annex 4: Benefit Valuation Methodologies

A4.1 Health Effects

Studies of the determinants of health effects (epidemiological studies) of air pollution have used regression analysis to relate concentrations of pollutants to effects. Regression analysis is a technique that identifies whether there is a statistically significant relationship between datasets. These studies have included:

- Short-term time-series analyses that relate (daily or similarly frequent) changes in health effects to pollutant concentrations over the same time (both in terms of frequency and duration of dataset). Regressing these data against each other provides an understanding of the acute effects of air pollution, ie the short term effects of air pollution on health.

- Long-run (and lagged) time-series analyses that use the same approach but over a longer period. Many have tracked the fate of individual cohorts within a population so that the effects are not influenced by the health outcomes for individuals who have moved location, eg Hales *et al* identified resident populations in census area units (CAUs) for which they modelled pollution levels and linked the resident population data to mortality data over the subsequent three years.[137]

- Cross-sectional analyses (which are often also cohort studies) that measure changes in effects and pollutant concentrations over space, ie the differences in effects between locations with different long-run pollution levels. Regression analysis of these data enables researchers to examine the effects of long-term exposure, such as in the influential study by Künzli *et al*[138] and the six cities study.[139]

The studies have suggested that the long-run effects have been most significant. For example, Künzli *et al* note that "*the number of deaths attributed to air pollution would be about 4–5 times smaller if the short-term effect estimates had been applied.*"[140] This is significant for policy studies, such as this one, because of the possibility that the benefits of reductions in concentrations may only emerge over the long-run. We examine this issue below.

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[137] Hales S, Blakely T, Woodward A. (2010). Air pollution and mortality in New Zealand: cohort study, Journal of Epidemiology and Community Health. doi:10.1136/jech.2010.112490

[138] Künzli N, Kaiser R, Medina S, Studnicka M, Chanel O, Filliger P, Herry M, Horak F Jr, Puybonnieux-Texier V, Quénel P, Schneider J, Seethaler R, Vergnaud J-C and Sommer H (2000) Public-health impact of outdoor and traffic-related air pollution: a European assessment. The Lancet 356: 795-801.

[139] Dockery DW, Pope CA III, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG Jr, and Speizer FE (1993). An association between air pollution and mortality in six US cities. N Engl J Med 329(24):1753–1759.

[140] Künzli *et al* (op cit), p798

In this study we do not review the literature on health effects in any detail; rather we rely on summaries of these studies and policy studies that have built on the underlying health studies.

We split our discussion of studies in New Zealand into static and policy analyses. The majority of studies in New Zealand on health effects have been static analyses that explain the current impacts of air pollution, rather than the effects of changes in concentrations that is of most interest to policy makers.

A4.2 Static Analyses in New Zealand

A4.2.1 Approach

Studies of the health effects of air pollution in New Zealand have estimated concentrations of pollutants (exposure) and have combined these with dose-response (or exposure-response)[141] functions, largely taken from international studies. The exposure-response functions relate concentrations of pollutants to key health effects that include mortality rates, hospital admissions (for respiratory and cardiovascular complaints) and asthma attacks. The general approach is:[142]

Health effects (cases) = Exposure × Exposure-response function × Population exposed

Some have gone on to estimate the costs for these effects as follows:

Social costs = Health effects (cases) × Cost per case

A4.2.2 NZ Studies

A number of studies have examined the overall effects of air pollution on health in New Zealand, starting from Fisher *et al*'s 2002 study on mortality impacts,[143] and extensions of that study to include morbidity effects by Fisher[144] and Environet,[145] and to examine the effects of transport emissions in Auckland.[146] A detailed study of Christchurch was

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[141] Kuschel G *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report.
[142] Kuschel *et al* (op cit)
[143] Fisher GW, Rolfe KA, Kjellstrom T, Woodward A, Hales S, Sturman AP, Kingham S, Petersen J, Shrestha R and King D (2002) Health effects due to motor vehicle air pollution in New Zealand. Report to the Ministry of Transport.
[144] Fisher G (2002) The Cost of PM_{10} Air Pollution in Auckland: A preliminary assessment. Discussion Paper. NIWA.
[145] Environet (2003) Health effects of PM10 in New Zealand. Air Quality Technical Report No39. Ministry for the Environment
[146] Jakob A, Craig JL and Fisher G (2006) Transport Cost Analysis: a case study of the total costs of private and public transport in Auckland. Environmental Science and Policy 9(1): 55-66

undertaken as a pilot of the HAPiNZ studies,[147] extended to the whole of New Zealand in 2007.[148]
Kuschel *et al* updated the 2007 HAPiNZ study in 2012[149] to take account of new data that included:

- population data taken from the 2006 census;
- updated monitoring, inventory and source apportionment data for ambient PM_{10} concentrations;
- epidemiological results for health impacts of air pollution for population sub-groups, eg Māori and children, as well as for the whole population; and
- updated VoSL.

The study used monitoring data for PM_{10} rather than relying on modelled concentrations.

In contrast to the previous studies that had relied on the exposure-response relationship derived from Künzli *el al*, it defined an exposure-mortality relationship based largely on the work of Hales *et al*[150] who undertook a cohort study in New Zealand in which geocoded mortality data over a three year period were regressed against modelled estimates of PM_{10} concentrations at a census area unit (CAU) level. They reported a significant positive association between estimated long-term exposure to air pollution (PM_{10}) and mortality, concluding that the odds of all-cause mortality (for those aged between 30 and 74 years at census) increased by 7% per 10µg/m^3 increase in average PM_{10} exposure. This was an increase in sensitivity over the 4.3% value[151] taken from Künzli *et al*[152] used in the original HAPiNZ study.[153]

Using the results from these approaches, Kuschel *et al* used the exposure response functions shown in Table 75.[154] The relative risk values are used as multipliers of

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147 Fisher GW *et al* (2005) Health and air pollution in New Zealand: Christchurch pilot study. NIWA Report to the Health Research Council, Ministry for the Environment and Ministry of Transport.
148 Fisher G, Kjellstrom T, Kingham S, Hales S and Shrestha R (principal authors) (2007) Health and Air Pollution in New Zealand: Main Report, A Research Project Funded by: Health Research Council of New Zealand, Ministry for the Environment and Ministry of Transport.
149 Kuschel G, Metcalfe J, Wilton E, Guria J, Hales S, Rolfe K and Woodward A (2012) Updated Health and Air Pollution in New Zealand Study Volume 1: Summary Report. Prepared for Health Research Council of New Zealand, Ministry of Transport, Ministry for the Environment and New Zealand Transport Agency
150 Hales S, Blakely T, Woodward A. (2010). Air pollution and mortality in New Zealand: cohort study, Journal of Epidemiology and Community Health. doi:10.1136/jech.2010.112490.
151 4.3% increase in mortality per 10µg/m3 increase
152 Künzli N, Kaiser R, Medina S, Studnicka M, Channel O, Fillinger P, Herry M, Horak F Jr, Puybonnieux-Texier V, Quénel P, Schneider J, Seethaler R, Vergnaud J-C and Sommer H (2000) Public-health impact of outdoor and traffic-related air pollution: a European assessment. The Lancet 356(9232): 795-801.
153 Fisher G, Kjellstrom T, Kingham S, Hales S and Shrestha R (principal authors) (2007) Health and Air Pollution in New Zealand: Main Report, A Research Project Funded by: Health Research Council of New Zealand, Ministry for the Environment and Ministry of Transport.
154 See explanatory notes in original

existing risk rates, eg the risk of death amongst adults is multiplied by 1.07 (increased by 7%).

Table 75 Exposure Response Functions used in Updated HAPiNZ

Health Outcome	Exposure Response Functions (Relative risks per 10µg/m^3 PM_{10})
1 Premature mortality, all adults, all ethnicities	**1.07** (1.03 – 1.10)
1a Premature mortality, all adults, Māori-only	**1.20** (1.07 – 1.33)
2 Premature mortality, babies, all ethnicities	**1.05** (1.02 – 1.08)
3 Cardiac hospital admissions, all ages, all ethnicities	**1.006** (1.003 – 1.009)
4 Respiratory hospital admissions, all ages, all ethnicities	**1.01** (1.006 – 1.017)
4a Respiratory hospital admissions, children all ethnicities, aged 1-4 years	**1.02** (1.01 – 1.04)
4b Respiratory hospital admissions, children all ethnicities, aged 5-14 years	**1.03** (1.00 – 1.05)

Source: Kuschel G *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report

Using these exposure-functions, the results were estimated for 2006 (Table 76). They suggest a significant increase over the 2007 HAPiNZ results, largely reflecting the increased population included in the analysis and the higher value for VoSL. The estimate of 2,307 deaths attributable to PM_{10} represents over 8% of total deaths, of which there were 28,389 in 2006.[155]

Table 76 Total impact of PM_{10} in New Zealand (2006)

Health effect	Motor vehicles	Natural	Other	Total	Cost per case	Social costs ($ m)
Premature mortality (adults)	255	1,136	916	2,307	$3.56 m	$8,211
Premature mortality (babies)	1	5	3	9	$3.56 m	$31
Cardiac admissions (all)	51	217	181	449	$6,350	$3
Respiratory admissions (all)	91	356	284	731	$4,535	$3
Restricted activity days (all)	352,300	1,440,000	1,134,200	2,926,500	$62	$181
Total social costs ($ m)	$934	$4,155	$3,340	$8,429		$8,429

Source: Kuschel G *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report

A4.3 Policy Studies in New Zealand

Policy studies have examined the impacts of changes in concentrations as a result of policy interventions. In contrast to emerging practice internationally, these have all assumed that the effects are instantaneous following emission reductions, with the long-run exposure-response relationship being used to predict the immediate effects.

155 Ministry of Health Mortality and Demographic Data 2006 (www.health.govt.nz/publication/mortality-and-demographic-data-2006)

Ministry for the Environment (2004)

The Ministry for the Environment (MfE) analysed the costs and benefits of proposed national environmental standards for air pollution.[156] The study included modelling of the expected impacts of the air quality standards on concentrations of PM_{10} in 24 sites across New Zealand for the years 2001 to 2021. A health effects model was used to estimate the number of premature deaths, hospitalisations and RADs with and without the new standards. The modelling is not explained in the report but it implies that a reduction in concentration is assumed to result in a reduction in premature deaths based on the long-run exposure-response relationships; we discuss the need for a marginal approach to analysis below. MfE estimates the number of premature deaths falling by 54 per annum by 2020 as a result of the standards.

It uses these results with a value of statistical life of $2.5 million, adjusted downwards to reflect age (see discussion below). Total benefits were estimated to include 625 premature deaths prevented by 2020, total benefits with a present value (to 2004 at a 10% discount rate) of $429 million, of which $420 million were from lives saved. The costs of the policy measures were estimated to be $111 million, yielding a net present value (NPV) of $318 million ($554 million at 5% discount rate). The analysis was also expressed as a cost per life saved of $177,000 ($232,000 at 5% rate), suggesting that much smaller benefit levels would justify the costs of the standards.

NZIER (2009)

NZIER conducted a review and update of the 2004 CBA.[157] The authors suggested a number of shortcomings of the original analysis, including (on the benefit side):

- The reduction in the VoSL because of the expected age of those affected – NZIER suggests that there is no empirical basis for assuming either that elderly people are most affected or that the VoSL differs with age (we discuss these issues below);
- The absence of any assessment of the costs of loss of life quality for those who suffer from chronic ill-health (see below);
- That no explicit allowance was made for medical costs saved by reducing bad air days.

The approach retains the structure of the 2004 analysis, but it increases the costs of some impacts, including an increased VoSL of $3.35 million (Table 77). NZIER also reduced the discount rate from 10% to 8%, consistent with updated NZ Treasury guidance on discount rates for public policy.[158]

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[156] MfE (2004) Proposed National Environmental Standards for Air Quality. Resource Management Act Section 32. Analysis of the costs and benefits.

[157] NZIER (2009) The value of air quality standards. Review and update of cost benefit analysis of National Environmental Standards on air quality. Report to Ministry for the Environment.

[158] NZ Treasury (2008) Public Sector Discount Rates for Cost Benefit Analysis.

Table 77 Costs of health impacts assumed in NZIER study

Health effect	Cost per event
Premature mortality (all)	$3.35 million
Hospitalisation (medical costs per event)	$7,700
Hospitalisation (loss of income per day)	$713
Restricted Activity Day	$46.50

[1] Assumes $60.43/day, 6.8 days in hospital and 5 days recuperation

Source: NZIER (2009) The value of air quality standards. Review and update of cost benefit analysis of National Environmental Standards on air quality. Report to Ministry for the Environment.

NZIER's updated estimate of benefits of standards being met by 2013 was $1,289 million (up from $429 million in the 2004 study).

Market Economics (2013)

McIlrath (Market Economics) assessed the costs and benefits of reducing emissions associated with domestic fires in Auckland.[159] The study used the cost per case assumptions from the updated HAPiNZ study (Table 75) and added a cost per chronic obstructive pulmonary disease (COPD) using values included in HAPiNZ (2007), despite the updated HAPiNZ not including COPD effects because of "limited scientific consensus on the relationships with air pollution".[160]

A4.4 Methodological Issues

In this section we address a number of issues that are raised by the studies to date in New Zealand. Specifically, these are:

- Marginal effects – the implications for analysis of health effects being dominated by chronic mortality, with full benefits only emerging after some time;
- Whether the mortality impacts should be characterised as premature deaths and whether this affects the analysis;
- Whether VoSL differs by age;
- VoSL vs VoLY.

A4.4.1 Marginal Effects and Lagged Benefits

The Problem: the difference between short-run and long-run impacts

The mortality impacts across a wide range of studies are dominated by the chronic effects. The long and short term impacts can be explained using a two by two matrix (Figure 29). Susceptibility to death may be increased because of air pollution or some other cause, eg illness, and the event of death may be triggered by air pollution or

[159] McIlrath L (2013) Auckland Council Air Quality Domestic Options: Cost Benefit Analysis 2013 Update. Auckland Council Technical Report TR2013/029

[160] Kuschel G *et al* (2012) Updated Health and Air Pollution in New Zealand Study. Volume 1: Summary Report, p22

another cause. The long term studies that demonstrate a linkage between rates of death and long run exposure to pollution, do not separate out causes A, B and C.

Figure 29 Long-term Frailty and Trigger of Death

Long-term frailty	Event of death	
	Related to air pollution	Not related to air pollution
Related to air pollution	A	B
Not related to air pollution	C	D

Source: Seethaler, RK, Künzli N, Sommer H, Chanel O, Herry M, Masson, S, Vergnaud J-C, Filliger P, Horak F Jr, Kaiser R, Medina S, Puybonnieux-Texier V, Quénel P, Schneider J, Studnicka M and Heldstab, J (2003) Economic Costs of Air Pollution Related Health Impacts: An Impact Assessment Project of Austria, France and Switzerland. Clean Air and Environmental Quality, 37/1: 35-43

While a reduction in emissions may reduce the number of deaths immediately related to air pollution (A and C), average levels of long term frailty in the population might only change slowly over time. The studies used to assess the chronic effect suggest that people are frail as a result of a long time living in elevated concentrations of pollutants. Even if air pollution is cut to zero tomorrow, these people might still be frail and some will die prematurely because of this frailty. The cessation of emissions stops additional frailty and would be expected to allow some repair. However, even if all pollution is eliminated, it might take many years without pollution for the full benefits to be realised.

This suggests a different approach from that used in the New Zealand policy studies to date. They have all assumed that a reduction in concentrations of PM_{10} results in the immediate reduction in chronic mortality, in proportion to the reduction in concentrations.

Response Elsewhere

The delay issues have been recognised in international studies for some time. In the US, the UK and elsewhere in Europe, studies of the costs and benefits of air pollution use lagged benefits. This reduces the present value of benefits because of the impacts of discounting. The approaches used are still developing and there is increased focus on studies that are testing the extent of lag, including some US studies that suggest that a significant proportion of the benefit is gained soon after a reduction in emissions.[161] Against this, the UK Committee on the Medical Effects of Air Pollutants (COMEAP)[162] suggests that "the US cohort studies do not, and cannot, lead to any clear conclusion on the likely latency between a change in average pollution levels and the appearance of effects",[163] while also noting that "current thinking suggests that the exposure in the weeks, months and short number of years prior to death is the most biologically

[161] Lepeule J, Laden F, Dockery D and Schwartz J (2012) Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities Study from 1974 to 2009. Environmental Health Perspectives, 120(7): 965-97; Pope CA III, Ezzati M and Dockery DW (2009) Fine-Particulate Air Pollution and Life Expectancy in the United States. The New England Journal of Medicine 360(4):376-386.

[162] COMEAP has been established as an expert committee to advise the UK government on all matters concerning the health effects of air pollutants

[163] COMEAP (2009). Long-Term Exposure to Air Pollution: Effect on Mortality. A report by the Committee on the Medical Effects of Air Pollutants

relevant time period of exposure for deaths from cardiovascular (or cardiorespiratory) causes, whereas the effect of exposure on lung cancer is likely to have a longer latency."[164]

This is clearly an emerging science, but assuming no lag in benefits is an extreme position, given current understanding.

USA

In the US, prior to 2004, the Environmental Protection Agency (EPA) and the Health Effects Subcommittee (HES) used a weighted 5-year time course of benefits in which 25% of the PM-related mortality benefits were assumed to occur in the first and second year, and 16.7% were assumed to occur in each of the remaining 3 years.[165]

Subsequently, following a suggestion from the EPA,[166] the Science Advisory Board (SAB) noted that considerable uncertainty remained but recommended that a lag structure is used in which 30% of the mortality reductions occur in the first year, 50% is distributed equally (12.5% per year) in years 2 through 5 and the remaining 20% is distributed equally over years 6 through 20.[167]

This approach is still used as the primary assumption, although in recognition of the uncertainty, a number of alternative lag structures have been used also:[168] a 5-year distributed lag (20% per year over 5 years) and an exponential decay model based on analysis by Roosli *et al*.[169]

EU

Work for the European Commission has examined the effects associated with a 1-year pulse change, ie a sudden reduction in pollution for one year, as a way to understand the marginal effects.[170] Here, in contrast to a 6% increase in mortality for a 10μg/m^3 increase in $PM_{2.5}$ concentrations otherwise used, they assumed a 2.4% increase in year 1, followed by 0.36% increases in years 2 to 11, followed by reversion to the original mortality rate.

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[164] COMEAP (op cit)

[165] US EPA (2004) Advisory on Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis—Benefits and Costs of the Clean Air Act, 1990-2020. Advisory by the Health Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis. (www.epa.gov/sab/pdf/council_adv_04002.pdf)

[166] US EPA (2004) Letter to Dr Trudy Cameron and Dr Bart Ostro, Science Advisory Board, August 11 2004. (www.epa.gov/sab/pdf/comments_on_council_adv_04001.pdf)

[167] Trudy Cameron (Advisory Council on Clean Air Compliance Analysis) and Bart Ostro (Health Effect Subcommittee). Advisory Council on Clean Air Compliance Analysis Response to Agency Request on Cessation Lag. Letter to MO Leavitt, US EPA. EPA-COUNCIL-LTR-05-001. December 6, 2004.

[168] US EPA (2011) The Benefits and Costs of the Clean Air Act from 1990 to 2020

[169] Röösli M, Künzli N, Braun-Fahrländer C and Egger M (2005) Years of life lost attributable to air pollution in Switzerland: dynamic exposure-response model. International Journal of Epidemiology 34(5): 1029-35.

[170] AEA Technology Environment (2005) Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment. .Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment.

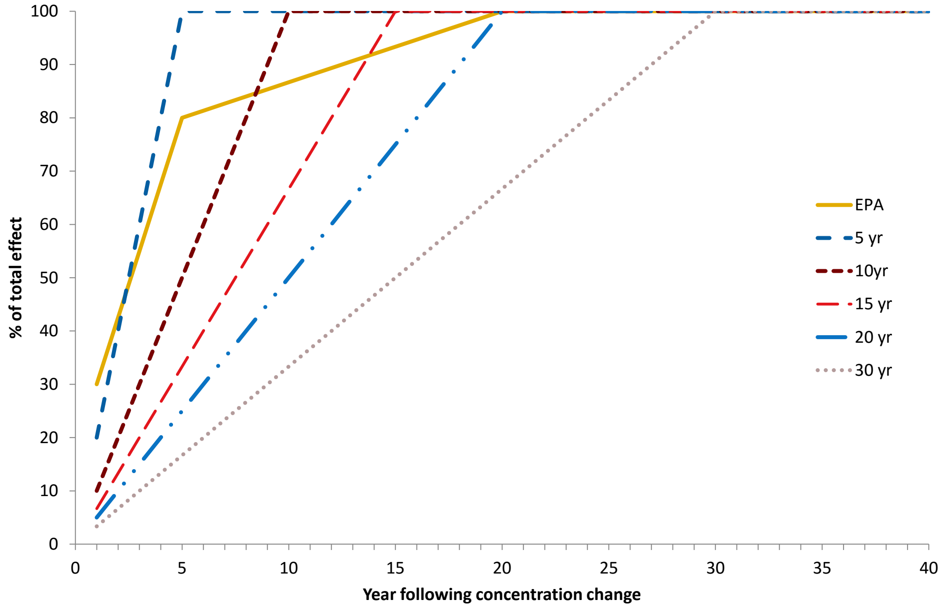
An analysis relating to the National Emissions Ceiling Directive (NECD) adopted the US EPA's lag structure.[171]

UK

In the UK, Walton analysed the issue of cessation lag for COMEAP and identified a range of possible lag structures (Figure 30).

Subsequently COMEAP used lag options that included no lag and 5, 10, 20 and 30 year phased-in lags in addition to the US EPA suggested lag structure.[172] Table 78 shows the implications of these different lag structures on damage estimates in relative terms, using different discount rates. At an 8% discount rate, usually used for public policy analysis in New Zealand, a 30-year lag reduces the impact to 41% of what it would be with no lag.

Figure 30 Selection of lag structures examined by Walton (2010)



Source: Walton HA (2010) Supporting paper to COMEAP 2010 report: The Mortality Effects of Long Term Exposure to Particulate Air Pollution in the United Kingdom. Working Paper: Development of Proposals for Cessation Lag(s) for use in Total Impact Calculations

Table 78 Implications of Lag Structures for Impact Estimates (Index: no lag = 100)

Discount Rate	No lag	EPA	5 yr	10yr	15 yr	20 yr	30 yr
0.0%	100	100	100	100	100	100	100
3.0%	100	91	94	88	82	77	67
5.0%	100	86	91	81	73	65	54
8.0%	**100**	**80**	**86**	**72**	**62**	**53**	**41**
10.0%	100	77	83	68	56	47	35

[171] Miller B, Hurley F and Shafrir A (2011) Health Impact Assessment for the National Emissions Ceiling Directive (NECD) – Methodological Issues. IOM Research Report TM/11/03

[172] COMEAP (2010) The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom. A report by the Committee on the Medical Effects of Air Pollutants.

The analysts using lagged benefits are using assumptions in the absence of studies that have defined the marginal effect statistically over the long run. However, they demonstrate that the assumptions of an instantaneous response to reductions in emissions over-estimate the measured impact.

We use a number of alternative lag structures in this analysis; the US EPA lag structure is used as the primary assumption, consistent with international practice.

A4.4.2 Premature death or life years lost

Impact studies in New Zealand have characterised the mortality impacts as increases in premature mortality. This has been used as a simple shorthand to explain the nature of impacts, but can be somewhat misleading when examining the impacts of policy which will not eliminate pollution but reduce emissions and concentrations to a lower level. People may still die prematurely, but not as prematurely; premature mortality is not so much reduced as is the prematurity of the mortality.

Because of reduced concentrations of air pollutants, some people will not become so frail and others will have reduced stress to interact with their frailty. As a result, some people will have lives extended by many years and others by very short periods. However, because the individuals cannot be identified (no-ones death is classified as being caused by air pollution), this is only observed as a reduction in the all-causes mortality rate (and the mortality rate for specific respiratory and cardiovascular conditions). Some studies have provided estimates of the impacts on life expectancy (or life years). For example, Pope *et al* find a 0.61 year increase in life expectancy,[173] while noting that "*indirect calculations point to an approximate loss of 0.7 to 1.6 years of life expectancy that can be attributed to long-term exposure to fine-particulate matter at a concentration of 10 μg/m*^{3}"; Künzli *et al* note that life expectancy is shortened by about 6 months per 10 μg/m^3.[174]

The effects of life extension on death rates can be understood by examining the way the probability of death changes with age. Figure 31 shows data for 2014 with probability defined as the number of deaths divided by population at that age. Because the probability of death increases with age (apart from year zero), if life is extended by a small percentage for all ages, there are more people in each successive (older) age group whose deaths are shifted to the next age group, such that the effect is observed as a reduction in deaths in every age group.

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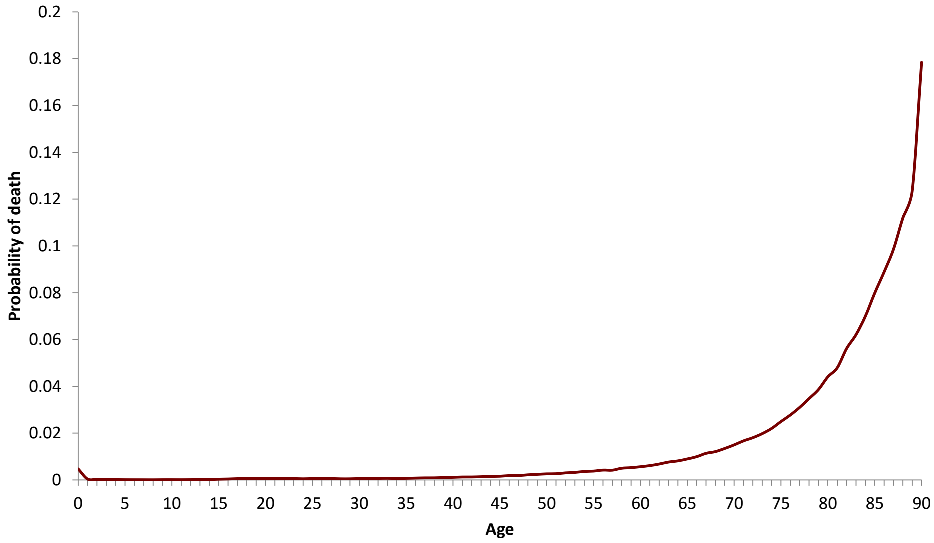
173 Pope CA III, Ezzati M and Dockery DW (2009) Fine-Particulate Air Pollution and Life Expectancy in the United States. The New England Journal of Medicine 360(4):376-386.
174 Künzli *et al* (op cit), p798

Figure 31 Probability of death by age



Source: Calculated from: Statistics NZ. Deaths by age and sex (Annual-Dec) and Estimated Resident Population. Average 2010-2014

Thus the effects that are observed as a reduction in the death rate of adults, and expressed as a change in the number of attributable deaths, is most likely to be the shortening of life of many individuals by a relatively short amount.

We find COMEAP's discussion of the effects and their descriptors useful. They note that "*there is, to some extent, a trade-off between full accuracy and accessibility*" and that the metrics can be "*valid representations of population aggregate or average effects, but they can misleading when interpreted as reflecting the experience of individuals.*"[175] They suggest that "total population survival time (life-years gained or lost)" is "t*he most accurate and complete way of capturing the mortality effects of air pollution reductions*" and "*by far the single most relevant metric for policy analysis*". This is largely because it most accurately describes what is happening at the population level.

In contrast, describing the impact in terms of the number of premature deaths can be misleading because there is no way of knowing how many deaths are attributable to air pollution. The results observed as a change in the death rate amongst adults could be the result of the whole population dying prematurely or a much smaller number.

Rabl comments:[176]

1. *It makes no sense to add the number of deaths caused by different contributing causes (such as air pollution, smoking, or lack of exercise) because one would end up with numbers far in excess of total mortality;*

[175] COMEAP (op cit), p84
[176] Rabl A (2003) Interpretation of Air Pollution Mortality: Number of Deaths or Years of Life Lost? J. Air & Waste Manage. Assoc. 53:41–50. DOI: 10.1080/10473289.2003.10466118

2. *Number of deaths fails to take into account the magnitude of the loss of life per death, very different between, for example, air pollution deaths and typical traffic accidents; and*
3. *By contrast to primary causes of death (such as accidents or cancers), the total number of premature deaths attributable to air pollution is not observable.*

Note, although some air pollution deaths may be classified as cancer, the point being made is that deaths attributable to air pollution itself cannot be identified.

COMEAP also notes that air pollution mostly affects older people,[177] which means it cannot be compared simply with the effects of road traffic accidents, suicide, or HIV/AIDS, which by comparison affect younger people. They suggest that, implicit in any communication about deaths is some understanding of age at death or, equivalently, the loss of life implied by death at various ages. This is best captured explicitly – which, in effect, means discussion in terms of total population survival time (or life-years gained).

In the UK, the benefits of policy measures targeted at reducing levels of particulates have been expressed in terms of 'total life-years' rather than reductions in numbers of deaths, eg in the economic analysis to inform the Air Quality Strategy.[178]

The approach to valuation is connected to the issue of how to define the impact. Premature deaths are valued using a value of statistical life (VoSL or VSL) and life years lost using a value of life years lost (VoLY or value per statistical life-year = VSLY). Despite premature deaths being only a characterisation of what is happening, it can easily be confused as being the actual outcome.

In contrast, NZIER argues that a value of statistical life (VoSL) should be used to measure the impact because "*characterizing the benefit of air quality improvement as an extension of life years before death at some distant point in the future will understate the value of risk reduction now: people do not know in advance when they are going to die with current air pollution and when with pollution reduced, so any expressed willingness to pay is for a generalized reduction in risk that is being incurred now.*" The difficulty is greater than even this implies; there is uncertainty over the length of the life time that is extended per person, the number of people whose lives are extended and who they are. When we compare this with traffic deaths, the context in which VoSLs have been established, we can at least identify after the event, how many people have died from accidents and who they are. Society is willing to pay to reduce these deaths partly because people wish to avoid the risk of death for themselves and/ or for those they know. With air pollution the deaths owing to air pollution cannot be identified even retrospectively. All we can know (or predict on the basis of statistical correlation) is that the death rate in younger age categories has increased and that lives have been shortened on average.

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177 We find this result through the simple assumption that the percentage impact is the same at all ages and there is a higher initial death rate amongst older people

178 Defra *et al* (2007) An Economic Analysis to inform the Air Quality Strategy. Updated Third Report of the Interdepartmental Group on Costs and Benefits

Despite the problems with premature deaths as a characterisation, we note that in the US the practice has been more to use premature deaths and VoSL rather than life years lost and VoLY.[179] However, the government's 2003 guidance on regulatory impact analysis suggests that it is "*appropriate to consider providing estimates of both VSL and VSLY, while recognizing the developing state of knowledge in this area*."[180] Consistent with this, the 2011 CBA of the Clean Air Act Amendments (CAAA) included results in terms of avoided premature mortality, life-years lost and changes in life expectancy.[181]

In the EU, a 2005 CBA of the Clean Air for Europe (CAFE) programme recommends that "*years of life lost as the most relevant metric for valuation.*"[182] However, in response to peer review recommendations, they include estimates of "*the number of deaths per year attributable to long-term exposure to ambient $PM_{2.5}$*" despite their acknowledging that it will over-estimate the impact; they argue that it has computational problems but is easy to understand.

The emerging international consensus is moving towards the use of life years lost as the key metric for analysis. We agree with this direction. Our preference is to use life years and value of life years as the primary means of quantifying the monetary impacts of air quality impacts.

How to Measure Life Years Lost

COMEAP estimates life years lost by multiplying the number of additional deaths at each age by the average life expectancy at that age. Across a number of different coefficients (change in mortality per unit change in PM concentration), its results expressed in terms of life years lost (or gained) were 11.8 – 12.2 times the estimated number of attributable deaths.[183].

Note, this is not suggesting each estimated premature death has its life shortened by 12 years. The assumption is still that lives are shortened by a few months. Rather the headline figure of premature lives lost (or saved) masks the true number affected within the population. Indeed, COMEAP estimates that for England and Wales, a population-weighted average concentration of $PM_{2.5}$ of 9.46μg/m^3 throughout their life results in approximately 6.5 months lower life expectancy for those born in the year (2008) of evaluation.[184] Rather, multiplying additional deaths by life expectancy is a simple way of estimating the increase in life years; a more complex way would be to estimate the change in life expectancy for all people in an age class, rather than simply for those that are estimated to have died "prematurely".

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[179] For example, in: Industrial Economics (2006) Expanded Expert Judgment Assessment of the Concentration-Response Relationship Between $PM_{2.5}$ Exposure and Mortality. prepared for: Office of Air Quality Planning and Standards, US Environmental Protection Agency

[180] US Office of Management and Budget (2003) Circular A-4 Regulatory Analysis

[181] US EPA (2011) The Benefits and Costs of the Clean Air Act from 1990 to 2020. Final Report Rev A.

[182] AEA Technology Environment (2005) Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment

[183] COMEAP (2010) – using data on p67

[184] COMEAP (2010)

We extend the HAPiNZ approach by using the impacts on life years as the primary approach to estimating impacts, while including the original impact on premature deaths in sensitivity analysis.

A4.4.3 Age

The issue of age is relevant to two issues:

1. Whether impacts apply to the population aged over 30 only; and
2. Whether impacts change with age.

Over 30s

The issue of whether to measure effects on those only 30 only is debated in the literature, but ultimately is unimportant because of the small number of deaths in those under 30. In 2014, 2.8% of deaths were amongst those under 30 and only 1.8% amongst those aged between 1 and 30 years old.

VoSL and Age

A number of early studies lowered the value of a statistical life (VoSL) used in analysis to reflect the age of people expected to die prematurely because of air pollution. For example, the 2004 CBA by MfE reduced the VoSL by 25% based on analysis by Jones-Lee.[185] More recently studies have tended not to reduce VoSL with age, including in the 2009 CBA by NZIER. The US EPA notes that there is insufficient evidence in the empirical literature to support an adjustment to the base VoSL for the age of the affected population,[186] and US OMB Circular A-4 cautions against age adjustments. Nevertheless, not all are in agreement. AEA suggests that "it is questionable to attach a high VSL to a life with very short remaining life expectancy."[187]

In addition, there is a certain logical difficulty with not reducing VoSL with age. The implication is that the cost is associated with the fact of prematurity rather than its extent. At the individual level, this would mean that, if a life is extended but the person still dies prematurely, there is no change in the cost of that premature death, and thus no benefit from life extension.

Using VoLYs as the primary approach is preferred.

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[185] In: Sommer H, Seethaler R, Chanel O, Herry M, Masson S and Vergnaud J-C (1999) Health Costs due to Road Traffic-related Air Pollution. An impact assessment project of Austria, France and Switzerland. Economic Evaluation Technical Report on Economy. Prepared for the WHO Ministerial Conference on Environment and Health London June 1999

[186] US EPA (2011) The Benefits and Costs of the Clean Air Act from 1990 to 2020. Final Report Rev A. p5-22

[187] AEA Technology Environment (2005) Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment

A4.4.4 Level of VoSL/VoLY

The current VoSL is estimated at $3.95 million per fatality based on willingness to pay studies (2014 prices).[188] We use this value as the basis for estimating the costs measured in terms of premature mortality.

VoLY can be estimated in various ways, although the simplest is to convert the VoSL into a discounted stream of annual life year values over the remaining lifetime of the subject. This is the approach adopted in the cost benefit analysis of the EU CAFE programme.[189] The formula used is:

$$VoLY = \frac{VoSL}{\frac{(1 - \frac{1}{(1+r)^n})}{r}}$$

Where: r = the discount rate
n = years over which the annuity is calculated (40 in this case)

This formula is represented by the PMT function in Excel.

To estimate the remaining lifetime we take the average age of death by accidents. NZTA publishes data on the number of people having fatal accidents in different age categories.[190] Taking the mid-point of these ranges and an age of 70 for those aged 60 and over, data over the last two years suggests an average age of death of 43. At this age the weighted average life expectancy is 40 years.[191]

The appropriate discount rate is that which would apply to the individuals: a social rate of time preference, rather than the Treasury's recommended discount rate for public policy analysis which reflects an opportunity cost of investment. Previous analyses of the social rate of time preference for New Zealand suggest that it would be in the 3-5% range[192]

Table 79 shows the estimated value of a VoLY at two discount rates: 4% and 8% when discounted over 40 years.

Table 79 Estimation of VoLY from VoSL

Indicator	Value
VoSL	$3,948,300
VoLY (@ 4%)	$199,482
VoLY (@ 8%)	$331,105

188 Ministry of Transport (2014) Social cost of road crashes and injuries 2014 update.
189 AEA Technology Environment (2005) Service Contract for Carrying out Cost-Benefit Analysis of Air Quality Related Issues, in particular in the Clean Air for Europe (CAFE) Programme. Methodology for the Cost-Benefit Analysis for CAFE: Volume 2: Health Impact Assessment
190 www.nzta.govt.nz/resources/road-deaths/toll.html
191 Statistics NZ (2013) New Zealand Period Life Tables: 2010-12
192 See for example: MED (2006) Choice of Discount Rate for the New Zealand Energy Strategy (NZES). POL/1/39/1/1; Parker (2009) The implications of discount rate reductions on transport investments and sustainable transport futures. NZ Transport Agency research report 392

We use the value based on the 4% rate ($199,000) in analysis. VoLYs derived using this approach need to be discounted when used in analysis, such that the result using VoLY is the same as that using VoSL for those dying with a life expectancy of 40 years.

The size of these values raises the question of whether they are credible as a measure of effect that might be very widely distributed across the population, and how any constraints might be set. Ability to pay, eg in terms of net wealth of individuals, cannot be used to constrain the amount as it merely constrains how much life extension could be afforded, not the amount paid per year. In New Zealand health studies it is common to use a threshold value for how much to spend to achieve a quality adjusted life year (QALY), essentially a life year in perfect health, or the alternative health-adjusted life year (HALY). One approach used has been to set GDP per capita as a threshold for the maximum amount to pay to achieve a QALY/HALY.[193] A QALY or HALY is worth more than a VoLY because it is in better health. GDP per capita in New Zealand is currently approximately $53,000;[194] using a ratio of QALY to VoLY of 1.2,[195] this would suggest a VoLY of approximately $44,000.

PHARMAC[196] measures its expenditures in terms of costs per QALY gained, but currently has no QALY threshold;[197] a proposal to invest in a pharmaceutical can be considered "cost-effective" only in comparison with another proposal.[198] Between 1998 and 2007 the costs per QALY of investments made by PHARMAC varied between saving $40,000 per QALY gained (ie negative $40,000) and spending over $200,000 per QALY.

Other approaches to defining VoLY have used survey-based approaches. The first survey, to our knowledge, that asked explicitly about the valuation of a gain in life expectancy was by Swedish researchers Johannesson & Johansson. They administered a telephone survey in 1995 of adults between 18 and 69 years old and asked the following question "*The chance for a man/woman of your age to become at least 75 years old is x percent. On average, a 75-year old lives for another 10 years. Assume that if you survive to the age of 75 years you are given the possibility to undergo a medical treatment. The treatment is expected to increase your expected remaining length of life to 11 years. Would you choose to buy this treatment if it costs y and has to be paid for this year?*"[199] The resulting VoLY values are

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[193] See, for example: Webber-Foster R, Kvizhinadze G, Rivalland G, Blakely T (2014) Cost-effectiveness analysis of docetaxel versus paclitaxel in adjuvant treatment of regional breast cancer in New Zealand. Pharmacoeconomics 2014; 32:707–724

[194] $52,672 in year to September 2014: Statistics NZ. Gross Domestic Product: September 2014 quarter. Table 22

[195] Dolan P, Metcalfe R, Munro V and Christensen MC (2008) Valuing lives and life years: anomalies, implications, and an alternative. Health Economics, Policy and Law, 3: 277–300

[196] The Pharmaceutical Management Agency (PHARMAC) is the New Zealand Crown agency that decides, on behalf of District Health Boards, which medicines and related products are subsidised for use in the community and public hospitals.

[197] Pharmaceutical Management Agency. (2012) Cost-Utility Analysis (CUA) Explained. Available at: www.pharmac.health.nz/assets/economic-assessment-guide.pdf

[198] PHARMAC (2012) Prescription for Pharmacoeconomic Analysis. Methods for cost-utility analysis. Version 2.1

[199] Johannesson M & P-O Johansson 1997. "Quality of life and the WTP for an increased life expectancy at an advanced age". J Public Economics, 65, 219-228 in: Desaigues B, Rabl A, Ami D, Boun My K,

between US$700 and US$1,300 in 1995 dollars (approximately NZ$1,600 - NZ$3,000 in current dollar values).[200] Half of the sample had a willingness-to-pay (WTP) of zero; the average of positive willingness to pay was about US$2,700. In contrast to the other values, these values are present values for some future benefit. Dolan *et al*[201] discuss a number of other studies with similarly low values, eg £242-£508/VoLY (NZ$890-1,875)[202] in a 2004 UK study and a Swedish study that found a low WTP for cigarettes with lower health risks that would extend life, implying a VoLY of NZ$4,400 to $10,700 in today's dollar values.

The CBA for the UK's Air Quality Strategy notes that work by Chilton *et al* (2004) was the only one to have derived VoLYs directly, rather than from VoSLs. The VoLYs derived from this work ranged from £6,040 to £27,630 in 2002 prices (NZ$25,500 to $116,800 in 2014 dollars).[203] However, the analysis did not discount the future values. It started with an annual WTP[204] for a 1, 3 or 6 month extension to life. Despite being derived from surveys of adults, these values were multiplied by a life expectation of 78 years without discounting, and grossed up to 12 months (1 month value multiplied by 12). If the values are, instead discounted (at 4%) over 40 years (expected lifetime of an adult), this would suggest a VoLY of £1,500 to £7,000 in 2002 prices (NZ$6,500 to $30,000 in 2014 dollars).

More recently surveys in a number of European countries were undertaken to suggest an EU-wide VoLY of €40,000 in 2010 (NZ$76,500 in 2014), but with the value varying with income across the EU.[205] However, these values too were derived without discounting. Using the same modified approach as above suggests values using their data of NZ$2,100 to $6,400 per VoLY based on 2010 WTP of €14 to €42/month to achieve a 3-month life extension.[206]

The way that we think about the impact has significant implications for the value used in analysis. We provide a series of values in Table 80 and the characterisation of the effect that leads to this result. There is an argument in favour of all of these approaches. Our preference is to use VoLY based on willingness to pay surveys; these suggest values for a VoLY of $7,000 to $30,000.

For analysis we use a central figure of NZ$25,000 just below the top of this range; we set a lower limit of NZ$5,000 to reflect a potential lower WTP in New Zealand because of lower income per capita.

Masson S, Salomon M-A and Santoni L (2004) Monetary Valuation of Air Pollution Mortality: Current Practice, Research Needs and Lessons from a Contingent Valuation (www.arirabl.com/papers/MortalVal-Desaigues%20et%20al04.pdf)

200 Converted to NZ$ using 1995 exchange rate and inflating using NZ CPI

201 Dolan *et al* (op cit)

202 Conversion to NZ$ using 2004 exchange rates and inflating using NZ CPI

203 Conversion to NZ$ using 2002 exchange rates and inflating using NZ CPI

204 An amount a person would be willing to pay each year

205 Desaiguesa B *et al* (2011) Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VoLY). Ecological Indicators 11 (2011) 902–910

206 We discount this over 40 years at 4%.

Table 80 Impact of Characterisation of Effect on Valuation

Characterisation of effect	Valuation approach/value	Issues/problems
An immediate reduction in the risk of death for people of all ages, with no certainty of how much life is gained	VoSL ($3.95 million at all ages)	Many studies suggest that life extension is short and largely for elderly If there is no change in value with age, short life extension, without preventing premature death, has no value
An extension to life expectancy; life is extended at the end of life, possibly many years in the future	VoLY ($7,000 - $30,000)	Does not take account of the uncertainty over when life extension will occur or by how much
An immediate extension to life for those for whom death is imminent.	VoLY ($199,000)	Derived from VoSL rather than directly via survey
As above but income constrained	VoLY ($44,000)	Does not account for willingness to pay for partial year life extension

A4.4.5 Life Quality Impacts

NZIER discusses the life quality impacts of air pollution, ie the fact that deaths are premature and that the quality of life of sufferers is lower before they die. This is used to argue that the VoSL values used may underestimate the full costs.

For policy interventions where life may be extended, but still people are dying prematurely, it is not clear what the quality-life extension trade-off is. Life may be longer but is the quality of that life increased also, or is life extended and suffering also? In the absence of information to clarify this, we have ignored quality effects in the analysis here.

A4.5 Data Used

Table 81 Population Data (2013)

	CBD & Port			Auckland Central			Auckland urban airshed		
	Male	Female	All	Male	Female	All	Male	Female	All
Age 0	102	99	198	657	600	1254	9,276	8,760	18,033
30-34	2,190	1,869	4,050	6,387	6,333	12,687	41,205	45,387	86,559
35-39	1,071	861	1,929	4,617	4,878	9,420	38,358	43,287	81,570
40-44	762	573	1,326	4,710	5,073	9,774	41,505	47,190	88,686
45-49	609	522	1,125	4,575	4,800	9,393	40,320	44,412	84,750
50-54	552	537	1,089	4,176	4,260	8,439	37,674	40,746	78,423
55-59	450	432	858	3,387	3,357	6,702	31,242	34,095	65,295
60-64	411	339	747	2,844	2,838	5,595	26,910	28,707	55,530
65-69	264	210	465	2,019	2,004	3,999	21,120	22,983	44,079
70-74	144	114	270	1,281	1,368	2,649	15,375	17,469	32,844
75-79	84	57	141	798	834	1,662	10,551	12,357	22,938
80-84	36	30	72	570	720	1,275	7,401	9,852	17,238
85+	15	15	33	417	933	1,302	5,568	11,244	16,764
Total 30+	6,588	5,559	12,105	35,781	37,398	72,897	317,229	357,729	674,676

Source: NZStat. Dataset: Age by sex, for the census usually resident population count, 1996, 2001, 2006, and 2013 Censuses (RC, TA, AU)

The probability of death by age is shown in Table 82. The population data are for the Auckland region District Health Board (DHB) areas, ie the Auckland, Maunukau and Waitemata DHBs.

Table 82 Probability of death by age

	Deaths		Population		Probability of death	
Age	Male	Female	Male	Female	Male	Female
0	180	165	35,805	33,887	0.0050	0.0048
00-04	75	70	169,820	159,920	0.0004	0.0004
05-09	12	12	154,440	145,670	0.0001	0.0001
10-14	18	21	154,810	148,200	0.0001	0.0001
15-19	90	38	169,970	162,770	0.0005	0.0002
20-24	126	53	175,070	169,920	0.0007	0.0003
25-29	87	55	171,360	176,300	0.0005	0.0003
30-34	112	60	149,130	162,730	0.0008	0.0004
35-39	151	108	155,960	172,380	0.0010	0.0006
40-44	242	177	160,700	174,890	0.0015	0.0010
45-49	334	271	159,420	168,560	0.0021	0.0016
50-54	455	349	136,580	143,040	0.0033	0.0024
55-59	587	398	112,820	118,240	0.0052	0.0034
60-64	772	569	99,220	103,590	0.0077	0.0055
65-69	939	703	72,440	77,740	0.0128	0.0090
70-74	1145	872	53,140	58,600	0.0211	0.0147
75-79	1407	997	36,740	42,950	0.0369	0.0227
80-84	1766	1706	26,670	35,170	0.0621	0.0463
85+	2697	4906	18,600	36,960	0.1266	0.1172

Source: Ministry of Health Mortality Data and Stats. www.health.govt.nz/nz-health-statistics/health-statistics-and-data-sets/mortality-data-and-stats

Life expectations are for 2005-7, which is the most recent years for which regional data are available (Table 83).

Table 83 Age-Specific Life Expectations for Auckland Region

Age	Male	Female	Age	Male	Female
0	79.4	83.2	**45**	36.4	39.5
1	78.8	82.6	**50**	31.8	34.8
5	74.9	78.6	**55**	27.3	30.2
10	69.9	73.7	**60**	23.0	25.7
15	65.0	68.7	**65**	18.9	21.4
20	60.2	63.8	**70**	15.0	17.3
25	55.4	59.0	**75**	11.6	13.5
30	50.7	54.0	**80**	8.7	10.0
35	45.9	49.2	**85**	6.5	7.3
40	41.1	44.3			

Source: Statistics NZ. Auckland Region Abridged Life Table, 2005–07

Because these values are for a specific age, eg the 50.7 years is the life expectation for a person aged 30, we need to convert these into life expectations for age categories. We assume that there is a straight line fall in life expectation between ages to calculate the life expectation of the mid-point of the age classes: 32, 37, 42 etc. For age 85+ we take the weighted average age of those aged 85 and above in Auckland (88 for males; 89 for females) as the midpoint and simply subtract the difference from 85 to produce life expectation; this is a reasonable approximation.

Table 84 Life expectation by age category (Auckland region)

Age	Male	Female
0	79.4	83.2
30-34	48.8	52.1
35-39	44.0	47.2
40-44	39.2	42.4
45-49	34.6	37.6
50-54	30.0	33.0
55-59	25.6	28.4
60-64	21.4	24.0
65-69	17.3	19.8
70-74	13.6	15.8
75-79	10.4	12.1
80-84	7.8	8.9
85+	3.5	3.3