Understanding trends in roadside air quality
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Contents

Executive summary

The primary aim of this research was to improve the understanding of how vehicle emissions are trending over time in New Zealand and how this relates to observed trends in local air quality.

Two roadside sites, Auckland and Christchurch, were used as case studies to assess the trends in roadside air quality monitoring from 2003 to 2014. Two pollutants were chosen as tracers of vehicle emissions: carbon monoxide (CO) and oxides of nitrogen (NO_x). Both sites showed similar trends in annual average CO concentrations which decreased consistently over the study period. The available data suggests concentrations of NO_x trended downward for the period 2006 to 2011, but remained relatively stable from 2011 to 2014.

A review of the available vehicle count and high-level fleet composition data for light and heavy duty vehicles at the case study sites suggested that vehicle counts and the light and heavy duty vehicle composition of the fleet were both relatively stable from 2003 to 2014 and therefore unlikely to be significant drivers of changes in air quality.

To assess the trends in on-road vehicle fleet profile and vehicle emissions, 10 days of roadside vehicle emission monitoring were undertaken using the remote sensor device (RSD) in Auckland in February and March 2015. Valid results were collected for approximately 38,600 light duty vehicles (LDVs) and 630 heavy duty vehicles (HDVs). The database was combined with data from previous remote sensing campaigns (2003, 2005, 2009 and 2011) and analysed to assess the trends in on-road vehicle fleet profile and vehicle emissions.

An analysis of the trends in key parameters of the monitored LDV fleet data showed an increase in the average age of LDVs (currently 10.7 years) and in the proportion of diesel vehicles (currently 18%), and a decrease in the proportion of Japanese used vehicles (currently 45%). An analysis of the monitored HDV fleet data showed an increase in the average age of an HDV (currently 12.3 years) and a decrease in the proportion of Japanese used vehicles (currently 48%).

To align with the roadside air quality data, CO and nitric oxide (NO) data from the RSD was used to track trends in vehicle emissions over time. Because vehicles emit NO and nitrogen dioxide (NO_2) in varying ratios, some caution is needed when using NO as a marker to assess trends in vehicle emissions. Despite this limitation, NO was considered a useful marker for the purposes of assessing trends in this study. The analysis of the RSD data showed emissions of CO and NO from the New Zealand LDV fleet decreased significantly between 2003 and 2015. An average vehicle in the Auckland LDV fleet monitored in 2015 emitted approximately half the 2003 CO and NO emission levels. Most of the improvement for fleet average NO emissions occurred prior to 2009; however, in the 2011and 2015 RSD monitoring campaigns the rate of improvement in LDV fleet average NO emissions slowed. Between 2009 and 2015 the average NO emissions for both New Zealand new and Japanese used diesel LDVs increased.

Median emissions of CO and NO from LDVs have also improved since 2003. For petrol vehicles the difference between the mean and the median CO and NO values has widened, suggesting that the impact of gross emitting petrol vehicles on mean emissions has increased. The effect of gross emitting vehicles within the diesel LDV fleet does not appear to have increased.

Relative to 2003, an average HDV in the Auckland monitored fleet in 2015 emitted half the CO and similar levels of NO. The HDV emission data from the RSD monitoring campaigns should be treated only as indicative because the profile of the monitored HDV fleet was significantly different from the national average HDV fleet.

Mean emissions of CO and NO from petrol vehicles reduced significantly with improvements in emissions control technology. Generally, mean emissions of NO from LDV diesel vehicles did not reduce with improvements in emissions control technology. For petrol LDVs, fleet average emissions of CO and NO increased significantly with vehicle mileage, while mileage had no significant impact on CO or NO emissions from diesel LDVs.

The information collected for this study suggests that the underlying causes for the observed downward trend in roadside CO concentrations from 2003 to 2014 were:

- steady traffic numbers, the LDV/HDV fleet composition and driving conditions (neutral pressure)
- reduced CO emissions from both LDV and HDV sectors of the vehicle fleet (downward pressure).

The information collected for this study suggests that the underlying causes for the observed trend in roadside NO_x concentrations from 2003 to 2014 were (in no particular order):

- reduced average emissions from the LDV petrol fleet (downward pressure)
- increased average emissions from the LDV diesel fleet (upward pressure)
- increasing proportion of diesel vehicles within the LDV fleet (upward pressure)
- increasing effect of older and gross emitting LDV petrol vehicles (upward pressure)
- steady traffic numbers, LDV/HDV fleet composition and driving conditions (neutral pressure)
- steady average emissions from the HDV fleet (neutral pressure).

From 2006 to 2010 the downward pressures on roadside NO_x concentrations were greater than the upward pressures, which resulted in an improvement in roadside NO_x concentrations. From 2010 to 2014 it appears the downward pressures were more or less balanced by the upward pressures, which combined to result in relatively stable roadside NO_x concentrations.

It is recommended that ongoing RSD monitoring of vehicle emission trends in New Zealand is continued. The main reasons for this recommendation include:

- The data collected by the RSD is suitable for tracking vehicle emission trends and will help address the relevant environmental enduring question from the transport domain plan.
- New Zealand (via the National Institute of Water and Atmospheric Research (NIWA)) has the equipment and expertise to undertake RSD monitoring programmes.
- With suitable maintenance the RSD kit should have a reasonably long life, perhaps another 10 years.
- RSD monitoring of vehicle emissions is relatively cost effective.
- There is an extensive back catalogue of data which has provided an excellent benchmark to assess trends in vehicle emissions.
- There are numerous potential spin-off benefits from the RSD data beyond tracking trends over time (eg validation of vehicle emission models).

There is a small number of disadvantages in monitoring trends in vehicle emissions with the RSD, such as a limited ability to capture emissions from HDVs. These disadvantages are noted and recommendations have been made to ensure these shortcomings are addressed in any future vehicle emission monitoring programmes.

Abstract

The primary aim of this research was to improve the understanding of how vehicle emissions are trending over time in New Zealand and how this relates to observed trends in local air quality.

Two sites (Auckland and Christchurch) were used to assess the roadside trends in CO and NO_x concentrations from 2006 to 2014. To assess trends in the on-road vehicle fleet profile and vehicle emissions, 10 days of roadside vehicle emission monitoring were undertaken using the remote sensor device (RSD) in Auckland in February and March 2015.

The information collected for this study suggests the underlying causes for the observed trends in roadside air quality at the case study sites from 2006 to 2014 were most likely (in no particular order):

- reduced average emissions from the LDV petrol fleet (downward pressure)
- increased average NO emissions from the LDV diesel fleet (upward pressure)
- increasing proportion of diesel vehicles within the LDV fleet (upward pressure)
- increasing effect of older and gross emitting LDV petrol vehicles (upward pressure)
- steady traffic numbers, LDV/HDV fleet composition and driving conditions (neutral pressure)
- steady average emissions from the HDV fleet (neutral pressure)

The report recommends continuing RSD monitoring of vehicle emission trends in New Zealand.

1 Introduction

1.1 Background

The potential benefits of new emission control technology, improved fuel quality and other factors such as improved traffic management with regard to vehicle emissions have been widely discussed and are well understood. In theory, as new vehicles replace older vehicles and as fuel gets progressively cleaner, the amount of air pollution discharged per vehicle should be decreasing. However, motor vehicles remain a significant source of air pollution in the urban areas of New Zealand.

Roadside ambient air quality monitoring data (Auckland Regional Council 2009) indicates we may not be realising the anticipated benefits in roadside air quality, which are expected as a result of stricter emissions and fuel standards, and improved vehicle technology for all pollutants.

Vehicle emissions are a complex function of many factors. However, a limited number of key parameters determine the total 'real-world' vehicle fleet emission levels and trends over time. These parameters are as follows:

- total distance in vehicle kilometres travelled (VKT), and number and length of individual trips
- fleet profile (fuel, engine and vehicle types, penetration of emission control technology)
- driving conditions (congestion, urban structure, road type and gradient)
- real-world emission performance of vehicles (effectiveness of emission control technology, fuel quality).

Real-world performance relates to the actual emissions from everyday use of vehicles, which differs substantially from those emissions measured using legislative test procedures (see Joumard et al 2000, for example). This difference in real-world emissions versus those measured in a test procedure environment could be one of the reasons for lower than expected improvements in vehicle roadside air quality. This is particularly important where expected improvements in air quality are derived from changes in vehicle emissions standards evaluated in a test procedure environment rather than in real-world conditions. It is therefore important to obtain accurate emissions data for real-world conditions.

1.2 Research purpose

The primary purposes of this research were to improve our understanding of how vehicle emissions are trending over time in New Zealand and abroad; how this relates to observed trends in local air quality; and to determine the effect that each of the key parameters listed in section 1.1 may have on roadside ambient air quality.

Understanding how the overall fleet emissions are changing over time is critical because it will determine whether the current vehicle emissions management policies and practices are likely to result in air quality goals for the region being met in the short-to-medium term.

This information can be used by the NZ Transport Agency (the Transport Agency) and the Ministry of Transport (MoT) to make better targeted and cost-effective decisions for regulating the vehicle fleet to manage air pollution. The information can then be used by the Ministry for the Environment (MfE) and regional councils for integrated environmental planning. Findings from the research may also be used for land-use planning by territorial authorities, and assessment of projects by road controlling authorities and regulators.

1.3 Research objectives

The key to the success of this project was to obtain and use the best available information on roadside air quality and the four key variables that determine total real-world vehicle emission levels over time. This required the project to achieve the following research objectives:

1. Identify and review international and New Zealand specific data that can be used to better understand current trends in vehicle emissions and local air quality concentrations near roadways.
2. Determine first order trends in roadside ambient air quality data by obtaining and analysing data for the years 2003 to 2014.
3. Undertake a roadside emission monitoring programme to supplement the existing remote sensing device (RSD) vehicle emission monitoring datasets (2003 to 2011).
4. Determine the first order trends in vehicle feet composition and emissions by analysing the existing (2003 to 2011) and new (2014/15) RSD vehicle emission data.
5. Report on the likely underlying causes for the trends observed in vehicle emissions and roadside ambient air quality.
6. Review and recommend a method for undertaking the on-going monitoring of vehicle emission trends.

1.4 Overview of method

Five principal tasks formed the proposed method for this project:

1. Review available local and international literature.
2. Determine trends in roadside ambient air quality data from 2003 to 2015 at two case study sites.
3. Undertake roadside monitoring of vehicle emissions and update the RSD vehicle emission database.
4. Determine trends in vehicle fleet characteristics and emissions from 2003 to 2015.
5. Establish the causes and quantify the relative impacts of the key parameters on the observed trends in vehicle characteristics and roadside ambient air quality.

1.5 Project outputs

The deliverables from this project consisted of the following outputs:

1. A comprehensive data set of approximately 14,000 individual vehicle emission measurements, supplemented with vehicle characteristics. The 2015 RSD and vehicle data would be integrated into the existing long-term RSD database.
2. A detailed report describing the project and its implications, with a focus on the Transport Agency’s priority research questions and the project’s objectives.
3. An end-user workshop presenting the results of the project.

1.6 Structure of the report

The report is structured as follows:

- Research objective 1:
  - chapter 2 provides a summary of the international literature review and presents the New Zealand literature review.
- Research objective 2:
  - chapter 3 describes two cases studies of trends in roadside air quality.
- Research objective 3:
  - chapter 4 provides an overview of the previous and 2015 roadside vehicle emission monitoring campaigns.
- Research objective 4:
  - chapters 5 and 6 detail the 2015 monitored light and heavy duty fleet profiles, respectively
  - chapter 7 explains how the vehicle emission data is presented
  - chapters 8 and 9 discuss the trends in the vehicle emissions from 2003 to 2015 for the monitored light and heavy duty fleet profiles, respectively
  - chapter 10 investigates the effect of vehicle emission standards on vehicle emissions
  - chapter 11 evaluates the effect of odometer reading on emissions.
- Research objective 5:
  - chapter 12 explains the trends observed in roadside air quality using the findings from the analysis of vehicle emission data.
- Research objective 6:
  - chapter 13 reviews the methods available for undertaking the on-going monitoring of vehicle emission trends
  - chapter 14 presents the overall conclusions
  - chapter 15 makes recommendations for future work.

2 Literature review

The information presented in this section addresses research objective number 1:

- Identify and review international and New Zealand specific data that can be used to better understand current trends in vehicle emissions and local air quality concentrations near roadways.

2.1 International literature review

This section presents a summary of the key points established in the international literature review which was undertaken for this project. The full review is contained in appendix A.

2.1.1 Methods

Accurate quantification of trends in vehicle emissions is complicated. Direct measurement of real-world vehicle emissions at fleet level in local, regional or national road networks is not possible due to the large number of on-road vehicles with different fuels, engine and emission control technology, the variation in driving conditions and variation in many other aspects that influence emissions.

As a consequence of the complications associated with the direct measurement of vehicle emissions, trends are commonly quantified and examined by means of vehicle emission models, as demonstrated by the international literature review. Vehicle emissions model simulation provides a fast and effective means of assessing motor vehicle emission levels trends. However, establishing the accuracy of these assessments is a challenge. Therefore, methods other than modelling are used to estimate or verify trends. They include dynamometer and on-board emission testing, tunnel measurements, remote sensing and near-road air quality measurements.

Each method has its own strengths and weaknesses. For instance, models typically reflect up-to-date knowledge and ensure consistency and comparability for trend analysis. However, they may be derived from small empirical datasets. As a consequence, various assumptions are required whose presence and effect are generally not immediately clear to model users. For example, recent evidence suggests that the use of ratios of emission standards to correct emission factors for new or future technologies is a method prone to significant errors in trend analysis.

On the other hand, remote sensing, tunnel and near road air quality measurements are typically restricted to a limited number of specific locations and traffic conditions. They can be significantly influenced by other emission sources or variation in topography and meteorological conditions. In addition, the choice of location will determine the relative importance of different types of emissions (eg hot running, cold start, non-exhaust).

2.1.2 Trend analysis in international literature

The international literature confirmed that a large number of factors affect total emission levels. All of these factors and their changes over time need to be accounted for and include:

- vehicle activity
- fleet composition
- driving and traffic conditions
- emission mitigation measures
- in-use deterioration and tampering.

International vehicle emission trend studies generally predict significant, ongoing and varying reductions in on-road vehicle emissions for legislated pollutants around the world, despite continued growth in total travel. China is an exception, where very strong growth in vehicle travel may offset reduced emission factors in the near future, with expected increases in total vehicle emission levels. Predicted emission reductions are most pronounced for carbon monoxide (CO) and volatile organic compounds (VOCs), and less pronounced for oxides of nitrogen dioxide (NO_x) and particulate matter (PM).

Increasing motor vehicle emissions have been reported for nitrogen dioxide (NO_2) in western countries due to increasing proportions of primary NO_2 in vehicle exhaust of particular diesel vehicle classes. Whereas petrol vehicles generally show significant and ongoing reductions in emissions of CO, hydrocarbons (HC) and NO_x, diesel vehicles have shown stable or even increasing emission levels for NO_x and NO_2 on a g/km basis.

The majority of international trend studies focus on legislated pollutants, and only a few studies also discuss other pollutants such as heavy metals and poly-aromatic hydrocarbons.

2.1.2.1 Discrepancies in international literature

Although some studies show reasonably consistent results between model predictions and near road measurements for various pollutants, this is not always the case. Some studies show that ambient concentrations increased over time, whereas (computed) emission trends predicted substantial reductions. This demonstrates that vehicle emission modelling results need to be verified with independent datasets, which often include empirical measurements.

2.1.2.2 Possible explanations for discrepancies

Care is required when comparing ambient monitoring directly with vehicle emission estimates, as there are several other factors that significantly affect ambient air quality monitoring results, such as emissions from other sources and variations in year-to-year meteorology. Therefore, predicted downward trends in vehicle emissions do not necessarily mean that air quality is similarly affected and that air quality criteria will be met in the future.

The literature review showed that the relative importance of road traffic emissions, and hence the impact on local air quality, can vary substantially between countries due to differences in on-road fleets, fuel quality, climate and local industry profiles. Because of this, it is important to have accurate estimates of background air quality, which will be influenced by emissions from sources other than road transport, such as shipping and industry, to put trends in motor vehicle emissions into perspective. It is noted that total motor vehicle emissions can be small compared with other sources in the airshed; however, they can still generate significant (local) air quality and health impacts due to the proximity of motor vehicles to urban populations.

The discrepancy between legislative standards and real-world vehicle emissions may be the main reason for ‘disappointing’ air quality improvements in relation to expectations based on progressively stricter tail-pipe emission standards.

Measurement location determines the relative importance of different types of vehicle emissions (hot running, cold start, non-exhaust), which themselves can increase or decrease fleet average emissions. It is possible these factors interact at local measurement level to generate trends that are different from those expected from (total) vehicle emission modelling. Reductions in non-exhaust and cold start emissions are smaller than reductions in hot running emissions, or can even increase. Consequently, the New Zealand fleet mix and its changes over the past 10 years may to some extent explain the ‘less than expected’ reductions in emissions on a per vehicle basis (g/VKT).

The literature also indicates that in-use deterioration of vehicle emissions may be underestimated in current and commonly used emissions models, leading to inaccurate prediction of trends.

There is also an additional complexity in assessing motor vehicle emission trends for chemically reactive pollutants such as NO_2 and PM (atmospheric chemistry and formation of secondary air pollutants). This is more of an issue at the airshed or road network level than at roadside locations because it takes time for these reactions to occur.

2.2 New Zealand literature review

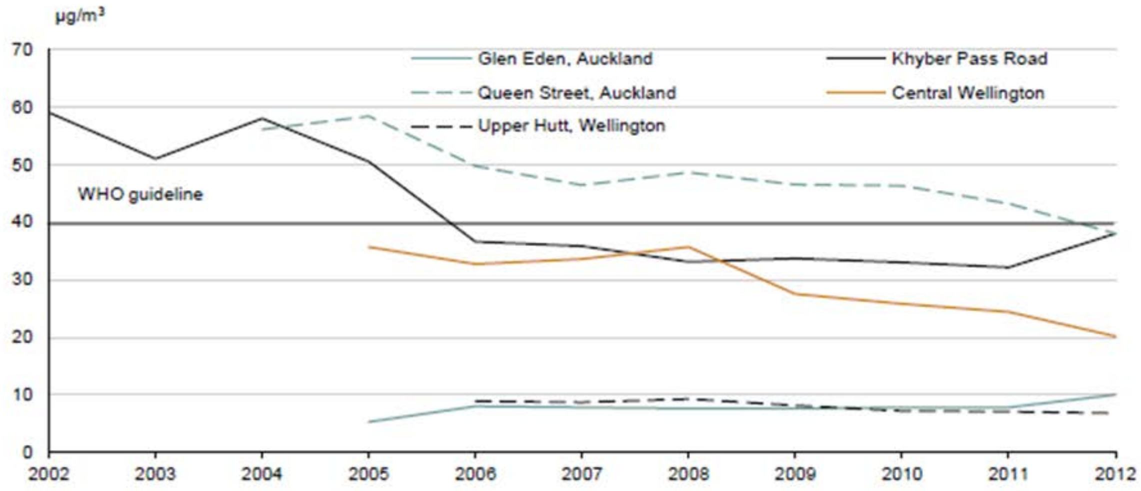
2.2.1 Observed trends in roadside air quality

The key indicator currently used by MfE and regional councils to assess roadside air quality in New Zealand is NO_2. This pollutant has been monitored at a number of locations around New Zealand since 1998. The MfE's (2014) air domain report presents a summary of annual average NO_2 concentrations (figure 2.1) monitored at three sites in Auckland and one site in Wellington from 2002 to 2012. Two types of sites are represented:

- 'peak sites' (where concentrations are expected to be high, such as busy transport sites – Queen Street and Khyber Pass Road in Auckland, and central Wellington)
- 'background sites' (where concentrations are expected to be low, such as urban areas away from busy roads – Glen Eden, Auckland and Upper Hutt, Wellington).

MfE concludes that at Khyber Pass Road, Queen Street and central Wellington, concentrations of NO_2 have decreased since monitoring began. These decreases are most likely a result of land-use planning and traffic control initiatives, including the introduction of pedestrian precincts and vehicle flow diversion. In contrast, concentrations at Glen Eden and Upper Hutt have remained low and relatively constant.

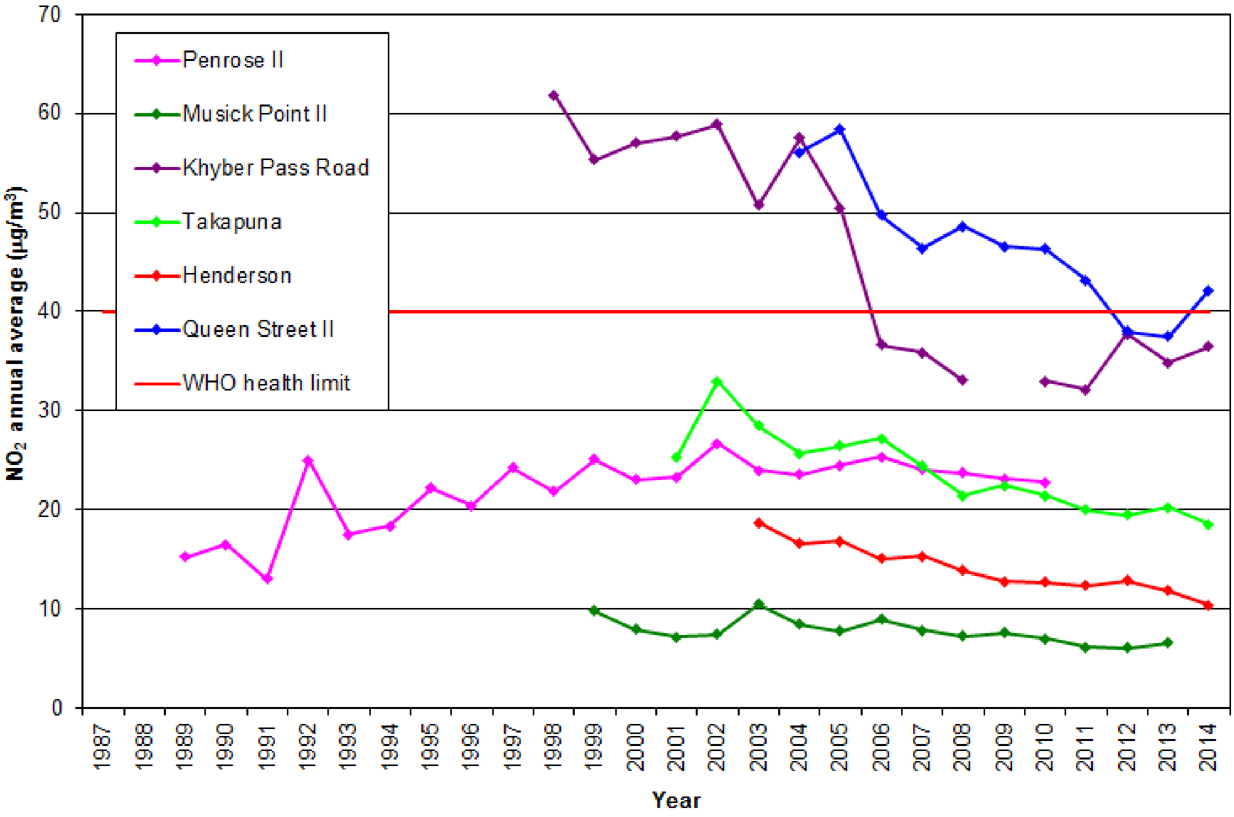
Figure 2.1 Annual average NO_2 concentrations – selected locations 2002 to 2012



Source: (MfE 2014)

Auckland Council's report on the health of Auckland's environment report (AC 2015) presents a summary of the NO_2 monitoring undertaken in Auckland from 1996 to 2014 (figure 2.2). AC (2015) concludes that over the last decade the monitoring data shows decreases in NO_2 concentrations at all peak and background sites in Auckland. AC (2015) notes that the decreasing levels of NO_2 at Queen Street are due to a council planning project which diverted traffic away from pedestrian areas.

Figure 2.2 Annual average NO_2 concentrations monitored in Auckland 1996–2014

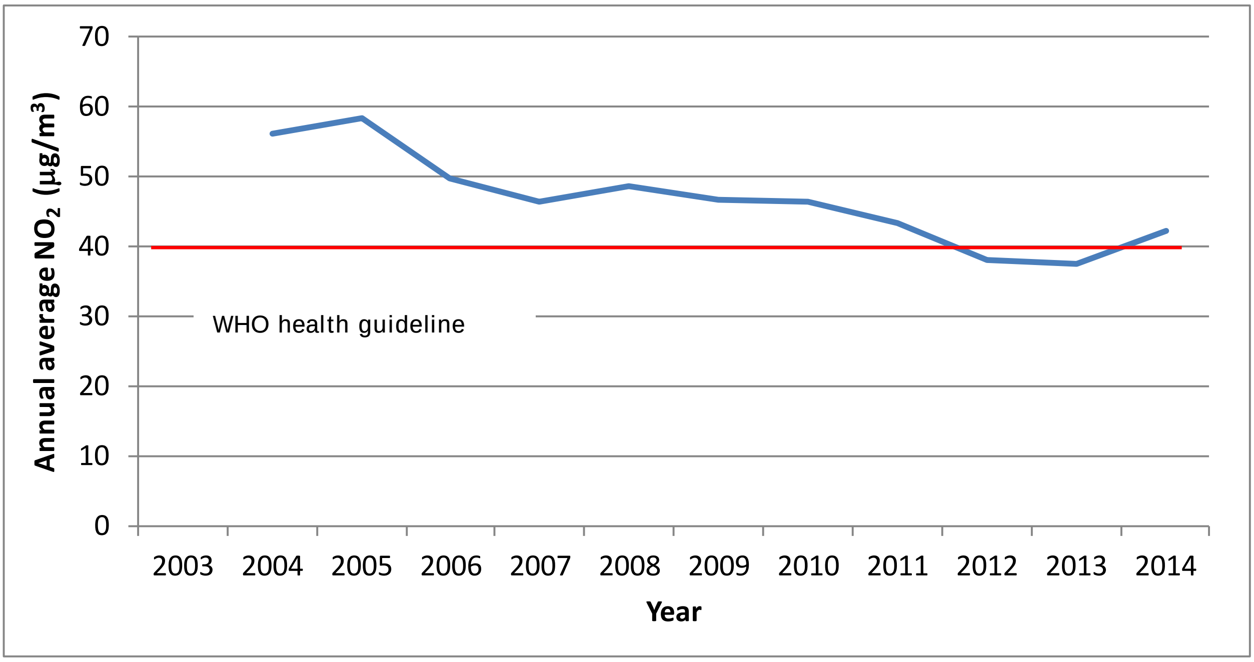


Source: AC (2015)

The annual average concentrations for NO_2 at Queen Street and Khyber Pass Road and the results of this updated analysis are presented in figures 2.3 and 2.4 respectively.

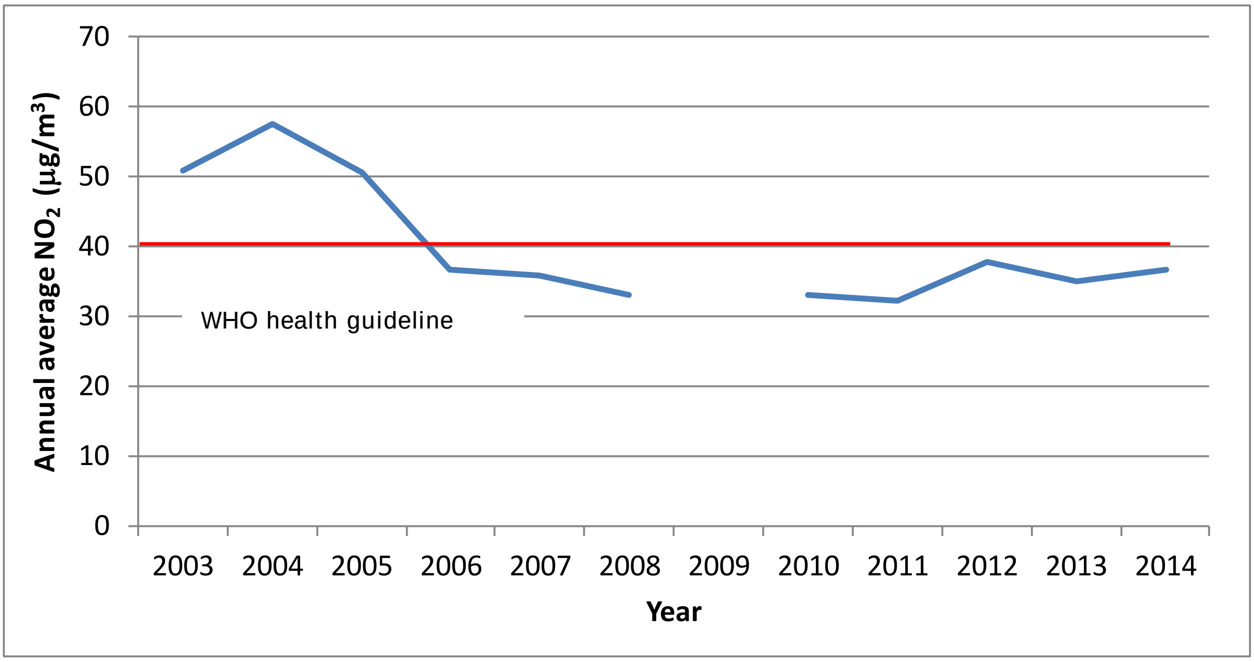
Figure 2.3 shows that annual average NO_2 concentrations at Queen Street declined steadily from 2005 to 2012, remained constant in 2013 and then increased slightly in 2014. Figure 2.4 shows there was a steep decline in annual average NO_2 concentrations between 2004 and 2006, and from 2006 to 2014 the annual average NO_2 concentrations were reasonably steady at around 35μgm^{-3}.

Figure 2.3 **Annual averages NO_2 concentrations and Queen Street 2004–2014**



Source: AC (2015)

Figure 2.4 **Annual averages NO_2 concentrations Khyber Pass Road 2003–2014**



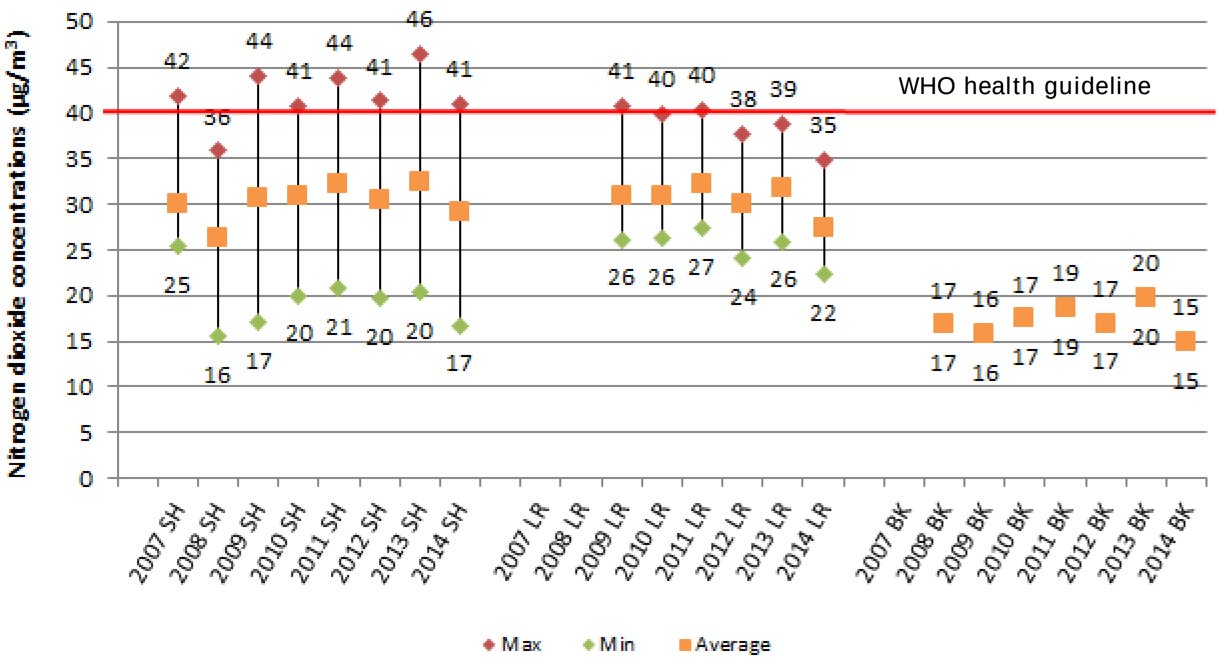
Source: AC (2015)

In 2007 the Transport Agency established a network of passive NO_2 monitors at roadside and background sites around the country. Details of the NO_2 monitoring network and summary results are presented in *Ambient air quality (nitrogen dioxide) monitoring network – annual report 2007 to 2014* (NZ Transport Agency 2015). The Transport Agency undertook a detailed analysis of NO_2 concentrations monitored at these passive monitoring sites from 2007 to 2012 (Hannaby and Kuschel 2013). This report concluded that across all of the monitored sites with complete data records (36 in total) annual average NO_2

concentrations in 2012 were 15% higher on average than in 2007, but results between 2010 and 2012 showed a 1% reduction on average. For the sites with complete data records, annual average NO_2 concentrations in 2012 increased by 15% on average versus 2007 but reduced by 1% on average between 2010 and 2012. Hannaby and Kuschel (2013) noted that the recent plateauing or reduction in average concentrations may reflect the impact of improvements in vehicle technology or may be a result of the state of the economy influencing vehicle movements or both.

Figure 2.5 shows trends in the annual average NO_2 concentrations from 2007 to 2014 for sites contained within the central Auckland monitoring zone.

Figure 2.5 Annual average NO_2 concentrations 2007–2014. SH = state highway, LR = local road, BK=background



Source: NZ Transport Agency (2015)

Figure 2.5 indicates that the annual average concentrations of NO_2 at state highway, local road and background sites in central Auckland were consistent over the eight years studied in this analysis.

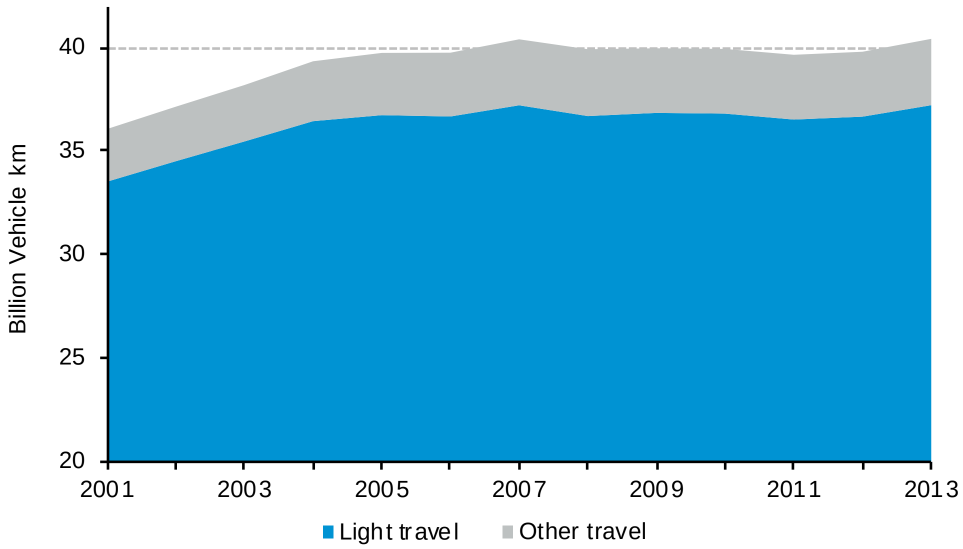
In summary, annual average NO_2 concentrations at a number of typical and key roadside sites have remained relatively constant over the last 10 years. However, for two central business district sites, Queen Street, Auckland and central Wellington, a steady and significant decline occurred from 2005 to 2013.

2.2.2 Trends in the vehicle fleet

2.2.2.1 Kilometres travelled

Vehicle fleet emissions are directly proportional to the number of kilometres travelled, provided that other factors remain the same (fleet mix, fuel quality, etc). Total travel is therefore an important variable in relation to total vehicle emissions. MoT (2014) provides an analysis of the VKT per annum by New Zealand's vehicle fleet. The MoT estimate of VKT is derived from the change in warrant of fitness (WoF) and certificate of fitness (CoF) odometer readings as recorded on the Transport Agency's vehicle register. Figure 2.6 shows VKT in New Zealand from 2001 to 2013.

Figure 2.6 Vehicle kilometres travelled in New Zealand- 2001-2013



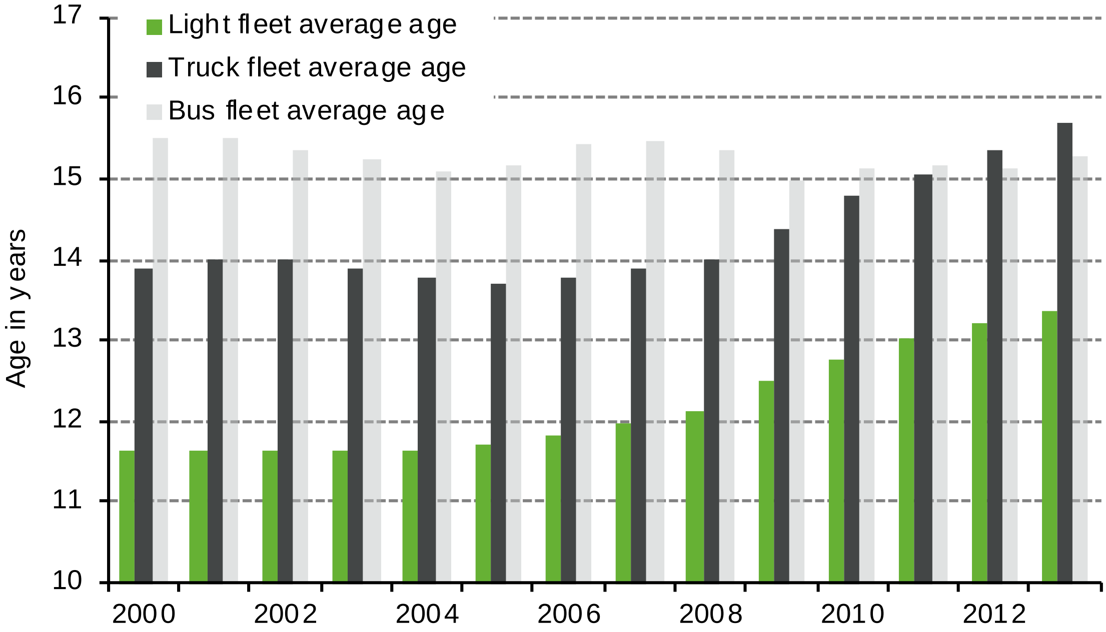
Source: MoT (2014)

MoT concludes the total annual travel in New Zealand was increasing until 2007 (up 12% from 2001 to 2007), but between then and 2012 three periods of high oil prices and the economic downturn saw a slight fall in travel (down 1.5% from 2008 to 2012). Travel was up 1.6% between 2012 and 2013 with total annual travel in 2013 back to the peak level of 2007. The major cause of this recovery was attributed to economic and vehicle fleet growth. The light fleet increased by 2.9% between 2012 and 2013 – the substantial number of New Zealanders returning home from working overseas was one of the reasons for the high level of vehicle registrations.

2.2.2.2 Mean vehicle age

The age distribution of the on-road fleet affects total emissions. Vehicle age reflects two important factors with respect to vehicle emissions: 1) engine and emission control technology; and 2) deterioration in emission performance over time. MoT (2014) provides a detailed analysis of the average age of vehicles in New Zealand's fleet. Figure 2.7 shows the average age of New Zealand's LDVs, trucks and buses from 2000 to 2013.

Figure 2.7 **Average age of New Zealand's light duty vehicles, trucks and buses, 2000–2013**



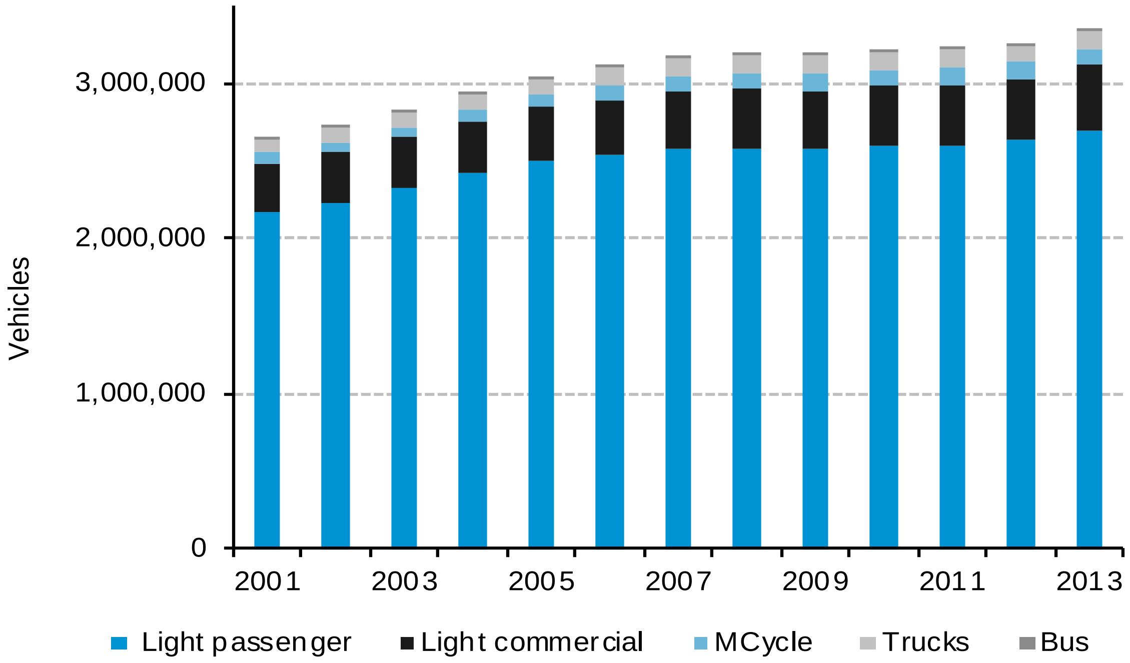
Source: MoT (2014)

Figure 2.7 shows the average age of New Zealand's LDVs, trucks and buses in 2013 was 13.4, 15.7 and 15.3 years, respectively. Figure 2.7 also shows the average age of New Zealand's LDVs and trucks increased from 2000 to 2013 while the average age of buses remained relatively steady.

2.2.2.3 Trends in vehicle fleet composition

Emission profiles can vary significantly with the type of vehicle. The fleet composition is therefore an important variable affecting total vehicle emissions. MoT (2014) provides an analysis of the composition of New Zealand's vehicle fleet. Figure 2.8 shows the basic composition of New Zealand's vehicle fleet from 2001 to 2013.

Figure 2.8 Composition of New Zealand's vehicle fleet 2001–2013



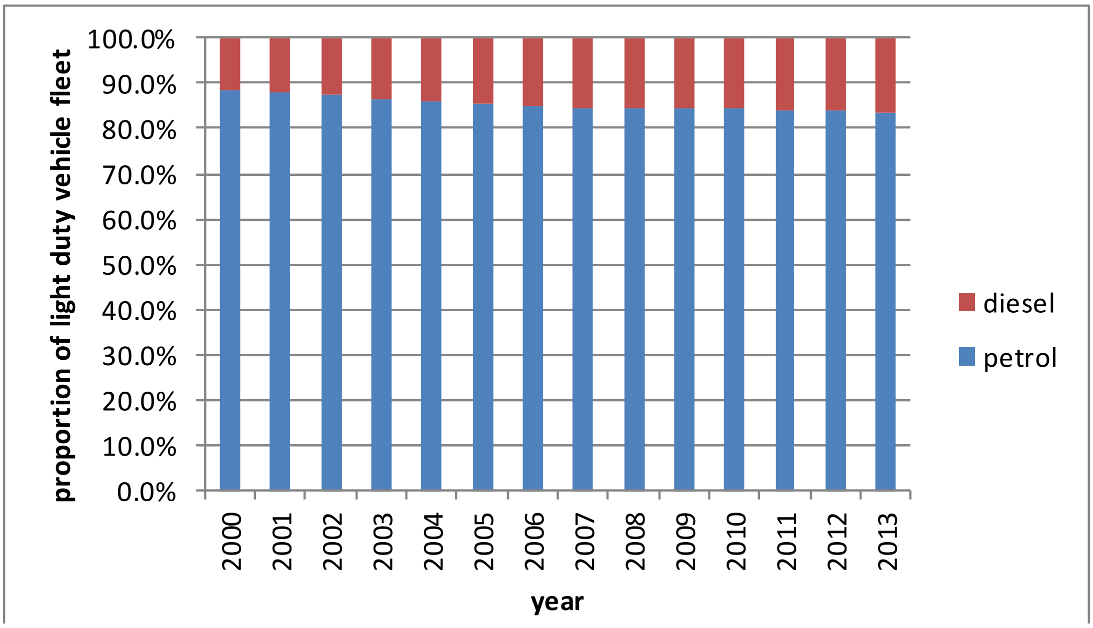
Source: MoT (2014)

Over 90% of the total vehicle fleet is composed of cars, vans, utes, four wheel drives, sports utility vehicles (SUVs), buses and motor caravans under 3.5 tonnes . MoT (2014) concludes that the light fleet grew by 19% between December 2000 and December 2006 but only by 4.4% from December 2006 to December 2012. Growth was 2.9% in 2013 reflecting the high numbers of registrations. MoT also concludes that the light fleet is not the fastest growing segment of the fleet. Bus numbers have increased by 70% since December 2000 and motorcycle/moped numbers have increased by 60%.

2.2.2.4 Trends in fuel type

Emission profiles can vary significantly with the type of fuel. The different fuel types used within the fleet are therefore an important variable affecting total vehicle fleet emissions. MoT (2014) provides an analysis of the composition of New Zealand's vehicle fleet. Figure 2.9 shows the proportion of the LDV fleet that used petrol and diesel fuel for the years 2000 to 2013. It also shows that the proportion of the LDV fleet using diesel increased from 11.6% in 2000 to 16.7% in 2013. Most of this increase occurred from 2000 to 2006; however, in 2012 and 2013, the proportion of the LDV fleet using diesel increased by a further 1%.

Figure 2.9 Breakdown of the light duty vehicle fleet by fuel type 2000–2013



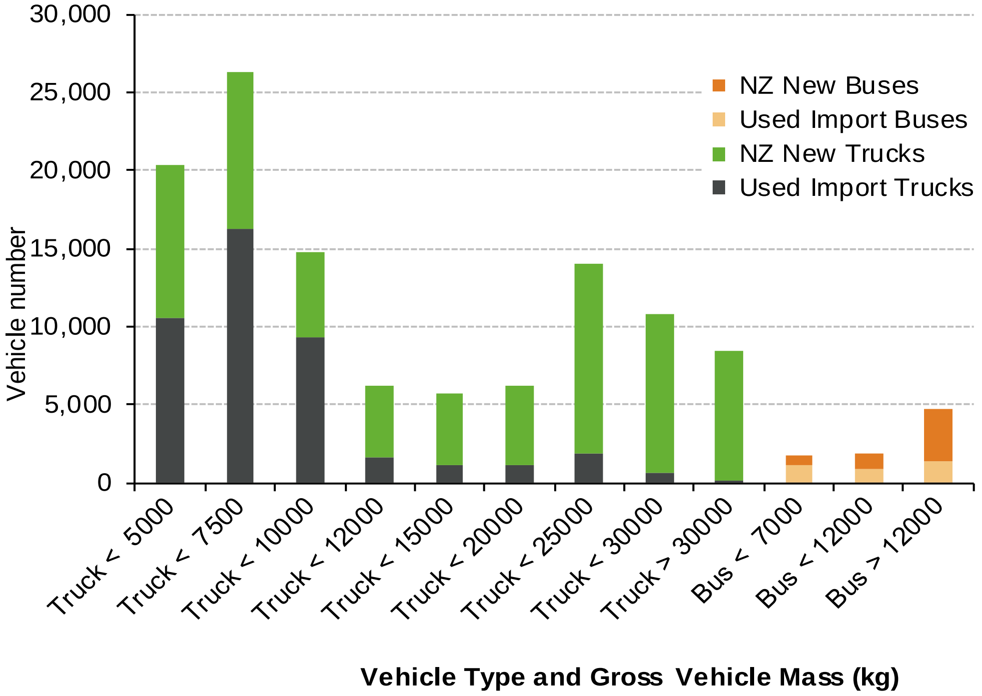
Source: MoT (2014)

2.2.2.5 Profile of heavy duty vehicle fleet

HDVs are defined as vehicles with a gross vehicle mass greater than 3,500kg. MoT (2014) provides an analysis of the composition of New Zealand's HDV fleet.

Figure 2.10 shows the composition of New Zealand's HDV fleet in 2013.

Figure 2.10 Composition of New Zealand's heavy duty fleet by vehicle type and gross vehicle mass



Source: MoT (2014)

An analysis of the data displayed in figure 2.10 shows:

- New Zealand's HDV fleet consists of 93% trucks and 7% buses.
- 62% of the HDV trucks are New Zealand new (NZN) and 38% imported used vehicles.
- 41% of the buses are NZN and 59% imported used vehicles.
- 54% of HDV trucks weigh less than 10 tonnes.
- 16% of HDV trucks weigh between 10 and 20 tonnes.
- 30% of HDV trucks weigh greater than 20 tonnes.

2.2.2.6 Vehicle emissions

The MfE and Statistics New Zealand commissioned NIWA in 2014 to produce a report detailing the methodology and results for the national air domain indicators including on-road vehicle emissions.

NIWA (2014) provides a detailed description of how the vehicle emissions were calculated by multiplying the VKT for the vehicle types by the estimated emission factor (from the Vehicle Emissions Prediction Model (VEPM)) for that vehicle class and the corresponding average speed. The report concludes that estimated pollutant emissions from on-road vehicles have decreased over the past 10 years. All key pollutants from on-road vehicles were estimated to have decreased from 2001 to 2012:

- CO down 39%
- NO_x down 36%
- PM_{10} down 25%
- VOC down 49%.

3 Roadside air quality

3.1 Introduction

The information presented in this chapter addresses research objective number 2:

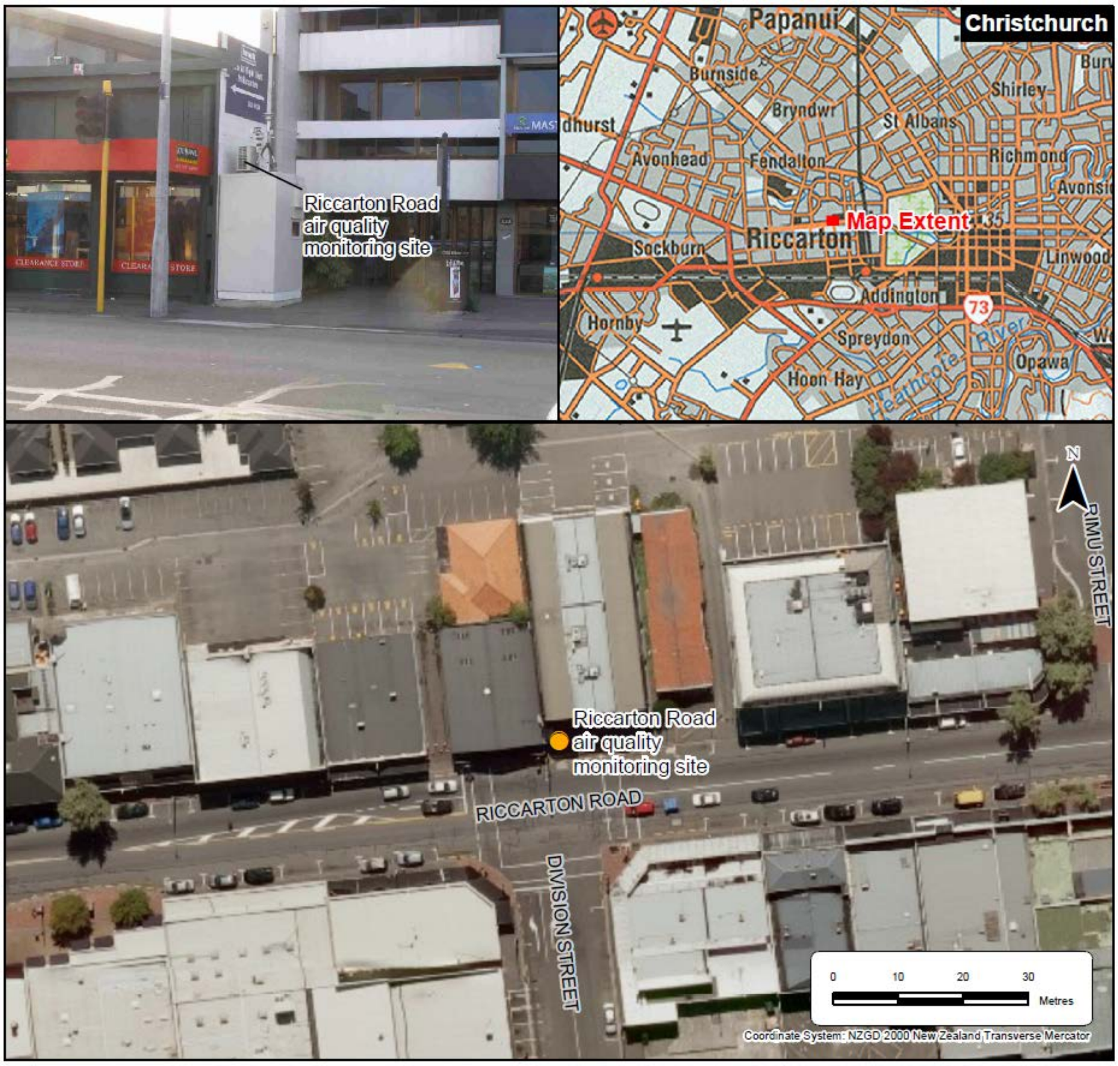
> Determine trends roadside ambient air quality data by obtaining and analysing data for the years 2003 to 2014.

This section presents a description of two roadside air quality sites along with a qualitative assessment of the trends in air quality over time observed at these locations. The vehicle emission data presented in chapters 5 to 12 of this report has been used to identify and explain the underlying causes of the trends in air quality observed at these two sites. For the purposes of this project, two key pollutants, CO and NO_x, were used as indicators of vehicle sourced contaminants.

3.2 Case study 1 – Riccarton Road, Christchurch

Environment Canterbury (ECan) has operated a roadside air quality monitoring site on Riccarton Road since 2006. Details of the site can be found in ECan (2010). The site monitors CO, NO_x and PM_{10} along with meteorological conditions. The methods used to undertake monitoring at this site are consistent with the requirements of the National Environmental Standards – Air Quality and with the good practice methods detailed by the Ministry for the Environment (MfE 2005). The location and photographs of ECan's Riccarton Road air quality monitoring site are shown in figure 3.1.

Figure 3.1 Location and photographs of ECan's Riccarton Road air quality monitoring site



3.2.1 Air quality

Figures 3.2 and 3.3 show the monthly and annual average CO concentrations monitored at Riccarton Road from 2006 to 2014.

Figure 3.2 **Riccarton Road monthly average CO concentrations 2006–2015**

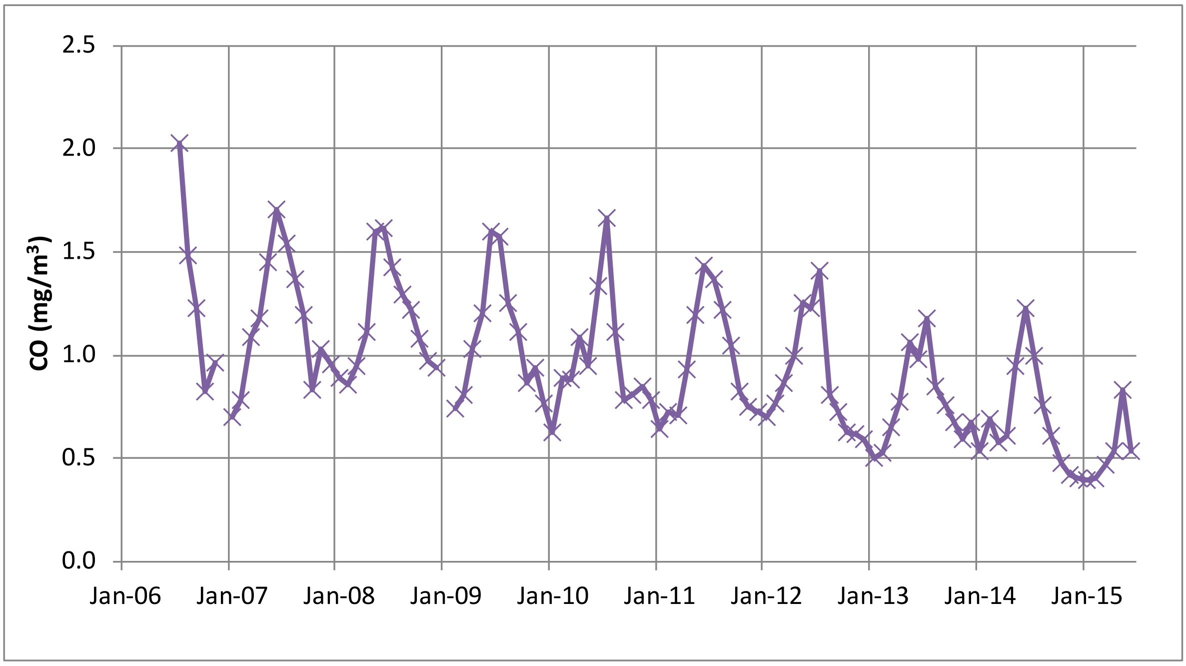


Figure 3.3 **Riccarton Road annual average CO concentrations 2006–2014**

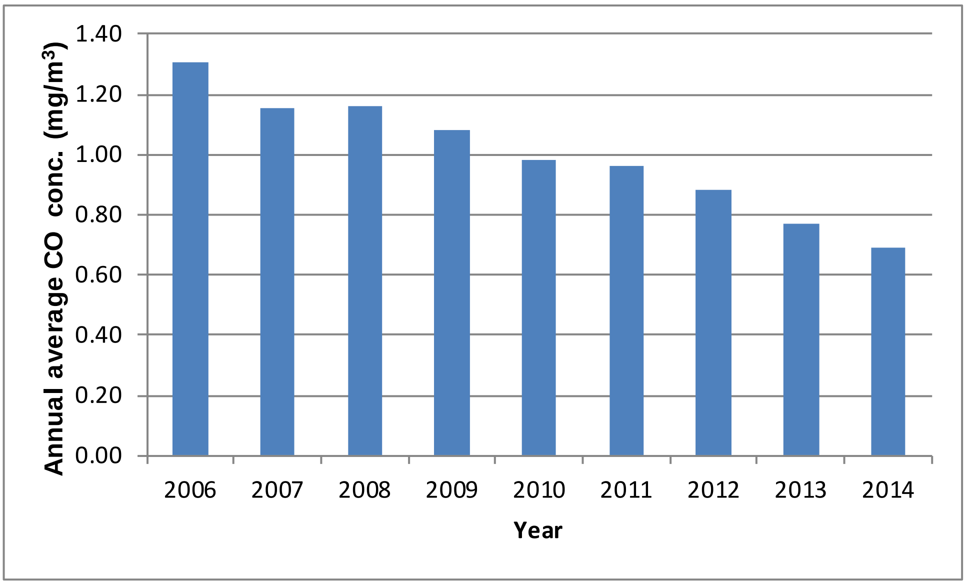
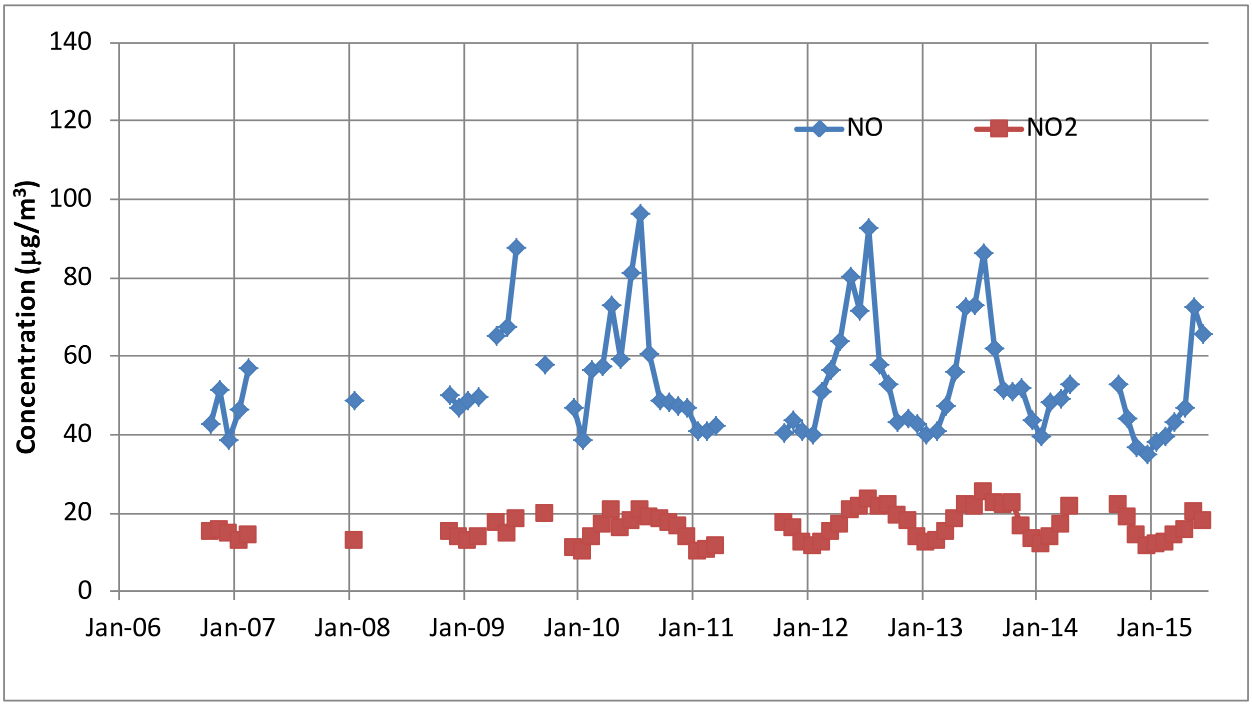


Figure 3.2 shows that CO concentrations follow a seasonal cycle with peak concentrations occurring in the colder months of the year, as would be expected due to a combination of higher cold start emissions and more adverse meteorological conditions. Figure 3.3 suggests a steady trend downward in annual average CO concentrations from 2006 to 2014. In 2006 the annual average CO concentration was 1.3mg/m^3 and in 2014 it was 0.7mg/m^3. This represents a 52% reduction in average CO concentration since 2006.

Figure 3.4 shows the monthly average NO and NO$_2$ concentrations monitored at Riccarton Road from 2006 to 2014.

Figure 3.4 Riccarton Road monthly average NO and NO_2 concentrations 2006–2015



Source: ECan data

Figure 3.4 shows the NO and NO_2 data capture rate is low between 2006 and 2009 and there are significant gaps in the middle of 2009, 2011 and 2014. Despite these gaps in the data, figure 3.4 shows NO and NO_2 concentrations follow a seasonal cycle with peak concentrations occurring in the colder months of the year, as would be expected due to more adverse meteorological conditions. Figure 3.4 indicates that over the longer term NO and NO_2 concentrations are reasonably steady and there is no obvious trend (upward or downward) visible from the chart. Due to insufficient data coverage, a comparison of annual average concentrations cannot be made. However, a review of the NO and NO_2 data shows that between 2006 and 2015 (10 years) the monthly average record is most complete for January (9 data points) and December (8 data points).

Figures 3.5 and 3.6 display the 2006 to 2015 monthly average NO_x concentrations recorded in the months of January and December, respectively.

Figure 3.5 shows average NO_x concentrations for January were reasonably consistent between 2007 and 2009, being slightly above 90µg/m³. In 2010 there was a step down in NO_x concentrations to slightly above 70µg/m³ and January monthly average concentrations remained reasonably constant around this concentration until 2014.

Figure 3.5 **Riccarton Road monthly average NO_x concentrations for the month of January 2006–2014**

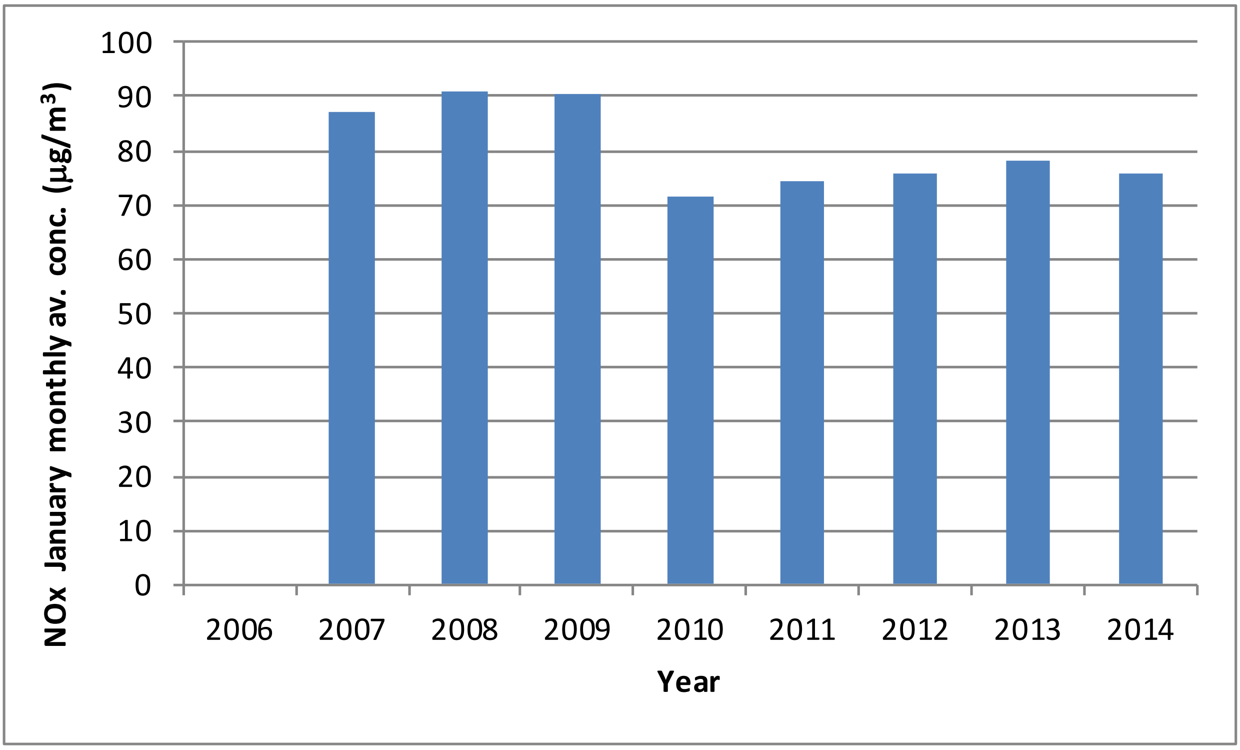


Figure 3.6 **Riccarton Road monthly average NO_x concentrations for the month of December 2006–2014**

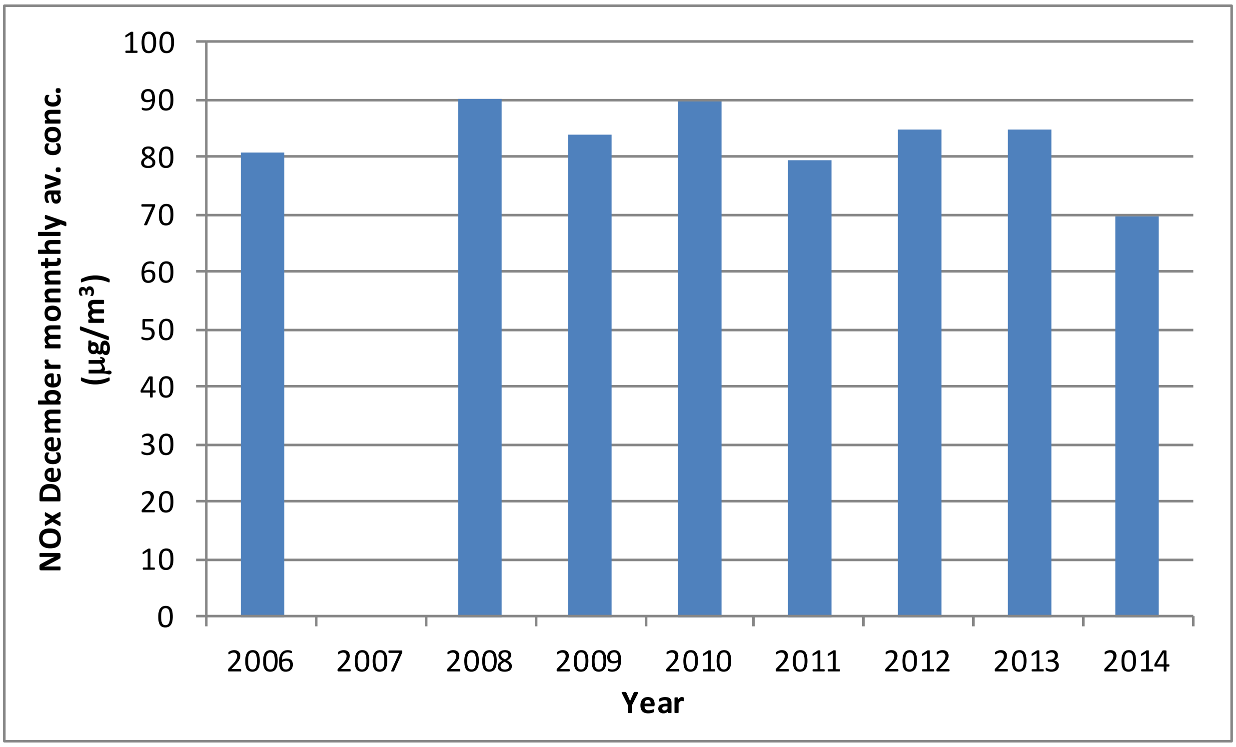


Figure 3.6 shows average NO_x concentrations for December were relatively low in 2006, at around 80µg/m³. Between 2008 and 2013, the December average concentration was reasonably consistent ranging between 84 and 90µg/m³. In 2014 there was a step down in concentrations to 70µg/m³.

As discussed, the Transport Agency began NO_2 monitoring using passive samplers at ECan's Riccarton Road site in 2010. Figure 3.7 shows the Transport Agency's measurements of NO_2 annual, summer (December and January) and winter (June July and August) average concentrations at the Riccarton Road site.

Figure 3.7 Riccarton Road NO_2 annual and seasonal average concentrations (NZ Transport Agency passive monitors)

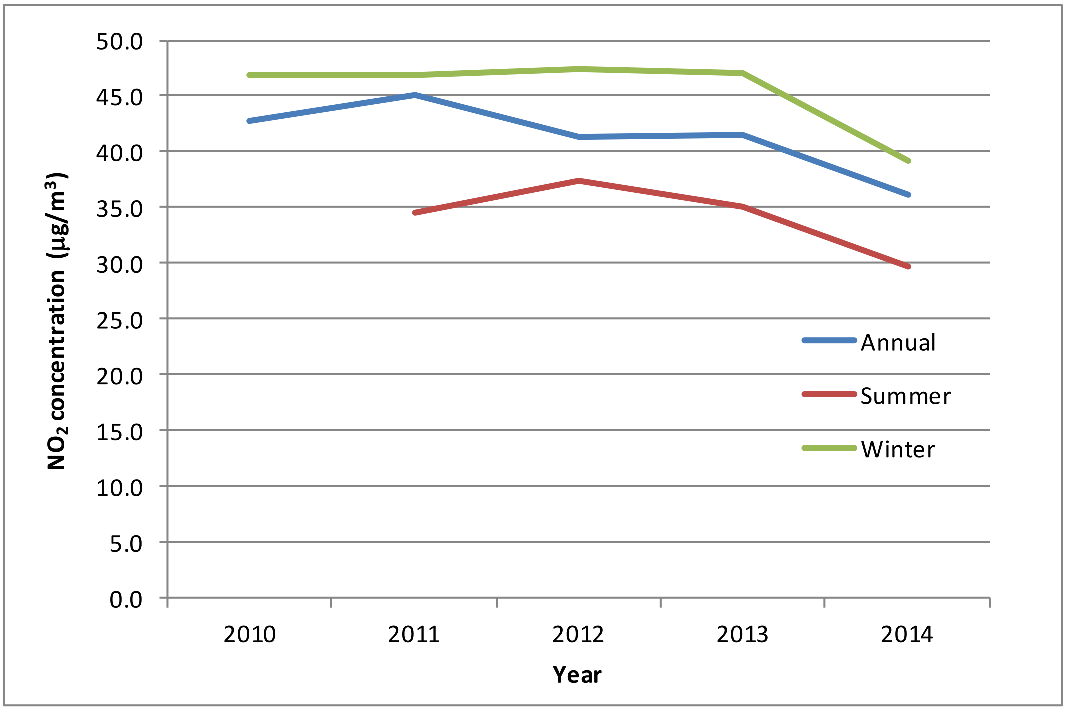


Figure 3.7 shows that from 2010 to 2013 the annual, summer and winter average concentrations were relatively stable at around 42, 35 and 46ug/m3, respectively. The 2014 values for all three averaging periods show a relatively large step downward of approximately 16% in 2014. A preliminary investigation into the 2014 data suggests that at least some of this decrease was likely to be due to a relatively warm winter and windier year.

3.2.2 Vehicle numbers and fleet composition

Christchurch City Council (CCC) collects traffic count data, which is used for road design change and the prioritisation of network improvements. Traffic count data (CCC 2014a) is collected by CCC at various key locations, including controlled and signalised intersections and link roads. For key sites vehicle counts are done every two years. CCC collects traffic count data at a number of locations along Riccarton Road. For the case study, data collected near the railroad crossing approximately 700m east of the air quality monitoring site was used.

The Christchurch Traffic Model (CTM) (CCC 2014b) was used to estimate the fleet composition of the traffic travelling on Riccarton Road. The CTM is a strategic traffic model owned by stakeholders including the Transport Agency, ECan and CCC.

Figure 3.8 shows the vehicle counts for Riccarton Road 1999 to 2013. Figure 3.9 shows the light and HDV composition of the fleet of vehicles using Riccarton Road between 2006 and 2013.

Figure 3.8 Vehicle count on Riccarton Road 1999–2013

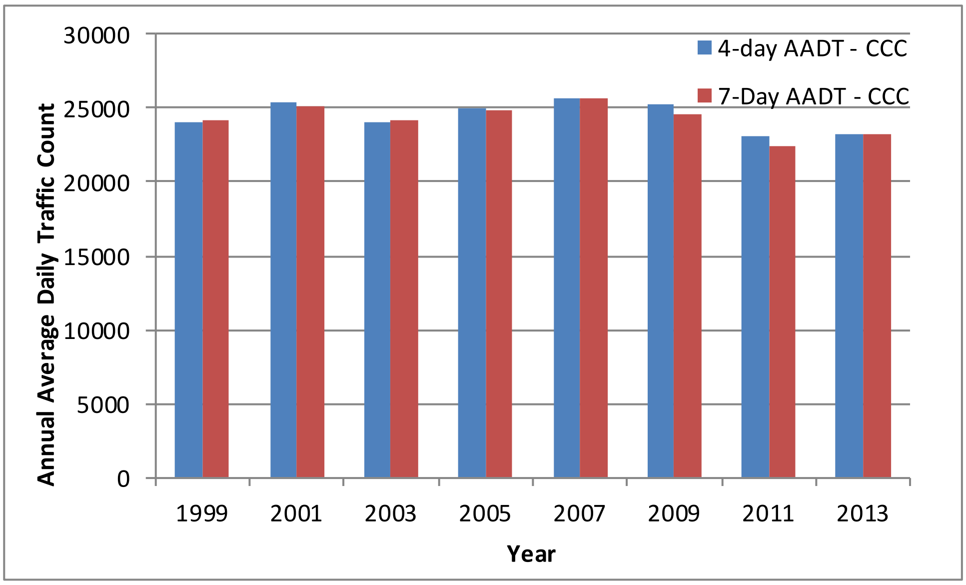


Figure 3.9 Riccarton Road vehicle fleet composition 2006–2013

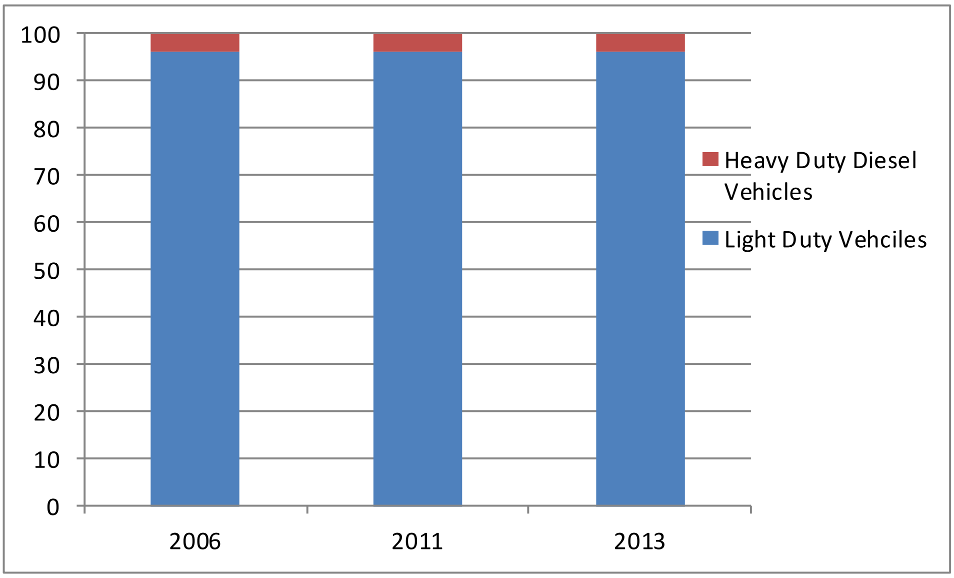


Figure 3.8 shows vehicle counts on Riccarton Road were steady at around 25,000 annual average daily traffic (AADT) between 1999 and 2009. There was an approximate 5% reduction in AADT in 2011 and this lower AADT was maintained in 2013. This reduction in AADT is possibly due to the effect of the Christchurch earthquakes (2010–2011) on suburban populations, and resulting change in the traffic flow.

The CTM (CCC 2014b) data displayed in figure 3.9 suggests that vehicle fleet composition on Riccarton Road remained consistent from 2006 to 2013 with 96% LDVs and 4% HDVs. It is important to note that CTM is only providing high-level fleet composition and does not show the progressive changes in technology and fuel mix within the vehicle classes.

Despite the considerable effort made in obtaining the Riccarton Road vehicle number and fleet composition data there are gaps and uncertainties in the data used for this project. However, the best data available has been used for the project. To improve the outputs of any future programmes, this issue is raised in section 15.2.

3.3 Case study 2 – Khyber Pass Road Auckland

Auckland Council, and its predecessor Auckland Regional Council, have operated a roadside air quality monitoring site at Khyber Pass Road since 1998. Details of the site can be found in AC (2006). The site monitors CO, NO_x and PM_{10} along with meteorological conditions. The methods used to undertake monitoring at this site are consistent with the requirements of the National Environmental Standards – Air Quality and with the good practices methods detailed by MfE (2005). The location and photographs of AC's Khyber Pass Road air quality monitoring site are shown in figure 3.10.

Figure 3.10 Location and photographs of Auckland Council's Khyber Pass Road air quality monitoring site

3.3.1 Air quality

Figures 3.11 and 3.12 show the monthly and annual average CO concentrations monitored at Khyber Pass Road from 2006 to 2014.

Figure 3.11 Khyber Pass Road monthly average CO concentrations 2006–2014

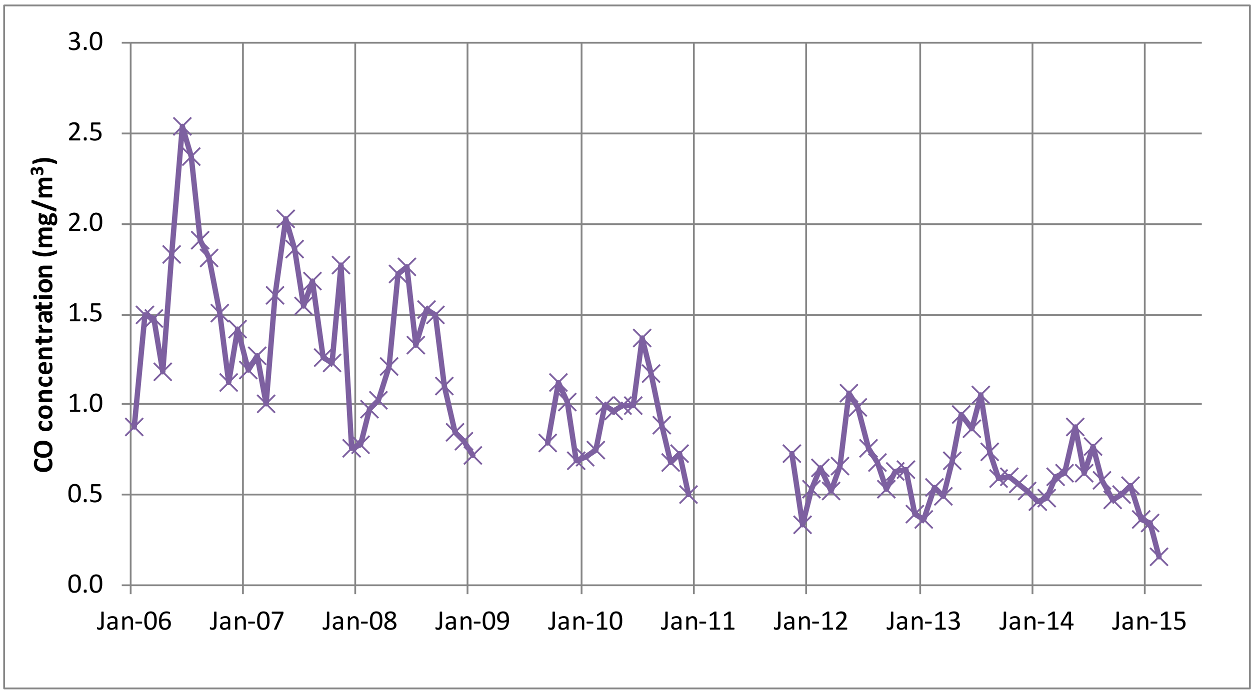


Figure 3.12 Khyber Pass Road annual average CO concentrations 2006–2014

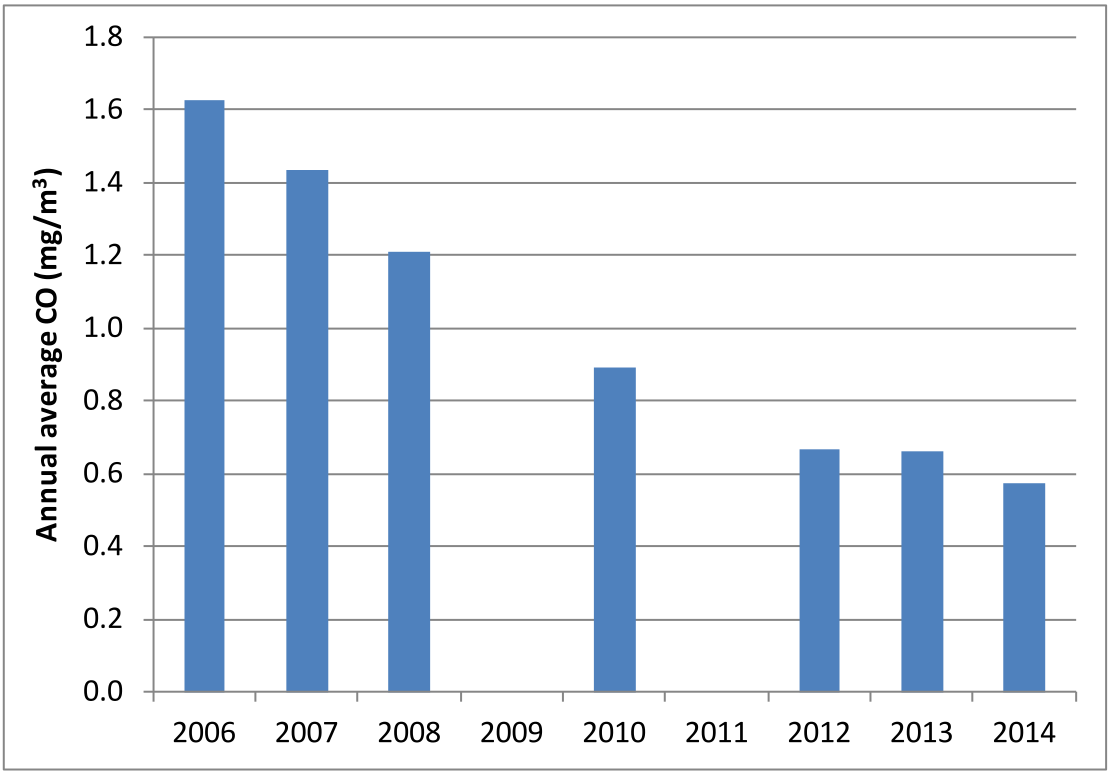
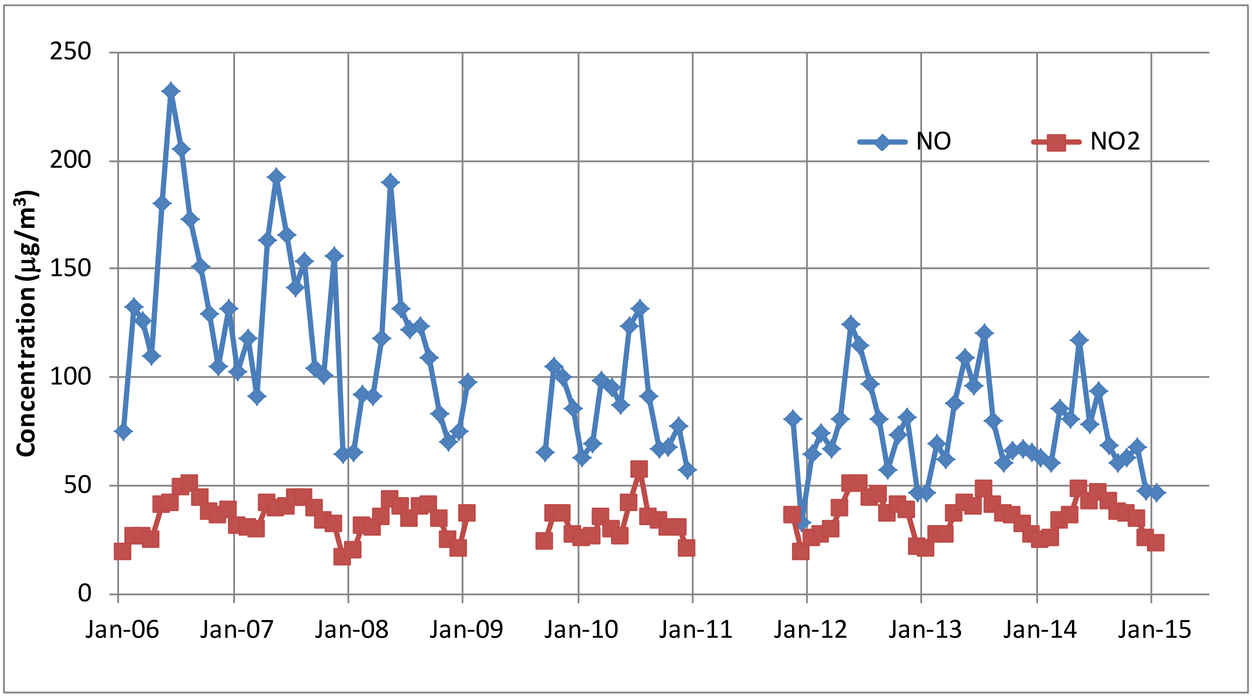


Figure 3.11 shows CO concentrations follow a seasonal cycle with peak concentrations occurring in the colder months of the year. Figures 3.11 and 3.12 show a steady trend downward in annual average CO concentrations from 2006 to 2014. In 2006 the annual average CO concentration was 1.6mg/m^3 and in 2014 it was 0.6mg/m^3. This represents a 63% reduction in average CO concentration since 2006.

Figure 3.13 shows the monthly average NO and NO_2 concentrations monitored at Khyber Pass Road from 2006 to 2014. Figure 3.14 shows the annual average NO concentrations monitored at Khyber Pass Road from 2006 to 2014.

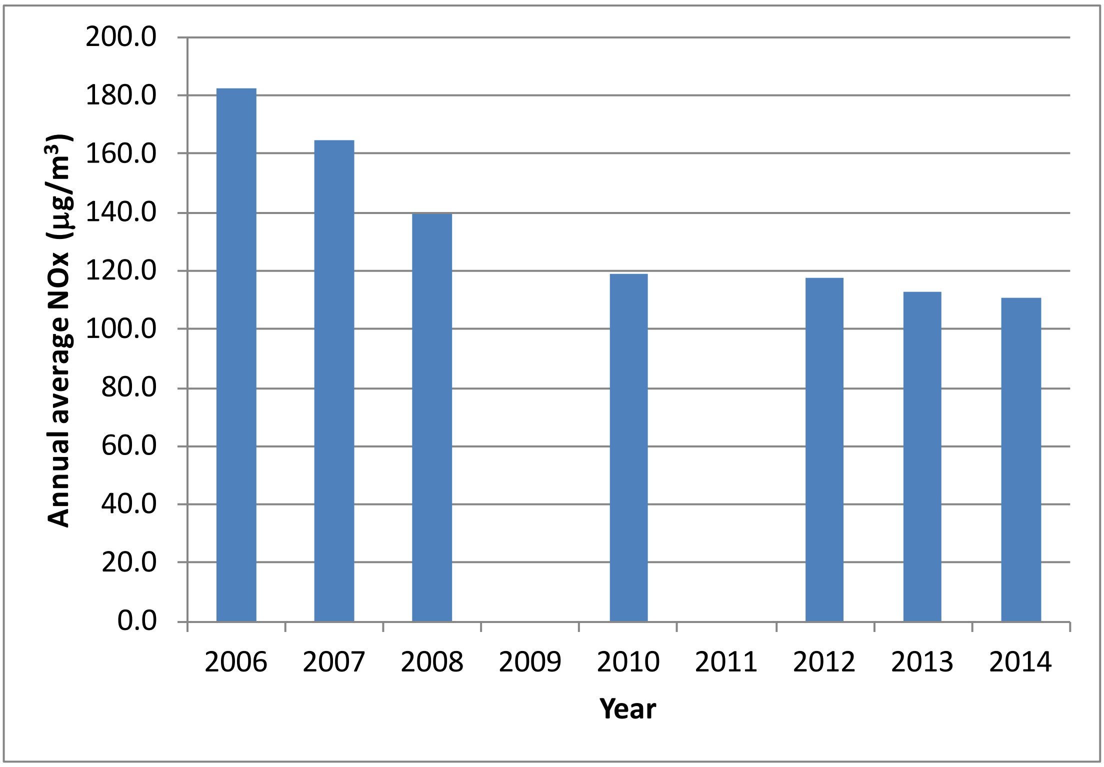
Figure 3.13 shows NO and NO_2 concentrations follow a seasonal cycle with peak concentrations occurring in the colder months of the year. Figures 3.13 and 3.14 show a steady trend downward in annual average NO_x concentrations from 2006 to 2010. Figure 3.14 shows the reduction in NO_x concentrations slowed significantly from 2010 to 2014. In 2006 the annual average NO_x concentration was 180µg/m^3 and in 2014 it was 110µg/m^3. This represents a 40% reduction in annual average NO_x concentration since 2006. However, almost 90% of this reduction occurred between 2006 and 2010. Since 2010, annual average NO_x concentrations have been relatively stable at around 115µg/m^3.

Figure 3.13 Khyber Pass Road monthly average NO and NO_2 concentrations 2006–2014



Source: AC data

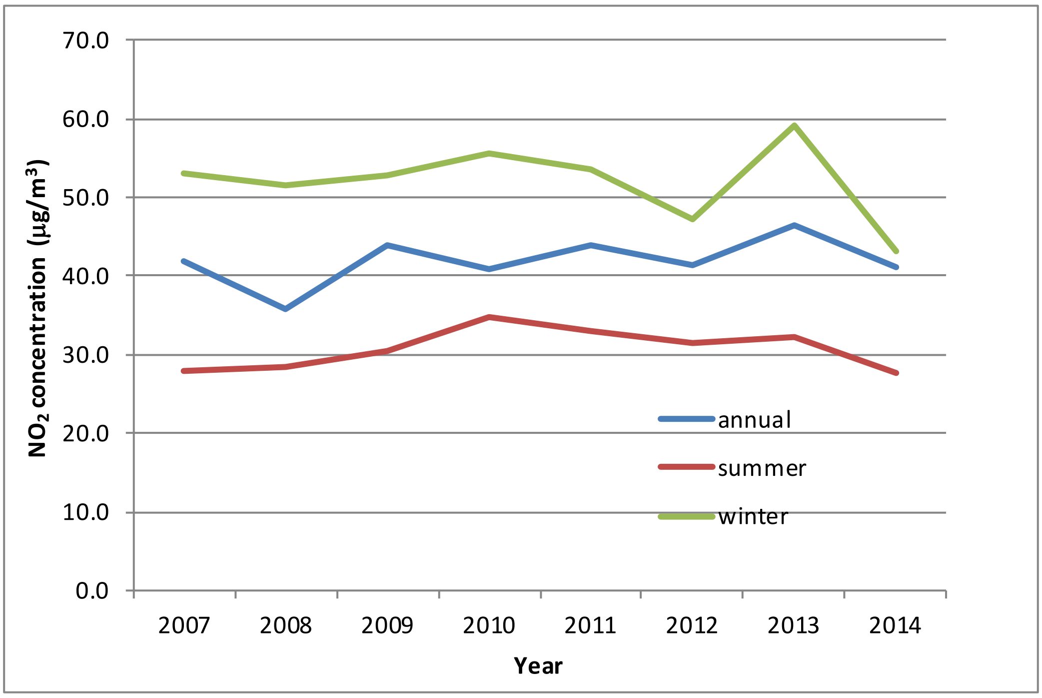
Figure 3.14 Khyber Pass Road annual average NO_x concentrations 2006–2014



The Transport Agency does not monitor NO_2 at Khyber Pass Road as part of the national ambient air quality monitoring network. However, there are a number of their sites within central Auckland and site number AUC009, Canada Street, is reasonably close to Khyber Pass at approximately 1.5km to the northwest. The Canada Street site is located in close proximity to SH1, so is a different site type from Khyber Pass Road. For this reason the Canada Street data can only be treated as indicative of what may be measured at Khyber Pass Road. The Transport Agency began NO_2 monitoring using passive samplers at the Canada Street site in 2007.

Figure 3.15 shows the Transport Agency's measurements of NO_2 annual, summer (December and January) and winter (June July and August) average concentrations at the Canada Street site.

Figure 3.15 AUC009 – CMJ/Canada St Central location Auckland – NO_2 annual and seasonal average concentrations



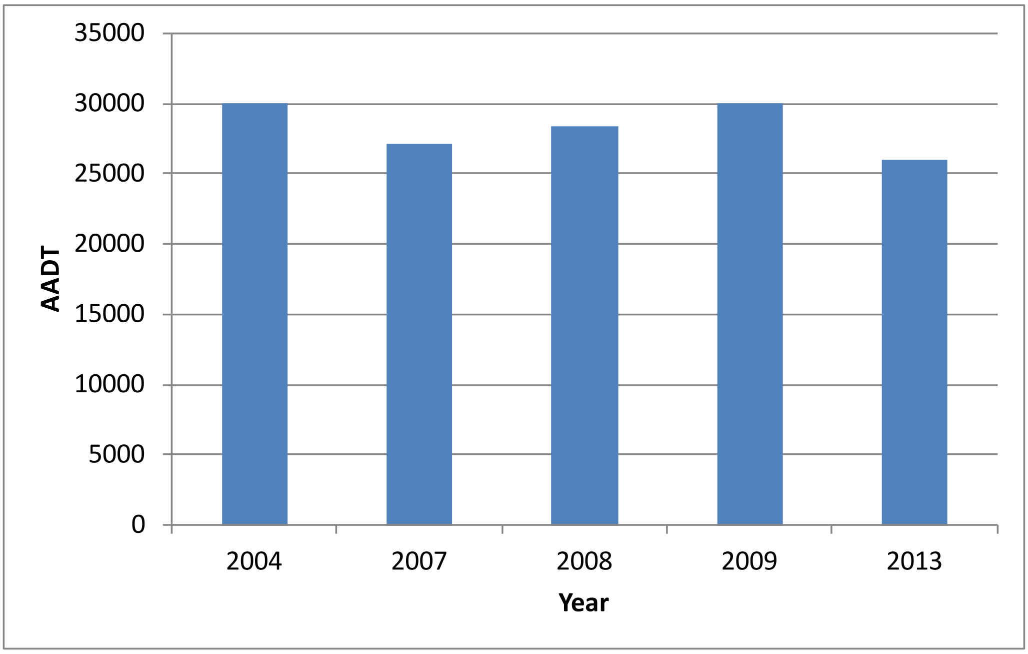
Source: NZ Transport Agency passive monitors

Figure 3.15 shows that from 2007 to 2012 the annual, summer and winter average concentrations were relatively stable at around 40, 30 and 50µg/m^3, respectively. The 2014 value for the winter averaging period shows a relatively large step downward of approximately 26% from the 2013 peak. This downward trend in 2014 is similar in magnitude to that observed at Riccarton Road in Christchurch and is also likely to be driven at least in part by warmer and windier weather experienced in 2014.

3.3.2 Vehicle numbers and fleet composition

Auckland Transport (AT) operates a Road Assessment and Maintenance Management (RAMM) database which contains, among a wider range of data, vehicle count data for carriageways in the Auckland region. RAMM vehicle count data for Khyber Pass Road was obtained and reviewed. Figure 3.16 shows the RAMM data available for Khyber Pass Road from 2004 to 2013. The RAMM data available on vehicle counts for Khyber Pass Road is limited and monitored vehicle counts have not been undertaken since 2009; the more recent data (2013) is an estimate of AADT provided by AT. This AADT data should be treated as an indicative representation of the numbers of vehicles that pass the AC air quality monitoring site because the 2004 to 2009 AADT are taken on different and varying sections of Khyber Pass Road and the 2013 AADT is an estimate. Notwithstanding the limitations of the AADT data, figure 3.16 suggests the AADT on Khyber Pass Road from 2004 to 2013 has been relatively stable at between 30,000 (2004) and 26,000 (2013).

Figure 3.16 Vehicle count on Khyber Pass Road 2004–2013



No data on the composition of the vehicle fleet was available from AT. For the purpose of this study it was assumed that it mirrored changes observed in the national fleet composition as detailed in figure 2.8.

Despite the considerable effort invested in obtaining the Khyber Pass vehicle number and fleet composition data there are gaps and uncertainties in the data used for this project. However, the best data available was used for the project. To improve the outputs of any future programmes, see section **15.2.**

4 Remote sensing device vehicle emission monitoring

The air monitoring data discussed in the previous chapter suggested a declining trend in CO vehicle emissions, and a stable or declining trend in NO_x and NO_2 vehicle emissions. This chapter analyses vehicle emission data collected with remote sensing over multiple years. This independent method is used to verify the emission trends with near-road air-quality data.

The information presented in this chapter addresses research objective number 3:

> Undertake a roadside emission monitoring programme to supplement the existing remote sensing device (RSD) vehicle emission monitoring datasets (2003 to 2011).

4.1 2003 to 2011 monitoring programmes

On-road measurements of vehicle emissions with the RSD began in New Zealand in 2003, with subsequent programmes undertaken in 2005, 2009 and 2011. The monitoring programmes and data analysis are described in detail in Kuschel et al (2012). For this study, the 2003 to 2011 on-road vehicle emission data has been supplemented with data collected in Auckland in February and March 2015.

4.2 2015 monitoring programme

The key points of the 2015 RSD monitoring programme are:

- The RSD equipment employed for the 2015 programme is the same equipment used for the 2005 to 2011 monitoring.
- The RSD was serviced, calibrated and operated in accordance with the manufacturer's instructions.
- Monitoring was undertaken in Auckland at the seven baseline monitoring sites in February and March 2015.
- The target number of valid monitoring results is 20,000 LDVs.

The RSD emission data and related vehicle data from the vehicle registration database has been integrated into the existing Microsoft Access vehicle emission database and analysed following a similar method that has been used in past programmes.

The RSD used to collect data in this study was the RSD 4000EN model. The RSD was operated on single lane motorway on ramps or arterial roads so that emissions from individual vehicles could be measured. The equipment was operated by NIWA, and was staffed while at the testing sites. Further detail on the RSD equipment and the data it collects is provided in appendix B. The procedures followed for data quality assurance are provided in appendix C.

The 2015 RSD monitoring was carried out at seven sites across the Auckland region as indicated in figure 4.1. These sites were selected based on the following three criteria:

1. The sites were previously used (or represented) in the 2005 and 2009 monitoring campaigns (and the 2003 campaign where possible).
2. The sites provided good geographical distribution across the Auckland region.
3. The sites experienced relatively high daily traffic counts and good data capture rates.

Figure 4.1 Map of the locations of the monitoring sites used in the 2015 RSD monitoring campaign

Ten days of monitoring were undertaken in February and March 2015, with three sites being monitored in two days, as shown in table 4.1. The RSD software has a built-in quality assurance system which compares each measurement against a set of criteria to determine whether the data is valid or not. In total, valid results were collected for approximately 38,600 LDVs, which equates to an average valid data capture rate of about 70%. Conversely, approximately 30% of measurements taken by the RSD in 2015 were not valid. The main reasons for an RSD measurement not meeting the valid data criteria were that during the measurement the vehicle was either accelerating quickly, decelerating, an adequate view through a representative section of the exhaust plume was not captured or the view through the plume was interrupted by a trailer (for example). The quality assurance criteria were carefully set and the RSD commissioned in the field to minimise any bias being introduced into the data set. Table 4.2 compares the number of vehicles monitored in the 2003, 2005, 2009, 2011 and 2015 measurement campaigns.

Table 4.1 Details of the 2015 RSD vehicle emission monitoring campaign

Site name	Date	Light duty vehicles tested (VT)	Valid test results (VTR)	Percentage (VTR/VT)
West End Rd	18/02/2015	3,549	2,870	80.87
Lagoon Drive	19/02/2015	4,758	2,737	57.52
Lambie Drive	20/02/2015	3,037	1,542	50.77
Elliott St	27/02/2015	2,793	1,867	66.85
Universal Drive	2/03/2015	4,528	3,005	66.36
Whangaparaoa Rd	3/03/2015	7,523	5,637	74.93
Upper Harbour Highway	4/03/2015	9,022	7,104	78.74
Whangaparaoa Rd	5/03/2015	8,269	5,520	66.76
West End Rd	6/03/2015	3,211	2,575	80.19
Upper Harbour Highway	9/03/2015	7,842	5,744	73.25
Total		**54,532**	**38,601**	**69.62**

Table 4.2 Comparison of valid test results captured at the baseline monitoring sites of vehicle numbers during the 2003, 2005, 2009 and 2015 campaigns

Site no.	Site name	Site code	Vehicle type	2015	2011	2009	2005	2003
1	Lagoon Dr	AUC2	Light	2,737	4,045	4,437	7,785	3,884
			Heavy	44	83	92	205	110
2	Lambie Dr (S)	MAN2	Light	1,542	930	1,339	4,295	2,379
			Heavy	30	20	28	98	53
3	Universal Dr	WAI5	Light	3,005	2,052	5,385	2,545	n/a
			Heavy	81	41	137	75	n/a
4	West End Rd	AUC8	Light	5,445	1,133	1,066	2,555	n/a
			Heavy	100	18	21	57	n/a
5	Whangaparaoa Rd	ROD3	Light	11,157	9,213	3,826	3,850	n/a
			Heavy	169	128	49	69	n/a
6	Elliot St (W)	PAP1	Light	1,867	1,349	1,342	1,367	1,447
			Heavy	18	24	32	42	36
7	Upper Harbour Highway (W)	NOR5	Light	12,848	5,660	5,558	2,992	1,937
			Heavy	292	74	121	28	36
Total valid test results			Light	**38,601**	**24,382**	**22,953**	**25,389**	**9,647**
			Heavy	**734**	**388**	**480**	**574**	**235**
Total individual vehicles*			Light	**29,470**	**20,895**	**21,383**	**23,310**	**9,338**
			Heavy	**630**	**347**	**447**	**528**	**222**

*Note some vehicles went through the remote sensor more than once and therefore the number of individual vehicles captured is lower than the number of valid test results.

The results presented in chapters 5 and 6, which detail the vehicle fleet profile, use only the data from individual vehicles for which valid RSD test results were obtained. The results presented in chapters 8 to

12, which analyse the emission data collected, use the total valid readings and include multiple measurements from individual vehicles.

The results presented in chapters 8 to 12 only detail the emission measurements of CO and NO from the RSD. The reason for the focus on these pollutants is that they relate to the roadside measurements of CO and NO_x from the two case study sites. In addition to CO and NO, the RSD measures HCs and a uvSmoke (an indicator of particulate emissions). While not analysed in detail, the full set of results from the measurement of CO, HC, NO and uvSmoke by the RSD in 2015 is presented in appendices D, E, F, G and H.

4.3 RSD measurements of heavy duty vehicles

Emissions from HDVs are generally higher on a g/VKT basis compared with light-duty petrol and diesel vehicles for important pollutants (but not all) such as NO_x and PM. As a consequence, the contribution of HDVs to total emission loads is substantially larger for those pollutants than would be expected on the basis of total vehicle numbers and on-road travel. For instance, Smit (2011) showed an example where HDVs account for about 10% of total vehicle travel, but are estimated to contribute approximately 60%, 25% and 10% to total vehicle fleet emissions for NO_x, PM_{10} and CO, respectively.

Real-world emissions from diesel buses and trucks are also known to be quite different (ie higher) from those measured in legislative test procedures, because manufacturers calibrate HDV engines for improved fuel economy rather than optimised emissions performance outside test conditions. For instance, Jiménez et al (2000) explained higher-than-expected NO_x emissions from HDVs in a RSD measurement campaign with the use of 'defeat devices' in HDVs to optimise fuel economy at the expense of significantly elevated NO_x emissions.

Similarly, emission control technology may not operate efficiently in all real-world conditions. An example is Euro V trucks that have excellent NO_x emission control in rural and highway conditions, but not in urban conditions where low engine load conditions can lead to reduced catalyst temperatures and high NO_x emission levels (eg Rexeis and Hausberger 2009). So, in addition to relatively high emission levels per VKT, HDVs may exhibit increased spatial variability in their emissions levels.

Models using emission data from laboratory (engine) tests may produce incorrect emission levels and trends for HDVs. RSD can be used to collect empirical HDV emissions data in real-world conditions with representative spatial variability. Another benefit of RSD is that emissions can be accurately allocated to specific vehicle technology types (year of manufacture), allowing for detailed assessment of HDV emission factors.

Carslaw et al (2011) used RSD and found that emission rates for HDVs have recently remained comparatively stable for NO_x following significant reductions observed in the early 2000s. This is in contrast with other vehicle types such as petrol cars, making HDV emissions increasingly more relevant to air quality effects. This information is relevant for accurate vehicle emission modelling.

However, measuring HDV emissions with RSD can also generate specific challenges. First, the typical RSD is set up with a sensing beam height of 20–45cm above ground level, which will exclude HDVs with vertical exhausts or other exhaust orientations outside of this height range. Second, trailers may interfere with measurements as they disperse exhaust emissions. Third, gear shift behaviour affects instantaneous vehicle emissions, and this is a particular issue for (heavily loaded) HDVs, which undergo many gear shift changes and associated variability in emissions with rapid engine transitions from effectively 'no load' to 'maximum load'.

As a consequence, modifications to the RSD roadside monitoring setup are required. These include, for instance, the use of multiple RSDs, the use of scaffolding to raise the device height for HDVs with vertical exhaust configurations and lowering the measurement beams to read the plume under HDVs with low exhausts. Other modifications are specific vehicle detection equipment (manual or automated) and detection algorithms, longer scanning times and data post-processing procedures (NIWA 2015).

It is also important to measure HDV vehicle emissions over sufficiently large samples in different traffic situations to capture variability in emissions. It is recommended to use results from other methods, such as tunnel studies with sufficiently varying HDV proportions or tent-like hoods to capture HDV exhaust plumes (Stedman 2014), to confirm the results found with the RSD.

5 Trends in the monitored light duty vehicle fleet profile

This information presented in chapters 5 to 12 addresses research objective number 4:

> Determine the first order trends in vehicle feet composition and emissions by analysing the existing (2003 to 2011) and new (2014/15) RSD vehicle emission data.

This chapter presents the major trends in key vehicle emission parameters measured for the LDV fleets monitored in Auckland 2003, 2005, 2009, 2011 and 2015. Results are presented for the monitored LDV fleet as a whole, which is then disaggregated and presented by fuel type (petrol and diesel) and by country of first registration (NZN and JPU imports).

5.1 Vehicle age

Vehicle age and year of manufacture influence emissions. The level of emission control technology installed tends to be correlated with the year of manufacture of a vehicle although this correlation is less pronounced in New Zealand where emission control standards have only been in place since 2003. In addition, as a vehicle ages its emission performance tends to degrade as engine parts and emission control systems wear.

Table 5.1 compares the mean and median ages of the vehicles monitored from 2003 to 2015.

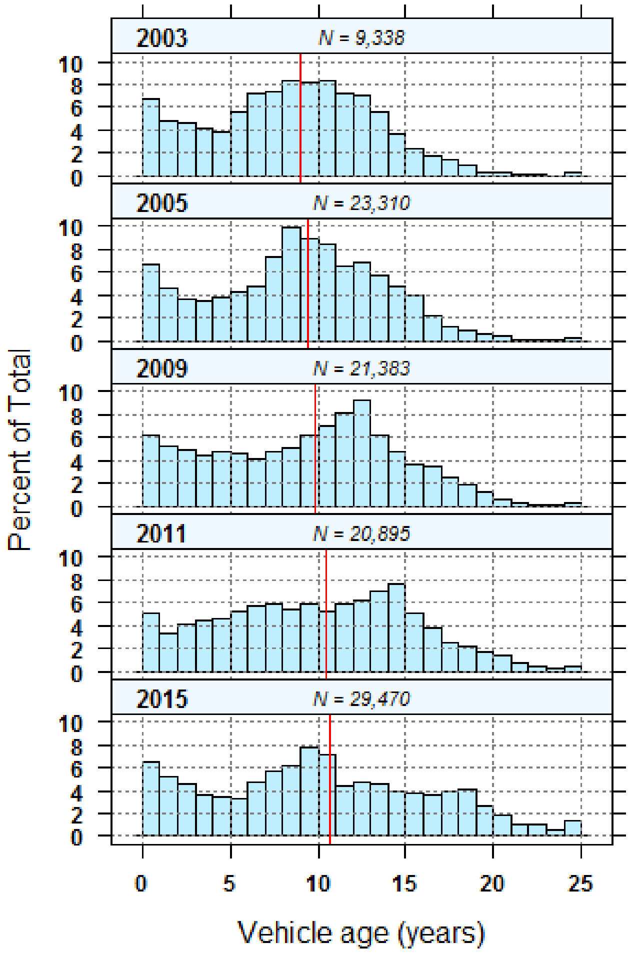
Table 5.1 Comparison of the mean and median ages of the 2003–2015 monitored LDV fleets

Campaign year	Number of vehicles	Mean age (years)	Median age (years)*
2003	9,338	9.03	9
2005	23,310	9.48	10
2009	21,383	9.86	10
2011	20,895	10.49	11
2015	29,470	10.74	10

Note: Median age is presented as whole numbers as this value is based on year of manufacture so can only be in whole years

The mean age of the monitored LDV fleet has steadily increased by 1.5 years from 2003 to 10.7 years in 2015. The median age has shown a similar trend. Although the RSD data shows a similar increase in mean age, the mean age measured with the RSD is substantially younger than the New Zealand LDV average age discussed in section 2.2.2. This finding is not unexpected. Analysis of the national fleet data on a regional scale shows the Auckland vehicle fleet is younger than the national average. In addition to this, the RSD measurement campaigns capture the vehicles being driven rather than vehicles that are registered. Because newer vehicles travel more than older ones, the RSD data tends to better reflect actual on-road travel and shows a younger age fleet. Figure 5.1 compares the age profiles of vehicles monitored from 2003 to 2015. Note the red line represents the mean age. Compared with other countries, New Zealand has an unusual vehicle fleet in that it is split almost evenly between imported new and imported used vehicles. However, imported used vehicles were generally sourced from countries, primarily Japan, with existing vehicle emission standards. For the purposes of this study imported new vehicles are termed NZN and imported used vehicles from Japan are termed JPU. Figure 5.1 shows the age distribution flattening in recent years suggesting that the influence of the JPU vehicles relative to NZN vehicles has begun to wane. The flattening of the age distribution between 2009 and 2015 most likely reflects the effect of changes to vehicle emissions legislation that have reduced the number of older JPU imported into New Zealand (MoT 2007; MoT 2010). However, in 2015 there was an increased contribution from vehicles around 10 years old, which reflects the influence of a recent increase in imports of JPU vehicles manufactured in and around 2005 (MoT 2014).

Figure 5.1 Comparison of the age profiles of the 2003–2015 monitored LDV fleet



5.2 Fuel type

Fuel type is another important emissions determinant as differently fuelled vehicles emit pollutants in different quantities and proportions.

Table 5.2 shows the trends in the proportions and mean ages of petrol and diesel vehicles since 2003.

Table 5.2 Comparison of the proportions and mean ages of the 2003 to2015 monitored LDV fleets by fuel type

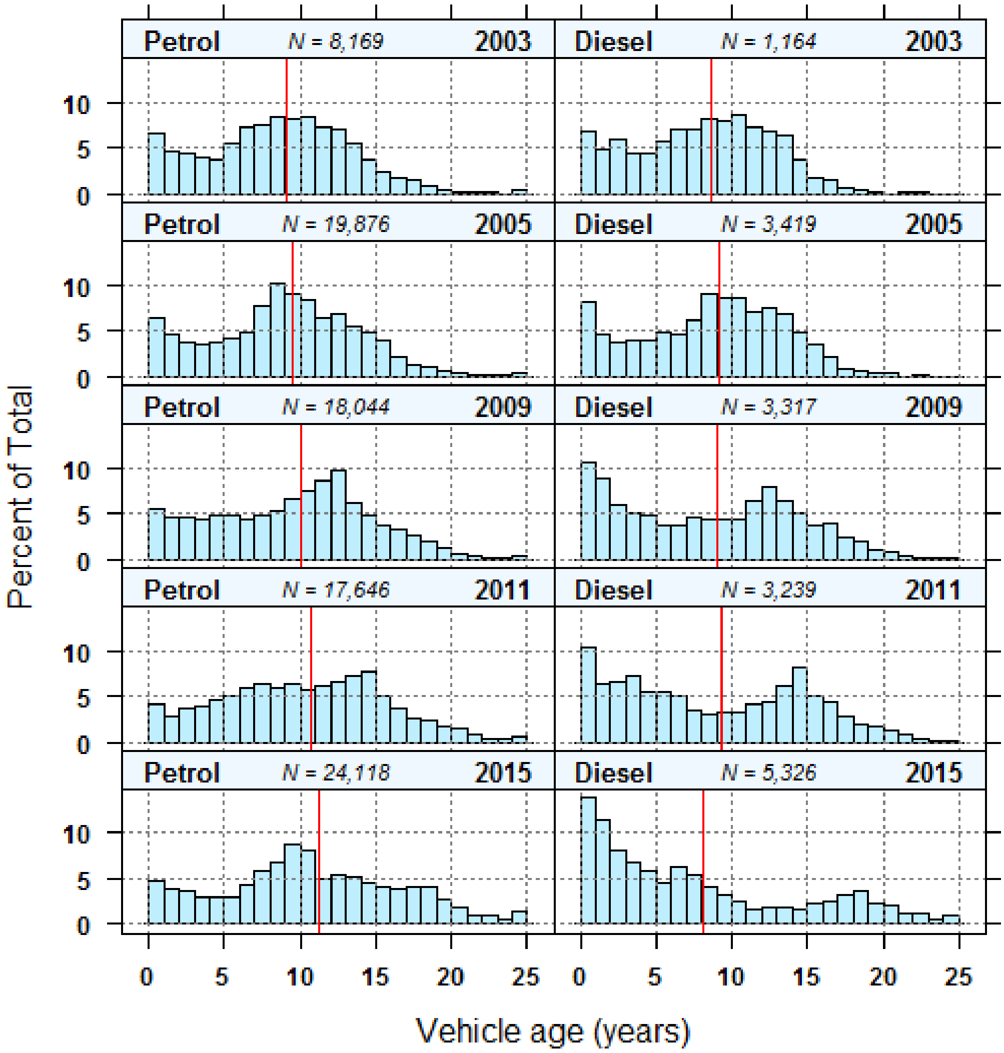
Campaign year	Number of petrol vehicles	Percentage of petrol vehicles	Mean age of petrol vehicles	Number of diesel vehicles	Percentage of diesel vehicles	Mean age of diesel vehicles
2003	8169	87.50%	9.08	1,164	12.50%	8.65
2005	19,876	85.30%	9.53	3,419	14.70%	9.19
2009	18,044	84.50%	10.02	3,317	15.50%	9.03
2011	17,646	84.50%	10.71	3,239	15.50%	9.31
2015	24,118	81.90%	11.3	5,326	18.10%	8.2

The proportion of petrol vehicles in the monitored fleet decreased by 3% between 2003 and 2011 and by 2015 had decreased a further 2.6%. This observation is consistent with trends seen in the New Zealand LDV fleet overall (section 2.2.2) which showed a steady increase in the proportion of diesel vehicles from 11.6% in 2000 to 15.5% in 2008, minimal change between 2009 and 2011 and then an increase to 16.7% in 2012/13.

Diesel vehicles currently comprise 18.1% of the LDV monitored fleet, compared with 12.5% in 2003.

Age profiles for the monitored petrol and diesel fleets differ markedly, with the petrol fleet's average age increasing more rapidly than that of the diesel fleet (see figure 5.2). The mean age of the petrol fleet has increased by 2.2 years (from 9.1 to 11.3 years) since 2003. Between 2003 and 2011 the mean age of the diesel fleet vehicles increased 0.7 years (from 8.7 to 9.3 years). However, between 2011 and 2015 the mean age of the diesel fleet vehicles decreased by 1.1 years (from 9.3 to 8.2 years), and in 2015 the average age of diesel vehicles was lower than in 2003.

Figure 5.2 Comparison of the age profiles of the 2003-2015 monitored LDV fleets by fuel type. Note the red line represents the mean age of vehicles



5.3 Country of registration

Table 5.3 compares the proportions and mean ages of the 2003 to 2015 monitored LDV fleets by country of first registration.

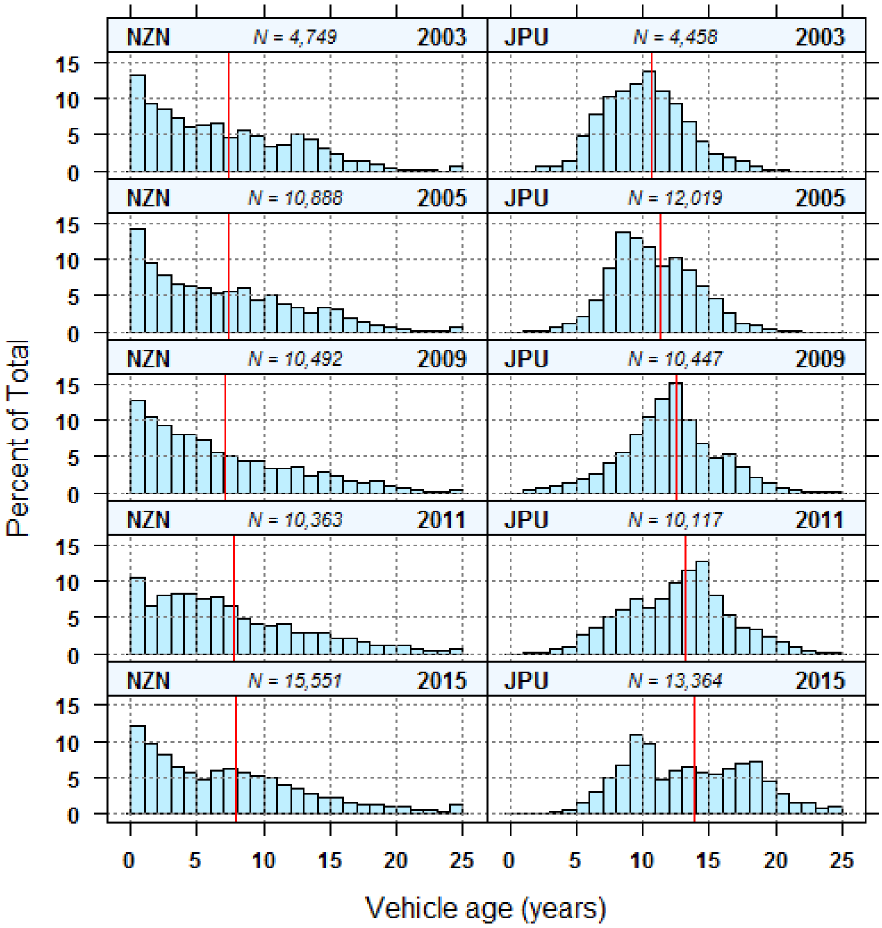
Table 5.3 Comparison of the proportions and mean ages of the 2003–2015 monitored LDV fleets by country of first registration

Campaign year	Number of NZN	% NZN	Mean age of NZN (years)	Number of JPU	% JPU	Mean age of JPU (years)	Number of other	% other	Mean age of other (years)
2003	4749	50.9%	7.39	4458	47.7%	10.73	131	1.4%	10.68
2005	10,888	46.7%	7.45	12,019	51.6%	11.3	403	1.7%	9.86
2009	10,492	49.1%	7.16	10,447	48.9%	12.54	444	2.1%	10.73
2011	10,363	49.6%	7.82	10,117	48.4%	13.17	415	2.0%	11.94
2015	15,551	52.8%	7.92	13,364	45.3%	13.97	555	1.9%	11.77

Table 5.3 shows the monitored fleet continues to be more or less evenly divided between New Zealand new and used vehicles imported from overseas (primarily from Japan), but the proportion of NZN vehicles has increased to 52.8% in 2015 from a minimum of 46.7% in the 2005 campaign. The most recent data shows a shift in the New Zealand/overseas split, with the decline in JPU vehicles from a peak of 51.6% in 2005.

Figure 5.3 compares vehicle age by country of origin and confirms that the JPU component of the monitored fleet is older than the NZN component, and is also ageing much more rapidly.

Figure 5.3 Comparison of the age profiles of the 2003–2015 monitored LDV fleets by country of first registration. Note the red line represents the mean age of vehicles



6 Trends in heavy duty vehicle fleet profile

6.1 Profile of monitored heavy duty vehicle fleet

An analysis of the vehicle data from the HDVs captured in the RSD monitoring campaign shows:

- 60% are trucks and 40% buses
- 44% of the HDV trucks are NZN and 56% JPU
- 38% of the buses are NZN and 62% JPU
- 83% of HDV trucks weigh less than 10 tonnes
- 8% of HDV trucks weigh between 10 and 20 tonnes
- 9% of HDV trucks weigh more than 20 tonnes.

The profile of the monitored HDV fleet differs significantly from the national HDV fleet average, which is based on the data from the vehicle registration database (see section 2.2.2). The average national HDV fleet composition is 93% trucks and 7% buses. Therefore, in the monitored HDV fleet, trucks (60%) are under-represented; conversely, buses (40%) are over-represented. Of the trucks in the monitored HDV fleet, the proportions of NZN (44%) and JPU (56%) are approximately reversed compared with the national HDV fleet average (62% NZN and 38% JPU). Of the buses in the monitored HDV fleet the proportions of NZN (38%) and JPU (62%) are very close to the national HDV fleet average (41% NZN and 59% JPU).

The weight profile of the monitored HDV trucks is significantly different from the national HDV fleet average. Of the monitored HDV trucks 83% are less than 10 tonnes compared with 54% of the national HDV fleet average. Of the monitored HDV trucks 17% are greater than 10 tonnes compared with 46% of the national HDV fleet average.

There are a number of reasons why a significant difference is seen in the national and monitored HDV profiles. These include:

- The RSD's inability to measure vertical exhaust stacks found more frequently on large trucks.
- The RSD monitoring sites more closely reflect urban travel characteristics than high-volume roads where larger freight trucks are relatively more frequent.
- There tend to be more small truck movements in urban areas where the RSD monitoring was undertaken.
- Because newer vehicles travel more than older ones (MoT 2014), the RSD data tends to better reflect actual on-road travel and show a younger age fleet.

Due to the relatively small numbers of HDV vehicles monitored and because there are significant differences in the vehicle type and weight profile between the monitored and national average HDV fleets, the vehicle emission data presented in this section should be treated as indicative only of the HDV fleet emissions. This issue will be considered in this report's recommendations (chapter 15.2).

6.2 Vehicle age

The mean and median ages of the HDVs monitored from 2003 to 2015 are compared in table 6.1. The mean age of the monitored heavy duty fleet steadily increased by 3.1 years from 2003 to be 12.3 years in 2015. The median age has shown a similar trend.

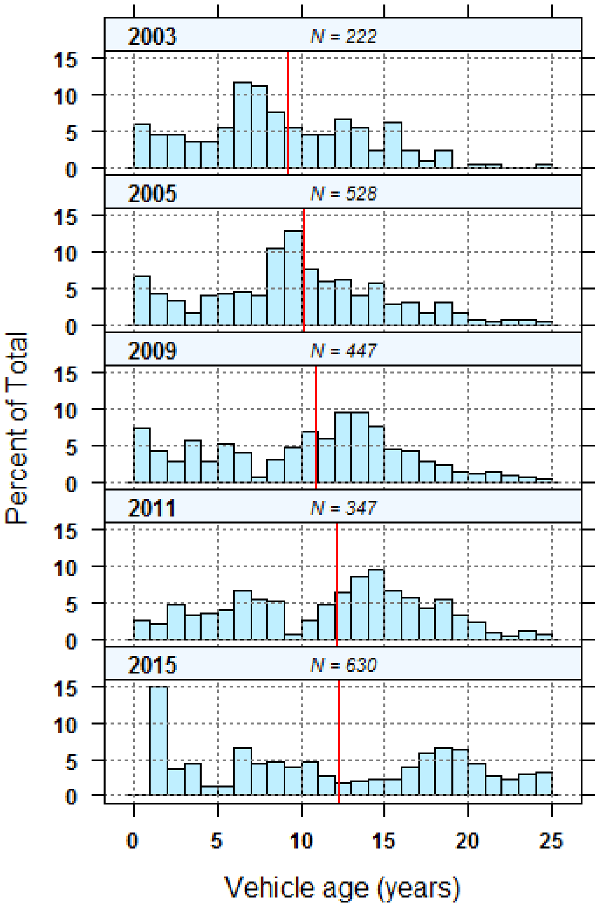
Table 6.1 **Comparison of the mean and median ages of the 2003–2015 monitored HDV fleets**

Campaign year	Number of vehicles	Mean age (years)	Median age (years)[(a)]
2003	222	9.18	8
2005	528	10.11	10
2009	447	10.89	12
2011	347	12.12	13
2015	630	12.29	11

(a) Median age is presented as whole numbers as this value is based on year of manufacture so can only be in whole years.

Figure 6.1 compares the age profiles of the HDVs monitored from 2003 to 2015. Note the red line represents the mean age.

Figure 6.1 **Comparison of the age profiles of the 2003–2015 monitored HDV fleets**



The mean age in the RSD data is significantly younger than that given in the national vehicle registration data (section 2.2.2). The average age of trucks and buses in the national HDV fleet in 2013 was 15.7 and 15.3 years, respectively, whereas the average age of trucks and buses in the monitored HDV fleet in 2015 was 12.9 and 11.3 years, respectively.

MoT's analysis of the national HDV fleet shows that from 2003 to 2008 the average age of trucks was relatively constant at close to 14 years, but from 2009 to 2013 the average age of trucks increased to almost 16 years. MoT's analysis of the national HDV fleet shows that from 2003 to 2015 the average age of buses was relatively constant at close to 15 years.

The two key entry points into the New Zealand HVD fleet have been from NZN and JPU vehicles. Figure 6.1 shows the age distribution flattening in 2015, suggesting that the influence of the JPU vehicles relative to NZN vehicles has begun to wane. Fewer JPU HDVs are now entering the New Zealand fleet due to changes in New Zealand emission standard requirements implemented in 2008, which limit the importation of JPU HDVs by requiring them to meet more recent emission standards. There is a significant increase in vehicles less than three years old observed in the 2015 data, which can only be from increased numbers of NZN HDVs.

6.3 Country of registration

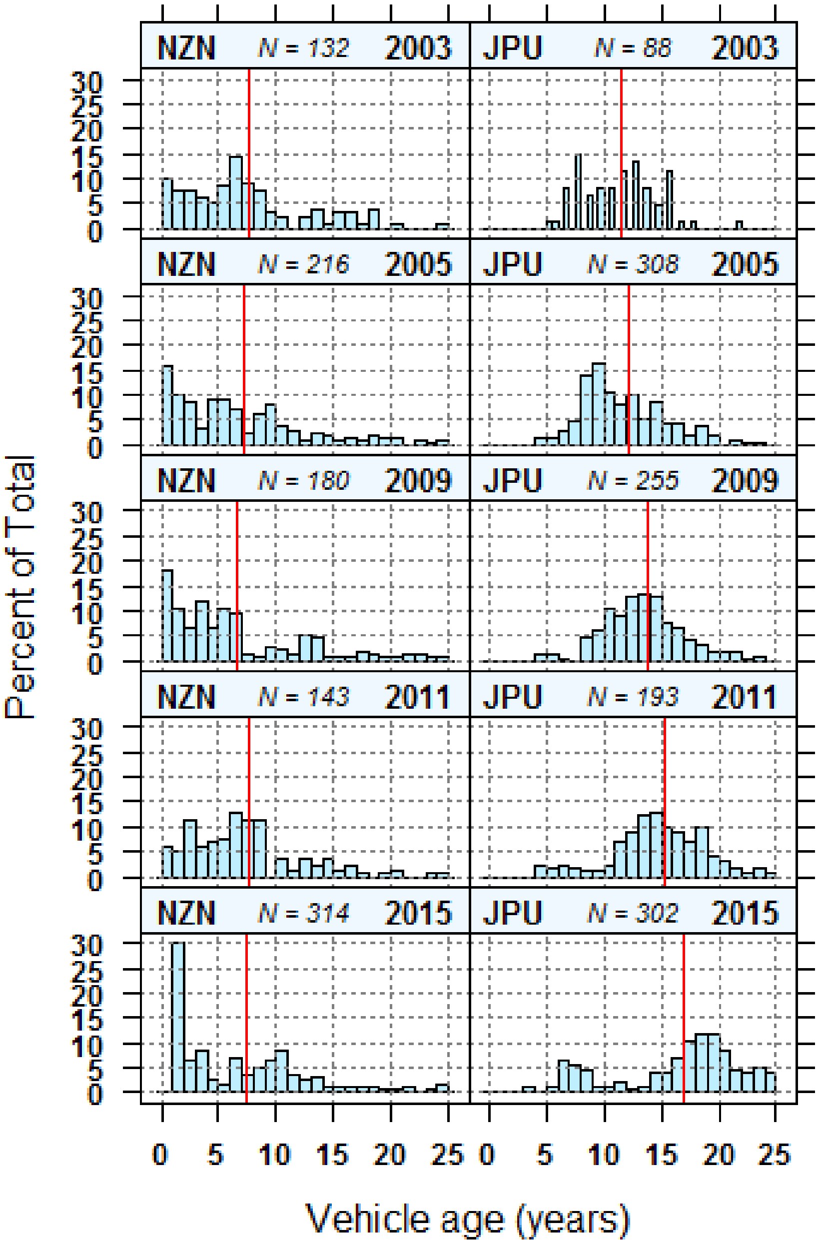
As with the LDV fleet, the New Zealand HDV vehicle fleet is split almost evenly between imported new and imported used vehicles. Table 6.2 presents a comparison of the proportions and mean ages of the 2003 to 2015 monitored HDV vehicle fleets by country of first registration. Figure 6.2 presents a comparison of the age profiles of the 2003 to 2015 monitored HDV fleets by country of first registration.

Table 6.2 and figure 6.2 show that the mean age for NZN HDV vehicles in the monitored fleet has been relatively stable since 2003, decreasing by 0.2 years from 2003 to 2015. By contrast, mean age for JPU HDV vehicles has risen by 5.5 years, from 11.6 years (in 2003) to 17.1 years (in 2015).

Table 6.2 Comparison of the proportions and mean ages of the 2003–2015 monitored HDV fleets by country of first registration

Campaign year	Number of NZN	% NZN	Mean age of NZN (years)	Number of JPU	% JPU	Mean age of JPU (years)	Number of other	% other	Mean age of other (years)
2003	132	59.5%	7.6	88	39.6%	11.6	2	0.9%	9.5
2005	216	40.9%	7.2	308	58.3%	12.1	4	0.8%	10.75
2009	180	40.3%	6.5	255	57.0%	13.9	12	2.7%	12.42
2011	143	41.2%	7.6	193	55.6%	15.2	11	3.2%	15.09
2015	314	49.8%	7.4	302	47.9%	17.1	14	2.2%	19.36

Figure 6.2 Comparison of the age profiles of the 2003–2015 monitored HDV fleets by country of first registration. Note the red line represents the mean age of vehicles



7 Presentation of emission measurement results

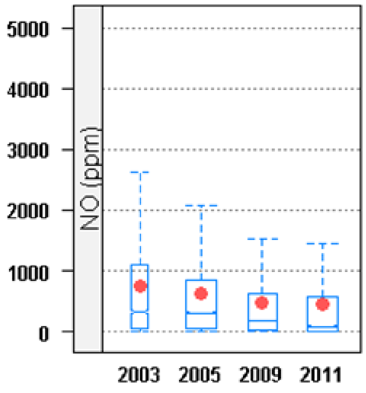
7.1 Box and whisker plots

Throughout this report box and whisker plots have been used to characterise vehicle emissions. These plots provide a compact summary of trends in the mean, median and range for each pollutant, in a format that emphasises variation among and within factors such as fuel type and vehicle age. This simplicity inevitably means that some of the detail inherent in our data is lost. For example, in this report, all valid negative RSD data has been included in the data analyses and the subsequent calculations of mean and median values. However, for ease of display and interpretation, the box plots which show the emission measurements only show the positive data. Further details of how the RSD data has been used for this report are provided in appendix C.

The conventions used to construct each plot (see figure 7.1) are as follows:

- Each box and whisker icon comprises a connected set of graphical elements which summarise the underlying data as measured along the vertical axis.
- The upper and lower limits of the central box show the upper and lower quartiles. Thus, the box contains the central 50%t of the raw data.
- The whiskers represent the 5th and 95th percentile values. More extreme data values, possibly extending well beyond the maximum axis value, are suppressed.
- Red circles show the mean, while the median is represented by the ‘belt’ or line across the middle of the ‘waist’ on the box.
- The extent of the ‘waist’ of the boxes (whether it is short or long) indicates the confidence intervals around the median. If the ‘waists’ of two adjacent boxes do not overlap then the means are statistically different and vice versa.
- Box width is proportional to sample size. In the example, sample size for 2003 is roughly half that for the other three years.

Figure 7.1 Example of a plot used to compare emissions results



7.2 Vehicle emission data

The results contained in chapters 8, 9, 10 and 11 present an analysis of trends in CO and NO emissions as these are the pollutants that have been used as indicators of trends in roadside air quality as detailed in chapter 3.

The RSD reports concentration levels in the exhaust gas (CO_2 (%), CO (%), HC (ppm) and NO (ppm)), corrected for water and excess oxygen not used in the combustion process. However, the exhaust plume path length and the density of the observed plume are highly variable from vehicle to vehicle and are a function of the height of the vehicle's exhaust pipe, wind direction, wind speed and turbulence behind the vehicle, amongst other factors. The RSD can therefore only reliably measure ratios of CO, HC and NO to CO_2. These ratios are assumed to be constant in a particular vehicle's exhaust plume. Due to the short time period involved in the measurement, this is expected to hold true for reactive species such as NO as well.

In this report the RSD measurements are presented as concentrations. This is appropriate for the current trend analysis, as the trends in concentrations are expected to mirror to a very good degree the trends in total emissions and therefore fit the requirements of this investigation.

It is possible to use the RSD reported ratio of pollutant to CO_2 to obtain an estimate of vehicle emissions in g/kg of fuel by using combustion equations and an approximate fuel C/H ratio and correcting for oxygen and water contained in the exhaust plume. The g/kg approach to reporting the RSD data is considered in section 15.3.

The complete sets of data tables and charts for the four pollutants measured by the RSD (CO, NO, HC and UvSmoke) are presented in appendices D, E, F and G.

7.3 Statistical analysis

The statistical significance of differences between the vehicle emission distributions compared in each plot has been analysed. Skewed datasets like emission data can be analysed using the Kruskal-Wallis (K-W) test, which is a non-parametric one-way analysis of variance. This test does not assume the data comes from a *normal* distribution but it does assume that all data comes from the *same* distribution. The routine converts all values to ranks before analysis, thereby creating a uniform distribution. Therefore the K-W test is an appropriate and useful tool to analyse highly skewed data sets, such as real-life vehicle emissions.

The K-W test routine tests the hypothesis that all samples have the same median rank, against the alternative that the median ranks are different. The routine returns a p-value for the likelihood the observed differences could occur purely by chance. The significance level used for all K-W tests in this report was 95% (ie $p = 0.05$).

Appendix H has a summary of the results of the K-W tests undertaken for the analyses presented in this report.

8 Trends in light duty vehicle emissions

This chapter discusses the major trends in LDV emissions measured in 2003, 2005, 2009, 2011 and 2015. Results are presented for the LDV fleet average, which is then disaggregated and presented by fuel type (petrol and diesel) and by country of first registration (NZN and JPU imports).

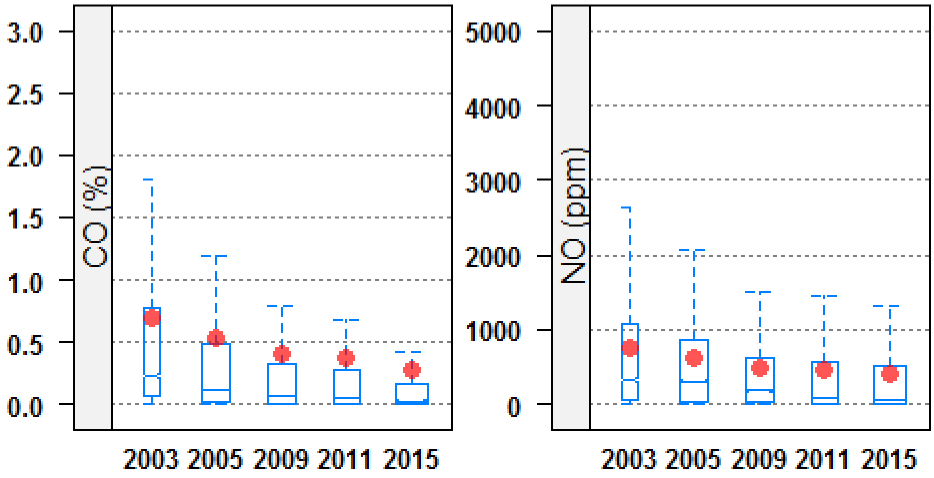
8.1 Fleet average

Table 8.1 and figure 8.1 compare the emissions of CO and NO from the overall LDV fleets monitored from 2003 to 2015.

Table 8.1 Comparison of the median and mean emissions of the 2003–2015 monitored LDV fleets

Campaign year	No. of measurements	CO (%)		NO (ppm)	
		Mean	Median	Mean	Median
2003	9647	0.69	0.23	764	330
2005	25,389	0.53	0.12	630	313
2009	22,953	0.41	0.07	489	186
2011	24,382	0.37	0.06	467	92
2015	33,942	0.27	0.03	421	56

Figure 8.1 Comparison of the emissions of the 2003–2015 monitored LDV fleets



Mean emissions of CO and NO decreased significantly from the light fleet between 2003 and 2015. Relative to 2003, the mean emissions from the 2015 LDV were:

- 40% of the CO
- 55% of the NO.

The rate of improvement for mean CO and NO values was relatively high between 2003 and 2009. The rate of improvement slowed between 2009 and 2011 and was maintained at the lower rate for the 2011–2015 period.

The median emissions of CO and NO have also shown a downward trend since 2003. The rate of reduction in median CO value improved between the 2011 and 2015 campaign. The rate of improvement in median values NO slowed in the 2015 campaign.

It is interesting to note the differences in the trends in mean and median emissions for both CO and NO between the 2009 and 2015 campaigns. For both pollutants the mean and median values show a decrease but the median value decreases much more quickly than the mean value.

The ratio of the mean to the median for CO, which sat at between 3.0 and 5.0 for previous years, increased to 6.2 in 2011 and 7.5 in 2015. The ratio of the mean to the median for NO, which sat between 2.0 and 2.6 for previous years, increased to more than 5.0 in 2011 and 7.5 in 2015. Vehicle emission data does not follow a normal distribution but is skewed with many very low values and a few very high values. For data distributed 'normally', the ratio of the mean to the median would be 1.0. It is important to note that a truly normal distribution of emissions from motor vehicles is unlikely because modern vehicles can emit zero emissions of pollutants and this can easily lead to measured medians of zero and therefore very high mean to median ratios. The higher the ratio over 1.0 the more skewed the data is towards higher values. The increasing mean-to-median ratio for CO and NO suggests that although 50% of the vehicles are cleaner (with a reduced median in 2015), this improvement is partially offset by gross emitters. The impact of gross emitters on the monitored fleet emissions performance for CO and NO has grown considerably.

8.2 Petrol

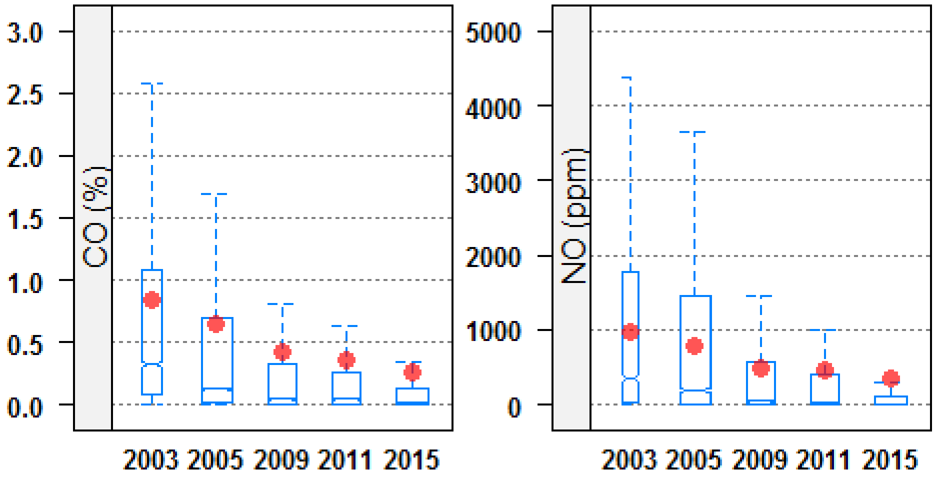
8.2.1 New Zealand new vehicles

Table 8.2 and figure 8.2 compare the emissions from 2003 to 2015 for the monitored NZN LDV petrol vehicles.

Table 8.2 Comparison of the median and mean emissions of the 2003–2015 monitored NZN LDV petrol fleets

Campaign year	No. of measurements	CO (%)		NO (ppm)	
		Mean	Median	Mean	Median
2003	4460	0.84	0.32	983	356
2005	10,391	0.65	0.13	795	203
2009	9,268	0.43	0.05	486	54
2011	9,742	0.37	0.05	450	27
2015	13,102	0.26	0.02	345	17

Figure 8.2 Comparison of the emissions of the 2003–2015 monitored NZN LDV petrol fleets



The NZN petrol fleet's mean emissions of CO and NO decreased significantly between each campaign from 2003 to 2015. Relative to 2003, an average vehicle in the NZN petrol light fleet in 2015 emitted:

- 30% of the CO
- 35% of the NO.

For NZN petrol vehicles, the ratio between the mean and median CO emissions increased from 2.6 in 2003 to 13.0 in 2015. Although the median emissions are now just 6% of what they were in 2003, the mean emissions only dropped to 30% of the 2003 value.

For NZN petrol vehicles, the ratio between the mean and median NO emissions increased from 2.8 in 2003 to 20.3 in 2015. Although the median emissions are now just 5% of what they were in 2003, the mean emissions only dropped to 35% of the 2003 value.

The increase in mean-to-median ratios suggests that despite the majority of the NZN petrol fleet now being much cleaner with respect to CO and NO, this improvement is partially offset by gross emitters. Therefore, potentially significant emission improvements arising from newer vehicles are being lost as a result of gross emitter vehicles, which is of additional Interest with ambient NO_2 concentrations stabilising.

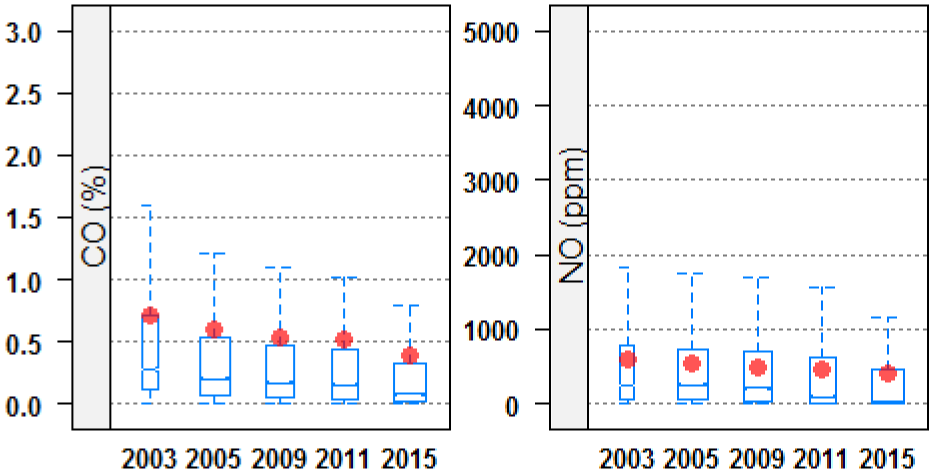
8.2.2 Japanese used vehicles

Table 8.3 and figure 8.3 compare the emissions from 2003 to 2015 for light duty (JPU) petrol vehicles.

Table 8.3 Comparison of the median and mean emissions of the 2003–2015 monitored JPU LDV petrol fleets

Campaign year	No. of measurements	CO (%)		NO (ppm)	
		Mean	Median	Mean	Median
2003	3,844	0.71	0.28	589	254
2005	10,829	0.59	0.2	536	256
2009	9,621	0.53	0.17	503	215
2011	10,210	0.51	0.15	462	101
2015	14,082	0.39	0.08	397	40

Figure 8.3 Comparison of the emissions of the 2003–2015 monitored JPU LDV petrol fleets



The JPU petrol fleet's mean emissions of CO and NO decreased significantly between each campaign from 2003 to 2015. Relative to 2003, an average vehicle in the JPU petrol light fleet in 2015 emitted:

- 55% of the CO
- 67% of the NO.

For JPU petrol vehicles, the ratio between the mean and median CO emissions increased from 2.5 in 2003 to 4.9 in 2015. Although the median CO emissions are now 29% of what they were in 2003, the mean emissions only dropped to 55% of the 2003 value.

For JPU petrol vehicles, the ratio between the mean and median NO emissions increased from 2.3 in 2003 to 9.9 in 2015. Although the median emissions are now just 15% of what they were in 2003, the mean emissions only dropped to 67% of the 2003 value.

As with the NZN petrol fleet, this suggests that despite the majority of the JPU petrol fleet now being cleaner with respect to CO and NO, the influence of the gross emitters is offsetting potentially significant emission improvements.

As seen in table 5.3 and figure 5.3 the JPU fleet overall is older than the NZN fleet. Therefore, the higher mean and median CO and NO emissions recorded for JPU vehicles relative to NZN vehicles may be due to engine deterioration in the older vehicles.

8.3 Diesel

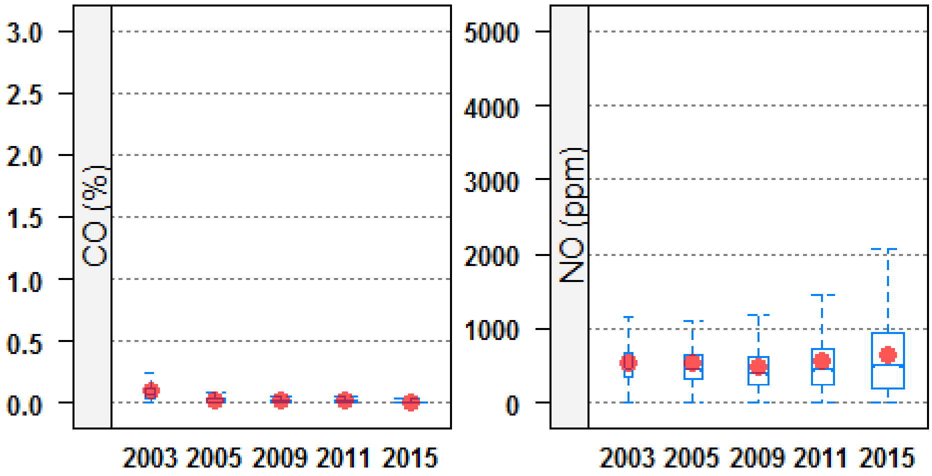
8.3.1 New Zealand new vehicles

Table 8.4 and figure 8.4 compare the emissions from 2003 to 2015 for NZN LDV diesel vehicles.

Table 8.4 Comparison of the median and mean emissions of the 2003–2015 monitored NZN LDV diesel fleets

Campaign year	No. of measurements	CO (%)		NO (ppm)	
		Mean	Median	Mean	Median
2003	470	0.1	0.07	539	475
2005	1485	0.03	0.01	535	461
2009	2021	0.01	0	490	404
2011	2438	0.02	0.01	563	452
2015	4808	0.01	0	660	511

Figure 8.4 Comparison of the emissions of the 2003–2015 monitored NZN LDV diesel fleets



The NZN diesel fleet's mean emissions of CO decreased significantly between 2003 and 2015. Mean emissions of NO increased, but not significantly, from the NZN diesel fleet between 2003 and 2015. Relative to 2003, an average vehicle in the NZN diesel light fleet in 2015 emitted:

- 10–20% of the CO
- 122% of the NO.

Emissions of CO, from NZN diesel vehicles, on average, reduced from 2003 to 2005 but the rate of decrease was slowed in 2009 and the emission concentration has remained more or less consistent since then, being at or near the RSD detection limit. In comparison, the mean NO emissions reduced from 2003 to 2009 but recorded an increase in 2011 and again in 2015.

Unlike the petrol fleet, the ratios of mean to median emissions for the diesel fleet are typically in the range 1.1 to 2.0. This indicates that the diesel fleet performance is less affected by the impact of gross emitting vehicles and so there is less scope to improve emissions by targeting the higher emitting vehicles.

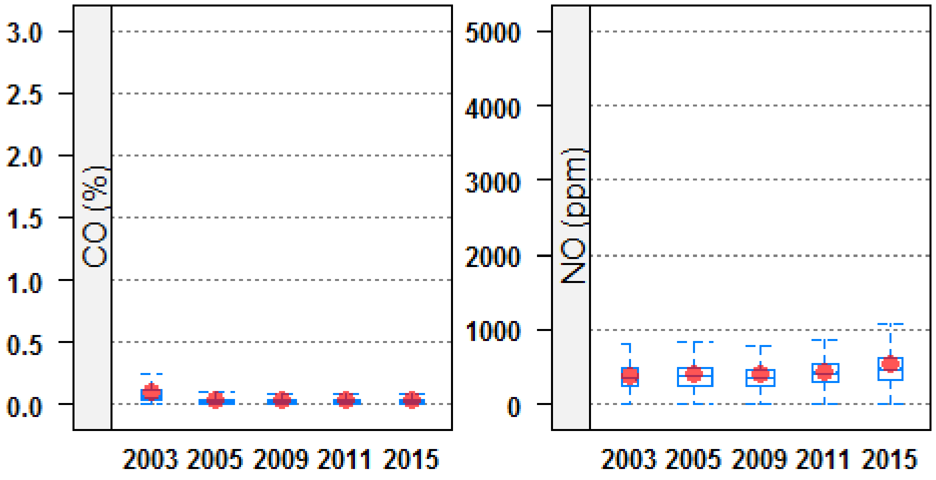
8.3.2 Japanese used vehicles

Table 8.5 and figure 8.5 compare the emissions from 2003 to 2015 for JPU LDV diesel vehicles.

Table 8.5 **Comparison of the median and mean emissions of the 2003–2015 monitored JPU LDV diesel fleets**

Campaign year	No. of measurements	CO (%)		NO (ppm)	
		Mean	Median	Mean	Median
2003	736	0.1	0.06	395	353
2005	2231	0.04	0.02	408	384
2009	1547	0.03	0.02	403	361
2011	1491	0.03	0.01	443	421
2015	1283	0.04	0.01	535	472

Figure 8.5 **Comparison of the emissions of the 2003–2015 monitored JPU LDV diesel fleets**



The JPU diesel fleet’s mean emissions of CO decreased significantly between 2003 and 2015. Mean emissions of NO increased significantly from the JPU diesel fleet between 2003 and 2015. Relative to 2003, an average vehicle in the JPU diesel light fleet in 2015 emitted:

- 30–40% of the CO
- 135% of the NO.

Emissions of CO from JPU diesel vehicles, on average, reduced from 2003 to 2005, but the rate of decrease was slowed in 2009 and the emission concentration has remained more or less consistent since then. In comparison, the mean NO emissions were reasonably consistent from 2003 to 2009 but recorded an increase in 2011 and again in 2015. Similar to the NZN LDV, the ratios of mean to median emissions for the JPU diesel fleet are relatively small (1.0 to 1.1) when compared with the petrol fleet. This indicates that the diesel fleet performance is less affected by the impact of gross emitting vehicles and so there is less scope to improve emissions by targeting the higher emitting vehicles. The JPU LDV fleet generally has lower mean and median NO emissions than the NZN LDV fleet.

9 Trends in heavy duty vehicle emissions

This chapter discusses the major trends in HDV emissions measured in 2003, 2005, 2009, 2011 and 2015.

9.1 Fleet average

Table 9.1 and figure 9.1 compare the emissions of CO and NO from the monitored HDV fleets from 2003 to 2015. Because there are significant differences in the national and monitored HDV fleet profiles (as detailed in chapter 6), the results presented in this section should be considered indicative rather than an accurate representation of the emission profile for CO and NO from New Zealand's HDV fleet. This issue is discussed further in chapter 15.2.

Table 9.1 Comparison of the median and mean emissions of the 2003–2015 monitored HDV diesel fleets

Campaign year	No. of measurements	CO (%)		NO (ppm)	
		Mean	Median	Mean	Median
2003	235	0.13	0.09	968	888
2005	574	0.07	0.05	1067	1001
2009	480	0.06	0.04	878	835
2011	388	0.06	0.04	994	887
2015	734	0.06	0.03	993	944

Figure 9.1 Comparison of the emissions of the 2003–2015 monitored HDV diesel fleets

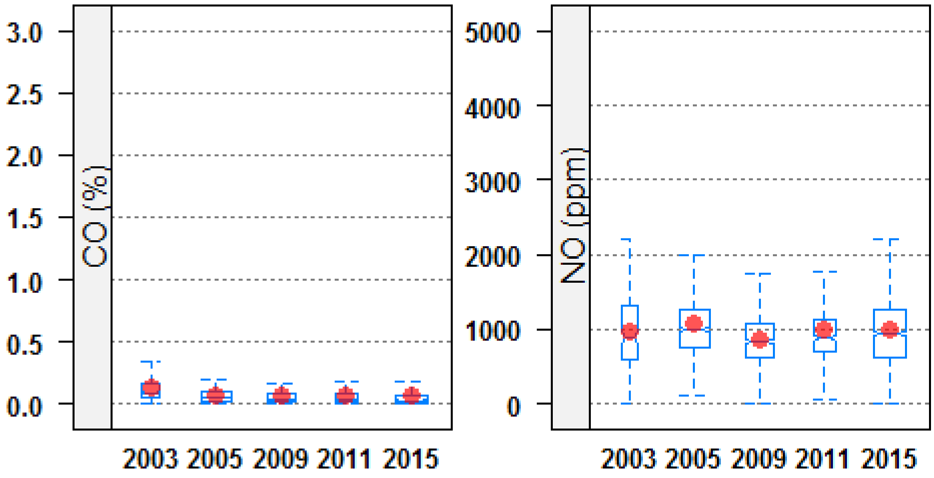


Table 9.1 and figure 9.1 show that mean CO emissions from the monitored HDV fleet decreased significantly between 2003 and 2005, remained relatively constant between 2005 and 2011 and reduced again in 2015. Table 9.1 and figure 9.1 show mean NO emissions remained relatively constant over these years. The NO emissions measured in 2003 were not significantly different from those measured in 2015. Relative to 2003, an average vehicle in the monitored HDV fleet in 2015 emitted:

- 46% of the CO
- 103% of the NO.

The median emission values of CO and NO also showed a similar pattern of change to the mean values over the years 2003 to 2015. The ratios of mean to median emissions for the HDV fleet were consistently in the range 1.1 to 2.0. This indicates that the average HDV fleet performance is not greatly affected by the impact of gross emitting vehicles.

9.2 New Zealand new vehicles

Table 9.2 and figure 9.2 compare the monitored emissions from 2003 to 2015 for NZN HDV diesel vehicles.

Table 9.2 Comparison of the median and mean emissions of the 2003–2015 monitored NZN HDV diesel fleets

Campaign year	No. of measurements	CO (%)		NO (ppm)	
		Mean	Median	Mean	Median
2003	138	0.12	0.09	1140	1067
2005	237	0.07	0.04	1213	1108
2009	193	0.06	0.03	949	881
2011	159	0.06	0.03	1061	976
2015	376	0.06	0.02	1022	964

Figure 9.2 Comparison of the emissions of the 2003–2015 monitored NZN HDV diesel fleets

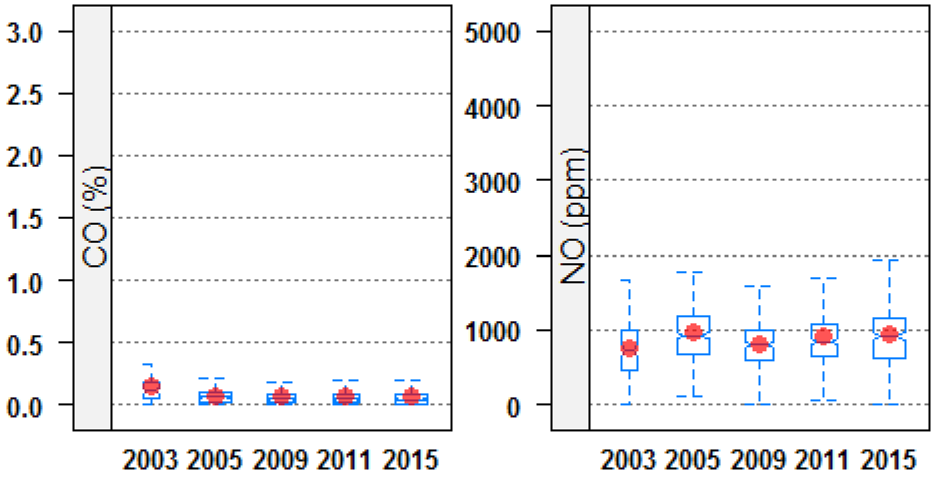


Table 9.2 and figure 9.2 show that CO and NO emissions from NZN HDV are similar to the overall HDV monitored fleet average emissions. CO from NZN HDV decreased significantly between 2003 and 2005 and remained at concentrations around 0.06mg/m^3 between 2005 and 2015. NO emissions remained relatively constant at about 1,100µg/m^3 from 2003 to 2015. The NO emissions measured in 2003 were not significantly different from those measured in 2015. In 2015, the NZN HDV NO mean emissions were slightly higher than the overall monitored HDV fleet mean (993µg/m^3).

9.3 Japanese used vehicles

Table 9.3 and figure 9.3 compare the monitored emissions from 2003 to 2015 for JPU HDV diesel vehicles.

Table 9.3 Comparison of the median and mean emissions of the 2003–2015 monitored JPU HDV diesel fleets

Campaign year	No. of measurements	CO (%)		NO (ppm)	
		Mean	Median	Mean	Median
2003	95	0.15	0.11	764	729
2005	332	0.07	0.06	959	926
2009	272	0.07	0.05	805	807
2011	215	0.07	0.05	913	845
2015	343	0.07	0.04	936	918

Figure 9.3 Comparison of the emissions of the 2003–2015 monitored JPU HDV diesel fleets

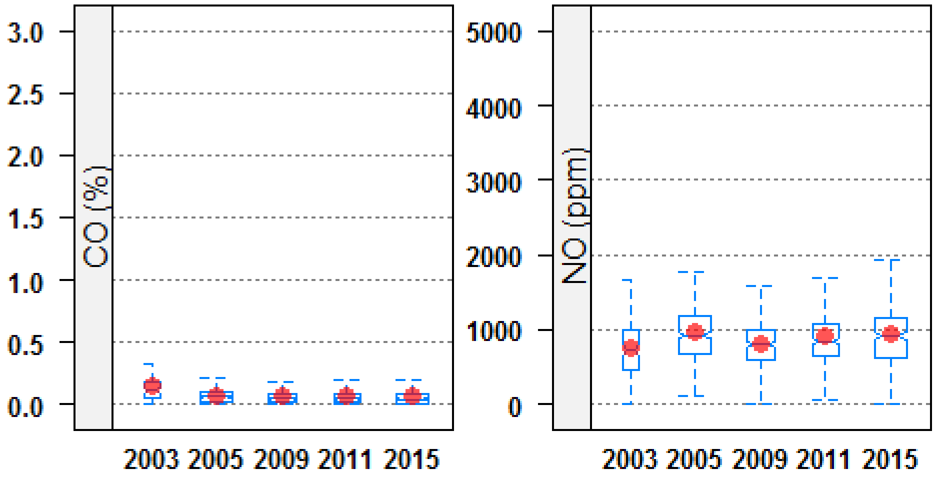


Table 9.3 and figure 9.3 show that CO and NO emissions from JPU HDV mirror the HDV monitored fleet average emissions. CO from JPU HDV decreased significantly between 2003 and 2005 and remained at concentrations around 0.07mg/m^3 between 2005 and 2015. The average CO emissions from JPU were slightly higher than for NZN HDVs. NO emissions from JPU HDVs remained relatively constant at about 875µg/m^3 from 2003 to 2015. The NO emissions measured in 2003 were not significantly different from those measured in 2015. In 2015, the JPU HDV NO mean emissions were lower than the overall monitored HDV fleet mean (993µg/m^3), despite the average age of JPU HDV being higher.

10 Effect of emission standards – light duty fleet

This section investigates the effect of vehicle emission standards on vehicle emissions to assess the on-road effectiveness of emission control technology.

10.1 New Zealand new vehicle fleet

Vehicle emission standard information for the NZN vehicles was obtained from the Transport Agency's motor vehicle register. For the analysis, the data for NZN LDVs was initially categorised into vehicles manufactured 'pre-2003' (when vehicles were not required to be built to any emission standard) and those manufactured 'post-2003'. For NZN vehicles that had emission standard information available from the motor vehicle register, the post-2003 vehicles were then further categorised into 'Euro 2', 'Euro 3', 'Euro 4' 'Euro 5' or 'Euro 6'. Eighty percent of vehicles manufactured post-2003 had a recorded emission standard. The remaining 20% of vehicles were built to an undetermined Euro emission standard. The data for vehicles with an unknown emission standard was combined to form a group of vehicles called 'post-2003' which represents all vehicles built to an unknown emission standard.

Table 10.1 shows the numbers of NZN vehicles monitored in 2015 by emission standard.

Table 10.1 Numbers of NZN vehicles monitored in 2015 by emission standard

Emission standard	Pre-2003	Post-2003 standard unknown	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6	Total#
Petrol	2,710	2,023	428	1,756	3,051	1,176	62	11,206
Diesel	395	535	280	412	1,939	515	33	4,109

* Note these figures are only for petrol and diesel vehicles with recorded emission standards

10.2 New Zealand new petrol vehicles

Table 10.2 and figure 10.1 compare the monitored 2015 NZN petrol fleet emissions by emission standard. Due to the large differences between the pre- and post-2003 emissions, the results are re-plotted on a second panel in figure 10.1 with a reduced scale on the y axis.

Table 10.2 Comparison of the mean and median emissions of the monitored 2015 NZN petrol fleet by emission standard

Variable	Pre-2003	Post-2003	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.82 (0.31)	0.17 (0.03)	0.19 (0.03)	0.08 (0.01)	0.06 (0.01)	0.04 (0.01)	0.03 (0.01)
NO (ppm)	1,212 (700)	229 (19)	142 (15)	46 (5)	19 (1)	24 (0)	0 (0)
No of readings	3,034	2,305	498	2,030	3,529	1,357	66

Figure 10.1 Comparison of the emissions of the monitored 2015 NZN petrol fleet for vehicles by emission standard

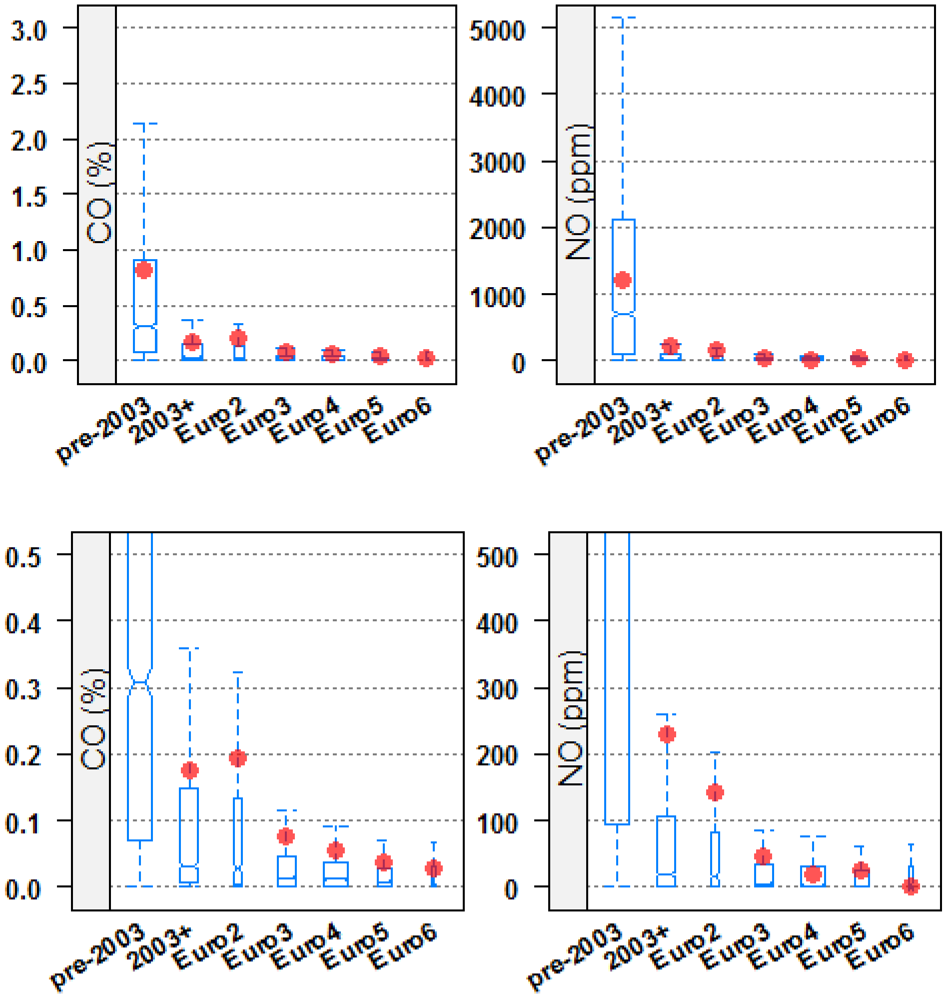


Table 10.2 and figure 10.1 show NZN petrol vehicles manufactured pre-2003 had significantly higher emissions of CO, and NO, on average, than vehicles manufactured post-2003. Significant reductions in measured emissions of CO from NZN petrol vehicles were seen with an improving emission standard out to Euro 5. While the mean value is lower, the difference between CO emissions from a Euro 5 vehicle is not significantly different from a Euro 6 vehicle. Significant reductions in measured emissions of NO from NZN petrol vehicles, on average, were seen with an improving emission standard but only as far as Euro 4. Euro 5 and 6 emissions showed no significant improvement over Euro 4. However, when considering this result it is important to note the small Euro 6 sample size, which may have skewed the result.

10.3 New Zealand new diesel vehicles

Table 10.3 and figure 10.2 compare the monitored 2015 NZN diesel fleet emissions by emission standard.

Table 10.3 Comparison of the mean and median emissions of the monitored 2015 NZN diesel fleet by emission standard

Variable	Pre- 2003	Post- 2003	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.04 (0.02)	0.02 (0)	0.01 (0)	0.01 (0)	0.01 (0)	0.01 (0)	0 (0)
NO (ppm)	672 (553)	699 (553)	757 (552)	708 (605)	614 (425)	711 (607)	419 (193)
No. of readings	452	610	329	497	2308	609	37

Figure 10.2 Comparison of the emissions of the monitored 2015 NZN diesel fleet by emission standard

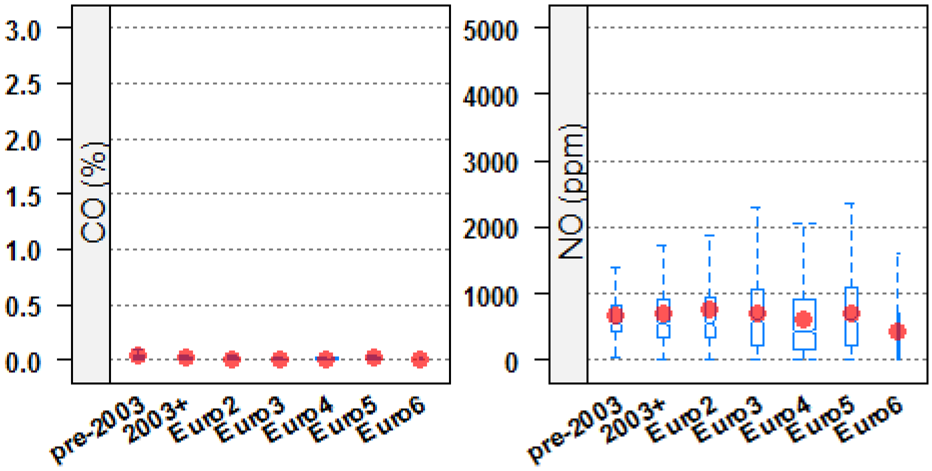


Table 10.3 shows NZN diesel LDVs manufactured pre-2003 had significantly higher emissions of CO, on average, than vehicles built post-2003. For vehicles built to the Euro 2 standard or newer, the measured emissions of CO were consistently around 0.01 mg/m^3 and did not show any improvement with an improving emission standard. For NZN diesel LDVs built prior to the Euro 6 standard, the measured emissions of NO from pre-2003 to Euro 3 and Euro 5 were not significantly different. Emissions of NO from Euro 4 vehicles were significantly lower than pre-Euro 4 and Euro 5 vehicles. While the numbers of monitored NZN diesel LDVs built to the Euro 6 standard are low, table 10.3 and figure 10.2 suggest there may be a significant reduction in emissions of NO compared with previous emission standards. Mean and median emission values are similar and show similar trends, suggesting that mean emission results are not significantly affected by outlier data.

10.4 Japanese used vehicle fleet

The Japanese motor industry has a complicated system of emission standards. The light-duty petrol and diesel vehicle test regimes contain at least 20 and 18 different emission standards, respectively. To simplify the comparisons in this report, the emission standards were grouped into categories covering key years as shown in table 10.4 for JPU petrol vehicles and table 10.5 for JPU diesel vehicles. The emission standard categories were determined based on advice from MoT and generally reflect the major step changes in Japanese emission control legislation that roughly equate to the year of first introduction in Japan.

Table 10.4 Emission standard categories used for the monitored JPU light duty petrol vehicles

Emission standard category		Emission standards covered	No. of petrol vehicles
Pre-1998		C, E, GA, GB, R. T, Z	3,270
1998		GC, GE, GF, HG, J98	1,438
2000–02		GH, GK, LA, LC, TA, TC, UA, ZA, J00/02	3,550
2005		ABA, CBA, CBE, CBF, DAA, DBA	4,451

Table 10.5 Emission standard categories used for the monitored JPU light duty diesel vehicles

Emission standard category	Emission standards covered	No. of diesel vehicles
Pre-1993	K, Q, S, U, Y	229
1993–94	KB, KC, KD	522
1997–99	KE, KF, KG, KH, KJ	213
2002–04	KN, KR	50
2005	ADF	99

10.5 Japanese used petrol vehicles

Table 10.6 and figure 10.3 compare the monitored 2015 JPU petrol fleet emissions by emission standard category.

Table 10.6 Comparison of the mean and median emissions of the monitored 2015 JPU petrol fleet by emission standard

Variable	Pre- 1998	1998	2000–02	2005
	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.8 (0.35)	0.53 (0.23)	0.22 (0.05)	0.13 (0.02)
NO (ppm)	911 (633)	798 (416)	186 (20)	25 (0)
No. of readings	3,270	1,438	3,550	4,451

Figure 10.3 Comparison of the emissions of the monitored 2015 JPU petrol fleet by emission standard category

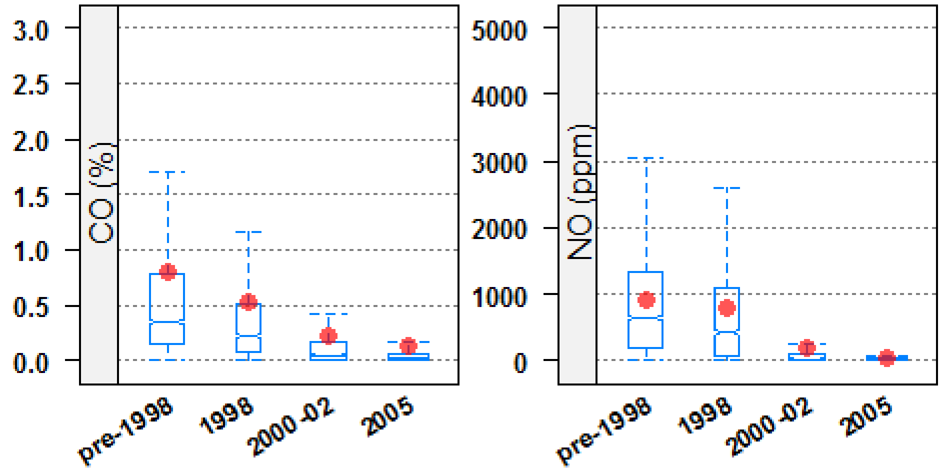


Table 10.6 and figure 10.3 show mean emissions of CO and NO from JPU petrol vehicles all reduced significantly with each change in the emission standard category.

10.6 Japanese used diesel vehicles

Table 10.7 and figure 10.4 compare the monitored 2015 JPU diesel fleet emissions by emission standard category.

Table 10.7 Comparison of the mean and median emissions of the monitored 2015 JPU diesel fleet by emission standard

Variable	Pre- 1993	1993–94	1997–99	2002–04	2005
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.07 (0.02)	0.05 (0.02)	0.02 (0.01)	0 (0.01)	0 (0)
NO (ppm)	502 (452)	470 (457)	578 (491)	865 (936)	719 (539)
No. of measurements	229	522	213	50	99

Figure 10.4 Comparison of the emissions of the monitored 2015 JPU diesel fleet by emission standard category

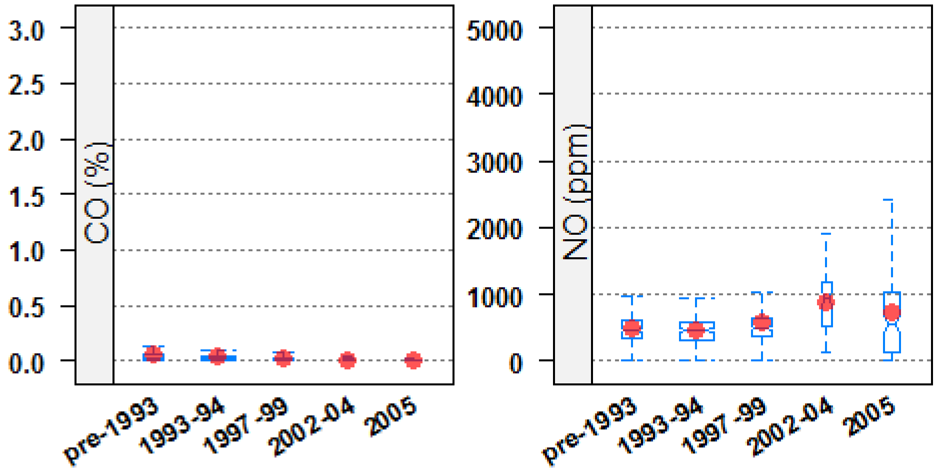


Table 10.7 and figure 10.4 show mean emissions of CO from JPU diesel vehicles improved significantly with each step between 1997–99 and 2005. Table 10.7 and figure 10.4 show emissions of NO from pre-1993 vehicles are not significantly different from those of vehicles built to the 2005 standard. However, there is a significant increase in emissions occurring with the 2002–04 category of emission standard, followed by a significant reduction in the 2005 emission standard.

11 Effect of mileage on emissions – light duty fleet

This chapter evaluates the effect of odometer reading on vehicle emissions as measured in the 2015 monitoring campaign. This analysis was undertaken as odometer reading can be a useful proxy for general vehicle wear and tear and degradation of the emission control system (if fitted). Results are presented for subsets of the fleet by country of first registration (NZN and JPU) and also split for fuel type (petrol or diesel) and emission standard.

The mileage values presented in this chapter were obtained from the motor vehicle registration database, which records the odometer reading at the time a vehicle goes for its WoF inspection. The distribution in odometer readings was determined for each subset of the fleet within the 2015 dataset. From this analysis, two categories within each subset were identified: high mileage (above the 75th percentile) vehicles and low mileage (below the 25th percentile value) vehicles. Emissions were then compared for each of these categories and assessed as to whether any differences found were statistically significant. To establish whether any change in emissions with odometer reading was a gradual or step change process, the vehicles from two specific emission standards for each vehicle type (eg NZN petrol) were selected and their emissions plotted against continuous odometer readings.

11.1 New Zealand new petrol vehicles

Table 11.1 shows the high (75th quartile) and low (25th quartile) odometer readings for the monitored NZN petrol vehicle fleet by emission standard. The differences in odometer reading between the high and low extremes varied considerably across the categories as the newer vehicles had not been in the fleet long enough to travel very far.

Table 11.1 Comparison of the upper and lower quartile odometer readings (km) for the monitored NZN petrol fleet by emission standard

Odometer reading (km)	Pre- 2003	2003+	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
low (25th quartile)	153,530	93,910	99,727	74,866	18,528	21	11
high (75th quartile)	257,684	183,750	176,042	144,274	76,586	31,022	105

Note: Lower quartiles for the Euro 5 and Euro 6 bins are dominated by vehicles that were brand new when their odometer reading was last recorded by MoT, and therefore are likely to be underestimates of their true mileage at the time of emission monitoring.

Figure 11.1 compares emissions for high and low mileage monitored NZN petrol vehicles by emission standard. Table 11.2 summarises the mean and median values for CO and NO and highlights (in bold) whether any differences between the high and low mileage vehicles were statistically significant.

Figure 11.1 Comparison of the emissions of the monitored high and low mileage NZN petrol vehicles by emission standard

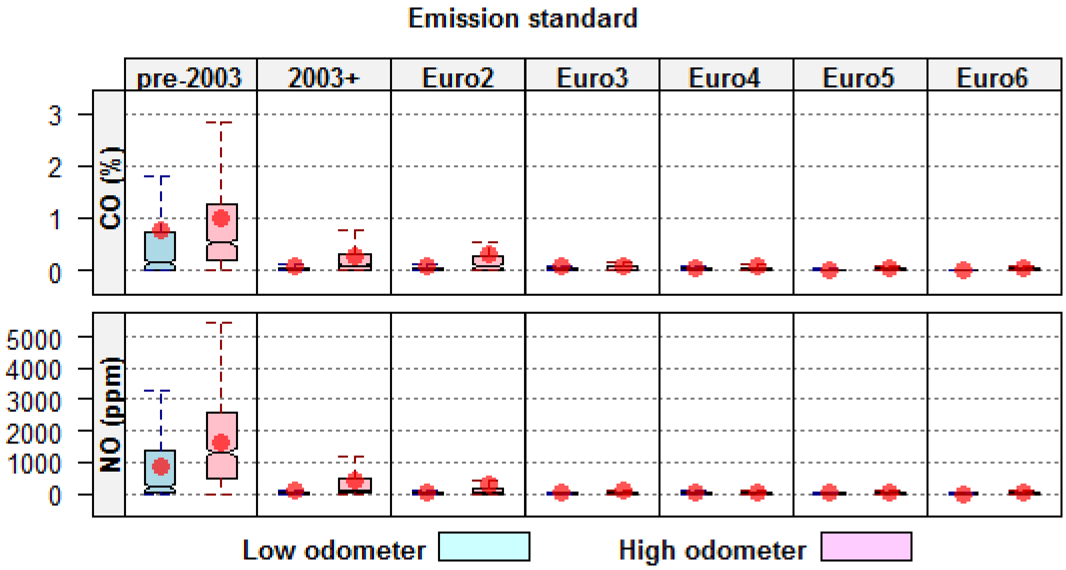


Table 11.2 Comparison of the emissions of the monitored high and low mileage NZN petrol vehicles by emission standard

Emission standard		CO (%)		NO (ppm)	
		Low km	High km	Low km	High km
Pre- 2003	Mean	0.751	1.014	835.2	1627.0
	Median	0.140	0.536	202.0	1318.9
2003+	Mean	0.089	0.286	80.5	441.5
	Median	0.010	0.093	4.5	73.9
Euro 2	Mean	0.066	0.327	60.5	271.3
	Median	0.019	0.078	5.1	27.7
Euro 3	Mean	0.063	0.091	28.1	76.8
	Median	0.010	0.015	1.5	11.5
Euro 4	Mean	0.039	0.079	13.6	44.2
	Median	0.008	0.019	1.6	8.9
Euro 5	Mean	0.015	0.052	18.2	51.4
	Median	0.004	0.008	0.0	4.4
Euro 6	Mean	0.003	0.029	0.0	16.6
	Median	0.005	0.021	0.0	0.0

Note the values shown in **bold** and in grey cells are statistically significantly different from each other.

Mean CO and NO emissions were consistently and significantly higher for the high mileage NZN petrol vehicles than for the low mileage vehicles, irrespective of emission standard up to and including Euro 6 although the Euro 6 result must be treated with some caution because of the small sample size.

A step change is exhibited between the pre-2003 fleet and subsequent standards both for low and high mileage vehicles.

For NO there is a significant difference between the low and high mileage vehicles for the Euro 4 and earlier standards with the ratio of medians ranging from approximately 5 to 16 (high mileage: low mileage). For these vehicles the ratio of means to medians is also generally high (up to approximately 19 x mean:median). These findings emphasise the difference in emissions between low and high mileage vehicles in general, and also suggest that within the mileage bands gross emitters have a significant effect on the mean.

Figure 11.2 investigates the mileage trends further by comparing the emission of the pre-2003 NZN petrol fleet by odometer reading. The pre-2003 subset was selected for this analysis because it contained:

- a relatively high number of vehicles (2,700 in total)
- vehicles that had travelled the most kilometres (on average)
- vehicles with little or no emission control equipment.

Figure 11.2 Comparison of the emissions of the monitored pre- 2003 NZN petrol vehicles by odometer reading (000s km)

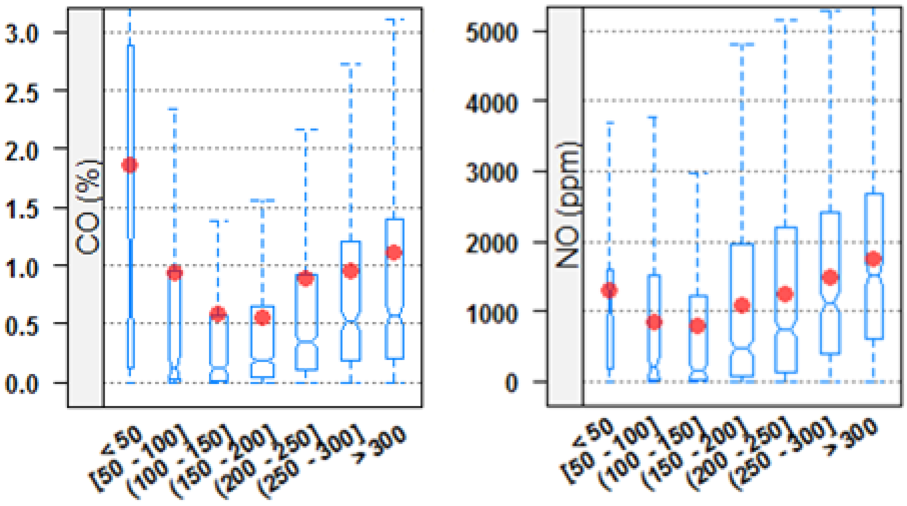


Figure 11.2 shows emissions of CO and NO from pre-2003 NZN petrol vehicles steadily increased as the odometer readings went from 100,000km to more than 300,000km. However, emissions from vehicles with odometer readings of less than 50,000km were unexpectedly high, which may have been caused by a number of factors including small sample size, ‘clocked’ five digit odometers and increased running in emissions.

Figure 11.3 investigates the mileage trends further by comparing the emission of the Euro 4 petrol fleet by actual odometer reading. The Euro 4 subset was selected for this analysis because it contained:

- a relatively high number of vehicles (3,051 in total)
- vehicles that had travelled sufficient kilometres to show the potential effect of wear
- vehicles with relatively good emission control equipment.

Figure 11.3 Comparison of the emissions of the monitored Euro 4 NZN petrol vehicles by odometer reading (000s km)

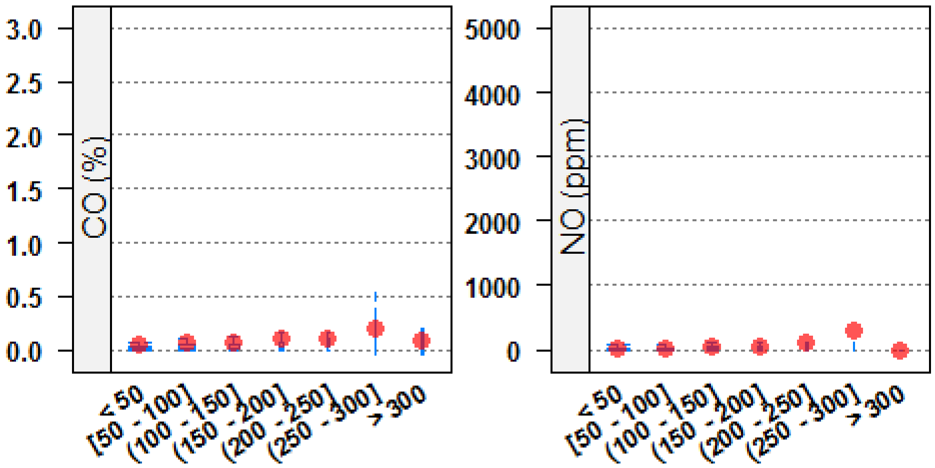


Figure 11.3 shows emissions of CO from Euro 4 vehicles are consistently low for vehicles that have travelled up to 150,000km. A slight increase is seen in CO emissions for vehicles that have travelled between 150,000 and 300,000km. An unexpected decrease is also seen in CO emissions from vehicles that have travelled more than 300,000km, which may be an artefact of a small sample size. Figure 11.3 shows emissions of NO from Euro 4 vehicles are consistently low for vehicles that have travelled up to 200,000km. A slight increase is seen in NO emissions for vehicles that have travelled between 200,000 and 300,000km. An unexpected decrease in NO emissions is seen in vehicles that have travelled more than 300,000km, which may be an artefact of a small sample size.

The results displayed in figure 11.3 suggest that Euro 4 emission control technology continues to be effective for vehicles that have travelled high kilometres. There may be some small deterioration in the effectiveness of Euro 4 emission control technology at very high odometer readings (>200,000km).

11.2 New Zealand new diesel vehicles

Table 11.3 shows the high (75th quartile) and low (25th quartile) odometer readings for the monitored NZN diesel vehicle fleet by emission standard.

Table 11.3 Comparison of the upper and lower quartile odometer readings (km) for the monitored NZN diesel fleet by emission standard

Odometer reading (km)	Pre- 2003	2003+	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
low (25th quartile)	217,021	113,350	155,055	97,730	13,466	8046	13
high (75th quartile)	323,285	225,891	232,219	186,457	86,140	51,731	1042

Note: Upper and lower quartiles for the Euro 6 bins is dominated by vehicles which were brand new when their odometer reading was last recorded by MoT and therefore are likely to be underestimates of their true mileage.

Figure 11.4 compares emissions for high and low mileage monitored NZN petrol vehicles by emission standard.

Table 11.4 summarises the mean and median values for CO and NO and highlights (in bold) whether any differences between the high and low mileage vehicles were statistically significant.

Figure 11.4 Comparison of the emissions of the monitored high and low mileage NZN diesel vehicles by emission standard

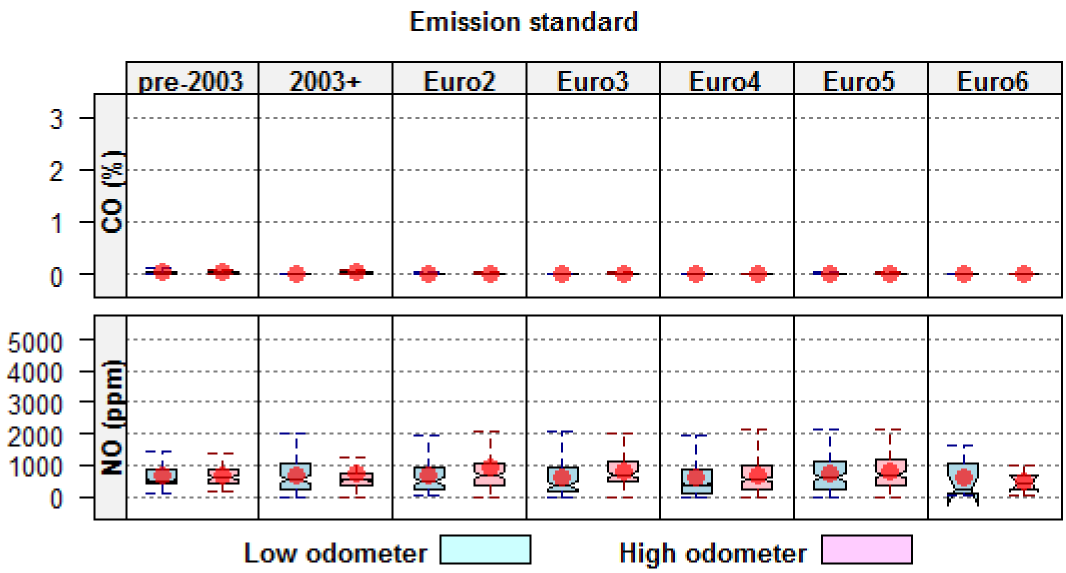


Table 11.4 Comparison of the emissions of the monitored high and low mileage NZN diesel vehicles by emission standard

Emission standard		**CO (%)**		**NO (ppm)**	
		Low km	**High km**	**Low km**	**High km**
Pre- 2003	Mean	0.055	0.034	657.8	679.1
	Median	0.021	0.017	509.3	579.1
2003+	**Mean**	**0.015**	**0.029**	690.2	713.0
	Median	**0.000**	**0.009**	547.7	514.8
Euro 2	Mean	0.009	0.005	**671.4**	**905.7**
	Median	0.000	0.003	**486.2**	**659.8**
Euro 3	**Mean**	**0.005**	**0.010**	**596.7**	**811.2**
	Median	**0.000**	**0.000**	**334.0**	**693.4**
Euro 4	Mean	0.000	0.016	**574.5**	**698.0**
	Median	0.000	0.000	**380.3**	**526.9**
Euro 5	Mean	0.006	0.014	724.0	794.9
	Median	0.003	0.005	610.8	695.6
Euro 6	Mean	0.000	0.004	611.6	457.5
	Median	0.000	0.003	193.2	433.6

Note: The values shown in **bold** and grey cells are statistically significantly different from each other

Figure 11.4 and table 11.4 show that odometer readings had a significant impact on the CO emissions for the 2003 and Euro 3 vehicles where there was an increase for the higher odometer vehicles. Figure 11.4 and table 11.4 show that odometer readings had a significant impact on the NO emissions for the Euro 2, Euro 3 and Euro 4 vehicles where there was a significant increase for the higher odometer vehicles.

Figure 11.5 compares the CO and NO emissions of the pre-2003 NZN diesel fleet against odometer reading. The pre-2003 subset was selected because it contained:

- a relatively high number of vehicles (535 in total)
- vehicles that had travelled the most kilometres (on average)
- vehicles with little or no emissions control equipment.

Figure 11.5 Comparison of the emissions of the monitored pre- 2003 NZN diesel vehicles by odometer reading (000s km)

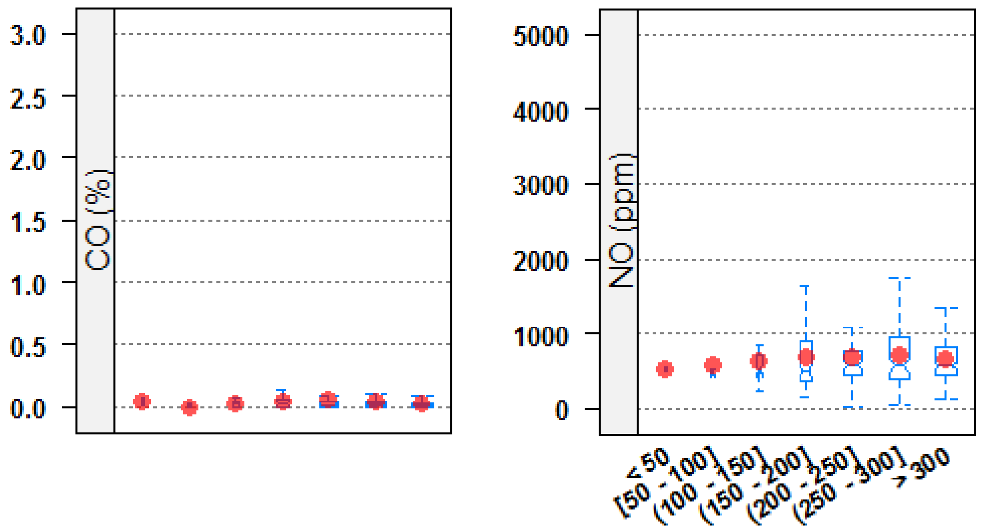


Figure 11.5 shows mean emissions of CO from pre-2003 NZN diesel vehicles trended upward very weakly with increasing odometer readings. NO emissions trended upward with odometer readings up to 200,000km. No obvious trend was observed with increasing mileage when odometer readings were above 200,000km

Figure 11.6 compares the CO and NO emissions of Euro 4 NZN diesel fleet against odometer reading. The pre-2003 subset was selected because it contained:

- a relatively high number of vehicles (1,939 in total)
- vehicles that had travelled sufficient kilometres to show the potential effect of wear
- vehicles with relatively good emission control equipment.

Figure 11.6 Comparison of the emissions of the monitored Euro 4 NZN diesel vehicles by odometer reading (000s km)

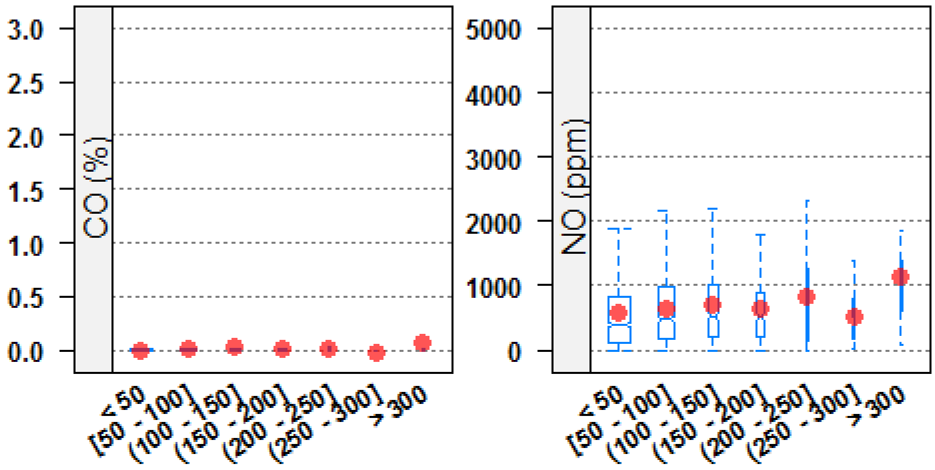


Figure 11.6 shows there is no trend in mean emissions of CO from Euro 4 NZN diesel vehicles with increasing odometer readings. NO emissions show a slight trend upward with odometer reading up to 150,000km. No trend in NO emissions was observed with increasing mileage when odometer readings were above 150,000km.

11.3 Japanese used petrol vehicles

Table 11.5 shows the high (75th quartile) and low (25th quartile) odometer readings for the monitored JPU petrol vehicle fleet by emission standard.

Table 11.5 Comparison of the upper and lower quartile odometer readings (km) for the monitored JPU petrol fleet by emission standard

Odometer reading (km)	Pre- 1998	1998	2000-02	2005
low (25th percentile)	164,804	142,760	107,722	66,980
high (75th percentile)	237,666	206,003	166,750	118,769

Figure 11.7 compares emissions for high and low mileage monitored JPU petrol vehicles by emission standard. Table 11.6 summarises the mean and median values for CO and NO and highlights (in bold) whether any differences between the high and low mileage vehicles were statistically significant.

Figure 11.7 Comparison of the emissions of the monitored high and low mileage JPU petrol vehicles by emission standard

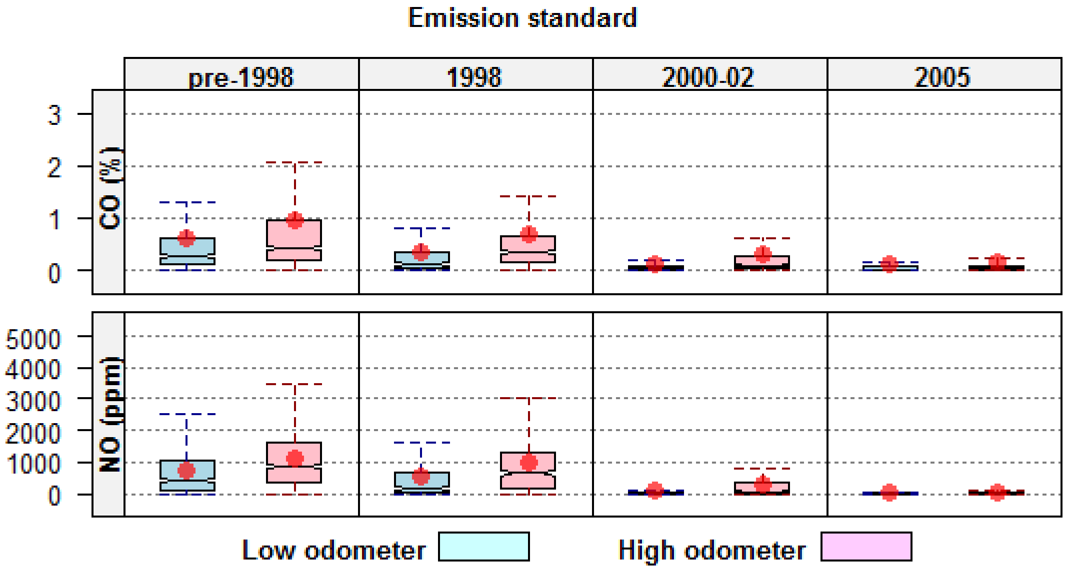


Table 11.6 Comparison of the emissions of the monitored high and low mileage JPU petrol vehicles by emission standard

Emission standard		CO (%)		NO (ppm)	
		Low km	High km	Low km	High km
Pre- 1998	Mean	0.6	1.0	737.7	1095.3
	Median	0.3	0.4	424.8	835.6
1998	Mean	0.3	0.7	539.7	969.6
	Median	0.1	0.3	141.0	650.2
2000–02	Mean	0.1	0.3	92.2	314.8
	Median	0.0	0.1	8.3	49.0
2005	Mean	0.1	0.2	4.2	42.4
	Median	0.0	0.0	0.0	3.5

Note: The values shown in **bold** and highlighted are statistically significantly different from each other

Figure 11.7 and table 11.6 show mean and median emissions of CO and NO pollutants were consistently and significantly higher (means approximately two times or more for CO and up to 10 times more for NO) for the high mileage JPU petrol vehicles than for the low mileage vehicles, for all emission standards. The ratio of mean to median NO emissions were relatively high for the more recent 2000–02 and 2005 standards for both low and high mileage vehicles when compared with the older pre-1998 and 1998 standards. This suggests that gross emitters have a significant impact on the mean emissions for the more recent standards but less of an impact on the emissions for the earlier standards. For the earlier standards, the mean NO emissions from the high mileage vehicles converge on the median suggesting the elevated emissions are generally associated with this segment of the fleet.

Figure 11.8 compares the CO and NO emissions of pre-1998 JPU petrol fleet against odometer reading. The pre-1998 subset was selected because it contained:

- a relatively high number of vehicles (3,270 in total)
- vehicles that had travelled the most kilometres (on average)
- vehicles with basic or no emissions control equipment.

Figure 11.8 Comparison of the emissions of the monitored pre- 1998 JPU petrol vehicles by odometer reading (000s km)

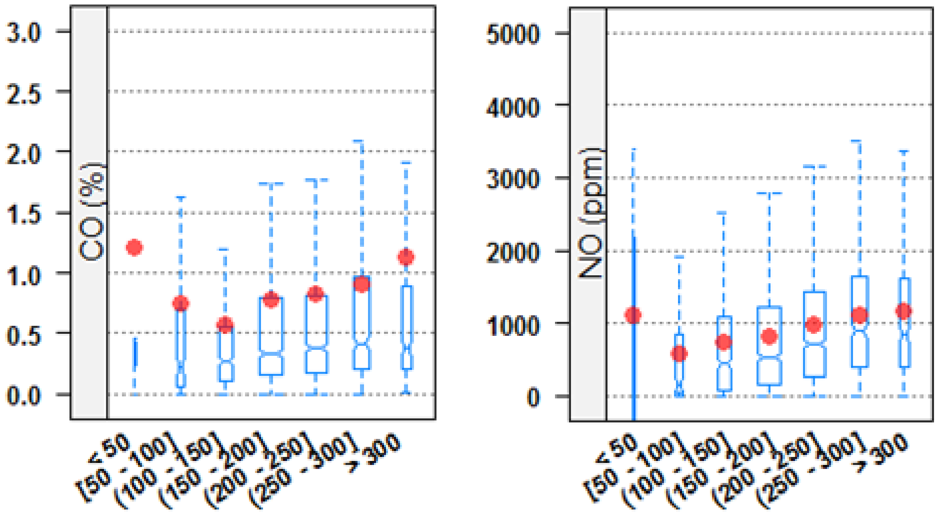


Figure 11.8 shows emissions of CO from pre-1998 JPU petrol vehicles steadily increased for vehicles with odometer readings above 100,000km, and shows that emissions of NO from pre-1998 JPU petrol vehicles steadily increased for vehicles with odometer readings above 50,000km.

However, as in the case of the NZN petrol fleet, emissions from vehicles with odometer readings of less than 100,000km for CO and less than 50,000km for NO were unexpectedly high. This may have been caused by a number of factors including a small sample size, vehicles going ‘around the clock’, and ‘running in’ emissions, although this last factor is unlikely for pre-1998 vehicles.

Figure 11.9 compares the CO and NO emissions of 2000-02 JPU petrol fleet against odometer reading. The 2000–02 subset was selected because it contained:

- a relatively high number of vehicles (3,350 in total)
- vehicles that had travelled sufficient kilometres to show the potential effect of wear
- vehicles with relatively good emission control equipment.

Figure 11.9 Comparison of the emissions of the monitored 2000–02 JPU petrol vehicles by odometer reading (000s km)

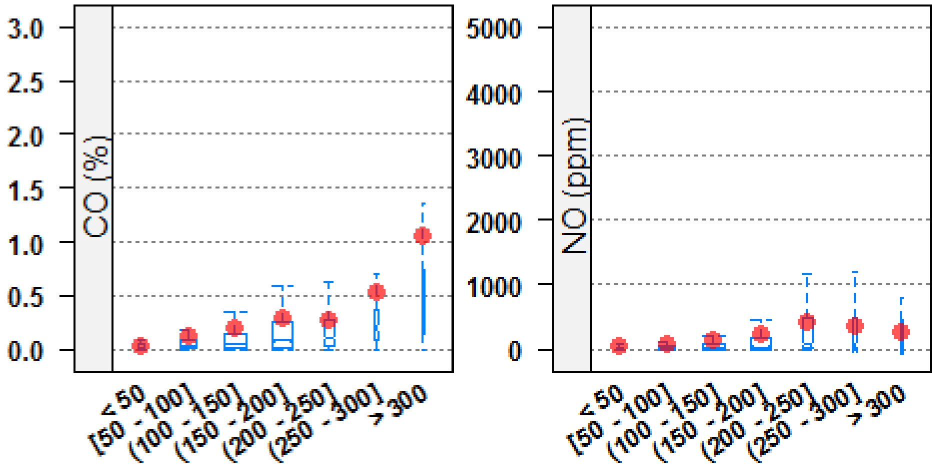


Figure 11.9 shows that the emissions of CO from 2000–02 JPU petrol vehicles increased significantly as the odometer readings went from 50,000km to more than 300,000km. Figure 11.9 shows that the emissions of NO from 2000–02 JPU petrol vehicles were small and steadily increased as the odometer readings went from 50,000km to more than 250,000km, but then shows an unexpected decrease for higher odometer readings. This result may be an artefact of the small number of data points in this mileage category or the fact that these very high mileage vehicles were running with a relatively high air/fuel ratio which brings down NO_x emissions. The results seen in figure 11.9 suggest that for 2000–02 for JPU petrol vehicles, emission control technology appeared to deteriorate as the vehicle travelled an increasing number of kilometres. The observed deterioration is more consistent for CO than NO. The Japan 2000–02 petrol standard is more comparable to Euro 3 than to Euro 4 especially with respect to longevity of the emission control technology. While Japan 2000–02 technology appears to reduce in effectiveness over time, a direct comparison cannot be made with the NZN analysis above.

11.4 Japanese used diesel vehicles

Table 11.7 shows the high (75th quartile) and low (25th quartile) odometer readings for the monitored JPU diesel vehicle fleet by emission standard.

Table 11.7 Comparison of the upper and lower quartile odometer readings (km) for the monitored JPU diesel fleet by emission standard

Odometer reading (km)	Pre- 1993	1993-94	1997-99	2002-04	2005
low (25th quartile)	205,713	206,631	199,234	135,311	116,908
high (75th quartile)	303,004	294,776	294,539	217,916	176,367

Figure 11.10 compares emissions for high and low mileage monitored JPU diesel vehicles by emission standard. Table 11.8 summarises the mean and median values for CO and NO and highlights (in bold) whether any differences between the high and low mileage vehicles were statistically significant.

Figure 11.10 Comparison of the emissions of the monitored high and low mileage JPU diesel vehicles by emission standard

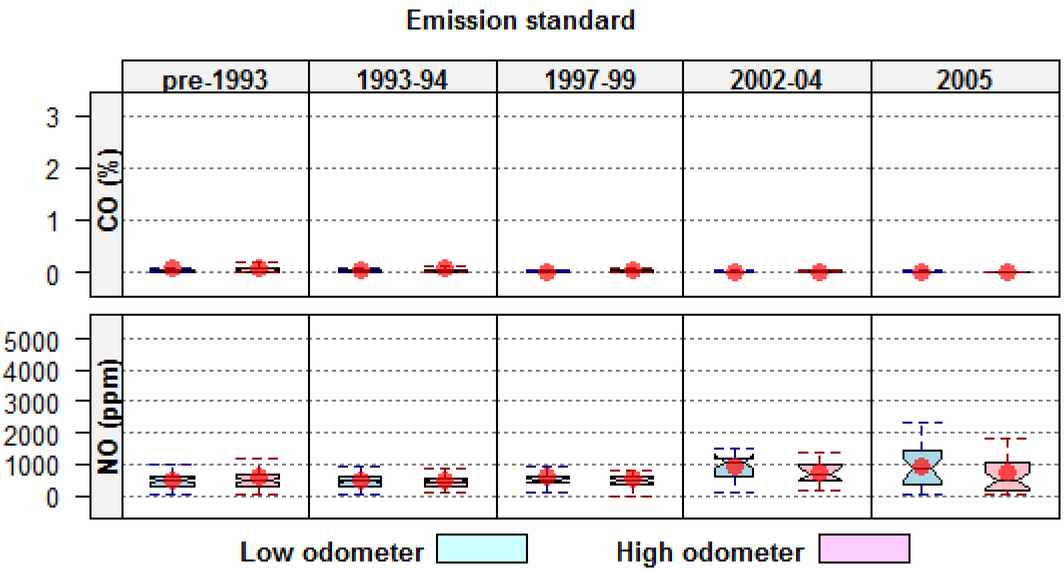


Table 11.8 Comparison of the emissions of the monitored high and low mileage JPU diesel vehicles by emission standard

Emission standard		CO (%)		NO (ppm)	
		Low km	High km	Low km	High km
Pre- 1993	Mean	0.087	0.080	456.8	619.9
	Median	0.019	0.021	463.3	484.2
1993-94	Mean	0.035	0.061	449.6	485.0
	Median	0.014	0.018	457.6	431.9
1997-99	Mean	0.022	0.054	581.5	547.4
	Median	0.010	0.012	489.8	456.4
2000-02	Mean	0.000	0.010	908.9	724.6
	Median	0.002	0.017	1,077.3	690.2
2005	Mean	0.000	0.000	925.1	732.1
	Median	0.001	0.000	860.2	452.1

Note: The values shown in **bold** and highlighted are statistically significantly different from each other.

Figure 11.10 and table 11.8 show there does not appear to be any significant deterioration (increase) in CO or NO emissions with mileage for JPU diesel vehicles.

Figure 11.11 compares the CO and NO emissions of the pre-1993 JPU diesel fleet against odometer reading. The pre-1993 subset was selected because it contained:

- a relatively high number of vehicles (229 in total)
- vehicles that had travelled the most kilometres (on average)
- vehicles with little or no emission control equipment.

Figure 11.11 Comparison of the emissions of the monitored pre-1993 JPU diesel vehicles by odometer reading (000s km.

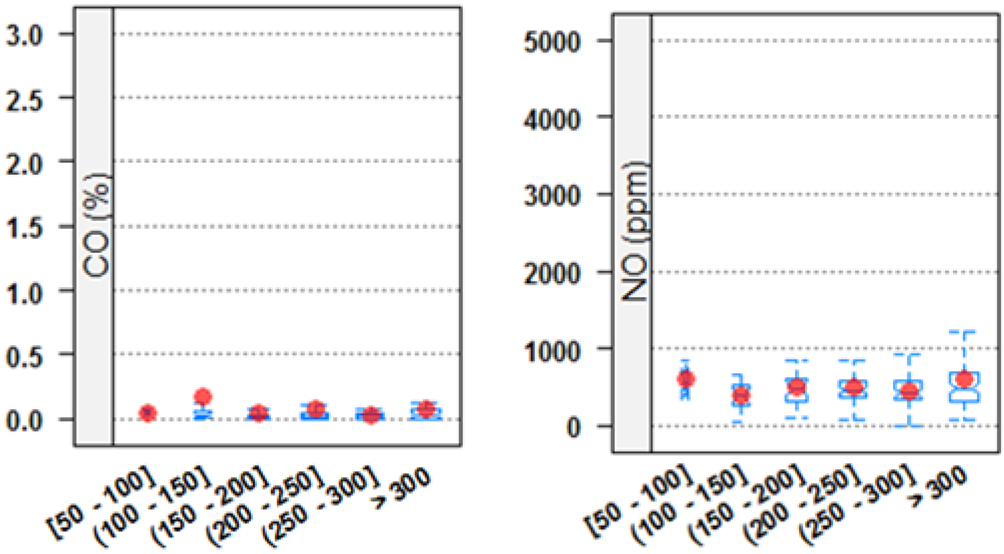


Figure 11.11 shows mean emissions of CO and NO from pre-1993 JPU diesel vehicles have no obvious trend with increasing odometer reading.

Figure 11.12 compares the CO and NO emissions of the 1997–99 JPU diesel fleet against odometer reading. The 1997–99 subset was selected because it contained:

- a relatively high number of vehicles (213 in total)
- vehicles that had travelled sufficient kilometres to show the potential effect of wear
- vehicles with relatively good emission control equipment.

Figure 11.12 Comparison of the emissions of the monitored 1997–99 JPU diesel vehicles by odometer reading (000s km)

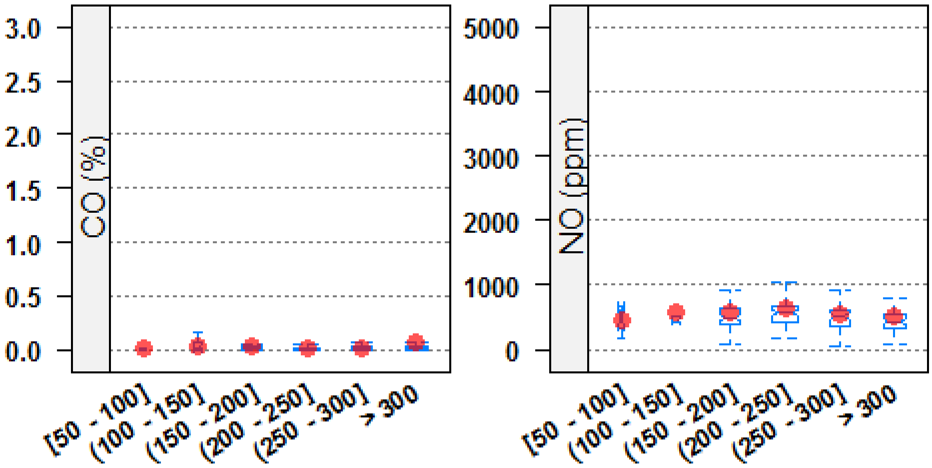


Figure 11.12, figure 11.10 and table 11.8 show there does not appear to be any significant deterioration (increase) in CO or NO emissions with mileage from 1997–99 JPU diesel vehicles.

12 Explaining trends in air quality at two roadside sites

This information presented in this chapter addresses research objective number 5:

> Report on the likely underlying causes for the trends observed in vehicle emissions and roadside ambient air quality.

The main drivers of the long-term trends in pollutant concentrations at roadside air quality monitoring sites are:

- the number of vehicle trips per day past the site
- fleet profile (changes in vehicle age distribution, vehicle types (eg LDV, HDD) and fuel type (eg petrol, diesel)
- driving conditions (eg congested or free flowing)
- real-world emission performance of vehicles (effectiveness of emission control technology, fuel quality).

This chapter will use the information on vehicle emissions provided in chapters 5 to 11 to explain the underlying causes for the observed trends in air quality at the two case roadside monitoring sites detailed in chapter 3.

12.1 Carbon monoxide

The analysis of data from the Riccarton Road site shows there was a steady decrease in annual average CO concentrations from 2006 to 2014. In 2006 the annual average CO concentration was 1.3mg/m^3 and in 2014 it was 0.7mg/m^3. This is a 52% reduction in average CO concentration since 2006. From 2006 to 2009 the number of vehicles passing the Riccarton Road site remained relatively constant at approximately 25,000 per day, whereas from 2010 to 2014 this decreased by approximately 5%. The high-level information available on fleet composition (LDV/HDV) suggests that the mix of vehicle types passing the site did not change significantly from 2006 to 2013.

The analysis of data from the Khyber Pass Road site also shows there was a steady decrease in annual average CO concentrations from 2006 to 2014. In 2006 the annual average CO concentration was 1.6mg/m^3 and in 2014 it was 0.6mg/m^3. This represents a 63% reduction in average CO concentration since 2006. This trend is consistent with what was observed at Riccarton Road during the same period. The amount and quality of data available on the number of vehicles passing the Khyber Pass Road site is limited. However, the available data suggests the AADT remained relatively constant at approximately 27,500 per day from 2004 to 2013. There is no site-specific information available on fleet composition. It was assumed that the trends in Khyber Pass Road fleet composition would follow the trends of the wider Auckland region.

Driving conditions have not been quantitatively assessed for either case study site – except that Riccarton Road is flat and Khyber Pass Road is on a grade. The main factors determining the level of roadway congestion are vehicle numbers per day, fleet composition and changes in traffic management (eg signal settings) and road design. Considering the lack of any obvious change in vehicle numbers or fleet composition, a qualitative assessment of the trends of driving conditions at both case study sites suggests there was not any significant change in roadway congestion at either site over the study period.

A comparison of the Riccarton and Khyber Pass Road case studies sites shows a number of similarities from 2006 to 2013:

- significant decrease in roadside CO concentrations
- stable vehicle numbers
- small if any changes in the LDV/HDV composition of the vehicle fleet passing the site.

The analysis of RSD CO vehicle emission data shows that from 2003 to 2015 average emissions from vehicles in the:

- LDV fleet decreased by approximately 60%
- HDV fleet decreased by approximately 54%.

The information collected for this study suggests the underlying causes for the observed trend in roadside CO concentrations from 2006 to 2014 were:

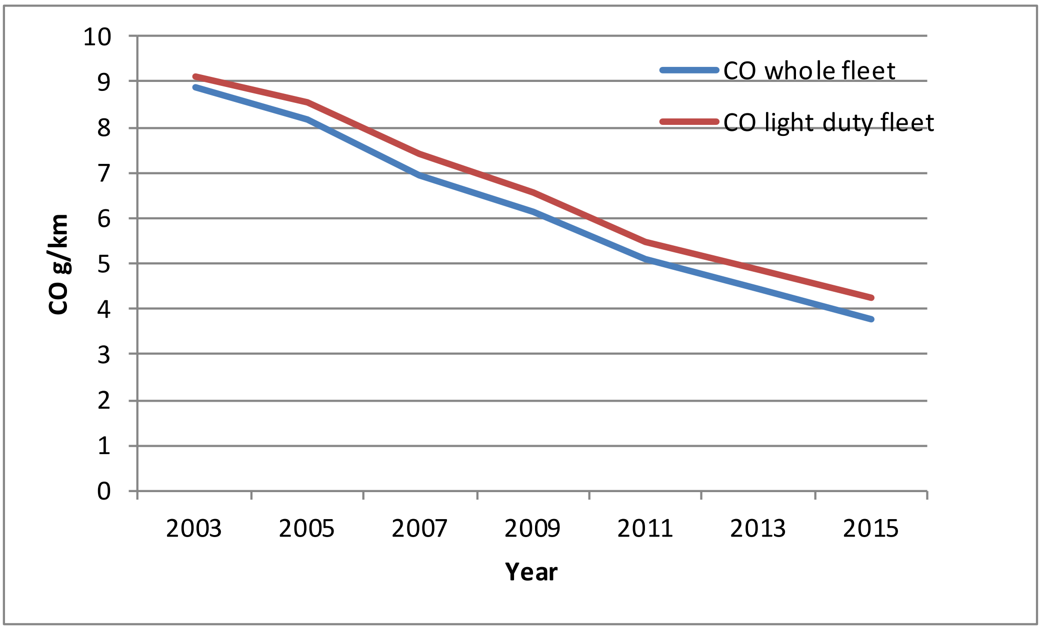
- steady traffic numbers, the LDV/HDV fleet composition and driving conditions (neutral pressure)
- reduced CO emissions from both LDV and HDV sectors of the vehicle fleet (downward pressure).

The observed decrease in on-road vehicle CO emission measurements can be used to check the theoretical decrease in emissions as a result of changes in emission control technology. To do this, the VEPM was used to track the theoretical trends in CO emissions over the study period. VEPM is described in detail in Jones et al (2011) and in the *Vehicle emissions prediction model (VEPM 5.1) users guide* (http://air.nzta.govt.nz/predictions/nz-vepm).

Figure 12.1 shows VEPM predictions of CO emission factors from 2003 to 2015 for the complete fleet (96% LDVs and 4% HDVs) and for the LDV fleet (82% petrol 18% diesel).

Figure 12.1 shows VEPM predicted CO emission factors would decrease by approximately 55% between 2003 and 2015. This closely aligns with the observed decrease in average on-road RSD measurements and suggests that the anticipated improvements in air quality due to changes in emission control technology were being realised at the tail-pipe and roadside with regards to CO emissions.

Figure 12.1 CO emission factors - 2003–2015



In conclusion, the RSD data suggests the decline in near-road CO concentrations was largely a result of significantly improved emission performance of LDVs. The trends in roadside monitoring, remote sensing monitoring and VEPM show consistent results with respect to CO. The roadside and RSD results provide useful high-level information to assist with the validation of the trends in CO emission factors predicted by VEPM from 2003 to 2015. However these conclusions are subject to the following limitations:

- Site-specific traffic volumes are not well defined.
- Site-specific fleet compositions are not well defined and may not match the fleet composition as measured by the RSD.
- Driving conditions (vehicle speed and acceleration) at the sites may not match those measured by the RSD.
- Trends in RSD measurements may not match trends in total emissions.

These limitations are considered in section 15.2.

12.2 Oxides of nitrogen

The amount of NO_x data available for Riccarton Road site over the study period is limited. However, using the data available, an analysis shows that for the summer months (December and January) the NO_x monthly average concentrations were relatively constant from 2006 to 2014 (approximately 75µg/m³). There is no sustained upward or downward trend for roadside monthly average concentrations of NO_x over the study period.

The NO_x air quality data record from Khyber Pass Road over the study period is more complete. The analysis of data from the Khyber Pass Road site shows there was a decrease in annual average NO_x concentrations from 2006 to 2014. In 2006 the annual average NO_x concentration was 180µg/m³ and in 2014 it was 110µg/m³. This represents a 40% reduction in annual average NO_x concentration since 2006. However, almost 90% of this reduction occurred between 2006 and 2010. Since 2010, annual average NO_x concentrations have been relatively stable, at around 115µg/m³.

A comparison of the NO_x data from Riccarton and Khyber Pass Road case study sites shows:

- sparse data is available for Riccarton Road prior to 2010
- there was a significant decrease in concentration (40%) at Khyber Pass Road between 2006 and 2010 but insufficient data to confirm a similar trend, or otherwise at Riccarton
- relatively stable concentrations at both sites from 2010 to 2014.

A comparison of the other relevant variables from Riccarton and Khyber Pass Road case study sites shows:

- stable vehicle counts
- small if any changes in the LDV/HDV composition of the vehicle fleet passing the site.

It is generally considered that most NO_x emissions in vehicle exhaust are emitted as NO and this is converted to NO_2 by oxidation in the atmosphere. The principal oxidation reaction is with ozone (O_3). This reaction is rapid and proceeds until either the ozone is depleted or all NO is converted to NO_2. RSDs have traditionally measured CO, HCs and NO, and UVsmoke. More recently, RSD equipment has expanded to measure other pollutants such as NH_3, NO_2 and SO_2.

NO_x emissions from motor vehicles are expressed as NO_2-equivalents, and include both NO and NO_2. Direct use of NO data from RSD would therefore result in an underestimation (bias) of RSD based NO_x emission rates. Therefore, two steps are needed to properly define NO_x in remote sensing data, ie 1) apply a correction factor to the RSD data to account for primary NO_2 emissions, and 2) express corrected RSD data as NO_2 equivalents (NIWA 2015).

At fleet level, primary NO_2 emissions are typically a small but significant portion of NO_x emissions. The NO_2-to-NO_x mass ratio is expected to be minor and in the order of 10–15% at fleet level (eg Carslaw et al 2005; Smit and Bluett 2011). This was confirmed by a recent tunnel study in Brisbane, Australia, which measured ratios typically close to 15% during times of day with significant traffic volumes (6am – 8am). This was found to be in line with the value of 13% predicted by COPERT Australia (DSITI 2015).

Increasing NO_2 emissions from motor vehicles over time have been reported in a number of studies (Grice et al 2009; Keuken et al 2012), whereas others have reported only small reductions in NO_2 emissions in comparison with large reductions in NO_x (Rexeis and Hausberger 2009 ; Zamboni et al 2009). The main reason for this is an increasing NO_2-to-NO_x mass ratio in diesel vehicle exhaust. The latter is due to the use of specific emission control technology such as diesel oxidation catalysts and certain types of diesel particulate filter. Measurements have shown that NO_2-to-NO_x mass ratios for individual vehicles can be as high as 0.75 (eg Gense et al 2006).

There is usually an excess of NO in the air, so the limit to its oxidation is often the depletion of available O_3. Under this assumption, controls aimed to reduce NO_x emissions might have only a small impact on local NO_2 concentrations, as it is not the availability of NO_x that is the limiting factor. However, if a significant proportion of the NO_x emissions is NO_2, as is increasingly the case, primary NO_2 emissions will add directly to local concentrations irrespective of the presence of ozone. Accordingly, reducing NO/NO_2 emissions will contribute to the control of NO_2 concentrations near to roads.

Given the above, the following conclusions are made with respect to the importance of accurate estimates of the proportion of primary NO_2 emissions in NO_x in a trend analysis using RSD data for NO.

- As the proportion of primary NO_2 emissions at fleet level is relatively small and relatively stable in time, consideration of primary NO_2 is less important for trend analysis at fleet level.

- However, for trend analysis that specifically examines individual vehicle classes, it is essential to have accurate estimates of primary NO_2 emissions at vehicle class/technology level. And this is particularly the case for diesel vehicle classes.

The analysis of RSD NO vehicle emission data shows that from 2003 to 2015 average NO emissions from vehicles in the:

- LDV fleet decreased by approximately 45%
- HDV fleet remained stable.

A more detailed breakdown of the RSD NO vehicle emission data from period 2003 to 2015 suggests:

- reduced average emissions from LDV petrol fleet
- increased average emissions from the LDV diesel fleet
- increasing proportion of diesel vehicles within the LDV fleet
- increasing effect of older and gross emitting LDV petrol vehicles
- steady average emissions from the HDV fleet.

The information collected for this study suggests that the underlying causes for the observed trend in roadside NO_x concentrations from 2006 to 2014 were:

- steady traffic numbers, LDV/HDV fleet composition and driving conditions (neutral pressure)
- reduced average emissions from LDV petrol fleet (downward pressure)
- increased average emissions from the LDV diesel fleet (upward pressure)
- increasing proportion of diesel vehicles within the LDV fleet (upward pressure)
- steady average emissions from the HDV fleet (neutral pressure)
- increasing effect of older and gross emitting LDV petrol vehicles (upward pressure).

This is a complex set of variables and further data collection (eg traffic count and meteorology) and statistical analysis would be required to determine how much each of these individual factors contributes to the observed trend in roadside NO_x concentrations. However, it appears that from 2006 to 2010 the downward pressures were greater than the upward pressures, which resulted in an improvement in roadside NO_x concentrations. From 2010 to 2014 the downward pressures were more or less balanced by the upward pressures, which combined to result in relatively stable roadside NOx concentrations.

The observed decrease in on-road vehicle NO emission measurements can be used to check the theoretical decrease in emissions as a result of changes in emission control technology. To do this, VEPM was used to track the theoretical trends in NO_x emissions over the study period. A comparison between the trends in predicted NO_x and RSD observed NO emissions provided a useful starting point to explore whether the anticipated improvements in air quality due to changes in vehicle fleet composition and emission control technology were being realised.

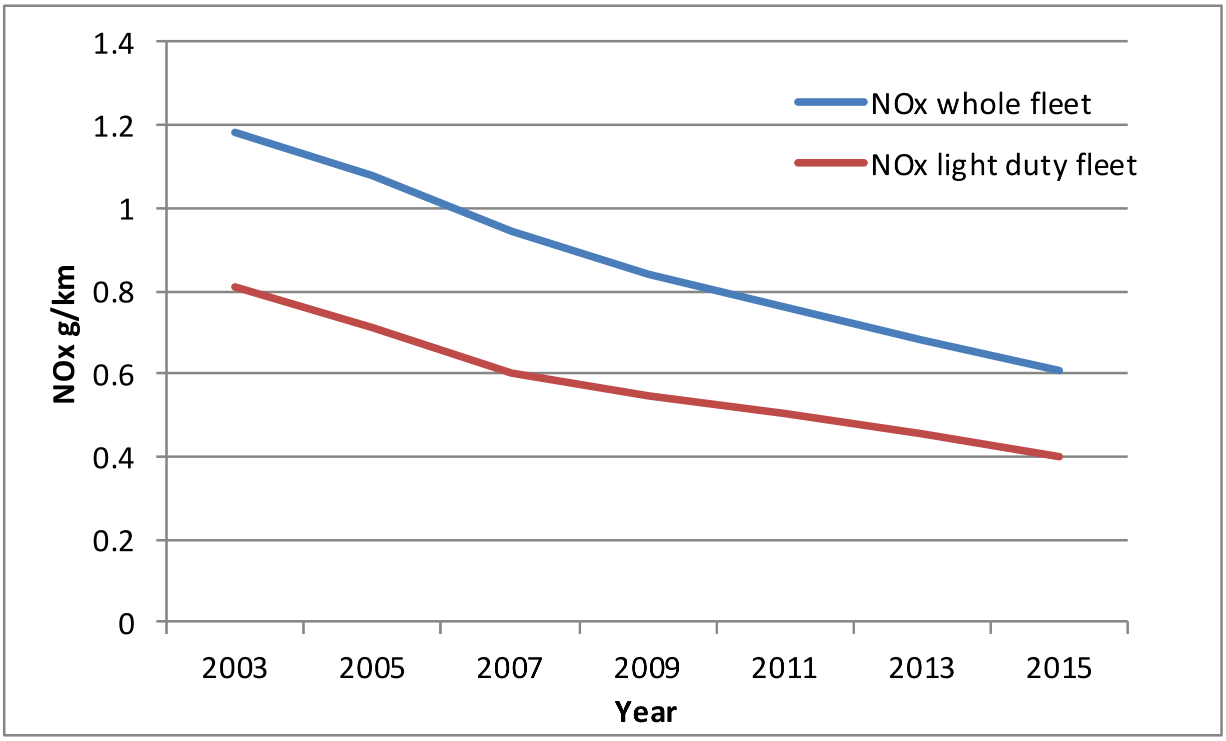
Figure 12.2 shows VEPM predictions of fleet-weighted average NO_x emissions from 2003 to 2015 for the complete fleet (96% LDVs and 4% HDVs) and for the LDV fleet (82% petrol, 18% diesel).

Figure 12.2 shows that VEPM predicted NO_x emissions would decrease by approximately 50% from 2003 to 2015.

Figure 12.2 shows a steeper rate of decrease was predicted by VEPM for LDV NO_x emissions from 2003 to 2007. The rate of decrease for LDV NO_x emissions was predicted to reduce from 2008 to 2015.

Figure 12.2 shows HDVs had a significant influence on fleet average NO_x emissions.

Figure 12.2 VEPM fleet weighted average NO_x emissions per kilometre travelled 2003 to 2015



A study of the roadside air quality data from the Khyber Pass Road site for the first seven years of the study period, concluded that the anticipated improvements in air quality due to changes in emission control technology were being realised at the tail-pipe and roadside, although not at the rate predicted with VEPM. However, over the last four years of the study period, the anticipated improvements in emissions and air quality were not being fully realised. The combined effect of upward and downward pressures on roadside air quality now appear to currently be balanced and roadside concentrations of NO_x are relatively stable. The roadside and RSD result provides useful information to assist with the validation of the trends in NO_x emissions predicted by VEPM from 2003 to 2015. However these conclusions are subject to the following limitations:

- Site-specific traffic volumes are not well defined.
- Site-specific fleet compositions are not well defined and may not match the fleet composition as measured by the RSD.
- Driving conditions (vehicle speed and acceleration) at the sites may not match those measured by the RSD.
- Trends in RSD measurements may not match trends in total emissions.

These limitations are addressed in section 15.2.

13 On- going monitoring of vehicle emission trends

The Transport Domain Plan (www.transport.govt.nz/research/transport-domain-plan/) is being jointly led by the MoT and Statistics NZ. It is a project that will identify the actions that need to be taken now to ensure information and statistics collected about the transport system are high quality and allow the government to make evidence-based policy, strategy and decisions into the future.

The Transport Domain Plan uses the concept of ‘enduring questions’. Enduring questions are a construct used within the Transport Domain Plan to categorise and structure the things that ‘we know we will need to know’ into the future to inform policy decisions.

The Transport Domain Plan considers the relationship between transport and the environment is critically important and identifies the following enduring question as making an important contribution to understanding the interdependency between transport and the environment:

- In what ways and to what extent does the transport system impact on the environment and how is this changing, including spatially, modally and temporally?

This information presented in this chapter considers this Transport Domain Plan enduring question and also addresses research objective number 6:

- Review and recommend a method for undertaking the on-going monitoring of vehicle emission trends.

13.1 Review of methods used to measure vehicle emissions

Different methods can be used to measure motor vehicle emissions. The most commonly used methods are chassis or engine dynamometer laboratory testing, tunnel studies, roadside air quality studies, on-board emission measurements (portable emission monitoring systems (PEMS)) and remote sensing studies (Smit et al 2010).

Table 14.1 lists the common methods used to monitor vehicle emissions and shows some of the differences in these methods.

Table 14.1 Typical characteristics of different approaches to measure vehicle emissions

Measurement technique	Subject of comparison	Input data *	Spatial features	Temporal features	Driving conditions
Laboratory	Emission factor [g/veh.km]	Measured (100%)	Urban journey, no gradient effects included	Resolution: typically 10 minutes (representing urban journey for one vehicle) with total sampling time of about 35 hours	Both urban and freeway traffic conditions
On-board	Emission factor [g/veh.km]	Measured (100%)	Urban journey, road gradients of -4 to +5% included in the driving patterns	Resolution: typically 4–14 minutes (representing urban journey) with total sampling time of several days	Both urban and freeway traffic conditions

Measurement technique	**Subject of comparison**	**Input data ***	**Spatial features**	**Temporal features**	**Driving conditions**
Tunnel	Emission factor [g/veh.km]	Measured (100%)	Section of road with lengths varying from a few hundred metres to 10km. Several studies done in tunnels with significant road gradients up to 4.2%	Resolution: typically one hour averages, but total sampling times vary widely from 10 hours to a month	Mainly high speed free-flowing traffic
Remote sensing	Emission factor, total emissions [g/veh.km]	Measured (100%)	Several locations varying from 3 to 35. Locations typically with slight or significant road gradients up to 5%	Resolution: typically less than one second and sampling times are substantial varying from 36 days to 7 months	Both urban and freeway traffic conditions
Ambient concentration	Concentration [µg/m^3]	Measured (50%), modelled (50%)	Typically one location only, but a few studies used more locations (2–3) up to 12) and 31 locations	Resolution: typically one hour averaged values, but total sampling times vary widely from only a few hours) to a full year	Mainly urban locations
Mass-balance	Emission flux [kg/h]	Modelled (100%)	Urban areas of 10 x 10 to 20 x 20 km^2	Resolution: typically 1 hour with total sampling time of a few hours.	Both urban and freeway traffic conditions

Source: Smit et al (2010)

The strengths and weaknesses of these methods are often overlooked. For the specific purpose of analysing vehicle emission trends over time the following considerations are made, where (+) indicates a relative strength and (-) a relative weakness:

- Laboratory tests use high-quality sampling and measurement equipment (+). However, there are only one or two suitably equipped vehicle emission test laboratories in New Zealand (-). Individual vehicle tests are often conducted over considerable time periods (drive/test cycles), thereby capturing significant emissions variability that occur in various driving conditions encountered in traffic (+). Due to the significant costs of these tests, often only a limited number of vehicles are tested, with a risk of not including or under-representing higher emitting vehicles(-). In addition, several real-world effects such as cold starts, long parking times, road gradient, air-conditioning use, gear shift behaviour and aggressive driving may not be properly reflected or accounted for in the laboratory test results (-). The quality of the dynamometer and the selected drive/test cycle may also not properly reflect real-world driving conditions (-).
- On-board emission tests using PEMS use compact, low-medium quality sampling equipment (-), as well as tracking of vehicle movement in time and space using GPS (+). The main strength of PEMS is capturing on-road emission data (+). Costs per vehicle test are relatively high due to the time

required for vehicle preparation, as well as the need for significant post-processing and data verification (-). The latter is required to create useful emissions information, including alignment with relevant location specific information (road gradient, weather conditions, etc. Due to significant costs of these on-board tests, often only a limited number of vehicles are tested (-).

- Tunnel studies have the benefit of sampling emissions semi-directly from a large number of vehicles, including high emitters, over a defined distance (+). In addition, measurements take place in relatively controlled conditions as compared with roadside air quality studies (+). A downside of tunnel studies is the commonly limited range of vehicle operating conditions (eg high speed free-flow) and impacts of specific tunnel conditions (road grade, air piston flow) (-). Significant time is required for post-processing of data, eg analysis of licence plate data (-). There are several unknowns such as the proportion of cold start vehicles and truck loads (-). Although fleet emission factors can be developed from tunnel emissions data for highly aggregated vehicle classes (eg HDV, LDV), emissions from individual vehicles are generally difficult to measure (-).
- Roadside air quality studies have the benefit of sampling a large number of vehicles, including high emitters potentially reflecting a range of driving conditions (+). A downside is that emissions are not measured directly (-). Dispersion models are needed to convert concentration measurements back into emission factors. The contribution of non-traffic emissions also need to be estimated and accounted for (-). Emission results will be location specific (snapshot) and therefore may not compare well with distance based emission factors (g/km) (-).
- Tunnel and roadside air quality monitoring do measure relatively large vehicle sample sizes and are therefore in principle well suited for emission trend analysis. However, an issue here is adequate control of various factors such as variation in weather and traffic conditions, and this can be a significant challenge (-). In contrast, laboratory tests, and to some extent on-board emissions testing, offer good control of these factors, but translation of these results to real-world conditions remains an issue (+).

In comparison to these methods, remote sensing studies provide the following benefits:

- Sampling emissions for a large number of vehicles (+). Given the large variability in emission profiles between vehicles, and the large variability in emission levels of individual vehicles during a trip (as was shown in this report, eg gross emitters), it is clear that large samples of on-road vehicles need to be measured in the field over significant time periods to enable an accurate and robust analysis of trends in vehicle emissions. Laboratory and on-board emission tests would typically not generate large enough sample sizes to meet this requirement.
- Sampling in a real-world on-road situation, not from a ‘tame fleet’ using in a simulated drive cycle (+).
- A robust trend analysis requires data for multiple sites over several years to properly reflect the real-world variation in weather, road features, local fleet mix and driving behaviour. The RSD meets this requirement (+).
- The RSD monitoring takes less than one second per vehicle allowing up to 1,500 vehicles to be monitored each hour (+). This compares with approximately 30 minutes to complete a single IM240 setup and test.
- Cost effective sampling ~ $2 to $3 per vehicle (+).
- RSD monitoring is unobtrusive because there is no physical connection to the vehicle and no specific behaviour is required of the driver (+).

AC (2012) describes the limitations of RSD monitoring as follows:

- The RSD measures a vehicle's emissions at a single point (generally under slight acceleration) as opposed to integrating the emissions for a series of driving events (which also include decelerations and steady state behaviour) and therefore may not be representative of the average emissions over a full drive cycle (-).
- The monitoring sites used are single lane on- or off-ramps, arterial roads, or one way streets. The emissions measured therefore reflect driving conditions that predominate on these roadways and may not necessarily represent emissions generated for other roadways (eg at busy intersections or suburban roads where vehicles operating under cold start conditions may be more common) (-).
- The measurement of particulate emissions using open path technology is problematic and is unlikely to be as accurate as that collected by a dynamometer set up (-). Despite this limitation, the RSD uvSmoke measurements are of good quality and fit for purpose of comparing emissions from different types of vehicles and for long term emission trend analyses.
- With the RSD, it is not possible to get under the bonnet of the vehicles to inspect the on-board diagnostic systems and identify any possible causes of high emissions (-).
- The RSD measures emissions just above road level, therefore emissions from vehicles that discharge exhaust vertically (eg some heavy duty trucks) cannot be measured. LDVs that discharge exhaust gases sideways can be measured by the RSD (-).
- Translation of the RSD results to distance based emission factors (g/km) requires specific post-processing methods (-).

Remote sensing has been used to measure vehicle emissions extensively over the last two decades for various purposes around the world, including identification of high-emitting vehicles, examination of on-road vehicle emissions distributions and trend analysis. Comparison of multi-year remote sensing data with other methods used to measure vehicle emissions such as dynamometer and tunnel studies have demonstrated reasonable to good comparability between the different approaches. This implies that remote sensing is able to accurately capture trends and changes in vehicle emissions due to fleet turnover, and can be used robustly for this purpose (NIWA 2015). The smooth trends observed in this data between the RSD emission results and the independent variables model year, emission control technology or accumulated mileage indicate the RSD data provided correct trend results.

14 Conclusion

The primary aim of this research was to improve the understanding of how vehicle emissions are trending over time in New Zealand, and how this relates to observed trends in local air quality. This aim required the project to meet four key data collection and analysis objectives as listed below. This chapter provides a summary of the key findings under each of the objectives and demonstrates that they have been achieved.

14.1 Determine trends in roadside ambient air quality

Air quality data recorded at Riccarton Road, Christchurch from 2006 to 2014 shows concentrations of CO decreased, and concentrations of NO remained relatively stable from 2010 to 2013 but may have decreased in 2014. However, some of the 2014 decrease may have been associated with meteorological conditions more conducive to good dispersion.

Air quality data recorded at Khyber Pass Road, Auckland from 2006 to 2014 shows concentrations of CO decreased and concentrations of NO decreased from 2006 to 2010 but were relatively stable from 2010 to 2014.

A review of the available vehicle count and high-level fleet composition data (LDV/HDV) over the study period shows that vehicle counts and the LDV/HDV composition of the fleet were both relatively stable from 2003 to 2014.

14.2 Undertake a roadside emission monitoring programme (remote sensing)

Ten days of roadside remote sensing monitoring were undertaken in Auckland in February and March 2015 at seven sites, with three sites being monitored for two days. In total, valid results were collected for approximately 38,600 LDVs which equates to an average capture rate of about 70%. The database was combined with data from previous remote sensing campaigns (2003, 2006, 2011).

14.3 Determine trends in vehicle fleet composition and emissions

14.3.1 Fleet composition

The mean age of the LDVs within the Auckland monitored fleet increased by 1.7 years from 2003 to be 10.7 years in 2015, mirroring the ageing seen in the national fleet. However, the fleet measured with remote sensing is significantly younger on average compared with the national fleet average, reflecting the difference between vehicle registration data and actual travel. Importantly, age profiles for the light petrol and diesel fleets now differ markedly, with a mean age for the petrol fleet of 11.3 years versus 8.2 years for the diesel fleet. Similarly, the difference in age between the NZN and JPU vehicles has widened considerably. The mean age of NZN vehicles is now 7.9 years (having aged only 0.5 years since 2003) while the mean age of the JPU vehicles is now nearly double that at 14.0 years (having aged 3.2 years over the same time). These changes in fleet mix are expected to have significant impacts on total vehicle emissions, as was demonstrated through analysis of ageing effects in the RSD data.

Diesel vehicles currently comprise 18% of the monitored light fleet, compared with 12.5% in 2003. This observed trend is consistent with the changes seen in the national LDV fleet.

The monitored light fleet using RSD was more or less evenly divided between NZN and overseas used vehicles (primarily from Japan) until 2011. The most recent data show a slight decline in the proportion of JPU vehicles (45%) and increase in NZN vehicles (54.3%).

The monitored HDV vehicle fleet using RSD is 100% diesel and is approximately 60% trucks and 40% buses. Due to the relatively small numbers of HDV vehicles monitored there are significant differences in the vehicle type and weight profile between the monitored and national average HDV fleets. The mean age of the heavy vehicles within the Auckland monitored fleet has increased by 3.1 years since 2003 to be 12.3 years in 2015. The monitored heavy fleet was more or less evenly divided between NZN and overseas used vehicles (primarily JPU).

The age of NZN HDV vehicles has remained reasonably steady over the 2003 to 2015 at 7.5 years. The age of JPU vehicles has increased over the period 2003 to 2015 from 11.6 to 17.1 years. There are significant differences between the monitored and national average HDV fleet profile. The main driver for these differences is likely to be the RSD's inability to measure vertical exhaust stacks, which are more frequently found on large trucks.

14.3.2 Fleet emissions

Using remote sensing, it has been determined that mean emissions of CO and NO from New Zealand's LDV fleet have decreased significantly between 2003 and 2015. The mean CO and NO emissions from Auckland LDV fleet monitored in 2015 were approximately half the 2003 levels. Most of the improvement for fleet average CO and NO emissions occurred prior to 2009. However, from 2011 to 2015 the rate of improvement slowed. The long-term RSD observed rate of decrease in CO and NO emissions is in line with that predicted by MfE (2014). However MfE (2014) predicts a steady rate of decrease in emissions, which contrasts with the RSD observed rate of decrease slowing significantly after 2009. This finding may have implications on policy which aims to improve vehicle emissions over time.

Since 2003 both the mean and median CO and NO emission levels have consistently improved. Throughout the RSD campaigns, the mean emissions levels have been significantly larger than the median values, which suggests that the emissions performance of most vehicles is much better than the mean emissions. For example during the two most recent campaigns (2011 and 2015) the performance of approximately 75% of the vehicles was better than mean emission levels.

In addition, there has been a generally steady increase in the ratio of the mean to the median emissions levels since 2003. In 2015, for the light-duty fleet, the ratio for CO was 9.0 (13.0 for petrol vehicles only) and the ratio for NO was 7.5 (20.3 for petrol vehicles only).

While there have been consistent improvements in LDV fleet emissions performance, it appears that gross emitting vehicles are having a significant impact on mean emission levels; especially on petrol fleet emissions.

Between 2011 and 2015 the average NO emissions for both NZN and JPU light duty diesel vehicles increased.

In terms of relative concentrations as measured by the RSD, the mean emissions from a light petrol vehicle were more than 10 times the CO and less than half the NO compared with an average light diesel vehicle in 2015.

The RSD monitoring shows NO emissions from diesel LDVs have increased from 2003 to 2015. Unlike the LDV petrol fleet, the RSD results indicate that the increase in NO emissions is generated by typical LDV diesel vehicles and not from gross emitters. When this result is considered in the context of an increasing number of LDV diesel vehicles within the fleet profile, a significant challenge is created for managing future roadside concentrations of NO_x.

Relative to 2003, mean HDV emissions in the Auckland monitored fleet in 2015 are half the CO and similar levels of NO.

Mean emissions of CO emissions decreased significantly from the monitored HDV fleet between 2003 and 2005 and remained relatively constant and low from 2005 to 2015. NO emissions from the HDV fleet remained relatively constant from 2005 to 2015.

Relative to the monitored NZN HDV fleet, the average JPN HDV is 10 years older, and mean discharges are approximately 20% more for CO but 10% less for NO.

14.3.3 Effect of emission control standards

RSD data is well suited for analysis of the effects of emission standards on vehicle emissions. In 2015, NZN petrol vehicles manufactured pre-2003 (before New Zealand introduced emission standards for new vehicles entering the fleet) had significantly higher emissions of CO and NO than vehicles manufactured post-2003. Significant reductions in CO and NO were observed in the 2015 remote sensing measurements with improving emission standards.

While CO emissions from diesel vehicles are relatively low, NZN diesel vehicles manufactured pre-2003 have significantly higher emissions of CO than vehicles built post-2003. CO from diesel vehicles show a gradual improvement with improving emission standards for vehicles built up to the Euro 2 standard. Post Euro 2 the measured emissions of CO do not show any change with improving emission standards. NO emissions are essentially independent from emission standards, except for Euro 6 where a step downward is observed.

Mean emissions of CO and NO from JPU petrol vehicles, on average, all reduced significantly with each change in the emission standards category.

Emission trends in JPU diesel vehicles showed a slight improvement in CO emissions with each successive change in the emission standards category. However, NO emissions are reasonably stable for the first three JPU emission standards and then show an increase in emissions occurring with the two later categories of emission standards.

14.3.4 Effect of mileage on emissions

Remote sensing data is well suited for the analysis of the effects of ageing on vehicle emissions. Mean CO and NO emissions were typically much higher for the high mileage NZN petrol vehicles than for the low mileage vehicles, irrespective of emissions standard, demonstrating the importance of ageing effects on vehicle emissions. Emissions of CO and NO from pre-2003 NZN petrol vehicles steadily increased as the odometer readings went from 50,000km to more than 300,000km. In contrast, emissions of CO and NO from Euro 4 NZN petrol vehicles were consistently low for vehicles that had travelled up to 300,000km. These results suggest that Euro 4 emission control technology is durable and continues to be effective for vehicles that have travelled a large number of kilometres.

For NZN diesel vehicles, mileage did not have a significant impact on the emissions.

Mean emissions of CO and NO were significantly higher (up to two times or more) for the high mileage JPU petrol vehicles than for the low mileage vehicles, for all emission standards. Emissions of CO and NO from pre-1998 JPU petrol vehicles steadily increased as the odometer readings went from 50,000km to more than 300,000km. Emissions of CO and NO from 2000–02 JPU petrol also increased with odometer reading. These results suggest that emission control technology for 2000–02 JPU petrol vehicles becomes less effective or is subject to more frequent break downs (ie creating a greater number of gross emitting vehicles) as the vehicle travels an increasing number of kilometres. As noted earlier the performance and longevity of the 2000–02 Japan standard is not directly comparable to the NZN Euro 4 standard analysis presented above.

For JPU diesel vehicles, odometer readings had no obvious impact on the emissions.

14.4 Determine underlying causes for the observed trends

At the case study sites the AADT were reasonably steady over the study period 2003 to 2015. Available data suggests that a light-duty heavy duty split in the fleet profile remained consistent over the study period at 96% and 4% respectively. The limited data available suggests the roadway congestion levels either remained consistent or decreased slightly over the study period. Notwithstanding the limitations of the case study vehicle data, the vehicle numbers, LDV/HDV fleet split or driving conditions were unlikely to be significant driving factors in the trends in roadside air quality observed at either Riccarton Road or Khyber Pass Road. Assuming that the contribution from non-motor vehicle sources did not alter significantly, it is concluded that changes in the composition of the LDV fleet profile, and changes in emissions over time from various sub-sectors of the fleet were the main drivers behind the observed trends in roadside air quality.

Trends in CO concentrations at the Riccarton and Khyber Pass Roads monitoring sites are downward. The predicted (VEPM) and observed (RSD) fleet average CO emissions are both providing a consistent explanation for the observed decrease in roadside CO concentrations.

Trends in NO_x concentrations at the Riccarton and Khyber Pass Roads monitoring sites are either flat or slightly upward. This observation does not fit the VEPM predicted decrease in NO_x vehicle emissions. Analysis of the remote sensing data suggests the reasons for this trend are most likely to be:

- The benefits of improved NO emission controls is not evident in on-road emission measurements of LDV diesel vehicles.
- The average age of LDVs is increasing.
- Older, higher-odometer, petrol vehicles discharge significantly larger amounts of NO.
- The proportion of diesel vehicles in the on-road LDV fleet is increasing (RSD data shows that mean NO concentrations are 60% higher from a LDV diesel compared with a petrol LDV).

15 Recommendations

15.1 Method for on-going monitoring of vehicle emission trends

It is recommended that RSD monitoring is continued for the on-going monitoring of vehicle emission trends in New Zealand. The main reasons for this recommendation include:

- The data collected by the RSD is suitable for tracking trends in the on-road vehicle fleet composition and emissions.
- The data collected by RSD monitoring programmes will help address the relevant environment enduring question from the Transport Domain Plan.
- New Zealand (via NIWA) has the equipment and expertise to undertake RSD monitoring programmes.
- With suitable servicing and maintenance the RSD kit should have a reasonably long life ~ perhaps another 10 years.
- RSD monitoring is relatively cost effective.
- An extensive back catalogue of data exists (five monitoring programmes from 2003 to 2015) which has provided an excellent benchmark to assess on-going trends in real-world vehicle fleet profile and vehicle emissions.
- There are numerous potential spin-off benefits from the RSD data, including but not limited to emission model validation, identifying and quantifying the effect of gross emitting vehicles, and investigating the effectiveness of regulatory changes to vehicle emission standards.

15.2 Complementary data streams

This study used two roadside air quality sites to provide a qualitative assessment of the trends in air quality overtime observed at these locations. During the course of the study a number of gaps in the data recorded at the roadside air quality monitoring sites became apparent and the quality of some data types was not high. To enhance the analysis of trends in roadside air quality it is recommended that key roadside air quality monitoring sites are identified and as far as practical future proofed to provide high-quality long-term data. Stake holders such as regional councils must be consulted to ensure they understand the value of the data being collected at roadside air quality monitoring sites. This will help ensure longer term data records continue to be available. In relation to this point, the Khyber Pass Road air quality monitoring site was closed due to building renovations in 2015. At this stage there are no plans to decommission or relocate this monitoring site.

The availability and quality of vehicle count data and vehicle fleet composition data for the roads running past the case study air quality monitoring sites were limiting factors when it came to assessing the drivers that could be influencing the changes in air quality observed at the sites. It is recommended that stakeholders such as Auckland Transport and Christchurch City council who operate the city transport models or RAMMS data base be engaged to ensure they understand the value of the vehicle count and fleet composition data being collected for the purposes of understanding trends in air quality. It would be beneficial to identify the key staff at the relevant organisation and invest in that relationship to enhance the availability, quality and value of the vehicle count data and vehicle fleet composition data for any future air quality trend analyses.

While the continuation of an RSD vehicle emission monitoring programme will provide useful and robust data that can be used to inform the on-going monitoring of vehicle emission trends, adopting this method for the long term does create some data/knowledge gaps. There are complementary data streams which can fill in some of the gaps created by the RSD instrument. The three most significant gaps in the RSD database are emission measurements:

- from HDVs
- of particulate matter
- of NO/NO_2.

If RSD monitoring is adopted as the method for data collection for the on-going vehicle emission trend analysis, it is recommended that the preliminary assessment of these three issues provided by the current study, is enhanced using complementary emission data. Enhancements could be achieved using a combination of HDV targeted RSD monitoring, (as done in 2005), vehicle emission modelling and/or the collection of additional emission data from, for example, an in-service emission testing programme (laboratory or PEMS) or a tunnel measurement programme.

15.3 Additional analyses

During the course of this study a number of interesting and relevant issues were identified that fell outside the current project scope but, if undertaken, would further enhance our understanding of how vehicle emissions are trending over time in New Zealand and how this relates to observed trends in local air quality. The additional issues identified are described briefly below. In relation to each of these issues it is recommended that consultation be undertaken with relevant stakeholders to assess the relative importance of these issues and the potential value which could be provided by specific investigations.

The current study focused on the trends in emissions and roadside concentrations of CO, and NO_x. However, in terms of human health effects particulate emissions, particularly from diesel vehicles, are arguably a more influential factor. Further investigation into the trends in particulate emissions from vehicles and the impacts these have in trends in roadside air quality would complement and enhance the findings of this study which considers two gaseous pollutants in detail. An investigation into the emissions of particulate would be more complicated than the CO/NO_x study due to the uncertainties of particulate emissions measured by the RSD and the difficulties of differentiating the effect of particulate discharged from vehicles from (often high) background sources of particulate.

This current study identified the positive and negative pressures that vehicle emissions exert on roadside concentrations of CO and NO_x. An extension of this investigation would be to apportion the influence of each of these factors on the overall trend, eg How much influence do gross emitting vehicles have on roadside air quality compared to an increase in the proportion of diesels in the LDV fleet?

The vehicle emission data in this report is presented as pollutant concentrations, which is not the same as total vehicle emissions – measured by weight (kg). The analysis could be extended to calculate the trends in total vehicle emissions by using the pollutant to CO_2 ratios measured by the RSD together with fuel use data to provide g/km emission factors for the various sectors of the vehicle fleet. When combined with vehicle travel data the g/kg emission factor would provide a real-world estimate of total vehicle emissions.

The findings of the current study could be independently verified with trend data collected by another emission measurement such as a tunnel investigation.

The RSD measurements relate most closely to free flowing traffic emissions. The relative amount and therefore the relative effects of pollutants discharged from vehicles passing through intersections are not well understood. The relationships between emissions as measured by the RSD and the speed and acceleration of the vehicles could be used to estimate emissions from vehicles that are decelerating into or accelerating out of intersections.

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Appendix A: International literature review

A1 Vehicle emissions standards

The use of increasingly advanced engine and emission control technology substantially reduces vehicle emissions. The development and application of emission control, however, increases costs and complexity of vehicle design. Therefore, vehicle manufacturers require inducements such as mandatory standards to develop and introduce those improvements. Mandatory vehicle emission standards are in effect in all industrialised countries and are the basis for national vehicle emission control programmes.

The main international systems of vehicle emission standards are those of the United States, the European Union (EU) and Japan. The emission standards set in these countries are, however, not directly comparable due to differences in the testing procedures. The first efforts for vehicle emission control date back to the 1960s. Exhaust emission standards for new cars were first set in 1968 in the United States (1965 in California due to severe air quality problems) and in Europe in 1970.

Since then, emission standards have become steadily more strict. Section A1 briefly discusses the evolution of emission standards in Europe and Japan for light-duty and heavy-duty vehicles. Vehicle emission standards are of interest for this study because 1) they drive technological change and reduction in vehicle emissions, and 2) they are directly used in the prediction of vehicle emissions. With respect to the last point, step changes in vehicle emission standards are commonly used to quantify the future impacts of increasingly stringent legislation on on-road fleet emission levels (eg Kousoulidou et al 2008). The percent change in the emission standard is then used to develop an emission factor (grams per vehicle-kilometres travelled – g/VKT) for future technology vehicles, ie multiplication of an emission factor for a current vehicle class with the ratio of the new to the previous standard. Fleet models are then used to simulate the penetration of these new vehicles and scrappage of current vehicles over time and estimate total travel for each vehicle class for a particular base year. Although this approach appears reasonable, it is prone to prediction errors as will be discussed later in this appendix. In addition, the discrepancy between legislative standards and real-world emission reductions may well be the main reason for ‘disappointing’ air quality improvements in relation to expectations based progressively on strict emission standards.

A1.1 EU vehicle emission legislation

A1.1.1 Light-duty vehicle emission standards

Light-duty vehicles were the first vehicles to be regulated under the United Nations Economic Commission for Europe (UN-ECE) process, starting in 1970 (base Directive 70/220/EC, ECE R15) after which several amendments (ECE R 15.01 to R 15.04) were implemented in the period 1974–1986. No special emission control equipment was needed to meet these early standards of carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x).

The ‘Consolidated Emissions Directive’ (91/441/EC) is the first directive of the well-known Euro standards. Directive 91/441/EC (Euro 1) introduced mandatory standards that applied to all EU member states for both exhaust (CO, HC, NO_x, PM) and evaporative emissions (HC). In order to comply with these standards petrol vehicles sold in the period 1992–1996 were fitted with closed-loop three-way catalyst converters and carbon canisters. Directive 91/441/EC brought some fundamental changes to the light-duty emission standards. It included a new driving cycle (ECE 15 + EUDC), emission limits were expressed in grams per kilometre (km) and durability testing requirements were introduced. Directive 94/12/EC (Euro 2) further restricted car emissions of vehicles sold in the period 1996–2000 and this time a distinction was made between diesel and petrol car emissions. This led to the general use of oxidation catalysts in Euro 2 diesel cars. In addition, randomly selected production cars were required to meet the same standards as those that applied to the type approval, whereas earlier directives had allowed for slightly less stringent conformity of production standards.

In 1992 the European Commission initiated a comprehensive programme (Auto-Oil) which was designed to determine a coherent strategy to achieve future air quality targets at the lowest cost for society. This led to the implementation of the tightened Euro 3 (2000) and Euro 4 (2005) emission standards through EU Directive 98/69/EC. These emission limits were generally met through the use of (cooled) exhaust gas recirculation (EGR) and optimisation of fuel injection in diesel cars or larger catalysts and better lambda control[1] (of fuel to air ratio) in petrol cars. A number of changes were imposed by this directive. For instance, durability requirements were extended from 80,000km in 2000 to 100,000km in 2005. This directive also introduced a change in the test cycle (ie the first 40 seconds of idling in cold start mode are now included in the emission tests) and separate standards for HC and NO_x were adopted. On-board diagnostics (OBD) were also required and phased in the period 2000–2007.

A new phase in EU standards was heralded by Euro 5 and 6, which was mainly driven by ongoing air quality problems in urban areas and increasing concern about health impacts of particulate matter. The main focus in Euro 5 and 6 can be described as to get vehicles to market that consume less and emit less in real-world conditions. Euro 5 and 6 standards are implemented in stages (a, b, c) in the period 2010–2014 (Euro 5) and 2012–2019 (Euro 6). These stages reflect a range of new requirements related to various aspects such as PM sampling procedures (including particle number), (operational) OBD requirements, more stringent emission limits for HC, NO_x and PM and an increase of the durability requirements to 160,000km. Compliance with these standards requires the use of new emission control technology such as diesel particulate filters (DPFs) and selective catalytic reduction (SCR). Carbon dioxide (CO_2) emission standards have also been set for passenger cars for the period 2012–2015 (EC 443/2009) and for vans for the period 2014–2017 (EC 510/2011).

Figure A.1 graphically shows the theoretical emission reductions that are achieved with the introduction of increasingly stringent Euro emission standards for petrol and diesel cars.

It is clear that significant reductions in vehicle emissions on a gram per VKT basis are imposed over time, that is, in laboratory test conditions over an artificial drive cycle (new European driving cycle, NEDC) with non-commercial fuel. The translation of these legislative emission reductions to actual reduction in the on-road fleet, has proved to be a challenge, as will be discussed in the next sections.

In terms of future standards, which include finalisation of Euro 6, there will be an increased focus on real-world emissions. For instance, the NEDC will be changed to the World Harmonized Light Vehicles Test Procedure, which will include changes to vehicle inertia settings and vehicle pre-conditioning procedures. Another change will be the use of portable emission measurement systems (PEMS) to quantify real drive emissions to verify on-road compliance with emission standards. There may also be an extension to pollutants that are not yet included in current standards. It is expected that these new developments will drive down real-world emissions from new vehicles.

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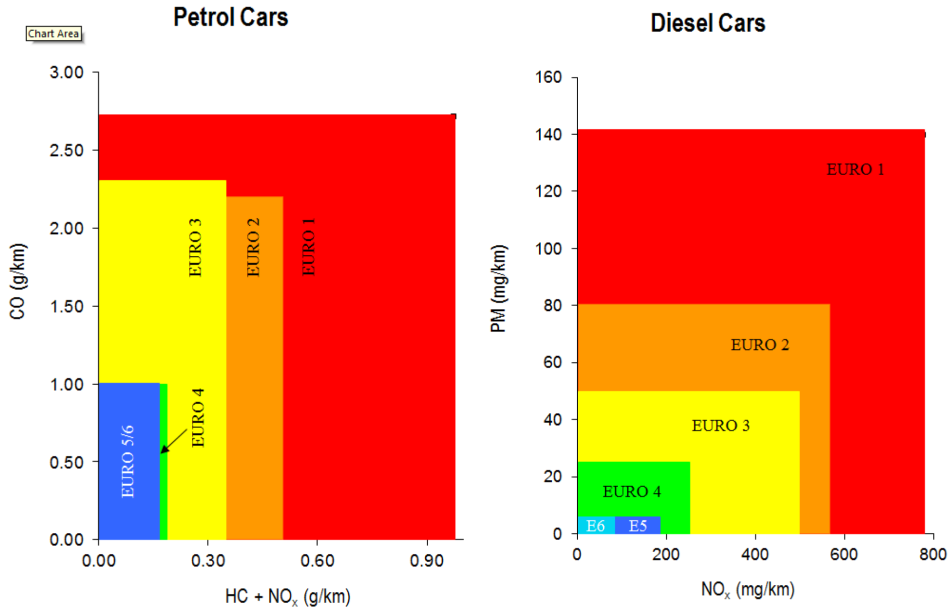
[1] An electronic device that measures the proportion of oxygen in the exhaust gas. It is key to feedback control of fuel injection to ensure effective catalyst control of air pollutant emissions from motor vehicles.

Figure A.1 European exhaust emission standards for light- duty vehicles



Source: CASANZ (2014)

A1.1.2 Heavy- duty vehicle emission standards

The most important difference between light- and heavy-duty regulations can be found in the type of approval testing method. Because single heavy-duty engines are used for a wide range of different types and models of trucks and buses, it is only practical that the engine is tested instead of different types of trucks. For this reason the emission of the pollutants are expressed as grams per kilowatt hour (kWh) instead of gram/km, as is the case for light-duty vehicles.

European emission regulations for new heavy-duty engines (mainly diesel) are commonly referred to as Euro I, II, etc. These emission standards apply to all motor vehicles with a loading capacity over 3,500kg. The heavy-duty engine regulations were originally introduced by Directive 88/77/EEC (Euro 0), which was amended a number of times. Before that time, visible smoke for heavy-duty diesel engines was controlled by Council Directive 72/306/EEC and CO, HC and NO$_x$ were controlled by Regulation 49 in the 1980s. Euro I standards were introduced in 1992, followed by the introduction of Euro II regulations in 1996, using a 13-mode test procedure. These standards applied to both truck engines and urban buses, the latter being voluntary.

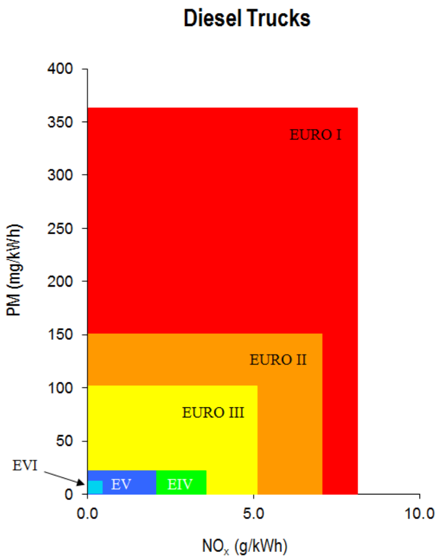
In 1999, the EU adopted Directive 1999/96/EC, which introduced Euro III standards (2000), as well as Euro IV and Euro V standards (2005/2008). New engine test cycles were introduced, including the European stationary cycle, the European load response procedure and the European Transient Test. In 2001, the European Commission adopted Directive 2001/27/EC, which prohibits the use of emission ‘defeat devices’ and ‘irrational’ emission control strategies. In 2005, HD regulations were consolidated by Directive 2005/55/EC, which introduced durability and OBD requirements, as well as re-stated the emission limits for Euro IV and Euro V. Optimisation of the combustion process (eg reconfiguration of engine maps, higher injection pressures) and the introduction of EGR systems was generally sufficient to meet the Euro I, II and III limits. Euro IV standards require the use of SCR and/or EGR, possibly in combination with a DPF, whereas Euro V (and VI) standards require the use of combined EGR/oxidation catalyst, SCR/EGR or DPF/EGR technology.

EC Regulations 595/2009 and 582/2011 introduced Euro VI standards (2013) using two new cycles for type approval, the Worldwide Harmonized Steady State Cycle and the Worldwide Harmonized Transient Cycle. In addition, several new requirements with respect to durability, OBD thresholds and particle number limits were included. A new element is the inclusion of in-service conformity testing of on-road complete vehicle driving using PEMS. Euro VI was recently extended to dual fuel and gaseous fuel heavy-duty engines and vehicles with Regulation 133/2014.

Figure A.2 graphically shows the emission reductions that are achieved with the introduction of increasingly stringent Euro emission standards for heavy duty engines. It is clear that significant reductions in vehicle emissions on a gram per kWh basis are imposed over time, that is in laboratory test conditions over an artificial test procedure with non-commercial fuel.

The future of EU heavy-duty emission standards will likely focus on durability of emission control systems, including OBD, and on PM and CO_2 emissions in particular.

Figure A.2 European exhaust emission standards for heavy- duty vehicles



Source: CASANZ (2014)

A1.2 Japanese vehicle emission legislation

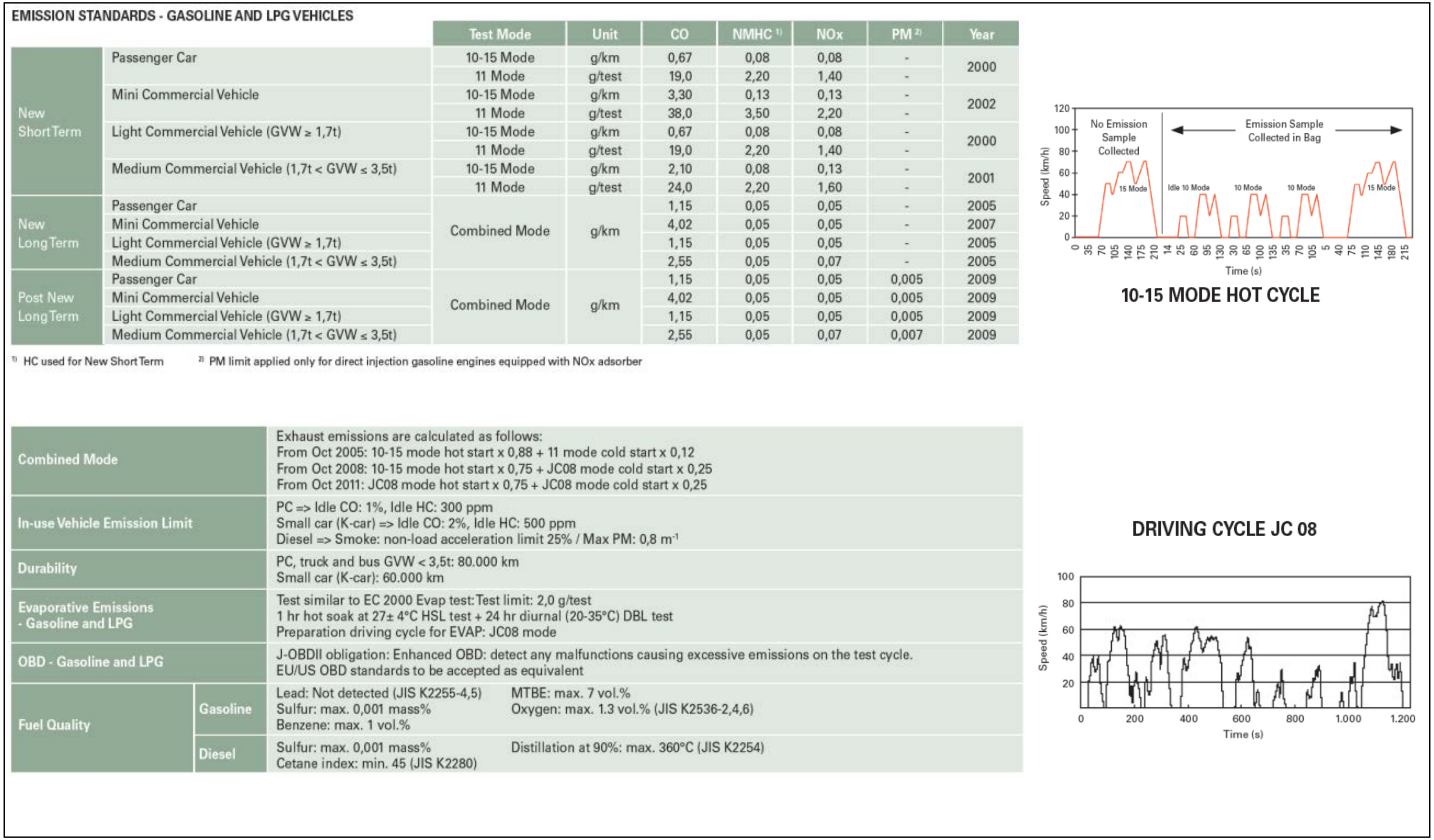
Japan has a long history of vehicle emission control. The first vehicle emission standards in Japan date back to 1966 when simple CO limits were introduced. In the 1970s limits were introduced for CO, HC and NO_x, which required catalysts on petrol cars – much earlier than the EU. Emission test procedures in Japan are complex, with various test procedures and emission limits that have changed over time. This complicates comparison of progressive standards, let alone their real-world impacts. An overview for light-duty petrol/liquid petroleum gas (LPG) vehicles is shown in figure A.3

A direct comparison with EU standards is also not possible due to these differences in test procedures. Nevertheless, the Japanese standard setting process is generally characterised by an active and progressively strict approach to reduce vehicle emissions, often aiming to the boundaries of what was technologically feasible. For instance, the Central Environment Council issued various versions of a report called ‘Future policy for motor vehicle exhaust emissions reduction’, which resulted in revisions and further tightening of Japanese emission standards.

Initially, artificial drive cycles such as the 6 mode test, the 10–15 mode test (figure A.3), the 11 mode test and the 13 mode test were used. More recently, similar to Europe, there has been an increased focus on better reflecting real-world driving conditions in the legislative test procedures. This resulted, for instance, in the introduction/phase in of new transient test cycles such as the JE05 heavy-duty test cycle and the JC08 light-duty cycle (figure A.3) since 2005. In addition, (idle) emissions testing has formed an integral part of Japanese in-use vehicle testing and the Tokyo Metropolitan Government has required all diesel vehicles to have DPFs installed since 2003.

In conclusion, comparison of different Japanese emission standards in time and comparison with EU regulation cannot be adequately done due to the complexity and variability in the Japanese vehicle emission legislation. It is, however, probably fair to say that imported (second hand) Japanese vehicles in New Zealand are generally expected to have reasonable and state-of-the-art (at the time of manufacture) levels of emission control.

Figure A.3 Japanese emission standards for light- duty engine vehicles



EMISSION STANDARDS - GASOLINE AND LPG VEHICLES

		Test Mode	Unit	CO	NMHC [1]	NOx	PM [2]	Year
New Short Term	Passenger Car	10-15 Mode	g/km	0,67	0,08	0,08	-	2000
		11 Mode	g/test	19,0	2,20	1,40	-	
	Mini Commercial Vehicle	10-15 Mode	g/km	3,30	0,13	0,13	-	2002
		11 Mode	g/test	38,0	3,50	2,20	-	
	Light Commercial Vehicle (GVW ≥ 1,7t)	10-15 Mode	g/km	0,67	0,08	0,08	-	2000
		11 Mode	g/test	19,0	2,20	1,40	-	
	Medium Commercial Vehicle (1,7t < GVW ≤ 3,5t)	10-15 Mode	g/km	2,10	0,08	0,13	-	2001
		11 Mode	g/test	24,0	2,20	1,60	-	
New Long Term	Passenger Car	Combined Mode	g/km	1,15	0,05	0,05	-	2005
	Mini Commercial Vehicle			4,02	0,05	0,05	-	2007
	Light Commercial Vehicle (GVW ≥ 1,7t)			1,15	0,05	0,05	-	2005
	Medium Commercial Vehicle (1,7t < GVW ≤ 3,5t)			2,55	0,05	0,07	-	2005
Post New Long Term	Passenger Car	Combined Mode	g/km	1,15	0,05	0,05	0,005	2009
	Mini Commercial Vehicle			4,02	0,05	0,05	0,005	2009
	Light Commercial Vehicle (GVW ≥ 1,7t)			1,15	0,05	0,05	0,005	2009
	Medium Commercial Vehicle (1,7t < GVW ≤ 3,5t)			2,55	0,05	0,07	0,007	2009

[1] HC used for New Short Term

[2] PM limit applied only for direct injection gasoline engines equipped with NOx adsorber

Combined Mode		Exhaust emissions are calculated as follows: From Oct 2005: 10-15 mode hot start x 0,88 + 11 mode cold start x 0,12 From Oct 2008: 10-15 mode hot start x 0,75 + JC08 mode cold start x 0,25 From Oct 2011: JC08 mode hot start x 0,75 + JC08 mode cold start x 0,25	
In-use Vehicle Emission Limit		PC => Idle CO: 1%, Idle HC: 300 ppm Small car (K-car) => Idle CO: 2%, Idle HC: 500 ppm Diesel => Smoke: non-load acceleration limit 25% / Max PM: 0,8 m^{-1}	
Durability		PC, truck and bus GVW < 3,5t: 80.000 km Small car (K-car): 60.000 km	
Evaporative Emissions - Gasoline and LPG		Test similar to EC 2000 Evap test: Test limit: 2,0 g/test 1 hr hot soak at 27± 4°C HSL test + 24 hr diurnal (20-35°C) DBL test Preparation driving cycle for EVAP: JC08 mode	
OBD - Gasoline and LPG		J-OBDII obligation: Enhanced OBD: detect any malfunctions causing excessive emissions on the test cycle. EU/US OBD standards to be accepted as equivalent	
Fuel Quality	**Gasoline**	Lead: Not detected (JIS K2255-4,5) Sulfur: max. 0,001 mass% Benzene: max. 1 vol.%	MTBE: max. 7 vol.% Oxygen: max. 1.3 vol.% (JIS K2536-2,4,6)
	Diesel	Sulfur: max. 0,001 mass% Cetane index: min. 45 (JIS K2280)	Distillation at 90%: max. 360°C (JIS K2254)

10-15 MODE HOT CYCLE

DRIVING CYCLE JC 08

Source: Delphi (2014)

A2 Trends in vehicle emissions

This section looks at international literature on reported trends in vehicle emissions, either modelled or derived from measurements (eg remote sensing, near road air quality measurements). European, Australian and Japanese studies are likely most relevant as the New Zealand fleet largely reflects vehicles from these countries. The focus is on recent studies, as they best reflect the current state of knowledge and issues.

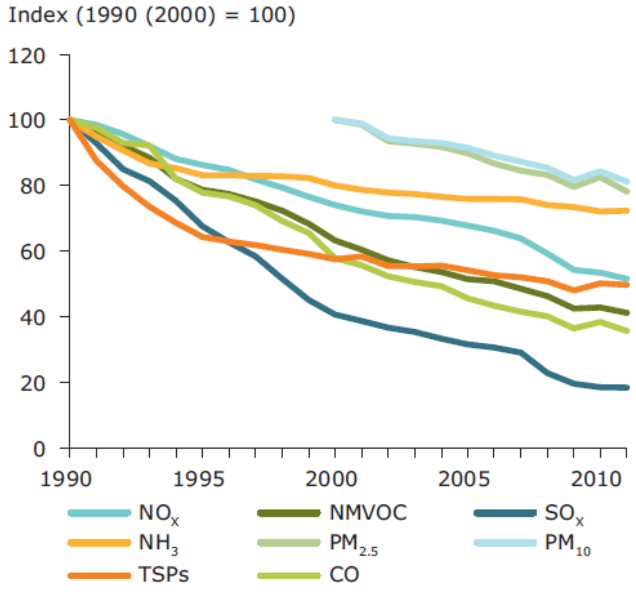
A good starting point is a recent report by the European Environment Agency (EEA 2013). This report collated detailed emission inventories from 27 EU countries for all major sources and multiple years. The data show substantial reductions in total emissions across the board in the EU since 1990, as is shown in figure A.4. An important driver for these reductions are vehicle emission standards, but also emission mitigation measures in industry and agriculture. This highlights an important complication in assessing 'real' trends in on-road vehicle emissions. Air quality is a function of the combined impact of various sources and their specific emission profiles, as well as meteorology and topography.

Figure A.4 shows the emission trends for road transport. It can be seen that NO_x emissions from the road transport sector have decreased by about 50% since 1990. But is noted that road transport remains a major source in a relative sense, as emissions from other sources are also reduced.

EEA (2013) draws a few useful conclusions regarding motor vehicle emissions. First, NO_x, CO, non-methane volatile organic compounds (NMVOC), PM_{10}, $PM_{2.5}$, lead and certain persistent organic pollutants (ie hexaclorobenzene (HCB) and polychlorinated biphenyls (PCBs)) are identified as pollutants where road transport is a major to significant source. In terms of contribution to total emissions, NO_x, CO, $PM_{2.5}$, PM_{10}, NMVOC, lead, HCB and PCBs are most important in the EU (40%, 26%, 17%, 14%, 14%, 14%, 5% and 4%, respectively). Not shown in figure A.4 is the large reduction (98%) of lead emissions from motor vehicles between 1990 and 2011. The promotion of unleaded petrol within the EU through a combination of fiscal and regulatory measures (phase-out of leaded petrol) is heralded as a success story. Nevertheless, the road transport sector remains an important source of lead contributing around 14% of total emissions in the EU-27.

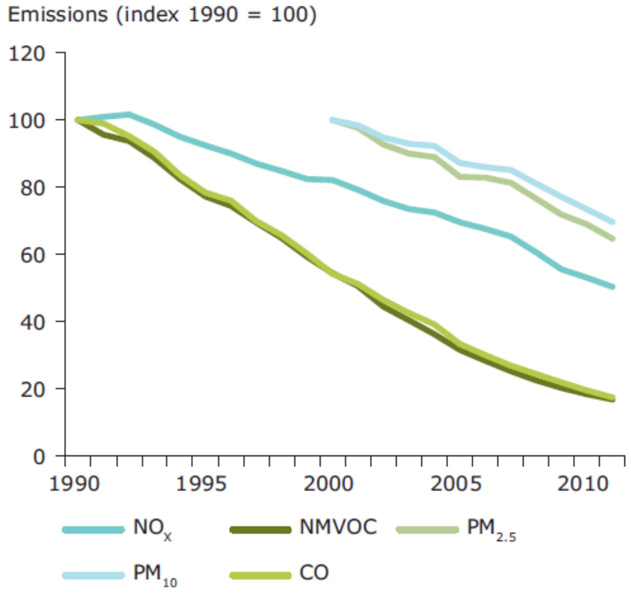
A recent motor vehicle emission inventory for Australia shows a somewhat different picture (figure A.6). UniQuest (2014) estimated state and national motor vehicle emission levels for base year 2010 and compared the numbers with total industry emissions reported to the National Pollutant Inventory.

Figure A.4 **EU emission trends – all sources**



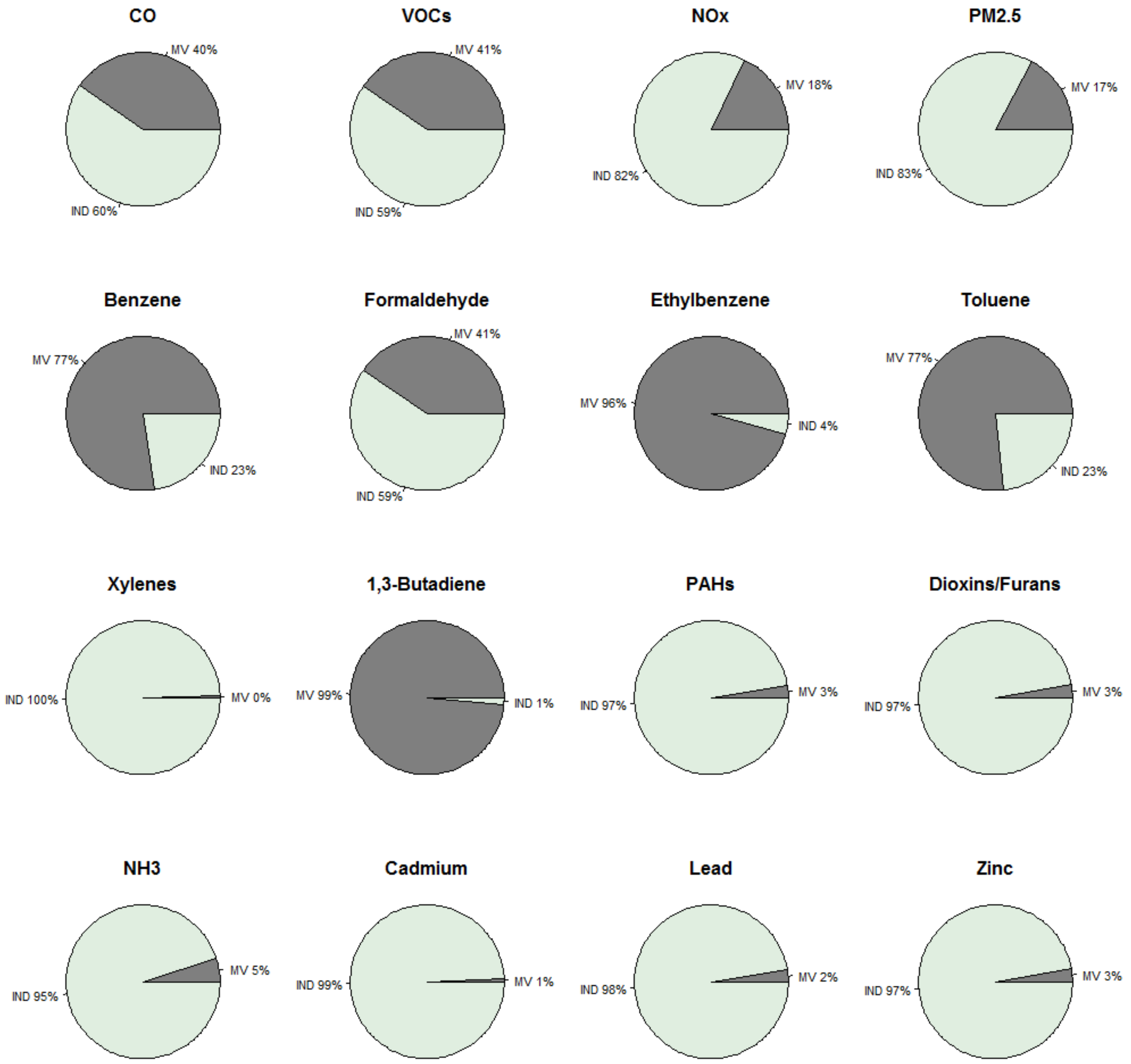
Source: EEA (2013)

Figure A.5 **EU emission trends – road transport**



Source: EEA (2013)

Figure A.6 Contribution of motor vehicle (MV) and industry (IND) emissions in Australia to their combined total emissions



Source: UniQuest (2014)

EU and Australian emissions data compare as follows in terms of motor vehicle contribution to total emissions:

- NO_x – EU 40% and AUS 18%
- CO – EU 26% and AUS 40%
- $PM_{2.5}$ – EU 17% and AUS 17%
- PM_{10} – EU 14% and AUS 1%
- NMVOC – EU 14% and AUS 38%
- Lead – EU 14% and AUS 2%.

This comparison shows that the relative importance of road traffic emissions, and hence the impact on local air quality, can vary substantially between countries due to differences in on-road fleets, fuel quality, climate and local industry profiles. For instance, the Australian fleet is different from the EU fleet – and more like the North American fleets – in terms of its fuel mix (eg mainly petrol fuelled LDVs), vehicle characteristics (eg large portion of SUVs and use of automatic transmissions, but also larger carbon canisters for evaporative emission control) and fuel quality (eg higher volatility, higher sulphur content).

In addition, the importance of the mining industry in Australia will (at least partly) explain the smaller relative contribution of motor vehicles to PM_{10} (fugitive dust emissions), lead and NO_X (non-road engines). It is thus clear that:

- the New Zealand situation needs to be carefully considered in terms of the on-road fleet characteristics as well as other emission sources[2]
- that the applicability of any conclusions drawn from overseas studies regarding vehicle emission trends needs to be carefully assessed in the New Zealand context.

It is emphasised that total annual emission levels are not the same as exposure levels. The actual contribution of motor vehicle emissions to population exposure (and thus health effects) is typically much larger than for industrial sources (eg Caiazzo et al 2013). This is because motor vehicle emissions are released close to ground level and in close proximity to where people live and work. In contrast, industrial emissions are typically emitted through vents and stacks, and are generally separated from populated areas. This means that industrial emissions are often significantly diluted before they reach the population. As a consequence, total motor vehicle emissions can be small or insignificant compared with other sources, but can still generate significant (local) air quality and health impacts.

The ‘type of vehicle emission’ also requires consideration in assessing trends in vehicle emissions and their changing impacts. Type of emissions refers to hot running exhaust emissions (all pollutants), cold start exhaust emissions (all pollutants), evaporative (non-exhaust) emissions (VOCs) and non-exhaust tyre, brake and road wear emissions (PM). This is important as they contribute differently to total motor vehicle emissions depending on the pollutant and they have a significantly varying spatial and temporal component, as is shown in figure A.7.

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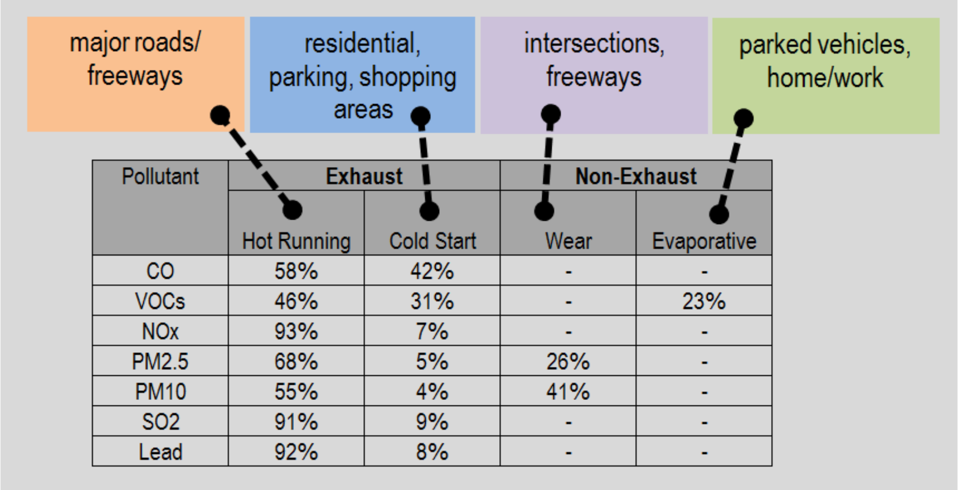
[2] It is clear for instance that motor vehicles and industry have quite different emissions profiles. In Australia, motor vehicle emissions are small to insignificant (< 5%) for some pollutants as compared with industry (eg heavy metals, SO_2, PM_{10}), but for other pollutants it is the other way around (eg 1,3-Butadiene, benzene, acrolein, toluene). For the criteria pollutants, motor vehicles contribute significantly to CO, NO_X and $PM_{2.5}$, but not significantly to total emissions of SO_2 and PM_{10}. For some pollutant total annual motor vehicle emissions are of similar magnitude as for industry (eg TVOCs, styrene, n-hexane).

Figure A.7 Contribution of different types of emissions to total motor vehicle emissions in Australia and typical situations where they occur



Pollutant	Exhaust		Non-Exhaust	
	Hot Running	Cold Start	Wear	Evaporative
CO	58%	42%	-	-
VOCs	46%	31%	-	23%
NOx	93%	7%	-	-
PM2.5	68%	5%	26%	-
PM10	55%	4%	41%	-
SO2	91%	9%	-	-
Lead	92%	8%	-	-

Source: data taken from UniQuest (2014)

Hot running (exhaust) emissions occur when vehicles are moving and the engine and the emission control system (eg catalytic converter) have reached their typical operating temperatures. Cold start (exhaust) emissions also occur when vehicles are moving, but when the engine, transmission system and catalyst are not (fully) warmed up and operating in an ineffective manner. These additional start emissions typically occur within the first few minutes of driving. Cold start emissions occur when vehicles are started, for example in and around residential areas, parking lots and shopping centres. Evaporative emissions are non-exhaust HC losses through the vehicle's fuel system, and occur mainly when vehicles are parked. Non-exhaust (PM) emissions are due to tyre, brake and road surface wear and are elevated in situations where there is increased speed fluctuation (braking) or in high-speed traffic conditions.

The temporal aspect is particularly relevant for cold start and evaporative emissions, which are largely affected by hourly and seasonal fluctuations in ambient temperature, as well as fuel volatility in the case of evaporative emissions. Non-exhaust tyre, brake and road wear particle emissions are also substantially affected by weather conditions. For instance, wet conditions will significantly reduce these emissions. So in terms of quantifying emission trends in New Zealand using air monitoring or remote sensing data, it is important to consider the measurement location, time of year and meteorological conditions to assess the relevance of the different emission types. Near-road ambient air monitoring data can be used to assess and verify trends in vehicle emissions, provided that background concentrations are known and measurements are not substantially affected by other emission sources.

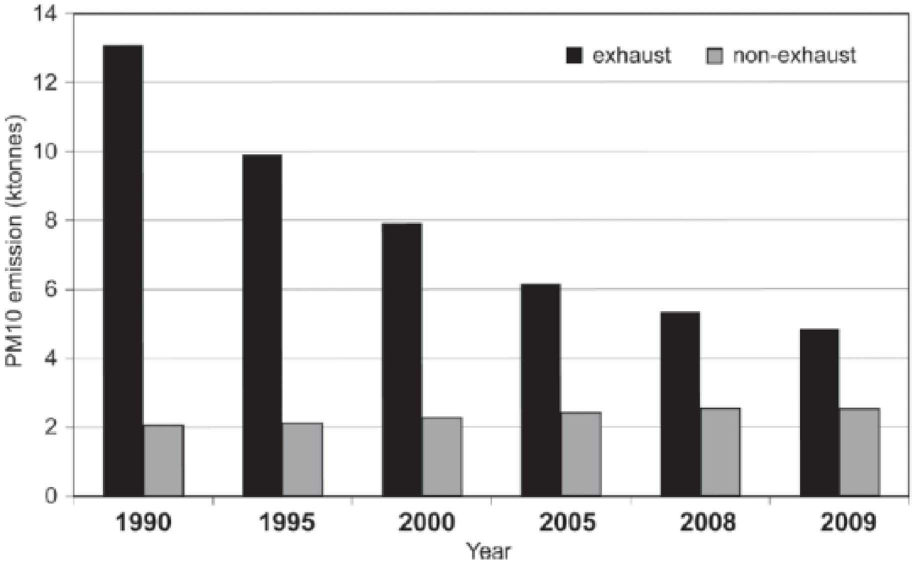
Although hot running emissions generally dominate total emissions for most pollutants (figure A.7), the importance of other emission types has increased over time due to a strong reduction in hot running emissions on a per vehicle kilometre basis, and this trend is set to continue in the future.

- For instance, cold start emissions of CO and HCs from modern petrol passenger cars now typically make up 50–80% of total vehicle trip emissions, and further penetration of these vehicles in the fleet will further increase the relevance of cold start emissions, in particular for CO and VOCs (Smit and Ntziachristos 2013).
- Similarly, non-exhaust PM emissions have increased over time due to increased vehicle activity and a lack of specific emission reductions regulations, whereas exhaust PM emissions have been substantially reduced due to increasingly vehicle emission standards. For instance, Denier van der Gon et al (2013) report an increased contribution of non-exhaust PM emissions of 13% in 1990 to 33% in

2009 for the Netherlands, although total PM emission levels have dropped substantially, as is shown in figure A.8. It is noted that non-exhaust PM emissions have a distinct chemical composition and in particular their relatively high heavy metal content (eg copper, zinc) is of concern from a health impact perspective.

- It is likely that evaporative emissions have increased in significance, at least in a relative sense, due to increasing (petrol) vehicle population and relatively unchanged emission standards. For instance, Haq et al (2013) forecast increasing total evaporative VOC emissions for EU27 in 2015–2030 in the absence of stricter emission standards. A significant factor in Europe is the use of ethanol petrol blends (E5/E10). Ethanol causes increased permeation and reduced working capacity of the carbon canister. Stricter evaporative emissions regulations in the US have led to the use of larger carbon canisters and better emission control compared with Europe. The use of larger carbon canisters and better quality activated carbon has also been found for Australian vehicles (Mellios et al 2013).

Figure A.8 Trend of PM_{10} emission from road transport exhaust and non- exhaust in the Netherlands



Source: Denier van der Gon (2013)

In conclusion, local measurements (air quality monitoring – AQM; remote sensing device – RSD) are significantly affected by local sources, changing meteorological conditions (rain, temperature, etc.), time of year and actual location. The latter determines the relative importance of different types of vehicle emissions, which show different trends varying from increase to decrease. It is possible these factors conspire at local measurement level to generate trends that are different from those expected from (total) vehicle emission modelling.

The (changing) composition of the New Zealand fleet will affect the relevance of these emission types in New Zealand, now and in the future. For instance, cold start and evaporative emissions are particularly important for vehicles with spark ignition engines (petrol, LPG, E10), whereas exhaust PM emissions are relatively low compared with diesel fuelled vehicles. Given the large portion of these vehicles in New Zealand, it is expected these emission types have contributed significantly to total emissions from the on-road New Zealand fleet, and that these contributions will further increase over time. As reductions in non-exhaust and cold start emissions are smaller than reductions in hot running emissions, or can even increase, the New Zealand fleet mix and its changes over the past 10 years may to some extent explain 'less than expected' reductions in emissions on a per vehicle basis (g/VKT). This suggestion can be verified by examining measured pollutant ratios and by running the Vehicle Emissions Prediction Model (VEPM).

Changes in pollutant ratios over time will also affect chemically active pollutants such as NO_2 and secondary air pollution (secondary organic aerosols, ozone, etc). For instance, McDonald et al (2012) observed a significant reduction of the non-methane HC to NO_x ratio in vehicle emissions in the period 1990–2008, which is a key factor in ozone generation. Yuan et al (2013) used ambient air quality data in combination with source apportionment in Hong Kong and observed a significant reduction in the PM contribution from motor vehicles in the period 1998–2008, but a substantial increase in secondary aerosol concentrations due to non-local sources (eg power stations in mainland China). This illustrates the additional complexity in assessing motor vehicle emission trends for reactive pollutants such as NO_2 and PM.

Generally, emission factors (g/VKT) have been decreasing or are expected to decrease for different vehicle types over time due to increasingly stringent emissions legislation. However, this is not always the case for all pollutants. An example is two-wheelers and, in particular, mopeds. These vehicles traditionally had low NO_x emissions and high CO and HC emissions as they operated on largely fuel-rich combustion. The Euro standards have imposed a reduction in CO and HC emissions, which has led to stoichiometric mixtures (and later use of the three-way catalyst) and higher NO_x emissions. As a result, mopeds and motorcycles have substantially higher NO_x emissions on a per-km basis (Kousoulidou et al 2008). The local effect of this depends on the proportion of two-wheelers and the emission standards applied in New Zealand.

Table A.1 shows an overview of reported trends or forecasts in total vehicle emissions. Not all studies include estimates of changing vehicle activity (eg total fuel use, total VKT) and focus on changes in emissions per vehicle (eg Kousoulidou et al 2008), effectively assuming vehicle activity remains constant. These studies are indicated in table A.1 by **. Obviously, any vehicle emission trend analysis needs to consider changes in traffic activity, which generally increases significantly every year.

Table A.1 Reported change in vehicle emissions by pollutants*

Location	Time period (T1 – T2)	Method	CO	VOCs	NO_X (NO2)	PM	Reference
UK	2004–2009	AADT, RSD AADT, Handbook of emission factors (HBEFA)	– –	– –	-21% -30%	– –	Beevers et al (2012)
USA	2018–2030	Emission Factor 2007 (MFAC2007), Motor Vehicle Emission Simulator (MOVES2010a)	-27%	-59%	-53%	–	Collet et al (2014)
USA	1990–2010	Fuel use, RSD, tunnel	–	–	-30%	–	McDonald et al (2012)
Austria **	2005–2020	Network Emission Model (NEMO 1.6)	-	-	-64% (-10%)	-	Rexeis and Hausberger (2009)
Genoa, Italy	1992–2010	Progress	-79%	-68%	-47% (-2%)	-48%	Zamboni et al (2009)
Greece	2000–2015	COmputer Programme to calculate Emissions from	-55%	-55%	-10%	-5%	Progiou and Ziomas (2012)

Location	Time period (T1 – T2)	Method	CO	VOCs	NO_x (NO2)	PM	Reference
		Road Transport (COPERT IV)					
Netherlands	2000–2015	VKT, Emission factors	–	–	(+88%)	-36%	Keuken et al (2012)
Global	2010–2050	Fuel use, Emission factors	–	–	–	-16%	Yan et al., 2014
Cities, USA	1990–2010	Fuel use, RSD, tunnel	-80/90%†	–	–	–	McDonald et al (2013)
10 EU countries	1995–2020	Transport and Mobility Lueven (TREMOVE), National Environmental Technology Centre (Netcen)	–	–	-75% (+15%)	–	Grice et al (2009)
Vienna, Austria	2005–2020	Transport model, HBEFA 3.1	-27%	–	-57%	-39%	Kurz et al (2014)
Beijing, China	1998–2020	EMBEV model	-80%	-80%	-50%	-80%	Zhang et al (2014)
Madrid, Spain	1998–2012	COPERT III	–	-70%	-54%	–	Lumbreras et al (2012)

* Change in emissions (E) is computed as (ET2 – ET1) ÷ ET2, ** no consideration of traffic activity, † only hot running emissions.

Table A.1 shows that models (or modelling methods) are commonly used to examine trends and forecast vehicle emissions. Typically emission factors are combined with measures of travel activity such as total fuel use and/or total vehicle travel (VKT).

The reviewed studies generally predict significant and ongoing but varying reductions in on-road vehicle emissions for legislated pollutants around the world, despite continued growth in total travel. China is an exception where very strong growth in vehicle travel may offset emission gains in the near future, with expected increases in vehicle emission levels (eg Wu et al 2012). Predicted emission reductions are most pronounced for CO and VOCs, and less pronounced for NO_x and PM, which have also been observed in some ambient monitoring studies (eg Querol et al 2014). Increasing motor vehicle emissions have been reported for NO_2 in Western countries (table A.1) and for various pollutants in developing countries (Shen et al 2011; Gu et al 2013).

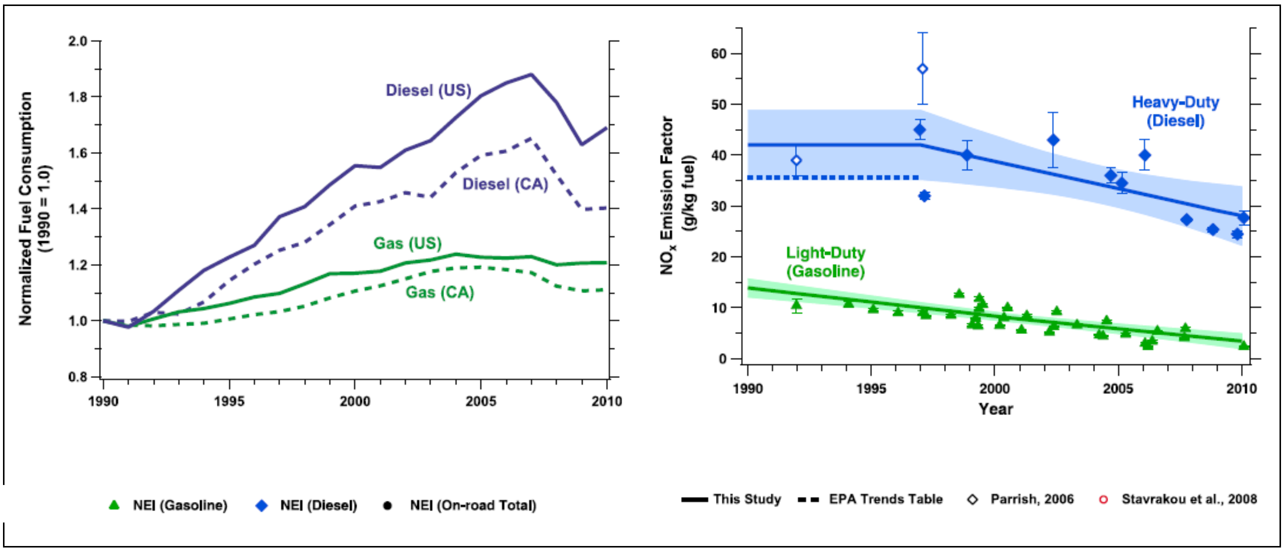
The overall trends in vehicle emissions summarised in table A.1 mask important underlying drivers for these changes, which will need to be assessed individually for New Zealand. These are changes over time in:

- vehicle activity
- fleet mix
- fuel mix
- emission factors
- emissions from other sources.

McDonald et al (2012) provide a good example of this. These authors estimated total emissions for the US using fuel sales data in combination with emission factors (g/kg fuel) derived from remote sensing and tunnel measurements. Key aspects of the study are visually presented in figure A9.

Overall fuel use has increased over time, but diesel use has grown more rapidly than petrol, showing a shift in the fuel mix. Whereas average emission factors for the petrol fleet are already low in an absolute sense, compared with the diesel fleet, they have also consistently decreased over time. In contrast, diesel emissions started to decrease at the end of the 1990s and have remained relatively high. The combination of these changes is then used to estimate national trends in NO_x emissions from on-road vehicles. The trend shows increasing emissions until about 2000, and after that a reduction in emissions. To put those numbers in perspective, on-road emission trends are finally compared with off-road (ships, trains, off-road equipment) and industry emission trends. On road vehicle emissions are the dominant NO_x emission source since about 2005.

Figure A.9 Visual presentation of different key steps in assessment of trends in vehicle emissions



Source: McDonald et al (2012)

Some studies did not separate motor vehicle emission trends from other sources, and are not included in table A.1.

For instance:

- Yan et al (2013) produced long-term projections for global transport emissions (road transport, shipping, rail, aviation) and reported a projected decline in emissions of CO, HC, NO_x and PM in 2010–2030 showing the effect of increasingly stringent emission standards, which offset the growth in fuel use. However, after 2030 and depending on the scenario, emissions increase again due to fast growth in vehicle activity and increasing emissions from non-road engines and shipping. For New Zealand this shows it is important to have accurate estimates of emissions from other sources than road transport.
- Gu et al (2013) used satellite observations of NO_2 columns over China from 2005–2010 and found an average annual increase of about 4%, but with large seasonal and regional variations. For instance, emissions were substantially reduced in some regions. Obviously these results relate to a rapidly expanding economy and a variety of emission sources, which is less relevant for New Zealand. But the study illustrates the importance of accounting for economic growth, fuel use and traffic activity, as well as all other relevant sources.
- Zhang et al (2011) examined ambient air quality measurements in Beijing for the period 1983–2007, and observed different trends depending on the pollutant, ie decreasing trends in NO_2, PM_{10} and benzo(a)pyrene, increasing trends in NO_x and a flat trend for CO, ozone and lead. These trends are affected by a shift from mainly coal burning to a mix of coal burning and vehicle exhaust, which makes the urban air quality characteristics quite different from eg Europe, Australia and New Zealand.
- Hara et al (2013) measured substantial reductions in $PM_{2.5}$ concentrations at ambient monitoring stations in Tokyo of 50% in 2001–2010, which was mainly attributed to a reduction in traffic volumes, particularly of diesel trucks and implementation of more stringent emission standards.

As is clear from table A.1, vehicle emission models are commonly used to estimate trends or make projections regarding vehicle emissions. This is not surprising as models are the only feasible way to do this at fleet level. Trends in vehicle emissions in New Zealand cannot be directly measured due to the large number of on-road vehicles, the variation in driving conditions and many other aspects that influence emissions. Spot measurements can be conducted to verify modelling results using eg RSD or AQM, but the conditions in which measurements are taken need to be carefully examined to ensure a proper assessment. Vehicle emission models on the other hand are based on a variety of empirical datasets (mostly laboratory emissions testing) of varying sample size, and importantly have significant data gaps that require extrapolation and assumptions, which can lead to prediction of inaccurate vehicle emission trends.

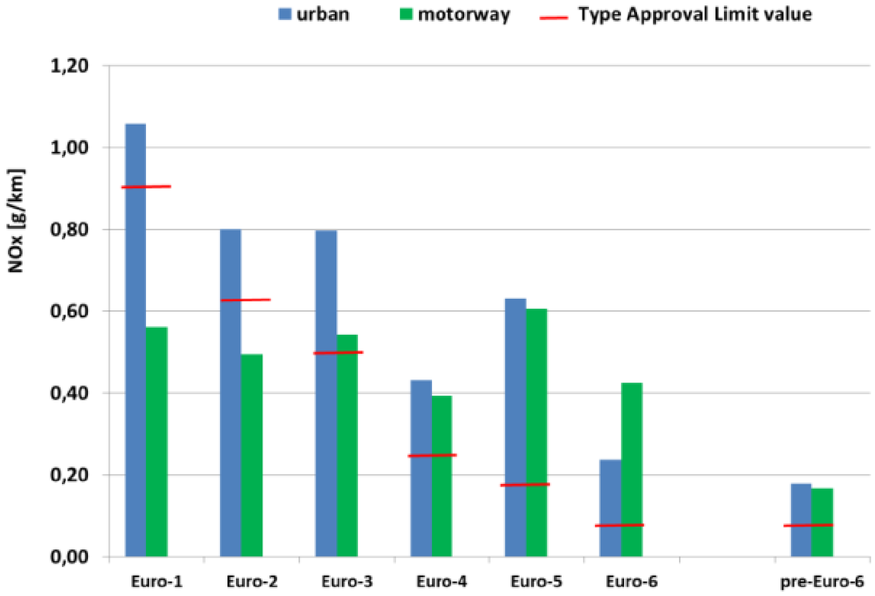
One example of this is the prediction of emissions for new technology vehicles. In the absence of emissions data for future vehicles, models commonly use emission standard ratios to create emission factors for future technology vehicles (eg Rexeis and Hausberger 2009; Zamboni et al 2009; Yan et al 2013; Zhang et al 2014). Although this may work for some vehicle categories and pollutants, it is quite clear this approach is prone to significant prediction errors.

For instance, Carslaw et al (2011) reported that measured roadside ambient NO_x trends are typically around -1/2% per year from 2004–2009, whereas UK road transport estimates are significantly more optimistic with an estimate of -5/6% per year. One needs to be careful when comparing ambient monitoring directly with vehicle emission estimates as there are several other factors that significantly affect ambient monitoring results such as emissions from other sources and variations in year-to-year meteorology. Nevertheless, the discrepancy has also been recently reported in emission testing studies.

Figure A.10 shows the result of chassis dynamometer and PEMS NO_x testing of diesel passenger cars in real world driving conditions for different Euro classes. The measurement data show a few important developments:

- Real-world driving results in significantly higher emissions per km than the Eurotest would suggest (red horizontal lines).
- Euro 5 is the worst performing diesel car, higher than any previous standards for motorway driving, and is significantly worse than Euro 4 for urban conditions.
- Motorway NO_x emission factors have not decreased since Euro 4.
- There are indications that early Euro 6 diesel cars ('pre-Euro 6') performed substantially better than current Euro 6 diesel cars entering the market ('Euro 6').

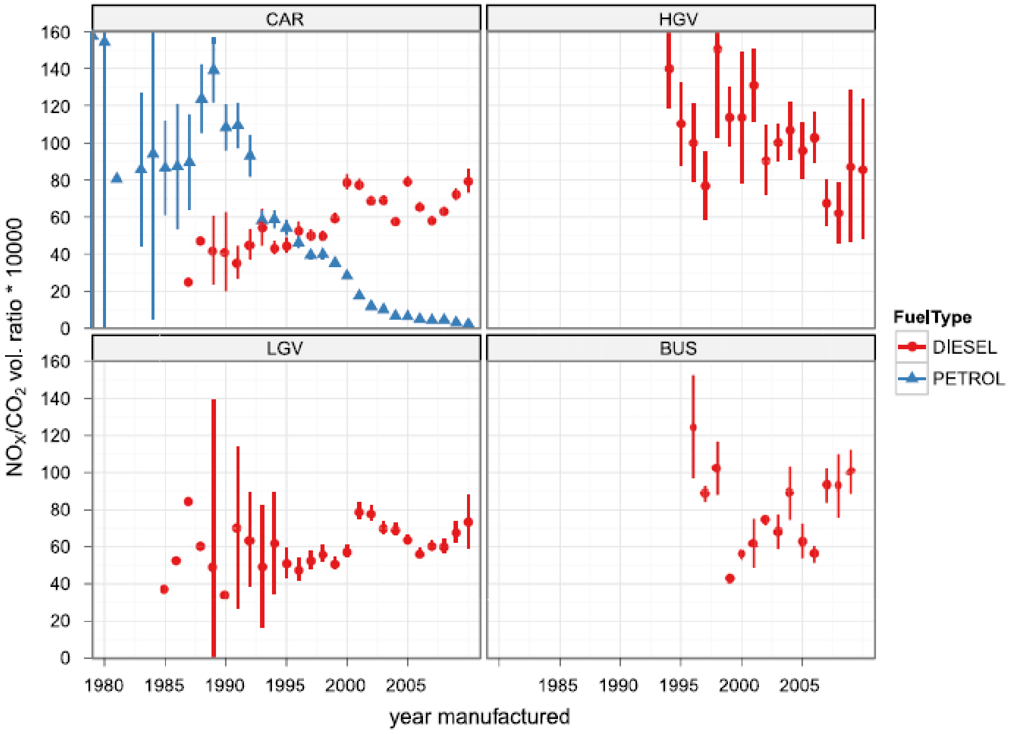
Figure A.10 NO$_x$ emission factors for diesel passenger cars



Source: TNO (2013)

This issue with NO$_x$ emissions from diesel cars has also been confirmed by remote sensing studies, as is shown in figure A.11. Whereas the NO$_x$/CO$_2$ ratio for petrol cars has substantially dropped over time, the ratio for diesel cars (and diesel light goods vehicles) tended to increase in the period 1987–2010. Emission ratios for heavy goods vehicles have remained comparatively stable, with a reduction over recent years. It is noted that real-world emissions from diesel trucks are also known to be quite different (ie higher) from those measured in legislative test procedures as manufacturers calibrate engines for improved fuel economy outside test conditions. In addition, emission control technology may not operate efficiently in all real-world conditions. An example is Euro V trucks that have excellent NO$_x$ emission control in rural and motorway conditions, but not in urban conditions where low engine load conditions can lead to reduced catalyst temperatures and high NO$_x$ levels (eg Rexeis and Hausberger 2009).

Figure A.11 **NO_x to CO_2 ratios by year of manufacture and basic vehicle type cars**



Source: Carslaw et al (2011)

Carslaw et al (2011) also used the remote sensing data presented in figure A.9 to compute g/km emission factors for each Euro class and then compared these values used in EU emission models. Whereas both methods show strong and similar reductions in NO_x emission factors for petrol cars over time, the results are very different for diesel cars with remote sensing showing substantially higher and stable levels and emission models showing strong reductions, effectively showing very different trends. Similar remote sensing results have been reported in other parts of the world. For instance, measurements in Hong Kong (Lau et al 2012) indicate strong and consistent reductions in CO, HC and NO emission factors (g/km) for petrol vehicles (1990–2008 years of manufacture), but quite stable emission factors for all three pollutants for light-duty diesel vehicles.

Several studies conclude that older vehicles often account for the largest part of total vehicle emissions (eg Progiou and Ziomas 2012). Lau et al (2012) also emphasised another important point that in-use vehicle emissions can substantially deteriorate over time (more than a factor of 2 in 4 years' time), in particular in high-use vehicles such as taxis. Beevers et al (2012) also reported large emission increases up to a factor of 4 between new and 12-year-old vehicles. This appears particularly relevant for New Zealand where there is a substantial portion of second-hand imports.

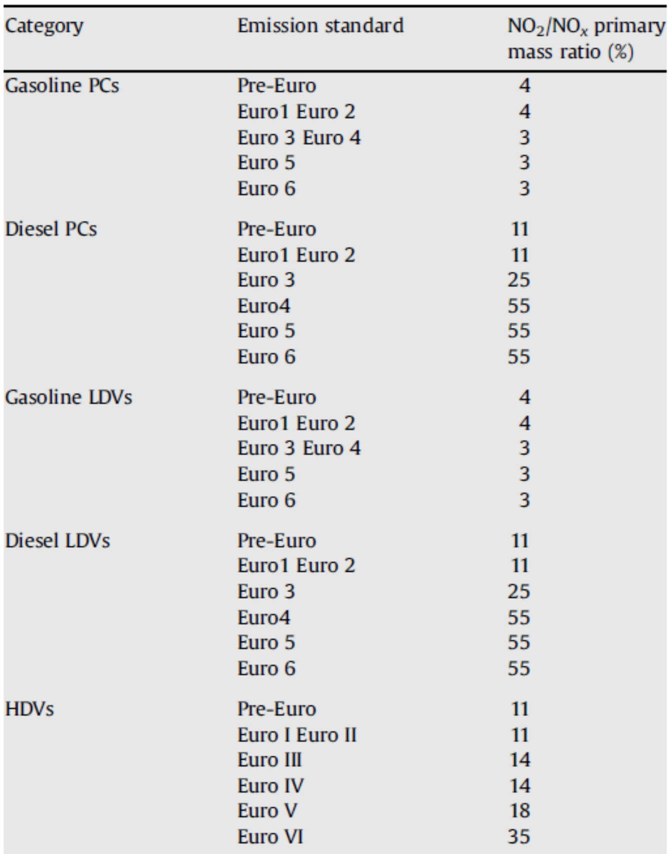
These results illustrate again the importance of the on-road fleet mix both in a national, but also in a local sense. Obviously the relevance of these developments needs to be assessed in the light of the current and future New Zealand fleet, ie the proportion of diesel LDVs or 'level of dieselisation' now and in the future. It also shows the need for verification of local models such as VEPM with independent methods. It is clear that vehicle emission models like VEPM can only predict accurate trends in both an absolute and relative sense when it is based on real-world emission measurements for past, and as much as possible, latest technology vehicles.

A3 Trends in roadside concentrations

Although some studies show reasonably consistent results between model predictions and near road measurements for various pollutants (eg Zamboni et al 2009; Querol et al 2014), this is not always the case. Predicted downward trends in vehicle emissions do not necessarily mean that air quality is similarly affected and that air quality criteria will be met in the future. A number of studies found general improvements, but also persistent air quality issues for critical pollutants such as NO_2, PM_{10} and O_3 in Europe (eg Kurz et al 2014; Querol et al 2014), the US (eg McDonald et al 2012; Collet et al 2014) and Asia (eg Yuan et al 2013). In some cases, ambient concentrations increased over time, whereas (computed) emission trends predicted substantial reductions (eg Beevers et al 2012 for NO_x in inner London), which demonstrates that modelling results need to be verified with independent datasets. The majority of studies focus on criteria pollutants, but a few studies also discuss other pollutants such as heavy metals (Gupta et al 2010) and polycyclic aromatic HC (Shen et al 2011).

Carslaw et al (2011) report that ambient NO_x monitoring data in Europe in the period 1995–2010 generally shows a reduction from the 1990s to the early 2000s, followed by a period of stable or gently decreasing concentrations. NO_2 concentrations, on the other hand, are quite stable across Europe for the same period. This effect is explained with increasing proportions of primary NO_2 in vehicle exhaust of particular diesel vehicle classes (Grice et al 2009). Primary NO_2/NO_x ratios in vehicle exhaust, and therefore NO_2 emissions from road traffic, are largely governed by the mix of engine (diesel, petrol, etc) and emission control technology (SCR, DPF, oxidation catalyst, etc), as well as engine calibration, used in the on-road fleet as shown in figure A.12.

Figure A.12 (assumed) primary NO_2/NO_x mass ratios for different vehicle technologies



Category	Emission standard	NO_2/NO_x primary mass ratio (%)
Gasoline PCs	Pre-Euro	4
	Euro1 Euro 2	4
	Euro 3 Euro 4	3
	Euro 5	3
	Euro 6	3
Diesel PCs	Pre-Euro	11
	Euro1 Euro 2	11
	Euro 3	25
	Euro4	55
	Euro 5	55
	Euro 6	55
Gasoline LDVs	Pre-Euro	4
	Euro1 Euro 2	4
	Euro 3 Euro 4	3
	Euro 5	3
	Euro 6	3
Diesel LDVs	Pre-Euro	11
	Euro1 Euro 2	11
	Euro 3	25
	Euro4	55
	Euro 5	55
	Euro 6	55
HDVs	Pre-Euro	11
	Euro I Euro II	11
	Euro III	14
	Euro IV	14
	Euro V	18
	Euro VI	35

Source: Kousoulidou et al (2008)

Appendix B: 2015 Vehicle emission monitoring

Appendix B provides a brief outline of the equipment used to collect the 2015 on-road emission and vehicle dataset. The text contained in appendix B is sourced from the more detailed description provided by Kuschel et al (2012)

B2 Remote sensing equipment

The remote sensing devices (RSD) used to collect data in this study were the RSD 3000 (2003 monitoring) and RSD 4000EN models (2005, 2009, 2011 and 2015 monitoring). The RSD system was developed by Donald Stedman and his team at the Fuel Efficiency Automobile Test Data Centre, University of Denver, Colorado, USA.

B3 Measurement of gaseous pollutants

The instrument consisted of an infrared (IR) component for detecting carbon monoxide (CO), carbon dioxide (CO_2) and hydrocarbons (HC), together with an ultraviolet (UV) spectrometer for measuring nitric oxide (NO). The source/detector module was positioned on one side of the road, with a corner cube reflector on the opposite side. Beams of IR and UV light were passed across the roadway into the corner cube reflector and returned to the detection unit. The light beams were then focused onto a beam splitter, which separated the IR and UV components.

The IR light is passed onto a spinning polygon mirror that spreads the light across the four infrared detectors: CO, CO_2, HC and a reference. The UV light is reflected off the surface of the beam splitter and is focused into the end of a quartz fibre-optic cable, which transmits the light to an UV spectrometer. The UV unit is then capable of quantifying NO by measuring an absorbance band in the UV spectrum and comparing it to a calibration spectrum in the same region.

The exhaust plume path length and the density of the observed plume are highly variable from vehicle to vehicle and are dependent upon, among other things, the height of the vehicle's exhaust pipe, wind and turbulence behind the vehicle. For these reasons, the remote sensor can only directly measure ratios of CO, HC or NO to CO_2. These ratios are constant for a given exhaust plume, and on their own are useful parameters for describing a HC combustion system. The remote sensor used in this study reported the %CO, ppm HC and ppm NO in the exhaust gas, corrected for water vapour and excess oxygen not used in combustion.

B4 Measurement of particulate pollutants

When light illuminates a small particle such as a pollution particle in an exhaust plume, the light is both scattered in all directions and absorbed by the particle. For a particular incident light beam, the nature of the scattering and absorption interaction is determined by the physical characteristics of the individual particles – their size, shape and material characteristics – as well as by the size and shape distribution of the suspension of particles. If the characteristics of the incident light are known (specifically its direction of propagation, polarisation, wavelength and intensity), then this knowledge, coupled with the nature of the scattered light and a laboratory calibration, can be used to determine some features of particles in an exhaust plume.

Very briefly, smoke is measured in vehicle exhaust plumes based on the absorption and scattering of light beams at ultraviolet (UV) wavelengths (~232 nm). These are the approximate wavelengths for peak mass density of diesel exhaust particulates (~100 nm). With a scattering configuration and an appropriate wavelength(s), and after making some realistic assumptions about particle properties (eg particle composition and size distribution), the smoke measurements are translated into particulate measurement units that approximate to grams of particulate per 100 grams of fuel burned. A fuel-based emissions factor, with units of grams of particulate per kilogram of fuel burned, can be calculated by considering the stoichiometry of fuel combustion and assumptions of fuel composition.

B5 Vehicle, speed and acceleration data

The RSD 4000EN system included a module to record the speed and acceleration of each vehicle when its emissions were measured. This provided valuable information about the driving conditions of the vehicles at the time of the measurements. The speed and acceleration measurement bars made their measurements before the vehicle passed through the emissions measurement equipment. The speed and acceleration bars were set up as close as practical (~2 m) to the source detector module (SDM) to minimise any changes in the vehicle's speed and acceleration between the points where the vehicle's speed and acceleration and emissions were measured.

B6 Vehicle information

The RSD 4000EN system included video equipment to record freeze-frame images of the licence plate of each vehicle measured. The camera took an electronic image of the licence plate which was integrated into the RSD's monitoring database. At the completion of the day's monitoring the licence plate information was transcribed into a text file.

The list of licence plates were submitted to the Transport Agency's vehicle register (Motochek) and information obtained for each vehicle. Table B.1 lists the relevant information obtained for the vehicles monitored in this project.

Table B.1 Information obtained on monitored vehicles from Motochek

Motochek database field	Description of data
Make	Company which manufactured the vehicle
Model	
Year of manufacture	
Body style	Saloon, hatchback, station wagon, utility, light van, flat deck truck, heavy bus/service coach etc.
Main colour	
Engine capacity	cc
Engine power	kW
Vehicle type	Passenger car/van, goods van/truck/utility, motorcycle, bus, trailer/caravan, tractor etc.
Purpose of vehicle use	Private passenger, taxi, commercial passenger transport, licensed goods, other (standard) goods, ambulance, fire brigade, diplomatic etc.

Motochek database field	**Description of data**
Fuel type	Petrol, diesel, LPG, CNG, other
Country of origin	Country where vehicle was manufactured
WOF expires	Warrant of fitness expiry date
Registration status	Active, cancelled or lapsed
Country of first registration	Country where vehicle was first registered
Gross vehicle mass	kg
Tare weight	kg
Odometer reading	km or miles
Plate type	Standard, trade, personalised, investment, diplomatic or crown
Ownership	Private (male or female), company, fleet or lease
Subject to RUC	Subject to road user charges

Appendix C: Quality assurance of data

Appendix C provides a brief outline of the processes used to quality assure the 2015 on-road emission and vehicle dataset. The text contained in sections C1 to C3 is sourced from the more detailed description provided by Kuschel et al (2012)

C1 Calibration and audit

Quality assurance calibrations and audits were performed in the field to ensure the quality of the data collected met specified standards. These were performed according to the equipment manufacturer's specifications as follows.

Every time the SDM was switched on and warmed up, the unit was calibrated using a method named cell calibration. A cell which contained a known concentration of calibration gases was placed in the IR beam path and the SDM was then calibrated to the known values of gas within the cell.

Each calibration was audited immediately after the calibration process and every hour thereafter that the equipment was operated. The purpose of the audits was to check the equipment remained correctly calibrated.

Audits were carried out by the computer-verified audit system which employed a gas puff method. This involved a puff of gas containing certified amounts of CO, CO_2, propane and NO being released from the gas dispenser box) into the calibration tube, which was mounted on the detector window of the SDM. The measured gas ratios from the instrument were then compared with those certified by the cylinder manufacturer. If the gas ratios measured during any of the audits did not fall within specified limits or if the alignment of the unit had been changed, then the RSD required recalibration and the audit process to begin again.

The primary data the RSD 4000EN measures to produce uvSmoke data is UV absorbance at wavelengths ~232 nanometres (nm). The UV signal is by far the most sensitive to the alignment of the SDM and the corner cube reflector. While no field calibration is undertaken for the uvSmoke measurements, the audit process requires that the SDM and the corner cube reflector are aligned to achieve a consistent and maximum UV signal value.

The audits accounted for hour-to-hour variation in instrument sensitivity, variations in ambient CO_2 levels and variation of atmospheric pressure and instrument path length. Since propane was used to calibrate the instrument, all HC measurements reported by the unit were given as propane equivalents.

C2 Treatment of negative RSD data

As with all scientific instruments, the RSD is not perfectly precise and there is some uncertainty or error associated with the data it records, eg HC concentrations can be ±6.6ppm of the value recorded. When measuring pollutant concentrations from newer, typically lower emitting vehicles, concentrations are frequently close to or at zero. The pollutant ratio method the RSD employs to measure emissions means that these low values may be recorded as negative concentrations. While in reality there is no such thing as a negative concentration, provided the RSD's quality assurance criteria are met, the negative concentration values produced are valid data as they reflect the uncertainty in the measurements. The negative values recorded are a useful indicator of the 'noise' contained within the data produced by the RSD instrument.

In this report, all valid negative data has been included in the data analyses and the subsequent calculations of mean and median values etc. However, for ease of display and interpretation, the box plots that show the emissions measurements only show the positive data.

C3 Vehicle specific power

The speed and acceleration measurements were also used to derive vehicle specific power (VSP). VSP is a performance measure for determining whether a vehicle is operating within an acceptable power range when it is measured by remote sensing. The RSD 3000 system did not have the capability to measure vehicle speed or acceleration and therefore VSP data is not available for the 2003 monitoring campaign.

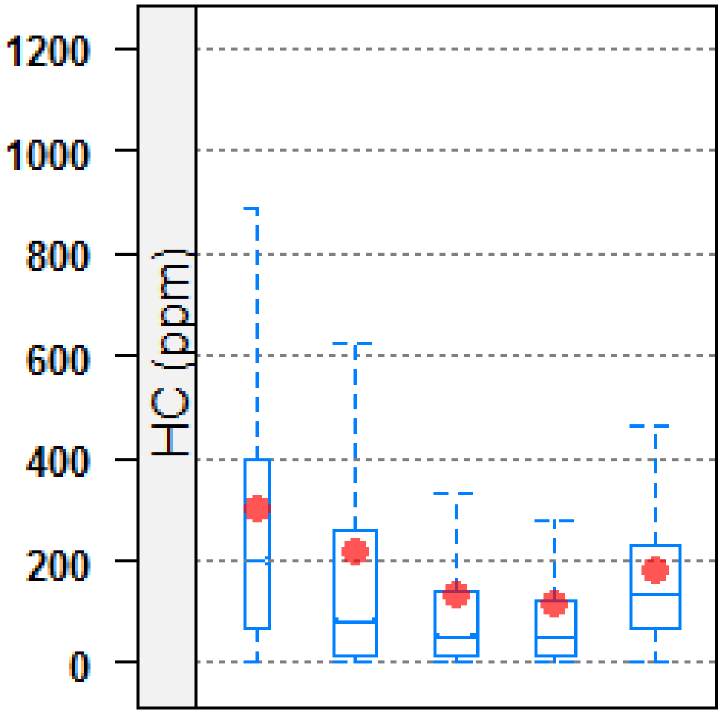
The emissions dataset from a vehicle was only considered valid if its VSP value fell between zero and 40kW/tonne. Monitoring sites that generate a relatively low proportion of vehicles providing valid data (a poor vehicle capture rate) can be scrutinised by considering the acceleration data. Sites with poor capture rates often show a large proportion of vehicles undergoing hard accelerations or decelerations during testing.

Engine load is a function of vehicle speed and acceleration, the slope of the site, vehicle mass, aerodynamic drag, rolling resistance and transmission losses. Under moderate to heavy load conditions, vehicle engines will enter enrichment modes that can increase emissions many times. These readings may bias the average results and the vehicles may be incorrectly classified as high emitters. Therefore, it was useful to have a performance measure (eg VSP) to screen out measurements of vehicles operating in enrichment mode.

C4 2015 Hydrocarbon data

During the initial analysis of the 2015 emission data unexpectedly high values for HC emissions were found (see figure C.1). The significant increase in HC concentrations between 2011 and 2015 did not fit with the downward trend in HC emissions observed over the years 2003 to 2011. A review of the monitored fleet vehicle data did not show any changes in the types of vehicles captured by the RSD that would cause an increase of this magnitude. In relation to the anticipated effect of theoretical improvements in vehicle emission control, and as demonstrated by the decrease in RSD CO data between 2011 and 2015, it seemed unlikely that the increase in the RSD monitored HC data was caused by increased HC vehicle emissions in 2015. The 2015 HC data was therefore considered suspect and was investigated further.

Figure C.1 Light duty fleet average HC emissions 2003 to 2015

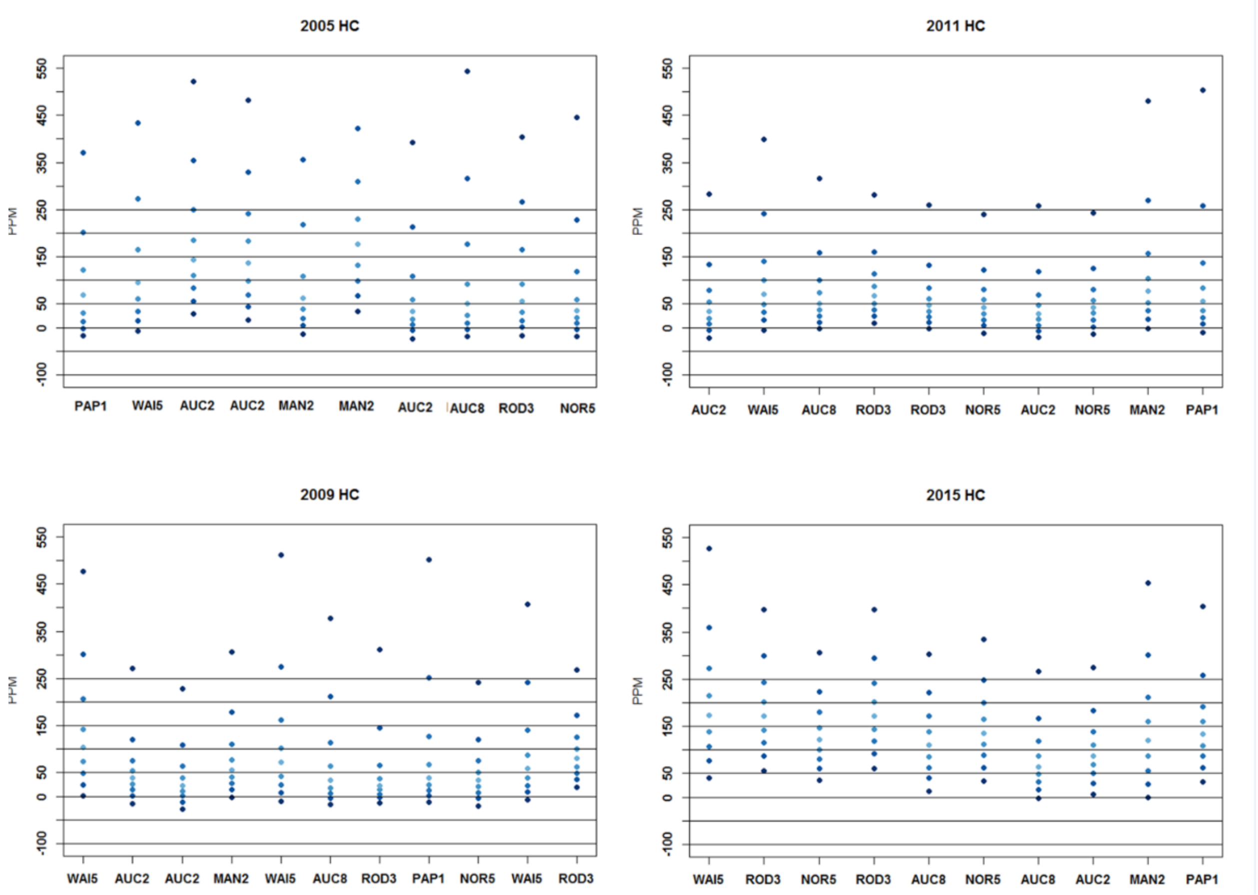


NIWA reviewed operational procedures used for the RSD in 2015. This included checking the calibration gas concentrations and other quality assurance procedures. One change in operational procedures did occur in 2015 and this was due to a failure of the auto-calibration equipment on day four of the monitoring programme. From day four onward in the 2015 monitoring programme the RSD calibration and audit checks were carried out using the manual gas calibration method. This approach was approved as valid by the equipment manufacturers (ESP). All other operational and data QA procedures were found to be sound and consistent with those used in previous years.

NIWA then further analysed the 2015 HC and compared it with previous years. Figure C.2 compares the HC data site by site for the years 2005, 2009, 2011 and 2015. NIWA sent the data and the results of the HC analysis to ESP for consideration. A phone meeting was held between ESP, NIWA and Golder to consider the issue. At this meeting it was agreed that:

- There was a significant difference between 2015 and 2011 HC data (and other years).
- 2015 HC data appeared to be unexpectantly high and to have a greater scatter than previous years.
- The 2015 data was different in two aspects from previous years. There was a shift up from zero in the lower percentile values in 2015. The spread in the lower percentile values was much greater in 2015 than in 2011.
- Two exceptions to the general 2015 changes were noted:
    - Two days in the 2005 campaign also showed similar shifts and spreads to that observed in 2015.
    - The first three days in the 2015 campaign did not show the shift up above zero for the lower percentile values (These were the days when the auto-calibration equipment was still operational).

Figure C.2 Comparison of HC data scatter 2005–2015



ESP suggested reasons for the change in 2015 data were most likely to be:

- change from using cell to puff calibrations
- misalignment of the RSD optics
- a wider ‘noise’ band in the HC light frequency occurred in 2105
- variation in the HC light frequency strength between 2011 and 2015.

Three other potential causes of the change in HC were discussed but discounted:

- Water droplets (fog or steam in the exhaust plume) were discounted because of the time of year and relatively warm weather conditions experienced during the sampling programme.
- Fuel tank evaporative emissions were discounted because of the temperate climate during sampling.
- RSD operator procedures – there were no real variables that the operator could have adjusted that would cause this degree of change.

At the end of the meeting, it was agreed that the most likely cause of the change in 2015 HC data was due to equipment changes and/or fault.

ESP/NIWA/Golder discussed the other three pollutants monitored in 2015 by the RSD. ESP analysed the 2015 CO and NO data and was confident that the values and spread of the CO, NO data were consistent with previous campaigns. ESP concluded there was no sign of any problems with the CO or NO data. UvSmoke was not discussed in any detail at the meeting, but no issues or concerns were raised by ESP around the measurement or data for this pollutant. ESP staff noted that the measurement of HC was much more sensitive to changes in environmental conditions, calibration procedures, optics alignment and signal strength than the other pollutants. ESP was able to reassure NIWA and Golder that while there was a problem with the HC data that needed to be resolved, they were confident that the data for the other three pollutants was robust.

Following the meeting ESP confirmed it was feasible to correct and report 2015 HC values, albeit with a caveat that the data had been subject to post-processing and a recommended that the data be presented with a description of the post-processing adjustment process undertaken. The HC data post processing adjustment required four steps:

1 Calculating average 2011 daily median HC ppm of vehicles 0–10years old (29.1ppm)

2 Calculating unadjusted 2015 daily median HC ppm of 0–10year old vehicles measured in 2015

3 Calculating 2015 daily HC ppm offsets: (29.1 (ppm) – 2015 daily median from step 2 (ppm))

4 Adding the daily HC ppm offsets (a negative number) to the HC measurements made that day.

Figure C.3 shows the 2015 unadjusted HC data deciles for vehicles 0–10 years old. Each HC decile value is represented on figure C.3 by a different coloured dot. Figure C.4 shows the 2015 adjusted HC data deciles for vehicles 0–10 years old. A comparison of figures C.3 and C.4 show that the 2015 HC shifted downward significantly after the 2015 offset had been applied.

Figure C.5 compares 2011 and 2015 HC emissions by vehicle age before the adjustment process has been applied. Figure C.6 compares 2011 and 2015 HC emissions by vehicle age after the adjustment process has been applied. A comparison of figures C.5 and C.6 show that the 2015 HC has shifted downward significantly after the 2015 offset has been applied and is then similar to the HC data monitored in 2011.

Figure C.3 HC deciles for vehicles aged 0 to 10 years before adjustment

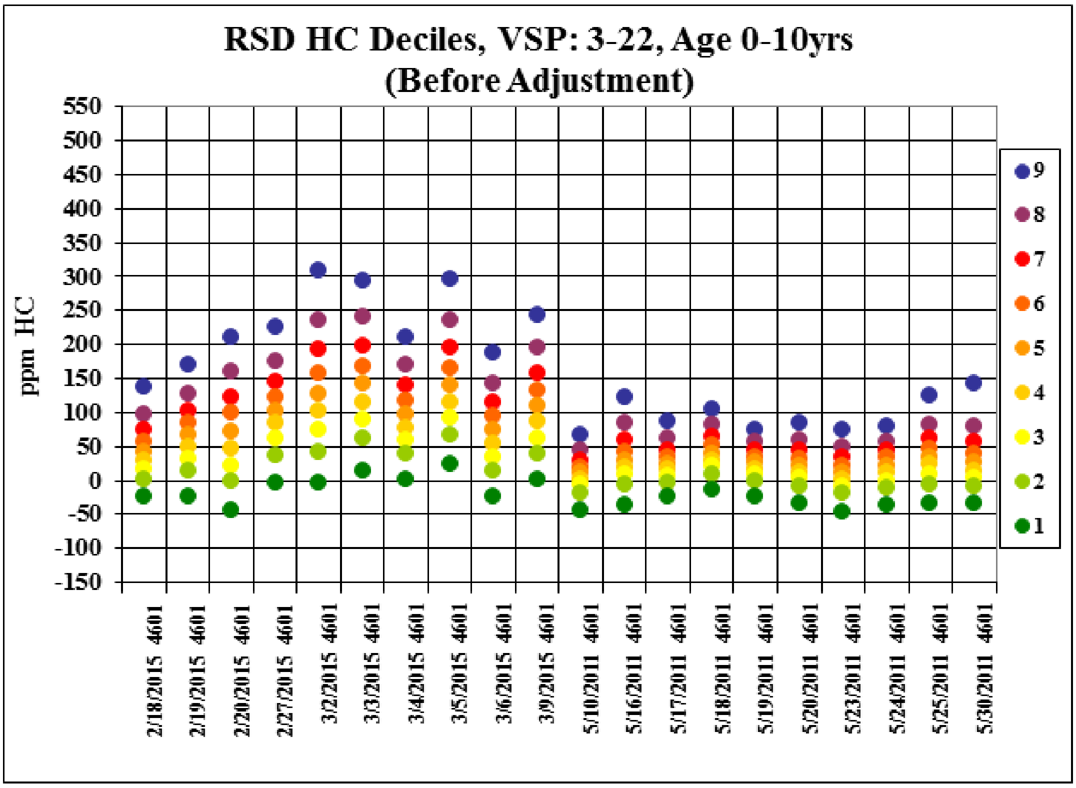


Figure C.4 HC deciles for vehicles aged 0 to 10 years after adjustment

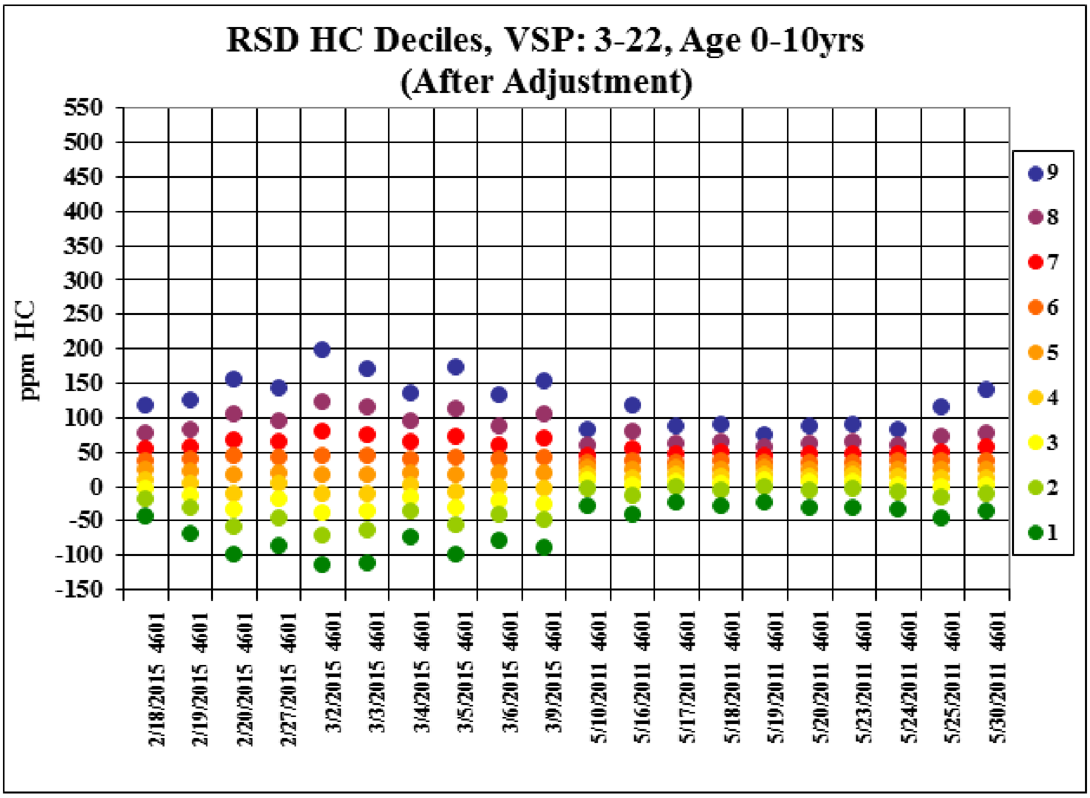


Figure C.5 Comparison of HC emissions by vehicle age before adjustment

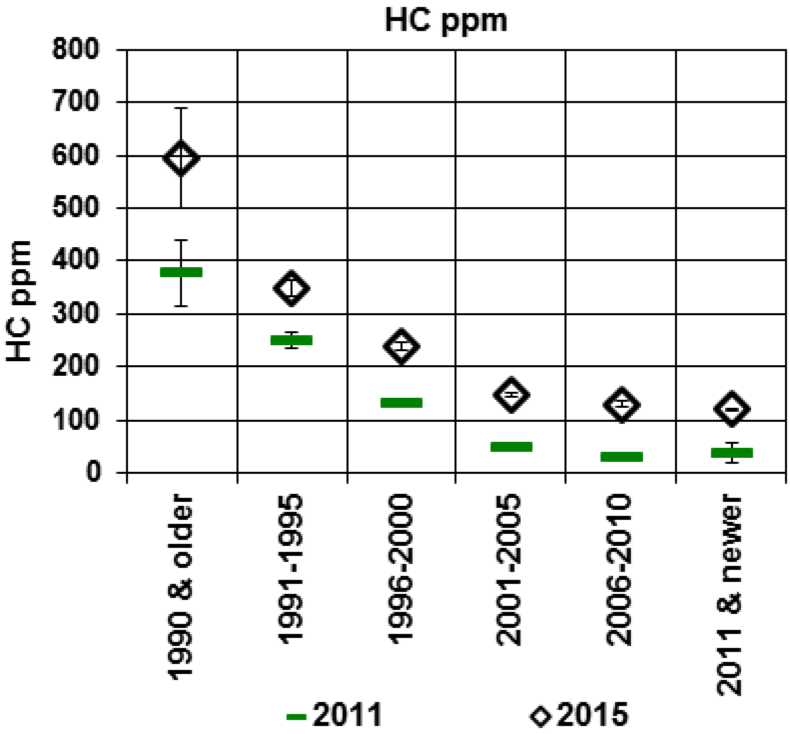
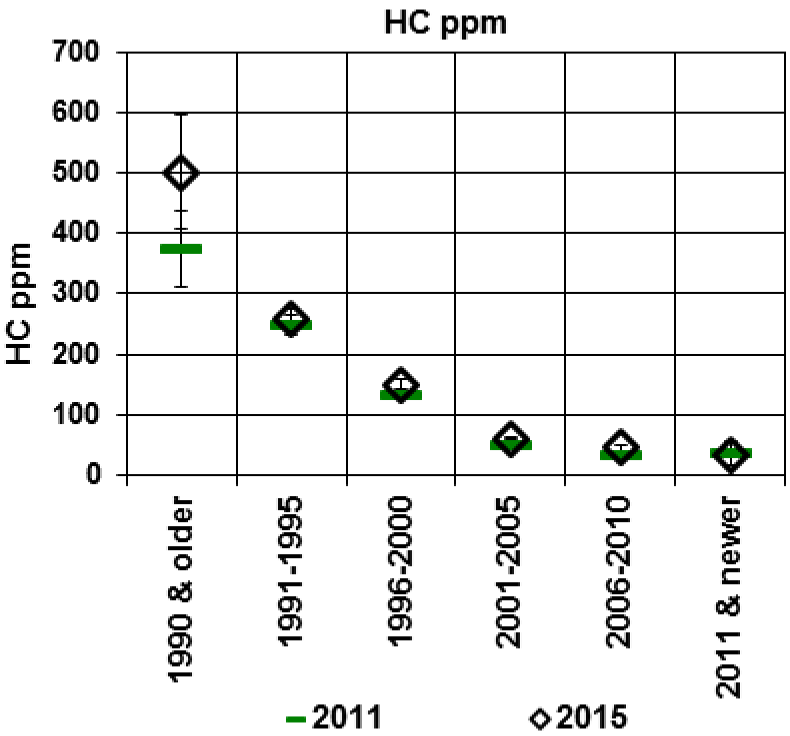


Figure C.6 Comparison of HC emissions by vehicle age after adjustment



The problems with the 2015 HC data have implications for the 2015 analysis and reporting which must be considered carefully. In summary:

- It is feasible to correct and report 2015 HC values, albeit with a caveat attached and a description of the post-processing adjustment being applied.
- The 2015 HC offset corrected data is suitable for making comparisons of HC emissions between different vehicle types and classes within the 2015 data set (eg old vs new vehicles).
- The 2015 HC offset corrected data is not suitable for assessing the changes in HC emissions between 2011 and 2015. This is because the median value of the 2015 HC data has been matched to that of 2011 and therefore any changes in HC data over time will be masked.

The problems with the 2015 HC data have implications for the wider New Zealand RSD stakeholder group and for future RSD vehicle emission monitoring campaigns. These include:

- The NIWA RSD would benefit from an ESP service.
- The RSD data quality assurance process used in New Zealand should be reviewed and if needed improved – especially with regard to HC.
- There is potential value in investigating the environmental and monitoring site factors which may cause a wider scatter of HC data at some sites during campaigns in New Zealand.

Appendix D: Trends in light duty vehicle emissions

D1 Fleet average

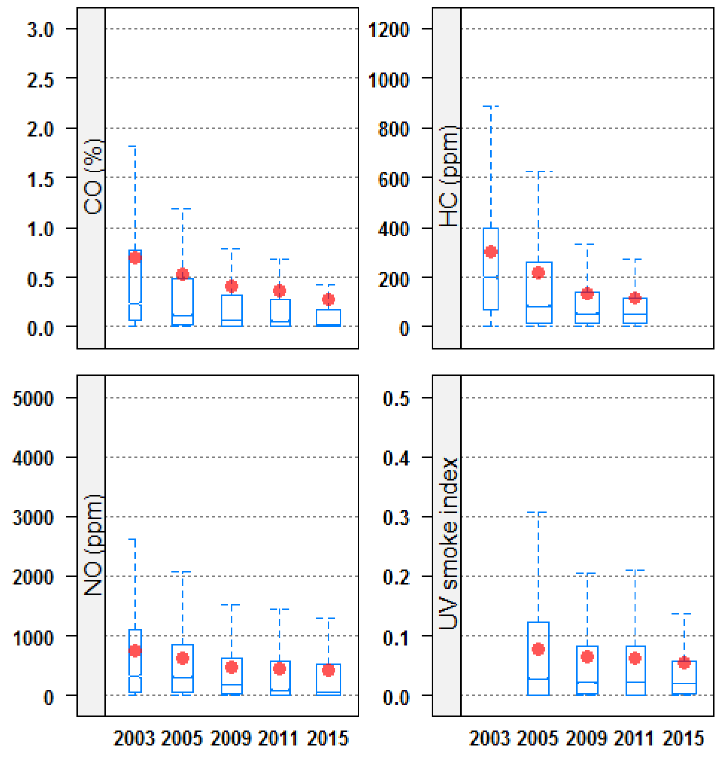
Table D.1 Comparison of the median and mean emissions of the 2003–2015 monitored LDV fleets

Campaign year	No. of vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	9,647	0.69	0.23	301	200	764	330	NA*	NA*
2005	25,389	0.53	0.12	220	83	630	313	0.078	0.029
2009	22,953	0.41	0.07	134	52	489	186	0.065	0.022
2011	24,382	0.37	0.06	115	49	467	92	0.063	0.023
2015	33,942	0.27	0.03	NA#	NA#	421	56	0.055	0.02

* The 2003 RSD equipment did not measure uvSmoke.

[#] The 2015 HC data was suspect. See appendix C, section C4.

Figure D.1 Comparison of the emissions of the 2003–2015 monitored LDV fleets



D2 Petrol

D2.1 Fleet average

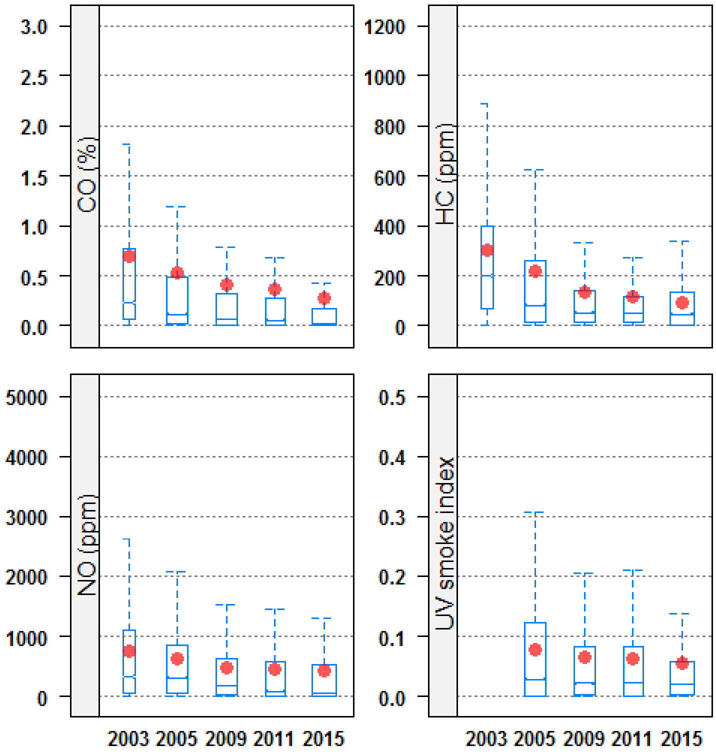
Table D.2 Comparison of the median and mean emissions of the 2003-2015 monitored LDV petrol fleets

Campaign year	No. of vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	8,430	0.77	0.29	325	220	810	286	NA*	NA*
2005	21,639	0.62	0.17	239	87	660	235	0.061	0.019
2009	19,342	0.48	0.11	143	49	495	118	0.049	0.015
2011	20,415	0.44	0.09	121	46	457	52	0.045	0.015
2015	27,662	0.33	0.04	NA#	NA#	374	27	0.035	0.015

* The 2003 RSD equipment did not measure uvSmoke

\# The 2015 HC data was faulty. See appendix C, section C4.

Figure D.2 Comparison of the emissions of the 2003-2015 monitored LDV petrol fleets



D2.2 New Zealand new

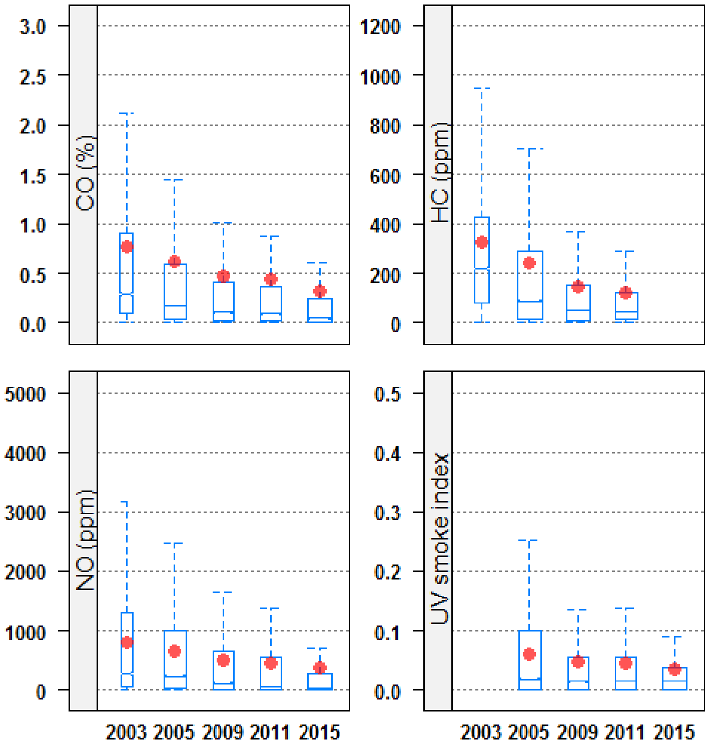
Table D.3 Comparison of the median and mean emissions of the 2003–2015 monitored LDV NZN petrol fleets

Campaign year	No. of vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	4,460	0.84	0.32	377	250	983	356	NA*	NA*
2005	10,391	0.65	0.13	286	110	795	203	0.081	0.024
2009	9,268	0.43	0.05	139	36	486	54	0.053	0.01
2011	9,742	0.37	0.05	116	39	450	27	0.047	0.01
2015	13,102	0.26	0.02	NA#	NA#	345	17	0.035	0.013

* The 2003 RSD equipment did not measure uvSmoke

The 2015 HC data was faulty. See appendix C, section C4..

Figure D.3 Comparison of the emissions of the 2003–2015 monitored NZN LDV petrol fleets



D2.3 Japanese used

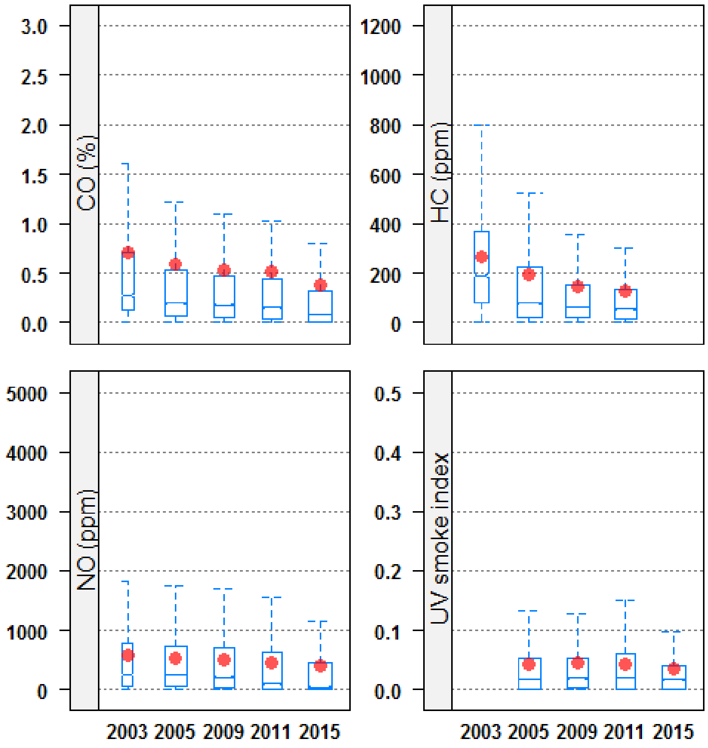
Table D.4 Comparison of the median and mean emissions of the 2003-2015 monitored LDV JPU petrol fleets

Campaign year	No. of vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	3,844	0.71	0.28	267	190	589	254	NA*	NA*
2005	10,829	0.59	0.2	195	77	536	256	0.043	0.018
2009	9,621	0.53	0.17	147	63	503	215	0.046	0.02
2011	10,210	0.51	0.15	126	54	462	101	0.044	0.021
2015	14,082	0.39	0.08	NA#	NA#	397	40	0.035	0.017

* The 2003 RSD equipment did not measure uvSmoke.

\# The 2015 HC data was suspect. See appendix C, section C4..

Figure D.4 Comparison of the emissions of the 2003-2015 monitored JPU LDV petrol fleets



D2.4 Comparison of NZN and JPU petrol vehicles

Figure D.5 Comparison of the emissions of the monitored NZN and JPU petrol vehicles from 2003–2015

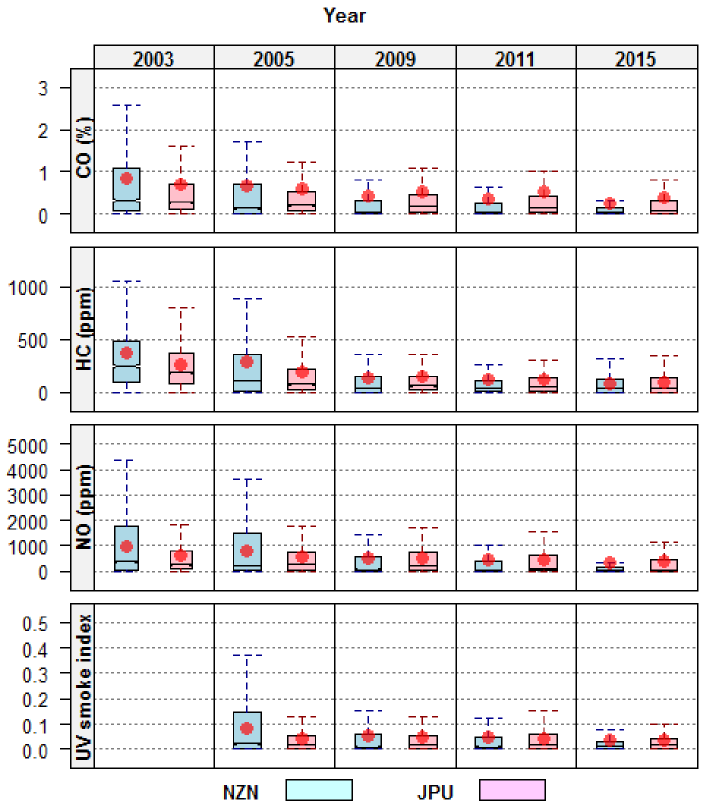
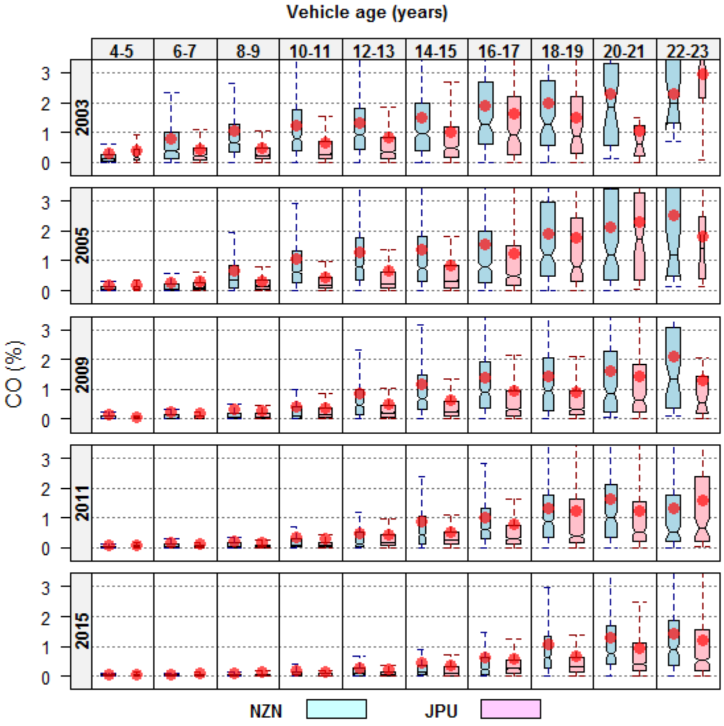


Figure D.6 Comparison of the CO emissions of the NZN and JPU petrol vehicles from 2003–2015 by age



D3 Diesel

D3.1 Fleet average

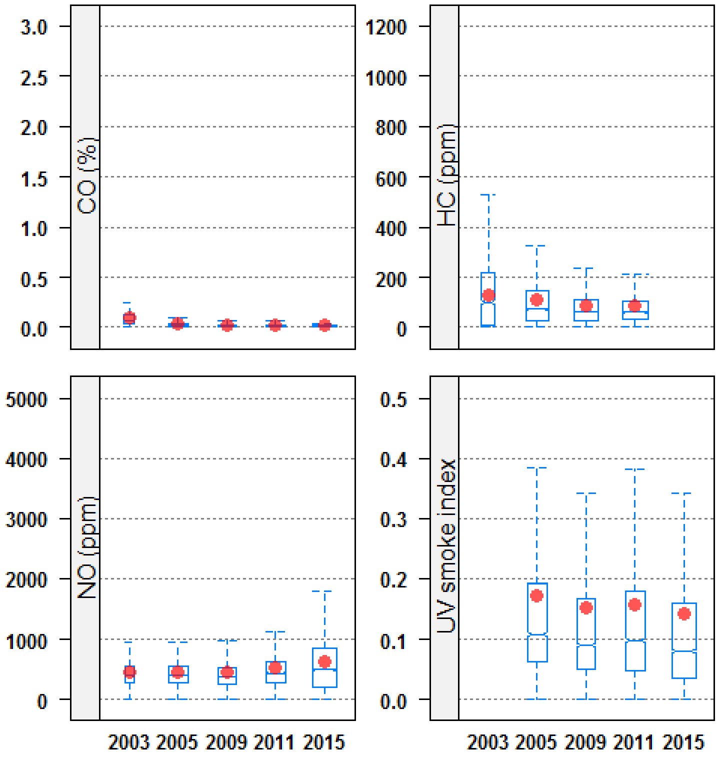
Table D.5 **Comparison of the median and mean emissions of the 2003-2015 monitored LDV diesel fleets**

Campaign year	No. of vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	1,212	0.1	0.06	129	100	452	396	NA*	NA*
2005	3,732	0.04	0.02	108	72	460	410	0.173	0.109
2009	3,588	0.02	0.01	86	62	454	382	0.153	0.09
2011	3,957	0.02	0.01	85	60	518	437	0.157	0.099
2015	6,251	0.02	0	NA[#]	NA[#]	632	494	0.142	0.081

* The 2003 RSD equipment did not measure uvSmoke.

[#] The 2015 HC data was suspect. See appendix C, section C4.

Figure D.7 **Comparison of the emissions of the 2003-2015 monitored LDV diesel fleets**



D3.2 New Zealand new

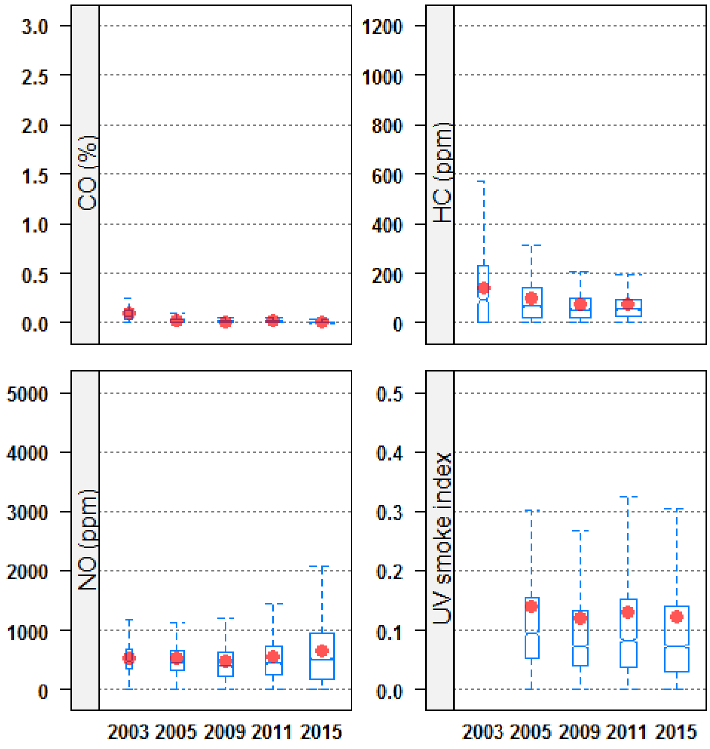
Table D.6 Comparison of the median and mean emissions of the 2003–2015 monitored LDV NZN diesel fleets

Campaign Year	No of Vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	470	0.1	0.07	137	90	539	475	NA*	NA*
2005	1,485	0.03	0.01	100	66	535	461	0.141	0.095
2009	2,021	0.01	0	74	53	490	404	0.121	0.073
2011	2,438	0.02	0.01	77	54	563	452	0.13	0.083
2015	4,808	0.01	0	NA#	NA#	660	511	0.123	0.072

. * The 2003 RSD equipment did not measure uvSmoke.

The 2015 HC data was suspect. See appendix C, section C4.

Figure D.8 Comparison of the emissions of the 2003–2015 monitored NZN LDV diesel fleets



D3.3 Japanese used

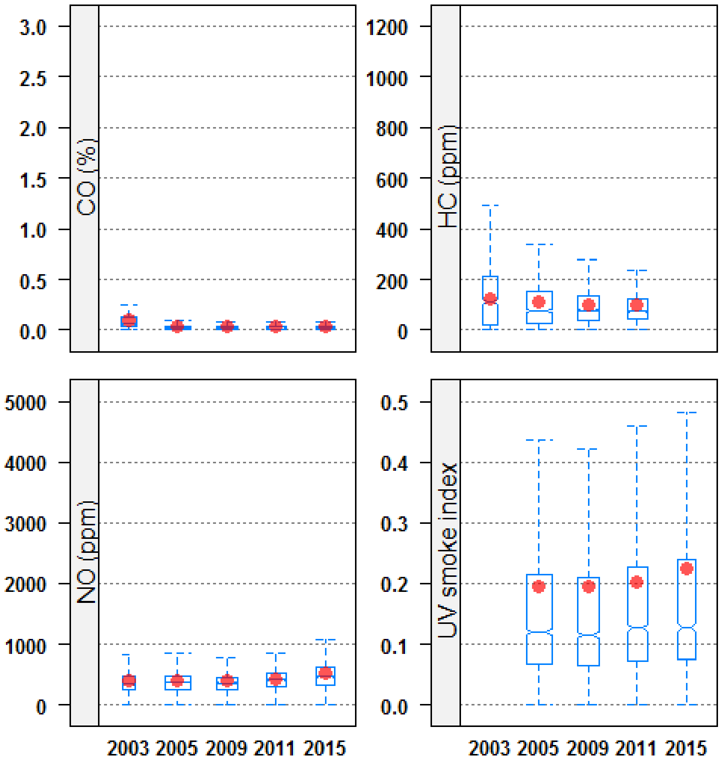
Table D.7 **Comparison of the median and mean emissions of the 2003–2015 monitored LDV JPU diesel fleets**

Campaign year	No. of vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	736	0.1	0.06	121	110	395	353	NA*	NA*
2005	2,231	0.04	0.02	113	75	408	384	0.195	0.121
2009	1,547	0.03	0.02	101	75	403	361	0.194	0.115
2011	1,491	0.03	0.01	99	73	443	421	0.202	0.127
2015	1,283	0.04	0.01	NA#	NA#	535	472	0.225	0.128

* The 2003 RSD equipment did not measure uvSmoke.

\# The 2015 HC data was suspect. See appendix C, section C4.

Figure D.9 **Comparison of the emissions of the 2003–2015 monitored JPU LDV diesel fleets**



D3.4 Comparison of NZN and JPU LDV diesel vehicles

Figure D.10 Comparison of the emissions of the monitored NZN and JPU LDV diesel vehicles from 2003–2015

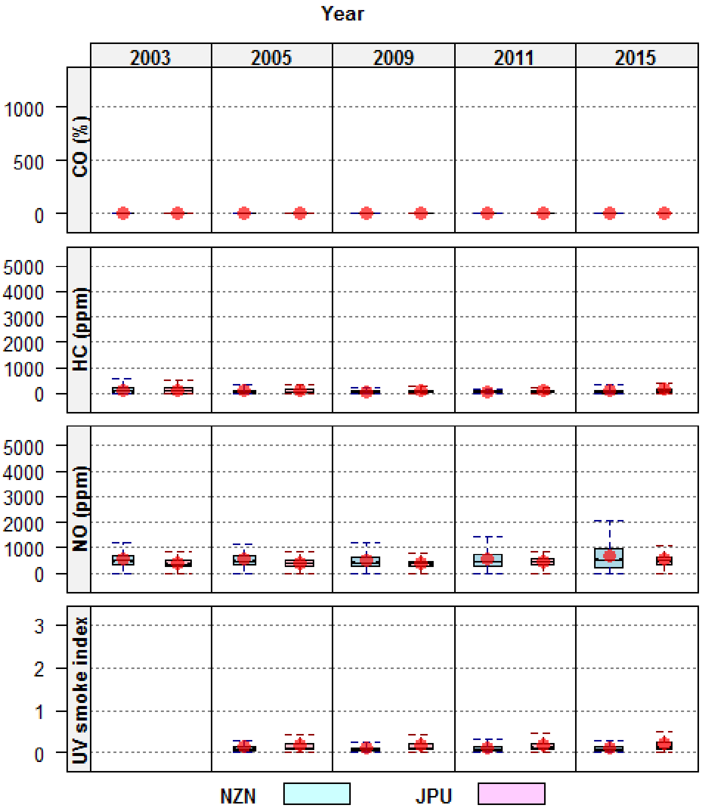
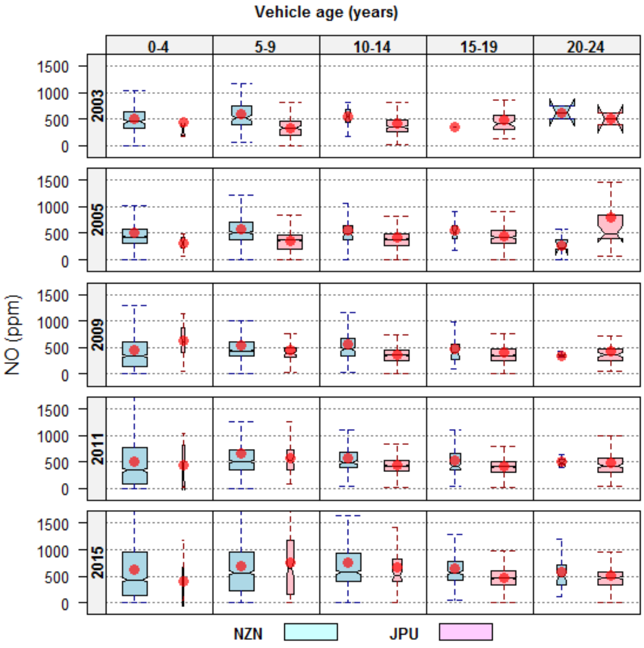


Figure D.11 Comparison of the NO emissions of the NZN and JPU LDV diesel vehicles from 2003–2015 by age



Appendix E: Trends in heavy duty vehicle emissions

E1 Fleet average

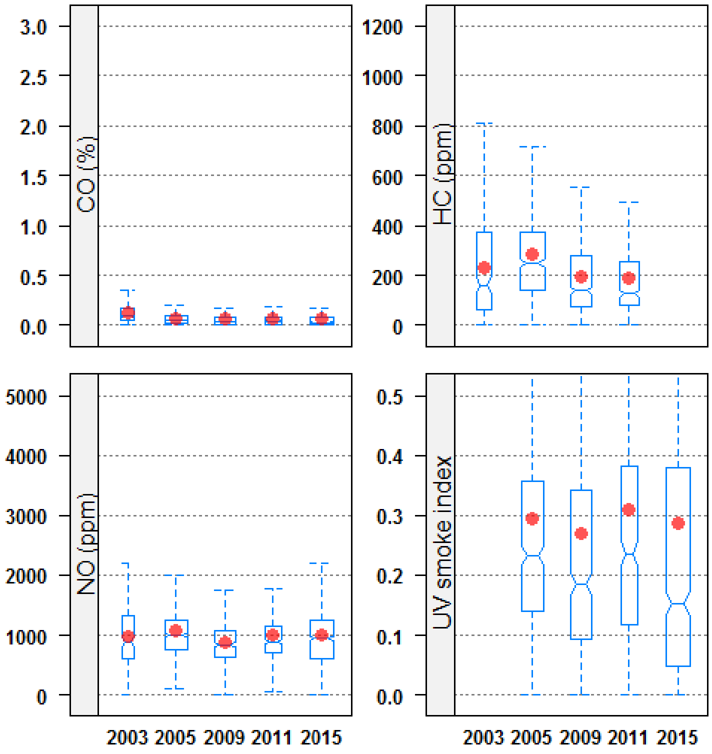
Table E.1 Comparison of the median and mean emissions of the 2003-2015 monitored HDV diesel fleets

Campaign year	No. of vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	235	0.13	0.09	232	160	968	888	NA*	NA*
2005	574	0.07	0.05	284	248	1067	1001	0.295	0.232
2009	480	0.06	0.04	193	137	878	835	0.271	0.185
2011	388	0.06	0.04	185	127	994	887	0.31	0.235
2015	734	0.06	0.03	NA#	NA#	993	944	0.286	0.153

* The 2003 RSD equipment did not measure uvSmoke.

\# The 2015 HC data was suspect. See appendix C, section C4.

Figure E.1 Comparison of the emissions of the 2003-2015 monitored HDV diesel fleets



E1.1 New Zealand new

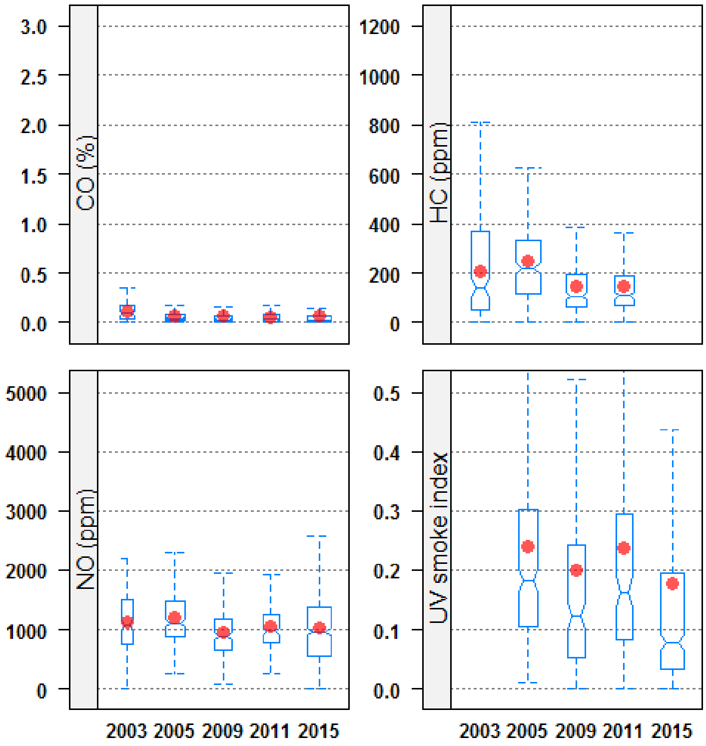
Table E.2 Comparison of the median and mean emissions of the 2003–2015 monitored HDV NZN diesel fleets

Campaign year	No. of vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	138	0.12	0.09	206	140	1140	1067	NA*	NA*
2005	237	0.07	0.04	247	219	1213	1108	0.241	0.183
2009	193	0.06	0.03	144	106	949	881	0.2	0.123
2011	159	0.06	0.03	147	107	1061	976	0.236	0.164
2015	376	0.06	0.02	NA#	NA#	1022	964	0.178	0.078

* The 2003 RSD equipment did not measure uvSmoke.

\# The 2015 HC data was suspect. See appendix C, section C4.

Figure E.2 Comparison of the emissions of the 2003–2015 monitored NZN HDV diesel fleets



E1.2 Japanese used

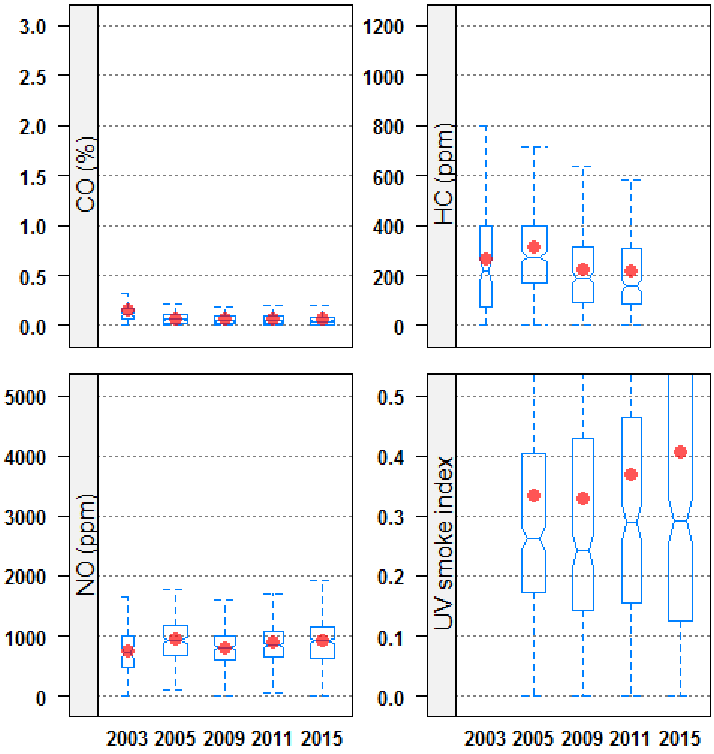
Table E.3 **Comparison of the median and mean emissions of the 2003-2015 monitored HDV JPU diesel fleets**

Campaign year	No. of vehicles	CO (%)		HC (ppm)		NO (ppm)		uvSmoke index	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	95	0.15	0.11	267	220	764	729	NA*	NA*
2005	332	0.07	0.06	314	273	959	926	0.336	0.263
2009	272	0.07	0.05	226	188	805	807	0.33	0.241
2011	215	0.07	0.05	216	156	913	845	0.37	0.289
2015	343	0.07	0.04	NA#	NA#	936	918	0.408	0.293

* The 2003 RSD equipment did not measure uvSmoke.

\# The 2015 HC data was suspect. See appendix C, section C4.

Figure E.3 **Comparison of the emissions of the 2003-2015 monitored JPU HDV diesel fleets**



Appendix F: Effect of emission control technology

F1 New Zealand new petrol vehicles

Table F.1 Comparison of the mean and median emissions of the monitored 2015 NZN petrol fleet by emission standard

Variable	Pre- 2003	Post- 2003	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.82 (0.31)	0.17 (0.03)	0.19 (0.03)	0.08 (0.01)	0.06 (0.01)	0.04 (0.01)	0.03 (0.01)
HC (ppm)	225 (129)	59 (32)	51 (24)	41 (18)	42 (23)	28 (12)	45 (-1)
NO (ppm)	1212 (700)	229 (19)	142 (15)	46 (5)	19 (1)	24 (0)	0 (0)
uvSmoke	0.114 (0.052)	0.019 (0.013)	0.017 (0.011)	0.009 (0.008)	0.008 (0.008)	0.007 (0.007)	0.001 (0.001)
No of readings	3,034	2,305	498	2,030	3,529	1,357	66

Figure F.1 Comparison of the emissions of the monitored 2015 NZN petrol fleet by emission standard

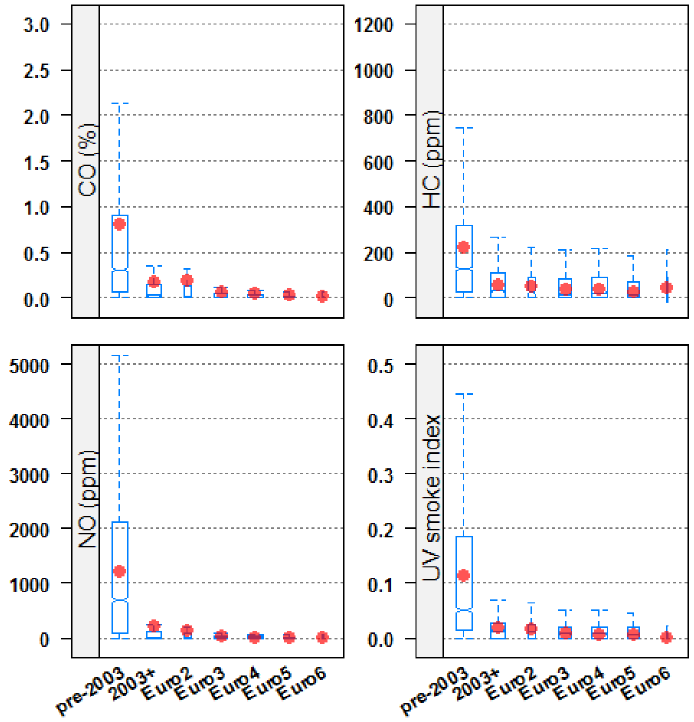
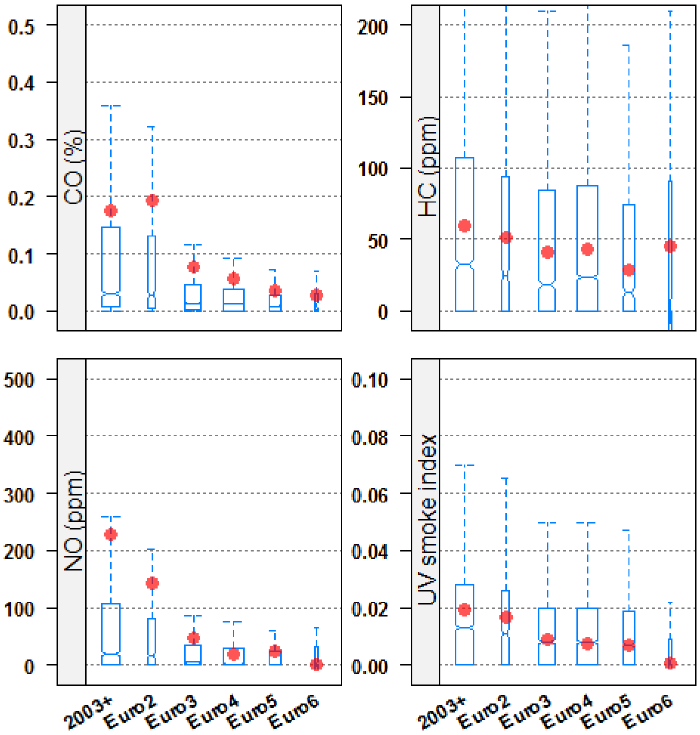


Figure F.2 Comparison of the emissions of the monitored 2015 NZN petrol fleet for vehicles manufactured after 2003 by emission standard

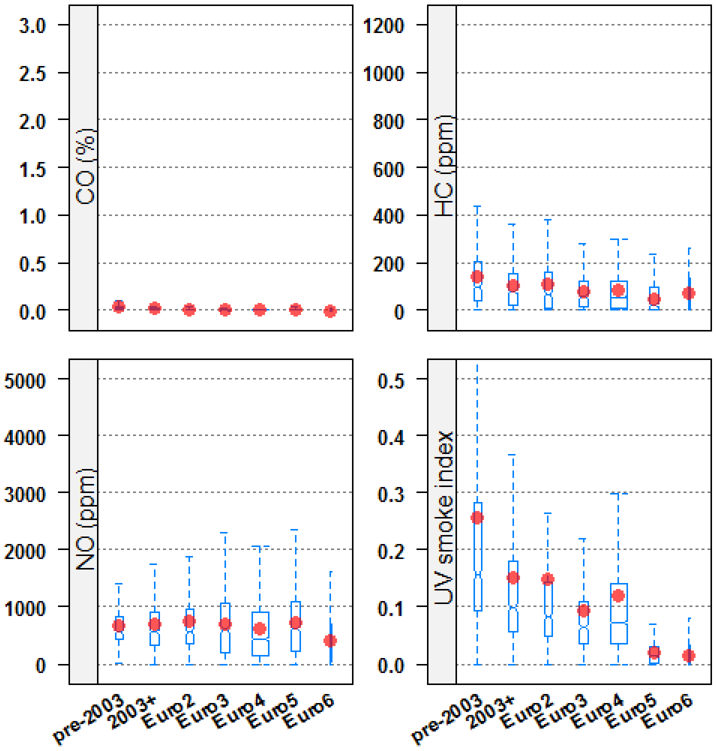


F2 New Zealand new diesel vehicles

Table F.2 Comparison of the mean and median emissions of the monitored 2015 NZN diesel fleet by emission standard

Variable	Pre- 2003	Post- 2003	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
CO (%)	0.04 (0.02)	0.02 (0)	0.01 (0)	0.01 (0)	0.01 (0)	0.01 (0)	0 (0)
HC (ppm)	140 (98)	105 (80)	109 (68)	79 (56)	84 (55)	49 (22)	74 (57)
NO (ppm)	672 (553)	699 (553)	757 (552)	708 (605)	614 (425)	711 (607)	419 (193)
uvSmoke	0.255 (0.156)	0.151 (0.098)	0.148 (0.083)	0.093 (0.065)	0.118 (0.072)	0.019 (0.014)	0.014 (0.01)
No of readings	452	610	329	497	2 308	609	37

Figure F.3 Comparison of the emissions of the monitored 2015 NZN diesel fleet by emission standard

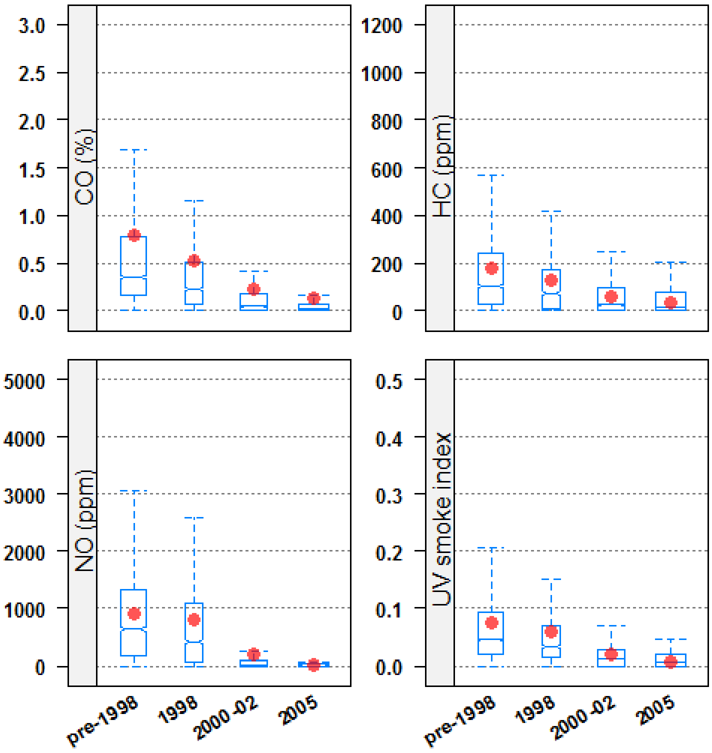


F3 Japanese used petrol vehicles

Table F.3 Comparison of the mean and median emissions of the monitored 2015 JPU petrol fleet by emission standard

Variable	Pre- 1998	1998	2000- 02	2005
	Mean (median)	Mean (median)	Mean (median)	Mean (median)
CO (%)	0.8 (0.35)	0.53 (0.23)	0.22 (0.05)	0.13 (0.02)
HC (ppm)	181 (105)	127 (75)	56 (25)	36 (14)
NO (ppm)	911 (633)	798 (416)	186 (20)	25 (0)
uvSmoke	0.075 (0.045)	0.058 (0.032)	0.019 (0.012)	0.008 (0.007)
No of readings	3270	1438	3550	4451

Figure F.4 Comparison of the emissions of the monitored 2015 JPU petrol fleet by emission standard category

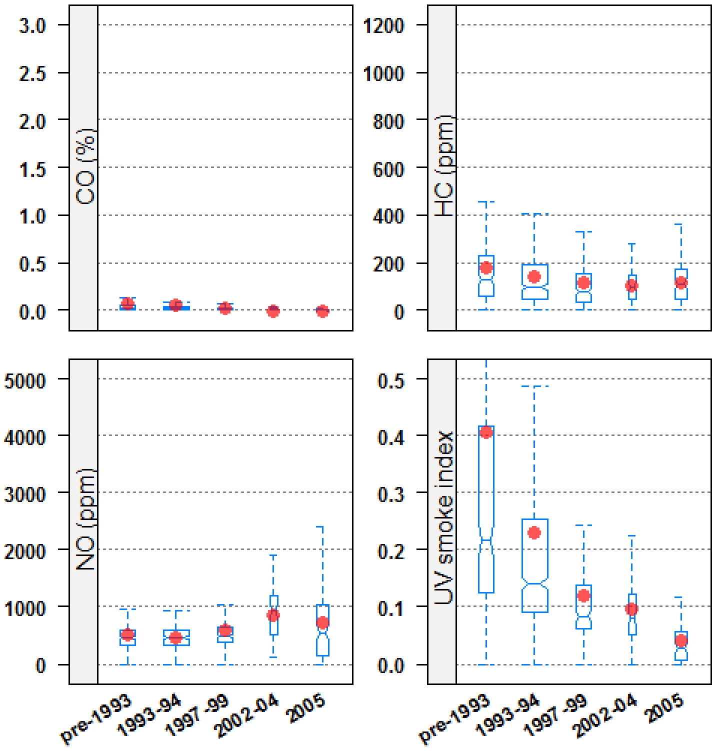


F4 Japanese used diesel vehicles

Table F.4 Comparison of the mean and median emissions of the monitored 2015 JPU diesel fleet by emission standard

Variable	Pre- 1998	1998	2000-02	2002-04	2005
	Mean (median)	Mean (median)	Mean (median)	Mean (median)	Mean (median)
CO (%)	0.07 (0.02)	0.05 (0.02)	0.02 (0.01)	0 (0.01)	0 (0)
HC (ppm)	177 (127)	138 (97)	118 (80)	102 (97)	118 (113)
NO (ppm)	502 (452)	470 (457)	578 (491)	865 (936)	719 (539)
uvSmoke	0.406 (0.216)	0.229 (0.141)	0.119 (0.084)	0.095 (0.08)	0.042 (0.027)
No of readings	229	522	213	50	99

Figure F.5 Comparison of the emissions of the monitored 2015 JPU diesel fleet by emission standard



category

Appendix G: Effect of mileage on emissions

G1 New Zealand new petrol vehicles

Figure G.1 Comparison of the emissions of the monitored high and low mileage NZN petrol vehicles by emission standard

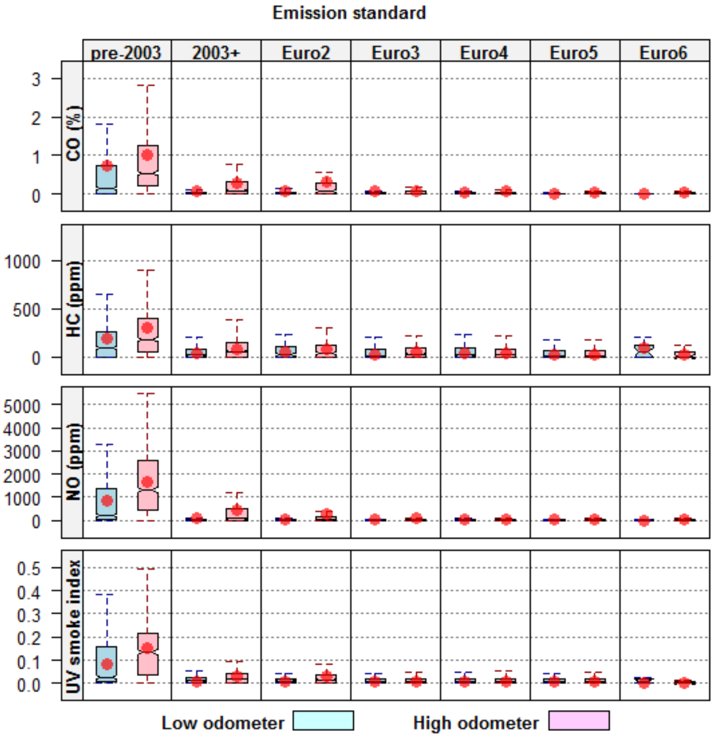


Table G.1 Comparison of the emissions of the monitored high and low mileage NZN petrol vehicles by emission standard

Emission standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-2003	Mean	0.8	1.0	190.9	303.6	835.2	1627.0	0.1	0.2
	Median	0.1	0.5	94.0	181.2	202.0	1318.9	0.0	0.1
2003+	Mean	0.1	0.3	41.3	87.1	80.5	441.5	0.0	0.0
	Median	0.0	0.1	21.6	59.5	4.5	73.9	0.0	0.0
Euro 2	Mean	0.1	0.3	47.5	76.9	60.5	271.3	0.0	0.0
	Median	0.0	0.1	23.4	36.9	5.1	27.7	0.0	0.0
Euro 3	Mean	0.1	0.1	30.7	58.1	28.1	76.8	0.0	0.0
	Median	0.0	0.0	11.1	30.3	1.5	11.5	0.0	0.0
Euro 4	Mean	0.0	0.1	43.5	41.9	13.6	44.2	0.0	0.0
	Median	0.0	0.0	20.2	24.1	1.6	8.9	0.0	0.0
Euro 5	Mean	0.0	0.1	28.9	24.4	18.2	51.4	0.0	0.0
	Median	0.0	0.0	10.1	10.7	- 3.9	4.4	0.0	0.0

Emission standard		**CO (%)**		**HC (ppm)**		**NO (ppm)**		**uvSmoke**	
		Low km	**High km**	**Low km**	**High km**	**Low km**	**High km**	**Low km**	**High km**
Euro 6	Mean	**0.0**	**0.0**	94.1	21.4	**- 6.9**	**16.6**	0.0	0.0
	Median	**0.0**	**0.0**	51.2	-1.4	**- 20.1**	**- 0.5**	0.0	0.0

* Note the values shown in **bold** and grey cells are statistically significantly different from each other

Figure G.2 **Comparison of the emissions of the monitored pre- 2003 NZN petrol vehicles by odometer reading**

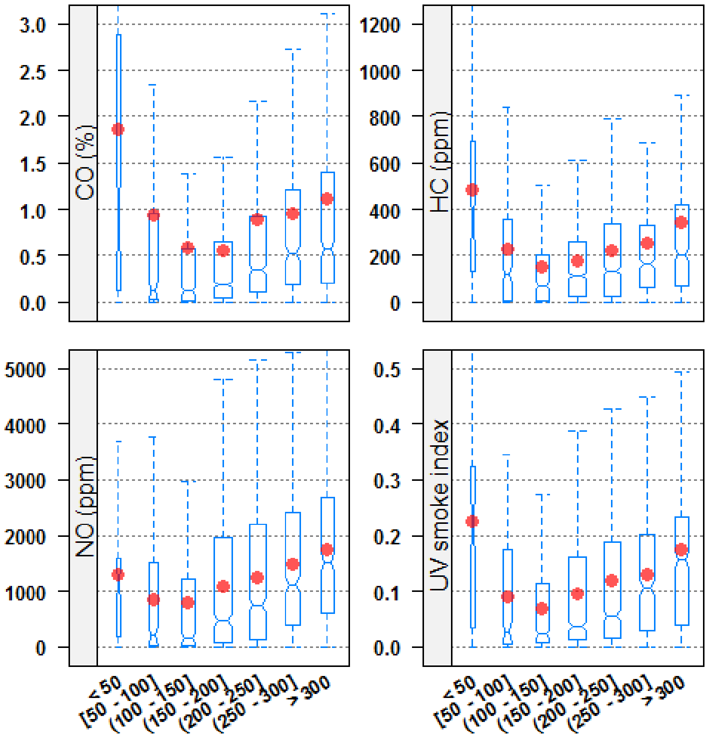
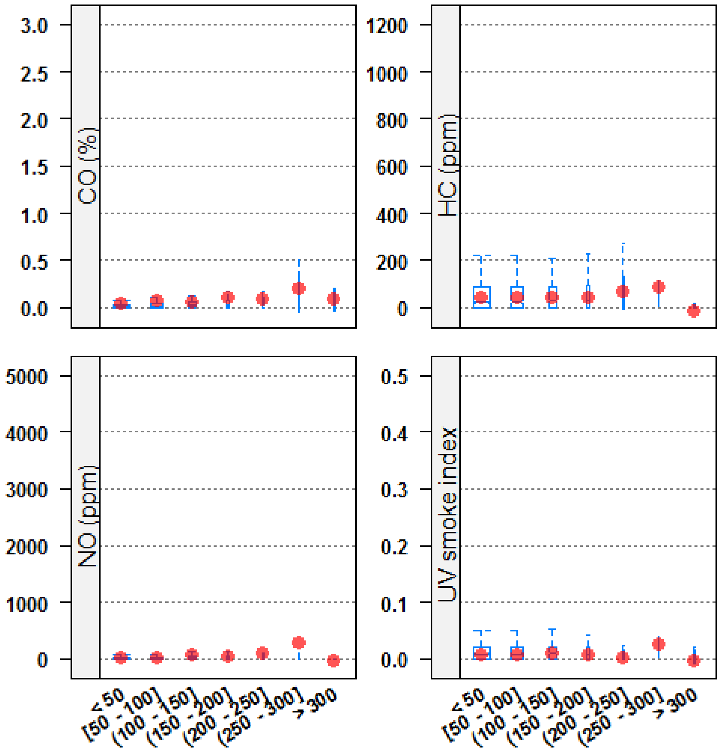


Figure G.3 Comparison of the emissions of the monitored Euro 4 NZN petrol vehicles by odometer reading



G2 New Zealand new diesel vehicles

Table G.2 Comparison of the emissions of the monitored high and low mileage NZN diesel vehicles by emission standard -

Emission standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-2003	Mean	0.1	0.0	156.9	134.4	657.8	679.1	0.3	0.3
	Median	0.0	0.0	103.6	104.2	509.3	579.1	0.2	0.2
2003+	Mean	**0.0**	**0.0**	**80.1**	**131.4**	690.2	713.0	**0.1**	**0.2**
	Median	**0.0**	**0.0**	**59.4**	**103.1**	547.7	514.8	**0.1**	**0.1**
Euro 2	Mean	0.0	0.0	92.6	102.7	**671.4**	**905.7**	0.1	0.1
	Median	0.0	0.0	79.1	63.9	**486.2**	**659.8**	0.1	0.1
Euro 3	Mean	**0.0**	**0.0**	75.0	85.4	**596.7**	**811.2**	**0.1**	**0.1**
	Median	**0.0**	**0.0**	62.5	49.6	**334.0**	**693.4**	**0.1**	**0.1**
Euro 4	Mean	0.0	0.0	85.3	90.3	**574.5**	**698.0**	0.1	0.1
	Median	0.0	0.0	60.9	59.5	**380.3**	**526.9**	0.1	0.1
Euro 5	Mean	0.0	0.0	46.3	45.2	724.0	794.9	**0.0**	**0.0**
	Median	0.0	0.0	22.4	19.8	610.8	695.6	**0.0**	**0.0**
Euro 6	Mean	0.0	0.0	69.5	75.8	611.6	457.5	0.0	0.0
	Median	0.0	0.0	58.6	57.9	193.2	433.6	0.0	0.0

* Note the values shown in **bold** and grey cells are statistically significantly different from each other

Figure G.4 Comparison of the emissions of the monitored high and low mileage NZN diesel vehicles by emission standard

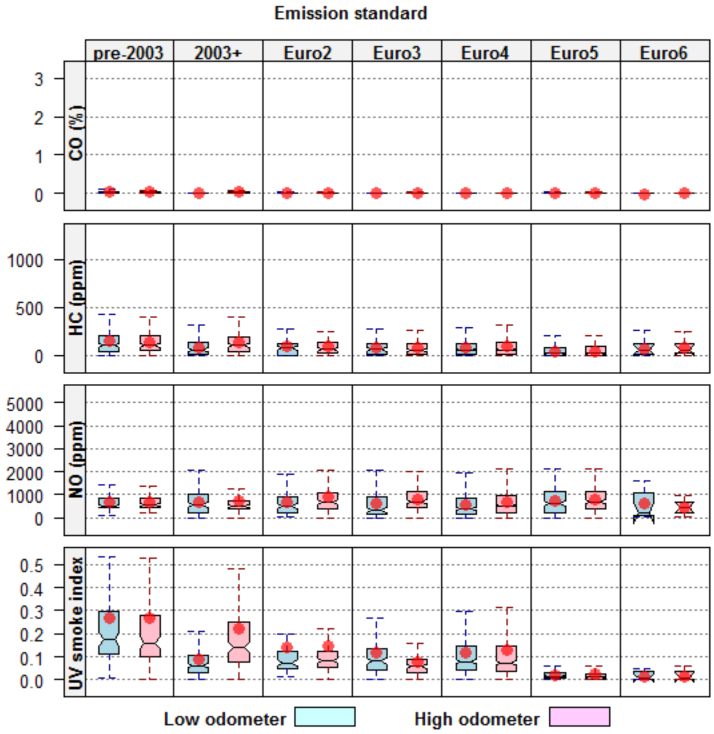


Figure G.5 Comparison of the emissions of the monitored pre- 2003 NZN diesel vehicles by odometer reading

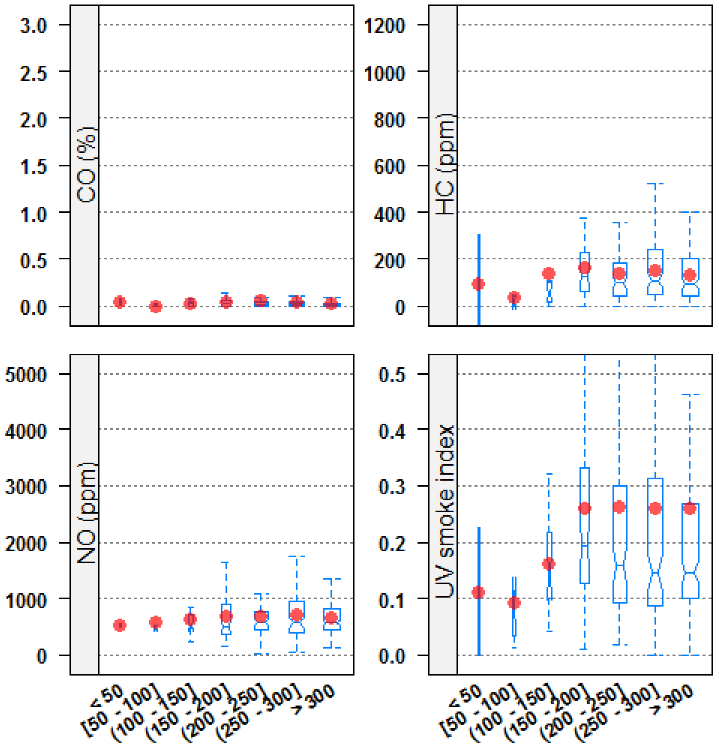
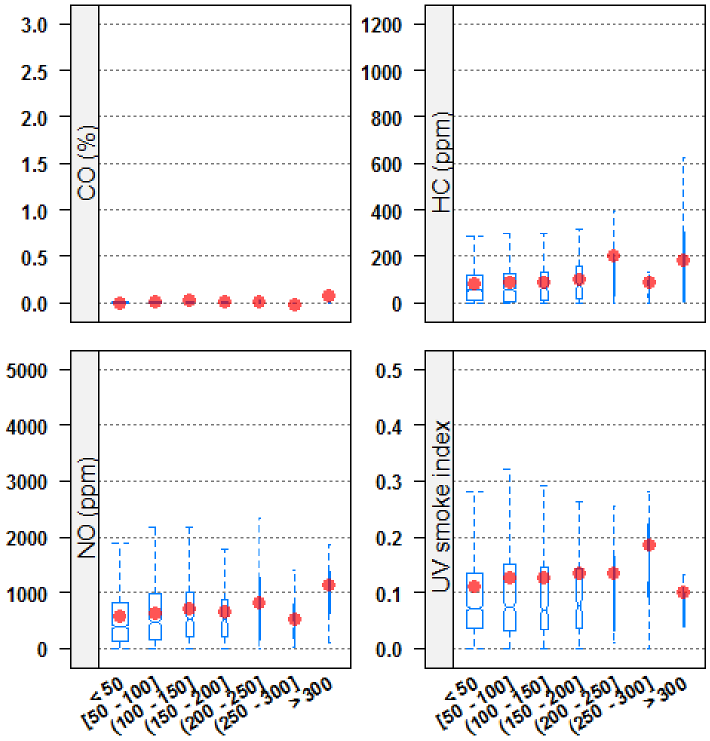


Figure G.6 Comparison of the emissions of the monitored Euro 4 NZN diesel vehicles by odometer reading



G3 Japanese used petrol vehicles

Table G.3 Comparison of the upper and lower quartile odometer readings for the monitored JPU petrol fleet by emission standard

Odometer reading (km)	Pre- 1998	1998	2000–02	2005
Low (25th percentile)	164,804	142,760	107,722	66,980
High (75th percentile)	237,666	206,003	166,750	118,769

Figure G.7 Comparison of the emissions of the monitored high and low mileage JPU petrol vehicles by emission standard

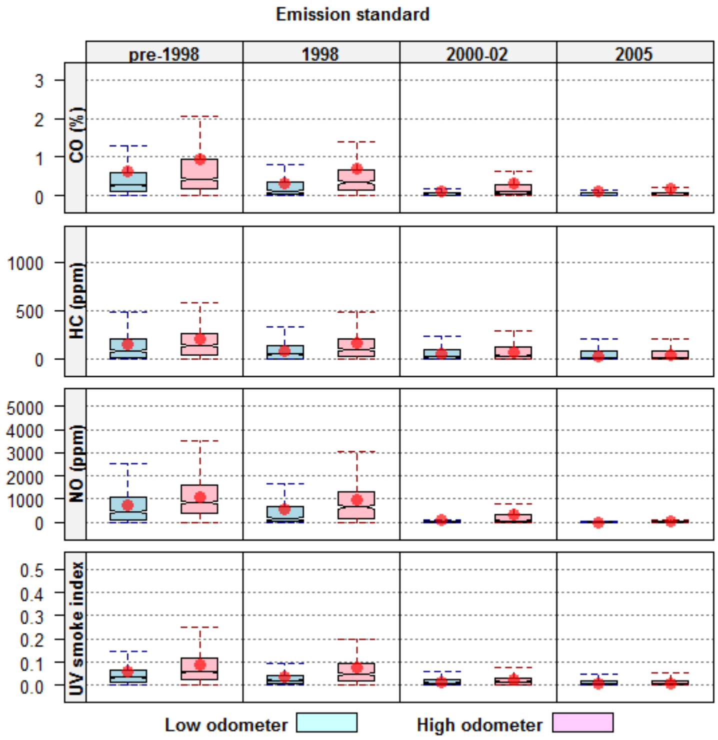


Table G.4 Comparison of the emissions of the monitored high and low mileage JPU petrol vehicles by emission standard

Emission standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-1998	Mean	**0.6**	**1.0**	**148.2**	**212.8**	**737.7**	**1095.3**	**0.1**	**0.1**
	Median	**0.3**	**0.4**	**80.5**	**134.9**	**424.8**	**835.6**	**0.0**	**0.1**
1998	Mean	**0.3**	**0.7**	**83.5**	**164.2**	**539.7**	**969.6**	**0.0**	**0.1**
	Median	**0.1**	**0.3**	**48.1**	**100.8**	**141.0**	**650.2**	**0.0**	**0.0**
2000-02	Mean	**0.1**	**0.3**	**47.9**	**73.0**	**92.2**	**314.8**	**0.0**	**0.0**
	Median	**0.0**	**0.1**	**24.1**	**31.6**	**8.3**	**49.0**	**0.0**	**0.0**
2005	Mean	**0.1**	**0.2**	32.4	41.6	**4.2**	**42.4**	0.0	0.0
	Median	**0.0**	**0.0**	12.8	14.9	**- 2.1**	**3.5**	0.0	0.0

* Note the values shown in **bold** and grey cells are statistically significantly different from each other

Figure G.8 Comparison of the emissions of the monitored pre- 1998 JPU petrol vehicles by odometer reading

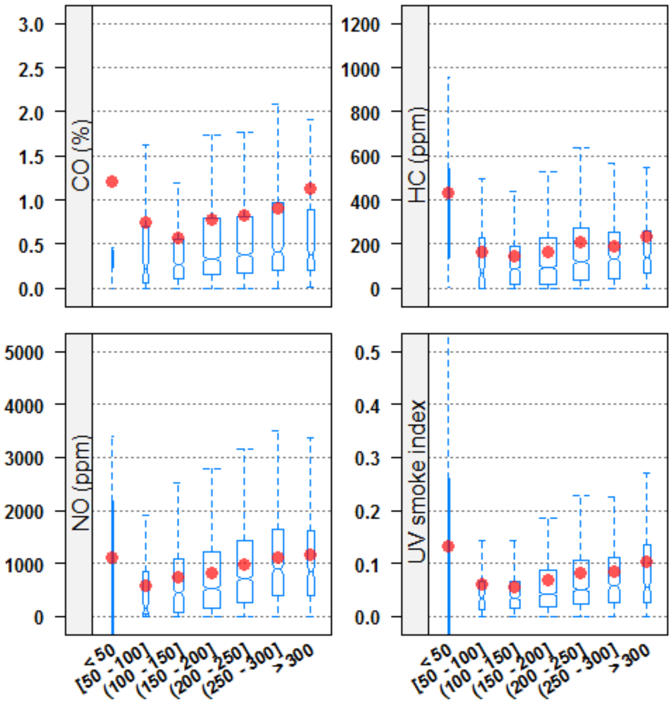
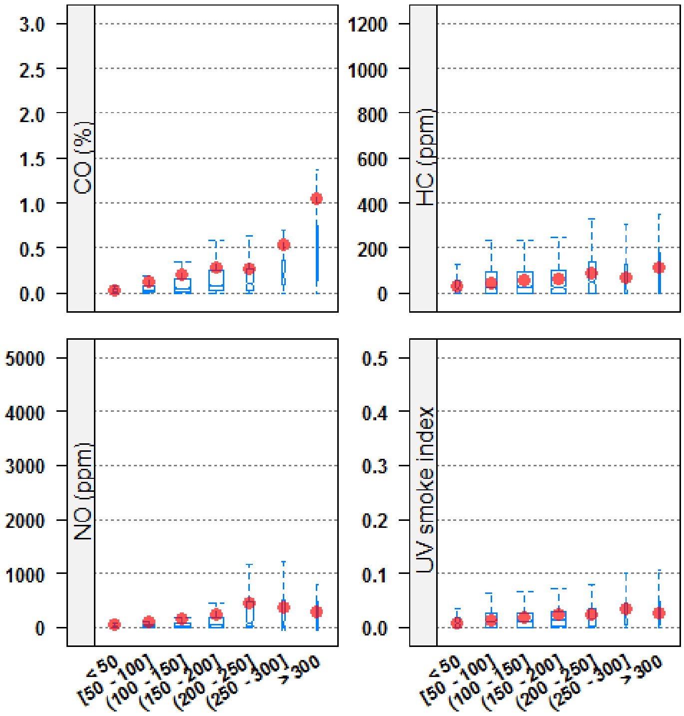


Figure G.9 Comparison of the emissions of the monitored 2000- 02 JPU petrol vehicles by odometer reading



G4 Japanese used diesel vehicles

Figure G.10 Comparison of the emissions of the monitored high and low mileage JPU diesel vehicles by emission standard

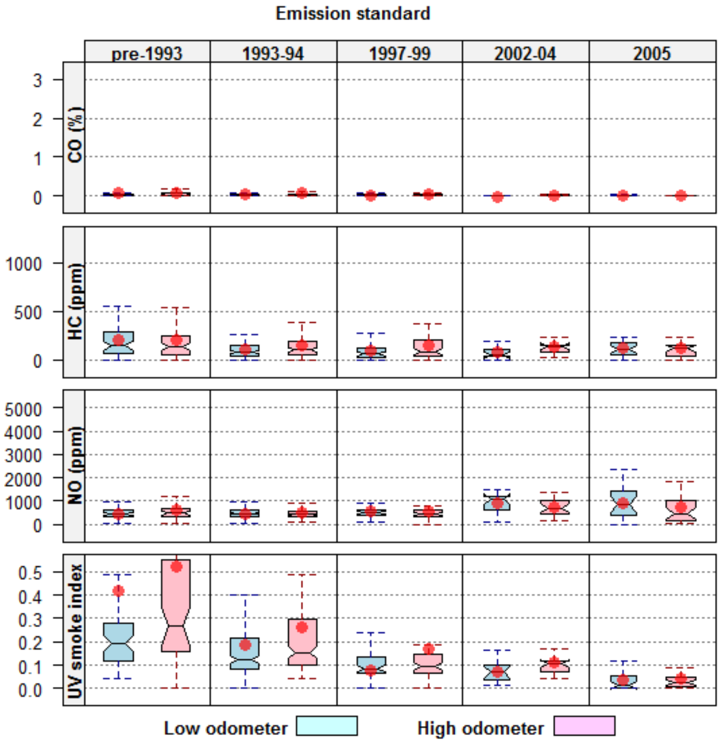


Table G.5 Comparison of the emissions of the monitored high and low mileage JPU diesel vehicles by emission standard

Emission standard		CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Low km	High km	Low km	High km	Low km	High km	Low km	High km
Pre-1993	Mean	0.1	0.1	203.2	202.1	456.8	619.9	0.4	0.5
	Median	0.0	0.0	147.7	134.6	463.3	484.2	0.2	0.3
1993-94	Mean	0.0	0.1	104.0	152.8	449.6	485.0	**0.2**	**0.3**
	Median	0.0	0.0	79.3	107.4	457.6	431.9	**0.1**	**0.2**
1997-99	Mean	0.0	0.1	91.9	149.3	581.5	547.4	0.1	0.2
	Median	0.0	0.0	63.5	87.4	489.8	456.4	0.1	0.1
2000-02	Mean	0.0	0.0	87.4	130.7	908.9	724.6	0.1	0.1
	Median	0.0	0.0	51.9	143.6	1077.3	690.2	0.1	0.1
2005	Mean	0.0	0.0	125.4	123.2	925.1	732.1	0.0	0.0
	Median	0.0	0.0	105.5	121.0	860.2	452.1	0.0	0.0

* Note the values shown in **bold** and grey cells are statistically significantly different from each other

Figure G.11 Comparison of the emissions of the monitored pre- 1993 JPU diesel vehicles by odometer reading

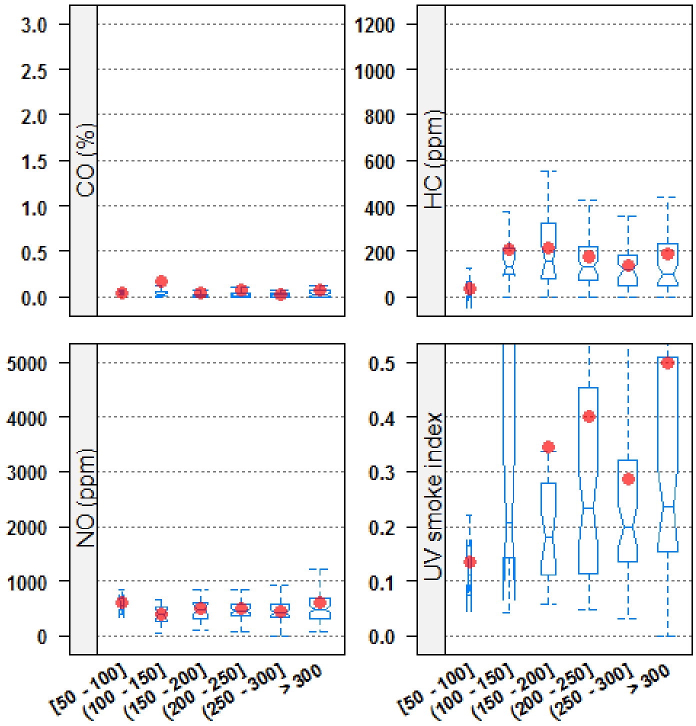
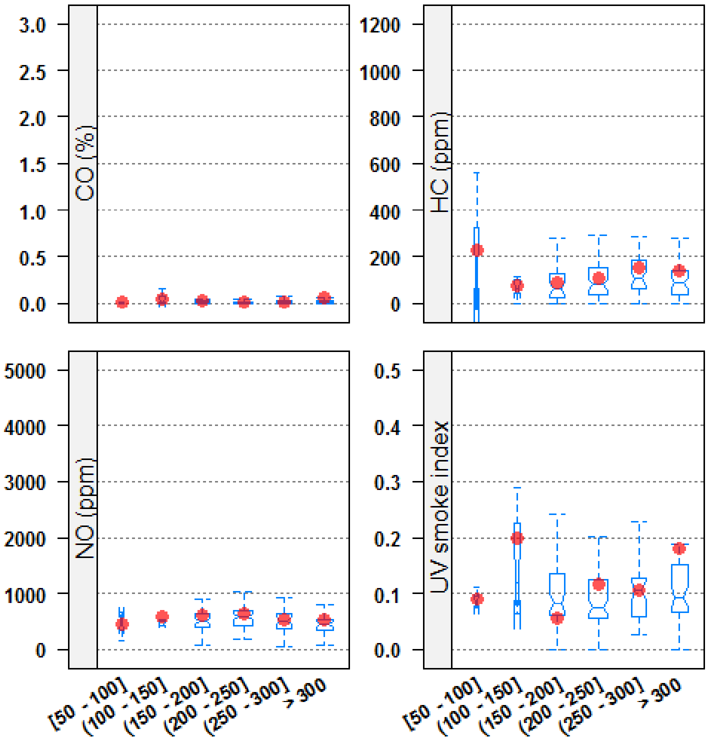


Figure G.12 Comparison of the emissions of the monitored 1997- 99 JPU diesel vehicles by odometer reading



Appendix H: K- W test results

In the body of this report, the Kruskall-Wallis (K-W) test has been applied to each analysis to establish whether the results presented are significantly different or not. However, for the sake of brevity, the actual K-W analysis for each is not presented in the report. This appendix presents the corresponding K-W test results for each analysis to indicate how the conclusions in the text have been reached.

H1 Chapter 8: Trends in light duty vehicle emissions 2003 to 2015

Within each row table H.1 presents the K-W results for a specific figure contained in chapter 8 of the report and covers the four pollutants (CO, HC, NO and uvSmoke). Each table compares the emissions from LDVs measured in the five roadside monitoring programmes. HC is excluded from 2015 analysis due to the issues highlighted in appendix C, section C4. The first set of columns labelled 2003 compares the 2003 data with 2005, 2009, 2011and 2015. The second set of columns labelled 2005 compares the 2005 data with 2009, 2011 and 2015. The third set of columns labelled 2009 compares the 2009 data with 2011 and 2015. The fourth set of columns labelled 2011 compares the 2011 data with 2015. Each cell in the matrix compares two years of monitoring data. If the cell is uncoloured, the difference between vehicle types is not significant (ns) at the 95% confidence interval (CI). If the cell is colour coded ‘yellow’, the difference between the two vehicles types is significant at the 95% CI, ‘orange’ indicates a difference at the 99% CI and ‘red’ indicates a difference at the 99.9% CI. A light grey cell indicates missing data.

Table H.1 Results of K- W test for figures presented in chapter 8

		2003 vs				2005 vs			2009 vs		2011 vs
Figure	**Pollutant**	**2005**	**2009**	**2011**	**2015**	**2009**	**2011**	**2015**	**2011**	**2015**	**2015**
Figure 8.1	**CO**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	HC	<0.001	<0.001	<0.001		<0.001	<0.001		<0.001		
	NO	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	uvSmoke						<0.001	<0.001	<0.001	<0.001	<0.001
Figure 8.2	**CO**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ns	<0.001	<0.001
	HC	<0.001	<0.001	<0.001		<0.001	<0.001		ns		
	NO	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	uvSmoke						<0.001	<0.001	<0.001	<0.001	ns
Figure 8.3	**CO**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	HC	<0.001	<0.001	<0.001		<0.001	<0.001		<0.001		
	NO	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	uvSmoke						<0.001	ns	ns	<0.001	<0.001
Figure 8.4	**CO**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	ns	<0.001	<0.001
	HC	<0.01	<0.001	<0.001		<0.001	<0.001		ns		
	NO	ns	<0.001	ns	ns	<0.001	ns	ns	<0.001	<0.001	<0.001
	uvSmoke						<0.001	<0.001	<0.001	ns	ns
Figure 8.5	**CO**	<0.001	<0.001	<0.001	<0.001	ns	ns	<0.05	ns	<0.05	ns
	HC	<0.01	<0.001	<0.01	<0.001		ns		ns		
	NO	ns	ns	<0.001	<0.001	ns	<0.001	<0.001	<0.001	<0.001	<0.001
	uvSmoke						ns	ns	<0.05	ns	<0.05

Uncoloured cells: the difference between vehicle types is not significant (ns) at the 95% CI.

H2 Chapter 9: Trends in heavy duty vehicle emissions 2003 to 2015

Within each row table H.2 presents the K-W results for a specific figure contained in chapter 9 of the report and covers the four pollutants (CO, HC, NO and uvSmoke). Each table compares the emissions from HDVs measured in the five roadside monitoring programmes. HC is excluded from the 2015 analysis due to the issues highlighted in appendix C, section C4. The first set of columns labelled 2003 compares the 2003 data with 2005, 2009, 2011and 2015. The second set of columns labelled 2005 compares the 2005 data with 2009, 2011 and 2015. The third set of columns labelled 2009 compares the 2009 data with 2011 and 2015. The fourth set of columns labelled 2011 compares the 2011 data with 2015. Each cell in the matrix compares two years of monitoring data. If the cell is uncoloured, the difference between vehicle types is not significant at the 95% CI. If the cell is colour coded ‘yellow’, the difference between the two vehicles types is significant at the 95% CI, ‘orange’ indicates a difference at the 99% CI and ‘red’ indicates a difference at the 99.9% CI. A light grey cell indicates missing data.

Table H.2 Results of K- W test for figures presented in chapter 9

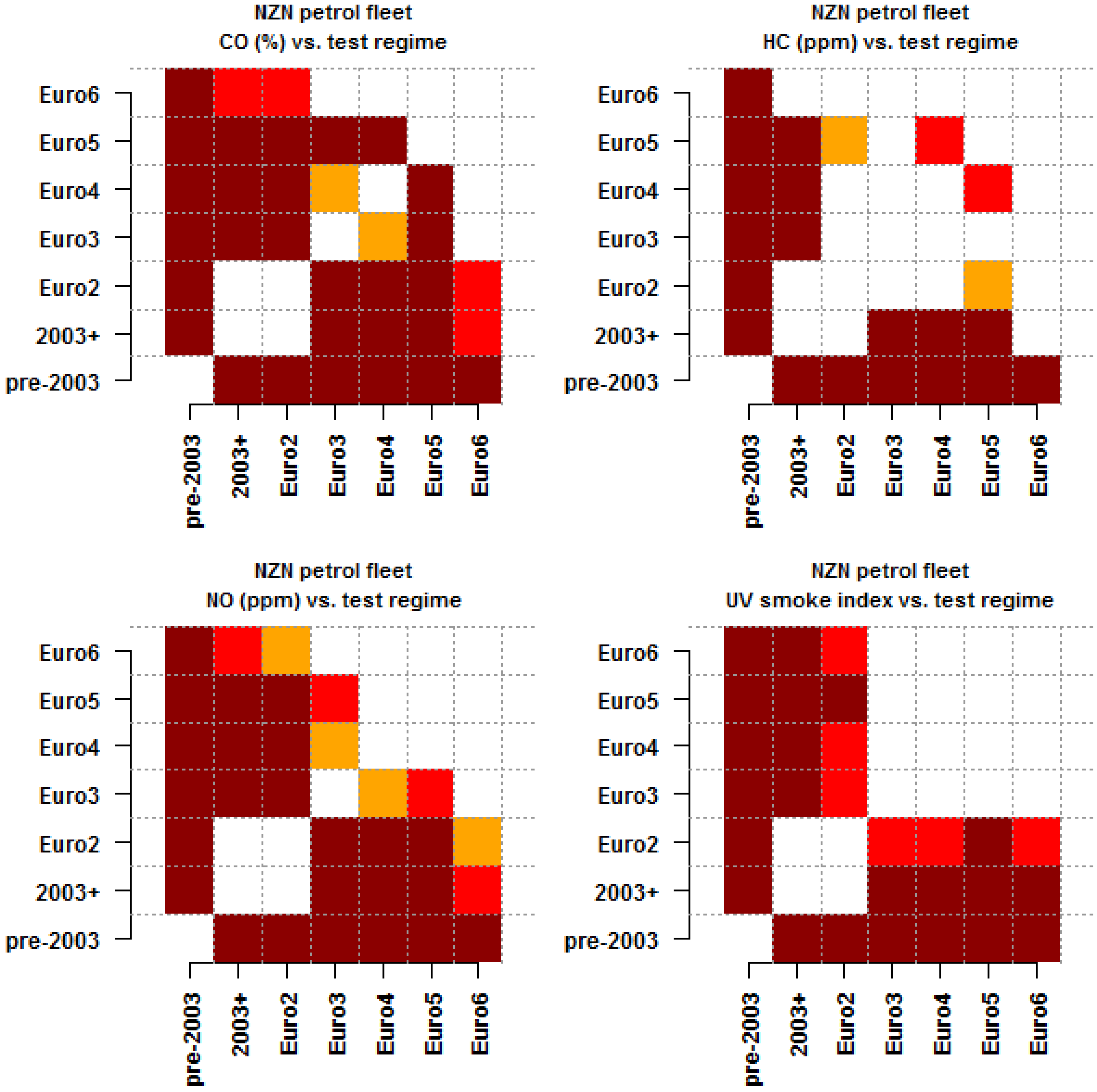
		2003 vs				2005 vs			2009 vs		2011 vs
Figure	**Pollutant**	**2005**	**2009**	**2011**	**2015**	**2009**	**2011**	**2015**	**2011**	**2015**	**2015**
Figure 9.1	**CO**	<0.001	<0.001	<0.001	<0.001	<0.05	ns	<0.001	ns	ns	<0.05
	HC	<0.001	ns	ns		<0.001	<0.001		ns		
	NO	ns	ns	ns	ns	<0.001	<0.05	<0.05	<0.05	<0.001	ns
	uvSmoke						<0.01	ns	<0.001	ns	ns
Figure 9.2	**CO**	<0.001	<0.001	<0.001	<0.001	ns	ns	<0.001	ns	ns	ns
	HC	<0.001	ns	ns		<0.001	<0.001		ns		
	NO	ns	<0.01	ns	ns	<0.001	<0.05	<0.001	ns	ns	ns
	uvSmoke						<0.001	ns	<0.001	ns	<0.01
Figure 9.3	**CO**	<0.001	<0.001	<0.001	<0.001	ns	ns	<0.001	ns	ns	ns
	HC	<0.05	ns	ns		<0.001	<0.001		ns		
	NO	<0.001	ns	ns	<0.01	<0.001	ns	ns	ns	<0.01	ns
	uvSmoke						ns	ns	ns	ns	ns

Uncoloured cells: the difference between vehicle types is not significant (n.s.) at the 95% confidence interval (CI).

H3 Chapter 10: Effect of emission control technology

Each of the following plots presents the K-W results for a specific figure contained in chapter 10 of the report and covers the four pollutants (CO, HC, NO and uvSmoke). Each figure compares the emissions from vehicles built to different emission control standards. X and y axes show the emission standard considered in the comparison. Note that the top half of each matrix is a mirror image of the bottom half and therefore is redundant. Each cell in the matrix compares two emission standard types. If the cell is uncoloured, the difference between vehicle types is not significant at the 95% CI. If the cell is colour coded ‘orange’, the difference between the two vehicles types is significant at the 95% CI. ‘Red’ indicates a difference at the 99% CI and ‘deep red/brown’ a difference at the 99.9% CI.

Figure H.1 Comparison of the emissions of the monitored 2015 NZN petrol fleet for vehicles by emission standard (figure 10.1)



NZN petrol fleet
CO (%) vs. test regime

NZN petrol fleet
HC (ppm) vs. test regime

NZN petrol fleet
NO (ppm) vs. test regime

NZN petrol fleet
UV smoke index vs. test regime

Figure H.2 Comparison of the emissions of the monitored 2015 NZN diesel fleet by emission standard (figure 10.2)

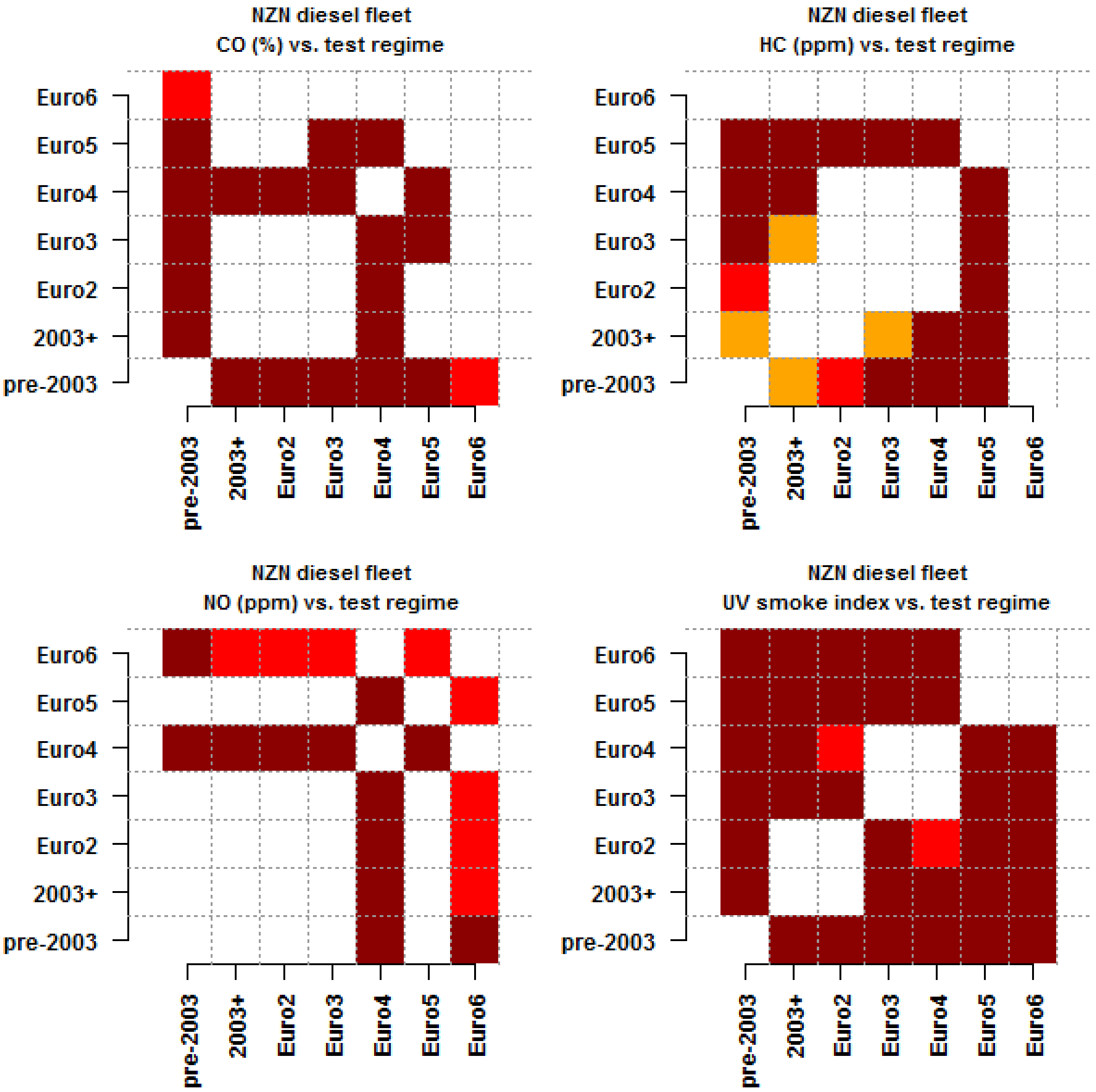


Figure H.3 Comparison of the emissions of the monitored 2015 JPU petrol fleet by emission standard category (figure 10.3)

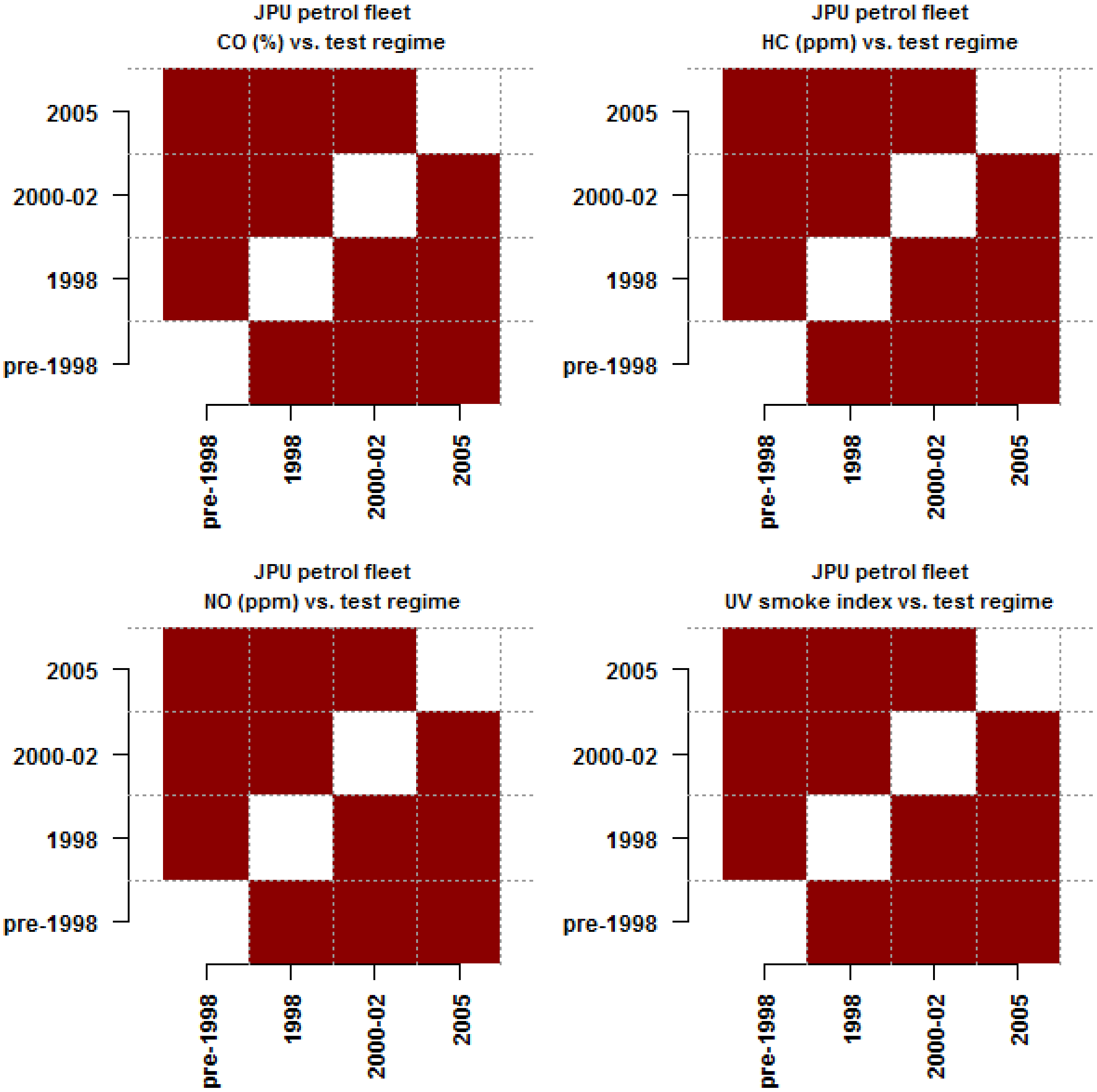
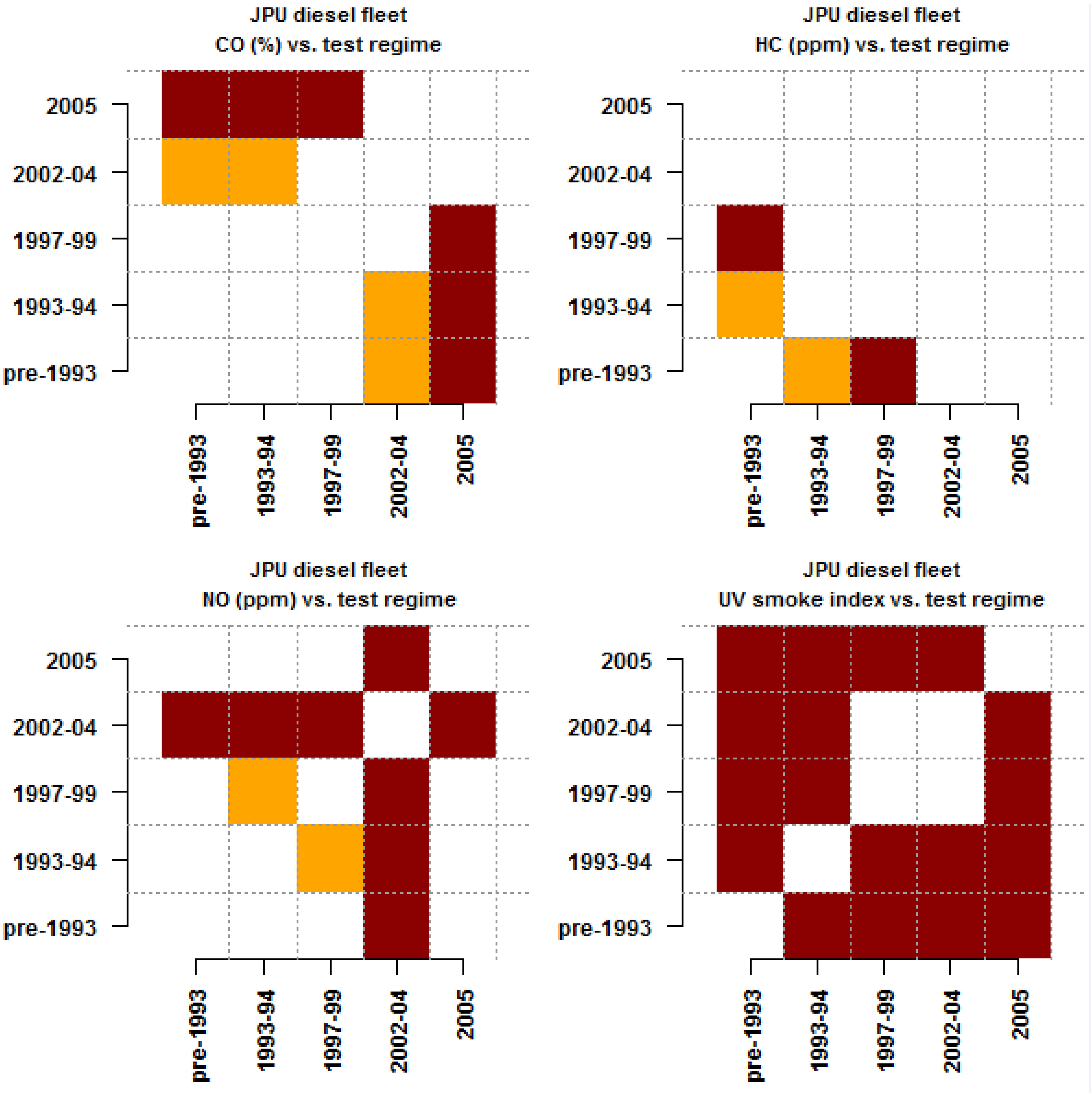


Figure H.4 Comparison of the emissions of the monitored 2015 JPU diesel fleet by emission standard category (figure 10.4)



JPU diesel fleet
CO (%) vs. test regime

JPU diesel fleet
HC (ppm) vs. test regime

JPU diesel fleet
NO (ppm) vs. test regime

JPU diesel fleet
UV smoke index vs. test regime

H4 Effect of mileage

Tables H.3 to H.6 present the K-W results for tables presented in chapter 11 of this report and cover the four pollutants (CO, HC, NO and uvSmoke). Each row compares the emissions from low and high odometer vehicles. If the cell is colour coded ‘yellow’, the difference between the vehicles with the low and high odometer reading is significant at the 95% CI, ‘orange’ indicates a difference at the 99% CI and ‘red’ indicates a difference at the 99.9% CI. A light grey cell indicates missing data.

Table H.3 Comparison of the emissions of the monitored high and low mileage NZN petrol vehicles by emission standard (KW test results for tables 11.2 and 11.3)

Test regime	Pollutant	p
pre-2003	CO (%)	**1.06E-28**
pre-2003	HC (ppm)	**3.20E-14**
pre-2003	NO (ppm)	**2.47E-47**
pre-2003	UV smoke index	**8.53E-33**
2003+	CO (%)	**5.12E-44**
2003+	HC (ppm)	**1.43E-09**
2003+	NO (ppm)	**3.22E-32**
2003+	UV smoke index	**6.98E-11**
Euro2	CO (%)	**9.58E-05**
Euro2	HC (ppm)	0.154913
Euro2	NO (ppm)	**5.85E-05**
Euro2	UV smoke index	**0.00103**
Euro3	CO (%)	**0.001116**
Euro3	HC (ppm)	**0.000722**
Euro3	NO (ppm)	**2.60E-05**
Euro3	UV smoke index	0.228443
Euro4	CO (%)	**8.94E-15**
Euro4	HC (ppm)	0.692131
Euro4	NO (ppm)	**0.000166**
Euro4	UV smoke index	0.859957
Euro5	CO (%)	**0.006643**
Euro5	HC (ppm)	0.931319
Euro5	NO (ppm)	**0.016623**
Euro5	UV smoke index	0.201905
Euro6	CO (%)	**0.004145**
Euro6	HC (ppm)	0.136198
Euro6	NO (ppm)	**0.045124**
Euro6	UV smoke index	0.259593

Table H.4 Comparison of the emissions of the monitored high and low mileage NZN diesel vehicles by emission standard (KW test results for tables 11.4 and 11.5)

Test regime	Pollutant	p
pre-2003	CO (%)	0.179431
pre-2003	HC (ppm)	0.601163
pre-2003	NO (ppm)	0.264607
pre-2003	UV smoke index	0.320759
2003+	CO (%)	**5.47E-05**
2003+	HC (ppm)	**0.000327**
2003+	NO (ppm)	0.689955
2003+	UV smoke index	**1.13E-12**
Euro2	CO (%)	0.829704
Euro2	HC (ppm)	0.56556
Euro2	NO (ppm)	**0.030969**
Euro2	UV smoke index	0.468673
Euro3	CO (%)	**0.001476**
Euro3	HC (ppm)	0.917138
Euro3	NO (ppm)	**6.71E-05**
Euro3	UV smoke index	**0.000976**
Euro4	CO (%)	0.272094
Euro4	HC (ppm)	0.811865
Euro4	NO (ppm)	**4.12E-05**
Euro4	UV smoke index	0.475181
Euro5	CO (%)	0.417134
Euro5	HC (ppm)	0.659874
Euro5	NO (ppm)	0.252478
Euro5	UV smoke index	**0.037512**
Euro6	CO (%)	0.183505
Euro6	HC (ppm)	0.969698
Euro6	NO (ppm)	0.909269
Euro6	UV smoke index	0.761121

Table H.5 Comparison of the emissions of the monitored high and low mileage JPU petrol vehicles by emission standard (KW test results for tables 11.6 and 11.7)

Test regime	pollutant	p
pre-1998	CO (%)	**3.71E-14**
pre-1998	HC (ppm)	**4.74E-10**
pre-1998	NO (ppm)	**1.54E-22**
pre-1998	UV smoke index	**1.28E-15**
1998	CO (%)	**2.48E-20**
1998	HC (ppm)	**4.15E-09**

Test regime	pollutant	p
1998	NO (ppm)	**3.63E-17**
1998	UV smoke index	**3.47E-17**
2000-02	CO (%)	**7.81E-43**
2000-02	HC (ppm)	**0.031176**
2000-02	NO (ppm)	**2.08E-32**
2000-02	UV smoke index	**4.95E-07**
2005	CO (%)	**0.000613**
2005	HC (ppm)	0.269471
2005	NO (ppm)	**9.21E-06**
2005	UV smoke index	0.383659

Table H.6 Comparison of the emissions of the monitored high and low mileage JPU diesel vehicles by emission standard (KW test results for tables 11.8 and 11.9)

Test regime	pollutant	p
pre-1993	CO (%)	0.793372
pre-1993	HC (ppm)	0.56252
pre-1993	NO (ppm)	0.328181
pre-1993	UV smoke index	0.074434
1993–94	CO (%)	0.067771
1993–94	HC (ppm)	0.070681
1993–94	NO (ppm)	0.609625
1993–94	UV smoke index	**0.005145**
1997–99	CO (%)	0.681131
1997–99	HC (ppm)	0.132555
1997–99	NO (ppm)	0.279838
1997–99	UV smoke index	0.567328
2002–04	CO (%)	0.114136
2002–04	HC (ppm)	0.087217
2002–04	NO (ppm)	0.174007
2002–04	UV smoke index	0.053636
2005	CO (%)	0.410802
2005	HC (ppm)	0.844177
2005	NO (ppm)	0.158063
2005	UV smoke index	0.400828

Appendix I: Glossary

AADT	annual average daily traffic
AC	Auckland Council, the unitary authority responsible for local and regional issues in the Auckland region
AQM	air quality monitoring
AT	Auckland Transport
CASANZ	Clean Air Society of Australia and New Zealand
CCC	Christchurch City Council
CI	confidence interval
CoF	certificate of fitness, a mandatory check to ensure the roadworthiness of heavy duty vehicle vehicles
CO	carbon monoxide, a type of air pollutant
CO_2	carbon dioxide, a type of greenhouse gas
CTM	Christchurch Traffic Model
DPF	diesel particulate filter
ECan	Environment Canterbury – the regional council responsible for local and regional issues in the Canterbury region
EGR	exhaust gas recirculation
g/veh.km	grams of pollutant discharged per vehicle kilometre travelled
HC	hydrocarbon/s, a type of air pollutant
HDV	heavy duty vehicles – vehicles with a gross vehicle mass of greater than 3,500kg
HNO	highway and network outcomes
IR	infrared
JPU	Japanese used imported vehicles – vehicle first registered in Japan and then imported (used) into New Zealand
K-W test	Kruskall-Wallis test of significant difference
kWh	kilowatt hour
LDV	light duty vehicles – vehicles with a gross vehicle mass of less than 3,500kg
LPG	liquid petroleum gas
MfE	Ministry for the Environment
MoT	NZ Ministry of Transport
Motochek	An internet based interface that enables registered users to access information from the NZ LANDATA (Motor Vehicle Registration and Relicensing and Road User Charges) database to obtain vehicle and owner details

m^3	cubic metre (1 m x 1m x 1 m)
μg	microgram (1 x10^{-6} gram)
$\mu g/m^3$	microgram per cubic metre
NIWA	National Institute of Water and Atmospheric Research Limited
NMVOC	non-methane volatile organic compounds
NO	nitric oxide, a precursor to the formation of NO_2
NO_2	nitrogen dioxide, a type of air pollutant
NO_x	oxides of nitrogen dioxide, mainly a mix of NO and NO_2
NZN	New Zealand new vehicles – vehicles first registered (new) in New Zealand
NZTA	New Zealand Transport Agency
OBD	on-board diagnostics
PEMS	portable emission measurement systems
PM	particulate matter
PM_{10}	fine particles less than 10 microns in diameter, a type of air pollutant
ppm	parts per million – note this can be expressed by mass (eg mg/kg) or by volume (eg ml/m^3)
RAMM	Road Assessment and Maintenance Management database
RSD	remote sensing device
SCR	selective catalytic reduction
SDM	source detector module
SUV	sports utility vehicle
Transport Agency	New Zealand Transport Agency
tare weight	weight of the unloaded vehicle
uvSmoke	a measure of the opacity but in the UV spectrum, sometimes used as a proxy for PM emissions
VEPM	Vehicle Emissions Prediction Model
VKT	vehicle kilometres travelled
VOC	volatile organic compound
VSP	vehicle specific power, a measure indicating whether a vehicle is operating within an accepted power range
WoF	warrant of fitness, a mandatory check to ensure the roadworthiness of private vehicles