Future trends in motor vehicle emissions in Auckland

July 2014 Technical Report 2014/028

Auckland Council
Technical Report 2014/028
ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-927302-43-9 (Print)
ISBN 978-1-927302-44-6 (PDF)

This report has been peer reviewed by the Peer Review Panel using the Panel's terms of reference

Submitted for review on 2 October 2013

Review completed on 9 July 2014

Reviewed by two reviewers

Approved for Auckland Council publication by:

Name: Regan Solomon

Position: Manager, Research, Investigations and Monitoring

Date: 9 July 2014

Recommended citation:

Sridhar, S., Wickham, L and Metcalfe, J (2014). Future trends in motor vehicle emissions in Auckland. Prepared by Emission Impossible Ltd for Auckland Council. Auckland Council technical report, TR2014/028

Future trends in motor vehicle emissions in Auckland

Surekha Sridhar
Louise Wickham
Jayne Metcalfe
Emission Impossible Ltd

Executive Summary

This report discusses future trends in motor vehicle emissions and is a component of the Auckland air emissions inventory which identifies key emission sources and how they change over space and time. The inventory is a critical component of managing air quality and plays a significant role in the development of air quality strategies and policies for maintaining or reducing emissions in Auckland. Auckland's air emissions inventory was last calculated for a base year of 2006 for all sources (Auckland Council, 2013) which estimated that in the Auckland region, motor vehicle emissions account for approximately 27% of total annual particulate emissions and 55% of total nitrogen oxide emissions on an annual basis.

Each year, air pollution causes approximately 300 premature deaths in Auckland, and results in increased number of reduced activity days and hospital visits, and higher usage of medications. It is estimated that the social cost from air pollution in Auckland is $1.07 billion per year (Kuschel *et al*., 2012).

The Auckland Plan sets a directive to reduce emissions by 50% by 2016 based on 2006 levels) to meet national and international ambient air quality standards and guidelines (Auckland Council, 2012b). Estimating projected emissions from motor vehicles can be used to assess how Auckland is tracking against its requirement to meet the national environmental standard for PM_{10} by 2016, and against the directives of the Auckland Plan.

This report estimates projected emissions from motor vehicles for 2016, 2021, 2031 and 2041, while also updating estimates for 2001, 2006 and 2011 using the most recent data. In order to estimate projections, emissions are calculated for each section of road in Auckland so that detailed spatial allocation and analysis of emissions can be undertaken. The estimates are based on the amount of travel and levels of congestion that are expected using fleet profile data from the Ministry of Transport and land use configurations proposed in the Auckland Plan.

Results and trends

Future projections show a continued reduction in fleet emissions with significant reductions expected for all pollutants. This is despite an expected rise in total vehicle kilometres travelled. The anticipated reductions in emissions from particulate matter (PM) arise primarily from expected improvements in diesel vehicle emissions and an anticipated increase of hybrid and electric vehicles after 2031.

Currently, diesel vehicles are disproportionate polluters for both PM_{10} (particulate matter less than 10 micrometres in size), $PM_{2.5}$ (particulate matter less than 2.5 micrometres in size) and total nitrogen oxides (NO_x) compared with petrol vehicles. Projections show that this will change in future years as emission controls improve on light diesel vehicles. However, the heavy diesel vehicles will remain disproportionate polluters. These heavy diesel vehicles operate primarily on regional arterial routes which will continue to lead to higher levels of exposure for people located near or along these routes.

The impact of increased hybrids and electric vehicles in the fleet on projected emissions of PM_{10} and NO_x becomes evident after 2031. The Ministry of Transport predicts that by 2041, hybrids and electrics will comprise 28% of the fleet. This should result in significant reductions in emissions of PM_{10}, $PM_{2.5}$ and NO_x.

A comparison of estimated vehicle PM_{10} emissions against Auckland Council's emissions reduction target of 50% by 2016 based on 2006 levels (Auckland Council, 2012b) suggests that the projected emissions reductions will fall short of the target by 30%. This has important implications for the ability of Auckland Council to comply with the National Environmental Standard for PM_{10}.

Uncertainty and sensitivity analysis

Sensitivity analysis on projected emissions yielded the following insights:

- Projected estimates for PM_{10}, $PM_{2.5}$ and NO_x are sensitive to the assumed proportion of hybrid and electric vehicles. Current fleet projections anticipate a 28% hybrid and electric fleet composition in 2041. Assuming the fleet does not change from existing patterns (i.e. 1% hybrid and electric vehicles) increases the projected PM_{10} emissions by 8%, projected $PM_{2.5}$ emissions by 10% and projected NO_x emissions by 16% in 2041.
- A recent review indicates that existing Euro V emission factors may underestimate PM_{10}, $PM_{2.5}$ and total nitrogen oxide emissions by 50 – 200%. The effect of doubling Euro V emission factors in 2041 would in turn increase projected emissions instead of reducing emissions, despite Euro V (diesel heavy commercial vehicles) comprising less than 7% of total vehicle kilometres travelled in that year.

Conclusions

Despite the uncertainty and sensitivity of emissions on the projected fleet profile and emission factors, it is clear that further measures need to be implemented if Auckland is to reduce emissions by 50% by 2016 from 2006 levels and comply with the national environmental standards for PM_{10}. The spatial distribution of emissions indicates that despite there being regional improvements in emissions, the air quality near state highways and regional arterial routes is not likely to change much. Emissions from diesel heavy commercial vehicles could potentially be much higher than estimated, particularly with regards to total nitrogen oxide (and as a result nitrogen dioxide) emissions which are continuing to cause concern overseas. This highlights the need for measures to be implemented to reduce exposure near these routes.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

The Auckland air emissions inventory identifies key emission sources and how they change over space and time. The inventory is a critical component of managing air quality and plays a significant role in the development of air quality strategies or policies for maintaining or reducing emissions.

1.1 Background

Levels of particulate matter and nitrogen dioxide in Auckland's air exceed national environmental standards, regional targets and global guidelines from time to time in Auckland (Auckland Council, 2012a). In the Auckland urban area, air quality has failed to meet the national standards and guidelines on average 13 days per year from 2005 to 2012. Auckland also suffers from a visible brown haze on average 30 days a year (Auckland Regional Council, 2010). Other guidelines and targets are most likely being exceeded, including guidelines for arsenic, benzene and benzo(a)pyrene. This means that the air in Auckland is impacting on the health of its residents.

Each year, air pollution causes approximately 300 premature deaths in Auckland, and results in increased number of reduced activity days and hospital visits, and higher usage of medications. It is estimated that the social cost from air pollution in Auckland is $1.07 billion per year (Kuschel *et al*., 2012).

Over the last few decades, both regional and central government have undertaken major initiatives to address air quality from transport (Auckland Council, 2014). These initiatives have gradually reduced the emissions per vehicle; however, these reductions are being offset by the growth in vehicle numbers, increased kilometres travelled and the increasing age of the vehicle fleet, especially for the light vehicle fleet as observed from the results of the four remote sensing campaigns undertaken by Auckland Council in 2003, 2005, 2009 and 2011 (Auckland Council, 2012c).

The Auckland air emissions inventory estimated that in the Auckland region, motor vehicle emissions account for approximately 27% of total annual particulate emissions and 48% of annual total nitrogen oxide emissions for 2011 (Auckland Council, 2012a). Domestic fires and industry were also identified as the other major sources, especially of particulate matter less than 10 micrometres in size (PM_{10}).

The Auckland Plan sets a strategic direction to reduce air pollutant emissions of PM_{10} by 50% by 2016 (based on 2006 levels) to meet national and international ambient air quality standards and guidelines, and achieve a further 20% reduction of air pollutant emissions by 2040.

1.2 Purpose of this report

This report presents emission estimates for 2011 and projected emissions from motor vehicles for 2016, 2021, 2031 and 2041. These projected emission estimates will assist with assessing how Auckland is tracking against its requirement to meet the national environmental standard for particulate matter that are less than 10 micrometres in size (PM_{10}) by 2016, and against the directives set in the Auckland Plan (Auckland Council, 2012b).

Note: The analysis undertaken for this report only calculates projected emissions based on the existing emission and fuel standards and does not undertake an analysis of scenarios that might achieve further emissions reductions.

1.3 Report structure

Section 2 of this report outlines the methods used to generate future projections and the updated motor vehicles inventory.

Section 3 presents the results for 2011 and projected years 2016, 2021, 2031 and 2041.

Section 4 discusses the trends estimated from 2001 to 2041.

Section 5 details the sensitivity analyses performed on the inventory data, which includes

- Uncertainty and
- Sensitivity analyses

Section 6 discusses the conclusions of the project and summarises the uncertainties.

2.0 Method

This report uses emission factors from the vehicle emission prediction model version 5.1 (VEPM5.1) and data from the Auckland regional transport model version 3 (ART3) to estimate emissions for the years 2016, 2021, 2031 and 2041.

Emissions have been estimated for the following pollutants:

- carbon monoxide (CO)
- total nitrogen oxides (NO_x)
- sulphur dioxide (SO_2)
- volatile organic compounds (VOCs)
- particulate matter less than 10 micrometres in diameter (PM_{10})
- particulate matter less than 2.5 micrometres in diameter ($PM_{2.5}$)

Fuel consumption and carbon dioxide (CO_2) emissions are also included. Emissions are calculated for each vehicle type and each road segment (referred to as road links) in the Auckland region. Road links are the spatial representation of actual road segments in the Auckland Regional Transport model, and have associated traffic and speed data. Speed based emission factors are calculated in VEPM by vehicle type, which are then applied to the traffic data for each road link to estimate emissions.

VEPM is an average speed model which predicts emission factors for the New Zealand fleet under typical road, traffic and operating conditions. VEPM is currently the best tool available in New Zealand to predict motor vehicle emissions in regional inventories, but, the model does not take into account the level of traffic (free flowing or congested) on a given road or include evaporative emissions. The uncertainties and limitations of VEPM are discussed later in section 4.2.

2.1 Emission factors

The emission factors used are the default values provided in the vehicle emissions prediction model (VEPM5.1). Emission factors are defined for:

- all speeds between 10 and 99 kilometres per hour;
- every vehicle type;
- every pollutant considered in the inventory (except as noted below); and
- for each year between 2001 and 2040 (inclusive).

The Auckland Council (formerly the Auckland Regional Council[1]) and the New Zealand Transport Agency (NZTA) developed the vehicle emissions prediction model (VEPM) to

[1] The Auckland Regional Council became part of the new Auckland Council in November 2010.

estimate emissions and to provide a tool to analyse policy options. As mentioned earlier, VEPM currently is the best tool available in New Zealand to estimate emissions from motor vehicles and is updated regularly with changes in fuel and emission standards since its release in 2008. Version 5.1 of the model was updated in 2012 to incorporate the following:

- $PM_{2.5}$
- latest international emission factors for all other pollutants
- updated fleet profile data
- the effect of gradient
- the effects of variations in actual speed

Sulphur dioxide (SO_2) is not included in the vehicle emission prediction model, so speed based SO_2 emission factors have been derived based on the sulphur content in diesel and petrol (for a given year) which are applied to the speed based fuel consumption data from VEPM. This is in accordance with the methodology described in the VEPM 3.0 user notes (Kar *et al*. 2008). For the purposes of this calculation, petrol is assumed to be of 80% regular and 20% premium petrol (Ministry of Economic Development, 2012).

Each update of VEPM takes into account the Land Transport Rule: Vehicle Exhaust Emissions 2007 and emission standards set under this rule (see Ministry of Transport, 2014). VEPM 5.1 currently includes the latest emission factors for Euro V heavy commercial vehicles, and Euro 6 light commercial and passenger vehicles, based on their implementation dates set by the Vehicle Exhaust Emission Rule. Emission factors for Euro VI heavy commercial vehicles are set to be incorporated into the next update of VEPM.

2.2 Traffic data

The Auckland regional transport model version 3 (ART3) provides traffic data for almost 17,000 individual road links for three time periods of the day:

- Morning peak hours (AM = 7am – 9am)
- Inter-peak hours (IP = 11am – 1pm)
- Evening peak hours (PM = 4pm – 6pm)

And includes:

- vehicle kilometres travelled (VKT),
- speed,
- proportion of cars (private passenger vehicles and light commercial vehicles), and
- proportion of heavy commercial vehicles (buses and trucks).

The inter-peak period was extended from 9 am to 3 pm to cover the entire period between peak hours. The 9 - 11am and the 1 - 3pm period within the inter-peak period are assumed to have the same vehicle kilometres travelled, speed and vehicle proportions as the inter-peak 11am to 1pm period.

School peak (SP = 3pm – 4pm) and off peak (OP = 6pm – 7am) numbers are not included in the ART3 model and have therefore been calculated based on the following assumptions (D. Young, Transport Modeller, personal communications, 8 August 2011).

- School peak VKT = 10% of daily total
- Off peak VKT = 16% of daily total
- The speed and proportion of vehicles for both school peak and off peak are assumed to be the same as the inter-peak period.

Estimated traffic flows were obtained from Auckland Council for the projected years of 2016, 2021, 2031 and 2041. To provide for trend analysis, data for 2001, 2006 and 2011 are also discussed (see Auckland Council, 2014 for more information). Traffic data for all years are from the ART3 model, however the data for 2011 to 2041 are based on forecasts for the Auckland Council's Auckland Plan scenarios.[2]

2.3 Vehicle type

Vehicle kilometres travelled are specified for each link in the ART3 model for the following vehicle types:

- heavy commercial vehicles (HCVs) and
- cars and light commercial vehicles (LCVs)

This fleet profile is further defined by the default fleet categories provided by the vehicle emissions prediction model (VEPM5.1). The vehicle fleet in VEPM5.1 is based on the Ministry of Transport's Vehicle Fleet Emission Model (VFEM) estimates. The Vehicle Emission Fleet Model uses the current vehicle utilisation rates based on actual registration information with future rates based on projected regional growth (Jones *et al*. 2011a).

2.4 Estimation of motor vehicle emissions

Motor vehicle emissions are calculated using Equation 1 (below) for each pollutant, vehicle type, road link and for each of the following time periods:

- Morning peak (AM = 7am – 9am)
- Inter-peak (IP = 9am – 3pm)
- School peak (SP = 3pm – 4pm)

[2] Scenario H, Auckland Plan (1 March 2012 version)

- Evening peak (PM = 4pm – 6pm)
- Off peak (OP = 6pm – 7am)

emissions (g/day) = emission factor x vehicle kilometres travelled	Equation 1

Calculating emissions by each road link allows for the spatial distribution and analysis of emissions.

Note: Emission factors for the year 2040 have been used to estimate emissions for the projected year of 2041. This is because VEPM5.1 is limited by the Ministry of Transport's future fleet projections which are only projected to 2040. It has been assumed that there is little change between the fleet in 2040 and 2041 therefore 2040 emission factors from VEPM5.1 have been used for 2041.

3.0 Results

The following sections present estimated emissions for 2011 and projected emissions for 2016, 2021, 2031 and 2041. Tabulated emission estimates for the years 2011 through 2041 are provided in Appendix A along with emission estimates for 2001 and 2006.

3.1 2011 emissions

3.1.1 PM_{10}

The motor vehicle inventory estimates PM_{10} emissions from motor vehicles for 2011 to be 578 tonnes per year. Diesel vehicles contribute 72% of annual PM_{10} emissions from exhaust emissions and 5% from brake and tyre wear. The remaining 22% of emissions are from petrol vehicles with only 8% from petrol vehicle exhaust emissions as illustrated by Figure 3-1. Petrol vehicles however, account for almost 75% of Auckland's vehicle kilometres travelled (as shown in Figure 3-2).

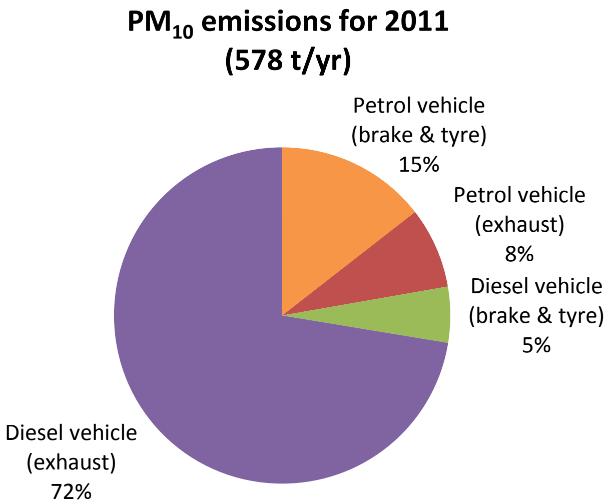

Figure 3-1 Estimated annual PM_{10} emissions for 2011

Figure 3-3 shows the proportion of annual PM_{10} emissions estimated in 2011 by vehicle type. Diesel cars account for almost 25% of the estimated annual PM_{10} emissions although they only represent 8% of vehicle kilometres travelled.

Diesel light commercial vehicles (LCV) account for 28% of PM_{10} emissions and represent 12% of vehicle kilometres travelled while diesel heavy commercial vehicles (HCVs and buses) account for 25% of PM_{10} emissions despite representing 7% of vehicle kilometres travelled respectively.

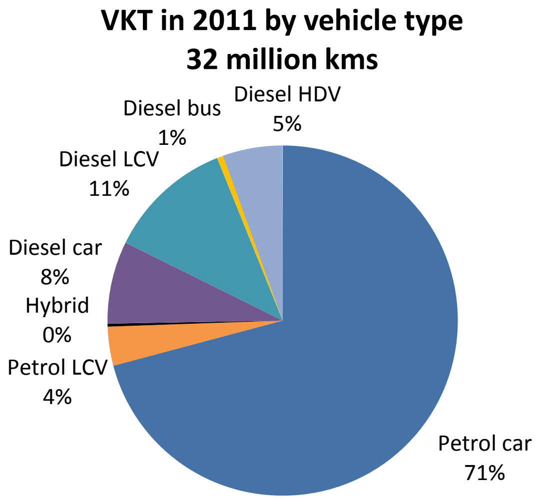

Figure 3-2 Vehicle kilometres travelled for 2011 by vehicle type

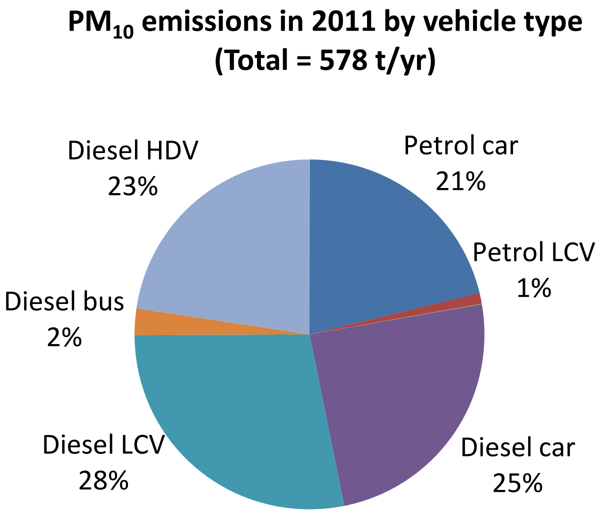

Figure 3-3 PM_{10} emissions for 2011 by vehicle type

3.1.2 Total nitrogen oxides

The 2011 motor vehicle inventory estimates total nitrogen oxides (NO_x) emissions from motor vehicles to be approximately 8,675 tonnes per year. Figure 3-4 presents NO_x emissions by fuel type.

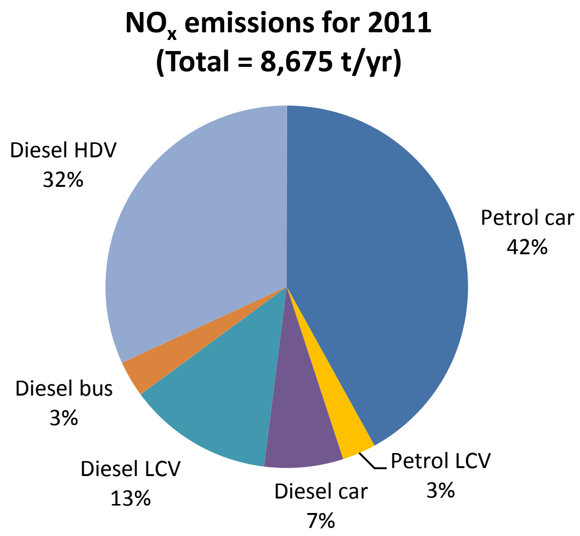

Figure 3-4 NO_X emissions for 2011 by vehicle type

3.2 Projections for 2016 to 2041

3.2.1 PM_{10}

This motor vehicle emissions inventory estimates that PM_{10} emissions from motor vehicles will be 504 tonnes per year for 2016, dropping to 355 tonnes per year in 2031. However, PM_{10} emissions are estimated to increase slightly again in 2041 to 379 tonnes per year as shown in Figure 3-5, assumed to be due to an increase in the fleet size and VKT.

Figure 3-7 shows that whilst exhaust emissions reduce between 2016 and 2041, non-exhaust (i.e. brake and tyre wear) emissions increase especially for diesel vehicles, and hybrid and electric vehicles. This is directly due to an increase in the VKT by these vehicles. The motor vehicle emissions inventory estimates that contributions from diesel exhaust emissions will drop to 41% of annual PM_{10} by 2031, while the proportion of exhaust emissions from petrol vehicles will increase slightly to account for 11% of annual PM_{10} emissions.

There is little change in overall emissions between 2016 and 2041 from petrol vehicles, diesel cars and diesel HCVs, despite there being an increase in VKT, particularly for diesel cars. Meanwhile, PM10 emissions from diesel LCVs reduce the most even though the amount of VKT remains relatively constant over these years.

A breakdown of emissions by vehicle type (Figure 3-5) indicates that by 2031, diesel cars will account for 20% of PM_{10} emissions and represent 22% of vehicle kilometres travelled, which are an improvement on their disproportionate contribution to PM_{10} emissions in previous years. By 2041, the projections estimate that diesel cars will only contribute towards 19% of PM_{10} emissions but represent almost 25% of vehicle kilometres travelled.

Emissions from light commercial vehicles (LCVs) are not projected to change much by 2021 but by 2031 the projections suggest that diesel light commercial vehicles will have significantly reduced their PM_{10} emissions accounting for 28% of PM_{10} emissions in 2016 and dropping to 9% (2031) and 7% of PM_{10} emissions by 2041 while representing only 10% of vehicle kilometres travelled by this time.

In 2016, heavy commercial vehicles (HCVs and buses) account for 25% of PM_{10} emissions while representing only 13% of vehicle kilometres travelled. Diesel heavy commercial vehicles continue to be disproportionate polluters through to 2031, comprising 32% of PM_{10} emissions while only representing 7% of vehicle kilometres travelled. This is only projected to get worse with heavy commercial vehicles accounting for 37% of PM_{10} emissions in 2041 and representing only 6% of the vehicle kilometres travelled.

The most significant change in emissions occurs in 2031 (shown in Figure 3-7) when hybrid petrol and electric vehicles start to penetrate the vehicle fleet. Notably, whilst they represent 12% of vehicle kilometres travelled, they are responsible for only 6% of PM_{10} emissions in 2031. Their continued impact can be seen in 2041, with hybrid petrol and electric vehicles projected to account for only 14% of PM_{10} emissions (all from brake and tyre wear as shown in Figure 3-9) but representing 28% of vehicle kilometres travelled.

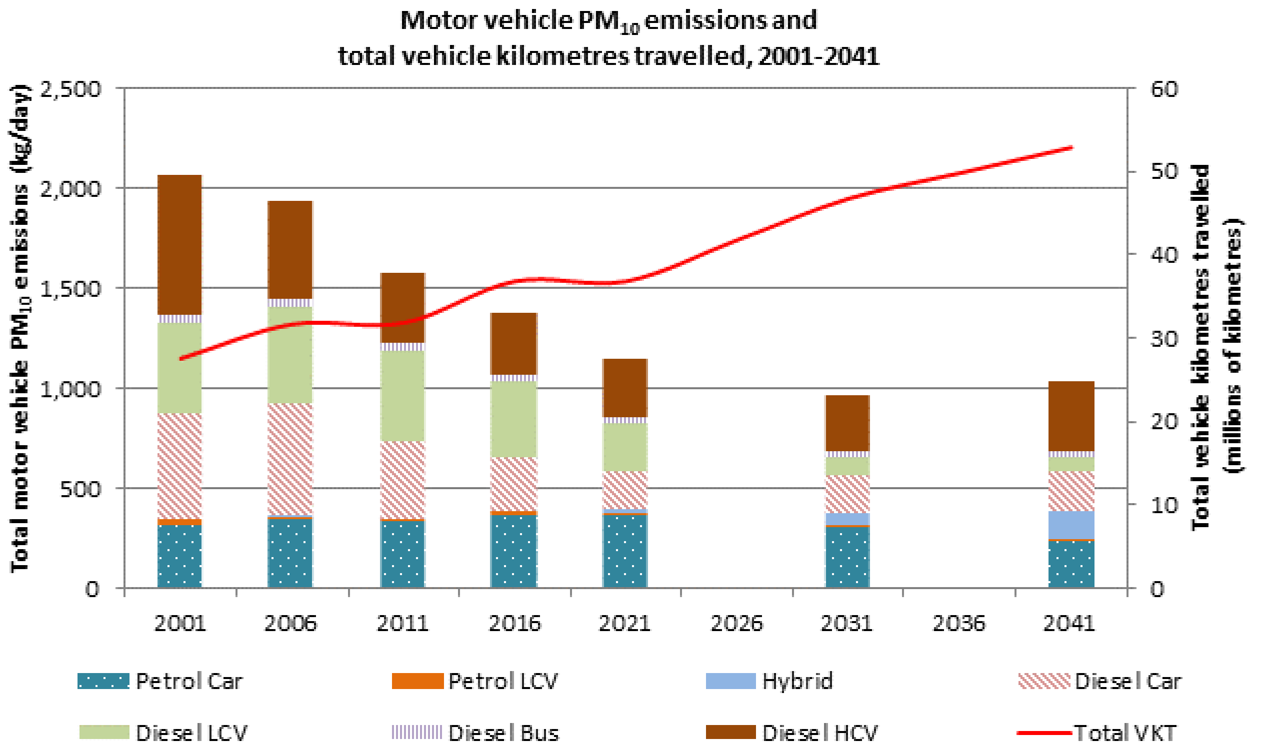

Figure 3-5 PM_{10} emission projections from 2001 to 2041 by vehicle type and total VKT

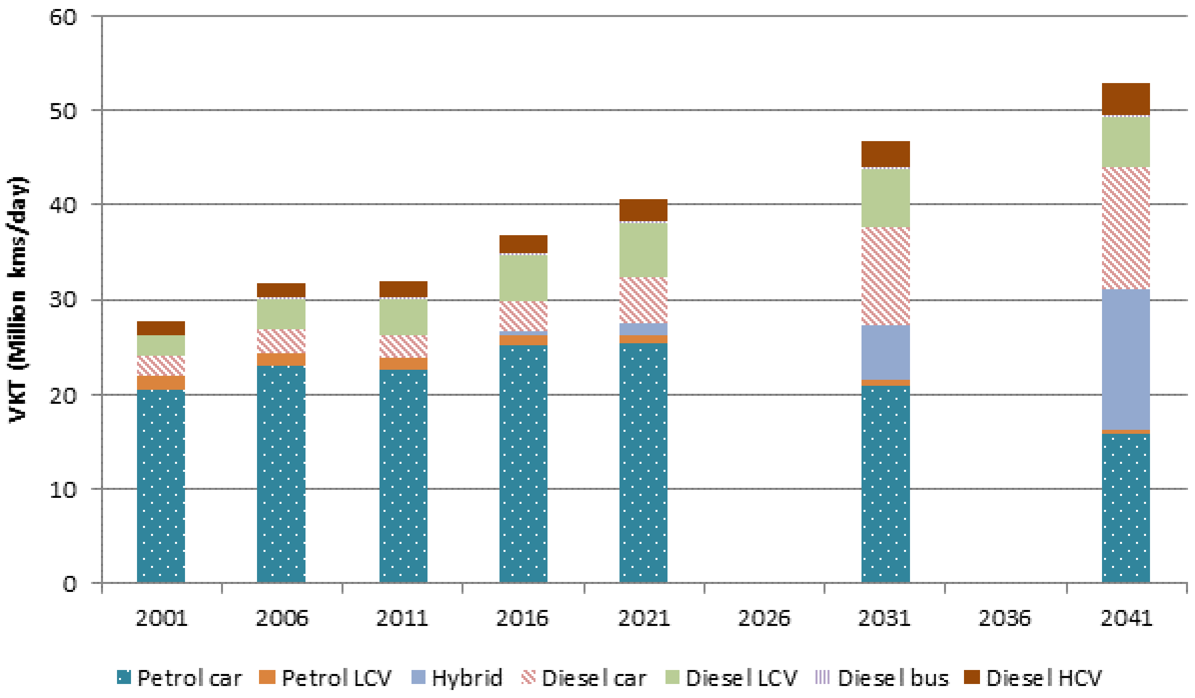

Figure 3-6 VKT projections from 2001 to 2041 by vehicle type

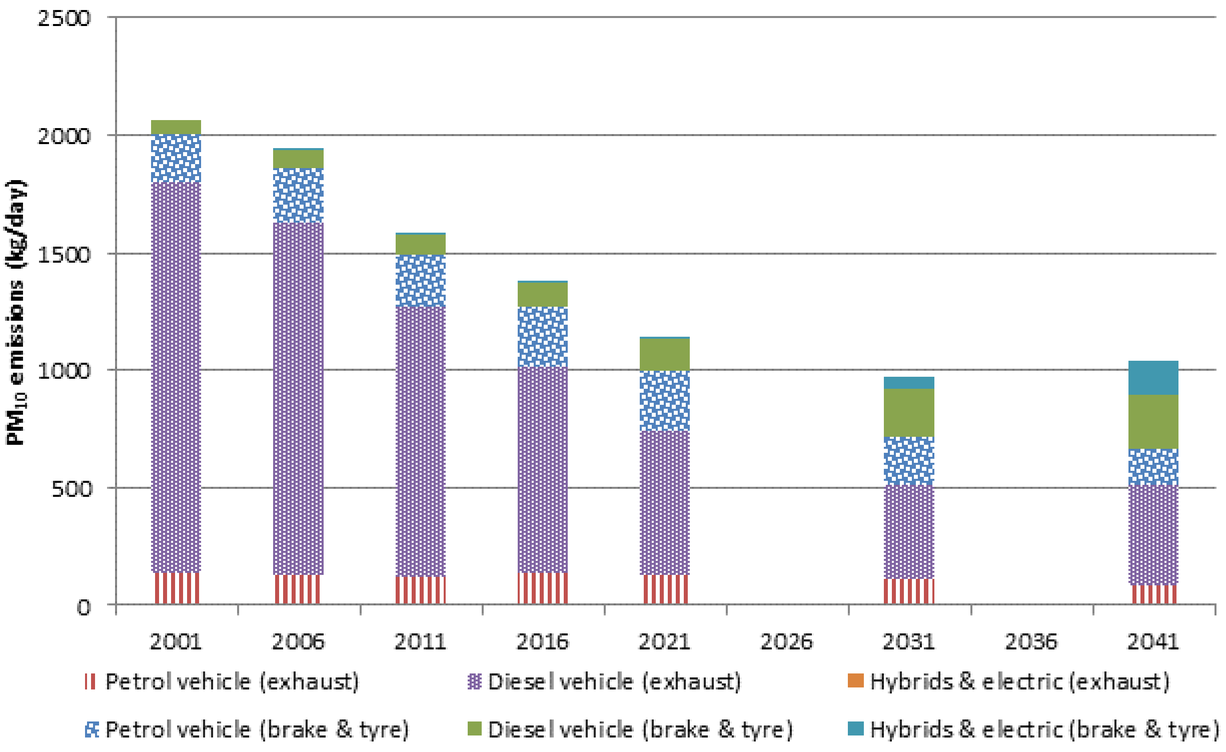

Figure 3-7 PM_{10} emission projections from 2011 to 2041 by emission type

3.2.2 Total nitrogen oxides

Figure 3-8 presents emissions of total nitrogen oxides (NO_x) by vehicle type. The motor vehicle emissions inventory estimates total nitrogen oxides emission from motor vehicles to be 7,909 tonnes per year in 2011. Projections for 2021 estimate that these emissions will reduce to approximately 6,600 tonnes per year, and even further to approximately 5,700 tonnes per year in 2031. Diesel vehicles however, will collectively contribute 75% of NO_x emissions in 2031 which is higher than the 64% contribution of 2021 and 59% contribution in 2016.

It is estimated that NO_x emissions will increase in 2041 to approximately 6,000 tonnes per year, with diesel vehicles continuing to be the primary source accounting for 83% of total NO_x emissions in 2041.

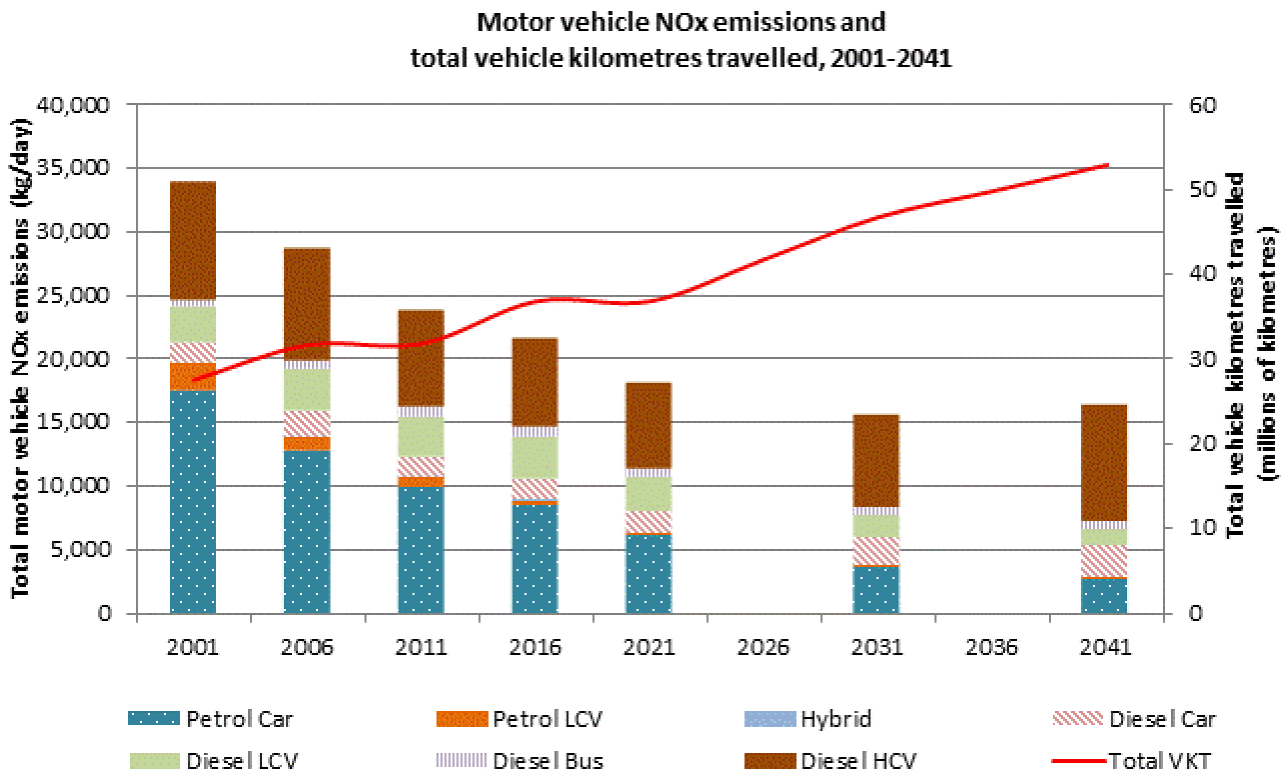

Figure 3-8 NO_X emission trends and projections from 2001 to 2041 by vehicle type and total VKT.

3.3 Spatial distribution of emissions

The spatial distribution of emissions from both PM_{10} and NO_x has been mapped for 2011 and for the projected years 2016 and 2041 (see Appendix B for all maps). Figure 3-9 and Figure 3-10 show the spatial distribution of emissions from PM_{10} and NO_x in 2016 respectively. These maps show that approximately 65% of total daily PM_{10} and almost 66% of total daily NO_x emissions in 2016 are from vehicles travelling along the state highway and arterial routes across the region (Auckland Regional Transport Authority, 2009). Spatial analysis of the data indicates that these percentage contributions are unlikely the change much between 2016 and 2041. Almost 16% of total daily PM_{10} and 23% of total daily NO_x emissions along these routes are estimated to be specifically from diesel HCVs.

Spatial analysis further shows that approximately 72% of total daily PM10 emissions and 70% of total daily NO_x emissions are generated from vehicles travelling on roads within the Auckland urban airshed. These emissions are estimated to reduce by only 5% by 2041.

It is estimated that approximately 54,000 people (almost 4% of Auckland's population based on the 2013 census) live within 70m of a regional arterial route or 150m of a strategic route (which includes a motorway or non-motorway). Auckland's population is expected to grow from approximately 1.5 million (in 2013) to 2.5 million by 2041 under a high growth scenario (Auckland Council, 2012b). In order to cope with this growth, the Auckland Growth Concept proposes to adopt more mixed use zones and higher density dwellings along the regional arterials and strategic routes (cited in Wickham, 2012).

Although overall emissions are estimated to reduce between 2016 and 2041 across the region, there is little improvement in emissions specifically from diesel HCVs. This means that the air quality at locations near state highways and regional arterials are unlikely improve much in future years. The impact of emissions from vehicles travelling along these routes could potentially be much higher, especially for the sensitive populations exposed to these emissions.

The Auckland Unitary Plan therefore proposes to apply separation distances between any new sensitive land use type (such as early childhood education centres) and the regional arterials and strategic routes. However, these separation distances can only limit or minimise the impact and exposure to vehicle emissions whereas primary strategies (e.g. vehicle emission controls) can directly reduce vehicle emissions (Wickham, 2012).

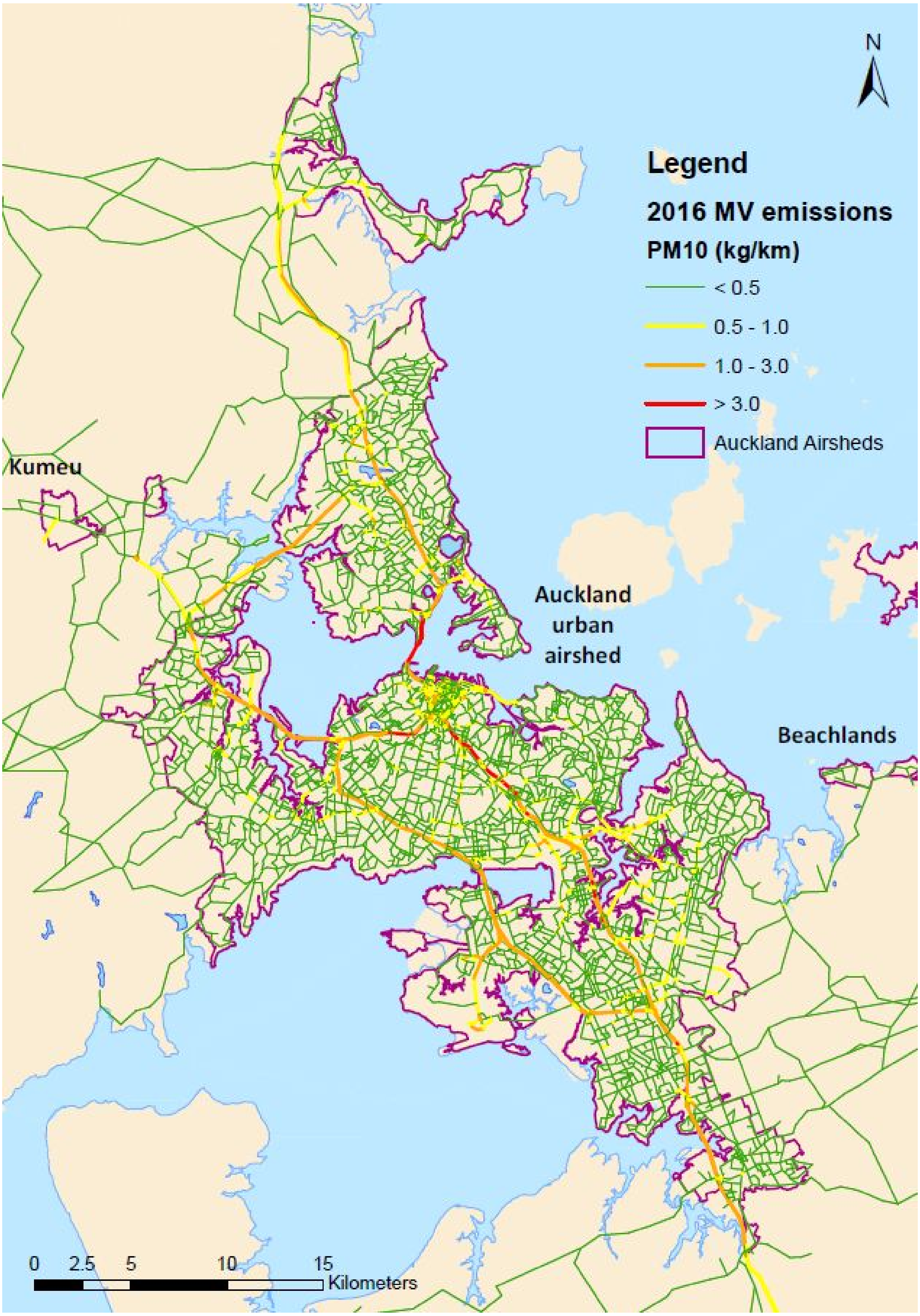

Figure 3-9 Spatial distribution of PM_{10} emissions in 2016.

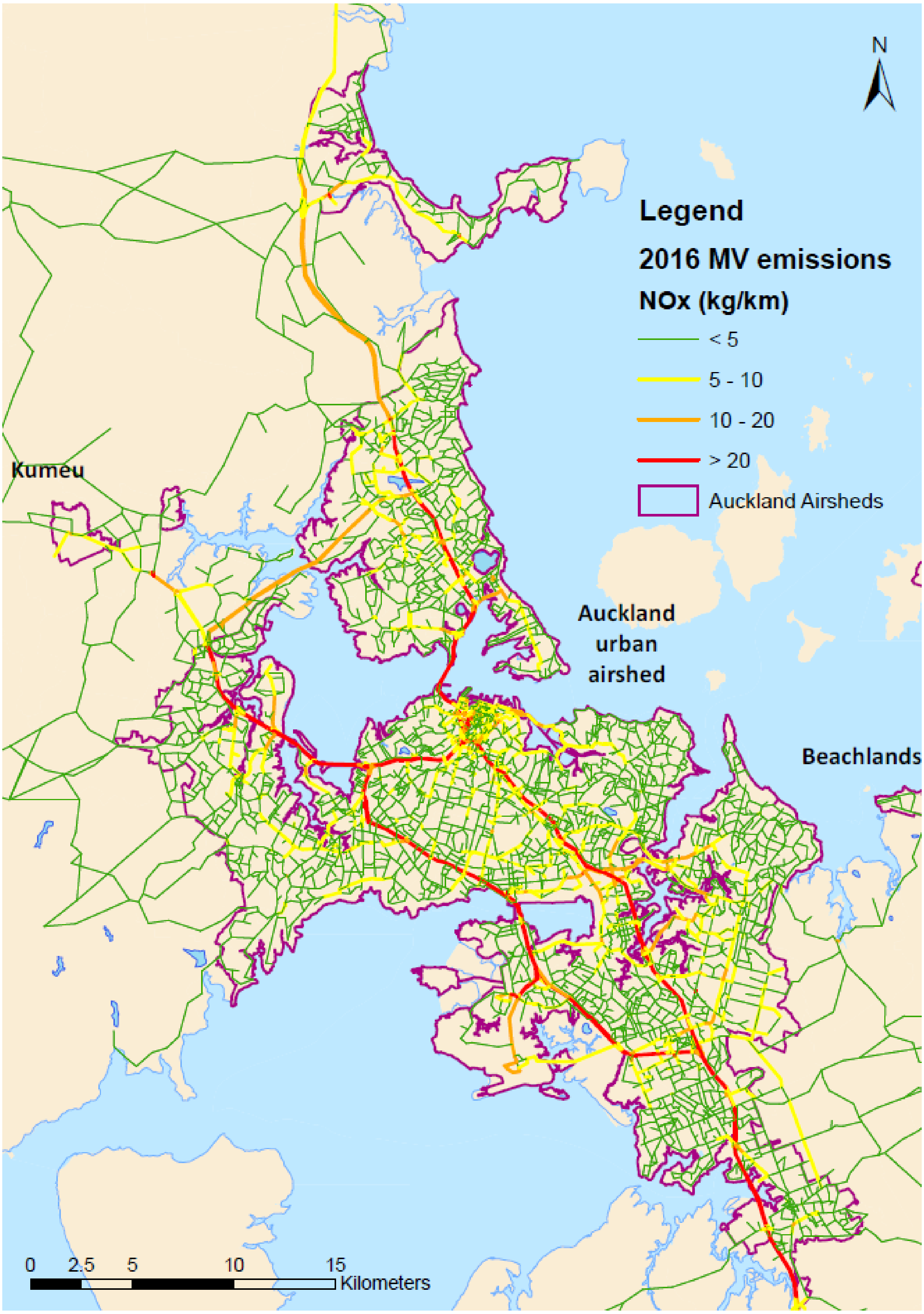

Figure 3-10 Spatial distribution of NOx emissions in 2016.

4.0 Discussion of trends

Projected (i.e. future) vehicle emissions are based on assumptions about (amongst other things) fleet composition, fleet turnover and total vehicle kilometres travelled. This report relies on historical and assumed fleet projections provided by the Ministry of Transport (MoT) Vehicle Fleet Emission Model as shown in Figure 4-1 (Ministry of Transport, 2008).

These emissions are informed by current information on fleet composition in New Zealand and overseas. For example, in 2010, 15% of all new cars in Japan were hybrids. Existing trends indicate that there will be an eight year lag before these vehicles will start penetrating the New Zealand market. This is based on how quickly these vehicles depreciate in Japan (and as a result no longer comply with Japanese regulations), before they are imported into New Zealand (Ministry of Transport, 2013, Figure 6.2a).

The Ministry of Transport has assumed therefore, that there will be an increased uptake of hybrid and electric vehicles by 2031 as shown in Figure 4-1 below and Figure 4-2. Figure 4-1 also shows that there is an increased uptake of diesel cars from 2025 while the uptake of petrol cars begin to decrease from 2020. This also indicates that the fleet is projected to grow from 2015, despite the size of the light passenger vehicle fleet remaining constant between 2005 and 2013. This has implications for VKT and emissions for diesel passenger vehicles especially after 2021.

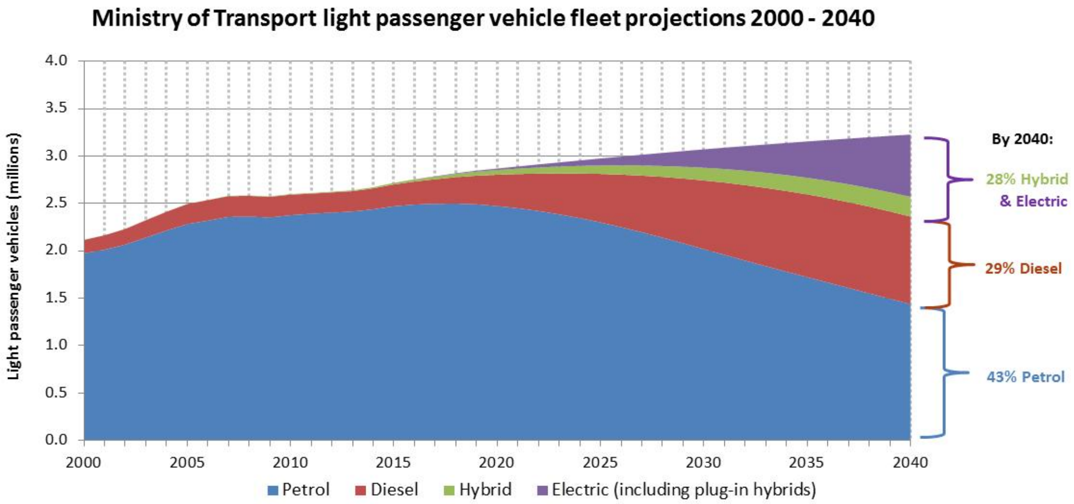

Figure 4-1 National historical and projected light passenger vehicle fleet composition, 2000-2040 from the Ministry of Transport Vehicle Fleet Emission Model (Ministry of Transport, 2008).

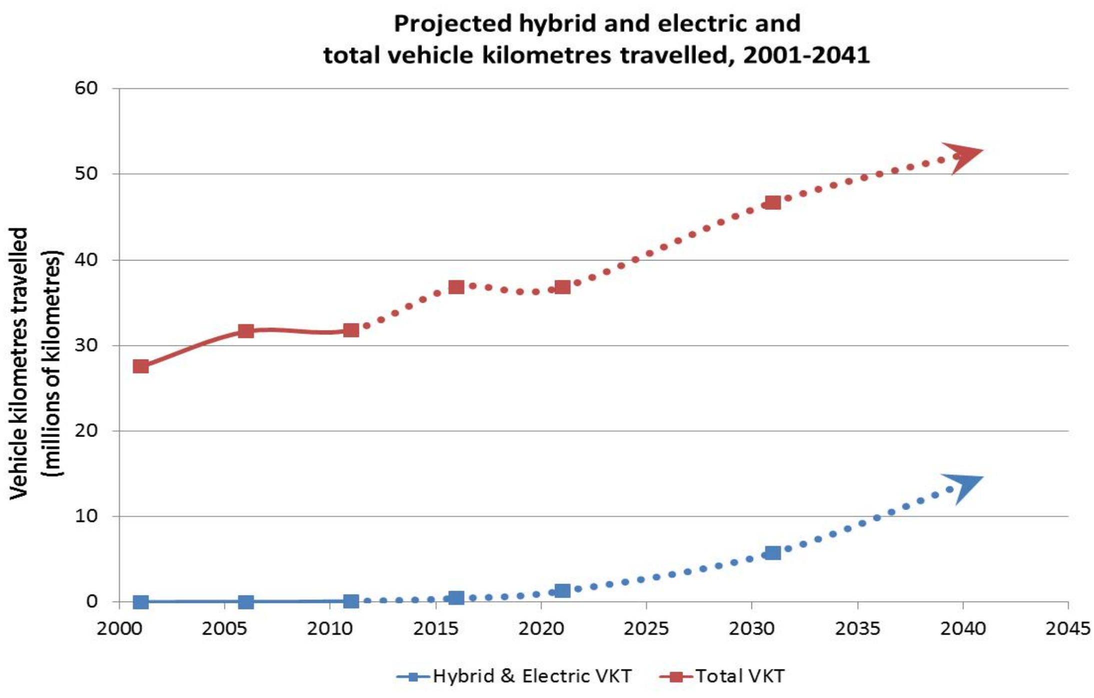

Figure 4-2 Historical and projected hybrid and electric vehicles and total VKT, 2001-2041

4.1.1 Projected trends for PM_{10}

Figure 4-3 presents estimated vehicle PM_{10} emissions against the Auckland Plan emissions reduction target for PM_{10} of 50% (based on 2006 levels) by 2016 (Auckland Council, 2012b). Figure 4-3 shows that projected emissions reductions will fall short of the target by 30%. This has important implications for the ability of Auckland Council to comply with the National Environmental Standard for PM_{10}.

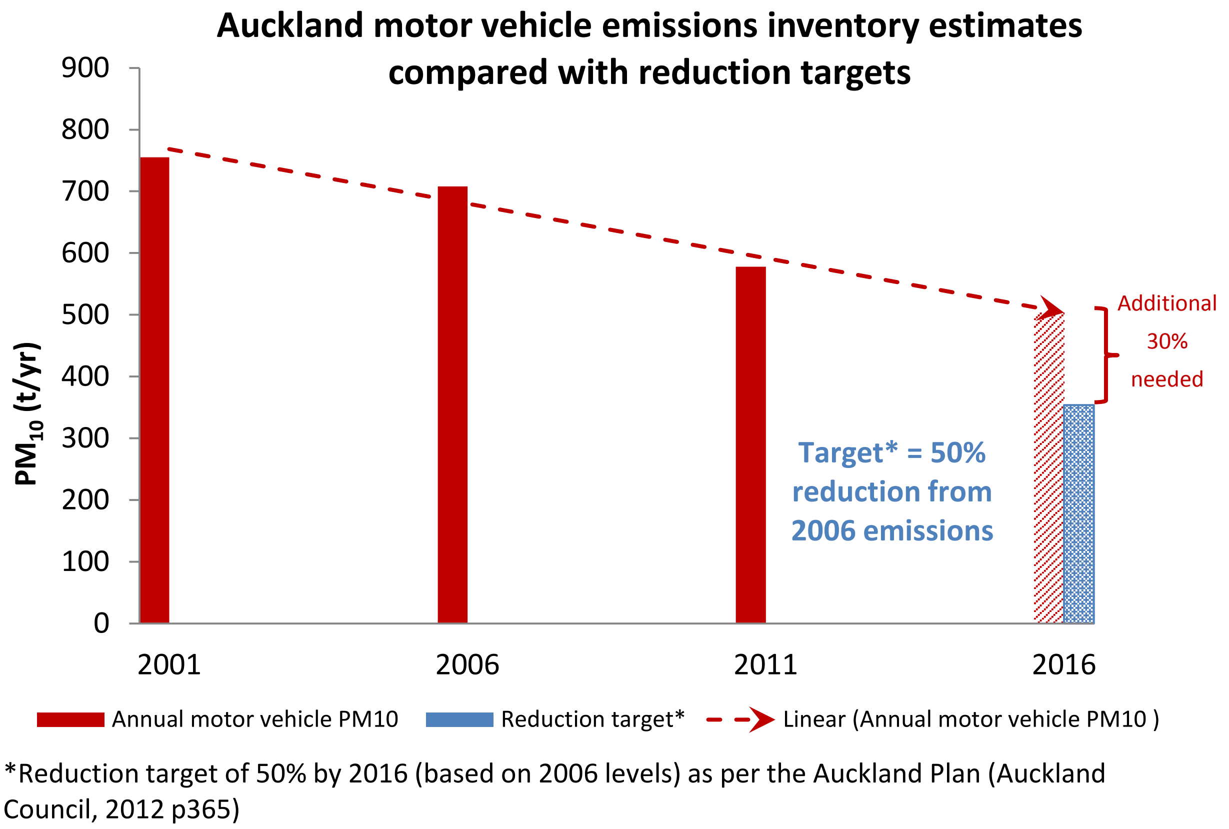

Figure 4-3 Estimated vehicle PM_{10} emissions compared with emission reduction targets

Figure 3-5 showed historical and projected PM_{10} emissions (2001 to 2041) by vehicle type and fuel as well as total vehicle kilometres travelled. This predicts a significant projected drop in PM_{10} emissions, despite a significant increase in total vehicle kilometres travelled. These reductions are largely a result of (projected) improved emissions from diesel cars (Figure 4-4) and diesel light commercial vehicles (Figure 4-5).

4.1.2 Projected trends for $PM_{2.5}$

Projected overall trends for $PM_{2.5}$ emissions (as shown in Figure 4-6) mirror those of PM_{10} with emissions projected to reduce between 2016 and 2031, but increasing again by 2041. This increase in $PM_{2.5}$ emissions is partly due to the steady increase in diesel HCV vehicle kilometres travelled by 2041 as shown in Figure 4-7.

$PM_{2.5}$ emissions are mainly from vehicle exhausts and as shown in Figure 3-7, vehicle exhaust emissions reduce significantly between 2016 and 2031. As a result, $PM_{2.5}$ emissions are expected to reduce more rapidly than PM_{10} emissions as it is likely that emissions due to brake and tyre wear will continue to increase (and become more important) as VKT increases in future.

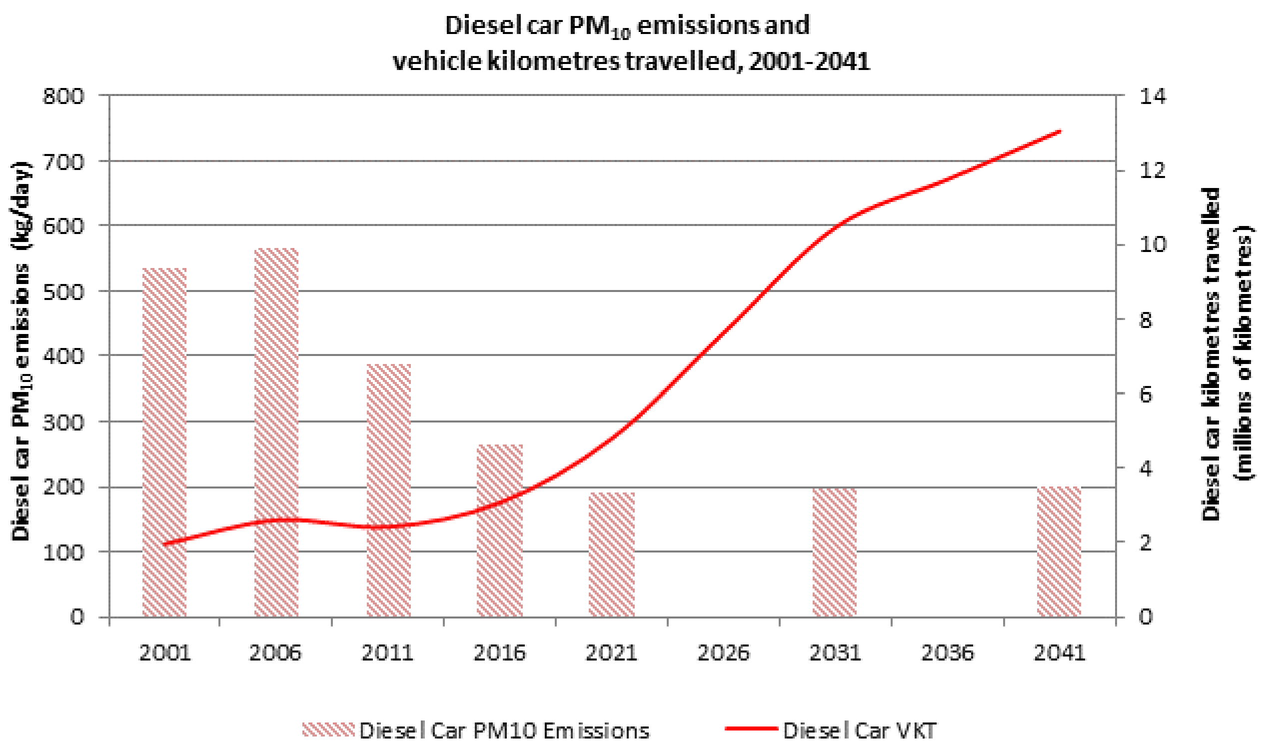

Figure 4-4 Historical and projected diesel car PM_{10} emissions and diesel car VKT, 2001-2041

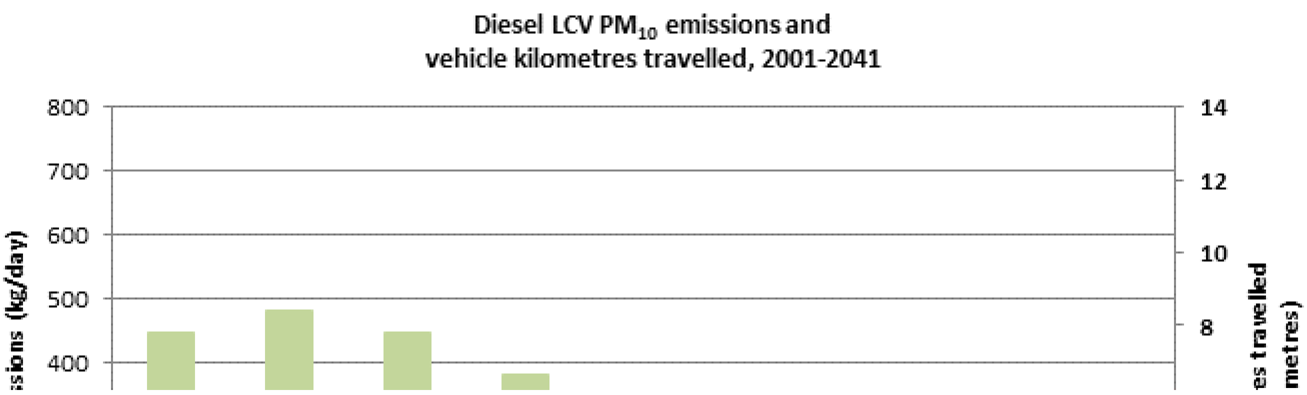

Figure 4-5 Historical and projected diesel LCV PM_{10} emissions and LCV VKT, 2001-2041

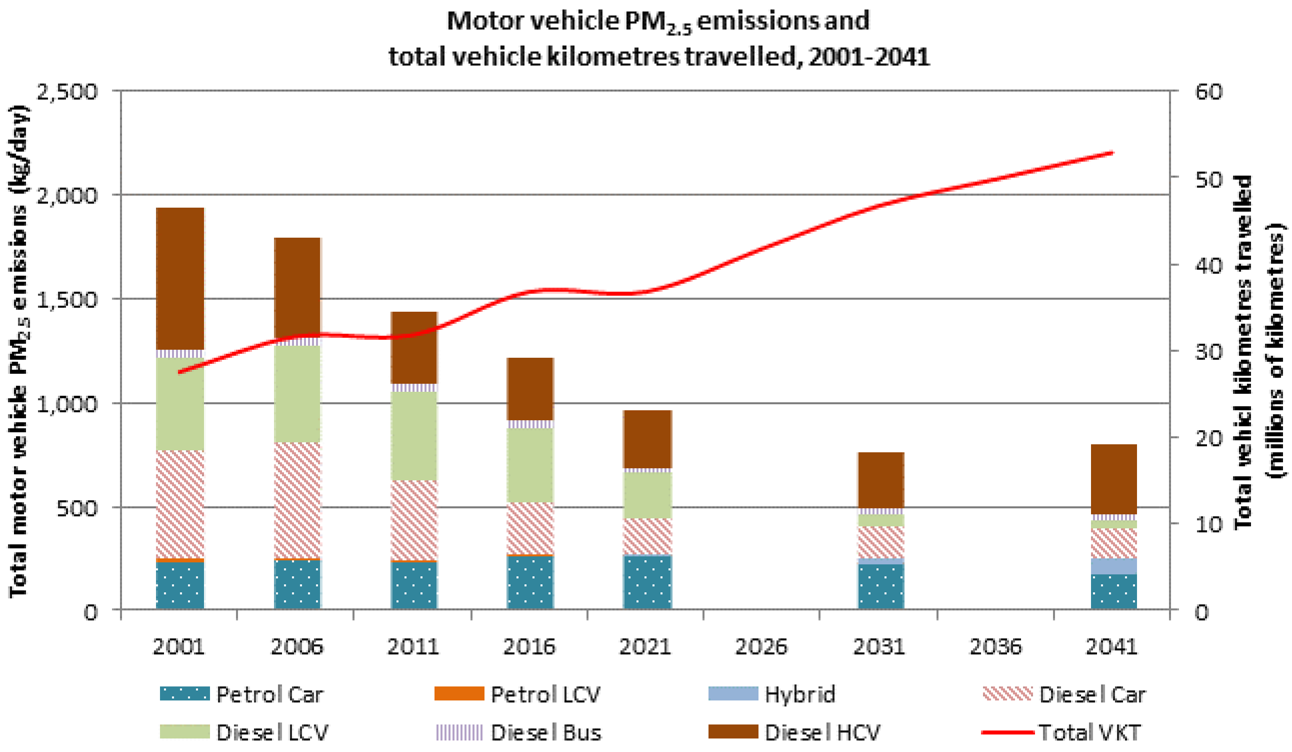

Figure 4-6 Historical and projected motor vehicle $PM_{2.5}$ emissions and total VKT, 2001-2041

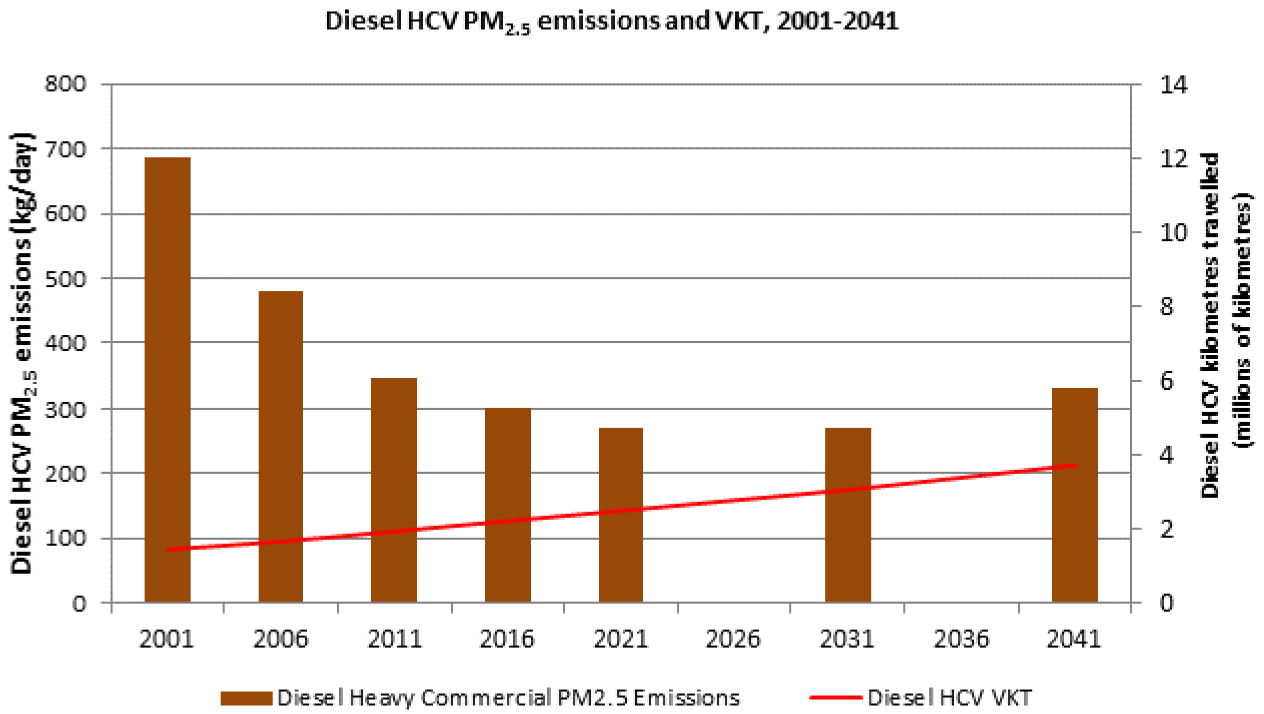

Figure 4-7 Historical and projected diesel HCV $PM_{2.5}$ emissions and HCV VKT, 2001-2041

4.1.3 Projected trends for total nitrogen oxides

Emissions of total nitrogen oxides (NO_x) are projected to decrease between 2001 and 2041 as shown in Figure 3-8. However, this reduction is limited mostly to changes associated with petrol cars (Figure 4-9) and reflects both improved emissions control and a greater shift to hybrid and electric cars assumed to occur after 2021.

Emissions from diesel cars (Figure 4-10) and diesel heavy commercial vehicles (Figure 4-11) are projected to increase in accordance with increased diesel vehicle kilometres travelled between 2021 and 2041.

The impact of decreasing NO_x emissions on ambient nitrogen dioxide (NO_2) concentrations is less clear. Emissions factors for the existing fleet show that whilst NO_x emissions are reducing, emissions of NO_2 (per vehicle) may increase. This is discussed further in section 5.1.

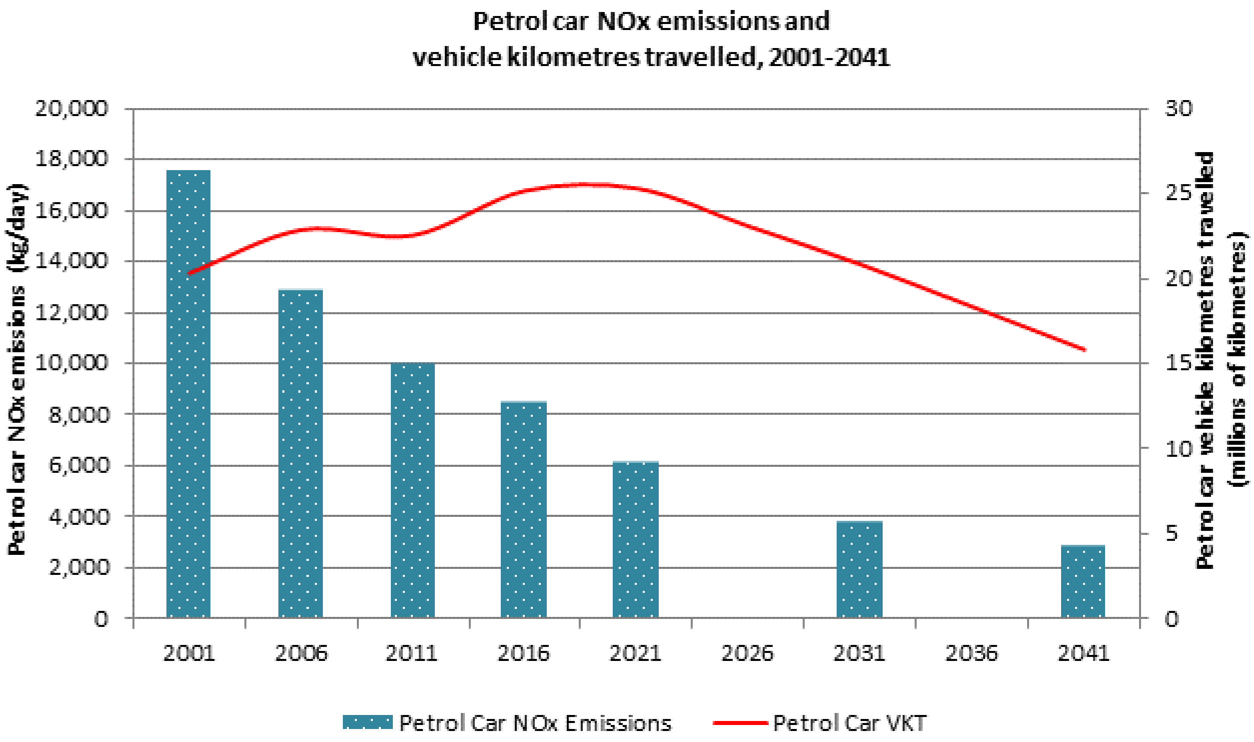

Figure 4-8 Historical and projected petrol car NO_x emissions and petrol car VKT, 2001-2041

4.1.4 Projected trends for volatile organic compounds

Volatile organic compounds (VOCs) emissions are projected to drop significantly between 2001 and 2041 as shown in Figure 4-12. This is largely a result of improvements in petrol car emissions, despite a significant increase in petrol car kilometres travelled (until 2021) as shown in Figure 4-13. This decrease in petrol car kilometres travelled after 2021 reflects the shift to hybrid and electric cars assumed to occur at this time.

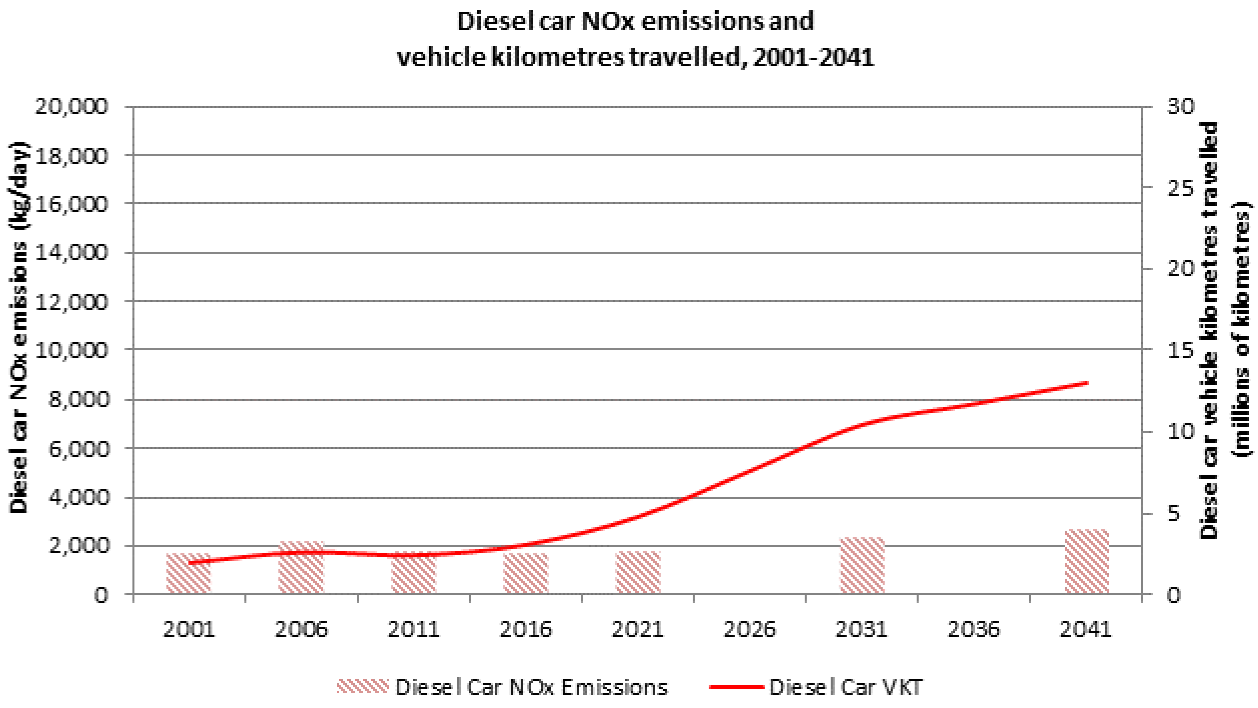

Figure 4-9 Historical and projected diesel car NO_x emissions and diesel car VKT, 2001-2041

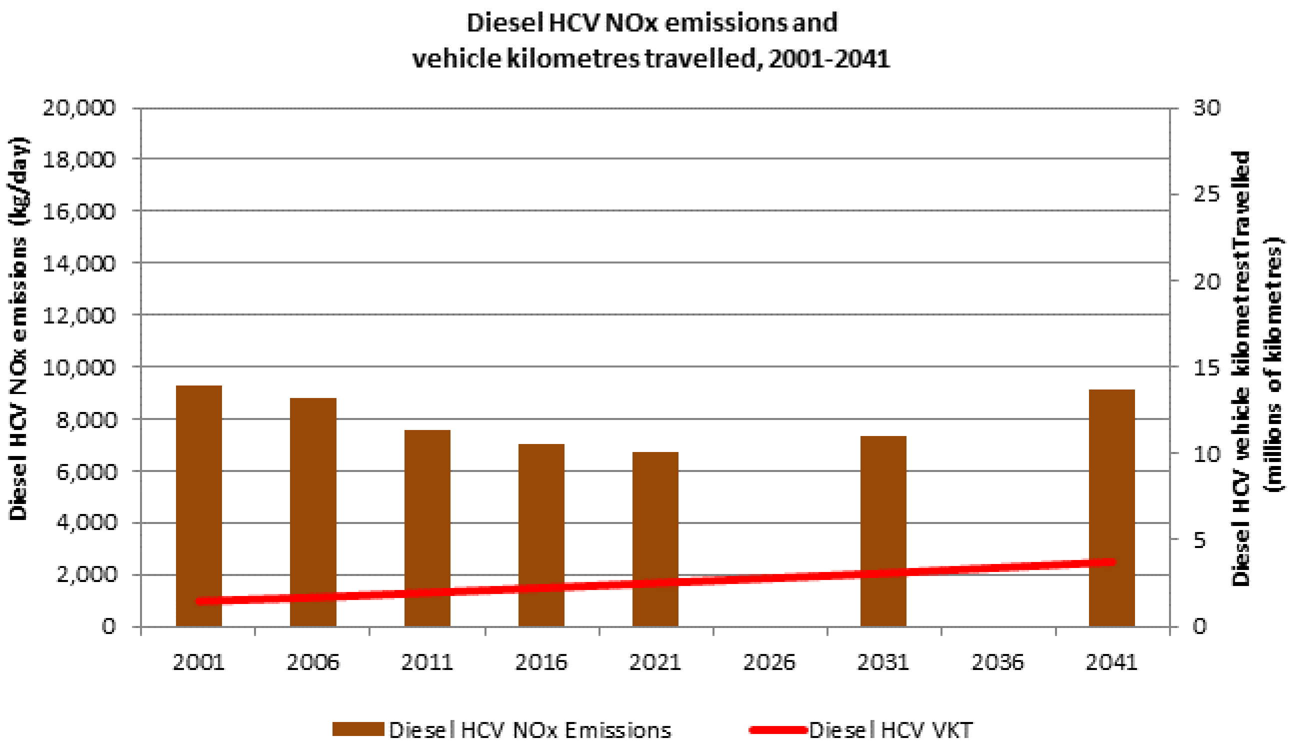

Figure 4-10 Historical and projected diesel HCV NO_x emissions and VKT, 2001-2041

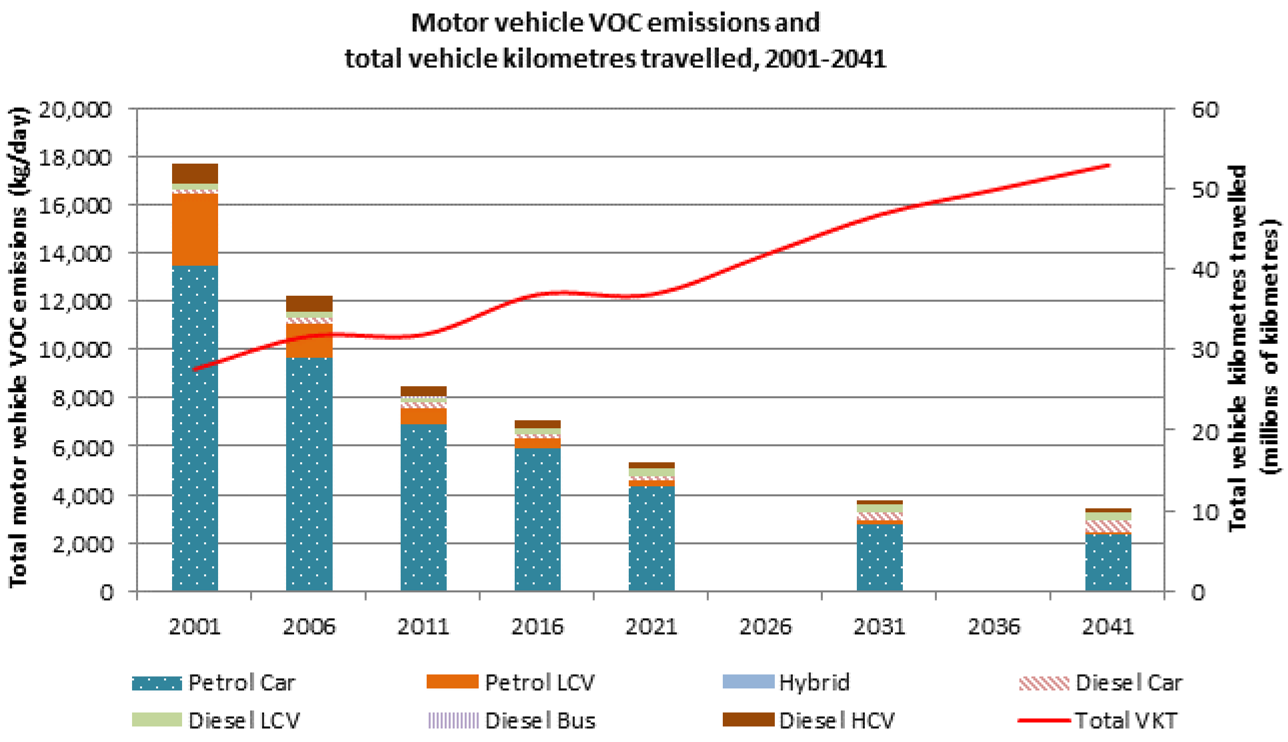

Figure 4-11 Historical and projected motor vehicle VOC emissions and total VKT, 2001-2041

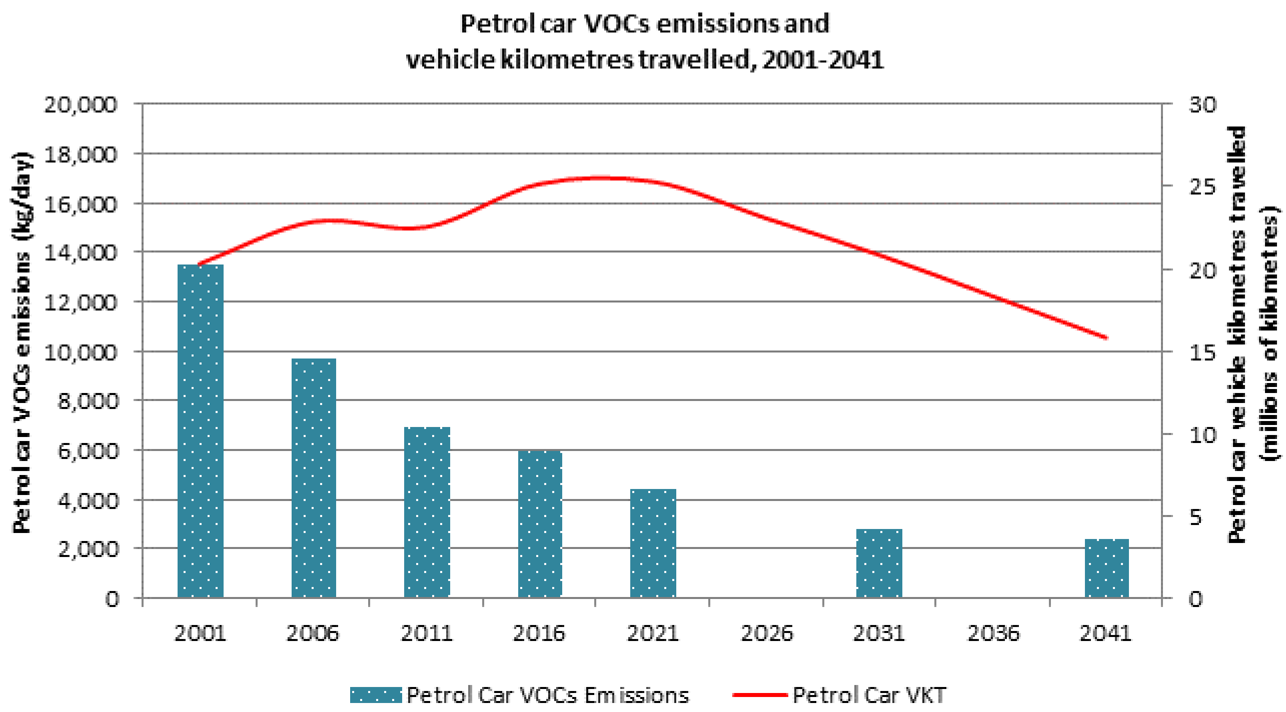

Figure 4-12 Historical and projected petrol car VOC emissions and petrol car VKT, 2001-2041

5.0 Uncertainty and sensitivity analysis

Whilst errors associated with the estimation of vehicle emissions are not easily quantified, the following section provides some indication of the overall accuracy of the inventory by discussing the uncertainties (around fuel consumption, emission factors, changes in standards) and undertaking a sensitivity analysis of key variables for PM_{10}, NO_x and fuel consumption.

5.1 Uncertainty

As with all emissions inventories, caution is required when assessing the results and considering the policy implications. Estimation of motor vehicle emissions for the emissions inventory relies on several models, each with its own limitations.

The projected emissions for 2016, 2021, 2031 and 2041 are subject to even greater uncertainty. Whilst every attempt has been made to keep the assumptions on which these are based reasonable, the resulting projections are nonetheless subject to significant uncertainty. The sensitivity analysis in the following section provides some context for this uncertainty.

5.1.1 Uncertainty in trends

The significant reduction in vehicle emissions over the last 10 to 20 years has been driven by continual improvements in both vehicle technology and cleaner fuels. Newer vehicles discharge less air pollution per kilometre travelled than older vehicles. As noted by NZTA (2011):

> *In theory, as new vehicles replace old in the New Zealand fleet and as fuel quality improves, the amount of pollutants discharges on a* ***per vehicle*** *basis should (on average) be reducing. However, it is unknown how much influence (if any) new technology and improved fuel is actually having on the 'real-world' emissions from New Zealand's light duty* ***vehicle fleet as a whole****.*

This is because fleet emissions are also directly influenced by other factors such as fleet composition, the rate of turnover and the total vehicle kilometres travelled.

The NZTA notes that between 2003 and 2009 (NZTA 2011):

- the average age of vehicles increased;
- vehicle kilometres travelled increased; and
- the proportion of diesel vehicles increased.

These factors are likely to offset, to some extent, anticipated fleet emissions reductions. There has also been extensive international discussion around "peak car travel" which suggests that vehicle kilometres travelled per capita has levelled off and is on the decline

(Goodwin, 2012), a trend that has been observed in New Zealand. This casts greater uncertainty around the projections estimated in this inventory. Trend analysis can, therefore, provide a reality check on the estimated vehicle emissions inventory.

In addition, trends in measured ambient levels of nitrogen dioxide (NO_2) at some Auckland monitoring sites do not necessarily reflect predicted reductions in (NO_x) emissions. Recent international analysis also found that the fraction of NO_x emitted as NO_2 by all types of diesel vehicles displayed a variable trend rather than a downward trend over the years (Carslaw *et al*., 2011; OECD, 2014). This may reflect a change in the proportion of NO_x emitted as NO_2, which is likely to be much higher in the future as the proportion of diesel vehicles in the Auckland fleet increases.

5.1.2 Comparison with fuel sales figures

To provide an indication of the accuracy of the emissions inventory, predicted fuel consumption can be compared with actual regional fuel sales. There is now relatively accurate fuel use data available for road transport at the national level (MED, 2010), and to some extent for the Auckland region as well.

The inventory does not include all users of all fuels and hence will always have lower estimated fuel use than reported sales. Although this provides a useful comparison, it should be noted that harmful emissions (e.g. PM, NO_x etc.) are not a direct function of fuel use and are primarily dependent upon engine technology and are therefore more difficult to estimate as compared to carbon dioxide (CO_2) emissions.

Table 5-1 compares estimated fuel consumption using VEPM5.1 and actual reported fuel sales. As noted above, estimated fuel consumption will never equal actual sales figures because the following uses are not included in the inventory.

Petrol fuelled emission sources:

- Motor boats
- Defence vehicles
- Generators
- Lawn mowing, gardening appliances (leaf blowers, and other two stroke devices such as chain saws and water blasters etc.)
- Unregistered motorbikes
- Competition vehicles
- Farm and forestry vehicles

Note: Fuel used by industrial operations is also not included in the fuel sales, but it does account for fuel used by industrial road transport (which falls into the diesel heavy commercial vehicles category).

With respect to petrol consumption (Table 5-1), each of the excluded sources listed above would easily consume 1% of total fuel consumption,[3] with farm and forestry vehicles likely consuming more. Allowing for this leaves a shortfall of around 10% between estimated petrol consumption and petrol sales figures. This is a reasonable agreement given the uncertainties in the inventory.

Table 5-1 Actual fuel sales compared with consumption

Year	Estimated fuel use (ML/yr)			Fuel sales (ML/yr)			Difference (%)		
	Petrol	Diesel	Total	Petrol	Diesel	Total	Petrol	Diesel	Total
2001	822	285	1,107	987	417	1,405	-17	-32	-21
2006	905	362	1,268	1,072	520	1,592	-16	-30	-20
2011	859	384	1,245	1,040	476	1,516	-17	-19	-18

Diesel fuelled emission sources:

- Motor boats
- Defence vehicles
- Construction equipment (cranes, diggers, bulldozers, etc.)
- Farm and forestry vehicles

A comparison of national diesel use in construction scaled down to the Auckland region is 38 million litres per annum (Auckland Council, 2011). Similarly, combining land use in the Auckland region (Auckland Regional Council, 2010) with off-road diesel consumption for farm land (OMS, 2008) yields an estimate of 5.1 million litres per annum. This accounts for 9% of total diesel fuel sales in the Auckland region.

With respect to diesel consumption, the inventory estimate is only 10% short of reported diesel sales when the above off-road uses (of 9%) are taken into consideration. This is a reasonable agreement given the uncertainties in the inventory.

Total estimated fuel consumption is around 20% less than actual total fuel sales. Given the sources not included in the inventory, and the uncertainties inherent in emissions estimates, this is considered reasonable.

[3] Based on an updated estimate of marine pleasure craft emissions using census data and/or projections and assuming a usage of 1,135 L/yr of petrol per boat.

5.1.3 Uncertainty around emission factors

In 2011, the Energy and Fuels Research Unit at the University of Auckland conducted a review of COPERT 4 (a programme that calculates emissions from road transport, the technical development of which is managed by the European Environment Agency). The review found that emission factors were regularly kept up-to-date in COPERT 4, while the source of some emission factors used in VEPM5.1 were updated rather infrequently (Jones *et al*. 2011b). The review also found that NO_x and PM emission factors for Euro V (and projected Euro VI) HCVs are between 50% and 200% higher than currently in VEPM5.1 (NZTA, 2012) as a result of using emission factors based more on projections rather than real world testing. This means that VEPM5.1 is currently underestimating NO_x and PM_{10} emissions for Euro V and VI classes of heavy commercial vehicles.

5.1.4 Changes to emission standards

As mentioned earlier, this report only estimates emission projections based under a "business as usual" scenario. The Ministry of Transport expects to review the timing of the introduction of any new vehicle standards (including Euro 6 for light vehicles, and Euro VI for heavy commercial vehicles) in 2014 (Ministry of Transport, 2012). VEPM5.1 already includes emission factors for Euro 6 light commercial and passenger vehicles and assumes these will take effect in 2015. So, the "business as usual" scenario assumes that there will be no new vehicle emission standards (including Euro 6 standards) after 2015.

Given that the European Union are not currently meeting their own air quality targets (Vidal, 2013), it is unrealistic to assume that new emission standards will not be developed. The emission projections under the "business as usual" scenario estimated here are therefore conservative because new emissions standards may further reduce per vehicle emissions in future which has not been allowed for in this assessment.

5.1.5 Uncertainty in vehicle fleet penetration

As mentioned above, VEPM5.1 includes emission factors for Euro 6 light commercial and passenger vehicles, although it assumes that the Euro 6 vehicles will only begin to start penetrating the fleet in 2015, accounting for 1.6% of total VKT, but increasing to almost 25% of total VKT in 2021. However, statistics show that Euro 6 light vehicles have already started to enter the fleet (Ministry of Transport, 2013). This means that Euro 6 vehicles are likely to be more significant than estimated for future years. A scenario analysing an earlier uptake of Euro 6 light vehicles was not tested here, again due to the time available for the project and the nature of the analysis being outside the scope of work, but the uncertainties identified here does highlight that the projected emissions estimates are in fact conservative.

5.1.6 Uncertainty around vehicle fleet size

The emission projections estimated as mentioned earlier are calculated under a “business as usual” scenario. This assumes that there will be constant growth in Auckland’s vehicle fleet until 2041 (based on forecasts for the Auckland Council’s Auckland Plan). However, international trends indicate that the global uptake of vehicles has shown little signs of growth in recent years (Goodwin, 2012) and a similar trend has also been observed here in New Zealand. Figure 3-5 shows that the size of the light passenger vehicle fleet remained constant between 2005 and 2013, although the projections indicate there to be growth in the fleet. Given these national and international trends, the assumption around constant growth in the vehicle fleet size seems unrealistic and it may be more ideal to estimate projections under a limited vehicle fleet growth scenario instead. This scenario analysis was not undertaken as part of this project, but as mentioned before, it indicates that future estimates of emissions may be lower than projected here.

5.2 Sensitivity analysis

The sensitivity of emission inventory estimates to key variables are analysed for PM_{10}, NO_x and fuel consumption. These results are discussed in section 5.2.1 (hybrid and electric fleet penetration), and section 5.2.2 (emission factor accuracy).

5.2.1 Effect of assumptions about hybrids

The projections assume a significant increase in hybrid and electric vehicles from 2021 (best seen in Figure 3-6). These are based on fleet composition assumed in the Auckland Regional Transport model version 3 (ART3) which are, in turn, based on the Ministry of Transport fleet projections (Figure 4-1). A ‘worst case’ scenario (for PM_{10} emissions), would be to assume zero change in proportion of hybrid and electric vehicles from 2016 onwards (i.e. constant 1% hybrid and electric vehicles until 2041). This also assumes the projected increase in total vehicle kilometres travelled by both passenger and light commercial vehicles is split equally between diesel and petrol cars.

Figure 5-1 shows the fleet breakdown by fuel for the base case (Ministry of Transport projections) and a ‘worst case’ scenario between 2001 and 2041.

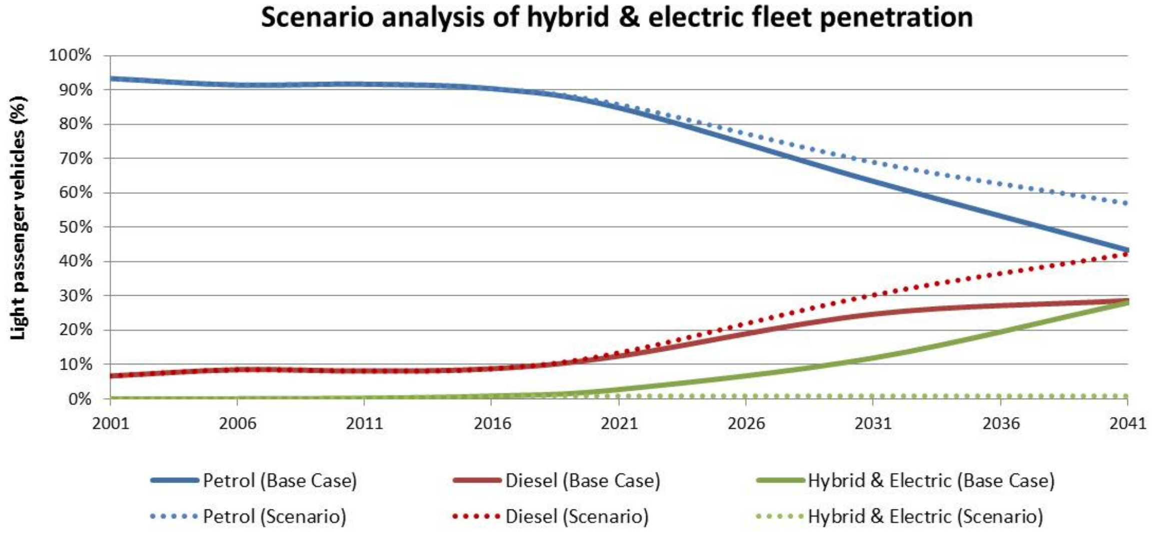

Figure 5-1 Scenario assuming 1% hybrid and electric vehicles penetrate the fleet from 2021.

Table 5-4, Figures 5-2 (PM_{10}) and 5-3 (NO_x) present the results of scenario analysis assuming that there is no change in the proportion of hybrid vehicles between 2011 and 2031 and 2041. As would be expected, emissions of PM_{10}, $PM_{2.5}$ and NO_x are higher than the base case. In particular, NO_x emissions would be 16% higher from the diesel and petrol cars replacing the projected hybrid and electric cars in 2041.

The implication is that if hybrids do not make significant inroads to the fleet, then the projected decreases in PM_{10} (see Figure 3-5), $PM_{2.5}$ (see Figure 4-6) and NO_x emissions (see Figure 3-8) will be less in future years.

Table 5-2 Sensitivity of estimated emissions to proportion of hybrid and electric vehicles

Scenario	Difference with respect to base case			
Base case (12% hybrid in 2031/ 28% hybrid in 2041)	PM_{10}	$PM_{2.5}$	NO_x	Fuel consumption
1% hybrid and electric vehicles in **2031** (remaining VKT split equally between diesel and petrol cars)	+4%	+5%	+6%	+7%
1% hybrid and electric vehicles in **2041** (remaining VKT split equally between diesel and petrol cars)	+8%	+10%	+16%	+22%

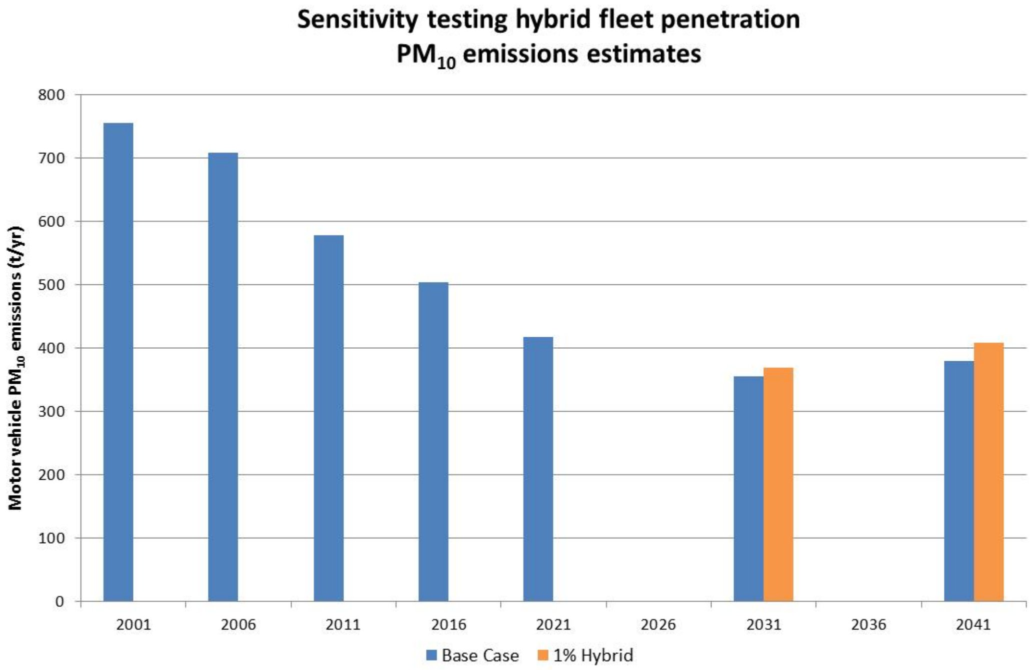

Figure 5-2 Sensitivity of estimated PM_{10} emissions to proportion of hybrid and electric vehicles

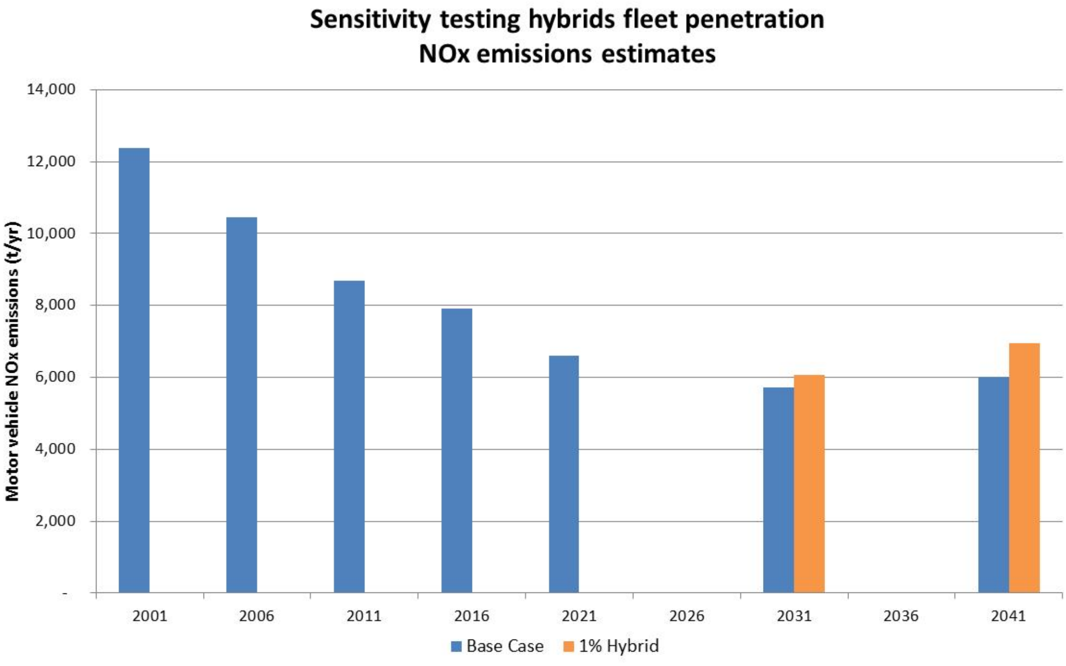

Figure 5-3 Sensitivity of estimated NO_x emissions to proportion of hybrid and electric vehicles

5.2.2 Effect of emission factor

There is growing local and international concern that emission standards for diesel vehicles, particularly HCVs are not delivering the expected emission reductions. This raises questions over the accuracy of the data used to estimate emissions, especially of emission factors given the uncertainties discussed in section 5.1.3. The effect of doubling (i.e. increasing by 100%) the NO_x and PM_{10} emission factors for Euro V diesel HCVs vehicles in the fleet in 2021 and 2031 were tested here and are shown in Table 5-5. Figure 5-4 which plots the difference with respect to base case for PM_{10} emissions and Figure 5-5 (NO_x emissions).

This shows that projected reductions in PM_{10} and NO_x emissions are heavily dependent on expected reductions in (Euro V) diesel heavy commercial vehicles. The implication is that NO_x emissions will continue be a problem in 2041, especially because the emission standards alone may not achieve the necessary (and desired) reductions in emissions. This is also the case for PM_{10} and $PM_{2.5}$ emissions.

Table 5-3 Sensitivity of estimated emissions to emission factor accuracy

Scenario	Difference with respect to base case		
Base case VEPM5.1 (2021/2031/2041)	PM_{10}	$PM_{2.5}$	NO_x
Euro V* emission factors for PM_{10} and NO_x doubled in 2021 (Euro V = 4.2% of total VKT)**	+8%	+10%	+20%
Euro V* emission factors for PM_{10} and NO_x doubled in 2031 (Euro V = 6.1% of total VKT)	+16%	+20%	+37%
Euro V* emission factors for PM_{10} and NO_x doubled in 2041 (Euro V = 6.9% of total VKT)	+22%	+28%	+48%

* Applied to Euro V diesel HCVs only

** VEPM5.1 estimates that in the current (2013) fleet, Euro V diesel HCVs account for approximately 6% of total VKT. This equates to almost 33% relative growth per year between 2013 and 2021 for Euro V diesel HCVs.

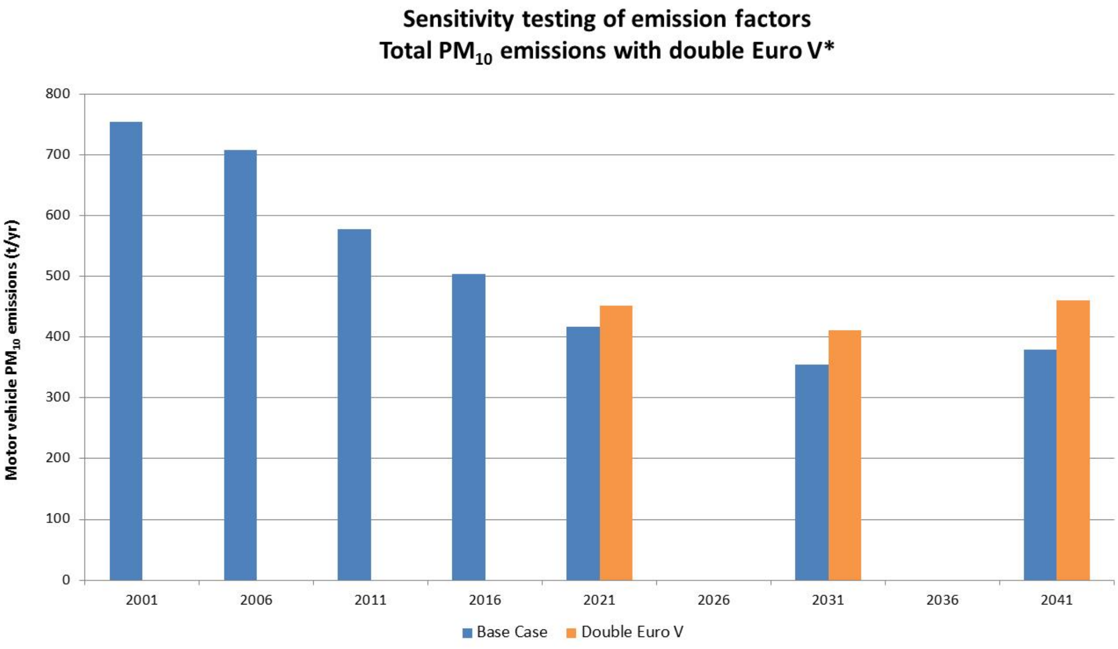

Figure 5-4 Impact of increased Euro V emission factors on projected PM_{10} emissions

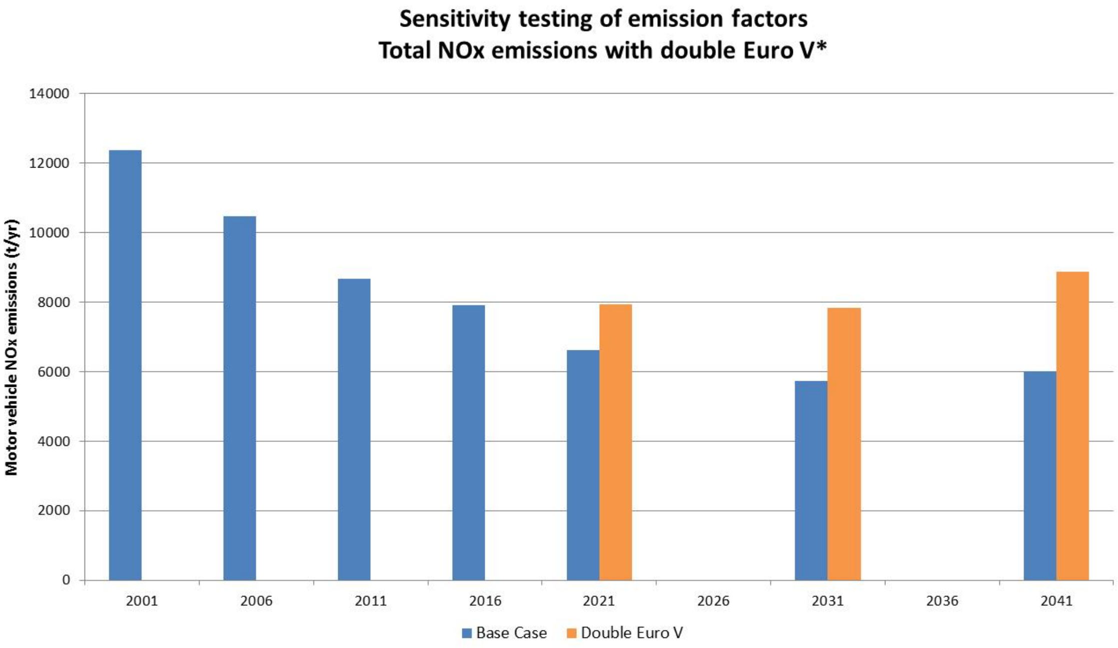

Figure 5-5 Impact of increased Euro V emission factors on projected NO_x emissions

5.3 Summary

Table 5-4 summarises the sensitivity analyses presented here for the key variables. The uncertainties surrounding the accuracy of emission factors for Euro V vehicles are more likely to have a significant impact on motor vehicle emission estimates. Given that hybrid and electric vehicles are only starting to penetrate into Auckland's fleet in 2011, the estimates presented here may not occur until much later. The factors coupled could mean that the results presented in this report are not conservative enough.

Table 5-4 Sensitivity of estimated emissions to key variables

Scenario	Difference with respect to base case			
	PM_{10}	$PM_{2.5}$	NO_x	Fuel consumption
Hybrid fleet penetration (base case 2031/2041)				
1% hybrid and electric in 2031	4%	5%	6%	7%
1% hybrid and electric in 2041	8%	10%	16%	22%
Emission factor accuracy (base case 2021/2031/2041)				
2021	8%	10%	20%	-
2031	16%	20%	37%	-
2041	22%	28%	50%	-

6.0 Conclusions

This report presents emission estimates for 2011 and projected emissions from motor vehicles for 2016, 2021, 2031 and 2041 under a 'business as usual' scenario. Future projections show a continued improvement in fleet emissions with significant reductions expected for all pollutants, despite an expected rise in total vehicle kilometres travelled. The anticipated reductions in particulate emissions arise primarily from expected improvements in diesel vehicle emissions control and an anticipated influx of hybrid and electric vehicles after 2031.

In summary, the overall conclusions are:

- Currently, diesel vehicles are disproportionate polluters for both PM_{10} and NO_x. Projections show that this will change in future years as the light diesel vehicles improve their emissions control. However, diesel heavy commercial vehicles will remain disproportionate polluters (unless there are further developments in emission technology). This is despite the uncertainty around Euro V emission factors, which may underestimate PM_{10} and NO_x emissions by 50 to 200%. This would offset the emission reductions made from other vehicle types and mean that Auckland would still require a further 25% reduction in emissions to meet the targets set in the Auckland Plan by 2040.
- The impact of increased hybrids and electric vehicles in the fleet on projected emissions of PM_{10}, $PM_{2.5}$ and NO_x becomes evident after 2031. The Ministry of Transport predicts that by 2041, hybrids and electrics will comprise 28% of the fleet. This should result in reductions in emissions of PM_{10} and NO_x. However, if these vehicles penetrate the fleet at a slower rate, then the projected reduction in emissions would also be less.
- The impact of brake and tyre wear emissions (which do not change over time) mean that $PM_{2.5}$ emissions reduce more rapidly than PM_{10} (as $PM_{2.5}$ emissions are mainly from vehicle exhausts). In addition, it is likely that emissions due to brake and tyre wear will continue to increase (and become more important) as VKT increases in future.
- Spatial distribution of both PM_{10} and NO_x emissions show that concentrations are higher along the state highway and arterial routes, which are heavily used by diesel HCVs. Spatial analysis shows that there is little change between 2011 and 2041 in the proportion of emissions generated by vehicles travelling along the state highway and arterial routes. This means that sensitive populations will continue to be exposed to elevated concentrations of pollutants.
- Projected emission reductions are heavily dependent on emission standards, especially for diesel vehicles. There is growing international concern that the emission standards for diesel heavy commercial vehicles are not delivering the

expected emissions reductions in real life. The uncertainty around emission factors (especially for Euro V diesel heavy commercial vehicles) means that future emission reductions (particularly for NO_x emissions) may not reduce as much as initially anticipated.

- Projected estimates for PM_{10} and NO_x are slightly sensitive to the assumed proportion of hybrid and electric vehicles. Current fleet projections anticipate a 28% hybrid and electric fleet composition in 2041. If the fleet does not change from existing patterns (i.e. 1% hybrid and electrics) this means projected PM_{10} and NO_x emissions would be higher than predicted in 2041.

Estimated projections indicate that emissions reductions will fall short of the target of 50% (Auckland Council, 2012b) by 2016 by 30% (compared to 2006 emissions). This has important implications for the ability of Auckland Council to comply with the National Environmental Standard for PM_{10}. The spatial distribution of emissions indicates that despite there being regional improvements in emissions, the air quality near state highways and regional arterial routes is not likely to change much, which means that there may be significant impacts for the population exposed to poor air quality near these routes.

7.0 Acknowledgements

We would like to thank Jojo Valero and Shanju Xie at Auckland Council and John Davies at Auckland Transport for their advice and for providing the data relevant for this project. We would also like to thank David Young (David Young Consulting) for his advice and assistance on this project and Iain McGlinchy at Ministry of Transport for supplying national fleet data, statistics and supporting information.

This project was funded by the Auckland Council. Thanks to Janet Petersen (Auckland Council), Iain McGlinchy and Haobo Wang (Ministry of Transport) who provided valuable feedback as peer reviewers.

8.0 References

Auckland Council (2011*). Off-road mobile sources – construction and farm* (Draft). Prepared by S. Xie for Auckland Council. March 2011.

Auckland Council (2012a). *State of Auckland: Air Quality Report Card.* Auckland Council factsheet, July 2012

Auckland Council (2012b), *The Auckland Plan*. Auckland Council, 2012. Available online at: http://theplan.theaucklandplan.govt.nz/.

Auckland Council (2012c), *Trends in Light Duty Vehicle Emissions 2003 to 2011*. Prepared for Auckland Council by NIWA and Emission Impossible Ltd, Auckland Council technical report, TR2012/032

Auckland Council (2013), *Auckland Air Emissions Inventory 2006*. Prepared by S. Xie (Auckland Council), S. Sridhar and J. Metcalfe (Emission Impossible Ltd). Auckland Council technical report, TR2014/015

Auckland Council (2014), *Auckland Motor Vehicle Emissions Inventory*. Prepared by Emission Impossible Ltd for Auckland Council, Auckland Council technical report TR2014/029

Auckland Regional Council (2006).*Auckland Air Emissions Inventory: 2004*. Prepared by J. Metcalfe, G. Fisher, M. Sherman, and G. Kuschel for the Auckland Regional Council, technical publication TP292, February 2006

Auckland Regional Council (2010). *State of the Auckland Region, 2009*. Auckland Council. Available at: http://www.arc.govt.nz/plans/reports/state-of-the-auckland-region-report-2010_home.cfm

Auckland Regional Transport Authority (2009). *Regional Arterial Road Plan*. Auckland Regional Transport Authority, February 2009.

Carslaw, D.; Beevers, S.; Westmoreland, E.; Williams, M.; Tate, J. *et al*. (2011).*Trends in NOx and NO2 emissions and ambient measurements in the UK*. Prepared for Department of Environment, Food and Rural Affairs, March 2011. Available online at: http://www.accent-network.org/accent_documents/Draft_NOx_NO2_trends_report.pdf

GNS (2011). *Source apportionment of airborne particles in the Auckland region: 2010 Analysis*. Prepared by P. Davy, B. Trompetter and A. Markwitz for Auckland Council. GNS Science Consultancy Report 2010/262. November 2011

Goodwin, P. (2012). *Peak Travel, Peak Car and the Future of Mobility: Evidence, Unresolved Issues, Policy Implications, and a Research Agenda*. Discussion Paper No. 2012-12 prepared for the Roundtable on Long-Run Trends in Travel Demand of the International Transport Forum (29-30 November 2012). London, UK.

Jones, K.; Graham, M.; Elder, S. and Raine, R. (2011a).*Vehicle Emission Prediction Model Version 5.0 Development and User Information Report*. Prepared by the Energy and Fuels Research Unit, University of Auckland for the New Zealand Transport Agency and Auckland Council. Nov 2011.

Jones, K.; Elder, S.; Raine, R. and Graham, M. (2011b).*Vehicle Emission Prediction Model Update: COPERT IV Review*. Prepared by the Energy and Fuels Research Unit, UniServices, University of Auckland for the New Zealand Transport Agency and Auckland Council. February 2011.

Kar, K.; Baral, B. and Elder, S. (2008). *Development of a Vehicle Emission Prediction Model*. Prepared by the Energy and Fuels Research Unit, University of Auckland for the Auckland Regional Council. December.

Kuschel, G.; Metcalfe, J.; Wilton, E.; Guira, J.; Hales, *et al*. (2012). *Updated Health and Air Pollution in New Zealand Study*, Reports and supporting models prepared for Health Research Council of New Zealand, Ministry of Transport, Ministry for the Environment and New Zealand Transport Agency, March 2012

Ministry for Economic Development (2010). *Delivering the Diesel – Liquid Fuel Deliveries in New Zealand 1990 – 2008*. Ministry for Economic Development February 2010. Available at: http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/technical-papers/delivering-the-diesel.pdf

Ministry of Economic Development (2012). *New Zealand Energy Data File*. Prepared by the Ministry for Economic Development 2012. Available at: http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/publications/energy-data-file/energydatafile-2011.pdf

Ministry of Transport (2008). *Vehicle Fleet Emissions Model database*. Ministry of Transport.

Ministry of Transport (2011).*Transport Monitoring Indicator Framework*. Available at: http://www.transport.govt.nz/ourwork/TMIF/Pages/TV001.aspx

Ministry of Transport (2012). *Regulatory Impact Statement. 2012 Amendment to the Land Transport Rule: Vehicle Exhaust Emissions 2007*. Prepared by Ministry of Transport.

Ministry of Transport (2013). *The New Zealand 2012 Vehicle Fleet: Data Spreadsheet Version 2.0, Aug 2013*. Ministry of Transport

NZTA (2011). *Are the harmful emissions from New Zealand's light duty vehicle fleet improving?* Prepared by J. Bluett (NIWA), G. Kuschel (Emission Impossible Ltd), M. Rijkenberg and K. Shrestha (NIWA) for NZ Transport Agency, NZTA research report 441. 94pp

NZTA (2012) *Vehicle Emissions Prediction Model (VEPM 5.1) Users Guide (Draft Version 0.2)*. Prepared by the Energy and Fuels Research Unit, UniServices, University of Auckland and Emission Impossible Ltd for NZTA. Draft April 2013

OECD (2014). *The Cost of Air Pollution: Health Impacts of Road Transport*. OECD Publishing.

OMS (2008). *Liquid Fuels Use in New Zealand*. Prepared by Outcome Management Services for Ministry of Economic Development. November 2008. Available online at:http://www.med.govt.nz/sectors-industries/energy/energy-modelling/technical-papers/liquid-fuels-use-in-new-zealand

Peeters, S. (2010). *Port-Related Air Emissions for the Auckland Region 2006 and 2010*. Report prepared by M&P Consulting Limited for Auckland Regional Council, September.

Vidal, J. (2013). London told to cut air pollution by 2020 - or face fines, *The Guardian*, 18 December 2013. Available at: http://www.theguardian.com/environment/2013/dec/18/london-air-pollution-2020-vehicles

Wickham, L. (2012).*Separation distances for roads – a discussion document.* Prepared for Auckland Council by Emission Impossible Ltd, May 2012.

9.0 Glossary

Term	Definition
AC	Auckland Council formed on 1 November 2010
ARC	Auckland Regional Council which merged with four city councils and three district councils in the Auckland region to form the Auckland Council on 1 November 2010.
ART	Auckland Regional Transport model
CO	Carbon monoxide
CO_2	Carbon dioxide
COPERT	COmputer Programme to calculate Emissions from Road Transport, the technical development of which is managed by the European Environment Agency
Euro	European vehicle emission standards, the stages of which are referred to with Roman numerals (e.g. Euro V, Euro VI) for heavy duty vehicle standards, and Arabic numerals (e.g. Euro 5, Euro 6) for light duty vehicle standards.
HCV	Heavy commercial vehicles
LCV	Light commercial vehicles
Link	Spatial representation of actual road segments in the Auckland Regional Transport model
MED	Ministry for Economic Development, which merged with three other ministries to form the Ministry of Business, Innovation and Employment on 1 July 2012.
MfE	Ministry for the Environment
MoT	Ministry of Transport
NESAQ	National environmental standards for air quality developed in 2004.
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NZTA	New Zealand Transport Agency formed on 1 August 2008 from merging Transit New Zealand and Land Transport New Zealand.
PM_{10}	Particulate matter measuring less than 10 micrometres in size.
$PM_{2.5}$	Particulate matter measuring less than 2.5 micrometres in size.
SO_2	Sulphur dioxide
VEPM	Vehicle Emissions Prediction Model
VFEM	Vehicle Fleet Emissions Model
VKT	Vehicle kilometres travelled
VOCs	Volatile organic compounds

Appendix A Tabulated results for 2001 to 2041

Projected motor vehicle inventory results for the Auckland region are shown in Table A-1 (2001), Table A-2 (2006), Table A-3 (2011), Table A-4 (2016), Table A-5 (2021), Table A-6 (2031) and Table A-7 (2041), using VEPM5.1.

Table A-1 Motor vehicle emissions estimates for the Auckland region in 2001

2001 daily estimates											
Vehicle type	Fuel type	VKT	% total VKT	CO	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	Fuel consumption	CO_2
		Million kms/day	%	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day	t/day
Car	Petrol	20.3	73.8%	218,862	17,542	1,523	13,499	322	232	2,051,018	4,433
Light commercial	Petrol	1.6	6.0%	23,033	2,137	149	2,988	26	19	200,181	427
Hybrid and electric*	Petrol	0.0	0.0%	0	0	0	0	0	0	0	0
Car	Diesel	2.0	7.1%	1,135	1,571	862	220	535	526	171,822	451
Light commercial	Diesel	2.2	7.8%	2,286	2,779	1,161	185	446	436	231,536	608
Bus	Diesel	0.1	0.4%	224	577	109	43	45	45	21,772	57
Heavy	Diesel	1.3	4.9%	2,961	9,300	1,786	825	694	686	356,000	937
Daily total		27.5	100%	248,501	33,907	5,590	17,761	2,067	1,944	3,032,330	6,913
2001 annual estimates											
		Million kms/yr	% total VKT	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr	kt/yr
Total		10,046		90,735	12,376	2,040	6,483	755	709	1,107	2,523
Total petrol		8,013	79.8	88,291	7,183	610	6,018	127	92	822	1,774
Total diesel		2,034	20.2	2,411	5,193	1,430	465	628	618	285	749

* There were no hybrids or electric cars in the fleet in 2001

Table A-2 Motor vehicle emissions estimates for the Auckland region in 2006

2006 daily estimates											
Vehicle type	Fuel type	VKT	% total VKT	CO	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	Fuel consumption	CO_2
		Million kms/day	%	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day	t/day
Car	Petrol	22.9	72.3	180,676	12,831	516	9,737	343	242	2,316,023	5,071
Light commercial	Petrol	1.4	4.3	16,079	1,080	37	1,424	20	14	164,336	355
Hybrid and electric	Petrol	0.0	0.1	0.9	0.3	0.1	0	0.2	0.1	974	2.2
Car	Diesel	2.6	8.2	1,180	2,057	20	240	568	556	235,594	619
Light commercial	Diesel	3.1	9.9	2,584	3,245	28	190	481	467	331,500	872
Bus	Diesel	0.1	0.4	256	662	2	46	36	36	28,255	74
Heavy	Diesel	1.5	4.8	2,715	8,789	33	683	491	482	397,074	1,047
Daily total		31.6	100%	203,491	28,664	636	12,320	1,939	1,797	3,473,757	8,041
2006 annual estimates											
		VKT (million kms/yr)	% total VKT	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr	kt/yr
Total		11,548		74,274	10,462	232	4,497	708	656	1,268	2,935
Total petrol		8,849	76.6	71,816	5,078	202	4,074	133	94	905	1,981
Total diesel		2,699	23.4	2,458	5,385	30	423	575	562	362	954

Table A-3 Motor vehicle emissions estimates for the Auckland region in 2011

2011 daily estimates											
Vehicle type	Fuel type	VKT	% total VKT	CO	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	Fuel consumption	CO_2
		Million kms/day	%	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day	t/day
Car	Petrol	22.5	70.8	127,119	9,975	165	6,952	336	237	2,217,510	4,902
Light commercial	Petrol	1.1	3.6	11,113	714	10	733	15	10	137,095	298
Hybrid and Electric	Petrol	0.1	0.3	3.3	1.1	0.1	0.1	0.8	0.5	3,869	8.9
Car	Diesel	2.4	7.6	854	1,670	3	181	389	378	204,896	539
Light commercial	Diesel	3.7	11.6	2,194	3,065	6	202	445	429	379,871	1,000
Bus	Diesel	0.2	0.6	267	770	1	45	39	37	37,819	101
Heavy	Diesel	1.8	5.5	1,835	7,573	7	417	358	347	430,419	1,151
Daily total		31.8	100%	143,385	23,768	193	8,530	1,583	1,440	3,411,478	8,000
2011 annual estimates											
		VKT (million kms/yr)	% total VKT	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr	kt/yr
Total		11,614		52,335	8,675	70	3,114	578	525	1,245	2,920
Total petrol		8,678	74.4	50,455	3,902	64	2,805	129	90	859	1,902
Total diesel		2,936	25.3	1,879	4,774	6	308	449	435	384	1,019

Table A-4 Motor vehicle emissions estimates for the Auckland region in 2016

2016 daily estimates											
Vehicle type	Fuel type	VKT	% total VKT	CO	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	Fuel consumption	CO_2
		Million kms/day	%	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day	t/day
Car	Petrol	25.2	68.4	105,502	8,478	35	5,978	373	262	2,361,188	5,265
Light commercial	Petrol	1.0	2.7	8,217	443	2	427	13	8	119,454	262
Hybrid and electric	Petrol	0.4	1.2	16	5.1	0.1	0.3	4.3	2.3	18,448	42
Car	Diesel	3.1	8.4	635	1,606	4	150	264	250	228,490	602
Light commercial	Diesel	4.9	13.3	2,044	3,425	8	266	380	359	489,731	1,291
Bus	Diesel	0.2	0.6	209	690	1	36	34	33	41,549	111
Heavy	Diesel	2.0	5.5	1,388	7,021	8	314	314	301	487,877	1,306
Daily total		36.8	100%	118,013	21,668	58	7,171	1,382	1,216	3,746,737	8,879
2016 annual estimates											
		VKT (million kms/yr)	% total VKT	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr	kt/yr
Total		13,436		43,075	7,909	21	2,618	504	444	1,368	3,241
Total petrol		9,716	72.3	41,513	3,258	13	2,338	142	100	912	2,033
Total diesel		3,720	27.7	1,561	4,651	8	279	362	344	455	1,208

Table A-5 Motor vehicle emissions estimates for the Auckland region in 2021

2021 daily estimates											
Vehicle type	Fuel type	VKT	% total VKT	CO	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	Fuel consumption	CO_2
		Million kms/day	%	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day	t/day
Car	Petrol	25.3	62.5	76,109	6,129	16.8	4,406	372	260	2,247,836	5,051
Light commercial	Petrol	0.8	2.1	5,756	263	0.7	261	10	6	99,390	220
Hybrid and electric	Petrol	1.3	3.2	38.9	11.8	0.4	0.8	12.5	6.8	43,060	98.7
Car	Diesel	4.8	11.9	560	1,644	2.5	163	191	170	301,033	794
Light commercial	Diesel	5.7	14.1	1,649	2,724	4.7	299	244	219	560,382	1,478
Bus	Diesel	0.2	0.6	151	601	0.4	26	28	27	44,298	119
Heavy	Diesel	2.3	5.6	1,033	6,742	4.6	233	286	272	550,498	1,475
Daily total		40.5	100%	85,297	18,116	29.7	5,389	1,144	961	3,846,497	9,234
2021 annual estimates											
		VKT (million kms/yr)	% total VKT	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr	kt/yr
Total		14,765		31,134	6,612	10.9	1,967	418	351	1,404	3,370
Total petrol		10,020	67.9	29,895	2,337	6.4	1,704	144	100	872	1,960
Total diesel		4,745	32.1	1,239	4,275	4.4	263	274	251	532	1,411

Table A-6 Motor vehicle emissions estimates for the Auckland region in 2031

2031 daily estimates											
Vehicle type	Fuel type	VKT	% total VKT	CO	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	Fuel consumption	CO_2
		Million kms/day	%	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day	t/day
Car	Petrol	20.8	44.6	44,238	3,711	12.7	2,850	312	220	1,707,866	3,862
Light commercial	Petrol	0.6	1.3	3,397	132	0.5	127	7	4	69,307	154
Hybrid and electric	Petrol	5.8	12.3	105	28.4	0.2	2.0	55.5	30.1	106,913	245.1
Car	Diesel	10.5	22.4	954	2,218	4.7	325	199	153	563,532	1,487
Light commercial	Diesel	6.0	12.9	1,477	1,651	4.9	342	89	61	589,389	1,555
Bus	Diesel	0.3	0.6	104	554	0.4	18	24	23	50,072	134
Heavy	Diesel	2.8	6.0	774	7,370	5.7	165	287	270	685,087	1,836
Daily total		46.7	100%	9,273	15,664	29.2	3,828	973	881	3,772,167	9,273
2031 annual estimates											
		VKT (million kms/yr)	% total VKT	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr	kt/yr
Total		17,060		18,633	5,717	10.6	1,397	355	278	1,377	3,385
Total petrol		9,921	58.2	17,425	1,413	4.9	1,087	136	93	688	1,555
Total diesel		7,138	41.8	1,208	4,304	5.8	310	219	185	689	1,829

Table A-7 Motor vehicle emissions estimates for the Auckland region in 2041

2041 daily estimates											
Vehicle type	Fuel type	VKT	% total VKT	CO	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	Fuel consumption	CO_2
		Million kms/day	%	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day	t/day
Car	Petrol	15.8	29.9	33,882	2,763	9.6	2,441	241	171	1,296,714	2,934
Light commercial	Petrol	0.4	0.7	2,405	89	0.3	88	4	3	46,392	103
Hybrid and electric	Petrol	14.7	27.8	188.4	40.2	0.2	3.3	142	77.0	162,213	371.9
Car	Diesel	13	24.7	1,329	2,558	5.8	431	200	143	688,697	1,817
Light commercial	Diesel	5.2	9.9	1,414	1,244	4.3	333	69	46	520,286	1,372
Bus	Diesel	0.3	0.6	110	620	0.5	19	28	26	58,944	158
Heavy	Diesel	3.4	6.5	858	9,121	7.4	181	355	333	879,893	2,359
Daily total		52.9	100%	40,185	16,435	28.1	3,496	1,038	798	3,653,140	9,115
2041 annual estimates											
		VKT (million kms/yr)	% total VKT	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr	kt/yr
Total		19,310		14,668	5,999	10.3	1,276	379	291	1,333	3,327
Total petrol		11,276	58.4	13,313	1,056	3.7	924	141	92	549	1,244
Total diesel		8,035	41.6	1,354	4,933	6.6	352	238	200	784	2,083

Appendix B Spatial distribution

The spatial distribution of PM_{10} motor vehicle emissions across the Auckland region were mapped for 2011 (Figure B-1) and two projected years of 2016 (Figure B-2) and 2041 (Figure B-3).

The spatial distribution of NO_x emissions from motor vehicles across the Auckland region were mapped for 2011 (Figure B-4), 2016 (Figure B-5) and 2041 (Figure B-6).

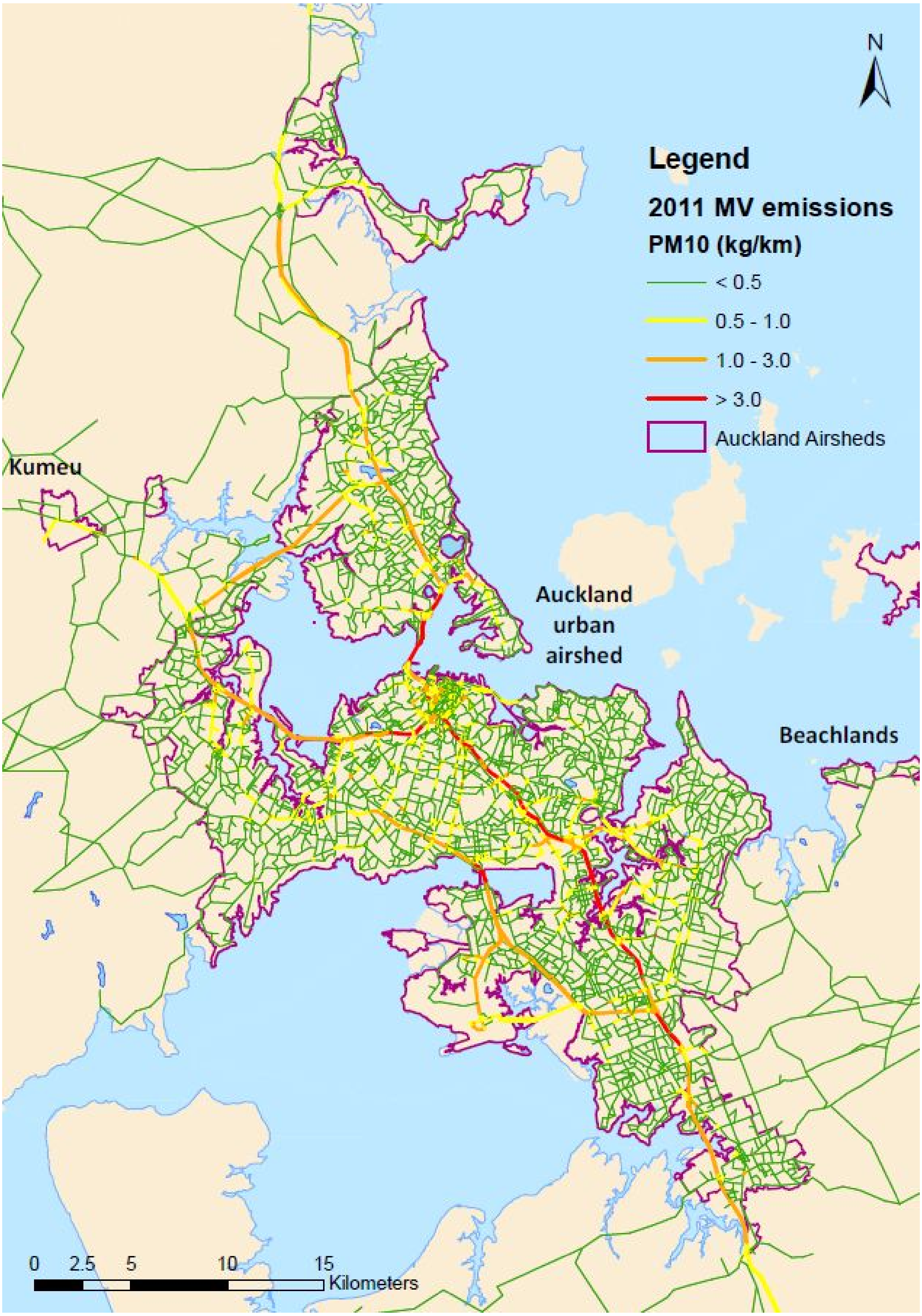

Figure B-1 Spatial distribution of daily PM_{10} emissions (kg/km) for 2011

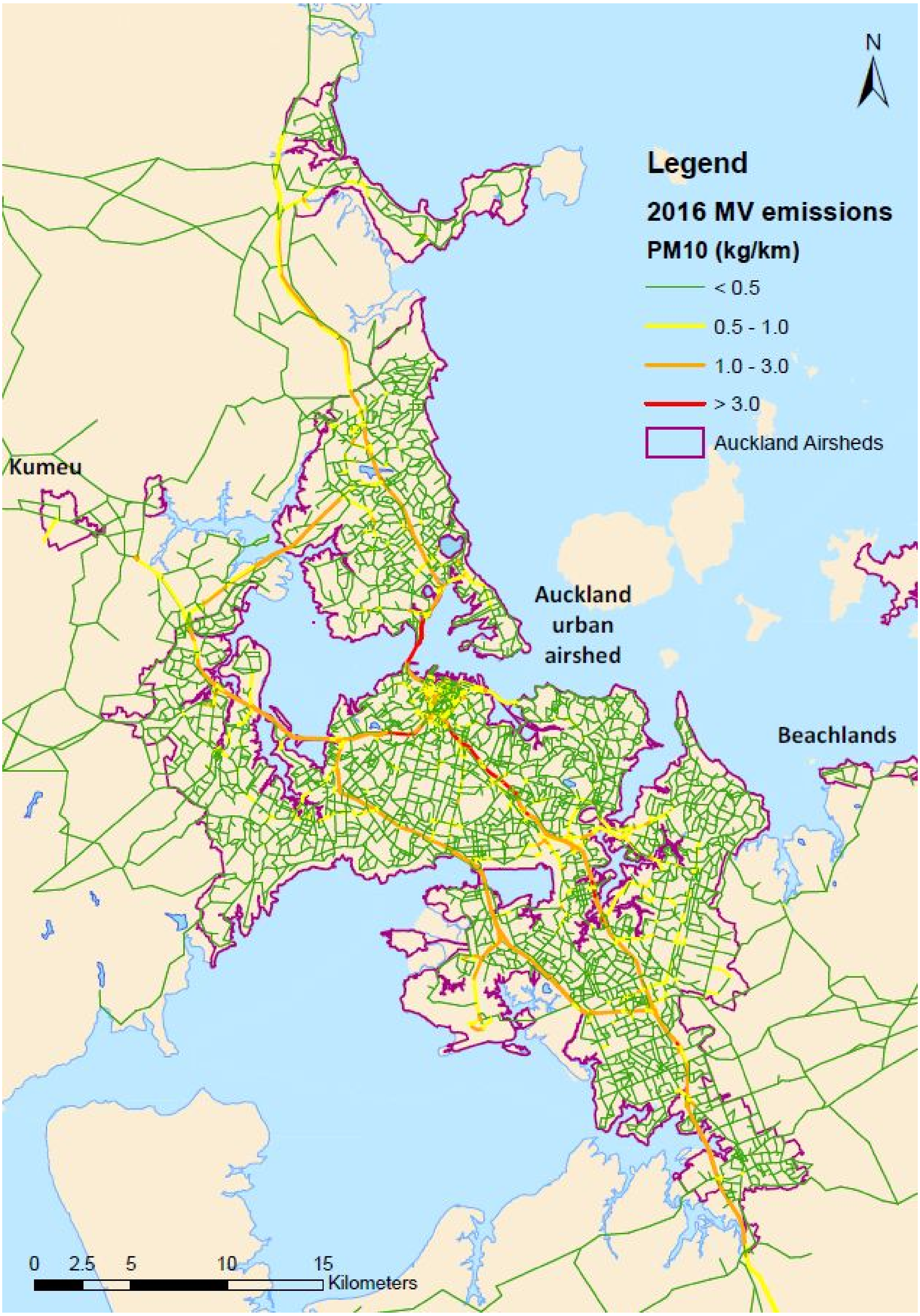

Figure B-2 Spatial distribution of daily PM_{10} emissions (kg/km) for 2016

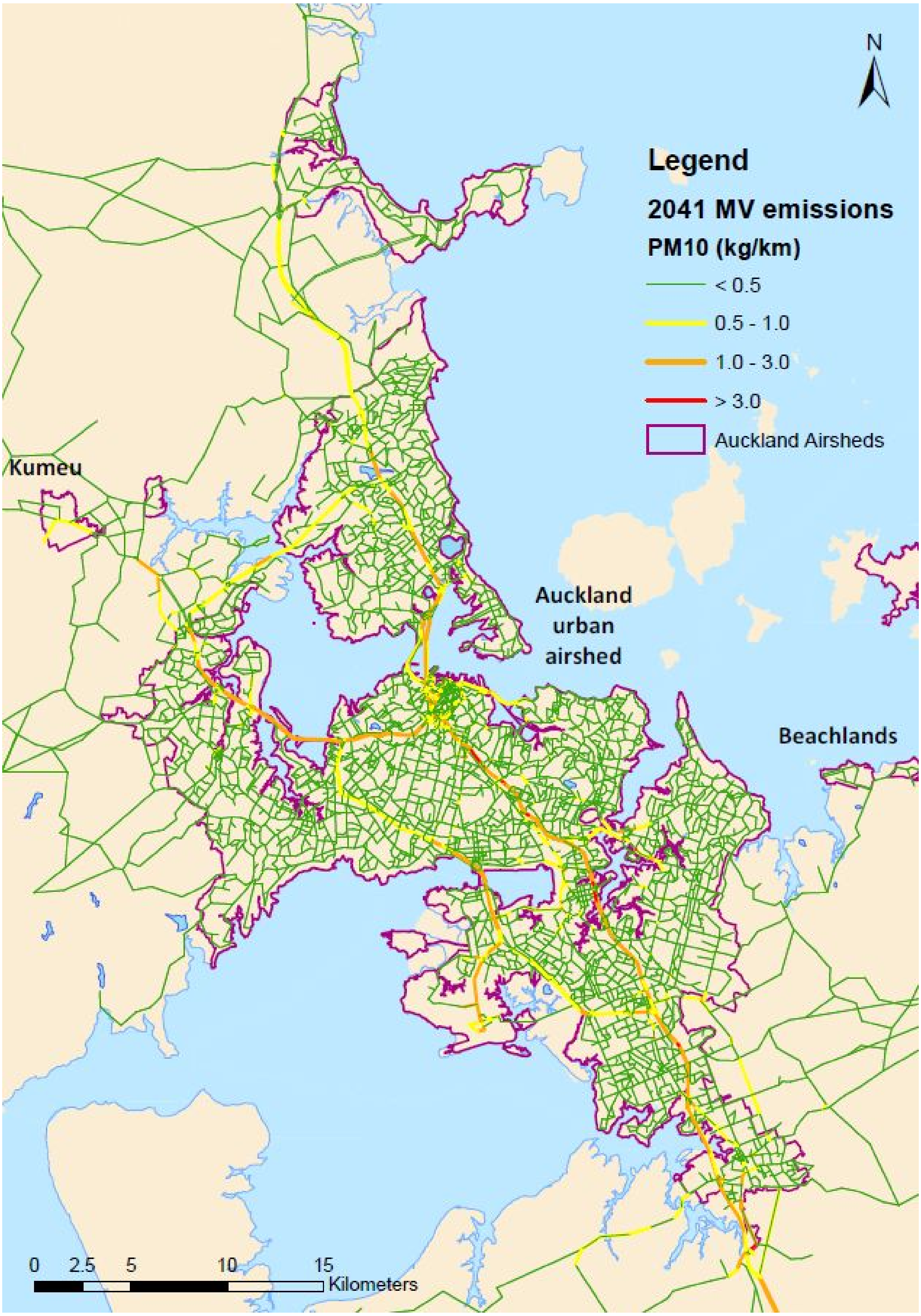

Figure B-3 Spatial distribution of daily PM_{10} emissions (kg/km) for 2041

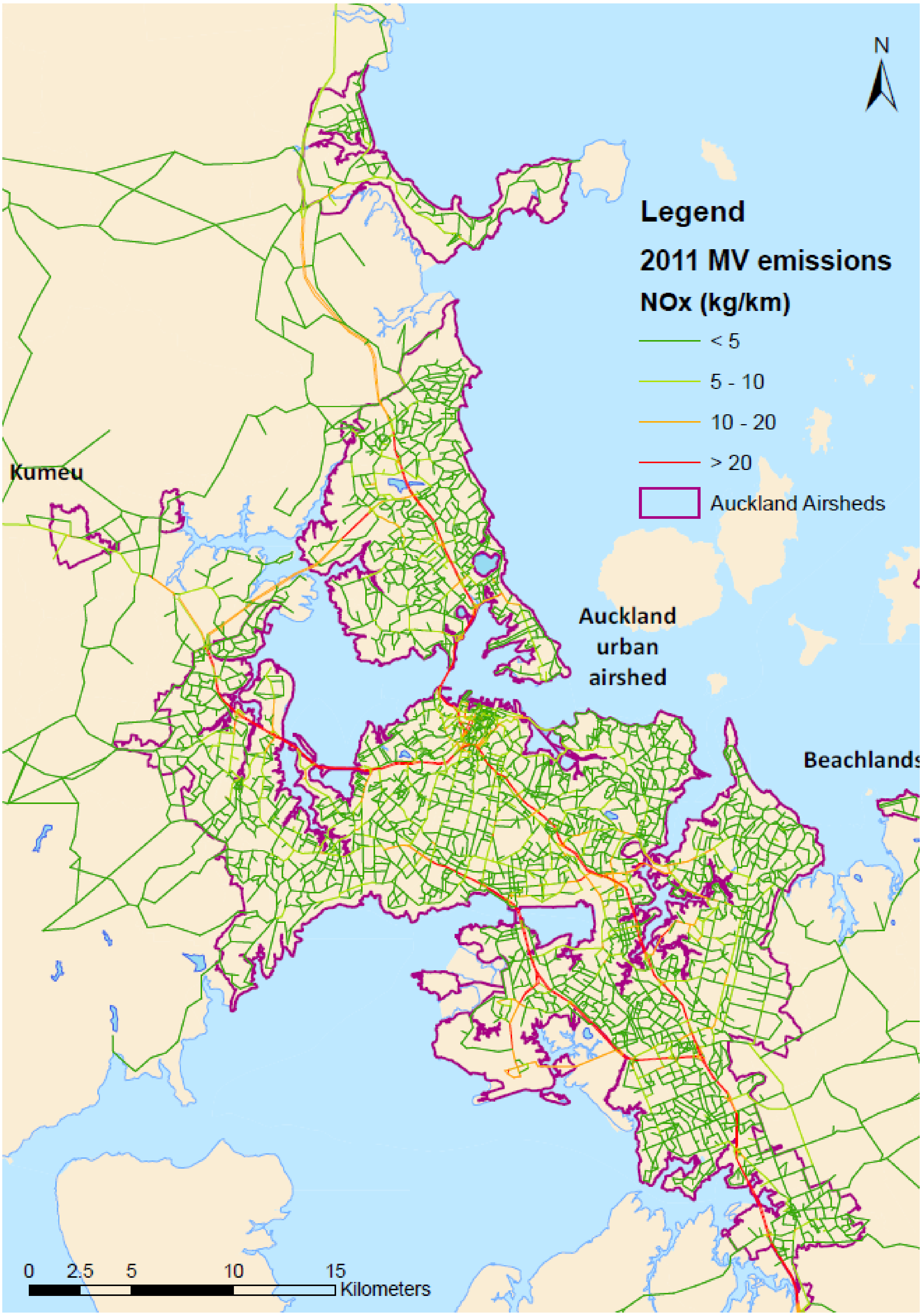

Figure B-4 Spatial distribution of daily NO_x emissions (kg/km) for 2011

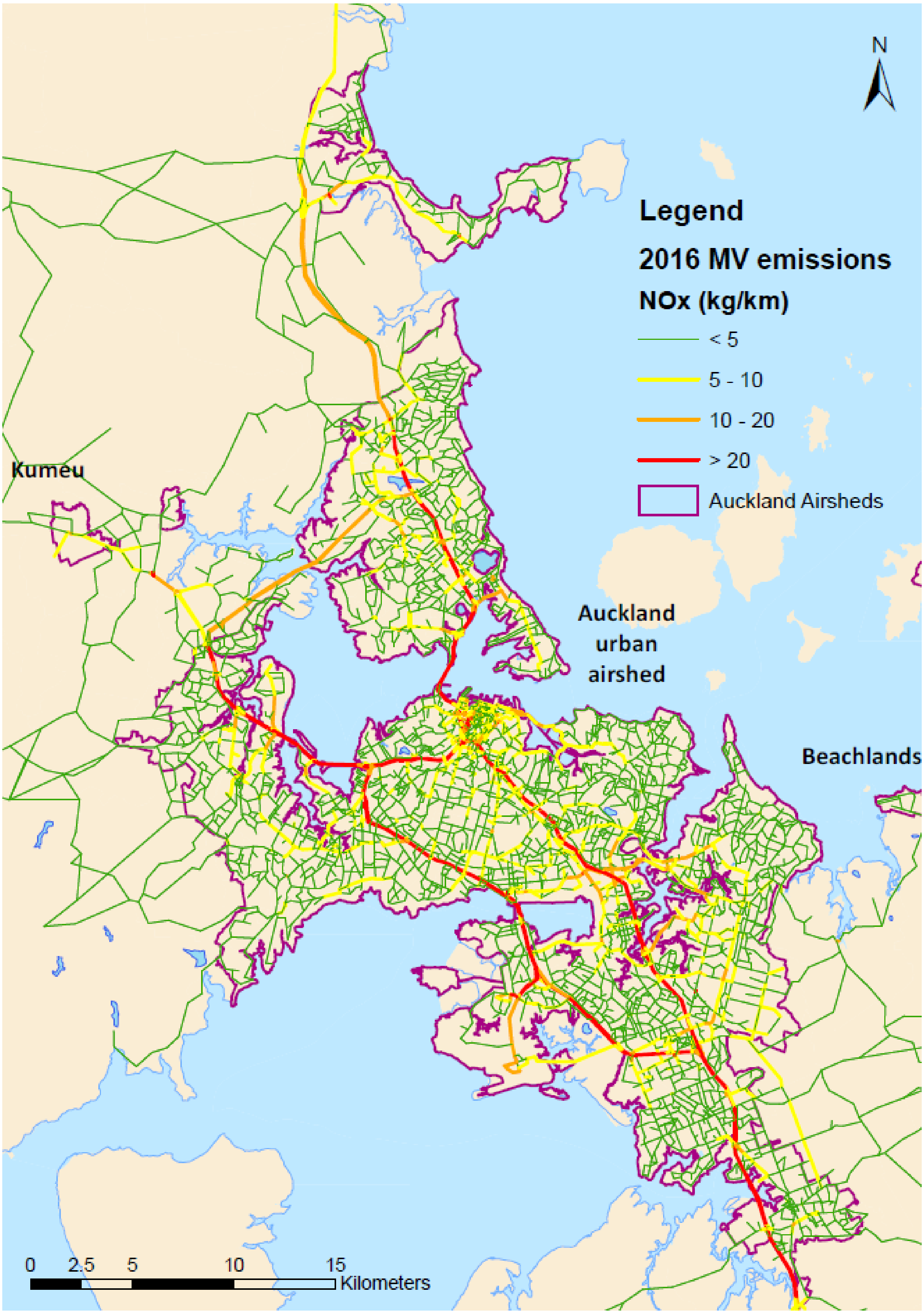

Figure B-5 Spatial distribution of daily NO_x emissions (kg/km) for 2016

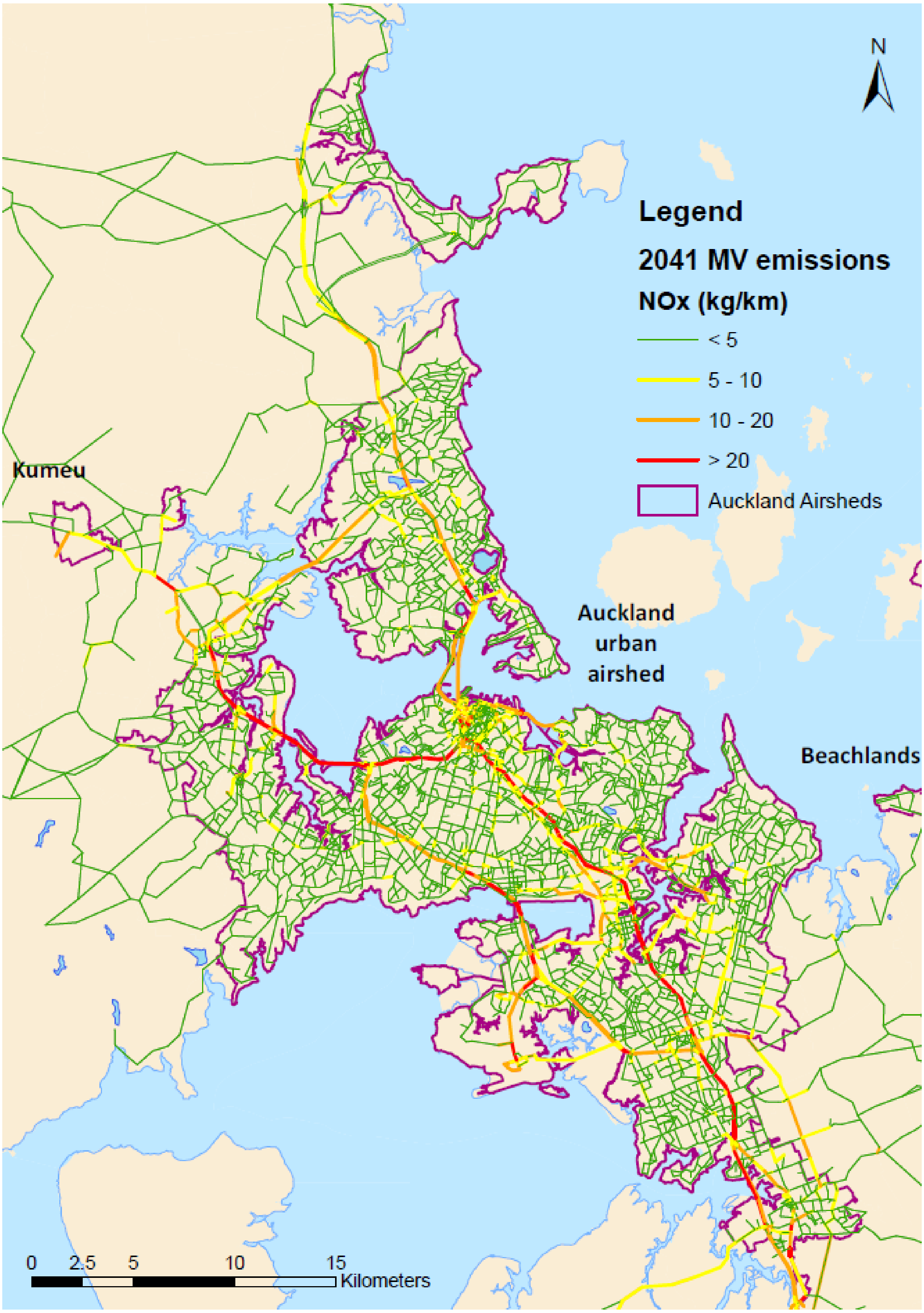

Figure B-6 Spatial distribution of daily NO_x emissions (kg/km) for 2041