Auckland Air Emissions Inventory 2006

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Notes:
1. This update of the air emissions inventory includes 2011 information.
2. This report was prepared as an evidence base for Auckland Plan and Proposed Auckland Unitary Plan reporting.

Auckland Air Emissions Inventory 2006

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Executive Summary

An air emissions inventory provides information about the amount of pollutants discharged into air from various pollution sources, mainly home heating, motor vehicles and industry, and their trends. It is used to determine major sources of air pollutants, establish emission trends over time, support air quality policy development and provide input for air dispersion modeling. This report estimates the emissions to air in the Auckland region from four major sectors (transport, domestic, industry and biogenic) with emphasis on emissions of five key ambient air pollutants (PM_{10}, $PM_{2.5}$, NOx, CO, VOCs) for the base year 2006. The emissions are also projected for year 2011. Emissions are broken down:

- sectorally (for the four major categories: transport, domestic, industry and biogenic)
- spatially (for the entire region versus the urban area only), and
- seasonally (for a typical winter's day versus a typical summer's day).

An Auckland air emissions inventory was first prepared in 1993. An upgrade of the emissions inventory was undertaken for 1998. Emissions were recalculated for 2004 and the results were published in 2006. This report updates the 2004 inventory to produce air emissions estimates for 2006. The year 2006 was chosen as it is a census year which means that the data used for emission calculations (such as census population data) are more reliable and up to date.

Emissions are estimated for fine particles (PM_{10} and $PM_{2.5}$), oxides of nitrogen (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), sulphur dioxide (SO_2) and carbon dioxide (CO_2). This report focuses primarily on PM_{10} because ambient concentrations measured in Auckland have exceeded the National Environmental Standard (NES) of 24 hour average concentration of 50 µg m^{-3} at both peak traffic and urban monitoring sites. PM_{10} has been considered a surrogate for health impacts from all air pollutants in New Zealand.

Breakdown of emissions by sector

The annual estimates of the total emissions across the entire Auckland region in 2006 of the seven contaminants are approximately:

- 3,170 t/yr PM_{10} (38 per cent transport, 47 per cent domestic, 15 per cent industry)
- 3,000 t/yr $PM_{2.5}$ (39 per cent transport, 50 per cent domestic, 11 per cent industry)
- 20,800 t/yr NOx (79 per cent transport, 16 per cent industry, 4 per cent biogenic)
- 113,000 t/yr CO (86 per cent transport, 12 per cent domestic, 2 per cent industry)

- 32,700 t/yr VOC (22 per cent transport, 40 per cent industry, 24 per cent biogenic, 14 per cent domestic)
- 2,800 t/yr SO_2 (52 per cent transport, 47 per cent industry, 1 per cent domestic)
- 8,170 kt/yr CO_2 (42 per cent transport, 52 per cent industry, 6 per cent domestic)

Breakdown of emissions by location

The emissions are mainly from the urban area, which represents less than 25 per cent of the total regional land area, contributing to the majority (73 per cent, or 2,300 t/yr) of the total regional PM_{10} emissions.

Breakdown of emissions by season

Seasonal variations in emissions are significant, both in terms of the amount as well as the relative contributions of sources, particularly for PM_{10} as follows:

- PM_{10} emissions on a typical winter weekday (18.8 t/day) are nearly four times those of a typical summer weekday (4.8 t/day).
- Domestic sources (principally home heating) account for 75 per cent of PM_{10} emissions on a typical winter weekday (June-August) but fall to five per cent of PM_{10} emissions on a summer weekday (December-February).
- Transport sources (principally motor vehicles) account for 18 per cent of PM_{10} emissions on a typical winter weekday (June-August) but rise to 69 per cent of PM_{10} emissions on a summer weekday (December-February) because emissions from domestic sources have decreased.

Trends

Emissions have been estimated for 2001, 2006 and 2011 to indicate trends:

- CO emissions have fallen and are predicted to continue to fall in future, mainly due to increasing numbers of vehicles in the fleet with improved vehicle technology and emission control equipment.
- CO_2 emissions have risen and are predicted to continue to rise in future, mainly due to increased fuel consumption resulting from increased numbers of vehicles in the region and increased vehicle kilometres travelled.
- NOx emissions have decreased slightly despite an increase in vehicle kilometres travelled, but this can be attributed to the improved vehicle control technology.
- SO_2 emissions have reduced slightly, mainly due to reduced sulphur levels in road transport fuel.

- PM_{10}, $PM_{2.5}$ and VOC emissions have fallen slightly, mainly due to a shift away from coal and wood for both domestic heating and industrial use, and are predicted to fall in future with fuel and technology improvements.

Further work

There are other potentially significant sources of PM_{10} that are not estimated by the current inventory, including secondary particulates, sea salt, and wind blown or re-suspended dust. In order to refine estimates of contributions from these sources, studies on source apportionment, detailed analysis of ambient monitoring, meteorological monitoring and atmospheric modelling studies need to be continued. In addition, work is necessary to validate assumptions in the existing inventory and confirm key trends.

Key conclusions

Domestic and transport sectors contribute to 47 and 38 per cent of annual PM_{10} emissions, respectively. Their contributions to annual $PM_{2.5}$ emissions account for 50 and 39 per cent, respectively. For NOx emissions, the principal source is the transport sector. Consequently, emissions management strategies that target these sources will have the greatest impact on improving air quality in Auckland.

1 Introduction

An air emissions inventory provides information about the amount of pollutants discharged into air from various pollution sources, mainly home heating, motor vehicles and industry, and their trends. It is used to determine major sources of air pollutants, establish emission trends over time, support air quality policy development and provide input for air dispersion modeling.

This report estimates the emissions to air in the Auckland region from four major sectors (transport, domestic, industry and biogenic) with emphasis on emissions of five key ambient air pollutants (PM_{10}, $PM_{2.5}$, NOx, CO, VOCs) for the base year 2006. The emissions are also projected for year 2011. The year 2006 was chosen as it is a census year which means that the data used for emission calculations (such as census population data) are more reliable.

The inventory estimates emissions for the entire Auckland region shown in Figure 1.1, and for the urban area (Auckland urban airshed). Emissions are estimated on an annual and daily (seasonal) basis. Seasonal emissions are estimated for typical summer (December-February), autumn (March-May), winter (June-August) and spring (September-November) days. Unless stated otherwise, all reported results are for the entire region.

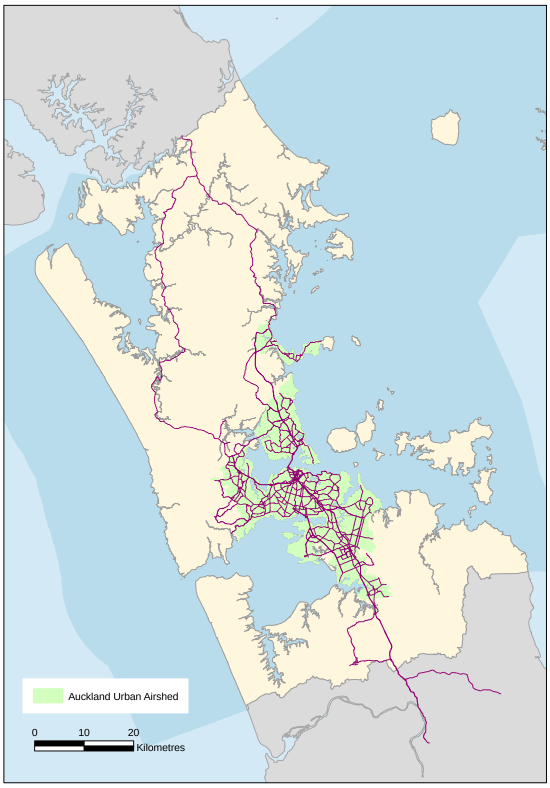


Figure 1.1 Auckland Council area and Auckland urban airshed.

1.1 Background

An Auckland air emissions inventory was first prepared in 1993 (ARC 1997). An upgrade commenced in 1998, which focused on improving estimates of the most significant pollution sources identified in the 1993 inventory (EPAV 2005). An update conducted in 2004 (referred to as "the 2004 inventory") is based on the same methodology as the 1998 inventory, with a number of improvements (ARC 2006).

This update (referred to as "the 2006 inventory") incorporates the results of substantial improvements on air emissions estimates for Auckland since 2006, including:

- A domestic fire emission prediction model (DFEPM) has been developed for home heating emissions estimates (ARC 2010c). The model is based on the results of a comprehensive home heating survey undertaken by the Auckland Regional Council in 2007 (ARC 2010b).

- A study has been undertaken to calculate motor vehicle emissions by using emission factors from the vehicle emission prediction model (VEPM) version 4.1 and outputs from the Auckland regional transport model version 3 (ART3) (AC 2011b).
- In 2010, a detailed study of air emissions from port related activities was commissioned by the Auckland Regional Council. The study included estimates of emissions from ships, port vessels (tug and pilot boats), ferry boats and commercial fishing boats as well as emissions from land based activities such as cargo handling equipment and dredging operations (Peeters 2010).
- In 2008, a new industrial inventory was compiled by reviewing the council's consent record files for each consented site. Emissions have been estimated based primarily on values taken from stack emission testing, assessment of environmental effects (AEEs), USEPA emission factors and the consent limits (URS 2009). Significant work has subsequently been carried out since then to improve the industrial inventory estimates for 2006 and 2011 emissions.
- An air emission inventory toolkit was developed and emission estimates from some sources (e.g., aircraft, railway locomotives) were also updated (SKM 2009, ARC 2010f). Emissions of off-road mobile vehicles were estimated with recent data (AC, 2011a).
- The geographic information system (GIS) has been incorporated into the current inventory update.

Overall, the 2006 inventory represents a significant improvement in air emissions estimates for Auckland. Changes to sources that have not been updated in this inventory will be incorporated in future updates.

1.2 Pollutants

This inventory estimates air emissions of particles (PM_{10} and $PM_{2.5}$), oxides of nitrogen (NOx), volatile organic compounds (VOC), sulphur dioxide (SO_2), carbon monoxide (CO) and carbon dioxide (CO_2). The significance of these pollutants in the Auckland region is briefly described in Table 1.1. Further information on ambient air pollutants can be found in the State of the Auckland Region Report 2009 (ARC 2010a).

Table 1.1 Key air pollutants in Auckland

Pollutant	Significance for Auckland
Particles (PM_{10}, $PM_{2.5}$)	PM_{10} and $PM_{2.5}$ are tiny solid and liquid particles in the air. PM_{10} are particles less than 10 microns in size and $PM_{2.5}$ are particles less than 2.5 microns in size. These particles can affect health, especially in asthmatics and people with heart and lung disease. Particles can carry carcinogenic (i.e., cancer producing) material into the lungs. Fine particles can increase hospital admissions and emergency department visits, school absences, lost work days and restricted activity days. Studies show a correlation between levels of fine particles and the number of people who die each year (the mortality rate). The finer ($PM_{2.5}$) size fraction is a subset of the PM_{10} size fraction and is particularly significant because of the ability of these particles to penetrate the lungs. Concentrations of PM_{10} measured in Auckland have exceeded the NES of 50µg m^{-3} (24-hour average) and the ambient air quality guideline of 20µg m^{-3} (annual average). $PM_{2.5}$ concentrations in Auckland have exceeded the Auckland regional air quality target of 25µg m^{-3} (24-hour average) and the World Health Organization (WHO) guideline of 10µg m^{-3} (annual average). As PM_{10} and $PM_{2.5}$ are "no safe threshold" contaminants, adverse health effects are likely to occur at concentrations lower than the standard and guideline levels.
NOx and NO_2	Nitrogen dioxide (NO_2) can irritate the lungs, increase the susceptibility and severity of asthma and lower resistance to infections such as the flu. It can also affect vegetation and can significantly degrade visibility because it contributes to the formation of brown hazes and smog. NO_2 concentrations are generally less than 66 per cent of the NES at urban monitoring sites in the region but regularly exceed the standard at roadside monitoring sites. NO_2 concentrations in Auckland have generally increased over the past decade. NO_2 together with other oxides of nitrogen (NOx) are also important contributors to the formation of ozone.
VOCs	Volatile organic compounds (VOCs) are of concern because they contribute to the formation of ozone in the atmosphere. VOCs also include air toxics (such as formaldehyde and benzene), which can cause skin, throat and eye irritation, headaches, nerve and organ damage, and increased risk of cancers and premature death. Limited monitoring of benzene in the Auckland region has demonstrated that levels may exceed the ambient air quality guideline at roadside sites, but are within the guideline in other areas.
SO_2	Sulphur dioxide (SO_2) irritates the lungs, causing coughing, wheezing and breathlessness. Asthmatics may suffer from reduced airflow to the lungs when levels of SO_2 exceed guideline values. Sometimes, concentrations of SO_2 measured in Auckland exceed the NES of 350µg m^{-3} (1-hour average) and the ambient air quality guideline of 120µg m^{-3} (24-hour average). In 2006 the WHO updated the SO_2 guideline for the 24-hour average from 125 µg/m^3 to 20 µg/m^3 because the previous guidelines were considered insufficient, due to new evidence about health effects. This change is not yet reflected in New Zealand's guidelines and standards. The WHO SO_2 guideline for the 10-minute average is at 500 µg/m^3.

Table 1.1 continued

Pollutant	Significance for Auckland
CO	Carbon monoxide (CO) interferes with the blood's ability to absorb and circulate oxygen. This makes it relatively toxic. High levels of CO can affect people with heart conditions such as angina and can impair co-ordination and attention. Maximum CO concentrations are generally less than the NES at urban monitoring sites in the region. Levels at roadside sites have dropped significantly over recent years, but still may occasionally exceed ambient air quality guidelines.
CO_2	Estimates of emissions of CO_2 are included in the inventory to provide information for greenhouse gas emission inventories.
Ozone	Although ozone (O_3) is a vital component of the upper atmosphere, at ground level it is an unwanted toxic gas. Ozone causes runny eyes, nose and throat irritations and breathing difficulties, especially for asthmatics. It also affects the functioning of the heart. Like PM_{10} and $PM_{2.5}$, no safe threshold has been identified below which effects of ozone do not occur. Ozone is referred to as a secondary pollutant because it is not emitted directly from typical pollution sources in the region. Ozone forms when NOx emissions react in the presence of sunlight and VOCs. Maximum ozone concentrations are close to the NES at ambient air quality monitoring sites within the region. The air emissions inventories estimate the emissions of NOx and VOCs, and their trends. This provides useful information about the possible trends of photochemically generated O_3 in Auckland.

National Environmental Standards for air quality (NES) were introduced by the Ministry for the Environment in October 2004 (MfE 2005). These include ambient air quality standards for carbon monoxide (CO), fine particles (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and ozone (O_3). In areas where the ambient air quality standards are not met, the national environmental standards for air quality requires regional councils to take action. Emissions estimates for all pollutants are presented in this report, with a focus on PM_{10}.

1.3 Sources of emissions

The inventory estimates emissions from significant sources, which are grouped into transport, industrial and commercial, domestic and biogenic categories as follows:

Transport
- Motor vehicles
- Off-road vehicles
- Trains
- Aircraft
- Ships and boats
- Bitumen (from road building)

Industrial and Commercial
- Industry
- Commercial and unallocated fuel combustion (e.g. boilers)
- Service stations
- Surface coatings (e.g. paints)
- Aerosols
- Dry cleaning
- Gas leakage

Domestic
- Domestic fuel combustion (including wood, coal, and gas for heating)
- Open burning of rubbish
- Lawn mowers

Biogenic (Natural)
- Emissions from vegetation and soils

This report summarises the emissions estimates, and briefly describes the methodology for estimating the emissions from all sources. However, the focus is primarily on motor vehicles and domestic heating because the 1993, 1998 and 2004 emissions inventories identified these as the main sources of PM_{10} in the region.

1.4 Results for ambient air pollutants

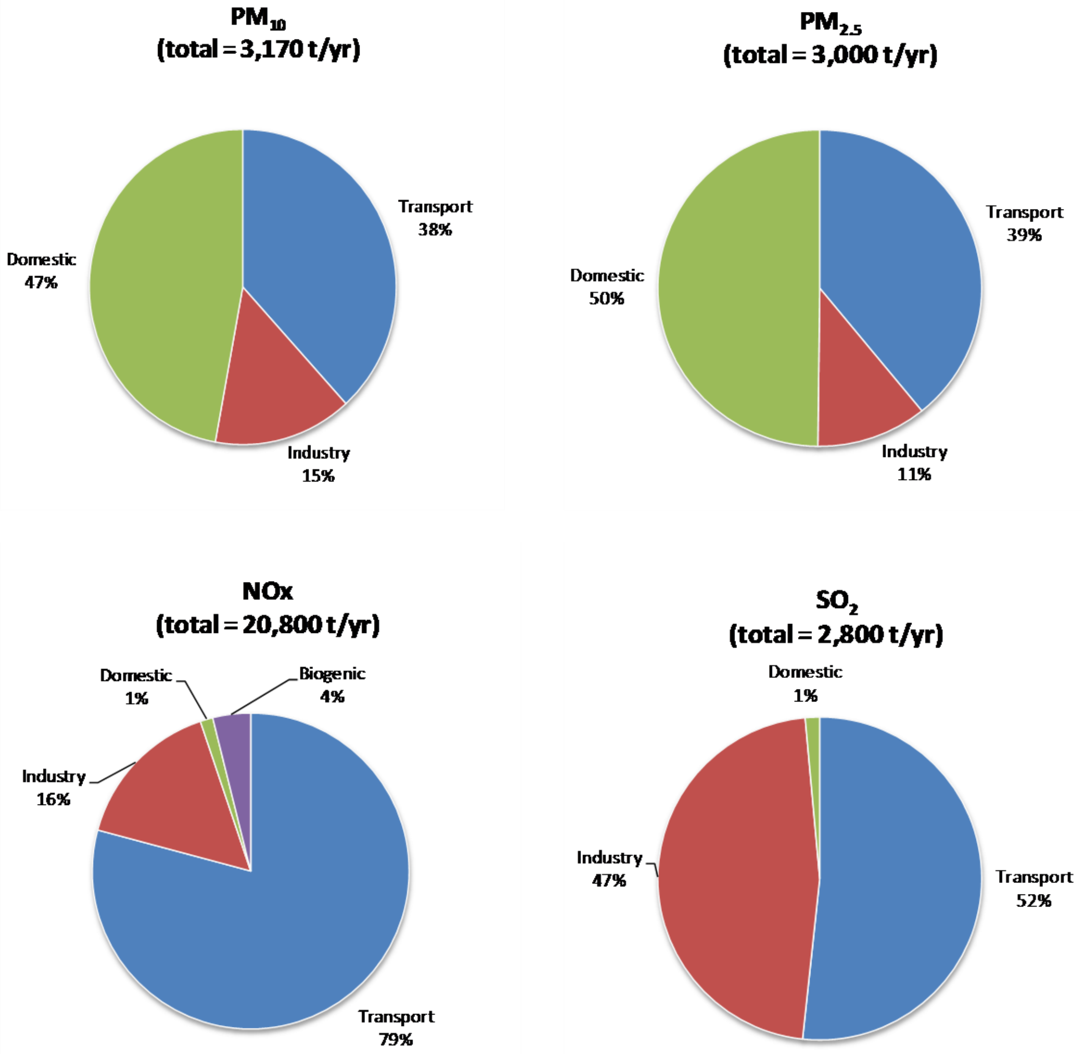
Figure 1.2 illustrates the contributions of various sources to total annual emissions of each ambient pollutant over the entire study area in 2006. A full summary of results is included in Appendix 1.

For annual anthropogenic emissions of PM_{10}, the inventory estimates that 38 per cent is from transport, 47 per cent from domestic sources and 15 per cent from industrial sources across the entire Auckland region.

It should be noted that there are additional (and potentially significant) sources of PM_{10} and $PM_{2.5}$ emissions that have not been estimated by the inventory. These include:

- natural sources, such as sea salt, bush fires and wind blown dust;
- road dust generated by abrasion of the road surface and re-suspension;
- particles formed in the atmosphere when primary pollutants react producing secondary particulate.

The likely contribution of these sources to ambient PM_{10} and $PM_{2.5}$ is discussed in the unaccounted emissions section of this report (Section 6).



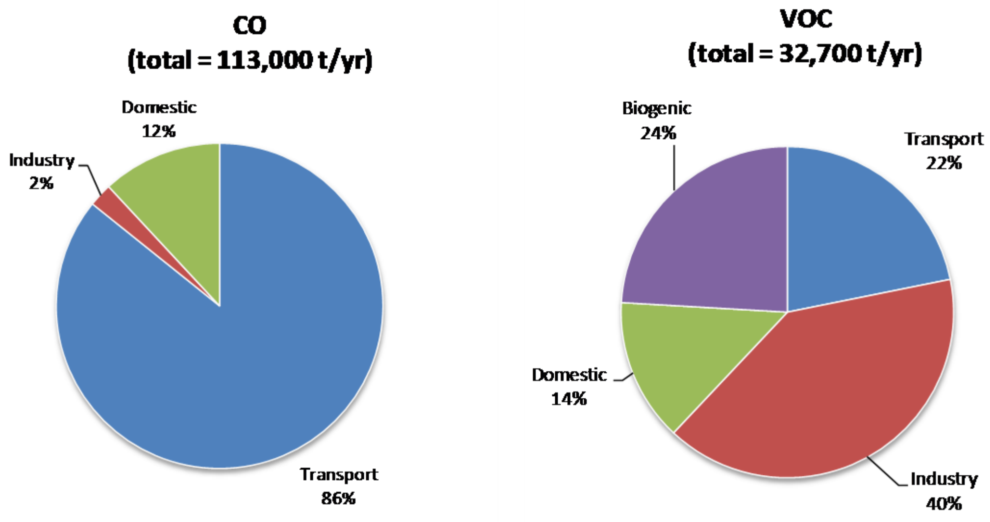


Figure 1.2 Annual ambient air pollutant emissions for the Auckland Region in 2006

1.5 Results for CO_2

The emissions inventory estimates that 42 per cent of CO_2 emissions are from transport, 52 per cent from industry and six per cent from domestic sources (see Figure 1.3). Other important greenhouse gases include methane and nitrous oxide, however these are not estimated in this inventory. At the national level, greenhouse gas emissions are monitored and managed by the Ministry for the Environment.

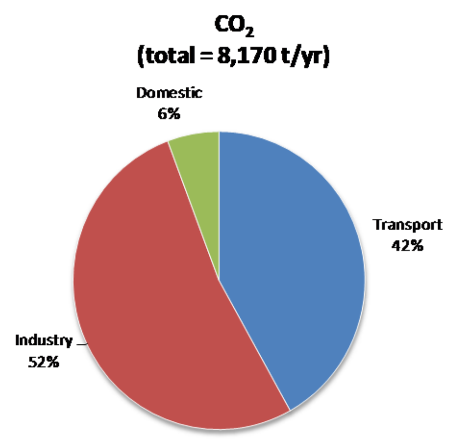


Figure 1.3 Annual CO_2 emissions for the Auckland region in 2006

1.6 Results for PM_{10} in the urban area

Transport and domestic sources contribute to 40 per cent and 50 per cent of total PM_{10} emissions on an annual basis in the urban area (see Figure 1.4). These proportions are higher than those for the whole region (see Figure 1.2), because of large industrial sources located outside the urban area.

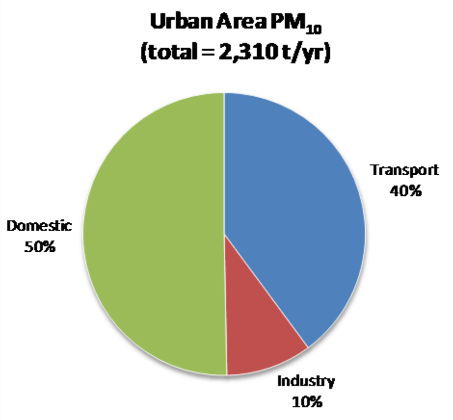


Figure 1.4 Annual PM_{10} emissions for the Auckland urban area only in 2006

1.7 Results by season

Annual emissions estimates indicate the likely contribution of sources to ambient air pollution over an entire year. The emissions inventory includes seasonal and hourly emissions data so that emissions can be predicted over shorter averaging periods, and compared with ambient air quality guidelines.

There is significant seasonal variation in PM_{10} emissions because of domestic heating in winter. This is discussed further in Section 2.

2 Domestic emissions

Domestic sources of air pollution include emissions from home heating (wood and coal), liquefied petroleum gas (LPG) and natural gas use, lawn mowing and outdoor burning of rubbish or green waste.

2.1 Estimation of emissions

The air emissions inventory estimates emissions for the base year of 2006. Emissions are calculated generally according to the fuel use data and emission factors.

2.1.1 Home heating

The methods used to estimate emissions from domestic heating for 2006 are described in detail in the report "Estimation of domestic fire emissions in 2006" (ARC 2010c) and are summarised here.

Emissions from home heating can be highly variable and are dependent upon the type of appliance used, the type and quality of fuel used, the amount of fuel used and operating practices. Appliance numbers for each type of appliance and the amount of fuel consumed are estimated for 2006 using the domestic fire emission prediction model (DFEPM) for wood and coal (ARC 2010c). The model is based on the results of a comprehensive home heating survey undertaken by the Auckland Regional Council in 2007 (ARC 2010b).

The estimated LPG and natural gas annual consumption for 2006 are obtained from the Auckland regional energy database. The overall number of households using wood, coal, LPG or natural gas is based on 2006 census data from Statistics New Zealand.

In 2005, the Ministry for the Environment introduced national environmental standards for air quality (NES) which restricts the discharge of particulates into the air from woodburners and requires that new woodburners meet certain emission standards. Woodburners that meet the requirements of the national environmental standards for air quality are provided on the Ministry's list of authorised woodburners and are referred to in this report as NES (post-2005) burners.

Domestic home heating emissions are calculated using emission factors (g/kg of fuel burnt) as well as estimates of the amount of fuel burnt per household. A number of variables can affect the amount of emissions produced from domestic heating, specifically, the type and quality of fuel. Auckland Council has undertaken a comprehensive programme of emissions testing to investigate the effect of the variables and to estimate real world emission factors based on typical fuel properties.

Emission factors for PM_{10} from woodburners are therefore updated based on the results of emission testing carried out in New Zealand and particularly Auckland Regional Council's emission testing results (ARC 2010c). Emission factors for other burners and other contaminants are updated based on a review of international emission factors and testing carried out in New Zealand which has been used in other regional inventories. These are shown in Table 2.1.

Table 2.1 Domestic home heating emission factors (wet weight for wood)

Appliance type	Emission factors					
	PM_{10} [1]	CO [2]	NOx [2]	SO_2 [2]	VOC [3]	CO_2 [4]
Open fire – wood (g/kg)	12	63	1.2	0.2	30	1800
Open fire – coal (g/kg)	21	70	4.1	5.1	15	2600
Pre-1991 woodburners (g/kg)	10.7	110	1.0	0.2	39	1800
1991-2005 woodburners(g/kg)	7.2	70	0.5	0.2	21	1800
NES (post-2005) woodburner (g/kg)	3.7	30	0.5	0.2	15	1800
Multifuel burner – wood (g/kg)	10.7	110	1.0	0.2	39	1800
Multifuel burner – coal (g/kg)	19	110	1.6	1.1	15	2600
Pellet burner (g/kg)	1.4	7.4	1.8	0.2	0.02	2000
LPG (kg/t) [5]	0.6	0.18	1.3	0.00*	0.2	2500
Natural gas (g/m^3) [5]	0.188	0.455	1.56	0.01*	0.085	1920

* The sulphur content in LPG and natural gas is very low and considered to be effectively zero (MED 2006).

[1] ARC (2010c)
[2] ECan (2008)
[3] ARC (2006)
[4] MfE (2007)
[5] Wilton (2003)

2.1.2 Other domestic sources

Emissions for outdoor burning are based on the amount of waste burnt by households in the region, while emissions from lawn mowers are based on the number of hours of lawn mower usage and population.

Outdoor burning of waste was allowed in Auckland in the past subject to council restrictions, however, since 2001, outdoor burning has been banned in the region through regulations in the Auckland Regional Plan: Air, Land and Water (ARC 2010d) and subsequently through the National Environmental Standards for air quality (MfE 2005). Outdoor burning is allowed in rural areas of the Auckland region subject to obtaining a permit from the council. It is assumed that emissions from outdoor burning will reduce 66 per cent (compared to 1993) by 2011 as a result of these regulations. This estimate is based on the observed effectiveness of burning restrictions implemented in Australian cities (ARC 2005). Emissions from outdoor burning for 2006 are based on the results of the 1993 domestic survey which estimated that approximately 14,000 tonnes of waste was combusted in the Auckland region.

Emission factors for outdoor burning (except for CO_2) are based on US Environmental Protection Agency emission factors for the open burning of municipal refuse (USEPA 1992). The emission factor for CO_2 is assumed to be the same as the emission factor for wood combustion (Fisher *et al.* 1997).

Lawn mowing emissions are also based on the results of the domestic survey carried out in 1993. Lawn mowers were used an estimated 4.23 hours per year per person. Based on data gathered from retailers, it was estimated that 40 per cent of lawn mowers were 2-stroke units in 1998, reducing to 10 per cent by 2021. Retailers indicated that there would be a gradual substitution of 4-stroke units at a rate of 10 per cent each year. For 2006, it is estimated that the ratio of 2-stroke to 4-stroke mowers would be 1:3. Emission factors for lawn mowers are based on the Australian National Pollutant Inventory (NPI 1999) for particulate matter, and from Priest *et al.* (2000) for all other pollutants, as summarised in Table 2.2. Population for the respective inventory year was used to calculate emissions.

Table 2.2 Emission factors for outdoor burning and lawn mowing.

Pollutant	Outdoor burning (kg/t)	Lawnmower	
		2-stroke (g/hr)	4-stroke (g/hr)
CO	42	731	489
CO_2	1,700	738	890
NOx	3	1.45	4.85
SO_2	0.5	0.062	0.036
PM_{10}	7.86	7.8	0.515
VOC	15	294	39.7

2.2 Results of domestic emissions

The 2006 air emissions inventory estimates that domestic sources contribute 47 per cent of the annual PM_{10} emissions as shown in Figure 2.1. The majority of these domestic emissions are from the combustion of solid fuels (wood and coal) for home heating especially during winter, which accounts for 94 per cent of annual domestic PM_{10} emissions as shown in Figure 2.2.

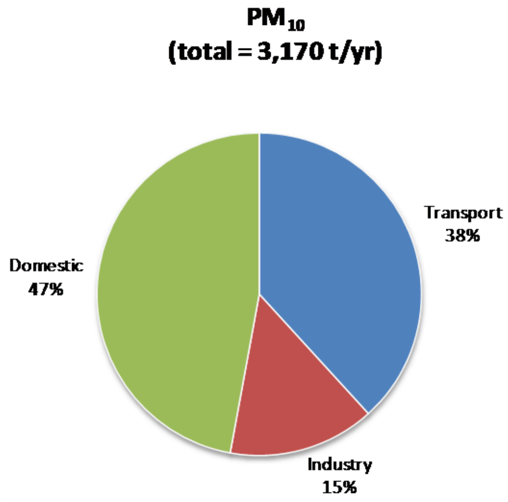


Figure 2.1 Annual PM_{10} emissions for the Auckland region in 2006

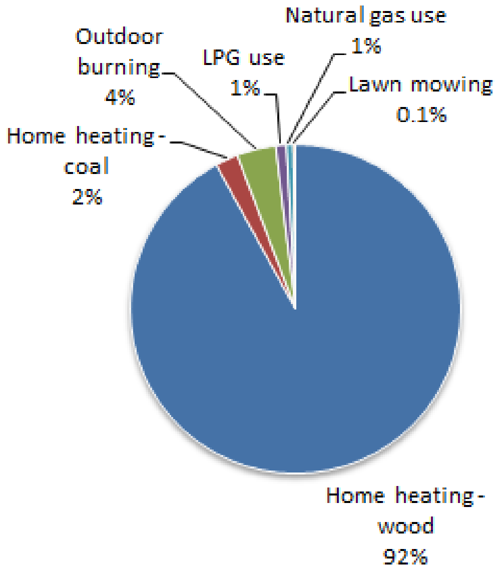


Figure 2.2 Annual domestic contributions to PM_{10} emissions in 2006

The contribution of domestic sources relative to other sources varies seasonally with 80 per cent of emissions occurring over the winter months and dropping to as low as

12 per cent and eight per cent during autumn and spring respectively. Figure 2.3 shows the monthly home heating distribution assumed in the inventory.

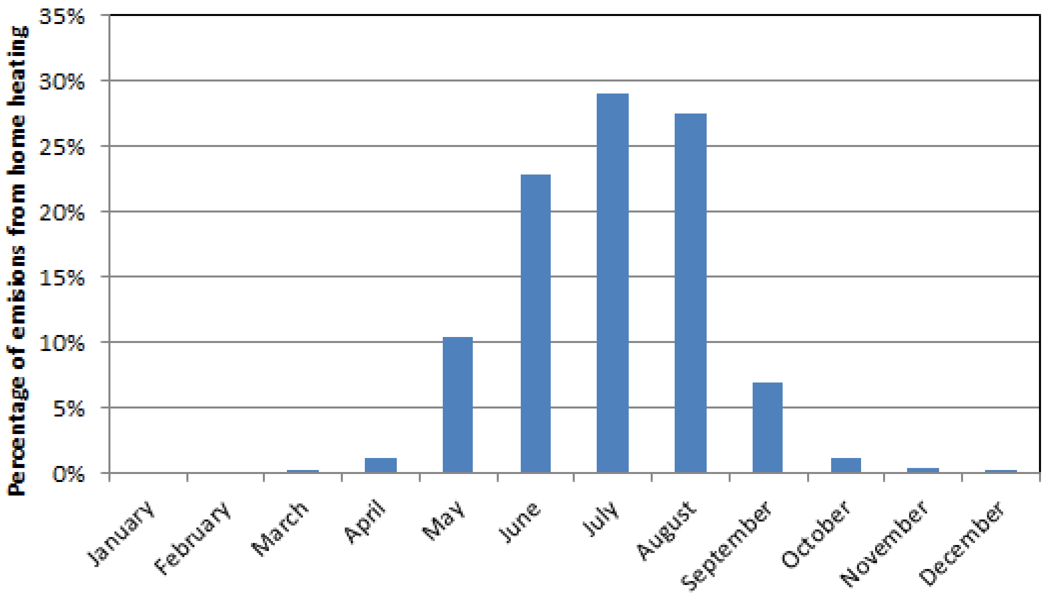


Figure 2.3 Monthly distribution in home heating emissions.

It is estimated that there were approximately 78,000 old (pre-2005) woodburners, 26,000 open fires, 4,500 NES (post-2005) woodburners and 900 pellet burners in the Auckland region in 2006 (proportions are shown in Figure 2.4), resulting in approximately 13 tonnes of winter weekday PM_{10} emissions (ARC 2010c). Of this, 73 per cent of emissions are from pre-2005 old woodburners as shown in Figure 2.5, and a further 24 per cent of emissions from open fireplaces.

Although woodburners can be economic, their efficiency can vary significantly depending upon the quality of construction, operation and maintenance. Burners that are not properly constructed, operated or maintained can produce excessive amounts of smoke and pollutants (ARC 2010a). Similarly, open fires are not very efficient or effective at heating, and will often actually cool the house, rather than heat them.

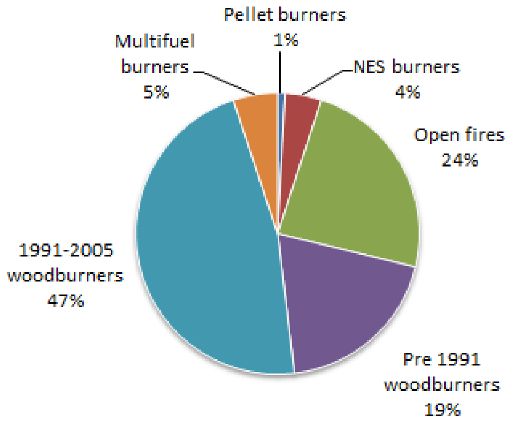


Figure 2.4 Proportion of appliances used for home heating in Auckland in 2006

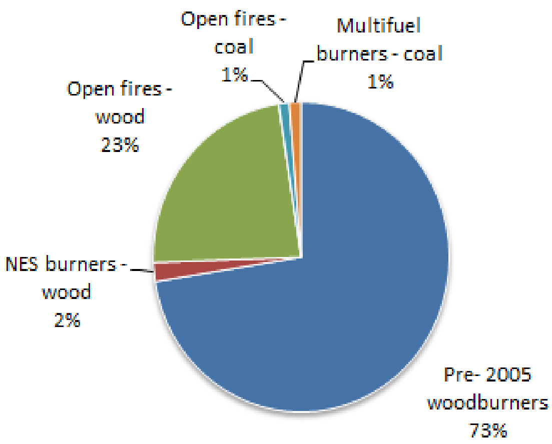


Figure 2.5 Annual home heating contributions to PM_{10} emissions in 2006

Home heating emissions also vary geographically across the Auckland region as shown in Figure 2.6. The distribution is based on the results of the 2007 home heating survey (ARC 2010b), census data and the domestic fire emissions prediction model (ARC 2010c).

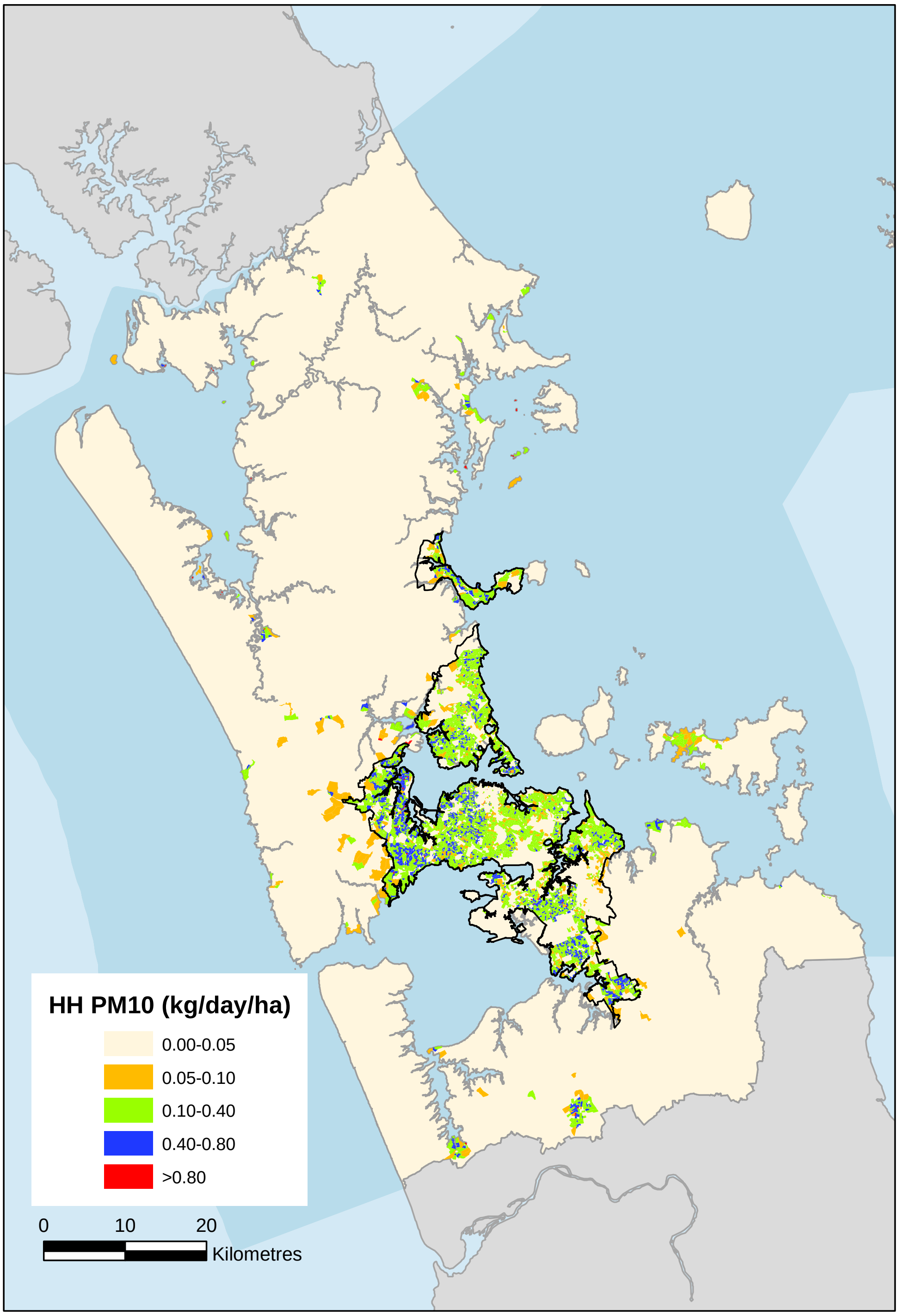


Figure 2.6 Spatial distribution of home heating PM_{10} emissions in winter at meshblock level for 2006.

3 Transport emissions

Transport sources include emissions from motor vehicles, ships and boats, trains, aircraft, off-road mobile vehicles and emissions from laying roads using bitumen.

3.1 Estimation of emissions

Emissions are calculated based on annual activity and the respective source emission factor. Motor vehicles and shipping are calculated using a bottom up approach from hourly or daily activity and aggregated up for an annual emission estimate. In contrast, other transport sources such as aviation are calculated using a top down approach from annual data. Estimation methods used for sources are outlined in the following sections.

3.1.1 Motor vehicles

The methods used to estimate motor vehicle emissions are described in detail in "Auckland Motor Vehicle Emissions Inventory for 2006" (AC 2011b) and are summarised here.

Motor vehicle emissions have been calculated using emission factors from the vehicle emission prediction model (VEPM) version 4.1 and outputs from the Auckland regional transport model version 3 (ART3). The vehicle emission prediction model was updated in June 2011 to include the latest fleet data and projections from the Ministry of Transport as well as the latest international emission factors.

Emission factors are generated by the vehicle emission prediction model for the year 2006 and defined for:

- all speeds between 10 and 99 kilometres per hour;
- all vehicle types (shown in Table 3.1); and
- all pollutants in the inventory (except $PM_{2.5}$ and SO_2).

Sulphur dioxide emission factors are calculated in accordance with the methodology described in the vehicle emission prediction model version 3.0 user notes (Kar *et al.* 2008).

$PM_{2.5}$ is assumed to be 100 per cent of PM_{10} for exhaust emissions and 80 per cent of PM_{10} for brake and tyre wear emissions, in accordance with recommendations by the Ministry for the Environment good practice guide (MfE 2008).

Table 3.1 2006 motor vehicle fleet split

Vehicle type	Fuel	Per cent of Fleet	Per cent of Total VKT
Car	Petrol	70.8	72.3
Light commercial	Petrol	4.2	4.3
Hybrid & Electric	Petrol	0.1	0.07
Car	Diesel	8.1	8.2
Light commercial	Diesel	9.7	9.9
Bus	Diesel	0.6	0.4
Heavy	Diesel	6.6	4.9
Total petrol (per cent of VKT)		**75.1**	**76.6**
Total diesel (per cent of VKT)		**24.9**	**23.4**

The Auckland regional transport model version 3 (ART3) provides traffic data for the region. Roads are represented spatially in the model as links which includes almost 16,000 individual road links. For each road link, the model defines vehicle kilometres travelled (VKT) for the periods of:

- AM peak: 7 am – 9 am,
- Inter-peak: 9 am – 3 pm and
- PM peak: 4 pm – 6 pm

Model outputs also include:

- speed, and
- proportion of light vehicles and heavy commercial vehicle splits.

The light to heavy vehicle split is further broken down based on the default fleet split provided by the vehicle emissions predictions model (VEPM 4.1) as shown in Table 3.1.

School peak (3 pm to 4 pm) and off peak (6 pm to 7 am) periods are not included in the Auckland regional transport model. Therefore, to calculate daily emissions, the following assumptions were made based on recommendations from Auckland Council transport modellers[6]:

- School peak (3 pm to 4 pm) vehicle kilometres travelled = 10 per cent of daily total
- Off peak vehicle (6 pm to 7 am) kilometres travelled = 16 per cent of daily total
- The speed and proportion of vehicles for both school peak and off peak are assumed to be the same as inter peak.

3.1.2 Shipping

Shipping emission estimates in previous Auckland regional inventories were based on the number of ship visits to port and on average emission factors for main and auxiliary engines on board the vessels. In 2010, a detailed study of air emissions from port-related activities was commissioned by the Auckland Regional Council for 2006 and 2010. The study included estimates of emissions from ships, port vessels (tug and pilot boats), ferry boats and commercial fishing boats as well as emissions from land based activities such as cargo handling equipment and dredging operations.

The methods used to estimate shipping emissions are described in detail in “Port-Related Air Emissions for the Auckland Region 2006 & 2010” (Peeters 2010) and are summarised here. Emissions calculations for each activity are based on vessel specific data (such as movements, gross tonnage, main engine power and maximum speed and berthing duration) obtained from Ports of Auckland Ltd, travel speeds derived from sampled automatic identification system (AIS) transponder data, reported annual fuel consumption data, public ferry timetables, and data supplied by the Ministry of Fisheries.

The methodology and emission factors are based on recommendations by USEPA (2009) but it should be noted that the emission factors were derived from a limited dataset.

3.1.3 Other transport sources

Estimates of aircraft emissions are based on annual movements for 2006 from Auckland Airport Ltd annual reports and emission factors are calculated in kilogrammes per aircraft movement as per the 2004 inventory (ARC 2005, ARC 2006). Rail activity are based on

[6] D. Young, contractor to the Auckland Council, personal communications, 8 August 2011

fuel consumption data for 1998 supplied by the Auckland Regional Council (which are projected to 2011) and emission factors in kilograms per kilolitre of fuel consumed by the types of engines in the 1998 locomotive fleet (ARC 1997).

Off-road vehicles include unregistered motorbikes, competition vehicles, farm and forestry vehicles and defence vehicles. The usage for 2006 is based on vehicle type/equipment specific annual fuel consumption, load factor and emission factors. The methods used to estimate off-road vehicle emissions are described in detail in “Off-road mobile sources – construction and farm” (AC 2011a). Marine pleasure craft activity estimates are based on registration data and results of the 1993 domestic survey. Emission factors for pleasure crafts are estimated on a per capita basis and are the same as those used in the 2004 inventory (ARC 2006).

Table 3.2 Emission factors for other transport sources (except rail)

Pollutant	Aviation All types (kg/movement)	Off-road vehicles (kg/yr per person)	Pleasure craft (kg/yr per person)
CO	9.68	0.256	1.75
CO_2	1,160	35.1*	20.4
NOx	5.36	0.628	0.149
SO_2	0.356	0.002	0.013
PM_{10}	0.420	0.05	0.0086
VOC	3.48	0.06	0.49

* Off-road CO_2 emission factor is the same as used in the 2004 inventory (ARC 2006)

Table 3.3 Emission factors for rail

Locomotive type	Pollutant						
	CO (kg/kL)	CO_2 (kg/kL)	NOx (kg/kL)	SO_2 (kg/kL)	PM_{10} (kg/kL)	$PM_{2.5}$ (kg/kL)	VOC (kg/kL)
2 stroke sup. switch	21	30	10	4.93	2.88	2.811	2354
4 stroke switch	15	59	46	4.93	2.88	2.811	2354
2-str. road (super)	16	42	7.9	4.93	2.88	2.811	2354
2-str. road (turbo)	3.06	40	19	4.93	2.88	2.811	2354
4 stroke road	11	56	22	4.93	2.88	2.811	2354

3.2 Results of transport emissions

The 2006 air emissions inventory estimates that emissions from transport sources contributes 38 per cent of annual PM_{10} emissions (refer to Figure 2.1), with 71 per cent of these emissions coming from motor vehicles as shown in Figure 3.1. The emissions contribution from motor vehicles are broken down further in Figure 3.2, showing 81 per cent of emissions are from diesel vehicles although they account for only 24 per cent of vehicle kilometres travelled (Figure 3.3).

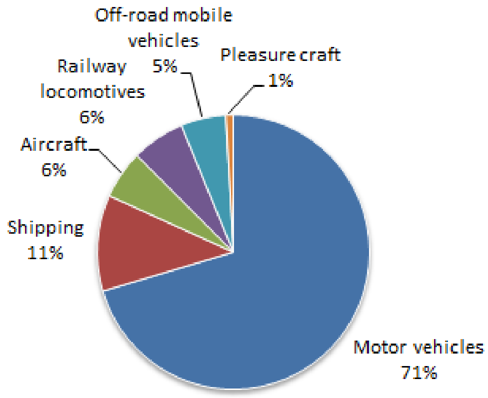


Figure 3.1 Relative source contributions to transport related PM_{10} emissions

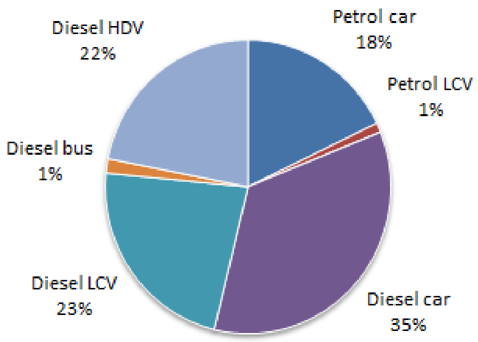


Figure 3.2
Sources of annual motor vehicle PM_{10} emissions

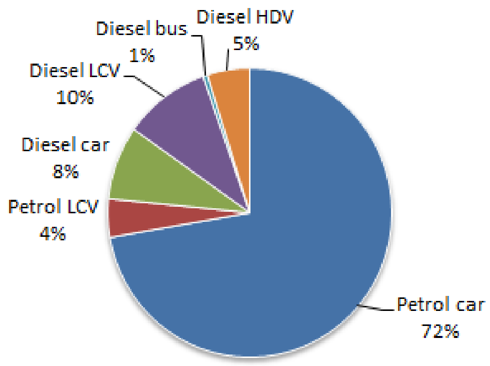


Figure 3.3
Motor vehicle kilometres travelled by vehicle type

Emission factors used in the 2006 inventory for motor vehicles are from the vehicle emission prediction model version 4.1. Fleet weighted emission factors for PM_{10} are approximately 0.3 g/km for diesel cars, 0.2 g/km for light commercial vehicles and 0.3 g/km for heavy duty vehicles. This is because heavy duty vehicles have been more stringently regulated since 1988, having to meet Euro 1 and 2 emission standards, while the same did not occur for diesel cars until 10 years later (ARC 2011b). It is therefore understandable that in 2006, the inventory estimates that an average diesel car produces the same amount of PM_{10} emissions as an average diesel truck. Since the total VKT is now similar for both these transport sources the total emissions are similar.

The emissions inventory also indicates that transport is the leading emissions contributor for other pollutants. The transport sector is responsible for:

- 86 per cent of annual carbon monoxide (CO) emissions;
- 79 per cent of annual nitrogen oxides (NOx) emissions;
- 51 per cent of annual sulphur dioxide (SO_2) emissions;
- 40 per cent of annual carbon dioxide (CO_2) emissions, and
- 22 per cent of annual volatile organic compound (VOC) emissions.

Motor vehicles, again, are the primary transport source of emissions, except in the case of SO_2. Emissions from shipping and port-related activities were estimated to contribute 35 per cent of annual sulphur dioxide emissions in 2006 (see Appendix 1 for emission data).

Transport emissions also vary geographically across the region, with more than 60 per cent of motor vehicle travel occurring within the urban area (as illustrated by Figure 3.4). Although motor vehicles are the biggest transport source regionally, shipping or aviation are potentially significant local sources.

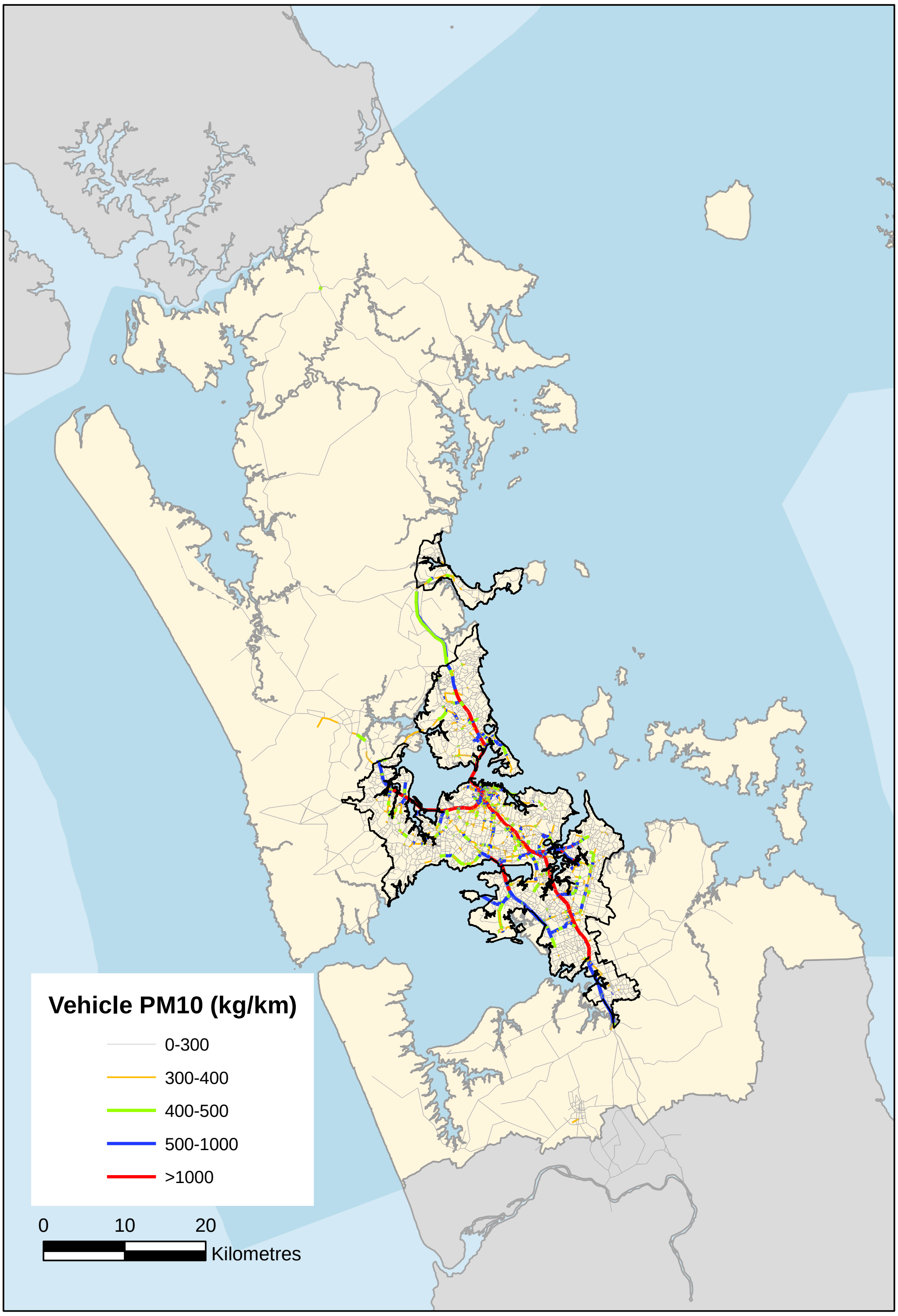


Figure 3.4 Spatial distributions of vehicle PM_{10} emissions for 2006.

4 Industrial emissions

This category includes consented industry, surface coatings & thinners, aerosols & solvent use, dry cleaning, service stations, gas leakage, and commercial gas combustion. However, unconsented combustion sources have not been allowed for.

4.1 Estimation of emissions

4.1.1 Consented industry

This source accounts for emissions from all consented industrial activities in the region. This includes activities from chemical plants, refineries, electric utility plants and other industrial sites which require resource consent from Auckland Council for discharge of contaminants to air. There are more than 290 different industrial consented sites within Auckland, which are assigned an industry type based on the activity or process (see Table 4.1).

The industrial inventory has been compiled by reviewing the council's consent record files for each consented site. Emissions have been estimated based primarily on information taken from stack emission testing, assessment of environmental effects (AEEs), USEPA emission factors and the consent limits (URS 2009).

Of the data sources used, measured concentrations and flow rates from stack emission testing are considered to be the most accurate. This is because emission testing data relates to the real emissions discharged from a site rather than being based on theoretical assumptions. However, note that frequently these data are based on a limited number of tests.

4.1.2 Other industrial and commercial sources

The methods used to estimate emissions from other industrial and commercial sources are described in detail in "Air Emissions Inventory Toolkit –User Guide (Draft)" (ARC 2010f) and are summarised here.

Surface coating operations involve the application of paint, varnish, lacquer or paint primer for decorative or protective purposes. Emissions from domestic, commercial and industrial uses of surface coatings and thinners are estimated based on the amount of product consumed by the population. It is assumed that all VOC contained in surface coatings and thinners are emitted to the atmosphere and there are no emissions of other types of air pollutants. A VOC emission factor of 3.9 kg/yr per person is used following an analysis of information in Australia and the US.

Domestic and commercial applications use a variety of products containing solvents and aerosols. These products contain VOCs as the active ingredient or in the form of propellants, solvents or co-solvents for the active agents. Emissions from the use of aerosols and solvents are calculated based on the amount of product consumed annually by population. Domestic and commercial applications use a variety of products containing solvents and aerosols. These products contain VOCs as the active ingredient or in the form of propellants, solvents or co-solvents for the active agents. The VOCs are emitted to the atmosphere when these products are used (immediate evaporation of aerosol spray) or after application, as the product dries. Based on New Zealand consumption data, the solvent and aerosol emission factor used is 3.43 kg/yr per person. Emissions of other pollutants from the use of aerosols and solvent products do not occur, and have therefore not been considered.

Dry cleaning involves the cleaning of fabrics with solvents in commercial premises. Emissions from dry cleaners are based on the consumption of the cleaning solvent used in the region. A 'top down' approach has been used for dry cleaners, where annual consumption is assumed to equal annual VOC emissions and distributed to dry cleaners in the Auckland region on a pro rata basis.

Service stations supply petrol, diesel and related products to motor vehicles. Petrol and diesel contain a mixture of VOCs. Emissions are generated when filling underground fuel storage tanks from tankers, breathing of underground tanks and refuelling of motor vehicle tanks. The level of emissions from each source varies according to the method of operation, the extent of vapour recovery and weather conditions. This source type covers the evaporative fuel loss at service stations. A 'top down' approach has been used for service stations, where fuel used in the Auckland region was based on sales data, and distributed to service stations in the Auckland region on a pro rata basis. Emission factors for petrol are from USEPA (1985), and for diesel from the national pollutant inventory (NPI 1999b), after considering the requirement of vapour recovery at all new service stations in the region. Emissions of other pollutants from service station operations are assumed to be negligible.

Emissions from the leakage of natural gas to the atmosphere from the gas distribution network are estimated by the gas consumption, assuming 1.5 per cent leakage, and using emission factors of VOC and CO_2 from the 2004 inventory (ARC 2005). Emissions of other pollutants are considered to be negligible.

Natural gas is used by commercial premises mainly for services, infrastructure and horticulture. Emissions from commercial gas combustion are estimated based on natural gas consumption by the commercial sector and emission factors for commercial boilers are used for natural gas combustion (USEPA 1998).

4.2 Results of industrial emissions

The 2006 air emissions inventory estimates that emissions from industrial sources contribute to 15 per cent of annual PM_{10} emissions (Figure 2.1), with almost all the emissions coming from consented industrial sources.

Each consented site has been assigned a primary and a secondary category based on the purpose of the site and the type of work. The primary category classifies the main industry type while the secondary category relates more to the actual activity being carried out. In total, there are 14 primary categories and 40 secondary categories. Table 4.1 shows the breakdown of PM_{10} emissions for industry types. Facilities involved in metal and non-metal product manufacture are responsible for the majority of industrial PM_{10} emissions.

Table 4.1 Relative source contribution to consented industrial PM_{10} emissions.

Primary category	**Secondary category**	**PM_{10} (%)**
Aggregate	Abrasive Blasting, Building Products, Concrete, Concrete Crushing, Quarry, Supplies	2%
Bitumen	Asphalt, Solvent-Coating	2%
Chemical	Cleaning Chemicals, Combustion, Explosives, Fumigation, Gases, Grease, Metal, Paint, Pesticide, Plastics, powder coating, Solvent, Solvent-Coating, Timber Treatment	2%
Combustion	Combustion, Crematorium, Generator	1%
Food/Animal Products	Combustion, Felmongery, Frying, Grain Processing, Milk Products, Rendering	11%
Metal	Combustion, Foundry, Galvanising, Soldering	46%
Miscellaneous	Chemical, Combustion	1%
Non-metal	Combustion, Building Products	15%
Power	Combustion	6%
Pulp, Paper and Cardboard	Combustion	2%
Storage		0%
Textiles	Metal, Coating	0%
Waste	Chemical, Combustion, Composting, Effluent Treatment, Landfill, Metal, Transfer Station	6%
Wood Processing	Biofilter, Combustion, Joinery, Resawing	6%

The contribution of industry to total emissions is very dependent on the spatial boundaries considered. Annual PM_{10} emissions in the urban area account for only 48 per cent of the regional emissions, due to a number of significant industrial sources being located outside the urban area (as illustrated by Figure 4.1).

For 2006, industrial sources contribute to 47 and 40 per cent of annual SO_2 and VOCs, respectively.

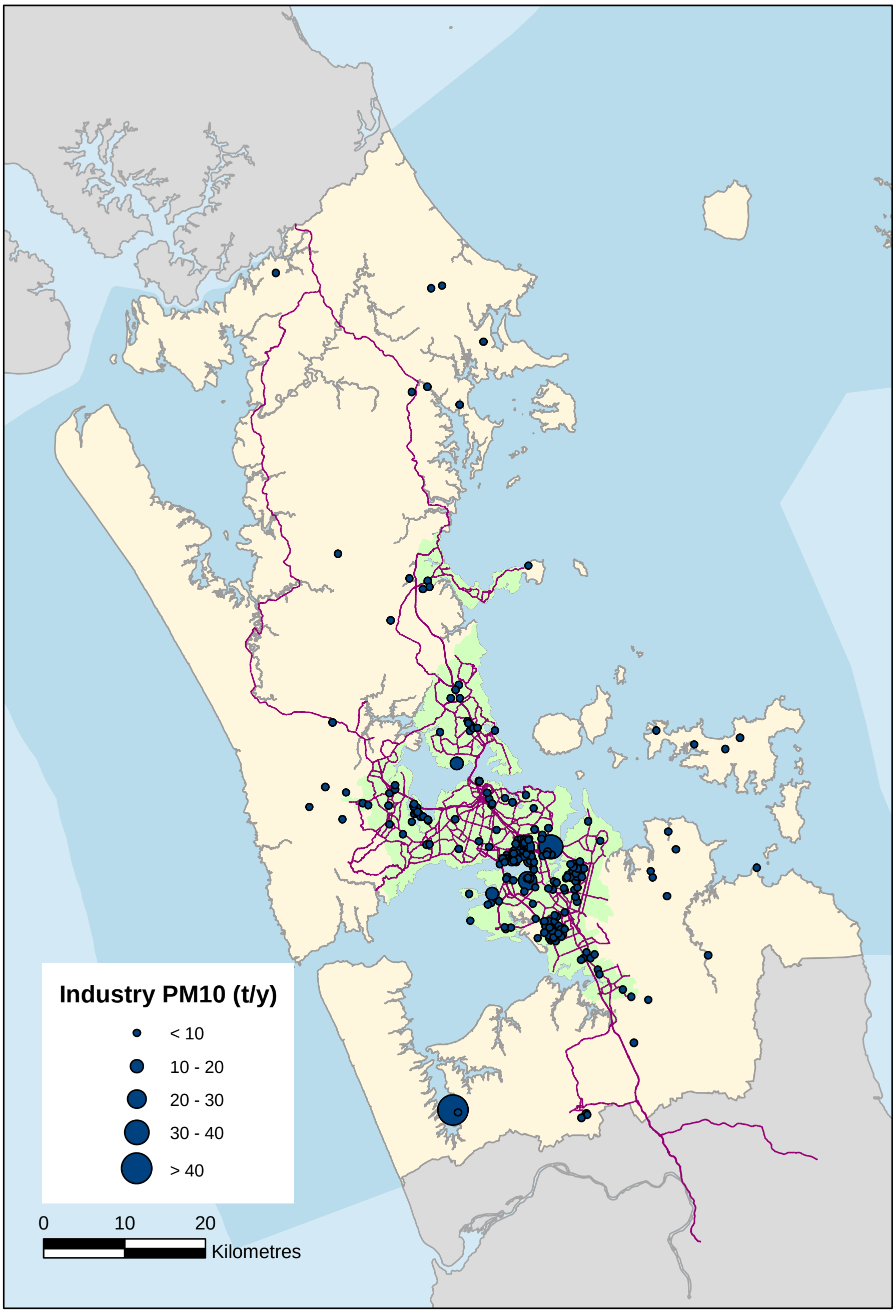


Figure 4.1 Spatial distribution of consented industrial PM_{10} emissions for 2006.

5 Trends

The emissions inventory includes back casted and projected emissions estimates for 2001 and 2011, respectively. Summary tables of emission estimates for these years are provided in Appendix 1.

5.1 Trends in domestic home heating emissions

The ARC domestic fire emission prediction model was used to predict PM_{10} emissions out to 2033. Emissions estimated for 2006, trends and 'business as usual' projections are detailed in full in ARC (2010c), while the various scenarios investigated (including the 'business as usual' scenario) are reported in ARC (2010e).

Trends in old woodburners, open fires and multifuel burners indicate an overall reduction in appliance numbers while the number of newer NES (post-2005) burners has increased. The domestic fire emission prediction model estimates that woodburner emissions have reduced approximately 13 per cent from 2001 to 2011 (ARC 2010c). Note that this is based on only a three census year trend, and therefore could be overly optimistic.

5.2 Trends in motor vehicle emissions

The vehicle emission prediction model (v4.1) and projections from the Auckland regional transport model outputs were used to estimate emissions for 2001 and 2011. Table 5.1 shows that despite a 20 per cent increase in vehicle kilometres travelled between 2001 and 2011, and an increase in the proportion of diesel vehicles, PM_{10} emissions have reduced by 21 per cent (due to the 26 per cent drop in PM_{10} exhaust emissions) and oxides of nitrogen emissions have decreased by 28 per cent.

Table 5.1 Trends in PM_{10} and NOx emissions

Year	VKT (million kms)	Per cent of VKT by diesel vehicles	PM_{10} (kg/day)			NOx (kg/day)
			Exhaust	Brake & Tyre	Total	
2001	10,046	20 per cent	758	145	903	13,629
2006	11,548	23 per cent	696	158	854	11,525
2011	12,181	25 per cent	563	164	727	9,845

5.3 Trends in industrial emissions

Industrial emissions estimates for 2001 were based on questionnaires completed by industry, as well as ARC resource consent information and USEPA emissions factors. Where stack test data were available, these were used in preference to literature emission rates (ARC 2006). The 2008 industrial inventory was used to estimate emissions for 2006 and 2011. Since the methods used for 2001 and later years (2006 and 2011) are not totally compatible, it is considered that the changes in emissions between 2006 and 2011 (which were estimated using the same method) are more realistic than between 2001 and 2011 (which were estimated using different methods). With improved technologies, some industrial processes are less polluting than in the past, and some industrial premises have ceased operations recently. This results in nine per cent reduction of industrial emissions between 2006 and 2011.

5.4 Overall trends

The overall trends, as indicated by Figures 5.1 to 5.3 show that in the period 2001 to 2011:

- PM_{10} emissions have reduced by 25 per cent between 2001 and 2011. During this period industrial and domestic home heating emissions have reduced by 47 per cent and 28 per cent, respectively. The reductions from domestic heating are due to less use of coal and wood for heating homes. The industrial emissions between 2001 and 2011 were estimated using different methods. The changes in emissions between 2006 and 2011, using the same method, are lower than those between 2001 and 2006, and are only nine per cent. Motor vehicle emissions have decreased by 19 per cent despite there being a 20 per cent increase in vehicle kilometres travelled by motor vehicles since 2001.
- Carbon monoxide emissions have reduced by 38 per cent due to older motor vehicles in the fleet being replaced by newer vehicles with improved vehicle technology and emission control equipment.
- Volatile organic compound emissions have decreased by 16 per cent since 2001 due to the shift away from the use of coal and wood for domestic home heating and also the reduction of benzene in petrol in New Zealand.
- Sulphur dioxide emissions dropped between 2001 and 2006 by 10 per cent due to the reduction of sulphur in fuel in New Zealand, but total emissions are expected to increase between 2006 and 2011 due to increased shipping movements.

- Nitrogen oxides emissions have decreased by 14 per cent despite 20 per cent increase in vehicle kilometres travelled, but this can be attributed to improved vehicle control technology.
- Carbon dioxide emissions have increased by nine per cent and are expected to continue to increase due to the expected increased fuel consumption (or travel) by the transport sector.

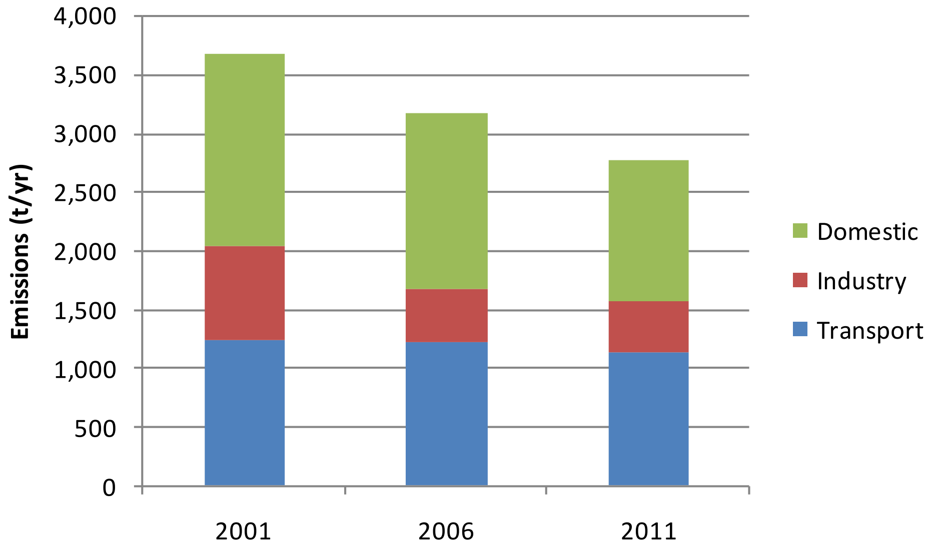


Figure 5.1 Predicted trend for PM_{10} emissions

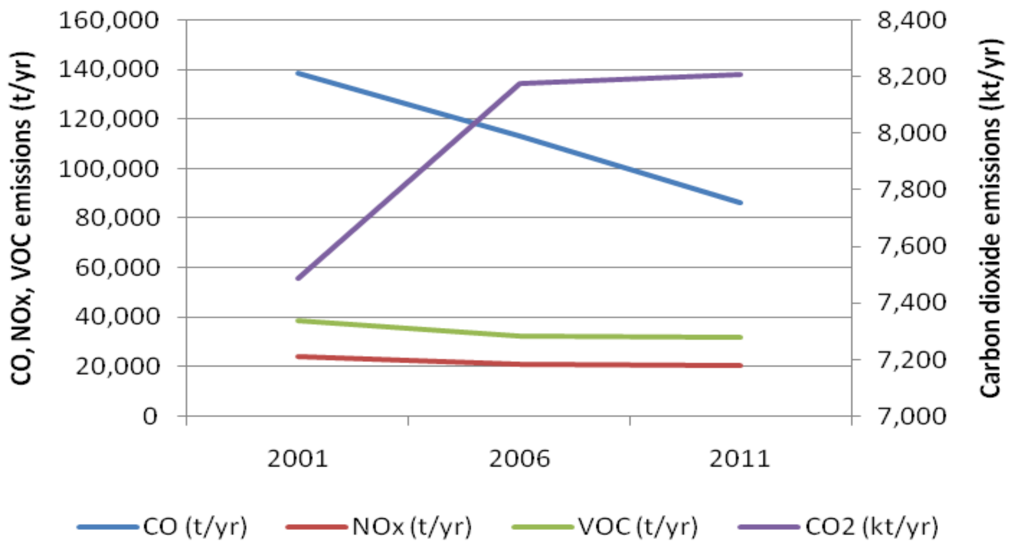


Figure 5.2 Predicted trends for emissions of CO, NOx, VOC and CO_2.

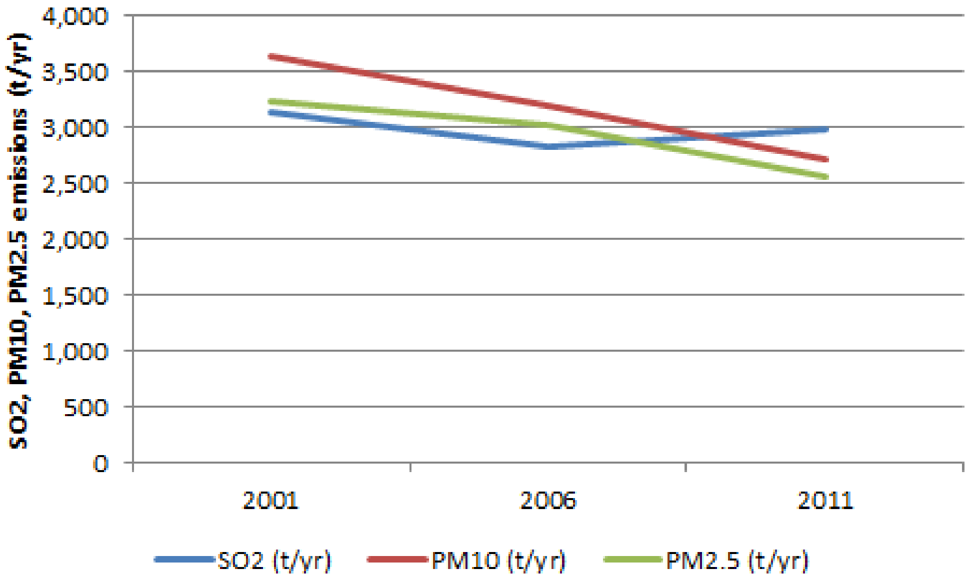


Figure 5.3 Predicted trends for emissions of sulphur dioxide, PM_{10} and $PM_{2.5}$

The inventory estimates a reduction in emissions for all pollutants (except carbon dioxide), however, it is useful to compare emissions estimates with ambient air quality monitoring data.

Figures 5.4 and 5.5 show PM_{10} annual averages at Auckland's monitoring sites. This suggests a reduction in PM_{10} measured at the Queen Street and Khyber Pass Road peak traffic sites in Auckland, particularly between 2000 and 2003. The reduction in PM_{10} concentrations at traffic sites coincides with substantial reductions in the sulphur content of diesel fuel in the early 2000's, so this could be a direct result of emission reductions. This reduction may also relate to changes of traffic conditions around the sites. However, the long-term, overall trend is less clear and PM_{10} annual averages at Auckland's residential monitoring sites have remained relatively constant between 2001 and 2010, despite an estimated overall reduction in emissions of 25 per cent between 2001 and 2011.

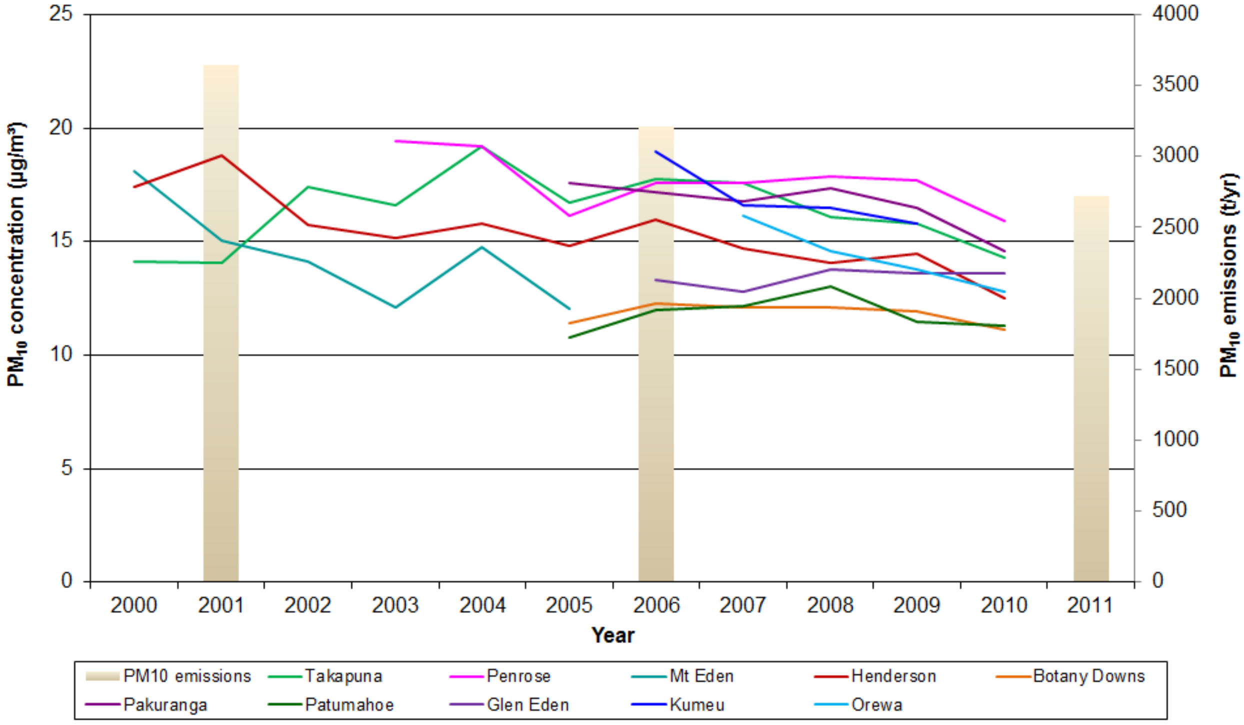


Figure 5.4 PM_{10} annual averages at Auckland monitoring sites from 2000 to 2010 (excluding traffic monitoring sites)

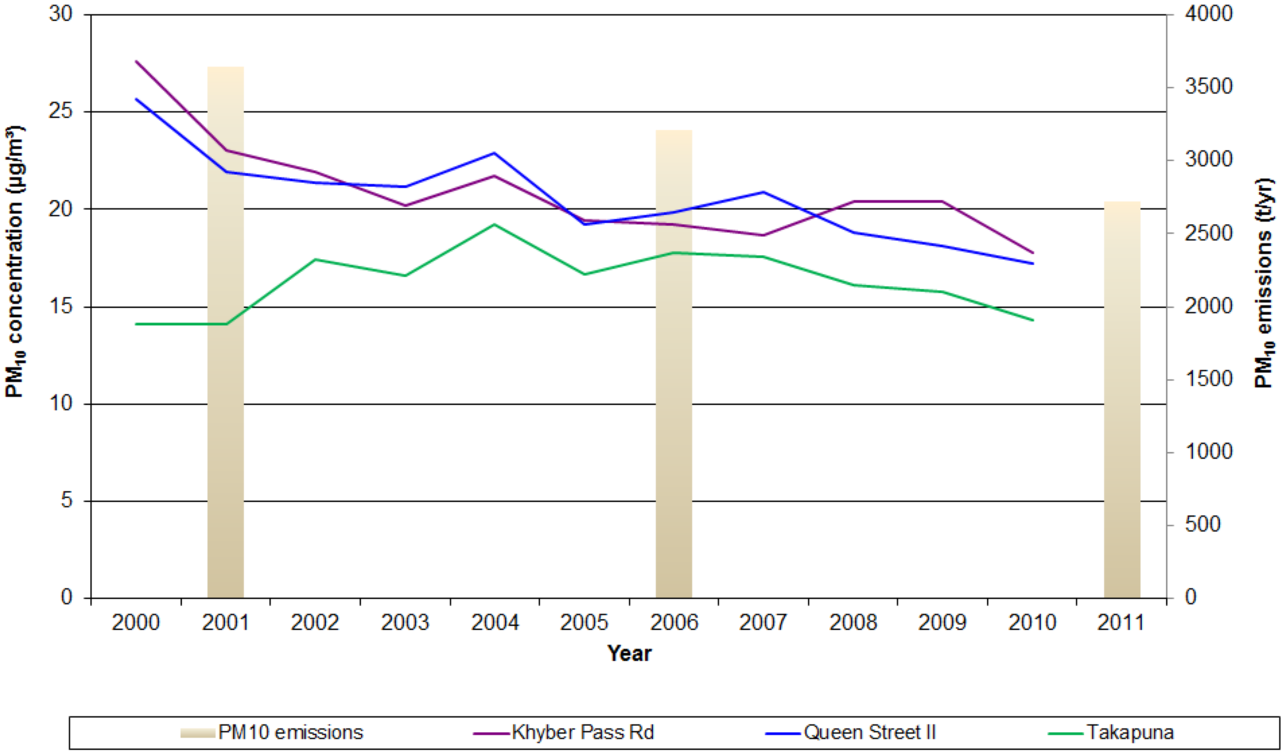


Figure 5.5 PM_{10} annual averages at Auckland traffic monitoring sites from 2000 to2010. Takapuna is not classified as a traffic monitoring site, but it is located near the northern motorway, therefore it has been included on this graph.

Figure 5.6 compares annual average nitrogen oxides for Auckland monitoring sites between 2000 and 2010. This shows a drop in ambient total nitrogen oxides, especially at the roadside traffic monitoring sites of Khyber Pass Road and Queen Street, which is proportional to the drop in emissions estimated by the inventory.

Trends in nitrogen oxides have been reviewed in some detail in the Auckland Motor Vehicle Emissions Inventory for 2006 (AC 2011b). This concluded that there is some doubt that total nitrogen oxides emissions will continue to reduce in accordance with emission inventory predictions, and there is considerable uncertainty about the effect of any total nitrogen oxides reductions on ambient nitrogen dioxide concentrations, particularly as NO_2 concentrations are also dependent on the proportion of NO_2 in NOx emissions from transport and the reactions in air of NO with ozone to form NO_2.

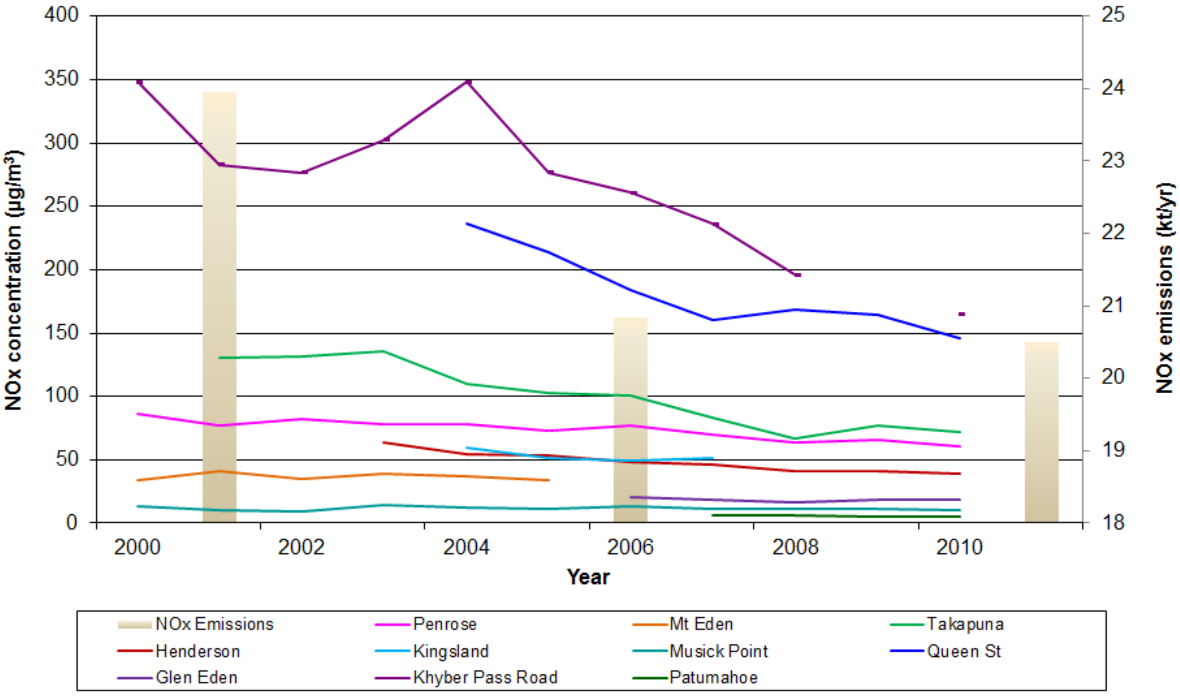


Figure 5.6 NO_x annual averages at Auckland monitoring sites from 2000 to 2010

6 Unaccounted emissions

This inventory does not include PM_{10} and $PM_{2.5}$ emissions resulting from secondary particulate formation, natural sources nor road dust. The potential likely contribution of these sources to ambient PM_{10} and $PM_{2.5}$ concentrations is discussed in the following sections.

6.1 Secondary particulate

Secondary particulate is created when precursor gases react to form particles. In Auckland, it is likely that secondary particulate will be dominated by nitrates (from the reaction of nitrogen oxides) and sulphates (from the reaction of sulphur dioxide).

Secondary particulate can be estimated through receptor modelling or advanced airshed modelling studies or can be measured directly. Recently, source apportionment studies have provided information about secondary sulphates in Auckland (Davy, Trompetter and Markwitz 2011). However, secondary nitrates and secondary organic aerosols in Auckland still need further investigations. Research is also needed to incorporate estimates of secondary particulate into the emission inventories, as the production of secondary particulate can occur at locations away from the precursor sources.

Secondary particulate in Auckland is expected to be primarily nitrates resulting from the emissions of NOx from motor vehicles and sulphates from industry, shipping or natural sources. There may also be a contribution from rural sources (e.g., nitrogen fertilisers).

6.2 Sea salt and wind blown dust

Natural sources of PM_{10} and $PM_{2.5}$ can include volcanoes, sea salt, pollens, fungal spores and wind blown dust. Natural sources are difficult to quantify both in terms of their magnitude, emission rate and temporal emission characteristics. Many sources of natural particles are produced by complex processes and are best described through atmospheric measurements and source apportionment studies (DEFRA 2005). Source apportionment work has been undertaken in Auckland (Davy, Trompetter and Markwitz 2011), the results of which can be incorporated into future inventories for contributions from sea salt and wind blown dust.

6.3 Other unaccounted sources

Particles can be generated by vehicle movements through:

- exhaust emissions;
- tyre wear;
- brake wear;
- clutch wear;
- road surface wear;
- re-suspended particulate;
- corrosion of vehicle components street furniture and crash barriers.

These processes can lead to the deposition of particles on the road surface. The material that collects on the road surface (road dust) can also include deposited particles from non-transport sources. Road dust may be subsequently suspended or re-suspended in the atmosphere as a result of tyre shear, vehicle-generated turbulence, and wind.

The emissions inventory estimates emissions from exhaust, brake wear and tyre wear as described in Section 3. There is still a degree of uncertainty on these amounts, and their fractional contribution to ambient PM_{10} and $PM_{2.5}$ concentrations. The emitted amounts depend on road surface types, driving conditions, driving behaviour, vehicle fleet profiles, etc. These factors can vary significantly between countries and even between cities in New Zealand. Other sources of PM_{10} from transport are not estimated in this emissions inventory, e.g., road dust.

A recent review of PM_{10} sources in the UK concluded that the re-suspended component of PM_{10} can be as large, and in some cases much larger than exhaust emissions (DEFRA 2005). However, because the significance of re-suspension is governed by many factors (e.g., vehicle type, road surface condition, meteorological conditions), resuspended material is highly variable in terms of its source emission rate and is difficult to quantify with any certainty. There is also a potential difficulty with double counting in inventories since a proportion of PM_{10} assumed to be re-suspended in origin might have already been accounted for elsewhere (for instance, PM_{10} from domestic heating deposited on the road).

Re-suspended road dust was estimated for Auckland in the 1998 emissions inventory using USEPA emissions factors. This resulted in an estimated annual emission of PM_{10} of over 5,000 tonnes per annum in 1998 (EPAV, 2005), which would amount to approximately 50 per cent of annual total PM_{10} emissions in the region. Given the extremely high level of uncertainty in estimating re-suspended road dust with emissions inventory techniques, it is considered more appropriate to estimate the unaccounted portion of road dust based on source apportionment, examination of ambient monitoring results and receptor modelling techniques in future inventory.

Emissions from unconsented industrial/commercial combustion sources may be significant. An investigation is needed to estimate their contributions.

6.4 Likely contribution of unaccounted emissions to ambient particulate

Unaccounted emissions, including secondary particulate, sea salt, wind blown dust and road dust, contribute to ambient levels of PM_{10} and $PM_{2.5}$. Emissions from natural sources are not expected to reduce over time, so it is important to understand their likely contribution to ambient air pollution levels, especially on high pollution days. This understanding is necessary in order to predict the reduction required in PM_{10} and $PM_{2.5}$ emissions (from transport/domestic/industry sources) to meet the required targets.

Source apportionment studies in Auckland have provided useful information about the source contributions, including unaccounted emissions, to ambient particulate (Davy, Trompetter and Markwitz 2011). The studies show five common source contributors (biomass burning, secondary sulphate, crustal matter, motor vehicle emissions and marine aerosol) for $PM_{2.5}$ and PM_{10}. For $PM_{2.5}$, biomass burning and motor vehicle emissions are the dominant sources during winter. Motor vehicle emissions are the primary source contributor during other seasons. Secondary sulphate and marine aerosol concentrations are highest during the summer. Crustal matter is present as a minor contributor at all sites except for Penrose where the crustal matter component includes contributions from nearby industries. For PM_{10}, biomass burning and motor vehicle emissions are the primary sources during winter at all sites with motor vehicle emissions dominating at roadside monitoring locations (Queen Street and Khyber Pass Road) and biomass burning at residential locations. For other seasons those sources with airborne particles mainly in the coarse fraction (marine aerosoland crustal matter) have higher mass contributions, particularly in the case of marine aerosol which dominates source contributions at times. Secondary sulphate mass contributions to PM_{10} are similar to that for $PM_{2.5}$.

Further work is needed to incorporate these resutls into the emission inventories. In addition, ambient monitoring data and results of remote sensing of vehicle emissions can be used to validate the emissions inventories.

Meterorological conditions significantly influence ambient air quality, and are expected to affect the magnitude of unaccounted sources. Estimation of unaccounted emissions is still uncertain and requires significant further work.

7 Conclusions and recommendations

7.1 Conclusions

Key results

The annual estimates of the total emissions across the Auckland region in 2006 of the seven contaminants are as follows:

- 3,170 t/yr PM_{10} (38 per cent transport, 47 per cent domestic, 15 per cent industry)
- 3,000 t/yr $PM_{2.5}$ (39 per cent transport, 50 per cent domestic, 11 per cent industry)
- 20,800 t/yr NOx (79 per cent transport, 16 per cent industry, 4 per cent biogenic)
- 113,000 t/yr CO (86 per cent transport, 12 per cent domestic, 2 per cent industry)
- 32,700 t/yr VOC (22 per cent transport, 40 per cent industry, 24 per cent biogenic, 14 per cent domestic)
- 2,830 t/yr SO_2 (51 per cent transport, 46 per cent industry, 2 per cent domestic)
- 8,590 kt/yr CO_2 (40 per cent transport, 50 per cent industry, 10 per cent domestic)

For PM_{10}, 73 per cent of the emissions occur in the urban area. Emissions vary significantly with season both in terms of the amount as well as the relative contributions of sources. PM_{10} emissions on a typical winter weekday (18.0 t/day) are nearly four times those of a typical summer weekday (4.8 t/day). Domestic sources (principally domestic heating) account for 75 per cent of PM_{10} on a typical winter weekday (June-August) but fall to five per cent of PM_{10} on a summer weekday (December-February).

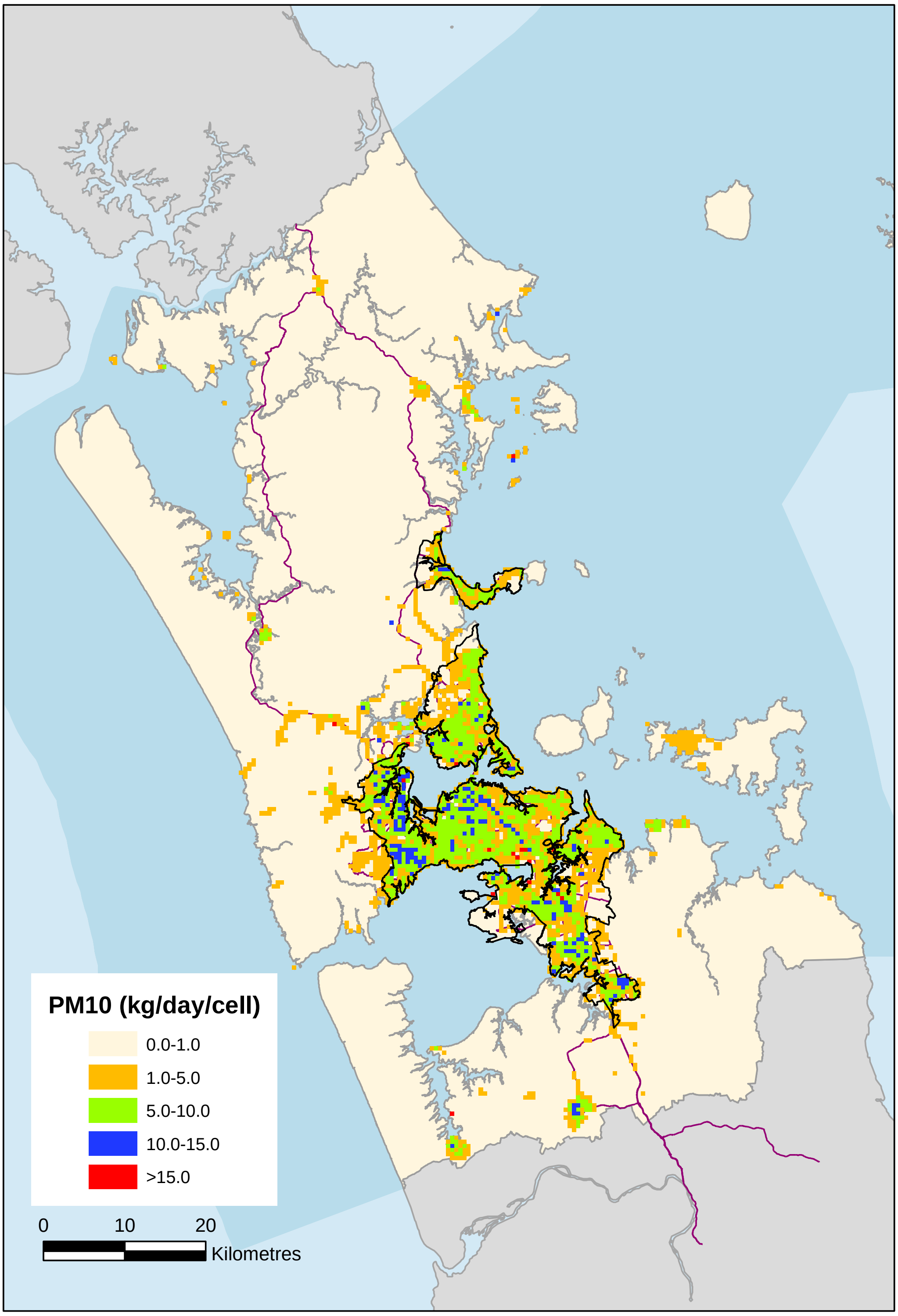


Figure 7.1 Spatial distribution of total PM_{10} emissions in winter from home heating, vehicle and industrial sources at 500m x 500m grid cells for 2006

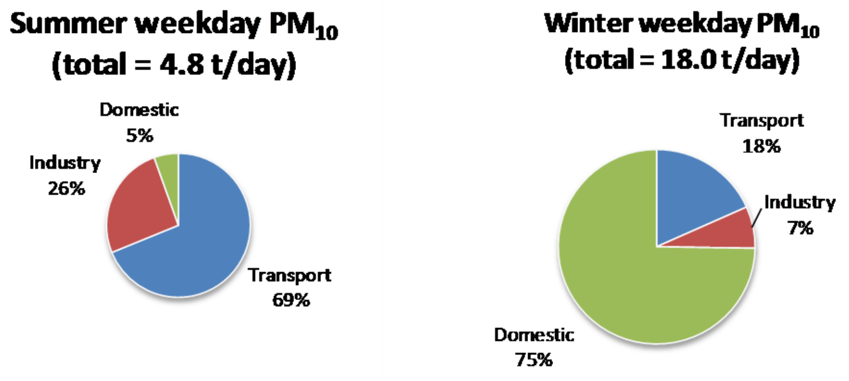


Figure 7.2 Seasonal variation of PM_{10} emissions for a typical summer and winter weekday

Domestic sources contribute to 75 per cent of PM_{10} emissions on a typical winter weekday, while only contributing to five per cent of PM_{10} emissions on a typical summer weekday (Figure 7.2). Transport is the biggest source of PM_{10} emissions in summer, contributing to 69 per cent of PM_{10} emissions on a typical summer weekday (Figure 7.2).

Key trends

The emissions estimates for 2001, 2006 and 2011 indicate that:

- CO emissions have fallen and are predicted to continue to fall in future, mainly due to increasing numbers of vehicles in the fleet with improved vehicle technology and emission control equipment.
- CO_2 emissions have risen and are predicted to continue to rise in future, mainly due to increased fuel consumption resulting from increased numbers of vehicles in the region and increased vehicle kilometres travelled.

- NOx emissions have decreased slightly despite an increase in vehicle kilometres travelled, but this can be attributed to the improved vehicle control technology.
- SO_2 emissions have reduced slightly, mainly due to reduced sulphur levels in fuel, but may increase in future due to increased shipping movements.
- PM_{10}, $PM_{2.5}$ and VOC emissions have fallen slightly, mainly due to a shift away from coal and wood for both domestic heating and industrial use, and are predicted to fall in future with fuel and technology improvements.

Uncertainties

There are other potentially significant sources of PM_{10} that are not estimated by the current inventory, including secondary particulates, sea salt, and wind blown or re-suspended dust. However, some studies, such as source apportionment in Auckland (Davy, Trompetter and Markwitz 2011), can provide information about the significance of these sources. Further work is necessary to validate assumptions in the existing inventory and confirm key trends.

Uncertainties have not been quantified for this emissions inventory because in most cases quantitative information is not available. The emissions inventory (and previous inventories) indicates that domestic fires and motor vehicles are the predominant sources of PM_{10} on an annual basis, and that domestic fires contribute to an even higher proportion in winter. As the emissions inventory is improved and refined, the proportions attributable to these sources may change, however the overall conclusion will probably not change.

7.2 Recommendations for future work

Unaccounted emissions

Unaccounted emissions cannot be quantified with any certainty based on current information, except for emissions from non-consented industry which could be estimated by some approaches. In order to provide an estimate, studies on source apportionment, detailed analysis of ambient monitoring, meteorological monitoring and atmospheric modelling studies are being undertaken.

Source apportionment

Source apportionment analysis, conducted appropriately, can provide further information on the causes of high pollution events. Measurement of PM_{10} composition is one way to validate the results of the emissions inventory and trends in individual sources. Significant geographical variation in home heating trends can occur in the Auckland region, and separate analysis will be required in several locations.

Vehicle emissions estimation

Analysis undertaken for the emissions inventory highlights the need to validate inventory results to determine whether emission trends predicted are realistic and being observed in monitoring data trends especially at traffic monitoring sites.

Domestic heating emissions estimation

In order to improve certainty in emission estimates, further work is needed with regards to tracking unused open fires or woodburners, removal or installations of woodburners and open fires and the types of new burners being installed. These can be achieved by conducting a repeat of the home heating survey.

A real-life emission testing programme is also required for woodburners and other new appliances. This is particularly important, especially in the case of the current NES post-2005 woodburners as this would test burner performance with changes over time.

8 Acknowledgements

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10 Glossary

Terms	Description
Airshed	A geographic area established to manage air pollution within the area as defined by the national environmental standard for air quality.
Anthropogenic	Emissions generated by man-made activities, such as the combustion of fuels.
ARP:ALW	Auckland Regional Plan: Air Land and Water
NES	Ministry for the Environment's national environmental standards for air quality
Biogenic	A category of air emission sources which include emissions of nitrogen oxides (NOx) and volatile organic compounds (VOC) from vegetation and soils
CO	Carbon monoxide, a type of air pollutant
CO_2	Carbon dioxide, a type of greenhouse gas
DFEPM	Domestic fire emission prediction model
Multifuel burner	A fully enclosed domestic heating device that is designed for burning coal as well as wood
NES woodburner	A woodburner that meets the Ministry for the Environment's national environmental standards for air quality requirements
NO_2	Nitrogen dioxide, a type of air pollutant
Open fire	An indoor heating device capable of burning wood or coal, including fireplaces, open hearths and visors. Excludes enclosed heating devices such as woodburners, pot belly stoves and the like.
Pellet burner	An indoor heating device that burns pellets of compressed

	wood sawdust, and where the pellets and air are mechanically delivered to an enclosed combustion chamber at a controlled rate.
PM_{10}, $PM_{2.5}$	Fine particles less than 10 microns and 2.5 microns in diameter respectively, a type of air pollutant
SO_2	Sulphur dioxide, a type of air pollutant
Solid fuel heating	Heating homes in winter by burning wood or coal
VEPM	Vehicle emission prediction model
VOC	Volatile Organic Compounds, a type of air pollutant
Woodburner	A fully enclosed domestic heating device designed for burning wood (as defined in the national environmental standard for air quality)

11 Appendix 1: Summary Tables

Table A1.1. Summary of annual emissions 2006 (entire region)

Source	CO (t/yr)	% of total	CO_2 (kT/yr)	% of total	NOx (t/yr)	% of total	SO_2 (t/yr)	% of total	PM_{10} (t/yr)	% of total	$PM_{2.5}$ (t/yr)	% of total	VOC (t/yr)	% of total
Motor vehicles	90,875	80%	2,990	35%	11,525	55%	236	8%	854	27%	823	27%	5,018	15%
Shipping	732	1%	106	1%	1,812	9%	1,003	35%	137	4%	134	4%	316	1%
Aircraft	2,508	2%	192	2%	870	4%	59	2%	69	2%	69	2%	604	2%
Railway locomotives	388	0%	62	1%	1,256	6%	130	5%	76	2%	74	2%	376	1%
Off-road mobile vehicles	333	0%	46	1%	818	4%	3	0%	65	2%	60	2%	72	0%
Pleasure craft	2,315	2%	27	0%	195	1%	17	1%	11	0%	11	0%	639	2%
Road laying	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	115	0%
Transport Subtotal	**97,151**	**86%**	**3,423**	**40%**	**16,476**	**79%**	**1,448**	**51%**	**1,213**	**38%**	**1,171**	**39%**	**7,139**	**22%**
Consented industry	2,609	2%	4,163	48%	3,169	15%	1,311	46%	454	14%	321	11%	4,105	13%
Surface coatings & thinner	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1,081	3%
Aerosols & solvent use	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	4,467	14%
Dry cleaning	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Service stations	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	2,803	9%
Gas leakage	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	680	2%
Commercial gas	19	0%	119	1%	90	0%	1	0%	11	0%	11	0%	3	0%
Industry Subtotal	**2,627**	**2%**	**4,283**	**50%**	**3,259**	**16%**	**1,312**	**46%**	**465**	**15%**	**332**	**11%**	**13,140**	**40%**
Home Heating - wood	12,093	11%	282	3%	118	1%	31	1%	1,373	43%	1,373	46%	4,220	13%
Home heating - coal	159	0%	4	0%	5	0%	5	0%	34	1%	34	1%	26	0%
Outdoor burning	311	0%	13	0%	22	0%	4	0%	58	2%	55	2%	111	0%
LPG use	5	0%	67	1%	35	0%	0	0%	16	1%	16	1%	5	0%
Natural gas use	24	0%	102	1%	83	0%	1	0%	10	0%	10	0%	6	0%

Lawn mowing	912	1%	1	0%	7	0%	0	0%	4	0.1%	4	0%	170	1%
Domestic Subtotal	**13,503**	**12%**	**469**	**6%**	**270**	**1%**	**41**	**1%**	**1,495**	**47%**	**1,492**	**50%**	**4,539**	**14%**
Biogenic	0	0%	0	0%	807	4%	0	0%	0	0%	0	0%	7,874	24%
Total	**113,281**	**100%**	**8,174**	**100%**	**20,812**	**100%**	**2,800**	**100%**	**3,172**	**100%**	**2,995**	**100%**	**32,693**	**100%**

Table A1.2. Summary of annual emissions 2001 (entire region)

Source	CO (t/yr)	% of total	CO_2 (kT/yr)	% of total	NOx (t/yr)	% of total	SO_2 (t/yr)	% of total	PM_{10} (t/yr)	% of total	$PM_{2.5}$ (t/yr)	% of total	VOC (t/yr)	% of total
Motor vehicles	109,735	79%	2,588	33%	13,629	57%	211	7%	903	25%	874	27%	7,102	18%
Shipping	180	0%	95	1%	1,870	8%	1,450	46%	190	5%	190	6%	60	0%
Aircraft	2,337	2%	179	2%	811	3%	55	2%	65	2%	64	2%	563	1%
Railway locomotives	283	0%	45	1%	916	4%	95	3%	56	2%	54	2%	274	1%
Off-road mobile vehicles	5,208	4%	41	1%	742	3%	27	1%	14	0%	13	0%	582	2%
Pleasure craft	2,059	1%	24	0%	173	1%	15	0%	10	0%	10	0%	568	1%
Road laying	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	155	0%
Transport Subtotal	**119,801**	**87%**	**2,972**	**38%**	**18,142**	**76%**	**1,853**	**58%**	**1,237**	**34%**	**1,205**	**37%**	**9,304**	**24%**
Consented industry	3,440	2%	3,959	50%	4,510	19%	1,250	39%	780	21%	410	13%	3,940	10%
Surface coatings & thinner	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	4,324	11%
Aerosols & solvent use	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	3,973	10%
Dry cleaning	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	209	1%
Service stations	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	2,682	7%
Gas leakage	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	688	2%
Commercial gas	18	0%	115	1%	87	0%	1	0%	10	0%	10	0%	3	0%
Industry Subtotal	**3,458**	**2%**	**4,074**	**54%**	**4,597**	**19%**	**1,251**	**40%**	**790**	**21%**	**420**	**13%**	**15,819**	**41%**
Home Heating - wood	13,570	10%	291	2%	131	1%	32	1%	1,513	41%	1,513	46%	4,750	12%

Home heating - coal	159	0%	4	0%	5	0%	5	0%	34	1%	34	1%	26	0%
Outdoor burning	422	0%	17	0%	30	0%	5	0%	79	2%	75	2%	151	0%
LPG use	3	0%	47	1%	25	0%	0	0%	11	0%	11	0%	4	0%
Natural gas use	27	0%	80	1%	62	0%	0	0%	8	0%	8	0%	5	0%
Lawn mowing	944	1%	1	0%	6	0%	0	0%	5	0%	5	0%	204	1%
Domestic Subtotal	**15,125**	**11%**	**441**	**6%**	**295**	**1%**	**43**	**1%**	**1,650**	**45%**	**1,646**	**50%**	**5,139**	**13%**
Biogenic	0	0%	0	0%	950	4%	0	0%	0	0%	0	0%	8,280	21%
Total	**138,384**	**100%**	**7,487**	**100%**	**23,948**	**100%**	**3,146**	**100%**	**3,678**	**100%**	**3,271**	**100%**	**38,542**	**100%**

Table A1.3. Summary of annual emissions 2011 (entire region)

Source	CO (t/yr)	% of total	CO_2 (kT/yr)	% of total	NOx (t/yr)	% of total	SO_2 (t/yr)	% of total	PM_{10} (t/yr)	% of total	$PM_{2.5}$ (t/yr)	% of total	VOC (t/yr)	% of total
Motor vehicles	66,697	77%	3,095	36%	9,845	48%	239	8%	727	26%	694	27%	3,665	11%
Shipping	753	1%	117	1%	1,913	9%	1,214	40%	158	6%	154	6%	313	1%
Aircraft	2,429	3%	186	2%	843	4%	57	2%	67	2%	67	3%	585	2%
Railway locomotives	511	1%	82	1%	1,657	8%	172	6%	101	4%	98	4%	495	2%
Off-road mobile vehicles	379	0%	52	1%	931	5%	3	0%	74	3%	68	3%	82	0%
Pleasure craft	2,634	3%	30	0%	222	1%	19	1%	12	0%	12	0%	727	2%
Road laying	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	78	0%
Transport Subtotal	**73,404**	**85%**	**3,563**	**41%**	**15,410**	**75%**	**1,704**	**57%**	**1,138**	**41%**	**1,094**	**42%**	**5,946**	**19%**
Consented industry	2,393	3%	4,021	49%	3,778	19%	1,245	41%	410	15%	301	22%	4,089	11%
Surface coatings & thinner	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	4,324	11%
Aerosols & solvent use	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	3,973	10%
Dry cleaning	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	209	1%

Service stations	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	2,682	7%
Gas leakage	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	688	2%
Commercial gas	21	0%	137	2%	103	1%	1	0%	12	0%	12	0%	4	0%
Industry Subtotal	**2,414**	**3%**	**4,158**	**48%**	**3,881**	**19%**	**1,245**	**41%**	**422**	**15%**	**314**	**12%**	**14,203**	**44%**
Home Heating - wood	9,218	11%	272	3%	98	0%	30	1%	1,092	40%	1,092	42%	3,312	10%
Home heating - coal	159	0%	4	0%	5	0%	5	0%	34	1%	34	1%	26	0%
Outdoor burning	200	0%	8	0%	14	0%	2	0%	37	1%	36	1%	71	0%
LPG use	6	0%	80	1%	41	0%	0	0%	19	1%	19	1%	6	0%
Natural gas use	40	0%	120	1%	94	0%	1	0%	11	0%	11	0%	7	0%
Lawn mowing	893	1%	1	0%	7	0%	0	0%	3	0%	3	0%	150	0%
Domestic Subtotal	**10,515**	**12%**	**486**	**6%**	**259**	**1%**	**38**	**1%**	**1,198**	**43%**	**1,196**	**46%**	**3,573**	**11%**
Biogenic	0	0%	0	0%	950	5%	0	0%	0	0%	0	0%	8,280	26%
Total	**86,334**	**100%**	**8,206**	**100%**	**20,501**	**100%**	**2,988**	**100%**	**2,758**	**100%**	**2,603**	**100%**	**32,002**	**100%**