Auckland Air Emissions Inventory 2016

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December 2019 Technical Report 2019/024

RIMU Research and Evaluation Unit

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Executive summary

Air pollution causes adverse health effects such as asthma, lung and heart conditions. To improve air quality, we must reduce air emissions. Auckland Council is responsible for the management of air quality in the Auckland region.

An air emissions inventory identifies and quantifies sources of air pollution and their trends. It provides a useful tool to determine major sources of air pollutants, and to evaluate our progress in reducing air pollution.

The *Auckland air emissions inventory* was last updated in 2014 for the base year of 2006. Over the last decade, Auckland Council and Central Government have invested significant resources towards improving Auckland's transport infrastructure, including motorways and public transport services. More people have chosen cleaner methods to warm their homes in winter. Some industries have closed, and others have installed better air pollution controls. While these changes have seen positive results, they are offset by the rate of growth in the region.

This inventory is therefore to assess how the changes in the Auckland region have impacted on emissions in the region. The main sources of air pollution in Auckland are from transport, domestic sources and industrial discharges. Emissions for 2016 and trends from these sources have been reported separately using the best available activity data and emission factors. This inventory is to summarise and integrate these reports to present an overall picture of air emissions and trends.

Total emissions from anthropogenic sources across the Auckland region in 2016 for seven common air pollutants and greenhouse gas are approximately:

- 3820 t/yrs. particulate matter <10µm in diameter (PM_{10}) (57.0% transport, 34.9% domestic, 8.0% industry) with 44.2 per cent from the urban area
- 2719 t/yr particulate matter <2.5µm in diameter ($PM_{2.5}$) (40.9% transport, 48.8% domestic, 10.3% industry) with 56.0 per cent from the urban area
- 65,757 t/yr carbon monoxide (CO) (66.8% transport, 28.1% domestic, 5.2% industry) with 65.6 per cent from the urban area
- 6852 kt/yr carbon dioxide (CO_2) (59.1% transport, 6.6% domestic, 34.3% industry) with 49.4 per cent from the urban area
- 20,520 t/yr oxides of nitrogen (NOx) (85.6% transport, 1.3% domestic, 13.1% industry) with 58.4 per cent from the urban area
- 2657 t/yr sulphur dioxide (SO_2) (59.2% transport, 1.5% domestic, 39.3% industry) with 29.6 per cent from the urban area

- 9109 t/yr volatile organic compounds (VOCs) (43.7% transport, 50.3% domestic, 6.1% industry) with 68.0 per cent from the urban area.

This inventory focuses primarily on PM_{10} and $PM_{2.5}$ because, of all the air pollutants that are measured in Auckland, fine particles (PM_{10} and $PM_{2.5}$) are still of most concern.

Across the region, transport is the biggest source for most pollutants (i.e., CO, CO_2, NOx, SO_2 and PM_{10}). Domestic sources, ie, home heating, cooking, lawn mowing and outdoor burning, are the biggest contributors to $PM_{2.5}$ and VOCs emissions. This is because nearly half of $PM_{2.5}$ (45.0%) and VOCs (48.3%) comes from wood burning used for home heating. The contribution of emissions from the urban area to regional emissions varies from pollutant to pollutant, ranging from 29.6 per cent for SO_2 to 68.0 per cent for VOCs. In the urban area, transport is also the biggest source for CO, CO_2, NOx and SO_2. Domestic sources are the biggest contributor to PM_{10}, $PM_{2.5}$ and VOCs emissions.

Seasonal variations in emissions are significant, both in terms of the amount as well as the relative contributions of sources. Transport and industrial activities are constant throughout the year, while domestic home heating is mainly for the winter season only. In summer, transport is the dominant source for all pollutants. In winter, domestic sources overtake transport as the dominant sector for CO, PM_{10}, $PM_{2.5}$ and VOCs.

From 2001 to 2016, emissions of air pollutants from transport, domestic and industrial sectors have decreased due to a downward trend in emissions from motor vehicles and domestic home heating. PM_{10} and $PM_{2.5}$ emissions have decreased by 18.7 per cent and 22.4 per cent between 2006 and 2016. The monitored PM_{10} and $PM_{2.5}$ ambient concentrations have shown a downward trend since regular measurements began in the late 1990s and met air quality standards and guidelines since 2014 and 2015, respectively. However, there were PM_{10} and $PM_{2.5}$ exceedances in 2019 due to the fire at the New Zealand International Convention Centre (NZICC) construction site, and Australian dust storms and bush fires. CO_2 emissions have fallen since 2006 mainly due to reduced industrial activities (therefore emissions). However, this has been partly offset with an increase in vehicle emissions.

Uncertainty in total emissions estimates is not assessed due to the different methods used for the uncertainty analysis of land and air transport, sea transport, domestic and industrial sources. This can be improved when consistent methods are applied for uncertainty analysis for these sources.

1.0 Introduction

Air quality is affected by emissions discharged into the air. Air pollution causes adverse health effects such as asthma, lung and heart conditions. In order to further improve air quality, we must reduce air emissions. Auckland Council is responsible for the management of air quality in the Auckland region. A suite of strategic plans and statutory regulations require the council to ensure ambient air is clean and healthy to breathe:

- The Resource Management Act 1991
- The National Environmental Standards for Air Quality 2004
- The Auckland Plan 2050
- The Auckland Unitary Plan.

An air emissions inventory identifies and quantifies sources of air pollution and their trends. It is used to:

- determine major sources of air pollutants
- assess if emissions have improved, remained the same, or deteriorated over the reporting period
- provide input for air pollution dispersion and exposure modelling
- inform the efficacy and efficiency of mitigation measures and policy initiatives and strategies.

The main sources of air pollution in Auckland are from transport, domestic sources and industrial discharges. The source-based inventories for 2016 are reported separately for land and air transport (Sridhar and Metcalfe, 2019), home heating (Metcalfe *et al*., 2018), sea transport (Peeters, 2018) and industry (Crimmins, 2018). This report summarises and integrates these inventories to present an overall picture of air emissions and trends. Table 1-1 shows the sources covered and reported in this inventory.

Detailed emissions inventories provide a powerful tool for policy and science analysis. For example, the *Auckland air emissions inventory* has been used to assess likely exposure, health effects of air pollution and costs and benefits of mitigation for various policies (Nunns, 2015). It has also been used to estimate background air quality concentrations (at the census area unit level), for assessment of resource consent applications (Auckland Council, 2014a).

The *Auckland air emissions inventory* was last updated in 2014 for the base year of 2006 (hereafter referred to as the “2006 inventory”) and estimated that emissions from the transport sector contributed towards 38 per cent of total annual particulate matter less than 10 micrometres in diameter (PM_{10}) and 79 per cent of nitrogen oxide (NOx) emissions (Auckland Council, 2014b). This report provides Auckland air emissions for the base year of 2016.

Over the last decade, Auckland Council and the Government have invested significant resources towards improving Auckland’s motorways, arterials and local roads, and public transport services and infrastructure. More people have chosen cleaner methods to warm their homes in winter. There have been fewer industrial activities. While these changes have seen positive results, they are offset by the rate of growth in the region. In 2016 Auckland’s population (1.6 million) was almost 18 per cent higher than in 2006 and is projected to be 2.3 million by 2043 (Statistics NZ, 2017). This future growth will add more pressure and demand on existing infrastructure, resources, goods and services.

An update of the air emissions inventory is therefore necessary to assess how the changes in the Auckland region have impacted on emissions in the region. Figure 1-1 maps the spatial extent of the region for the purposes of this inventory. Emissions are aggregated for the whole region, also for the urban area (Auckland urban airshed) as the urban area is the focus of air quality management. Table 1-1 lists the ambient air pollutants and specific sources included in this inventory. Emissions are reported at the annual and seasonal levels, and backcast for 2001, 2006 and 2011 to provide an indicative analysis for trends.

Common air pollutants reported here are carbon monoxide (CO), oxides of nitrogen (NOx), sulphur dioxide (SO_2), particulate matter <10μm in diameter (PM_{10}), particulate matter <2.5μm in diameter ($PM_{2.5}$), and volatile organic compounds (VOCs) as shown in Table 1-1. While the greenhouse gas (GHG) carbon dioxide (CO_2) is also included, Auckland’s greenhouse gas inventory provides a more comprehensive report on GHG emissions and trends for the region (Xie, 2019). Emissions of other air pollutants in the Auckland region can be found elsewhere. Metcalfe *et al*. (2018) estimated emissions of arsenic, mercury, benzo(a)pyrene and dioxins and furans from home heating. Crimmins *et al*. (2019) reported on black carbon emissions for Auckland. This report primarily focuses on PM_{10} and $PM_{2.5}$ because, of all the air pollutants that are measured in Auckland, fine particles (PM_{10} and $PM_{2.5}$) are still of most concern (Auckland Council, 2016a).

In line with the national air emissions inventory (Metcalfe and Sridhar, 2018), this report focuses on anthropogenic sources, with omissions of several notable anthropogenic sources owing to a lack of data:

- VOCs emissions from consumer product uses, such as paints, furniture and building products;
- Combustion emissions from non-consented industrial and commercial facilities;
- Combustion emissions from small boats for recreational activities.

Emissions from biogenic sources (natural, vegetation and soils) were previously estimated in the 2006 inventory for NOx and VOCs (Auckland Council, 2006b). The contribution of sea salt, wind-blown dust and secondary particulate (generated when precursor gases react to form particles) to ambient particulate for 2006-2013 was assessed in the source apportionment study (Davy *et al*., 2016).

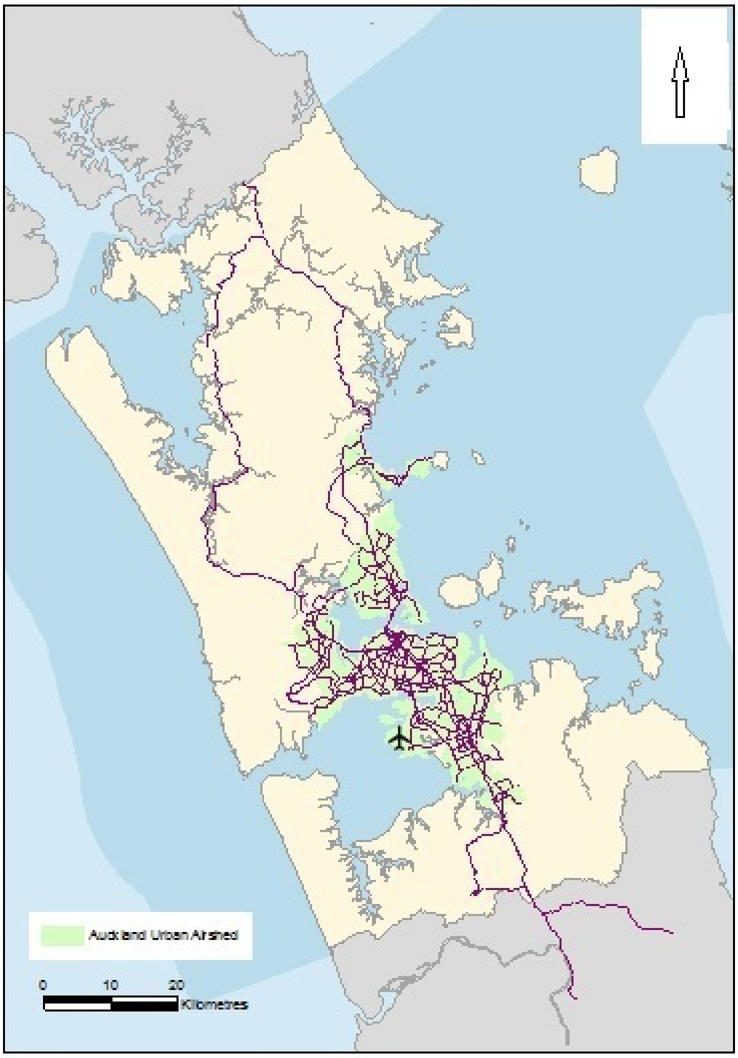


Figure 1-1: Spatial extent of the Auckland region

The structure of this report is as follows. Section 2 outlines the overall methodology for the estimation of emissions. The aggregated emissions and trends of all sources are presented in Section 3. The subsequent sections summarise emissions and methods of calculations for each source category: land and air transport (Section 4), sea transport (Section 5), domestic (Section 6) and industry (Section 7). Section 8 presents conclusions and recommendations.

Table 1-1: Pollutants and sources covered in this inventory

Pollutant	Source

• Carbon monoxide (CO)
• Carbon dioxide (CO_2)
• Oxides of nitrogen (NOx)
• Sulphur dioxide (SO_2)
• Particulate matter <10µm in diameter (PM_{10})
• Particulate matter <2.5µm in diameter ($PM_{2.5}$)
• Volatile organic compounds (VOCs)
	• Land and air transport (Sridhar and Metcalfe, 2019)
	  ○ Motor vehicles
	  ○ Aviation
	  ○ Rail
	  ○ Road dust (sealed and unsealed)
	  ○ Off-road vehicles
	  ○ Road laying
	• Sea transport (Peeters, 2018)
	• Domestic
	  ○ Home heating (Metcalfe *et al.*, 2018)
	  ○ Outdoor burning (this report)
	  ○ Lawn mowing (Sridhar and Metcalfe, 2019)
	• Industry
	  ○ Consented industry (Crimmins, 2018)
	  ○ Fishing (excluding recreational fishing) (Peeters, 2018)

2.0 Method

This section outlines the overall method for estimation of emissions and uncertainty. The detailed methodology and assumptions for each source category are described in the sections that follow.

Emissions are calculated by multiplying activity data by an emission factor associated with the activity. Activity data is a quantity of an activity that results in emissions during a given period of time (for example, vehicle kilometres travelled in a year). Activity data and emission factors come from a variety of sources and are described for each source category in the subsequent sections of this report. Emissions were estimated using the best available activity data and emission factors for each source and the associated uncertainty of emissions estimates.

Emission = Activity data x Emission factor

Typically, calculations generate a range of emission estimates. An uncertainty analysis helps prioritise efforts to improve the accuracy of inventories and guide decisions on methodological choice (IPCC, 2006). Uncertainty was estimated quantitatively for emissions calculations for land and air transport (Sridhar and Metcalfe, 2019), home heating (Metcalfe *et al*., 2018) and industry (Crimmins, 2018). This was undertaken according to the European emission inventory guidebook (hereafter referred to as the EMEP/EEA guidebook) (EEA, 2016). For PM_{10} emissions in 2016, uncertainty is estimated as approximately +/- 31 per cent for motor vehicles, +/- 38 per cent for home heating, and +/- 14 per cent for industry. For sea transport, uncertainty was estimated qualitatively only due to lack of detailed data for quantitative assessment (Peeters, 2018). This summary report does not provide an uncertainty analysis for total emissions since different methods were used for the estimation of uncertainty.

Emissions from each source category were also estimated for 2001, 2006 and 2011. It should be noted that because the methodology, emission factors, and activity data for the 2016 inventory may differ from previous inventories, the results may not be directly comparable. Therefore, the trends of total emissions analysed in this report should be considered as indicative only.

3.0 Total emissions and trends

In this section, total emissions from all sources together with emissions profiles and trends are presented in three sectors: transport, domestic and industrial. Emissions reductions are also discussed. Emissions and trends from individual sources are estimated in their respective source-based reports (Sridhar and Metcalfe, 2019; Peeters, 2018; Metcalfe *et al.*, 2018; Crimmins, 2018) and are summarised here in Tables A1.1 to A1.4 (Appendix A).

3.1 Emissions and sources

Emissions by sector and location

The total emissions across the entire Auckland region in 2016 are approximately:

- 3820 t/yr PM_{10} (57.0% transport, 34.9% domestic, 8.0% industry) with 44.2 per cent from the urban area
- 2719 t/yr $PM_{2.5}$ (40.9% transport, 48.8% domestic, 10.3% industry) with 56.0 per cent from the urban area
- 65,757 t/yr CO (66.8% transport, 28.1% domestic, 5.2% industry) with 65.6 per cent from the urban area
- 6852 kt/yr CO_2 (59.1% transport, 6.6% domestic, 34.3% industry) with 49.4 per cent from the urban area
- 20,520 t/yr NOx (85.6% transport, 1.3% domestic, 13.1% industry) with 58.4 per cent from the urban area
- 2657 t/yr SO_2 (59.2% transport, 1.5% domestic, 39.3% industry) with 29.6 per cent from the urban area
- 9109 t/yr VOCs (43.7% transport, 50.3% domestic, 6.1% industry) with 68.0 per cent from the urban area.

Across the region, transport is the biggest source for most pollutants (i.e., CO, CO_2, NOx, SO_2 and PM_{10}) (Figure 3-1). Domestic sources, ie, home heating, cooking, lawn mowing and outdoor burning, are the biggest contributor to $PM_{2.5}$ and VOCs emissions. This is because nearly half of $PM_{2.5}$ (45.0%) and VOCs (48.3%) comes from wood burning used for home heating. The contribution of emissions from the urban area to regional emissions varies from pollutant to pollutant, ranging from 29.6 per cent for SO_2 to 68.0 per cent for VOCs. In the urban area, transport is also the biggest source for CO, CO_2, NOx and SO_2. Domestic sources are the biggest contributor to PM_{10}, $PM_{2.5}$ and VOCs emissions. Figures 3-2 and 3-3 show more details about PM_{10} and $PM_{2.5}$ emissions profiles for the region and the urban area, respectively.

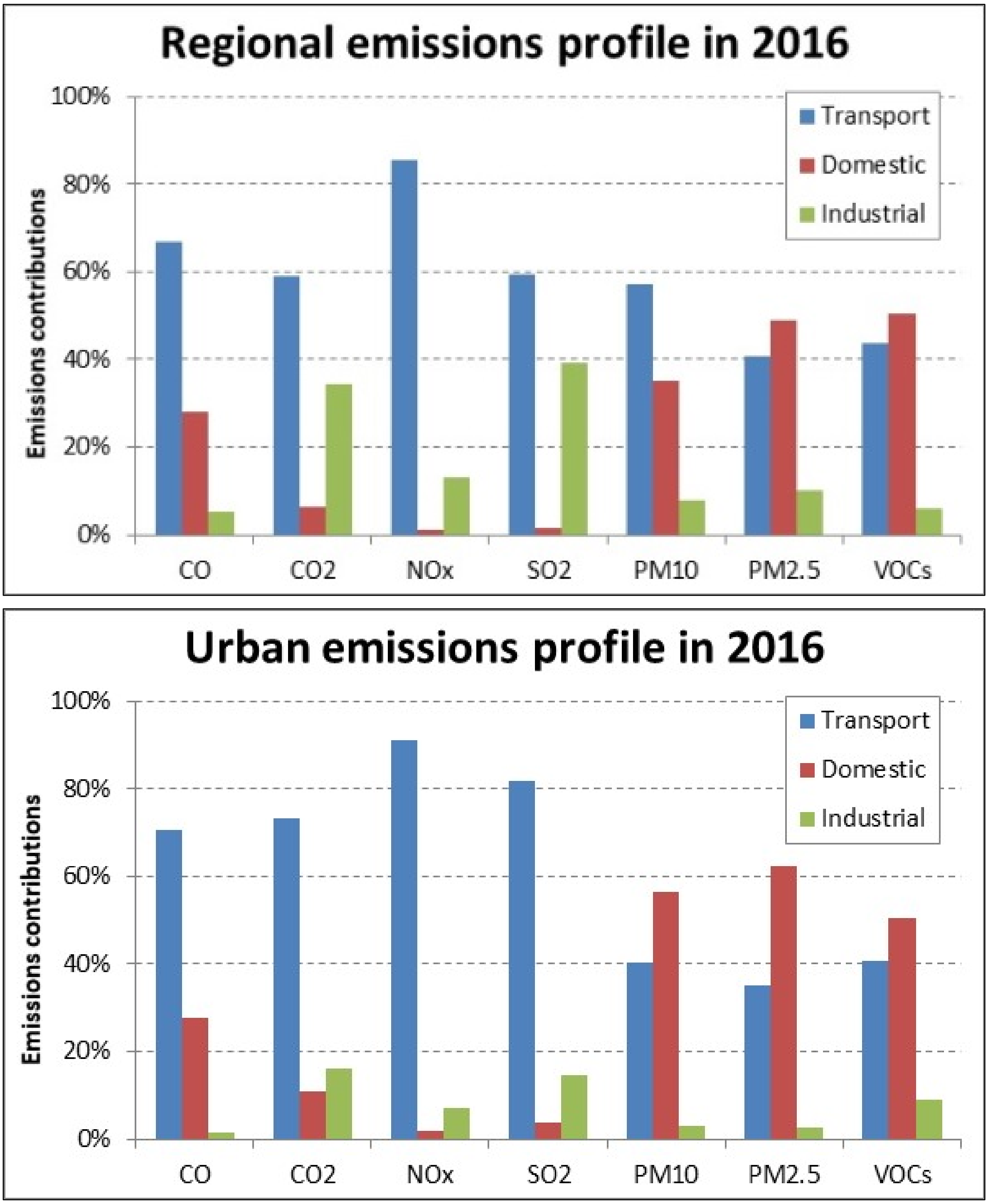


Figure 3-1: Total emissions profiles in 2016

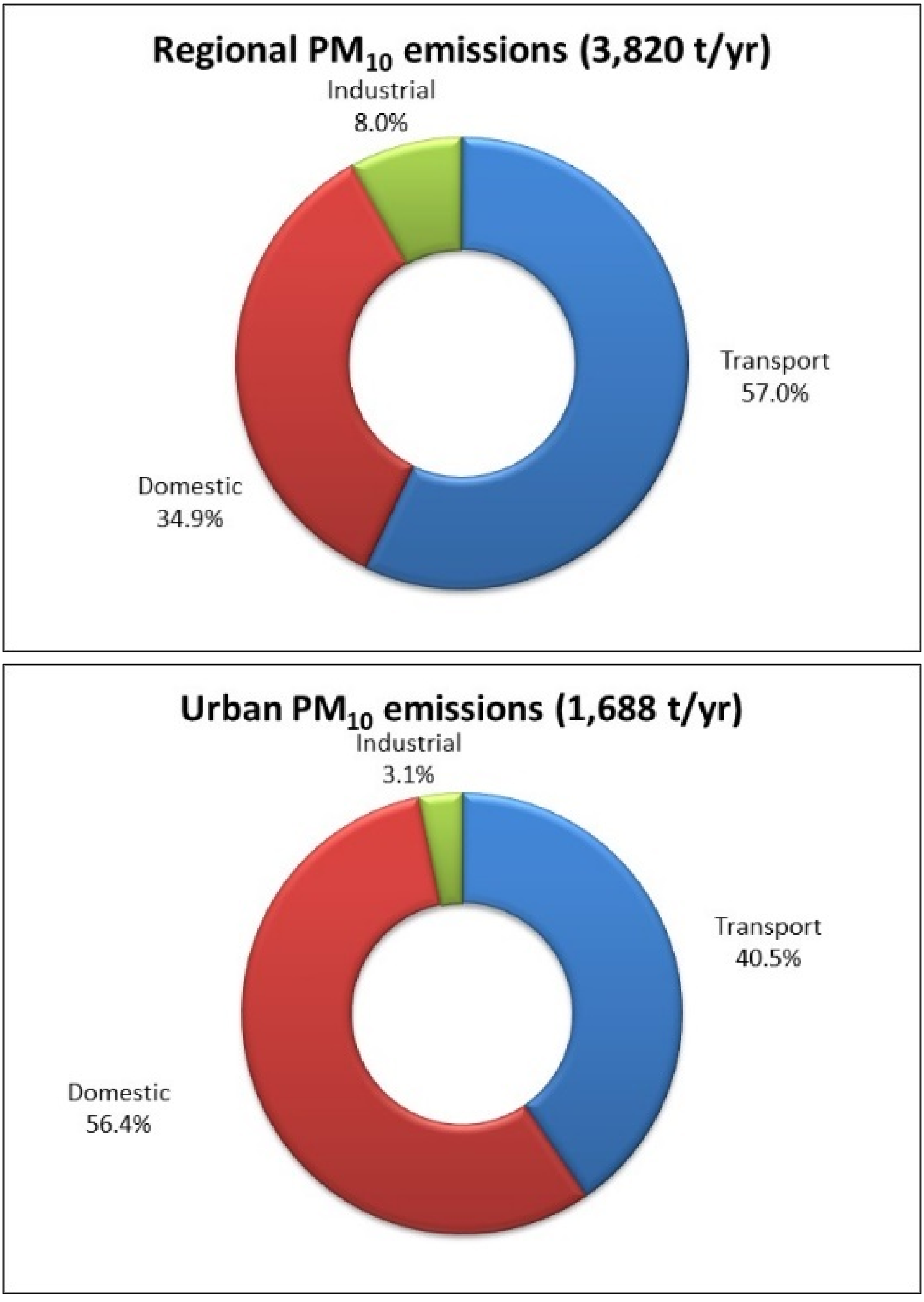


Figure 3-2: Total PM_{10} emissions profiles in 2016

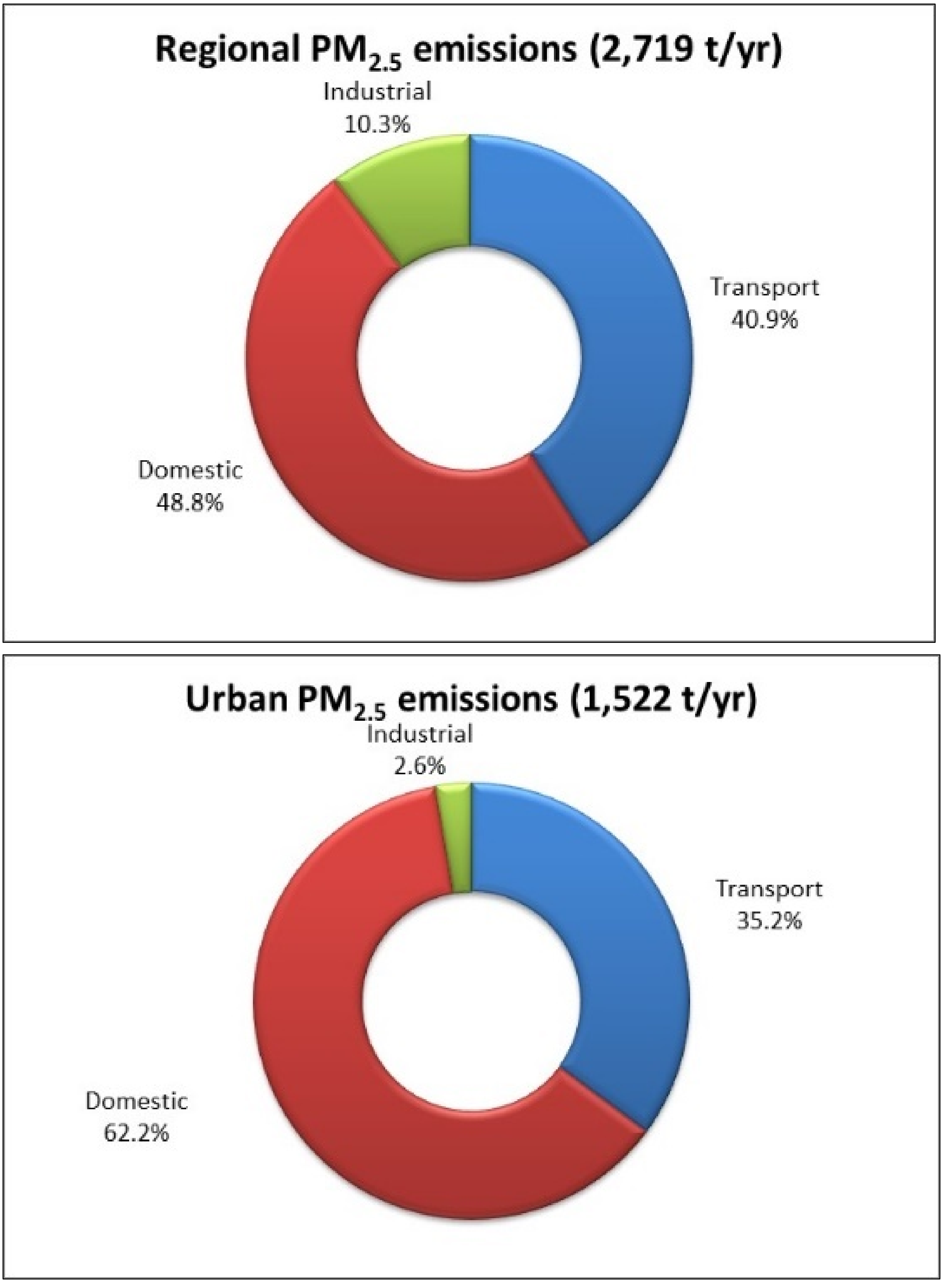


Figure 3-3: Total $PM_{2.5}$ emissions profiles in 2016

Emissions by season

Seasonal variations in emissions are significant, both in terms of the amount as well as the relative contributions of sources. Transport and industrial activities are fairly constant throughout the year while domestic home heating occurs mainly during the winter season only. This results in dominance of the transport sector for all pollutants in summer (Figure 3-4). In winter, domestic sources overtake transport as the dominant sector for CO, PM_{10}, $PM_{2.5}$ and VOCs (Figure 3-5). Regional and urban emissions profiles show a similar seasonal pattern.

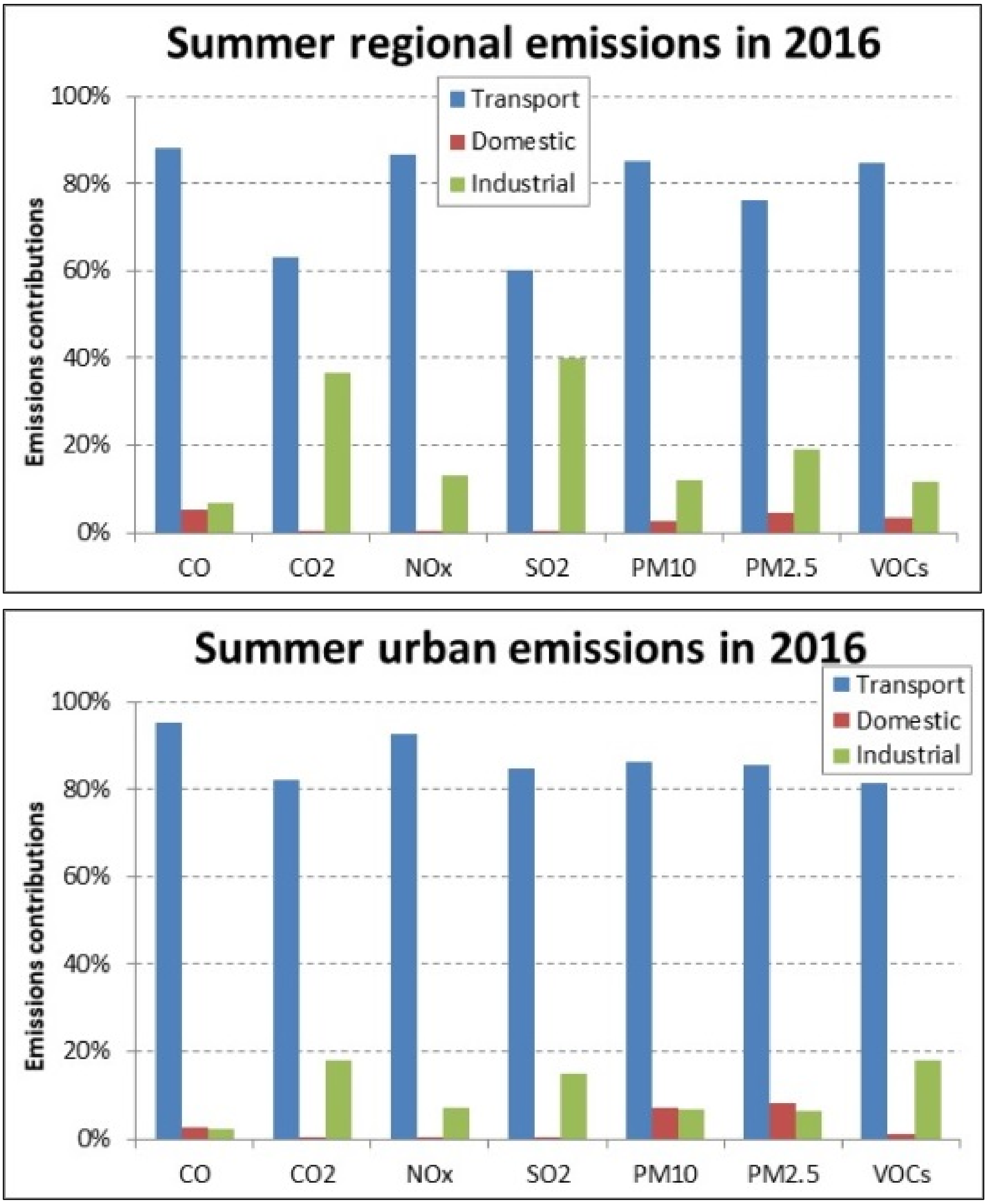


Figure 3-4: Summer emissions profiles in 2016

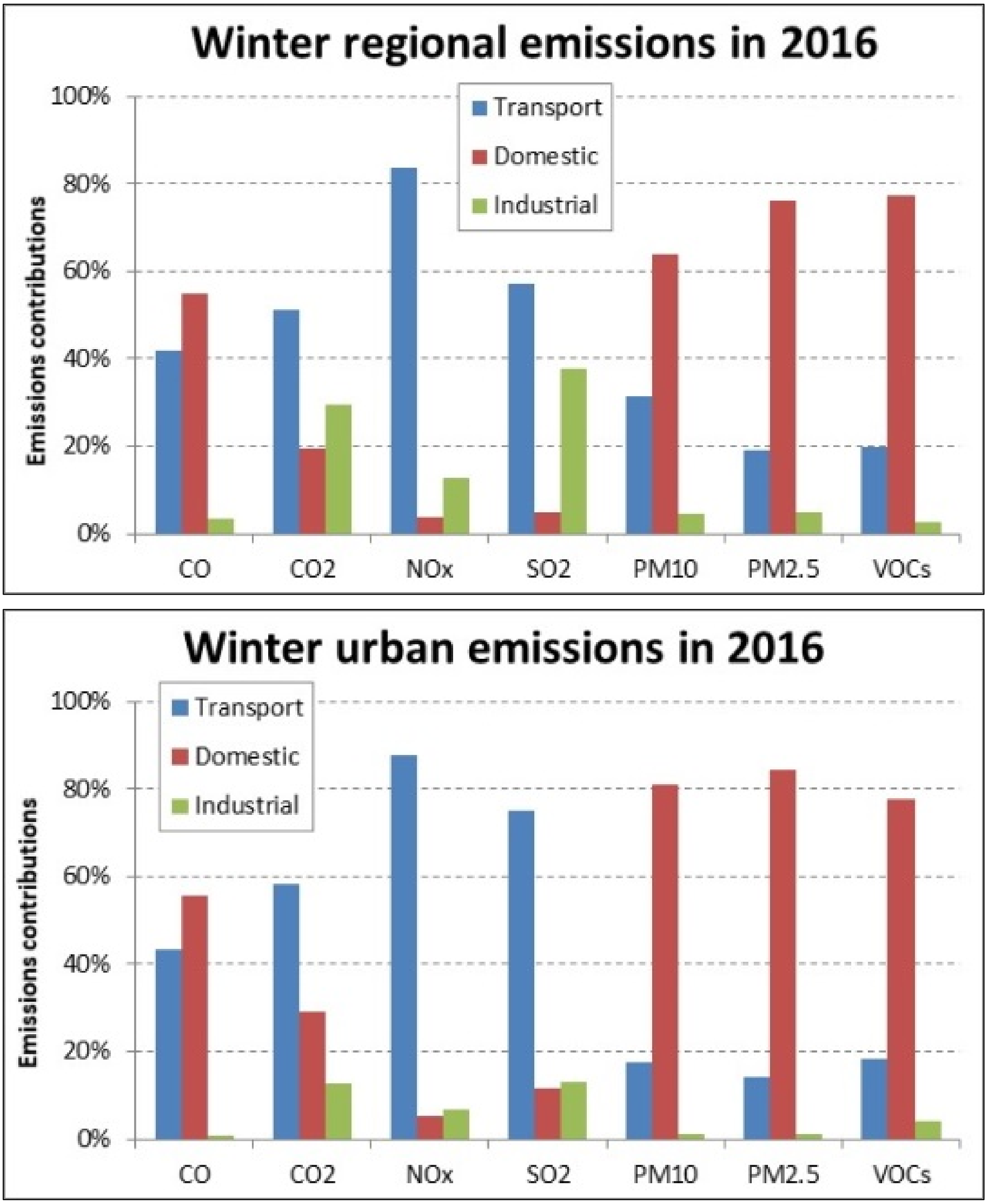
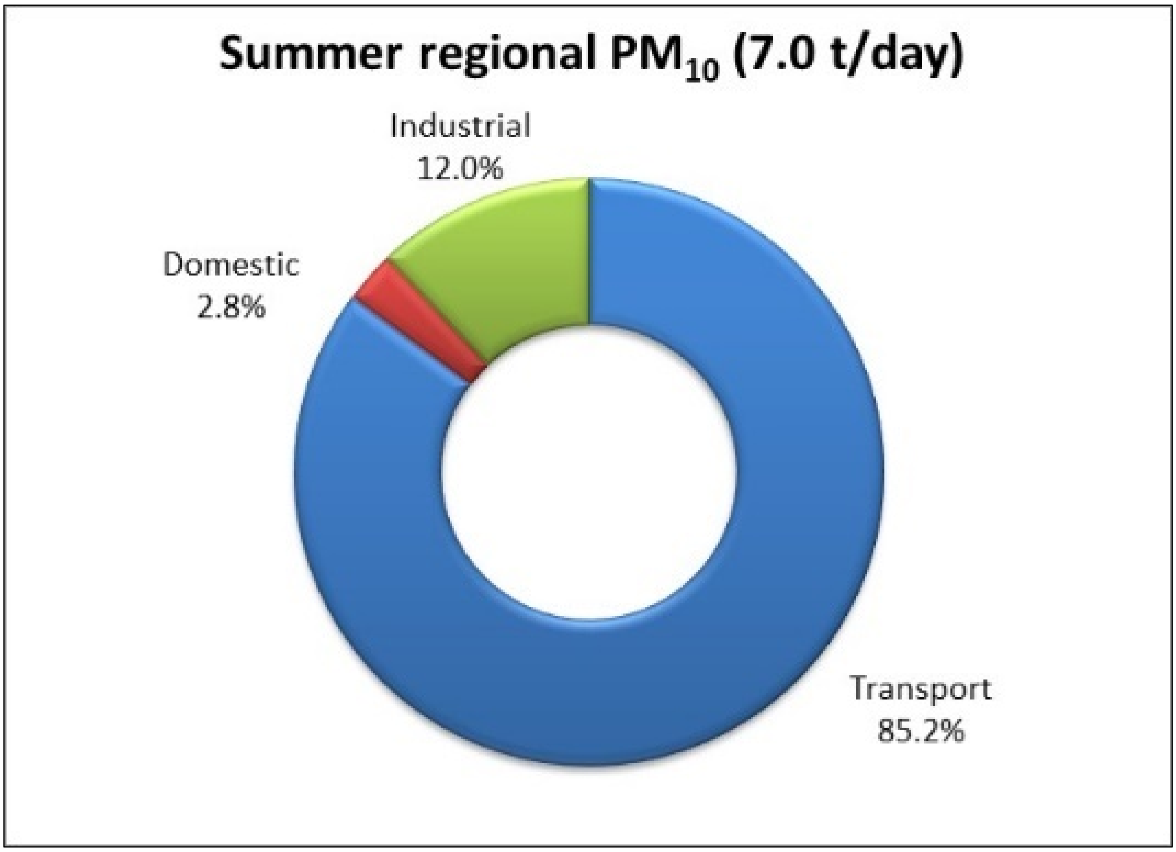


Figure 3-5: Winter emissions profiles in 2016

Regional PM_{10} emissions on a typical winter weekday (18.9 t/day) are more than two times the emissions of a typical summer weekday (7.0 t/day) (Figures 3-6 and 3-7):

- Domestic sources (principally home heating) account for 64.0 per cent of PM_{10} emissions on a typical winter weekday (June-August) but fall to 2.8 per cent of PM_{10} emissions on a summer weekday (December-February).
- Transport sources (principally motor vehicles) account for 31.5 per cent of PM_{10} emissions on a typical winter weekday (June-August) but rise to 85.2 per cent of PM_{10} emissions on a summer weekday (December-February) because emissions from domestic sources have decreased.
- Similarly, industrial sources contribute 4.4 per cent of PM_{10} emissions on a typical winter weekday (June-August) but increase to 12.0 per cent of PM_{10} emissions on a summer weekday (December-February) due to decreased contributions from domestic sources.

Urban PM_{10} emissions on a typical winter weekday (10.6 t/day) are more than four times the emissions of a typical summer weekday (2.2 t/day) (Figures 3-6 and 3-7). They show a similar seasonal variation pattern to regional PM_{10} emissions: the dominance of the domestic sector in winter and the dominance of the transport sector in summer.



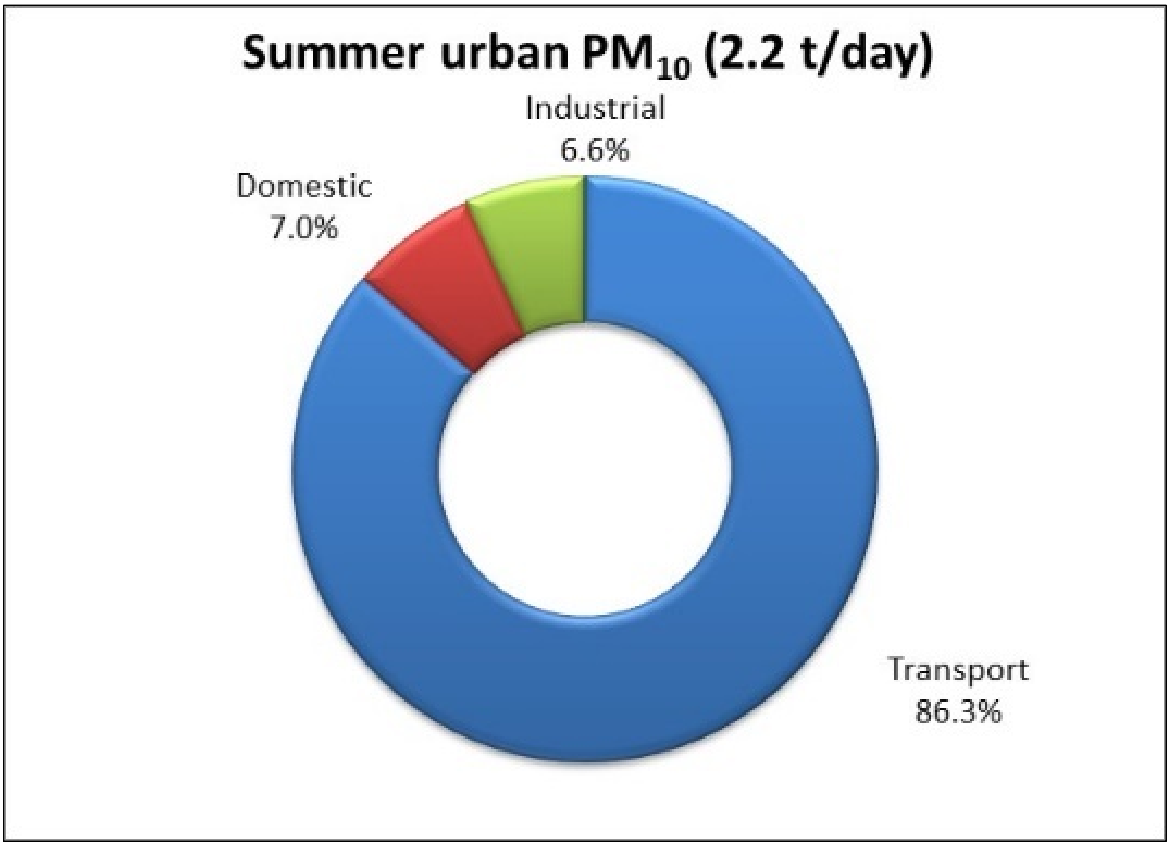
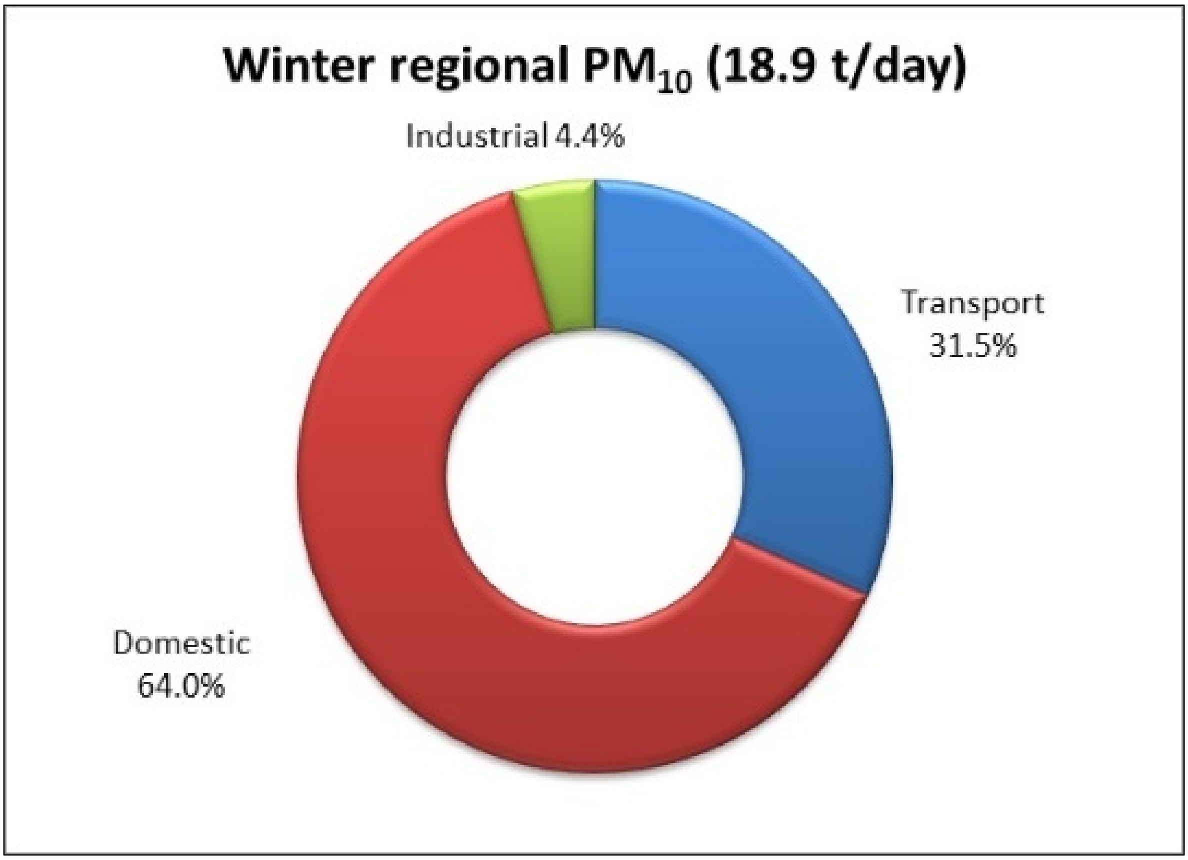


Figure 3-6: Summer PM_{10} emissions profiles in 2016



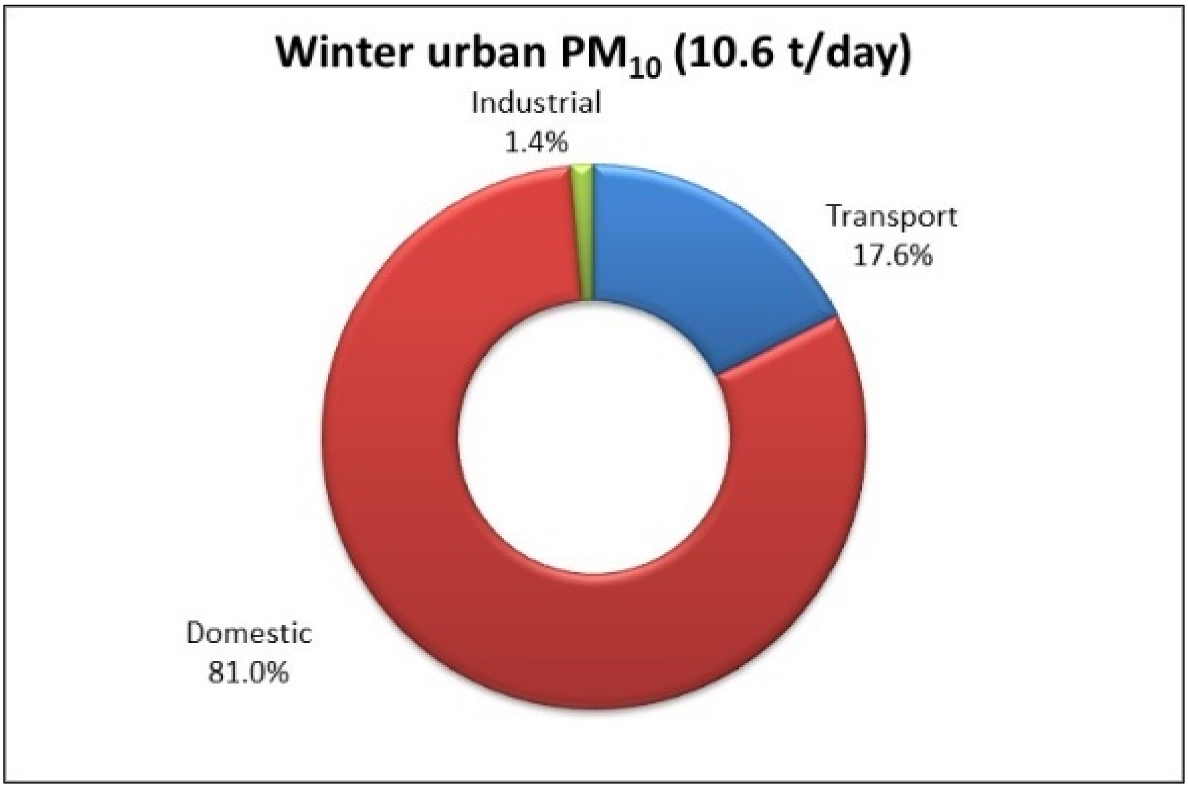
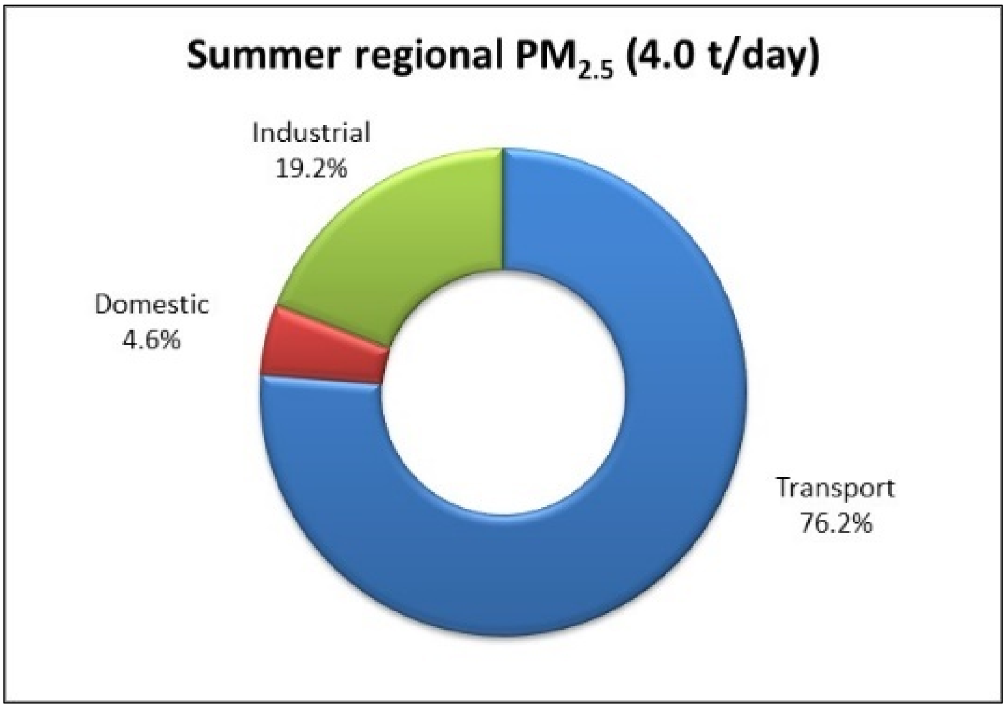


Figure 3-7: Winter PM_{10} emissions profiles in 2016

$PM_{2.5}$ emissions show a similar seasonal variation pattern to PM_{10} emissions. Transport sector dominates the emissions in summer while domestic sector dominates the emissions in winter. Regional $PM_{2.5}$ emissions on a typical winter weekday (15.9 t/day) are close to four times the emissions of a typical summer weekday (4.0 t/day) (Figures 3-8 and 3-9). Urban $PM_{2.5}$ emissions on a typical winter weekday (10.2 t/day) are six times the emissions of a typical summer weekday (1.7 t/day) (Figures 3-8 and 3-9).



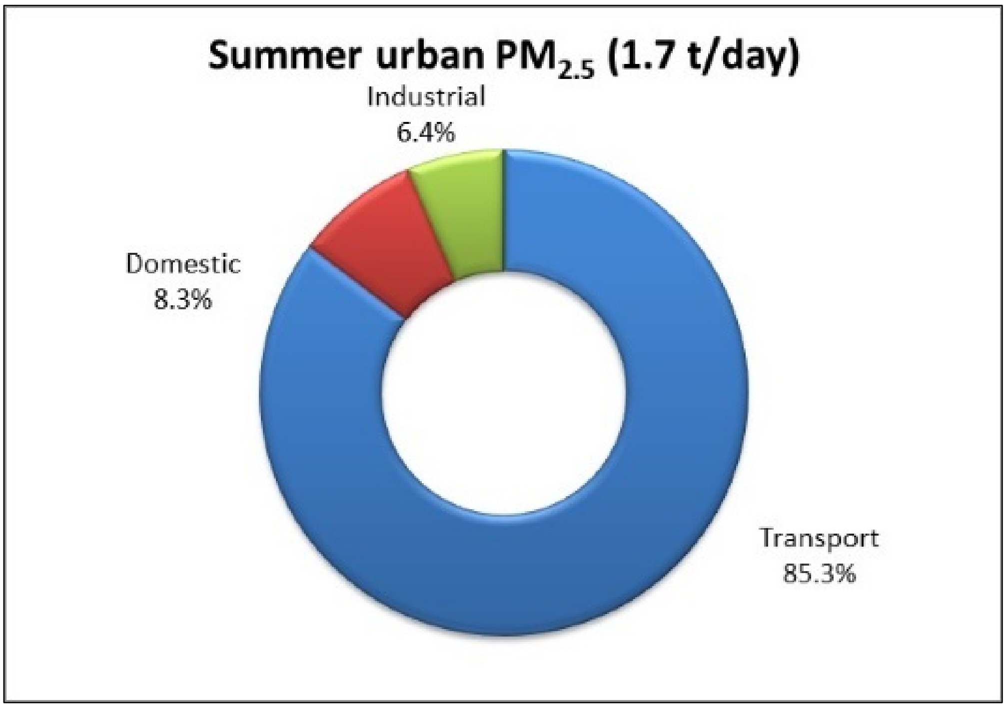
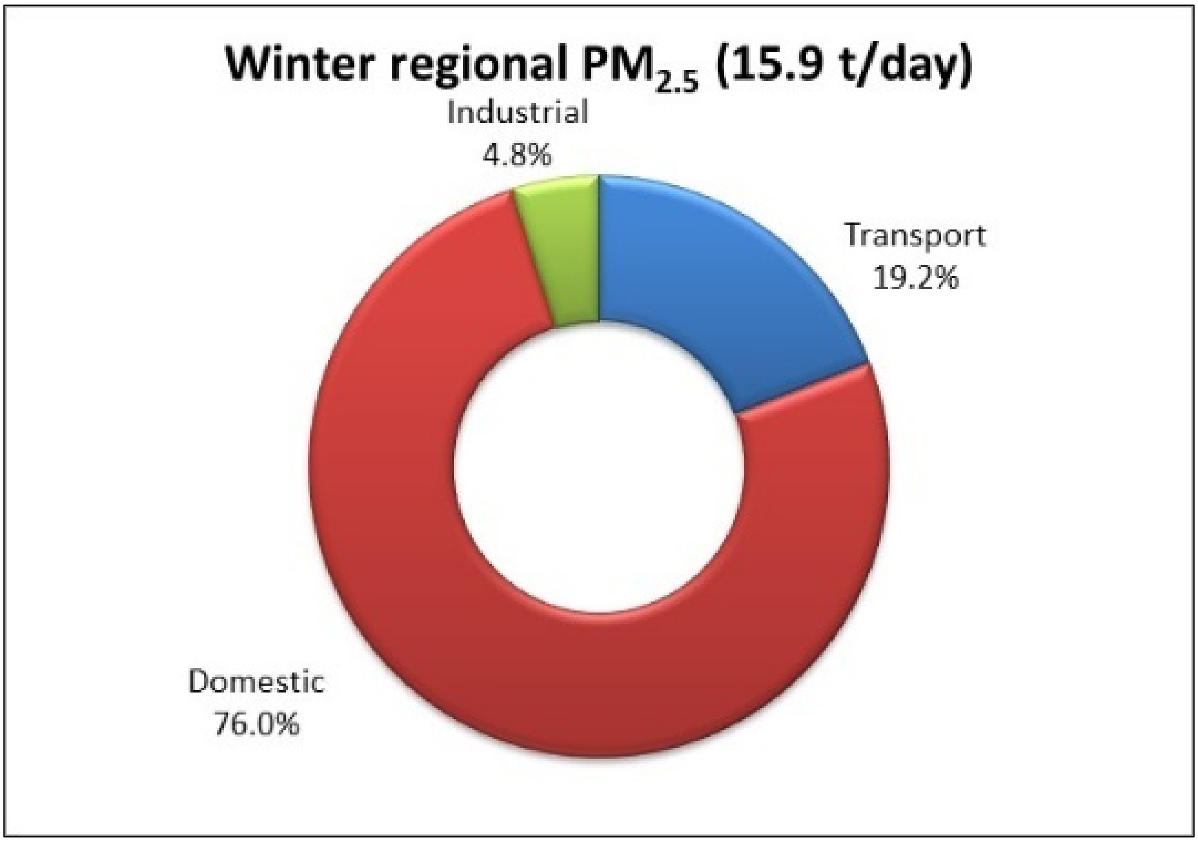


Figure 3-8: Summer $PM_{2.5}$ emissions profiles in 2016



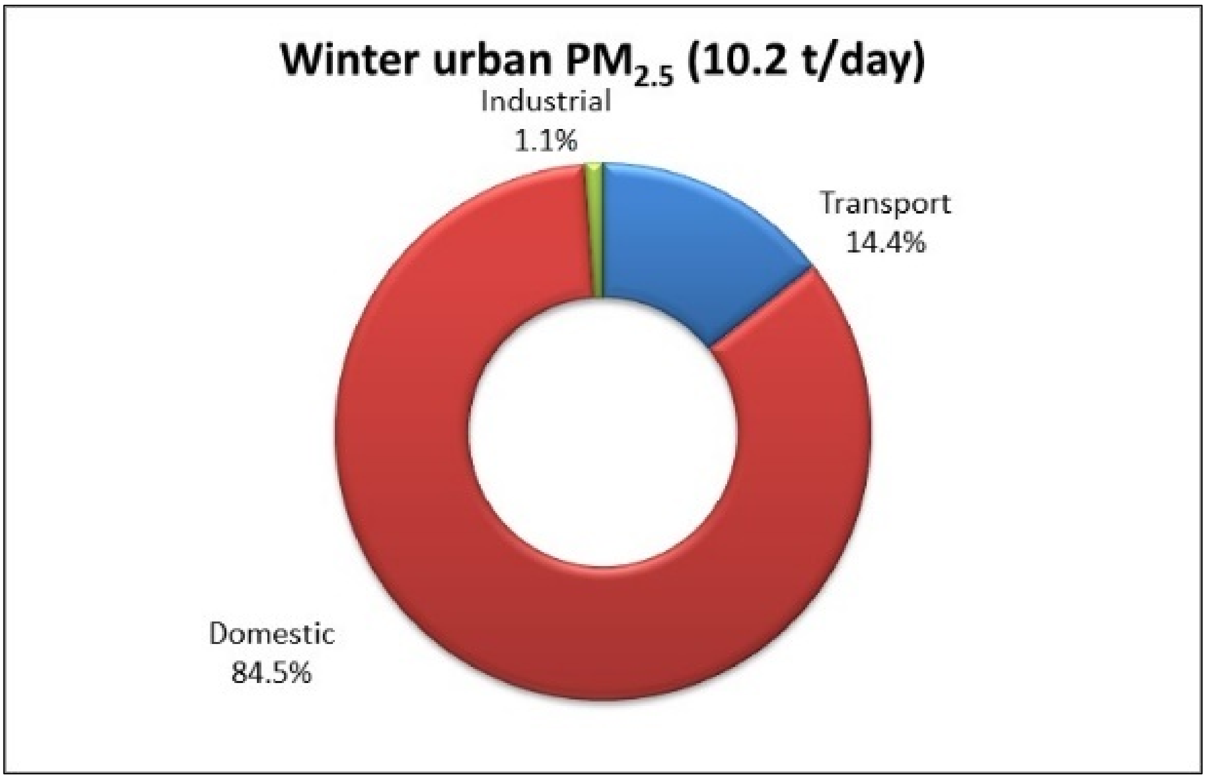


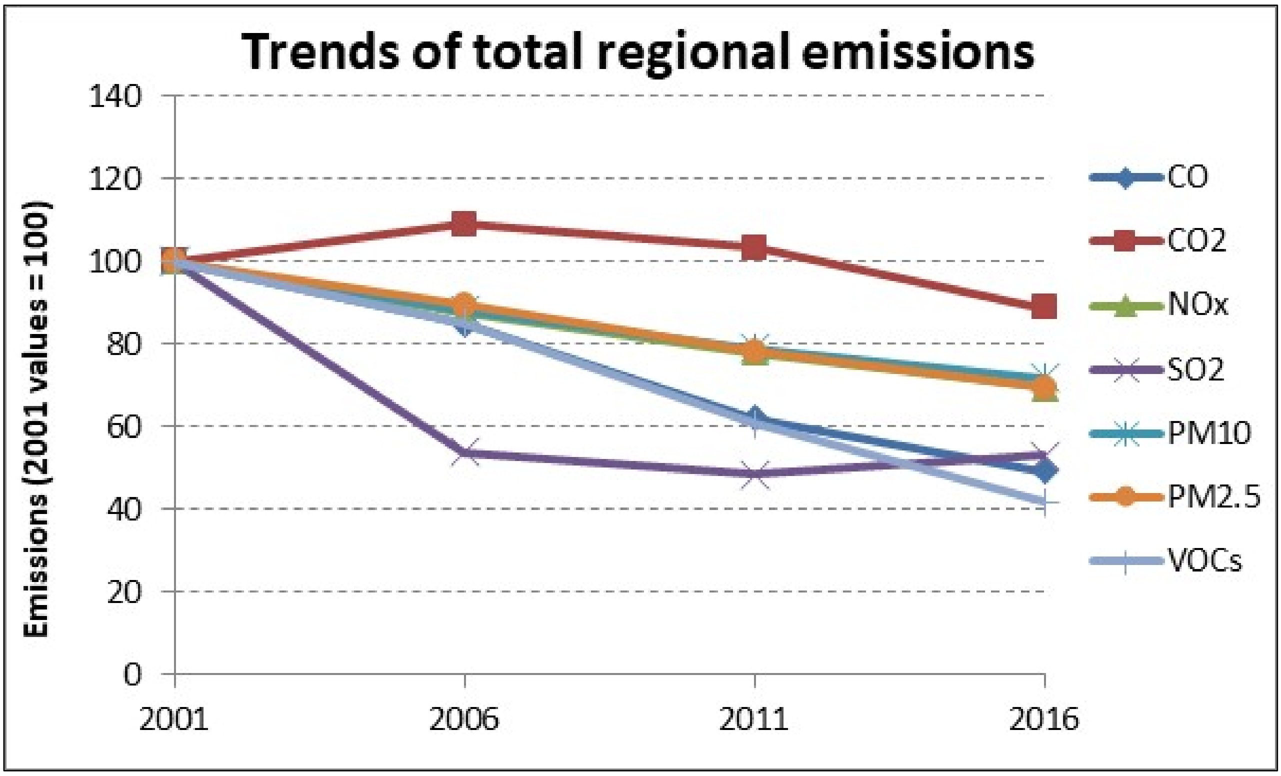
Figure 3-9: Winter $PM_{2.5}$ emissions profiles in 2016

3.2 Trends

Regional and urban emissions for 2001, 2006, 2011 and 2016 indicate the following trends:

- CO emissions have fallen mainly due to more vehicles in the fleet with improved vehicle technology and emission control equipment.
- CO_2 emissions have fallen since 2006 mainly due to reduced industrial activities (therefore emissions). This has been partly offset by increased vehicle emissions due to more fuel consumption resulting from increased vehicle numbers and vehicle kilometres travelled.
- NOx emissions have decreased despite an increase in vehicle kilometres travelled, and this is attributed to the improved vehicle control technology.
- SO_2 emissions have reduced mainly due to reduced sulphur levels in road transport fuel and decreased industrial activities. This has been partly offset in recent years by increased fuel consumption by vehicles.
- PM_{10}, $PM_{2.5}$ and VOC emissions have fallen mainly due to a shift away from coal and wood for both domestic heating and industrial use, the improved vehicle control technology, and reduced industrial activities.

Overall, regional and urban emissions have decreased from 2001 to 2016 for transport, domestic and industrial sectors, respectively, except for increased CO_2 emissions from the transport sector.



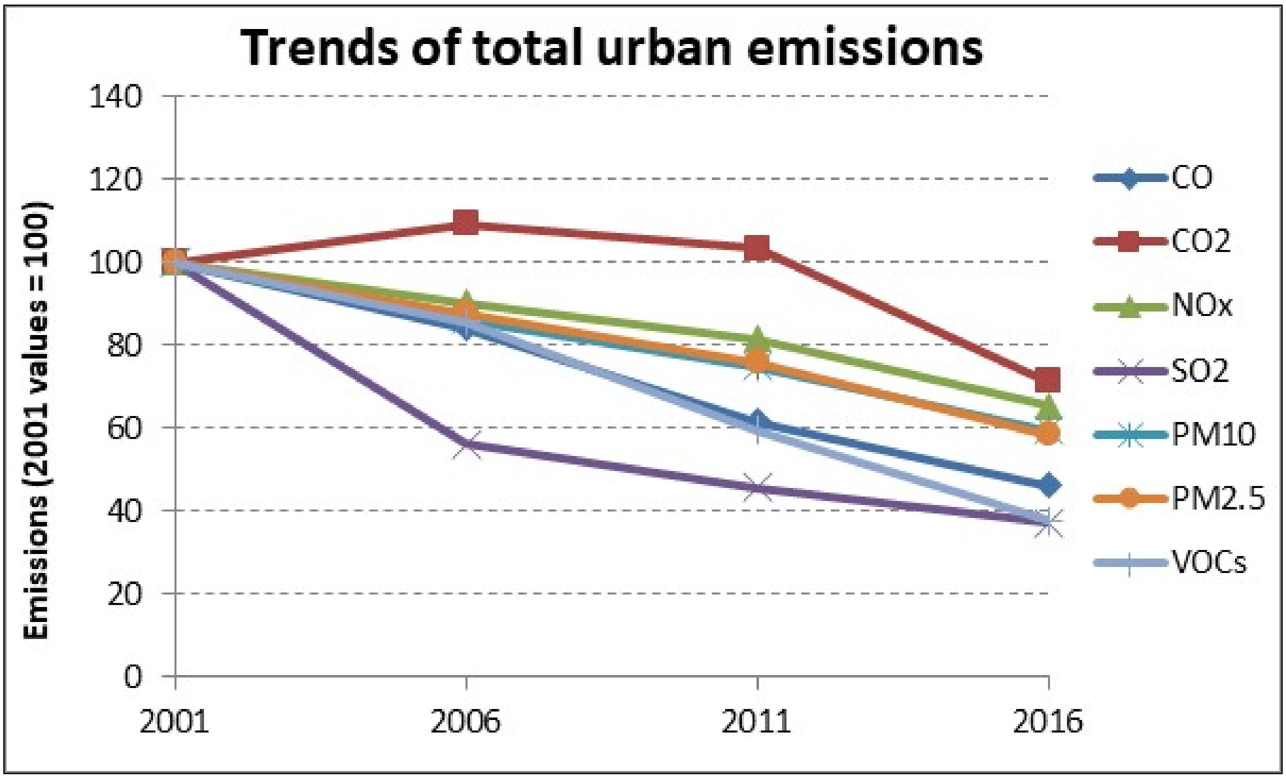


Figure 3-10: Trends of total emissions from 2001 to 2016

3.3 PM_{10} and $PM_{2.5}$ emissions reductions

Total PM_{10} and $PM_{2.5}$ emissions were estimated to reduce by 18.7 per cent and 22.4 per cent between 2006 and 2016. PM_{10} and $PM_{2.5}$ emissions also showed a downward trend from land and air transport (Sridhar and Metcalfe, 2018), home heating (Metcalfe *et al*., 2018) and industry (Crimmins, 2018).

Annual average levels of PM_{10} in Auckland have declined since regular measurements began in the late 1990s (Talbot *et al*., 2017). PM_{10} concentrations have met air quality standards and guidelines since 2014 except for the exceedances in 2019 due to the fire at the New Zealand International Convention Centre (NZICC) construction site, and Australian dust storms and bush fires. Figure 3-11 shows annual average PM_{10} for residential sites compared with peak monitoring sites for traffic (Khyber Pass) and industry (Penrose). Please note that the Khyber Pass site was discontinued from February 2015 due to change of property ownership where the site was installed.

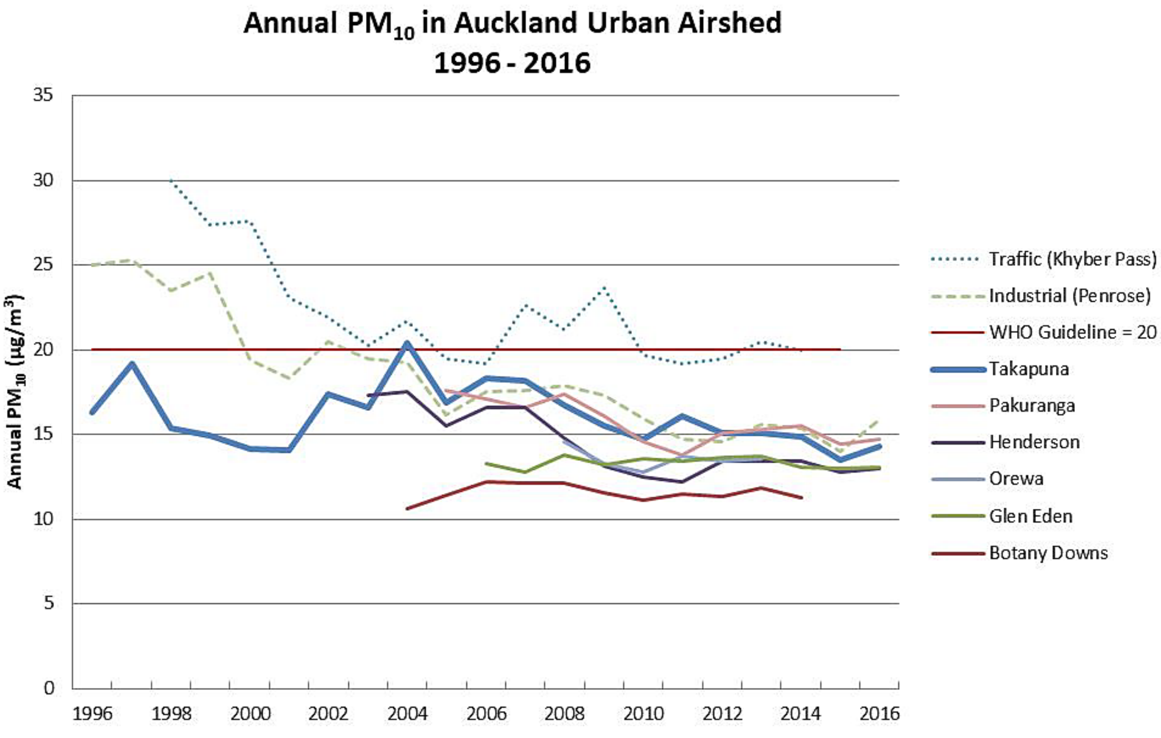


Figure 3-11: Annual average PM_{10} concentrations at selected Auckland monitoring sites from 1996 to 2016

Annual average levels of $PM_{2.5}$ in Auckland have also declined since regular monitoring began in the late 1990s. Figure 3-12 presents annual average $PM_{2.5}$ between 1997 and 2016. $PM_{2.5}$ concentrations have met air quality standards and guidelines since 2015 except for the exceedances in 2019 due to the fire at the NZICC construction site.

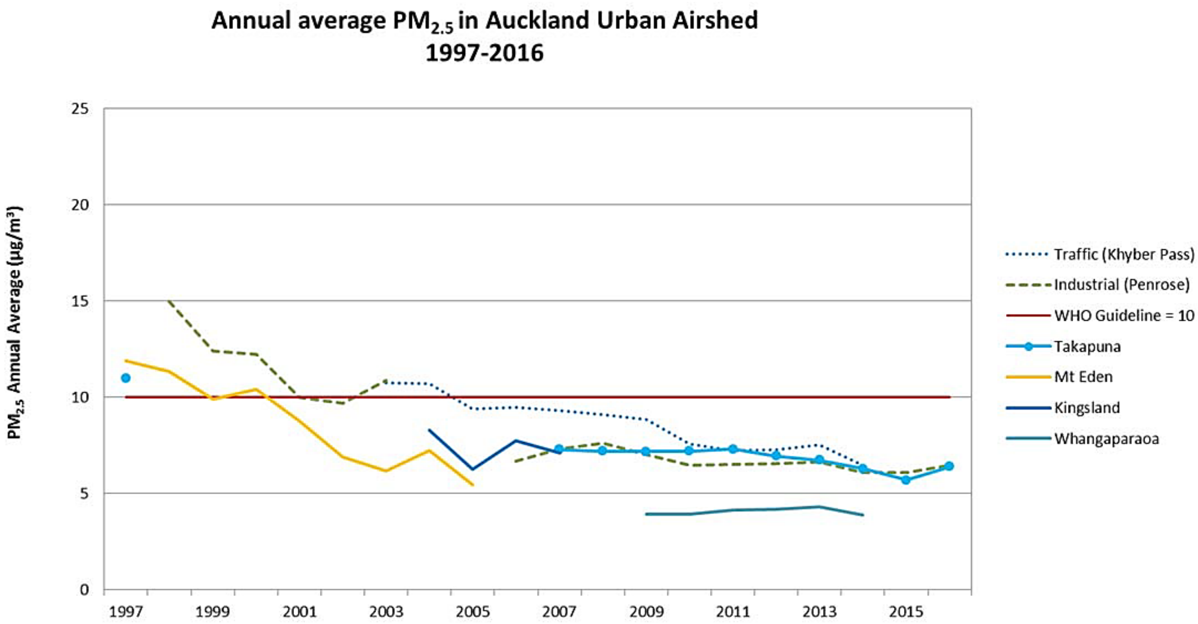


Figure 3-12: Annual average $PM_{2.5}$ concentrations at selected Auckland monitoring sites from 1997 to 2016

Overall, PM_{10} and $PM_{2.5}$ emissions have reduced in recent years. The monitored PM_{10} and $PM_{2.5}$ concentrations have also shown a downward trend and met air quality standards and guidelines since 2014 and 2015, respectively. However, there were PM_{10} and $PM_{2.5}$ exceedances in 2019 due to the fire at the NZICC construction site, and Australian dust storms and bush fires.

Emissions and trends of each source category are summarised in the following sections: land and air transport (Section 4), sea transport (Section 5), domestic (Section 6) and industry (Section 7). Emissions from individual sources in 2001, 2006, 2011 and 2016 are provided in Appendix A (Tables A1.1 to A1.4).

4.0 Land and air transport emission sources

Land and air transport generates emissions from motor vehicles, rail, road dust (sealed and unsealed), off-road vehicles and road laying. In Auckland, emissions from aviation are mainly from take-off and landing phases and are therefore reported in this sector.

4.1 Motor vehicles

Emissions from motor vehicles were estimated using traffic data from the Auckland Regional Transport (ART) model and emission factors from the Vehicle Emission Prediction Model (VEPM). Emissions were 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 ART model and have associated traffic and speed data. Speed based emission factors were calculated in VEPM by vehicle type. These emission factors were then applied to the traffic data for each road link to estimate emissions.

4.1.1 Activity data

The Auckland Regional Transport model version 3.2 (ART 3.2) provides traffic data for almost 15,000 individual road links in the Auckland region. The ART model outputs provide spatial allocation of vehicle kilometres travelled (VKT) and include:

- speed; and
- proportion of light and heavy vehicles, where
    - Light vehicles = <7.5t,
    - Heavy vehicles = >7.5t.

The light to heavy vehicle split was further broken down based on the default fleet provided in the VEPM (version 5.3) (Metcalfe and Sridhar, 2017).

The ART model base year is 2013 and does not include data for earlier years. To accommodate trend analysis, traffic data from the motor vehicle emissions 2014 report (Auckland Council, 2014c) was used for 2001, 2006 and 2011.

4.1.2 Emission factors

The Vehicle Emission Prediction Model (VEPM) is an average speed model which predicts emission factors for the New Zealand fleet under typical road, traffic and operating conditions. The latest version, VEPM 5.3, is currently the best tool available in New Zealand to predict motor vehicle emissions in regional inventories, but the model does not include evaporative emissions. VEPM was updated in March 2017 to include the latest fleet data, updated country of origin assumptions, updated emission factors and NO_2 emission factors (Metcalfe and Sridhar, 2017).

Emission factors were generated from VEPM 5.3 for each year and for:

- all speeds between 10 and 99 kilometres per hour,
- all vehicle types, and
- all pollutants in the inventory (except SO_2).

Sulphur dioxide emission factors are based on the sulphur content in diesel and petrol for the inventory year and were applied to the speed-based fuel consumption data from VEPM to derive SO_2 speed-based emission factors.

4.2 Aviation

Emissions to air are estimated from aircraft at Auckland International Airport, the largest airport in Auckland as well as New Zealand. There are three other airports in the Auckland region (Ardmore Airport, North Shore Aerodrome, and the military airbase at Whenuapai) which service mainly smaller planes and military aircraft. These smaller airports were not included in this inventory as detailed data were not available. Previous inventories estimated that almost 97 per cent of aircraft movements in the region are at Auckland International Airport while Ardmore airport accounted for 2.5 per cent of movements, and Whenuapai airbase and North Shore Aerodrome accounted for <1 per cent each (Auckland Council, 2014b).

An aircraft movement includes several phases of a flight including taxi out, take-off, climb, cruise, descent, approach, landing and taxi-in. For the purposes of this inventory, an aircraft movement is a phase that takes place below a height of 915 metres (3000 feet) and includes taxi-out, take-off, climb-out, approach, landing and taxi-in. It is referred to through the rest of this report as the landing and take-off (LTO) cycle of an aircraft. Emissions from cruise, climb, and descent phases (CCD) were not quantified for this inventory.

Emissions were calculated based on the EMEP/EEA guidebook (EEA, 2016) and associated Master emissions calculator 2016 workbook.

4.2.1 Activity data

The EMEP/EEA guidebook requires data on the number of aircraft movements by aircraft type. A schedule of departures and arrivals at Auckland International Airport were extracted for a week in June 2017 to collate data on the number of LTO movements by aircraft type. There are 33 different types of aircraft operating at

Auckland International Airport. Total aircraft movements for 2001, 2006 and 2011 were sourced from Auckland International Airport.

4.2.2 Emission factors

The EMEP/EEA workbook has LTO fuel consumption and emission factors for various types of aircraft, the type of model most commonly associated with that type of aircraft and the most frequently used engine type. It does not list emission factors for all aircraft types and models, so the next best model representing the aircraft type was chosen where data for a particular aircraft was not available. An emission factor per LTO was calculated for each pollutant based on 2016 estimates to calculate emissions for other inventory years.

4.3 Rail

Emissions from railways occur from the combustion of fuels in engines and from non-exhaust particulates from brake and wheel wear on the tracks. The 2016 inventory uses fuel consumption as the basis for estimating emissions. The EMEP/EEA guidebook was used to estimate emissions from rail (EEA, 2016).

4.3.1 Activity data

Rail is mostly used in Auckland for the mass transit of daily commuters within the region (managed by Auckland Transport) or for moving freight within or to and from Auckland from other regions (managed by KiwiRail).

Diesel consumption from 2010 to 2016 specifically for passenger rail was obtained from Auckland Transport. Diesel consumption for 2001 and 2006 was estimated based on 2013 fuel consumption and journey to work data for 2001, 2006 and 2013. Electric passenger trains went into service from 2014 and will replace all diesel trains by 2019.

Diesel consumption for freight services was calculated based on the total gross tonne kilometres (GTKs) over the Auckland corridor multiplied by a fuel burn rate (in litres per GTK) for 2006, 2011 and 2016. Data were not available for 2001 and therefore were back-calculated based on the assumption that the period between 2001 and 2006 experienced the same trend as 2006 and 2011.

4.3.2 Emission factors

The emission factors from the EMEP/EEA guidebook were used as specific fuel consumption data were available for individual locomotive types (i.e. railcar and line haul locomotives) (except for SO_2).

4.4 Road dust

Road dust is the generation and release of particulate matter into the air, mainly from the interaction between a vehicle's wheels and the road surface, both on sealed and unsealed roads. Fine dust material is additionally created when vehicle wheels further grind down the road aggregate (Bluett *et al*., 2017). Airborne dust from roads has a range of particle sizes. This report focuses on PM_{10} and $PM_{2.5}$ and does not estimate road dust from coarser fractions which are largely associated with dust nuisance or amenity effects.

4.4.1 Unsealed road dust

There are 7300km of legal roads in the Auckland region, of which approximately 868km (12%) is unsealed (AT, 2017). Most of the unsealed roads (78%) are in Rodney and the remaining 190km are found mainly in the Hauraki Islands, Franklin and Waitakere.

VKT for unsealed roads in the Auckland region was obtained from the NZ Transport Agency for 2016 (NZTA, 2018). Additional data on unsealed roads in the Auckland region was extracted from the Road Assessment and Maintenance Management (RAMM) database by Auckland Transport. This data was used to calculate the proportion of unsealed roads located within the Auckland Urban Airshed compared to the whole region (excluding the islands in the Waitematā Harbour and Hauraki Gulf). Emission factors for unsealed roads were calculated using the US EPA methodology (US EPA, 2006).

4.4.2 Road surface wear (sealed roads)

PM_{10} and $PM_{2.5}$ emissions from road surface wear of sealed roads were calculated using VKT data (by vehicle type, see Section 4.1.1 on Motor vehicles) and EMEP's/EEA's emission factors. The emission factors are based on limited information and are highly uncertain (EEA, 2016).

4.5 Off-road vehicles

Emissions from off-road vehicles (e.g., equipment, machinery and vehicles used for industrial activities) were estimated using fuel consumption data from the Energy Efficiency and Conservation Authority (EECA) energy use database (EECA, 2016). The EECA database provides estimated diesel consumption for "non-transport, motive power, mobile" in Auckland for 2012. For other years, fuel consumption was estimated based on national trends in off-road diesel consumption (EECA, 2016). Emission factors are sourced from the Australian National Pollutant Inventory (NPI) methodology for industrial vehicles (Australian Department of the Environment, Water, Heritage and the Arts, 2008).

4.6 Road laying

Emissions of VOC from road laying were estimated in the 1993 emissions inventory based on information from the New Zealand Bitumen Contractor's Association (EPA Victoria, 1998). Estimated emissions were scaled up for the 2016 inventory based on the estimated increase in national asphalt consumption since 1993 (MfE, 2016), assuming that the emissions of VOC per tonne of bitumen consumed have not changed.

4.7 Emissions and trends

Emissions from individual sources in 2001, 2006, 2011 and 2016 are provided in Appendix A (Tables A1.1 to A1.4). Motor vehicles continue to be the most significant source of transport air pollution in the Auckland region. Emissions from motor vehicles decrease from 2001 to 2016, except for increased CO_2 emissions due to more fuel consumption resulting from increased vehicle numbers and vehicle kilometres travelled.

5.0 Sea transport emission sources

This section reports emissions from ocean going vessels (OGVs), harbour vessels, ferries and fishing activities. It does not include minor emissions from recreational vessels and dredging activity due to lack of detailed activity data.

For indicative trend analysis, emissions 2001, 2006 and 2011 are sourced from Endpoint (2006) and Peeters (2011).

5.1 Vessels

The methodologies and emission factors were based on US Environmental Protection Agency guidelines (US EPA, 2009). Vessel activity data for 2016 originate from two sources: ship movements recorded by Ports of Auckland Ltd (POAL) and Automatic Identification System (AIS) data from MarineTraffic Ltd. At-sea emissions for OGVs, harbour vessels and ferries were calculated based on AIS derived travel data, whereas at-berth emissions for OGVs were derived from POAL records. AIS is an automatic tracking system used aboard vessels to communicate information about the vessel to other vessels and/or to coastal authorities automatically, such as vessel name, position (latitude/longitude), speed, heading, vessel length and vessel type.

OGVs, harbour vessels and ferry vessels activity for 2006 and 2010 emissions was estimated from movement records and timetables (Peeters, 2011). It is a significant improvement to use AIS data to accurately model the activity from OGVs, harbour vessels and ferries over a whole year, compared to 2006 and 2010 emissions estimate. With AIS data, vessel emissions can be estimated at a high spatial and temporal resolution. AIS also allows the quantification of emissions from vessel activity that were previously difficult to quantify, such as vessels that pass through Auckland waters but do not visit its port.

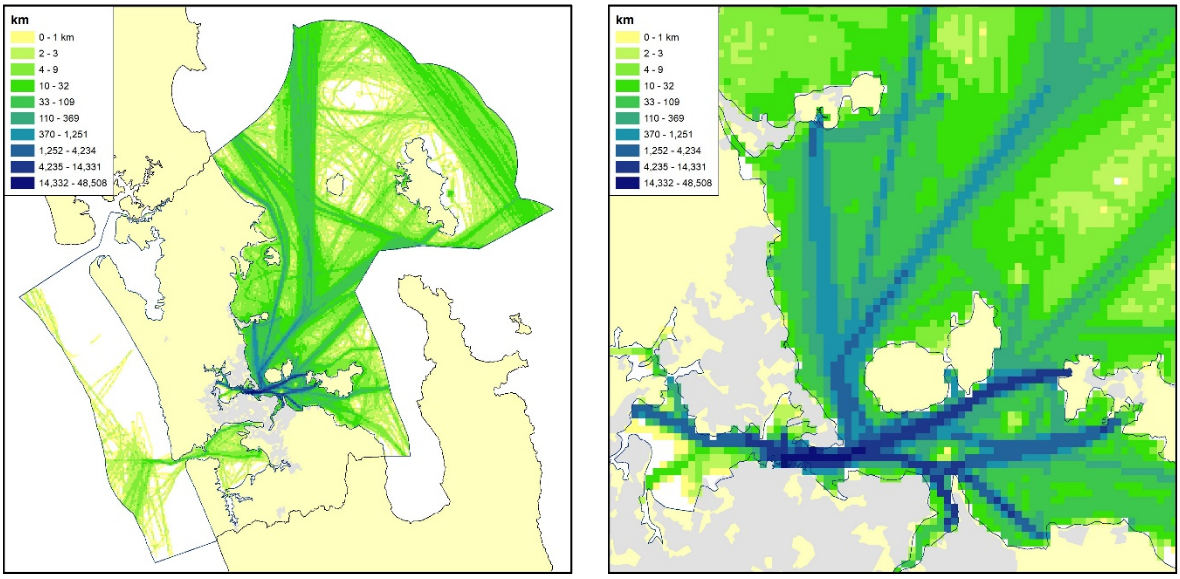


Figure 5-1: AIS vessel traffic density for 2016, distance travelled in kilometres: left, within Auckland Council boundaries; right, close up of the Waitematā Harbour – Hauraki Gulf area (Peeters, 2018).

The fuel type used varies from vessel to vessel. Some OGVs use more than one fuel type, e.g., heavy fuel oil (HFO) for the main engine and marine diesel oil (MDO) for the auxiliary engine. Different emission factors are applicable to each fuel-type/engine-type combination. For most OGVs, the fuel type used by the main engine and the auxiliary engine was assumed based on the vessel category (Entec, 2007).

Most of the fuel consumed by OGVs has very high sulphur content (e.g. 2.7% or 27,000 ppm by mass) compared to road vehicle fuels (10 ppm for diesel or five ppm for petrol). It is expected that SO_2 emissions from OGVs may drop by up to 75 per cent if MARPOL Annex VI fuel sulphur content regulations come into force in 2020. MARPOL is the International Maritime Organization's first comprehensive treaty to address maritime pollution. Ferries, harbour vessels and fishing boats use low sulphur automotive grade fuels. Their SO_2 emissions are negligible compared to those of OGVs. While OGVs are also responsible for the bulk of NOx and particulate emissions, NOx emissions from ferries are not negligible. Harbour vessels, ferries and fishing boats are the main sources of CO emissions.

Vessels operating near the Waitematā Harbour area are an important source of SO_2, NOx and particulate emissions in close proximity to the CBD. In 2016, approximately one third of SO_2, NOx and particulate emissions from commercial vessels in the Auckland region are released within a radius of three kilometres from the CBD.

5.2 Fishing boats

The majority of the fishing vessels operating in the Auckland waters are small boats less than seven metres long. There are virtually no vessels with a gross tonnage (GT) larger than 500 tonnes fishing within twelve nautical miles from the coast. Emissions were calculated in terms of the volume of diesel and petrol consumed by the vessel engines. Fishing activities in 2016 were estimated based on fishing records from the Ministry of Primary Industries (MPI). Emissions from fishing boats for 2006 and 2010 (Peeters, 2011) were recalculated using 2016 assumptions and emission factors, except for 2006 where SO_2 emissions were recalculated based on a sulphur content of 150 ppm. Emissions of fishing boats are categorised in the industry sector.

5.3 Emissions and trends

Emissions from individual sources in 2001, 2006, 2011 and 2016 are provided in Appendix A (Tables A1.1 to A1.4). Ocean going vessels (OGVs) are the dominant source of sea transport emissions in the region as well as in the area around the city centre. In 2016, approximately one-third of SO_2, NO_x and particulate emissions from OGVs, harbour vessels and ferries were released in a small area of $14km^2$ located within a three-kilometre radius from the CBD. Emissions from OGVs are largely stable between 2001 and 2016 as the impact of increased vessel visit was offset by better fuel quality and improved engine technology.

6.0 Domestic emission sources

Domestic emissions cover those from burning wood, coal, LPG and natural gas for home heating; from outdoor burning and from lawn mowers.

6.1 Home heating

For wood burning, emissions were estimated based on the following equation:

Emission (g) = number of appliances x emission factor (g/kg fuel) x fuel use per appliance (kg)

For coal, LPG and natural gas, emissions were calculated based on total estimated fuel consumption for the region using the following equation:

Emission (g) = emission factor (g/kg fuel used) x total fuel use (kg)

6.1.1 Wood burning appliance numbers

The appliance numbers for 2001, 2007 and 2012 were sourced from the 2006 domestic fire emissions inventory (Auckland Regional Council, 2010a). The appliance types included were:

- open fire,
- wood burner,
- multifuel burner, and
- pellet burner.

Wood burners were further categorised by age. Most significantly, wood burners installed after 2005 were assumed to comply with the design standard for new wood burners specified by the National Environmental Standards for Air Quality. The home heating appliance numbers for 2016 were estimated by analysing historical trends from census and home heating surveys.

6.1.2 Fuel use per appliance (wood)

The hourly and daily fuel consumption rates for each burner type were assumed the same as those reported in the Estimation of Domestic Fire Emissions in 2006 (Auckland Regional Council, 2010a), which was estimated based on the results of the 2007 home heating survey (Auckland Regional Council, 2010b). Annual and monthly fuel use was estimated using the seasonal variation from the Auckland domestic heating emission inventory 2001 report (Wilton, 2002).

6.1.3 Fuel use for coal, LPG and natural gas

The 2006 domestic fire emissions inventory (Auckland Regional Council, 2010a) estimated that total coal consumption for the Auckland region was 1740 tonnes per year. This equates to approximately 100 kg per household per year based on the number of households burning coal for heating from the census in 2006. For the 2016 inventory, total coal combustion was calculated based on the number of households burning coal for heating (from the 2013 census), and the assumption that average consumption per household was 100 kg per year. LPG and natural gas consumption was based on data from the Energy Efficiency and Conservation Authority's (EECA) Energy end use database (for 2012) (EECA, 2016). The EECA's consumption captures the use for both cooking and heating.

6.1.4 Emission factors

To promote consistency with other inventories in New Zealand, the emission factors used in this 2016 inventory were updated to be generally consistent with emission factors from the Home heating emission inventory and other sources evaluation report prepared for Ministry for the Environment (Wilton *et al*., 2015). The only exceptions are open fire emission factors and emission factors for pollutants and fuel types that were not included in Wilton *et al*., 2015. The emission factors used are summarised as follows:

- Emission factors for PM_{10}, $PM_{2.5}$, CO, NOx and SO_2 for wood burners, multifuel burners and pellet burners are from Wilton *et al.,* 2015.
- Open fire emission factors, and emission factors for VOC and CO_2 from wood and coal are the same as the 2006 domestic fire emissions inventory (Auckland Regional Council, 2010a).
- Emission factors for LPG and natural gas were the same as those reported in the 2006 *Auckland air emissions inventory* (Auckland Council, 2014a).

6.2 Outdoor burning

Emissions for outdoor burning are based on the amount of waste burnt by households in the region. Outdoor burning of waste was allowed in Auckland in the past subject to council restrictions, however, since 2001, outdoor burning was banned in the urban area through regulations in the Auckland Regional Plan: Air, Land and Water (Auckland Regional Council, 2004) 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 previously, now from Fire and Emergency New Zealand, typically limited to the periodic incineration of green wastes; crop burning for land clearance or soil reconditioning (which is not a common activity). Emissions from outdoor burning were previously estimated for 2001, 2006 and 2011 (forecast) in the 2006 inventory (Auckland Council, 2014b). The emissions are recalculated using updated emission factors. The CO_2 emission factor is sourced from the New Zealand's Greenhouse Gas Inventory (MfE, 2016). Emission factors for other pollutants are sourced from the EMEP/EEA guidebook (EEA, 2016). Waste generated per household in 2016 is assumed the same as in 2011.

6.3 Lawn mowers

Petrol consumption from lawn mowers was estimated by the Ministry of Transport at 10 to 12 litres per annum per mower, with approximately one mower per 1.5 households (MoT, 2017). The lower estimate of 10 litres of petrol per mower per annum was assumed for Auckland. Based on the number of households in the 2013 census (471,837), fuel consumption from lawn mowers was estimated as 3.1 million litres of petrol per annum. This equates to 0.3 per cent of regional total petrol consumption. Emissions from lawn mowers were estimated based on the EMEP/EEA guidebook methodology for non-road mobile machinery (household and gardening). Emissions for other years are assumed unchanged as they are a minor source.

6.4 Emissions and trends

Emissions from individual sources in 2001, 2006, 2011 and 2016 are provided in Appendix A (Tables A1.1 to A1.4). Burning wood for home heating in winter is the dominant source of domestic emissions across the region as well as in the urban area. Emissions from wood burning decrease between 2001 and 2016 due to more households using alternative means for home heating, e.g., electricity, improved household insulation or better new wood burners.

7.0 Industrial emission sources

Industries are generally centred around key industrial hubs, most notably Penrose/Ōtāhuhu/Onehunga, East Tamaki, Wiri and the Rosebank Peninsula. They are within the urban limits, as defined by the Rural Urban Boundary of the Auckland Unitary Plan (Auckland Council, 2016b). Auckland's single most significant industrial site – in terms of manufacturing volumes, employment and air emissions – is the Bluescope New Zealand Steel Ltd (NZ Steel) steel mill. This site is located outside of the Rural Urban Boundary in rural Glenbrook, near to the region's southern boundary (Figure 7-1).

The Auckland Unitary Plan requires industries with notable air discharges to obtain a resource consent (Auckland Council, 2016b). Its air discharge rules include a number of Permitted Activity thresholds. Sites that comply with these thresholds are not required to obtain resource consent and are not included in this inventory due to lack of data.

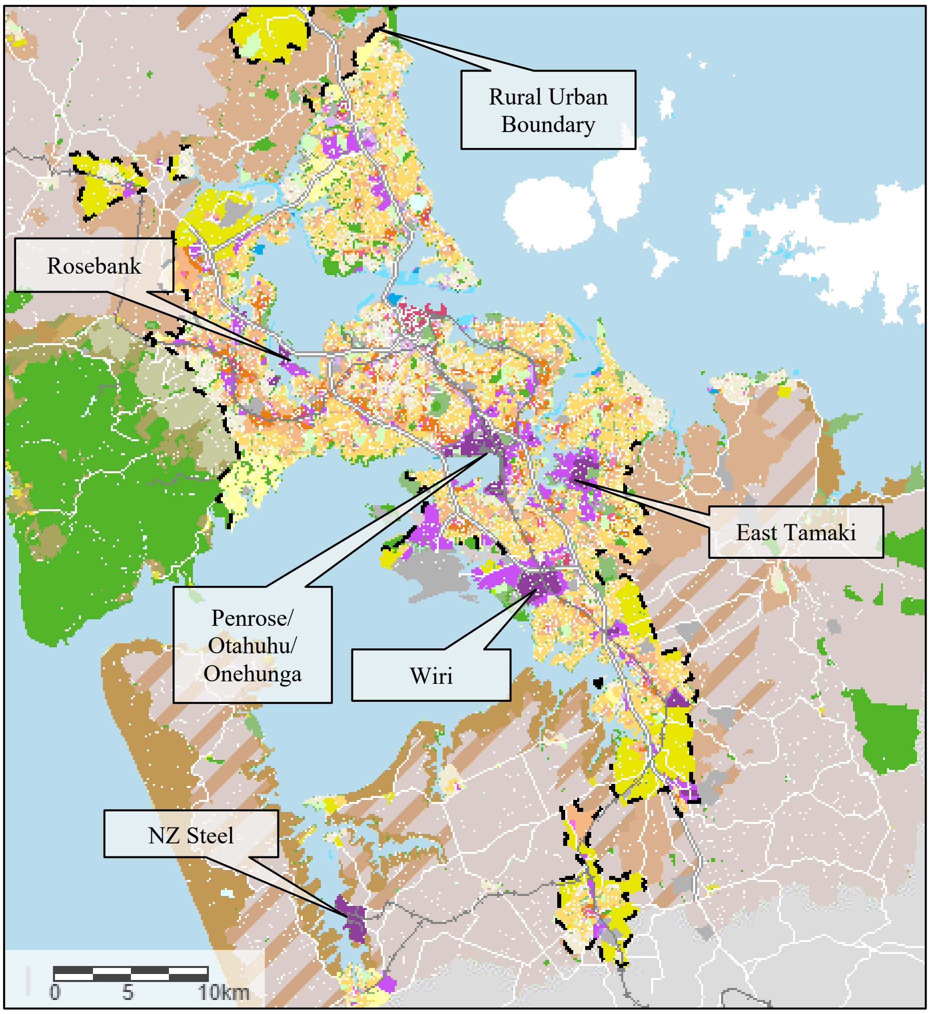


Figure 7-1: Map of Auckland's significant industrial areas (in purple) with Rural Urban Boundary (black dashed line).

7.1 Activity data

Emissions for 2016 were estimated for industrial sites that held resource consent for air discharges in 2016, specifically only for discharges from point sources at consented industrial facilities. Point sources are typically chimney stacks, but vents have also been included where the emissions were able to be quantified. Air pollutant emissions from stacks can be accurately quantified by source emission testing methods set by the US Environmental Protection Agency (US EPA) or by estimating emissions from combustion sources through emission factors.

Emissions not discharged through a point source are referred to as 'fugitive'. Fugitive emissions are difficult to measure and are therefore not included in this inventory. These include dust emissions from unpaved surfaces and aggregate handling, and VOCs emissions from solvent uses where active extraction to a stack does not occur (such as the drying of solvent-based paints at ambient temperatures or the filling of fuel storage tanks). Other excluded sources are baghouses that do not have a stack. The particulate emissions from these types of filtration systems are not available. Such filter systems are commonly employed at concrete batching facilities, of which there are more than 30 throughout the Auckland region.

Of all the reported emissions sources, 131 sources (35 per cent) had stack testing information available in accordance with conditions of consent. Emissions of a further 60 per cent of sources were estimated from assessment of environmental effects (AEE) reports and emission control manufacturer's information. For the remainder of sources (approximately 5 per cent), where stack testing or AEE information was not available, discharges were estimated from the consented emission rate limits. Emissions of combustion sources, in the absence of stack testing data, were calculated with fuel consumption emission factors.

7.2 Emission factors

PM_{10} and $PM_{2.5}$ emission factors were sourced from Huntley (2012) for natural gas combustion and from Tonkin & Taylor (2010) for landfill gas combustion. Other emission factors were from the US EPA AP-42 database (US EPA, 2004). AP-42 particulate discharge rates for gaseous fuels are considered to be unrealistically high and Huntley's data (2012) are considered more realistic. In Auckland, extensive emission testing for particulate was undertaken at Redvale Landfill's electricity generation facilities. The measurements from Tonkin & Taylor (2010) were used.

Emissions from consented industrial point sources were estimated for 2011 (Grange & Xie, 2015), 2009 and 2006 (Kevern *et al.*, 2009). These studies were iterative updates, utilising the same quantification methodologies and tools. Generally minor changes to emissions of air pollutants from consented industrial point sources were estimated to have occurred between the iterations.

7.3 Emissions and trends

Emissions from individual sources in 2001, 2006, 2011 and 2016 are provided in Appendix A (Tables A1.1 to A1.4). Consented industry is the dominant source of industrial emissions across the region as well as in the urban area. Emissions from consented industry decrease between 2001 and 2016 due to closures and upgrades of air pollution controls.

8.0 Conclusions and recommendations

Concluding findings of the inventory are as follows:

- In 2016, Auckland's air emissions from anthropogenic sources are:
  - 65,757 t/yr CO
  - 20,520 t/yr NOx
  - 2657 t/yr SO_2
  - 3820 t/yr PM_{10}
  - 2719 t/yr $PM_{2.5}$
  - 9109 t/yr VOCs
  - 6852 kt/yr CO_2
- Across the region, transport is the biggest source for most pollutants (i.e., CO, CO_2, NOx, SO_2 and PM_{10}). Domestic sources are the biggest contributor to $PM_{2.5}$ and VOCs emissions. This is because nearly half of $PM_{2.5}$ (45.0%) and VOCs (48.3%) comes from wood burning used for home heating.
- The contribution of emissions from the urban area to regional emissions varies from pollutant to pollutant, ranging from 29.6 per cent for SO_2 to 68.0 per cent for VOCs. In the urban area, transport is also the biggest source for CO, CO_2, NOx and SO_2. Domestic sources are the biggest contributor to PM_{10}, $PM_{2.5}$ and VOCs emissions.
- In summer transport is the dominant source for all pollutants. In winter domestic sources overtake transport as the dominant sector for CO, PM_{10}, $PM_{2.5}$ and VOCs. This is because transport and industrial activities are constant throughout the year, but domestic home heating occurs mainly over the winter season only.
- From 2001 to 2016, emissions of air pollutants from transport, domestic and industrial sectors decreased due to a downward trend in emissions from motor vehicles and domestic home heating. CO_2 emissions have fallen since 2006 mainly due to reduced industrial activities (therefore emissions). This has been partly offset by an increase in vehicle emissions.
- PM_{10} and $PM_{2.5}$ emissions decreased by 18.7 per cent and 22.4 per cent between 2006 and 2016. The monitored PM_{10} and $PM_{2.5}$ concentrations showed a downward trend since regular measurements began in the late 1990s and met air quality standards and guidelines since 2014 and 2015,

respectively. However, there were PM_{10} and $PM_{2.5}$ exceedances in 2019 due to the fire at the NZICC construction site, and Australian dust storms and bush fires.

- Uncertainty in total emissions estimates was not assessed due to different methods being used for the uncertainty analysis of land and air transport, sea transport, domestic and industrial sources. This can be improved when consistent methods are applied to calculate uncertainty for these sources.

9.0 Acknowledgements

Lauren Simpson and Mike Harvey of Auckland Council contributed to the Auckland Air Emissions Inventory 2016 project.

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11.0 Appendix: Emissions 2001-2016

Table A-1: Annual emission estimates for the Auckland region in 2001

Source	CO (t/yr)	CO_2 (kt/yr)	NO_x (t/yr)	SO_2 (t/yr)	PM_{10} (t/yr)	$PM_{2.5}$ (t/yr)	VOCs (t/yr)
Motor vehicles	102,050	2,524	18,244	2,149	1,059	1,014	10,216
Aircraft	1,175	417	2,376	111	9	9	140
Railway locomotives	59	13	210	0	5	4	20
Off-road mobile vehicles	758	199	1,680	1	142	131	171
Road dust - sealed	0	0	0	0	92	49	0
Road dust - unsealed	0	0	0	0	1,024	101	0
Road laying	0	0	0	0	0	0	213
OGV at-sea	138	80	1,631	1,245	166	166	36
OGV at-berth	43	15	239	203	32	32	16
Harbour vessels	3	2	24	0	1	1	1
Ferries	30	15	213	0	7	7	8
Transport subtotal	**104,256**	**3,265**	**24,617**	**3,709**	**2,537**	**1,514**	**10,821**
Outdoor burning	900	0	51	2	73	68	20
Wood	22,615	323	113	36	1,862	1,862	6,709
Coal	192	6	7	18	44	39	33
LPG	3	44	23	0	10	10	3
Natural gas	29	122	99	1	12	12	5
Lawn mowers	1,726	7	15	0	2	2	141
Domestic subtotal	**25,465**	**502**	**308**	**56**	**2,003**	**1,992**	**6,911**
Consented industry	3,440	3,959	4,510	1,250	780	410	3,940
Fishing	276	8	93	0	6	5	69
Industry subtotal	**3,716**	**3,967**	**4,603**	**1,250**	**786**	**415**	**4,009**
Grand total	**133,437**	**7,733**	**29,528**	**5,015**	**5,326**	**3,921**	**21,741**

Table A-2: Annual emission estimates for the Auckland region in 2006

Source	**CO (t/yr)**	**CO_2 (kt/yr)**	**NO_x (t/yr)**	**SO_2 (t/yr)**	**PM_{10} (t/yr)**	**$PM_{2.5}$ (t/yr)**	**VOCs (t/yr)**
Motor vehicles	84,144	2,955	15,570	232	937	885	7,308
Aircraft	1,278	454	2,586	121	10	10	152
Railway locomotives	90	22	326	0	8	7	33
Off-road mobile vehicles	1,002	271	2,266	1	188	174	224
Road dust - sealed	0	0	0	0	105	57	0
Road dust - unsealed	0	0	0	0	1,024	101	0
Road laying	0	0	0	0	0	0	228
OGV at-sea	75	35	919	564	77	71	34
OGV at-berth	29	28	378	421	46	42	11
Harbour vessels	3	2	24	0	1	1	1
Ferries	30	15	213	0	7	7	8
Transport subtotal	**86,651**	**3,782**	**22,282**	**1,339**	**2,403**	**1,355**	**7,999**
Outdoor burning	1,012	0	58	2	82	76	22
Wood	20,757	303	104	34	1,693	1,693	6,109
Coal	152	5	5	14	35	31	26
LPG	3	44	23	0	10	10	3
Natural gas	29	122	99	1	12	12	5
Lawn mowers	1,726	7	15	0	2	2	141
Domestic subtotal	**23,678**	**481**	**304**	**50**	**1,834**	**1,824**	**6,307**
Consented industry	2,609	4,163	3,169	1,311	454	321	4,105
Fishing	276	8	93	0	6	5	69
Industry subtotal	**2,885**	**4,170**	**3,262**	**1,311**	**460**	**326**	**4,174**
Grand total	**113,214**	**8,433**	**25,848**	**2,700**	**4,697**	**3,505**	**18,480**

Table A-3: Annual emission estimates for the Auckland region in 2011

Source	**CO (t/yr)**	**CO_2 (kt/yr)**	**NO_x (t/yr)**	**SO_2 (t/yr)**	**PM_{10} (t/yr)**	**$PM_{2.5}$ (t/yr)**	**VOCs (t/yr)**
Motor vehicles	56,978	2,964	12,677	71	770	718	4,603
Aircraft	1,245	442	2,519	118	9	9	148
Railway locomotives	118	30	430	0	11	10	45
Off-road mobile vehicles	779	209	1,750	1	146	135	175
Road dust - sealed	0	0	0	0	109	59	0
Road dust - unsealed	0	0	0	0	1,024	101	0
Road laying	0	0	0	0	0	0	243
OGV at-sea	80	37	976	603	83	76	37
OGV at-berth	39	40	509	604	65	60	15
Harbour vessels	3	2	25	0	0	0	1
Ferries	35	17	248	0	5	4	9
Transport subtotal	**59,277**	**3,741**	**19,134**	**1,397**	**2,222**	**1,172**	**5,276**
Outdoor burning	830	0	47	2	67	62	18
Wood	18,490	289	95	32	1,473	1,473	5,322
Coal	116	3	4	11	27	23	20
LPG	3	44	23	0	10	10	3
Natural gas	29	122	99	1	12	12	5
Lawn mowers	1,726	7	15	0	2	2	141
Domestic subtotal	**21,193**	**466**	**283**	**45**	**1,592**	**1,583**	**5,510**
Consented industry	2,042	3,767	3,505	982	386	300	2,363
Fishing	315	7	81	0	5	5	80
Industry subtotal	**2,357**	**3,774**	**3,586**	**982**	**391**	**305**	**2,443**
Grand total	**82,827**	**7,981**	**23,003**	**2,424**	**4,205**	**3,060**	**13,229**

Table A-4: Annual emission estimates for the Auckland region in 2016

Source	CO (t/yr)	CO_2 (kt/yr)	NO_x (t/yr)	SO_2 (t/yr)	PM_{10} (t/yr)	$PM_{2.5}$ (t/yr)	VOCs (t/yr)
Motor vehicles	41,138	3,186	10,251	73	647	588	3,238
Aircraft	1,283	455	2,595	121	10	10	153
Railway locomotives	44	8	154	0	3	3	12
Off-road mobile vehicles	994	274	2,272	1	188	173	221
Road dust - sealed	0	0	0	0	118	64	0
Road dust - unsealed	0	0	0	0	1,024	101	0
Road laying	0	0	0	0	0	0	258
OGV at-sea	133	57	1,300	906	125	116	62
OGV at-berth	40	34	488	472	53	48	15
Harbour vessels	157	4	46	0	1	1	5
Ferries	116	33	461	0	9	8	15
Transport subtotal	**43,905**	**4,051**	**17,567**	**1,573**	**2,178**	**1,112**	**3,979**
Outdoor burning	877	0	50	2	71	66	19
Wood	15,752	276	86	31	1,224	1,224	4,397
Coal	71	2	2	7	16	14	12
LPG	3	44	23	0	10	10	3
Natural gas	29	122	99	1	12	12	5
Lawn mowers	1,726	7	15	0	2	2	141
Domestic subtotal	**18,458**	**451**	**275**	**41**	**1,335**	**1,328**	**4,577**
Consented industry	3,110	2,344	2,606	1,043	302	275	481
Fishing	284	6	72	0	5	5	72
Industry subtotal	**3,394**	**2,350**	**2,678**	**1,043**	**307**	**280**	**553**
Grand total	**65,757**	**6,852**	**20,520**	**2,657**	**3,820**	**2,719**	**9,109**

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