Ministry for the Environment
Manatū Mō Te Taiao

Stats NZ
Tatauranga Aotearoa

>> New Zealand's Environmental Reporting Series

Our air 2018

DATA TO 2017

newzealand.govt.nz

Crown copyright ©

Unless otherwise stated, this copyright work is licensed for re-use under a Creative Commons Attribution 4.0 International licence. Except for any photographs, in essence, you are free to copy, distribute and adapt the work, as long as you attribute the work to the New Zealand Government and abide by the other licence terms. To view a copy of this licence, visit Creative Commons Attribution 4.0 International licence. To reuse a photograph please seek permission by sending a request to the stated image owner.

Please note that neither the New Zealand Government emblem nor the New Zealand Government logo may be used in any way which infringes any provision of the Flags, Emblems, and Names Protection Act 1981 or would infringe such provision if the relevant use occurred within New Zealand. Attribution to the New Zealand Government should be in written form and not by reproduction of any emblem or the New Zealand Government logo.

If you publish, distribute, or otherwise disseminate this work (or any part of it) to the public without adapting it the following attribution statement should be used:

> Source: Ministry for the Environment, Stats NZ, and data providers, and licensed by the Ministry for the Environment and Stats NZ for re-use under the Creative Commons Attribution 4.0 International licence.

If you adapt this work in any way, or include it in a collection, and publish, distribute, or otherwise disseminate that adaptation or collection to the public, the following attribution statement should be used:

> This work uses material sourced from the Ministry for the Environment, Stats NZ, and data providers, which is licensed by the Ministry for the Environment and Stats NZ for re-use under the Creative Commons Attribution 4.0 International licence.

Where practicable, please hyperlink the name of the Ministry for the Environment or Stats NZ to the Ministry for the Environment or Stats NZ web page that contains, or links to, the source data.

Disclaimer

While all care and diligence has been used in processing, analysing, and extracting data and information for this publication, the Ministry for the Environment, Stats NZ, and the data providers give no warranty in relation to the report or data used in the report – including its accuracy, reliability, and suitability – and accept no liability whatsoever in relation to any loss, damage, or other costs relating to the use of any part of the report (including any data) or any compilations, derivative works, or modifications of the report (including any data).

Citation

Ministry for the Environment & Stats NZ (2018). *New Zealand's Environmental Reporting Series: Our air 2018.* Retrieved from www.mfe.govt.nz and www.stats.govt.nz.

Published in October 2018 by
Ministry for the Environment and Stats NZ

Publication number: ME 1384
ISSN: 2382-0179
ISBN: 978-1-98-852591-4

Cover photo: Mount Maunganui. (Getty Images)

Contents

Message to our readers

Air quality is essential to life, but we cannot take it for granted. We all make choices – perhaps unwittingly – that directly affect the quality of the air we, and others around us, breathe.

It might be when smoke drifts onto our property from a neighbour burning rubbish, or when we smell the smoky chimney from wet firewood being burnt that we consider air quality.

Our role at Stats NZ and the Ministry for the Environment is to report on the state of our environment, including issues such as air pollution. We do this through our ongoing environmental reporting series.

In this report, we are focused on air, and we present the available data on the pressures, current states, and the impact of poor air quality on the health and well-being of New Zealanders and our environment.

This is our second air report and the problems identified across both reports are similar. However, in this report we explore in more detail the air quality issues that are important in New Zealand, where they come from, and why they matter. This will help us make informed decisions about the actions we need to take to improve our air quality.

The report shows that New Zealand's air is generally good, particularly when compared with heavily industrialised countries. But it's not perfect. There are times in some areas when air quality does not meet national air quality standards or international guidelines. Often this happens during the cooler months.

When air quality is poor, there are health implications. Air pollution can cause shortness of breath and coughing and potentially lead to more serious health effects particularly in the very young, older people, and those with pre-existing lung and heart conditions.

Air quality is the main focus of this report, but we have also provided information on light pollution, noise pollution, and odours because they too can affect our quality of life.

This report stresses that our knowledge of environmental issues in the New Zealand air domain is incomplete. Knowledge gaps and data needs are described throughout the report and summarised at the end.

How we tackle these environmental issues in the air domain is beyond the scope of this report. However, understanding the problems that affect our air quality and the gaps in knowledge is essential for us to continue making improvements.

Other products complement this report, giving readers the opportunity to delve deeper. The Environmental indicators Te taiao Aotearoa website contains graphs, maps, tables, and more detailed technical information. We've also produced an 'at a glance' summary which gives a pictorial view of our key findings, while our data service provides the raw data we used in our analysis.

Vicky Robertson
Secretary for the Environment

Liz MacPherson
Government Statistician

Our air – key findings

Our air quality is good in most places and at most times of the year. However, in cooler months emissions from home heating can raise particulate matter to levels above standards and guidelines, especially when the weather and landscape contribute to pollutants building up.

- The national emissions inventory indicates burning wood and coal for home heating was the biggest single human-made source of particles suspended in the air, or particulate matter (PM). In 2015, it made up 25 percent of PM_{10} (particles less than 10 micrometres) and 33 percent of $PM_{2.5}$ (particles less than 2.5 micrometres).
- Data from monitoring sites indicate air quality is poorer in autumn and winter when temperatures were cooler. From 2007 to 2016, 79 percent of instances when PM_{10} and $PM_{2.5}$ were higher than guidelines occurred during winter. However monthly average PM_{10} concentrations between 2007 and 2016 have seen decreasing (ie improving) trends in 17 of 39 airsheds (monitoring areas) in winter, when home-heating emissions are at their highest.

Vehicle emissions contributed to poor air quality in places, particularly for nitrogen dioxide pollution, which can cause serious health problems.

- The national emissions inventory indicates on-road vehicles were the single biggest source of human-generated nitrogen oxides in 2015 (39 percent). But regional council and New Zealand Transport Agency data both indicate a slightly decreasing trend in Auckland, Bay of Plenty, Hamilton, Northland, and Wellington between 2004 and 2016.

International studies show that air pollution can affect people's health. Effects include shortness of breath and coughing, heart attack, stroke, diabetes, and premature death. New Zealand specific studies on the health impacts are limited, but modelled data provides information on the changes over time.

- PM_{10}

  In 2016, modelled data estimated the number of premature adult deaths per 100,000 people from exposure to PM_{10} in New Zealand was 8 percent lower than in 2006. The number of days per 100,000 people when people were not able to go about their regular daily activities was 12 percent lower. But relative improvements in air pollution effects appear to be largely due to more people living in areas with lower PM_{10}, such as Auckland, rather than a reduction in PM_{10}.

- $PM_{2.5}$

  New Zealand is one of the few developed countries with no air quality standard for $PM_{2.5}$, although monitoring is undertaken in some parts of the country. Reporting for $PM_{2.5}$ is shown against the World Health Organization's (WHO) guidelines.

  - Long term: 4 of 11 airsheds with data for $PM_{2.5}$ had an annual average higher than the WHO guideline between 2014 and 2016.
  - Short term: 15 of 21 airsheds had at least one day with a 24-hour average higher than the WHO guideline between 2014 and 2016.

While New Zealand has low levels of light pollution and some areas have pristine night skies, all major urban areas had light pollution. Light pollution could affect cultural practices (including mātauranga Māori), natural ecosystems, and biodiversity.

- Based on estimates from satellite data in 2014, 74 percent of the North Island and 93 percent of the South Island had night skies that were either pristine or only degraded by light pollution near the horizon. But 56 percent of New Zealanders are unable to see the Milky Way.

Some emerging issues need more investigation to understand effects on our health, our environment, and our economy.

- There is increasing evidence for health effects from ultrafine particulate matter (smaller than 0.1 micrometres).
- Shipping is an important source of sulphur dioxide emissions, and the size and number of international cargo ships and cruise ships visiting New Zealand continues to grow.
- Recent intensification of agriculture could be causing an increase in ammonia emissions, which could affect ecosystems and biodiversity.

There are several knowledge and data gaps that prevent fuller understanding of the state and trends of our air.

- Air pollutant monitoring is limited in its coverage over space and time because it is generally only done where high air quality risks have already been identified.
- More consistent and improved data is needed on key sources of air pollutants; for example, estimates of emissions from home heating.
- New Zealand specific research and data on the health impacts of exposure to air pollutants, especially $PM_{2.5}$ and nitrogen dioxide is required.
- There is very little data about the impact of air pollutants on natural ecosystems and biodiversity.
- There is limited information on indoor air quality in New Zealand; this is important because we spend 80 to 90 percent of our time inside and outdoor air (which could be polluted) can make its way inside.

Introduction to air

About *Our air 2018*

We often take the air we breathe for granted, yet good air quality is fundamental to our well-being. Our air can become contaminated by particulate matter (particles suspended in the air) and gaseous pollutants. This can negatively affect our health, quality of life, ecosystems, and primary production. Poor air quality can become a serious public health issue and cost society greatly.

The quality of our air is directly affected by the personal choices we make. Emissions from the way we heat our homes, or how we get to work, have a direct impact on our neighbours and communities.

This report is written to:

- raise awareness and understanding of air pollution
- provide information on the health impacts of poor air quality
- provide information on the current state of our air and explain how human activities are influencing air quality
- provide information on other factors in the air that influence our quality of life, including light pollution, noise pollution, and odours
- provide information to help people and organisations make informed decisions to protect air quality, and other aspects of air affected by human activities – including light and noise pollution and odours.

Environmental reporting and the scope of this report

Our air 2018 is part of New Zealand's Environmental Reporting Series. It is the second report in the series dedicated to air quality, following from *2014 Air domain*, and is the first written under the Environmental Reporting Act 2015. Under this Act, the Ministry for the Environment and Stats NZ are required to report regularly on the **state** of the environment, the **pressures** affecting this state, and the **impacts** on New Zealand's environment and human well-being.

New Zealand's environmental reporting is in line with international best practice and provides fair, accurate, and independent information to help the public and decision-makers understand environmental issues.

Environmental reporting guidelines for topics covered in the air domain include the:

- pressures on air quality from human activities, climate and natural processes, and the physical form of the land
- state of air quality and concentrations of air pollutants
- impacts of poor air quality on public health; the economy; biodiversity and ecosystem processes; mātauranga Māori (Māori knowledge and philosophy), tikanga Māori (Māori culture and customs), and kaitiakitanga (guardianship of the environment); customary use and mahinga kai (traditional food-gathering areas); sites of significance; and culture and recreation.

Five domains are regularly reported on: air, atmosphere and climate, marine, fresh water, and land; as well as synthesis reports that incorporate information across all domains. A recent environmental report, Our atmosphere and climate 2017, focused on greenhouse gas emissions and subsequent impacts on climate.

In this report, air emissions that contribute to greenhouse gas emissions are mentioned, although this is not the main focus of *Our air 2018*.

Our air 2018 largely focuses on the current state of our air, the pressures on our air quality, and the impact of ambient (outdoor) air quality on the health and well-being of New Zealanders.

Report structure

The report begins by describing the approach to developing *Our air 2018* before explaining air, air pollutants and their effects, and air quality standards – legislation and guidelines.

For the body of the report, after describing the processes influencing air quality, two main types of air pollutants are discussed: particulate matter and gaseous pollutants. Most of the report's discussion of pressures, states, and impacts occurs within those chapters because they are different for the two types of air pollutants.

Each chapter begins by describing the impacts of those particular air pollutants, mainly on human health, to set the scene for why the reported pollutant concentrations (or state) matter.

Ongoing economic, technological, and cultural changes, as well as shifts in our understanding, mean that previously unimportant or unknown issues may currently be affecting our air quality – some of these are identified as emerging issues in the sections on particulate matter and gaseous pollutants.

Other issues are also examined, including:

- arsenic from burning treated timber
- dust from unsealed roads
- Auckland brown-haze events
- indoor air.

Other quality-of-life issues related to air, aside from air quality, are also explored. They include light pollution, noise pollution, and odours.

Te ao Māori and air quality

Te ao Māori (the Māori world view) recognises the interconnectedness of all things, and the holistic relationship that exists between people and the environment (Harmsworth & Awatere, 2013). This is reflected in the way mātauranga Māori (Māori knowledge system) has been developed over thousands of years in close connection to the environment.

The whakapapa (genealogy) of the air domain can be derived from Māori creation traditions that tell of the separation of Papatūānuku (Earth Mother) and Ranginui (Sky Father). A variant of this story is shared below.

The origins of the realm of Ranginui – the air domain

Papatūānuku and Ranginui once lived together in a tight embrace and their children, the atua (gods), lived in darkness between them. Fed up with living in perpetual darkness, the atua devised a plan to separate their parents so they could enter te ao mārama, the world of light. Tāwhirimātea opposed his siblings, and did not want to separate Papatūānuku and Ranginui. Nevertheless, the rest of the atua persisted with their plan and Tānemahuta eventually succeeded at separating Earth from the heavens. Enraged by this outcome, Tāwhirimātea decided to join Ranginui in the sky, where he became the guardian of the winds.

Good air quality is critical to sustain all life on Earth. As they exercise kaitiakitanga (responsibilities as guardians of the environment in accordance with tikanga Māori), it is important for Māori to ensure the mauri (life force) and hau (vitality) of the air is protected and enhanced. Mauri can be compromised in many ways, such as through air and noise pollution. Diminished mauri upsets the balance within a system and affects the relationship between people and the environment, and the ultimate health of all living things.

Ensuring good air quality is achieved fits within a te ao Māori health paradigm that links the physical, cultural, and spiritual well-being of people with the environment. Durie (1999) uses the concept of waiora to outline the relationship between Māori well-being and the environment. He says:

> Good health is difficult to achieve if there is environmental pollution; or contaminated water supplies, or smog which blocks the sun's rays, or a night sky distorted by neon lighting, or earth which is hidden by concrete slabs or the jangle of steel which obliterates the sound of birds… health promotion must take into account the nature and quality of the interaction between people and the surrounding environment. (Durie, 1999).

At a broad level, a te ao Māori view sees all things as interconnected and part of a system reflecting the deep and enduring relationship of the physical and spiritual worlds, in a woven universe that spans the past, present, and the future in an interconnected way (Marsden, 2003).

Air explained

Air is defined as the shallow gas layer surrounding Earth; that is, the lower atmosphere (troposphere) in which people live. This gas layer is primarily made up of oxygen (21 percent) and nitrogen (78 percent). It also includes small amounts of other gases, vapours, and particulate matter.

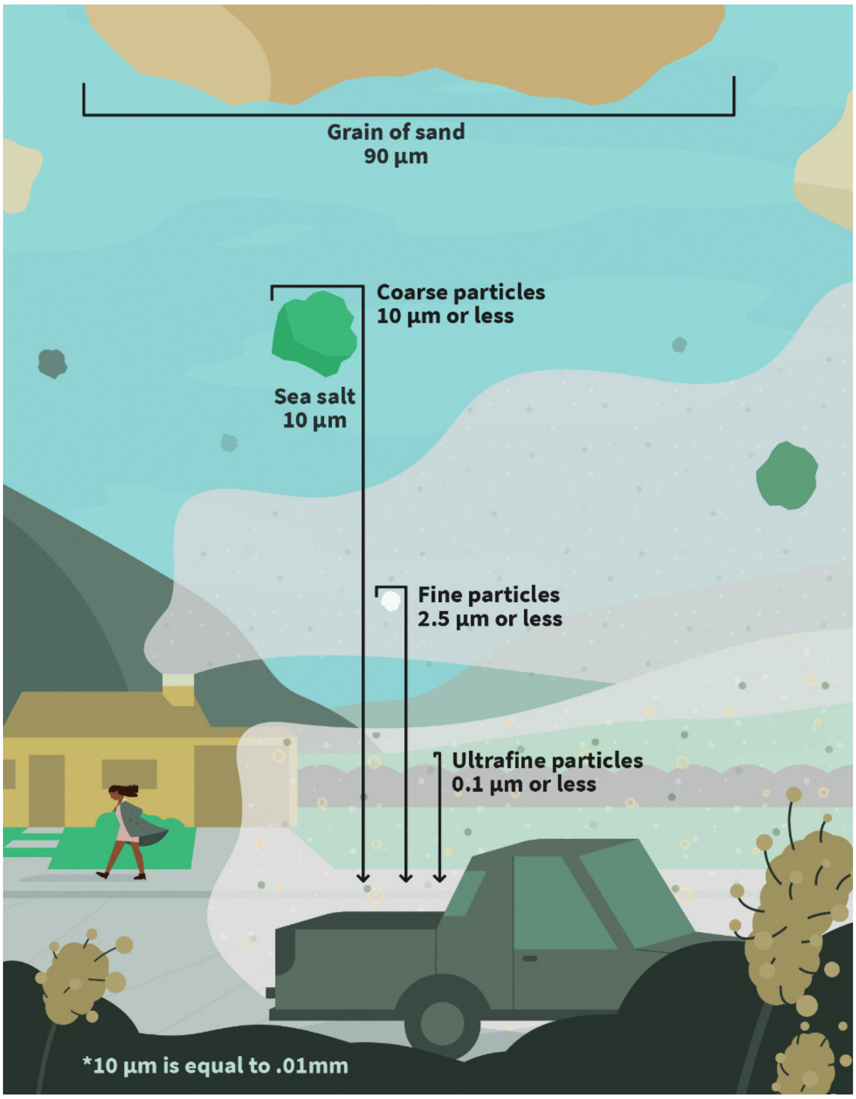
Human activities can emit gases and particles into the air. Some of these emissions can have a negative impact on air quality and can harm our health, our environment, and our economy. There are also natural sources of pollutants that influence air quality. The main pollutants in our air are classed as either particulate matter or gaseous pollutants.

Particulate matter

Particulate matter (PM) is a collective term for solid and liquid particles suspended in the air that are small enough to be inhaled. PM varies greatly in structure and chemical composition, depending on the source of the material; it correspondingly varies in the potential to cause harm, as described below.

PM comes from human activities and natural sources and is often classified according to its size. PM_{10} has a diameter of 10 micrometres (µm) or less. $PM_{2.5}$ has a diameter of less than 2.5 µm and is, therefore, a subset of smaller particles within the PM_{10} range. Ultrafine particles are an even smaller subset (less than 0.1 µm or 25 times smaller than $PM_{2.5}$). In general, the smaller the particle, the greater the impact on human health, as the smaller particles can penetrate more deeply into the human body. Figure 1 shows the relative sizes of the PM size classes.

Figure 1: Relative sizes of particulate matter



Gaseous pollutants

Gaseous pollutants exist as a gas in the atmosphere and are generally released or generated by human activities with some from natural sources (volcanic and geothermal activity). These pollutants include nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ground-level ozone (O_3), and carbon monoxide (CO). Although each gaseous pollutant is measured and reported separately, we rarely encounter them in isolation. Most often the air is a complex mixture of varying amounts of different gaseous pollutants, depending on what the main sources of air pollution are at a particular locality.

Knowing what's in our air

To understand the effects of air pollution, we must understand what is in the air and where it comes from. Two tools that are often used are emissions inventories and monitoring.

Emissions inventories

Emissions inventories account for the quantities of different pollutants emitted to the air by different sources, over a certain time period. This can be done in different ways. The simplest method is to use readily available information at a national scale, such as fuel use or production volume, and then translate that into the amount of pollution emitted. A more complex way is to calculate the amount of emissions from individual sources, using customised emission factors, and then add them together to calculate the amount of pollutants from different source types and regions.

Emissions inventories can provide information on the relative contributions of different sources and how they change over time, but they have a level of uncertainty in their estimates.

In this report, an emissions inventory was used to examine sources (pressures) of particulate matter and gaseous pollutants.

Air quality monitoring

Knowing the amount of each different pollutant that is emitted to the air does not tell us how much of it is present in the air (its concentration) at any given time. That is because concentrations depend not only on how much of a pollutant is added to the air, but also how quickly it is, or isn't, dispersed. Monitoring directly samples the air to measure how much of a pollutant is present. This results in much greater certainty about the amount of pollutant in the air, but without additional analysis does not provide information on its sources.

In this report, air quality monitoring data from regional councils, unitary authorities, and the New Zealand Transport Agency have been compiled and reported in the particulate matter and gaseous pollutants concentrations sections.

The impacts of air pollution

Exposure to moderate or low concentrations of air pollutants may not be immediately obvious but can be dangerous to our health. Serious adverse health effects can occur after short-term (acute) exposure to air pollutants. However, studies indicate that the most important impacts at a population-level are associated with the cumulative effects of long-term (chronic) exposure. These health impacts result in premature deaths, hospital admissions, sick days, and restricted-activity days. This creates a burden on the health system, the economy, and society as a whole.

Air pollution has other impacts, including:

- damage to natural ecosystems, biodiversity, and crops
- limiting our enjoyment of outdoor recreational facilities and scenic areas
- effects on cultural values and quality of life.

Air pollution – a global problem

Many areas of the world experience poor air quality, and air pollution has been described as the biggest environmental risk to health globally (Health Effects Institute, 2018). The United Nations Sustainable Development Goal 3 also notes that globally "indoor and ambient air pollution is the greatest environmental health risk" (United Nations, 2017).

New Zealand's air quality profile is different to most of the rest of the world and our air quality is good in most places and at most times of the year. However, in cooler months emissions from home heating can raise pollutants to levels that affect human health and are frequently higher than air quality standards and guidelines, especially when weather and landscape (topography) are favourable for the build-up of pollutants. Pollutants from vehicle emissions are a concern as well, mainly in large urban centres, while other pollutants can be important locally.

Air quality standards: legislation and guidelines

Our air 2018 refers to the thresholds in three main regulations or guidelines when discussing air pollutants in New Zealand (figure 2). Three regulations or guidelines are used because, for some air pollutants, they differ or are absent. Standards and guidelines are often developed for both the short-term (hours to days) and long-term (months to years) because health effects can differ for different lengths of exposure.

The air pollutants and concentrations for each standard and guideline are summarised in table 1 and table 2.

Figure 2: Air quality legislation, regulations, and guidelines

National Environmental Standards for Air Quality

The National Environmental Standards for Air Quality (NESAQ) are regulations made under the Resource Management Act 1991, which aim to set a guaranteed minimum level of health protection for all New Zealanders.

The NESAQ came into effect on 8 October 2004 and were last updated in 2011. They are made up of 14 separate but interlinked standards that regulate air quality.

Regional councils and unitary authorities are responsible for managing air quality under the Resource Management Act. They are required to identify and monitor areas where air quality is likely, or known, to exceed the NESAQ. These areas are known as airsheds.

Airsheds and monitoring sites explained

An airshed is a geographic boundary defined by the regional council or unitary authority for air-quality management, where part of the atmosphere is assumed to behave in a coherent way, particularly in how emissions disperse.

Monitoring is done in airsheds that are at risk of breaching the NESAQ for one or more pollutants. The number of monitoring sites within an airshed varies. Airsheds may have more than one monitor, because individual sites are often not representative of the entire airshed and can monitor different sources of pollutants.

World Health Organization guidelines

The World Health Organization (WHO) air quality guidelines were developed in response to the threat that air pollution poses to public health globally.

The WHO guidelines are not standards or legally binding criteria, but are designed to offer guidance in reducing the health impacts of air pollution, based on the ongoing expert evaluation of scientific evidence. They are relevant to the diverse conditions of all six WHO regions – New Zealand is in the Western Pacific Region – and support a broad range of policy options for air quality management.

WHO guidelines are used in this report when there are no national standards, or for comparison when there are differences.

The guidelines summarise the hazardous properties of air pollutants and indicate the risk related to exposure; that is, they provide a scientific contribution to developing strategies for air quality management (WHO, 2006).

Table 1: National Environmental Standards for Air Quality (NESAQ) and international guidelines (WHO)

	National Environmental Standards for Air Quality			World Health Organization Guideline	
Air pollutant	Concentration	Time period	Permissible exceedance (before a breach occurs) See note below table	Concentration	Time period
Particulate matter (PM_{10})	50 μg/m³	24-hour	1 permissible exceedance in 12 months (Exceptions apply in some cases. See clause 16B of the NESAQ for details)	50 μg/m³	24-hour
				20 μg/m³	Annual
Fine particulate matter ($PM_{2.5}$)	NA			25 μg/m³	24-hour
	NA			10 μg/m³	Annual
Nitrogen dioxide (NO_2)	200 μg/m³	1-hour	9 permissible exceedances in 12 months	200 μg/m³	1-hour
				40 μg/m³	Annual
Sulphur dioxide (SO_2)	350 μg/m³	1-hour	9 permissible exceedances in 12 months	500 μg/m³	10 minutes
	570 μg/m³	1-hour	NA	20 μg/m³	24-hour
Carbon monoxide (CO)	10 mg/m³	8-hour	1 permissible exceedance in 12 months	30 mg/m³	1-hour
				10 mg/m³	8-hour
Ozone (O_3)	150 μg/m³	1-hour	NA	100 μg/m³	8-hour

Data source: New Zealand Legislation, 1991; WHO, 2006; WHO Regional Office for Europe, 2000

Note: the air quality standard for a contaminant is breached if it is higher than its threshold concentration in an airshed and the exceedance is not a permissible exceedance. NA = not applicable.

Ambient Air Quality Guidelines

In addition to the NESAQ, New Zealand has Ambient Air Quality Guidelines (AAQG) that take into account a wider variety of pollutants and ecosystem health as well as human health (Ministry for the Environment, 2002). They were first prepared in 1994 and updated in 2002 by the Ministry for the Environment and the Ministry of Health. They precede the NESAQ and are guidelines, rather than regulations. This report refers to them at times for comparison where no NESAQ is set, or where it differs from other guidelines, particularly for the four air pollutants in table 2.

Table 2: Ambient Air Quality Guidelines

	Ambient Air Quality Guideline	
Air pollutant	Concentration	Time period
Arsenic	0.0055 μg/m³	Annual
Benzene	3.6 μg/m³ from 2010 onwards (10 μg/m³ initially)	Annual
Benzo(a)pyrene	0.0003 μg/m³	Annual
Sulphur dioxide	120 μg/m³	24-hour

Data source: Ministry for the Environment May (2002)

Our data for the air domain

This report is based on data that have been quality assured by Stats NZ and that meet quality standards for the Environmental Reporting programme. Where possible, this report includes data up to 2017. However, 2017 data were not available for all indicators, or could not be collected, validated, and analysed in time to meet the publication schedule.

The main sources of information are data analyses derived from Environmental indicators Te taiao Aotearoa: Air.

These indicators provide information on data collection and methodologies, and are available on the Stats NZ website. Links to the data and additional analysis are provided on the Stats NZ website. The datasets are available on the MfE Data Service. The data on ambient (outdoor) air concentrations mostly come from regional councils and unitary authorities, the New Zealand Transport Agency, the National Institute of Water and Atmospheric Research, and the Institute of Geological and Nuclear Sciences.

Health impact data is mostly sourced from the Health and Air Pollution in New Zealand model.

Large portions of our data are from regional councils' and unitary authorities' monitoring sites. Monitoring ambient air concentrations for some pollutants is required under the Resource Management Act (for regulation purposes) where poor air quality might be expected (eg major roading networks, residential areas, and industrial parks).

The Ministry for the Environment's Good Practice Guide for Air Quality and Data Management 2009 guided data analysis.

In this report, we only report on data collected from sites:

- that have a timely record of reliable, good quality data
- where people are.

Although the data used in this report are reliable and accurate, several considerations should be kept in mind when interpreting results:

- data from sites do not spatially represent the entire country because monitoring is only undertaken when there is a perceived problem; therefore, data should not be used to determine a single, nationwide picture of our country's air quality
- caution is needed when comparing sites with each other; air quality issues can be highly localised so issues relevant to one site may not be relevant for another
- although emissions can be a significant influence on air quality, use caution when attempting to determine a link between emissions and pollutant concentrations – other factors (particularly local weather patterns and topography) often influence the amount of pollutants in the air at a given time and place
- use caution when comparing results in *Our air 2018* with those from other reports, which may use data from different locations, have different methodologies, or cover different lengths of time – this may include comparisons with the previous 2014 Air domain report.

Where possible we have categorised sites into types (eg residential, traffic, industrial) based on classifications compiled by Land, Air, Water Aotearoa (LAWA) and regional councils and unitary authorities. This allows us to compare similarly situated sites in different locations, and reduce the over-representation of urban areas with multiple monitoring sites. Different monitor classes are also representative of different areas. For example, industrial-focused monitors are generally targeted at a small number of localised sources while residential-focused monitors usually spatially represent a wider area.

We assessed all trends described in this report at the 95 percent confidence level. For more information about our trend assessments, see Trend assessment – technical information.

We assessed the majority of our trends using the most recent decade (2007–16) of monitoring. At times we focus on averages and exceedances in the latest three-year period (2014–16) for which we have complete data, to provide a timely snapshot of air quality in New Zealand.

We sourced data on the health impacts from exposure to particulate matter pollution in New Zealand from the Health and Air Pollution in New Zealand model (Kuschel et al, 2012). Where possible, air quality and health impact data are presented within the context of national standards (NESAQ) and international guidelines (WHO).

Data gaps that became apparent are identified and discussed, based on peer-reviewed research. We summarise these data gaps in the final chapter of this report, Our air – our future.

Processes influencing air quality

This section explains air pollution's sources and other factors that affect air quality.

Sources of air pollution

Air pollution can either be the result of human activities or come from natural sources (see figure 3). The main sources are:

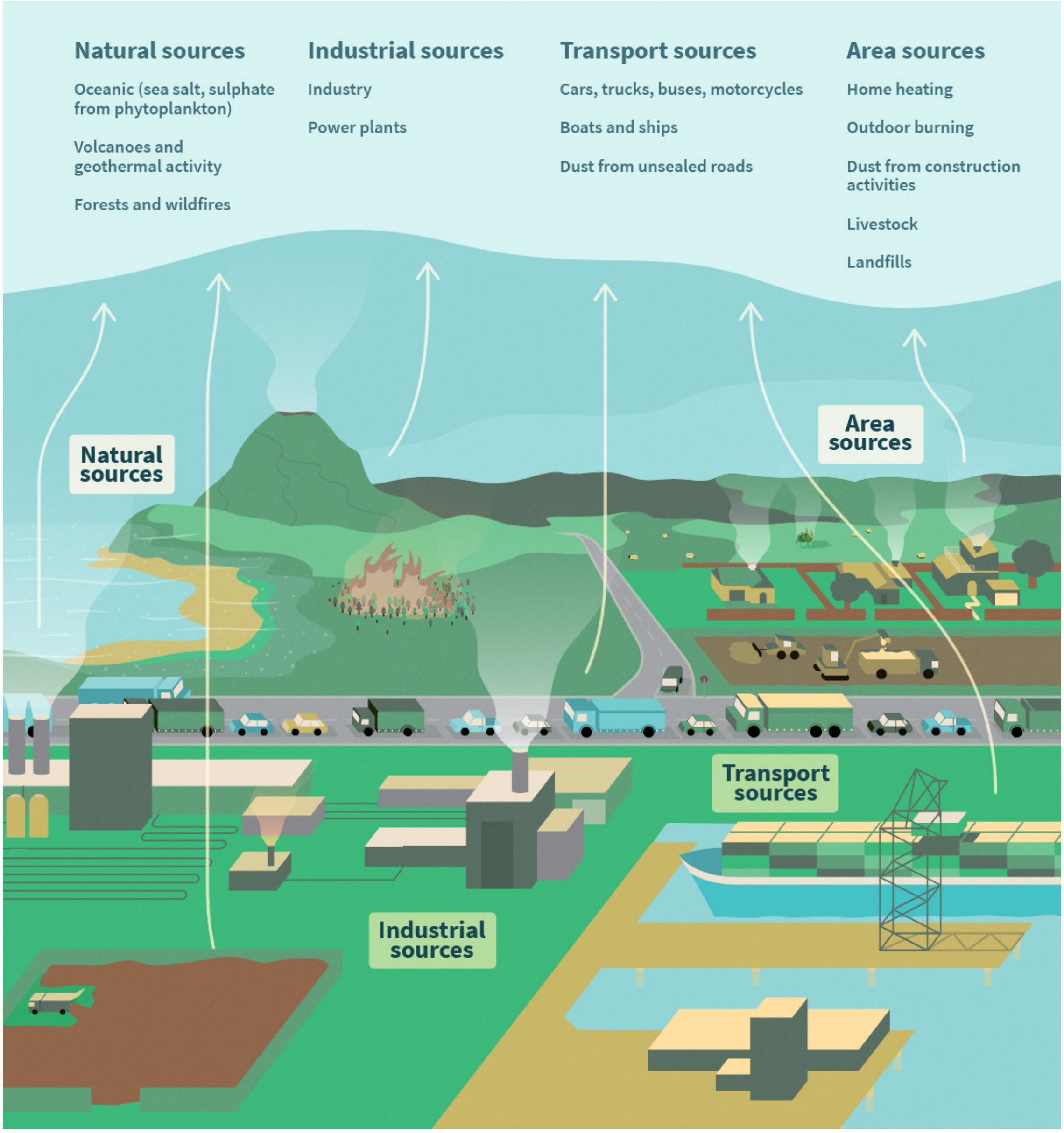
- **Human activities** – eg burning fuels for home heating, vehicle exhaust from combustion engines, emissions from industrial processes, power generation, agriculture, pesticides, and dust from unpaved roads and unpaved areas such as quarries, farms, or construction sites.
- **Natural sources** – eg wind-blown dust, pollen, smoke from wildfires, sea salt, and ash and gases from volcanic activity.

Pollutants that are emitted directly into the air from their source are known as **primary pollutants**. Particulate matter (PM), carbon monoxide, and sulphur dioxide are typically primary pollutants. **Secondary pollutants** form when primary pollutants react in the atmosphere to form new pollutants, such as ozone.

Nitrogen dioxide is present in the air as both a primary and a secondary pollutant since it can be emitted directly from combustion processes, along with nitrogen oxide. Nitrogen oxide can then oxidise to form more nitrogen dioxide. PM can also be present as a secondary pollutant since gases such as sulphur dioxide, nitrogen dioxide, and ammonia can react to form sulphate, nitrate, and ammonium particles.

The ozone layer in the upper atmosphere forms a layer that blocks out harmful ultraviolet radiation and protects life on Earth. But at ground level, ozone is a gaseous pollutant that can irritate our airways and eyes, and damage our lungs.

Figure 3: Air pollution sources in New Zealand



Factors that influence air quality

Some of our towns and cities are prone to air quality problems over the winter period, whereas other locations with similar emissions have better air quality. This is because factors other than emissions influence air quality. These factors include geography, topography, weather, and time and seasonality, as described below.

Geography

New Zealand is an island nation, far from sources of pollution in other countries. This means that, except for rare events such as bushfires and dust storms from Australia, we generate most of our air pollution. Our location in the mid-latitudes means we have a windy climate that dilutes and carries pollutants away quickly, but it also increases the proportion of natural sea salt in our air.

Topography

The shape of the land is important, as pollutants can be trapped in valleys or basins. Towns and cities located in basins (eg Alexandra and Rotorua) tend to have greater problems with air quality, particularly when there are temperature inversions (see Temperature inversions influence air quality) during clear, calm weather. Ridges and hills can also provide localised screening of how air pollutants move, resulting in poor air quality near a source of a pollutant, or better-than-expected air quality on the other side of the ridge or hill.

Weather

Temperature, sunshine, humidity, and wind patterns can all influence air quality. High pressure periods can lead to calmer stable conditions, so pollutants are more likely to accumulate. In contrast, higher winds can disperse pollutants and raise the level of natural sea salt in the air. Wind patterns are also important as wind can blow pollutants towards or away from urban areas.

Time and seasonality

There are daily, weekly, seasonal, and even inter-annual patterns in air quality that are influenced by cycles in both emissions and atmospheric conditions. Air pollutant concentrations can vary by:

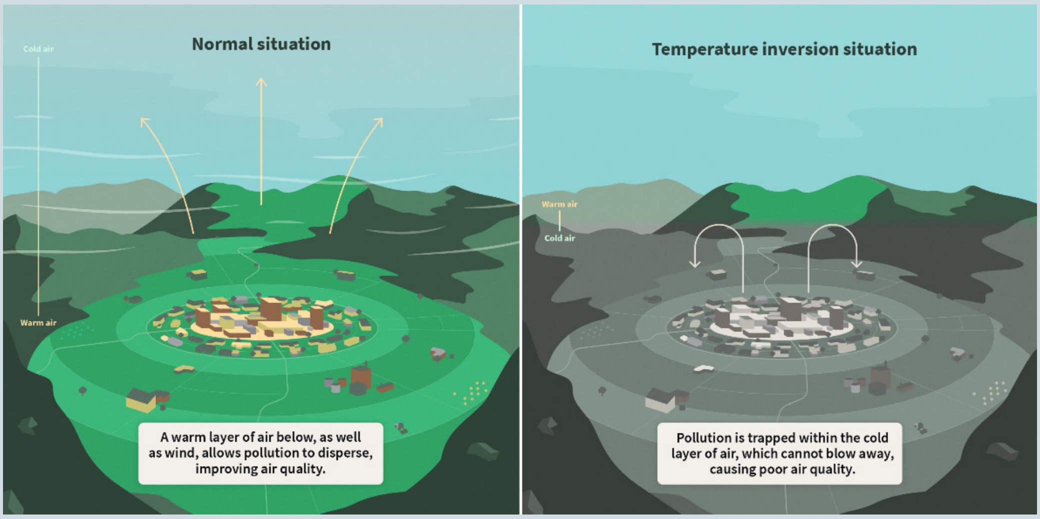
- time of day – emissions of different pollutants rise and fall during the day; eg vehicle emissions peak during rush hour traffic, while home-heating emissions peak in the evening and the morning as people fire up their wood burners
- day of the week – motor-vehicle emissions are higher during weekdays when workers are commuting and more commercial vehicles are on the road; also, industrial emissions are generally higher on weekdays
- season – our air quality changes seasonally along with the weather; eg colder temperatures during autumn and winter lead to an increase in home-heating emissions, while windier weather in spring and summer disperses pollutants; however, some pollutants (eg ozone) need sunlight to form, so their concentrations are higher in summer
- inter-annual cyclical climatic factors – particularly El Niño and La Niña phases of climate oscillations that cause certain weather patterns to become more prevalent. For example, a study in the Wairarapa region found that an increase in westerly winds associated with El Niño was likely a major factor in better air quality in the winter of 2015 (Pezza & Mitchell, 2016).

Temperature inversions influence air quality

Temperature inversions exacerbate air quality problems in some towns and cities during the cooler months, when people are burning wood or coal to heat their homes. On clear nights, cooling near the ground's surface leads to cold air near the ground being overlaid by a layer of warm air, the opposite of the normal temperature gradient. This warm air acts as a lid, trapping pollutants (both particulate matter and gaseous pollutants), and allowing them to build up (see figure 4). Topography such as valleys and basins can act as additional barriers.

These inversion events are responsible for peak PM concentrations at many of the monitoring sites in residential areas. Natural sources of PM, such as sea salt, are low under these conditions so most of the air pollution is from human activities, particularly emissions from domestic heating.

Figure 4: Local weather and topography can cause temperature inversion that traps pollution



Particulate matter pollution

This section discusses health impacts from particulate matter (PM), sources of PM (or pressures), and concentrations (or state). This section refers to thresholds in legislation and guidelines, which are summarised in Air quality standards: legislation and guidelines.

Health impacts of particulate matter pollution

In New Zealand and worldwide, the most significant human health impacts from poor air quality are associated with exposure to PM (Health Effects Institute, 2018).

At the less-severe end, breathing PM can cause mild and reversible effects such as shortness of breath, coughing, or chest pain. At the other end of the scale, there is strong evidence for much more severe effects of exposure to PM. It can cause disease and premature death from cardiovascular and respiratory problems, such as heart attack, stroke, or emphysema. It can also cause lung cancer and exacerbate asthma. Recent studies point to possible links with diabetes and atherosclerosis due to an increase in inflammation (WHO, 2013).

People with pre-existing heart or lung disease, young children, and the elderly, are the most likely to suffer adverse health effects. Exposure to PM can be especially serious for the very young. It has been associated with premature birth, low birth weight, and infant bronchiolitis. Associations have also been identified between PM exposure and respiratory infections, asthma, and chronic reduced rate of lung growth in young children (US EPA, 2009; WHO, 2013).

The effects that exposure to PM can have on our health depends on factors that include:

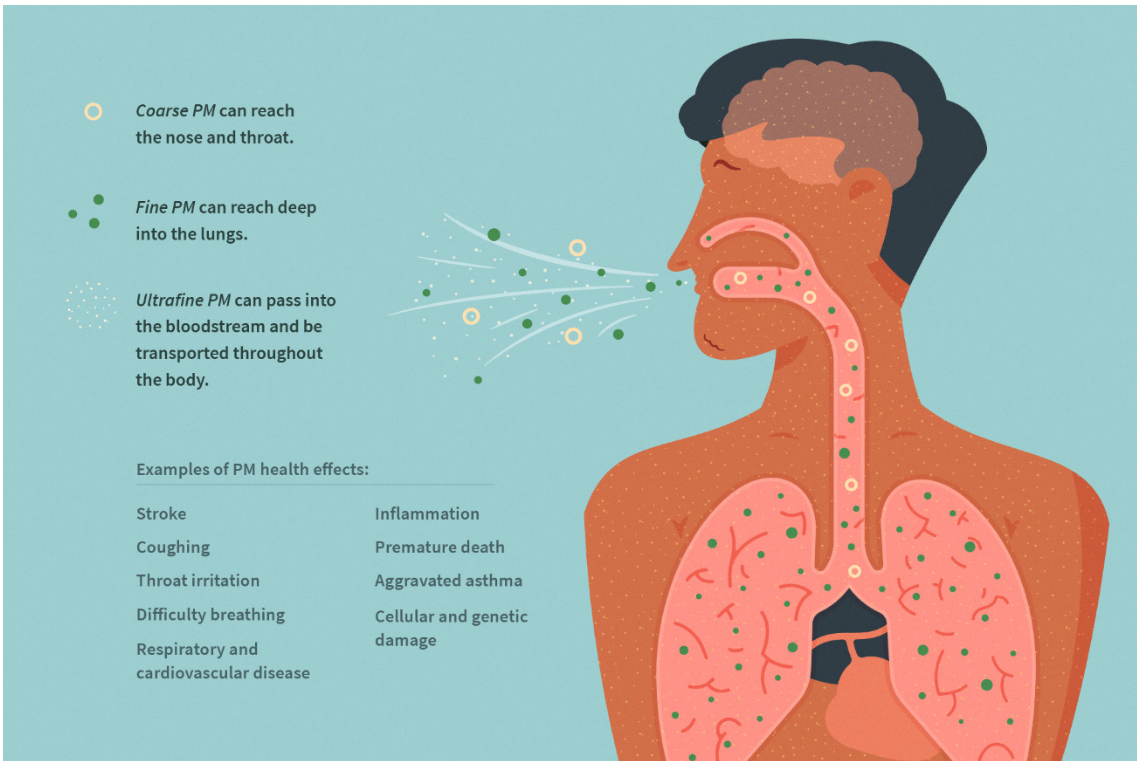
- the size of the particles
- the amount of particles, and length of time exposed to them
- their composition
- individual susceptibility.

The smaller the particle, the greater the health impact

The smaller a particle is, the farther into the respiratory tract it will penetrate – to interact and cause adverse health effects (see figure 5). Different sizes of PM can result in differing health effects. This is because they deposit in different parts of the respiratory tract, they have diverse sources, and they can interact partly through different biological mechanisms (WHO, 2013). Fine particles are now recognised as having the highest health risk and are mainly created by human activities.

Larger, coarse PM (2.5–10 μm) generally deposits in the nose, throat, and upper airways, while fine PM (2.5 μm and smaller) can deposit deep in the lungs where the air-blood exchange occurs. Ultrafine particles (0.1 μm and smaller), the smallest of the small, behave more like a gas than a particle. They are small enough to cross into the blood and circulate throughout the body (see Ultrafine particles have health impacts).

Figure 5: The impact of particulate matter on the human body



Exposure matters for health consequences

The amount (concentration) of PM and length of time someone is exposed to it contributes to the health consequences.

Higher concentrations of PM result in an increased risk of health impacts. For example, long-term risk of death from heart and lung disease increases by 6–13 percent for every 10 micrograms per cubic metre (μg/m^3) increase in annual $PM_{2.5}$ concentration. However, evidence has also been building for impacts at levels below the current WHO $PM_{2.5}$ long-term exposure guideline of 10 μg/m^3 (WHO, 2013; WHO Regional Office for Europe, 2016). This indicates there is no threshold for safe exposure where adverse effects do not occur (WHO, 2013).

The length of time someone is exposed to PM also influences their health outcomes.

Studies show that short-term exposure to PM can have significant impacts, even in people with no pre-existing health issues. Some impacts, such as shortness of breath are reversible, but repeated exposure can cause chronic inflammation, leading to respiratory and cardiovascular disease. Short-term exposure to fine PM can even cause premature death in vulnerable people, whereas, short-term exposure to coarse PM is only associated with these impacts.

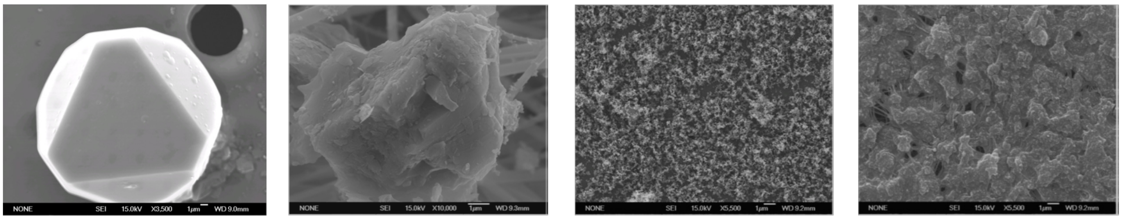
It is increasingly recognised that health effects from PM exposure may occur at much shorter timescales than previously thought (WHO, 2013). Physiological changes can occur within hours of exposure to high concentrations, and can be associated with premature death and illness immediately after exposure and in the following days (WHO, 2013). This is an important consideration for places with low long-term average $PM_{2.5}$ concentrations, but that experience periodic spikes of high $PM_{2.5}$ levels.

Evidence for effects from long-term exposure (years) to fine PM is strong and continues to build for cardiovascular, respiratory, and other chronic diseases. Risk factors for outcomes such as premature death from heart and lung disease are higher for long-term exposure, and it has much greater health impact than short-term exposure (hours to days). This is because effects from repeated short-term exposure can develop into chronic disease, and partly because it may progress underlying diseases (WHO, 2013). However, there is currently only limited evidence for the health effects from long-term exposure to coarse particles – it has only recently begun to attract researchers' attention (WHO, 2013).

Particle composition affects health

Because the size, source, and composition of particles are intricately linked, the source and composition of airborne particles are also relevant to health impacts. Research shows that PM's effect on health may be associated with specific sub-components of particle composition. Understanding the effect of a particle's composition can be difficult because atmospheric particles are a complex mixture of elements and compounds, with particle sizes that span nanometres to millimetres (see figure 6). Mixtures of particles also vary depending on the time of the day, season, and location.

Figure 6: Relative sizes of particulate matter in the air



Human-generated combustion particles tend to be much smaller than natural particles (Left to right: particles of sea salt, soil, motor-vehicle emissions, and home-heating emissions. All images are at approximately the same scale).

Source: GNS Science

Generally the most prevalent human-made source of particles in our urban atmospheres are emissions from the combustion of fuels (such as wood and petrol). The composition of the particles produced generally depends on the composition of the fuel burnt and the temperature at which it burns – elements and compounds with their own health effects may be incorporated into the particles during the combustion process. These include arsenic, lead, or other heavy metals present in the fuel; and polycyclic aromatic hydrocarbons from incomplete combustion of the fuel itself.

To date, most work has investigated traffic-related, industrial, and secondary PM; however, recent studies indicate that particles from burning organic matter (eg vegetation or forest residue) are equally as harmful (WHO, 2013).

There is some evidence for health effects (such as heart and lung disease and premature death) specifically from exposure to black carbon particles (WHO, 2013). Black carbon comes from all combustion processes, such as burning wood, diesel, and coal. However, the health effects associated with black carbon may be those of combustion-related PM in general (WHO, 2013). Black carbon is discussed in more detail in the section on air pollution and the climate because it also has negative implications for the climate.

In contrast, there is little evidence that sea salt particles (the most significant natural source of PM in New Zealand) are harmful to human health. Sea salt in the air comes from oceanic and meteorological processes. A 2008 study found that exposure to sea salt PM was much less toxic than the same amount of PM from combustion sources (WHO, 2013).

Particulate matter pollution affects New Zealanders

See Health impacts of PM_{10}

PM pollution causes a wide array of health impacts. Although there is a depth of knowledge from international studies on the effects PM can have on the human body, few studies have measured the health impacts on New Zealanders specifically. Recent research, based on data from the 'Growing up in New Zealand' child cohort study, found that living in a neighbourhood with a higher density of wood burners was associated with the increased risk of a non-accidental emergency department visit before the age of three by 28 percent (Lai et al, 2017).

Modelling the health effects of exposure to PM_{10} in New Zealand

Because of the difficulty in separating air pollution effects from other causes, modelling is commonly used to estimate health impacts from air pollution. In New Zealand, we use a modelling methodology taken from the Health and Air Pollution in New Zealand (HAPINZ) study, which was developed in accordance with international best practice (Kuschel et al, 2012).

The HAPINZ model determines air pollution health effects by estimating the concentration of PM_{10} in the air that the population is exposed to (using air quality and population data), and the relative risk of different health impacts occurring at that concentration, based on national and international studies. Air pollution health impacts are typically estimated for the number of days that people feel unable to undertake daily activities (eg going to school or work), hospitalisations, and premature death (see table 3).

The primary purpose of using the HAPINZ model is to estimate the relative impact that air pollution has on our health and the likely socio-economic effects. It can also be used to see changes over time (eg comparing 2006 with 2016) and understand the drivers behind any changes.

Although the model has limitations, HAPINZ is the only New Zealand-specific model available. The figures represent the most robust estimates of the number of New Zealanders experiencing serious health impacts from air pollution.

However, caution should be used when comparing the results in this report with those in previous reports because the output of HAPINZ depends on the input available at the time. The HAPINZ modelling in this report used more-recent information, including: updated health incidence data, updated source apportionment, updated population data, and a change to using census area units for all population information.

Modelling estimated the number of premature adult (over 30 years of age) deaths per 100,000 people in New Zealand was 8 percent lower in 2016 than in 2006. It also estimated 4,500 fewer restricted activity days per 100,000 people (ie 12 percent fewer days where individuals were not able to go about their daily activities because of poor health).

The relative improvements in human-generated air pollution health effects (per 100,000) appear to be largely due to more people living in areas with lower PM_{10}, such as Auckland, rather than a reduction in PM_{10}, lowering the overall health impacts per 100,000 people. Although PM_{10} concentrations appear to have decreased in other areas, these have only a minor contribution to health impacts calculations because of the smaller populations that are exposed.

Table 3: Modelled health effects from exposure to human-generated PM_{10}, 2006 and 2016

Health effect		Number of cases per 100,000 people	
		2006	2016
Premature mortality (adults 30+)		29	27
Hospital admissions	Cardiac hospital admissions	6	5
	Respiratory hospital admissions	9	9
	Total hospital admissions	15	14
Restricted activity days		36,300	31,800

Data source: HAPINZ Exposure Model (Kushel et al, 2012), Emission Impossible Ltd

Note: The health effects from exposure to PM_{10} are modelled. The estimates are determined from the PM_{10} concentrations that the population is exposed to and the estimated health risks associated with these concentrations. Hospital admissions are not a direct reflection of hospital records because they indicate the illness being experienced but cannot confirm the cause. The estimated health risks are determined from national and international epidemiological studies.

Number of cases per 100,000 people for premature adult mortality and hospital admissions are rounded to the nearest whole number and restricted activity days to the nearest one hundred.

Population estimates are based on estimated resident population data at 30 June of the given year.

Premature mortality is calculated assuming a 7 percent increase in mortality per 10 $\mu g/m^3$ increase in annual average PM_{10} exposure (Hales et al, 2010).

Other impacts of particulate matter pollution

Aside from the impact on human health, PM has other impacts, including those on natural ecosystems and biodiversity, agriculture, visibility, recreation, and cultural values. Data are lacking in New Zealand for these types of impacts, but they have been studied extensively overseas. There are also climate change implications related to PM (see Air pollution and the climate affect each other).

Impact on natural ecosystems and agriculture

Overseas studies have shown that when PM settles from the air onto land and water bodies, it can affect the natural environment, resulting in damage to vegetation and loss of biodiversity (Grantz, Garner, & Johnson, 2003; Varela et al, 2018). When PM lands on crops it can reduce the amount of sunlight available for photosynthesis, thus reducing yields (Grantz, Garner, & Johnson, 2003).

When PM containing hazardous substances eventually makes its way back to the ground and waterways, some of these substances can bioaccumulate; that is, they build up in higher levels of the food chain. This can lead to toxic effects on animals, and can be dangerous to humans that eat them, which potentially affects mahinga kai (traditional food gathering areas). These hazardous substances include heavy metals (eg arsenic, lead, mercury, and zinc), polycyclic aromatic hydrocarbons, and pesticides.

More data are needed to understand the specific effects of air quality on New Zealand ecosystems and agriculture.

Impact on visibility and recreation

Visibility is the most widely perceived measure of air quality and is highly influenced by PM. Reduced visibility can influence people's perception of air quality and sometimes the activities they engage in.

Tourism is New Zealand's largest export industry by foreign exchange earnings (Stats NZ, 2017). Visitors come to enjoy our abundant scenic richness and the beauty of our natural environment. The clarity of New Zealand's air is essential for people to enjoy the exceptional scenery and for perceiving this country as a clean, green, natural environment.

We do not have quantitative measures of the impact of air pollution on visibility in New Zealand, or on how air pollution affects recreation activities.

Particulate matter in New Zealand

Information on the sources of human-made emissions is provided by an emissions inventory – an accounting of sources and the quantity of pollutants emitted. National emissions are reported for 2015, the most-recent year that data are available.

Changes to the emissions inventory

Emissions were calculated using nationwide fuel consumption and other statistics, mostly from New Zealand's National Greenhouse Gas Inventory 1990–2015 (Ministry for the Environment, 2017), which were multiplied by an emissions factor (the amount of pollutant released by a specific fuel or process) to calculate the amount of pollutant released from each emission-source type.

The emissions inventory for this report used a different methodology from previous inventories (eg *Environment Aotearoa 2015*, *2014 Air domain report*), which summed individual sources, rather than national data, to obtain emissions estimates. Because the coverage of sources is now wider, it includes emissions from sources that may be in remote or unpopulated areas (eg unsealed road dust). The new methodology has the advantage of being more complete at a national level and more easily updatable, but with more uncertainty in finer-scale estimates than summing individual sources offers.

The comprehensive nationwide nature of the current methodology results in significant differences from previous inventories (described in more detail below). Due to the different methodologies used, current results should not be compared with previous inventories. In addition, because of the high-level approach, localised inventories that are focused on urban areas will more accurately reflect the dominant emission sources at those locations.

Industrial emissions are about double the quantity in the previous inventory because the latest inventory accounts for all fuel consumption from all sources, as well as non-combustion PM emissions, and diesel burned by off-road vehicles and equipment. New Zealand is the only country in the OECD without a pollutant release and transfer register to keep track of individual sources of industrial emissions. Having such a register would increase the accuracy of industrial sources in future inventories.

Likewise, outdoor burning in the previous inventory only included household burning of green waste – the updated inventory now includes crop residue and forest and grassland burning. Unsealed road dust, a significant source of localised PM_{10}, was omitted from earlier inventories but is now included.

Due to data not being readily available or updatable, several sources were not updated or included. These omissions include: industrial non-combustion sources of dairy processing (especially milk-powder processing), and the manufacture of particle board, fibreboard, and other wood processing. Residential wood burning was not updated because emissions data rely on survey and census data.

Because 2018 Census data had not been released when this report was written, data from the 2013 emissions inventory were used for residential wood burning, with the assumption the figures were relatively unchanged for 2015. Only human-generated emissions are included in this updated emission inventory.

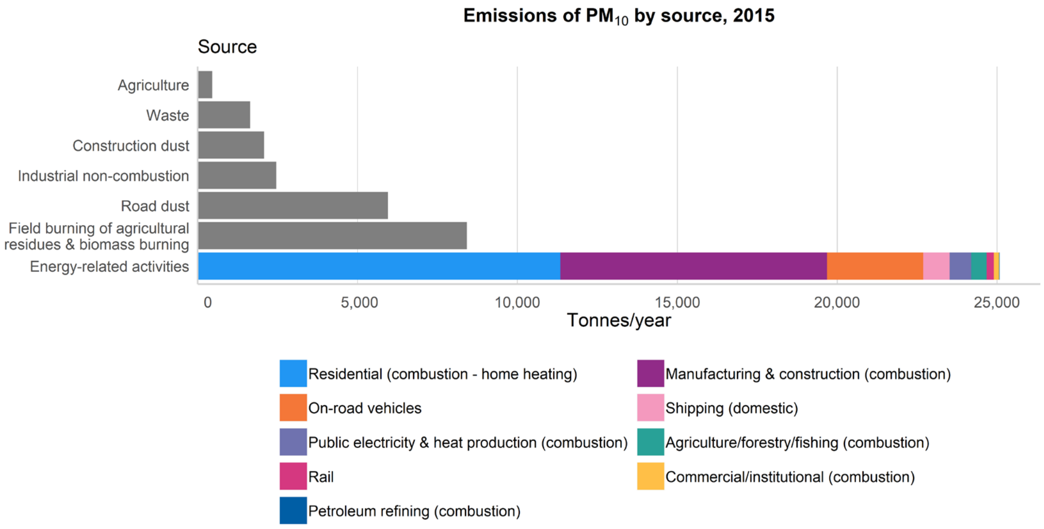
Home heating is the largest source of particulate matter

In 2015, the most-recent year data are available, residential emissions (primarily burning wood for home heating), were the single biggest source of both PM_{10} (25 percent, see figure 7), and $PM_{2.5}$ (33 percent, see figure 8). Residential emissions were 36 percent more for PM_{10} and 57 percent more for $PM_{2.5}$ than the next-biggest source, highlighting their important contribution.

See PM_{10} concentrations

See $PM_{2.5}$ concentrations

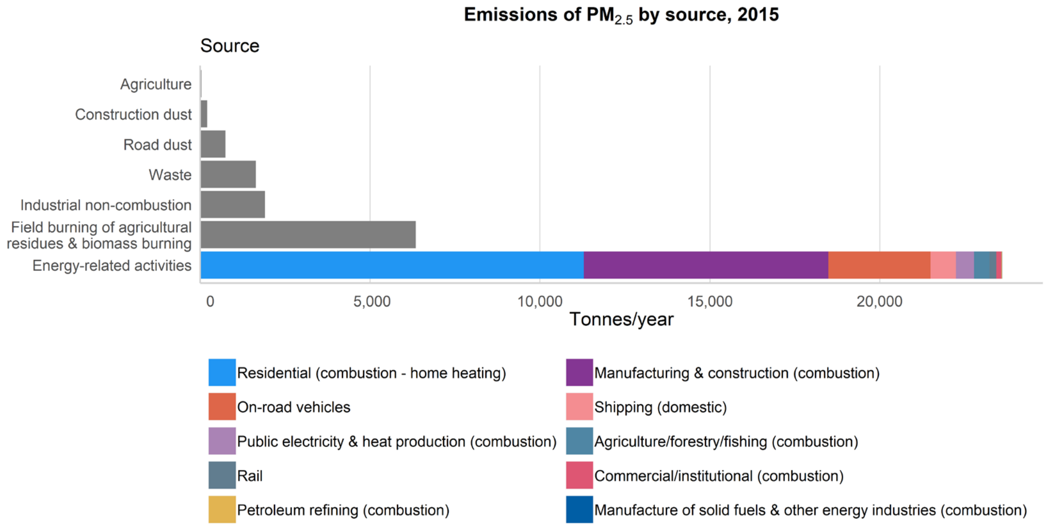
Figure 7



Data source: Emission Impossible Ltd

Note: Sub-sectors with less than 1% of sector emissions are excluded. Home heating emissions are assumed to be the same as the 2013 national emissions inventory (Wilton et al. 2015) because updated population data were not readily available. PM_{10} – particulate matter 10 micrometres or less in diameter.

Figure 8



Data source: Emission Impossible Ltd

Note: Sub-sectors with less than 1% of sector emissions are excluded. Home heating emissions are assumed to be the same as the 2013 national emissions inventory (Wilton et al. 2015) because updated population data were not readily available. $PM_{2.5}$ – particulate matter 10 micrometres or less in diameter.

This was a smaller proportion than that found using previous emissions inventory data (see Environment Aotearoa 2015), when 58 percent of total PM_{10} and 63 percent of total $PM_{2.5}$ was from home heating. Although home-heating emissions are the largest source of PM in both inventories, the difference in proportions is mainly because the method used for this report is more complete in the sources included, particularly for rural inputs.

While the updated inventory provides a good national overview, it has several limitations. Importantly, because it is an annual total, it does not capture the seasonal nature of home-heating emissions. The national-level picture provided by the updated inventory also does not account for how sources are distributed, or regional patterns. Home-heating emissions are mainly concentrated in urban areas, where most exposure to PM occurs. In contrast, many of the newly included sources that are driving the inventories' differences in proportions, such as off-road diesel use, dust from unsealed roads, and biomass burning on forest land, occur in rural areas where people's exposure is low.

Where detailed local inventories have been developed, they will provide a more accurate local overview of emissions sources, rather than the national approach used in this inventory. For example, emissions inventories commissioned by regional councils that examine specific areas in detail find that home heating can be responsible for up to 90 percent of total PM_{10} and 91 percent of $PM_{2.5}$ on winter days (Wilton; 2015, 2016, 2017).

New Zealand's unique air quality profile

The number of homes burning wood for heat has decreased over time, but it is still an important home-heating method in New Zealand. Wood burners heated 33 percent of North Island homes and 47 percent of South Island homes in 2013, with even higher percentages in some rural areas (Environmental Health Indicators New Zealand, 2015). Although coal burning is important in some local areas, nationally it only accounted for 4 and 3 percent of the PM_{10} and $PM_{2.5}$, respectively, from residential emissions. However, this may be an underestimate of residential coal use.

Most PM from home heating came from burning wood (96 percent of PM_{10} and $PM_{2.5}$). The amount and types of PM and hazardous emissions people are exposed to is highly dependent on how well the wood burns (which depends on the wood burner, the temperature of the fire, and the moisture content of the wood), what is being burnt (eg treated timber offcuts and painted timber), how quickly the smoke disperses, and how long someone is exposed to it.

Because residential wood burning is the primary source of PM emitted to the air, New Zealand has a unique air quality profile when compared with other developed countries. Most PM from wood smoke is in the fine fraction and most of it is emitted during the winter: in 2015, home heating emitted about 11,300 tonnes of PM_{10} and more than 99 percent of this was the smaller $PM_{2.5}$. This means that when PM_{10} concentrations are high, most PM_{10} is actually the smaller $PM_{2.5}$ particles. This differs from many other countries that have a larger proportion of coarse particles in their human-made PM_{10} – due to different sources dominating their emissions (Querol et al, 2004).

Other home heating emissions

Home-heating emissions are made up of many constituents other than PM. Gases such as nitrogen dioxide and carbon monoxide (CO) (see Gaseous pollutants) are also emitted, and other toxic substances can be attached to, or constitute particles themselves.

While on-road vehicles emit significant amounts of CO, most CO in New Zealand in 2015 was produced by residential wood burners.

Benzo(a)pyrene, a polycyclic aromatic hydrocarbon is produced from incomplete combustion of organic matter and is present in wood smoke. It is a known carcinogen and was measured at levels that were 10 times higher than the Ambient Air Quality Guidelines (AAQG) in Christchurch in 2009, and 16 times higher in Timaru in 2007 (Cavanagh et al, 2012). A more recent study found that during 2012–13, benzo(a)pyrene concentrations were 14 times higher than the AAQG in Timaru. Levels were low for most of the year but peaked during winter with home heating emissions (Salomon, 2015).

Other dangerous substances in PM include heavy metals such as arsenic and lead. Arsenic can be emitted when offcuts of treated timber are burned (see Arsenic from burning treated timber) and lead can be emitted when timber containing old paint is burned.

See Heavy metals

Leaded petrol was the main source of lead emitted to the air until 1996, when lead in petrol was banned. Lead, even at low levels, can impair cognitive function in children. The main source of lead now is burning painted timber at home (Davy & Trompetter, 2017); however, lead concentrations measured at Henderson in Auckland were well below the national guideline between 2007 and 2016.

Arsenic from burning treated timber

- Small particles of heavy metals such as arsenic, can become airborne, or they can attach to other PM, which can then be inhaled.
- Once in the body, arsenic can have a serious impact on health; eg it can cause lung cancer and may be linked to diabetes and reproductive effects (IPCS, 2001).
- The primary source of arsenic in New Zealand's urban air is from copper-chrome-arsenate treated timber when it is burned to heat homes (Cavanagh et al, 2012).
- A study of air quality in Wainuiomata between 2011 and 2012 found the annual average arsenic concentration was 7.1 nanograms per cubic metre (ng/m^3), which is more than twice as high as the typical background level for an urban area; the peak values occurred in the cooler months (Mitchell, 2013; WHO, 2001).
- Data from Henderson, Takapuna, and Penrose – Auckland (2006–16) show that arsenic (and lead) concentrations peak during winter, and were associated with residential wood burning (Davy et al, 2017).
- Measurements at Henderson – Auckland were higher than the Ambient Air Quality Guidelines for annual average arsenic (5.5 ng/m^3) five times during 2007–16.
- At locations further south, where winter PM levels are higher due to wood burning (eg Richmond, in Tasman district), annual average arsenic concentrations for 2014 were about three times the guideline (Ancelet & Davy, 2016).
- Ash from burned, treated wood has high concentrations of heavy metals and could affect gardens if sprinkled over them.

Particulate matter concentrations are declining

PM_{10} concentrations were measured at 96 sites across the country between 1996 and 2017. Of these, 45 sites had enough data to calculate trends. The majority of these sites are solely residential-focused monitoring sites that are predominantly influenced by home-heating emissions. The remaining sites are a mixture of residential-, industrial-, traffic- and coastal-focused monitoring sites.

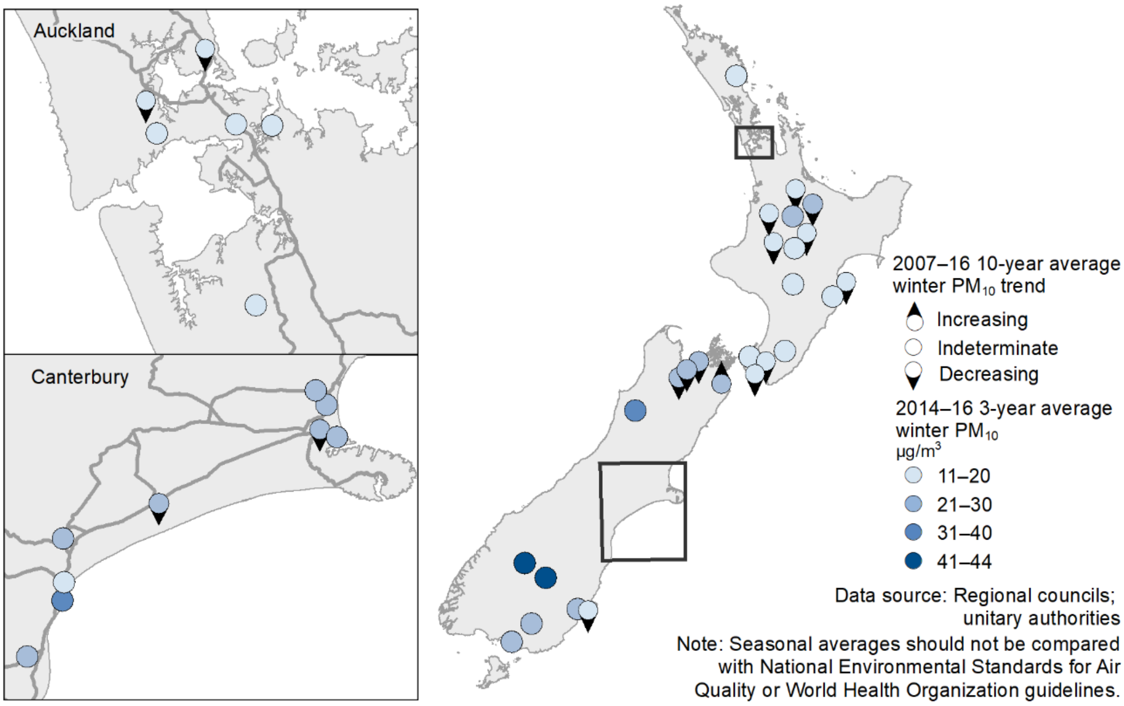
See PM_{10} concentrations

PM_{10} concentrations have decreased at many locations over the most-recent decade for which we have complete data (2007–16); this decrease occurred mostly during spring and winter (see figure 9).

Monthly average PM_{10} concentrations between 2007 and 2016 had decreasing (ie improving) trends in 17 of 39 airsheds (18 of 45 monitoring sites) in winter, when home-heating emissions are at their highest (89 percent of the sites with a decreasing trend in winter had a residential focus). One site – Blenheim, had an increasing trend during winter. Decreasing trends were also found at 20 sites during spring, 11 sites during autumn, and eight sites during summer. Eight sites had an increasing trend in summer. Decreases were seen at sites across both the North and South Islands, in both large cities and small towns.

Figure 9

Average PM_{10} 10-year trend, winter 2007–16, and 3-year average PM_{10} concentration, winter 2014–16



There is much less monitoring of $PM_{2.5}$ than PM_{10} in New Zealand, but of the sites with enough data to calculate trends in the monthly average from 2007–16, three of four airsheds (four of five sites) had a decreasing trend in winter. Decreasing trends were also found at three sites during spring and two sites during summer. One site (St Albans – Christchurch) had an increasing trend in summer.

Auckland has a long-term dataset of total suspended particulate concentrations (PM < 100 µm) from 1964 to 2016, which also shows a long-term decrease in PM levels.

See Total suspended particulate matter concentrations in Penrose, Auckland

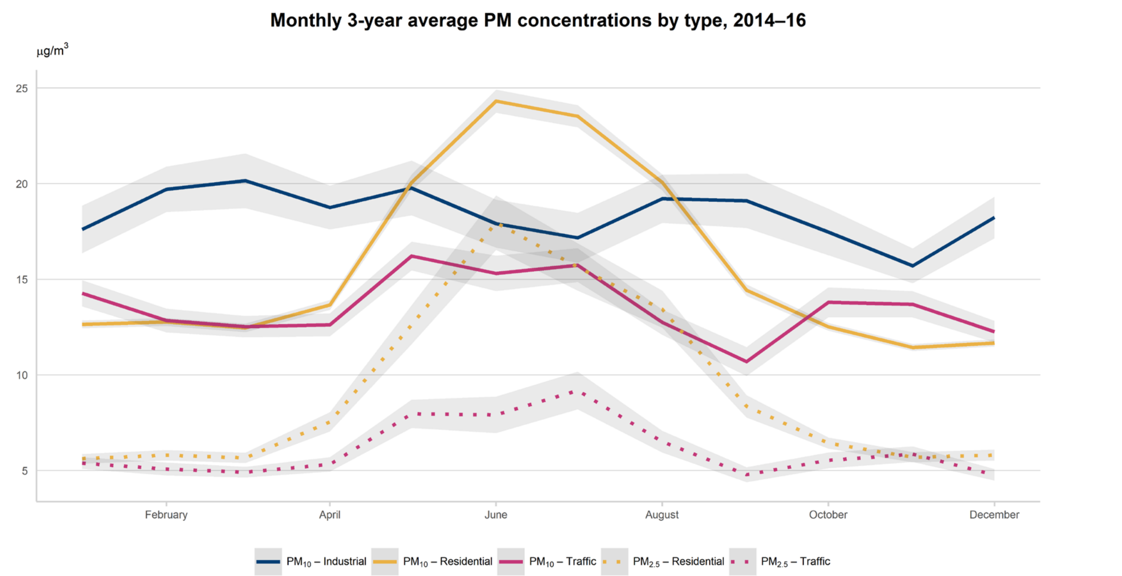
Particulate matter levels can be high in cooler months

Many sites have shown declines in PM concentrations. However, PM levels remain elevated in winter (June to August) at many residential-focused monitoring sites. The highest average concentrations were generally found not in large cities, but in small and medium-sized towns. This is likely driven by emissions from residential home heating, which are almost entirely $PM_{2.5}$, and by natural features (topography and weather) that favour the build-up of pollutants during certain times of year.

Concentrations of $PM_{2.5}$ measured at residential-focused monitors increased during the cooler months and peaked in June, illustrating that much of the winter PM_{10} peak at residential sites from 2014 to 2016 was dominated by fine particles (see figure 10). Average winter concentrations of both PM_{10} and $PM_{2.5}$ were generally higher in the South Island where the colder climate contributes to higher average home heating emissions. In contrast, industrial- and traffic-focused monitoring sites did not exhibit the same winter peak in PM concentrations.

Note: the categories in figure 10 (industrial, residential, and traffic) have different sample sizes of sites.

Figure 10

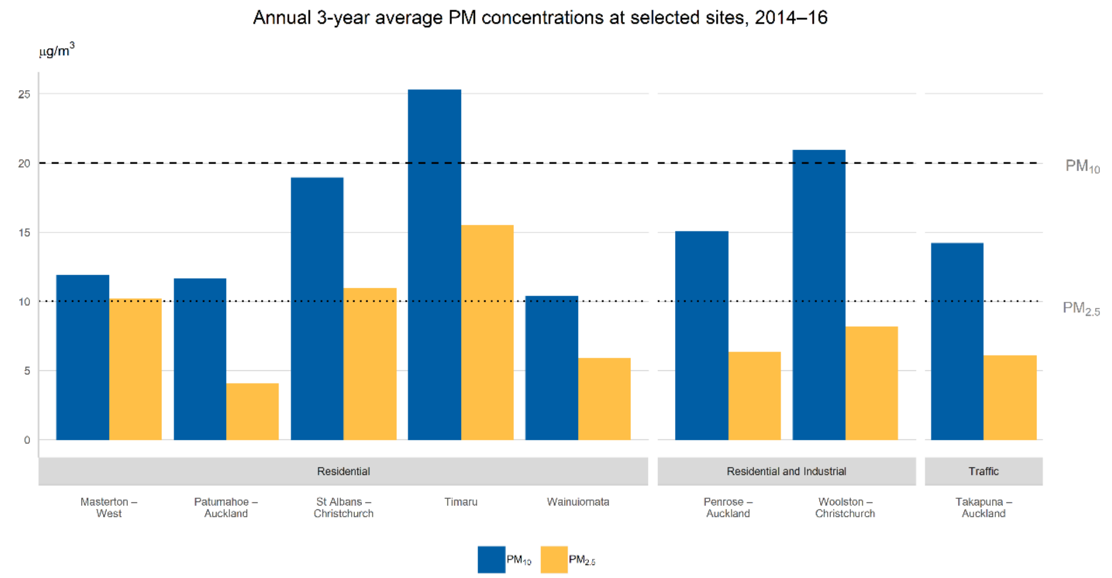


Data source: Regional councils; Unitary authorities

Note: PM_{10} – particulate matter 10 micrometres or less in diameter. $PM_{2.5}$ – particulate matter 2.5 micrometres or less in diameter. Does not include sites that have a mixed focus. Not all types have the same number of sites. There were no $PM_{2.5}$ industrial-focused sites with sufficient data.

Fine particles ($PM_{2.5}$) made up a larger proportion of PM_{10} at sites such as Masterton, Geraldine, and Timaru during the most-recent three years for which we have complete data (2014–16) (see figure 11). These sites have a relatively high density and use of wood burners during winter and favourable conditions for temperature inversions.

Figure 11



Data source: Regional councils; Unitary authorities

Note: Dotted line shows World Health Organization (WHO) guideline (10 µg/m³) for $PM_{2.5}$. Dashed line shows WHO guideline (20 µg/m³) for PM_{10}. Only sites with with both $PM_{2.5}$ and PM_{10} data are shown.

PM_{10} levels are sometimes higher than the air quality standard

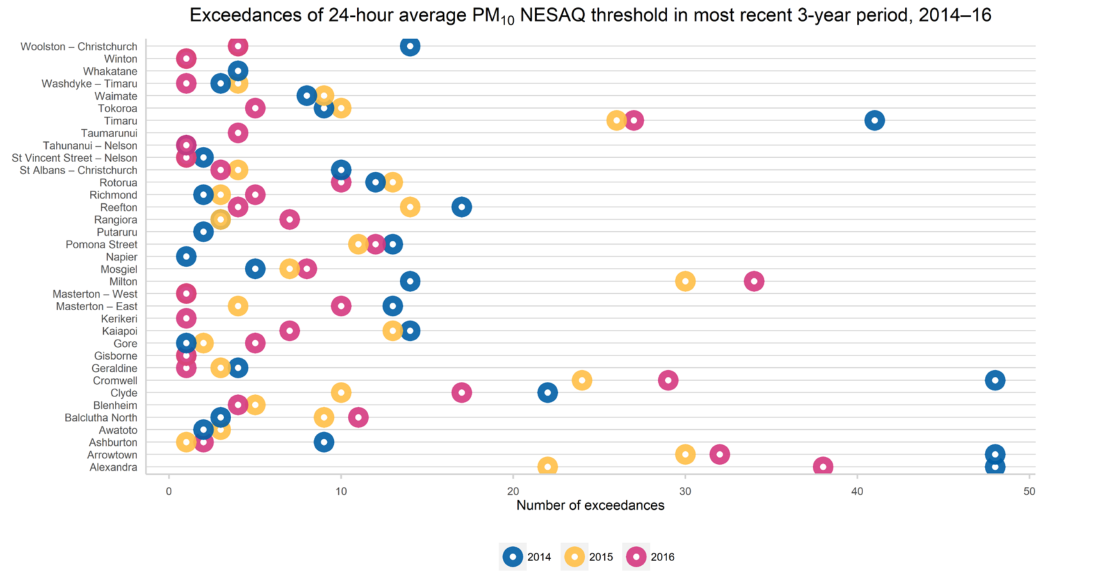
The most extensive data on PM levels in New Zealand is for PM_{10}. PM_{10} concentrations have often been higher than the National Environmental Standards for Air Quality (NESAQ) when home-heating emissions are high in the cooler months and weather conditions are favourable for the build-up of pollutants. See table 1 on NESAQ and WHO guidelines for more information on thresholds.

Over the most recent three years for which we have PM_{10} data (2014–16), 30 of 51 airsheds (35 of the 69 monitoring sites) exceeded the NESAQ for **24-hour average** PM_{10} (figure 12). The majority of these 35 sites included a residential focus. The most exceedances in a year were in the residential-focused monitoring sites in Alexandra (51 times in 2014), Arrowtown (48 times in 2014), and Cromwell (48 times in 2014). This is a higher percentage of airsheds than the 2014 Air domain report which found that 19 of 38 airsheds exceeded the 24-hour average PM_{10} NESAQ in 2012. Between 2007 and 2016, most PM_{10} exceedances occurred in winter (80 percent) and autumn (17 percent).

Data available for some sites for 2017 showed that 13 of 18 airsheds (15 of 23 monitoring sites) exceeded the 24-hour average PM_{10} NESAQ.

Note: Not all sites have complete data for all years in figure 12.

Figure 12



Data source: Regional councils; Unitary authorities

Note: PM_{10} – particulate matter 10 micrometres or less in diameter. Exceedances of National Environmental Standards for Air Quality (NESAQ) for PM_{10} occur above 50 µg/m³ (micrograms per cubic metre). Not all sites have complete data for all years.

$PM_{2.5}$ levels are sometimes higher than the WHO guidelines

There is no air quality standard for $PM_{2.5}$. Therefore, the WHO **annual average** (long-term) guidelines have been used to assess $PM_{2.5}$ exceedances in New Zealand. Over the most-recent three-year period (2014–16) for which there is complete $PM_{2.5}$ data, four of 11 airsheds (five of 14 monitoring sites) were higher than the WHO annual average $PM_{2.5}$ guideline (10 µg/m³) for long-term exposure. All were residential-focused. The sites were:

See $PM_{2.5}$ concentrations

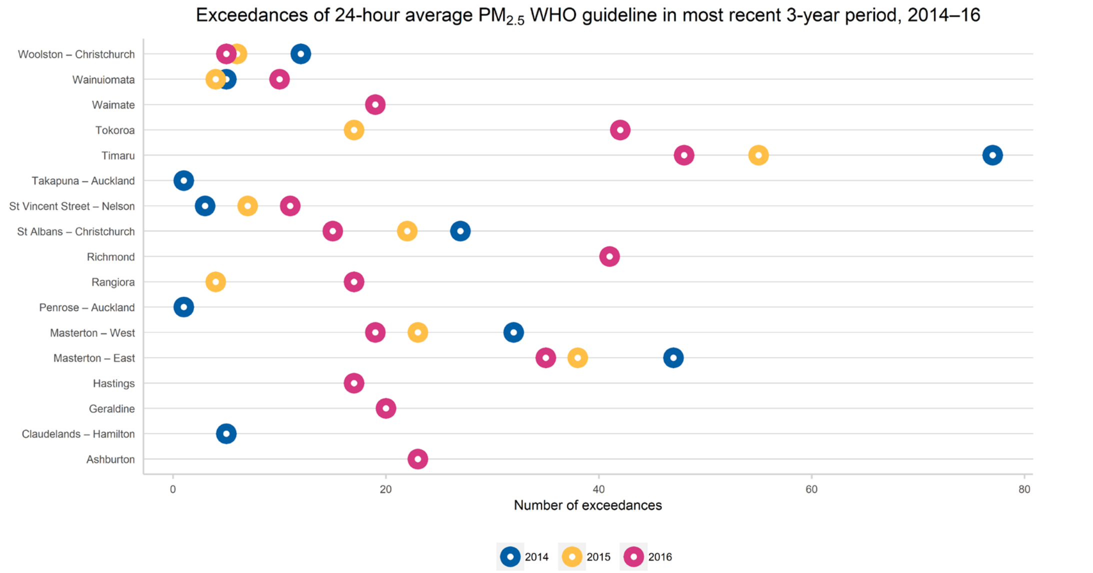
- Timaru (2014: 17 µg/m³, 2015: 16 µg/m³, 2016: 13 µg/m³)
- St Albans – Christchurch (2014: 12 µg/m³, 2015: 12 µg/m³)
- Masterton – East (2015: 11 µg/m³)
- Masterton – West (2014: 11 µg/m³)
- Geraldine (2016: 11 µg/m³).

Data available for one site in 2017, Blenheim (15 µg/m³), was higher than the WHO annual $PM_{2.5}$ guideline. None of the other monitored sites had complete enough data in 2017 to be comparable with the annual WHO guideline.

Fifteen of 21 airsheds (17 of 25 monitoring sites) were higher than the WHO **24-hour average** $PM_{2.5}$ guideline between 2014 and 2016 (see figure 13). All sites included a residential focus except for Takapuna – Auckland, which was solely traffic-focused. Only sites that had an exceedance are displayed in figure 13. Data were available for some sites for 2017. Of these, all 12 airsheds (14 monitoring sites) had at least one day that was higher than the WHO short-term guideline. The most exceedances were in Blenheim (72).

Note: Not all sites have complete data for all years in figure 13.

Figure 13



Data source: Regional councils; Unitary authorities

Note: $PM_{2.5}$ – particulate matter 2.5 micrometres or less in diameter. Exceedances of World Health Organization (WHO) guideline occur above 25 $\mu g/m^3$. Not all sites have complete data for all years

As with PM_{10}, there is a strong seasonality factor for exceedances of the 24-hour WHO guideline at sites with data for $PM_{2.5}$. Between 2007 and 2016, 78 percent of exceedances of the WHO daily $PM_{2.5}$ guideline occurred during the winter, and 18 percent in the autumn. This compared with 3 percent in spring and less than 1 percent in the summer, again indicating the importance of home-heating emissions. Note percentages do not add to 100 due to rounding.

When home-heating emissions are low during the warmer months, PM concentrations at residential-focused monitoring sites are at their lowest and we generally experience good air quality.

Other sources of human-generated particulate matter

Combustion is the most important source of PM in New Zealand. In addition to home-heating emissions, other important sources of PM emissions in 2015 were burning of wood in construction and manufacturing processes, such as boilers powered by heat from wood burning (15 percent of PM_{10} and 17 percent of $PM_{2.5}$), and open burning (18 percent of PM_{10} and 18 percent of $PM_{2.5}$).

Emissions from on-road vehicles are the most important non-biomass combustion source of PM, most of which is $PM_{2.5}$. For $PM_{2.5}$, only one traffic-focused site had enough data to calculate a trend (Takapuna – Auckland), which was decreasing between 2008 and 2016. For PM_{10}, two traffic-focused monitoring sites had enough data to determine a trend (Henderson – Auckland, Takapuna – Auckland) and both had decreasing trends in concentration between 2007 and 2016, indicating improved air quality. Analysis of source contributions in Auckland shows that a decrease in $PM_{2.5}$ motor-vehicle emissions was largely responsible for these decreasing trends (Davy et al, 2017).

In addition to PM from vehicle exhausts, traffic also generates PM through the wearing and abrasion of pavement, tyres, and brake pads. This PM generally has a larger amount of coarse particles and can be an important source for heavy metals such as zinc, cadmium, barium, antimony, and copper in urban environments (Schauer et al, 2006).

These non-exhaust traffic emissions will become relatively more important as exhaust emissions reduce. Toxicological research increasingly indicates that such non-exhaust pollutants could be responsible for some of the observed adverse effects on health (WHO, 2013).

$PM_{2.5}$ makes up an unusually high percentage of estimated human-made PM emissions in New Zealand. In 2015, $PM_{2.5}$ made up nearly all combustion PM emissions (94 percent), and across all sources made up 75 percent of PM emissions. In New Zealand, one important source of human-made PM is dominated by larger, coarse PM: dust from unsealed roads (see Dust from unsealed roads). Nationwide it was estimated to contribute 12 percent of PM_{10}, but only 2 percent of $PM_{2.5}$. Fine particles ($PM_{2.5}$) make up only a small portion of road dust, an estimated 13 percent.

Dust from unsealed roads

- Dust from unsealed roads is primarily an issue in rural areas where population exposure is low, but can be important locally. Almost 40 percent of New Zealand's roads are unsealed, with a much higher proportion in regions with a large area but relatively lower population (Bluett, Aguiar, & Gimson, 2017).
- 71 percent of roads in the Far North district are unsealed; other districts with high percentages of unsealed roads are Wairoa, Marlborough, and Hurunui.
- All vehicles cause dust to be suspended in the air near unsealed roads, but heavy vehicles can generate particularly large amounts; dry periods and higher vehicle speeds can also exacerbate the problem (Bluett et al, 2017).
- Road dust includes particles that are mainly of coarse size, which have been shown to have important health consequences (see Health impacts of particulate matter pollution)
- Road dust can also have nuisance effects by dirtying personal property (cars, houses, or gardens); it also adds sediment to water sources, which reduces plant and crop growth, dairy yields, and even property values (Bluett et al, 2017).

Natural sources of particulate matter in New Zealand

Natural sources of PM are an important consideration for air quality. The natural component of PM cannot be managed, but is still counted as part of PM and measured as part of the NESAQ. It must be factored into any air pollution reduction strategy. A source is only considered 'natural' if it involves no direct or indirect human activity. For example, dust from a construction site would not be considered natural PM (European Environment Agency, 2012).

See Natural sources of particulate matter

Typical natural sources of PM include sea salt, windblown dust (airborne soil), pollen, ash from volcanic eruptions, and particles formed from gaseous precursors (eg secondary sulphate from sulphur-containing gases produced by phytoplankton in the ocean, or volcanic emissions).

Analysis of particle size, composition, and sources in New Zealand shows that sea salt provides the largest contribution to natural PM; airborne soil in urban areas is not considered natural PM as it is largely the result of human activity (eg re-suspended road dust, construction, and earthworks).

Secondary sulphate was found to have both human-generated (ie burning sulphur-containing fuels, industrial processes) and natural (oceanic phytoplankton, volcanic emissions) precursor sources, but the proportions are likely to vary between locations and are not easily quantified. Therefore, sea salt is judged as the most significant natural source, contributing mostly to the coarse part of PM.

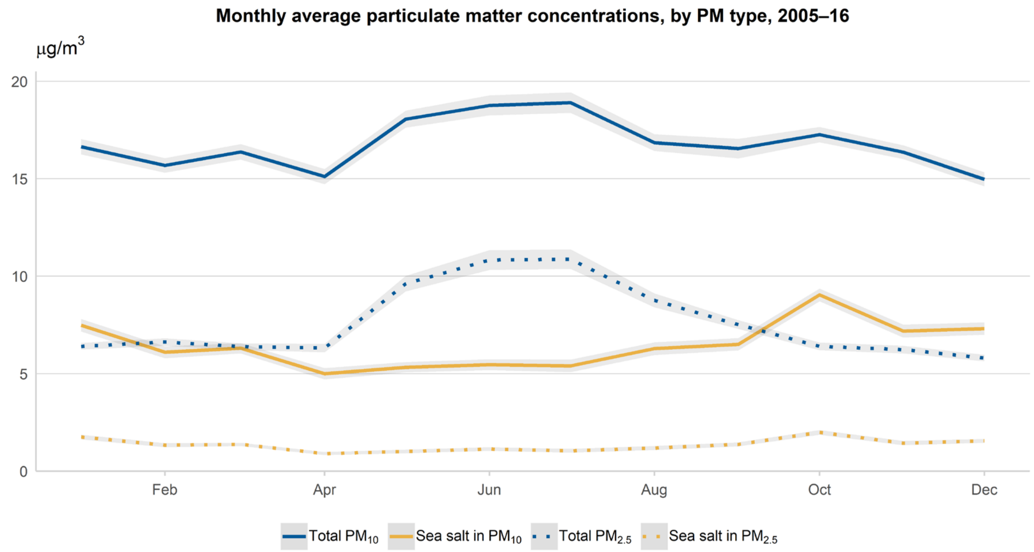
As New Zealand is a small island nation in the vast Southern Ocean, the westerly sweep of winds plays the major role in generating airborne sea salt. Concentrations of sea salt decreased with distance from the ocean, most likely due to atmospheric settling. Mountain shadowing may cause sea salt levels to be lower in some places, for example in Nelson (Ancelet, Davy, & Trompetter, 2013).

Airborne sea spray in the Catlins, New Zealand. Photo: Derek Morrison, photonewzealand

Importantly, PM compositional data shows that the association of higher sea salt concentrations with windy weather means that during cold, calm weather in winter, when PM concentrations from human-generated sources (biomass combustion) are generally high, natural source concentrations tend to be low.

Since most exceedances occur during the cooler months, sea salt was unlikely to have made a large contribution to exceedances of the PM_{10} NESAQ, or WHO $PM_{2.5}$ 24-hour guideline between 2005 and 2016 (see figure 14). Across 12 sites between 2005 and 2016, sea salt PM_{10} and $PM_{2.5}$ only contributed a small proportion to total PM (11 percent and 3 percent, respectively) on days where concentrations exceeded the NESAQ and WHO guidelines for PM_{10} and $PM_{2.5}$. On days without exceedances, sea salt PM_{10} and $PM_{2.5}$ on average contributed larger proportions to total PM (38 percent and 21 percent, respectively). On winter days with an exceedance the difference was even larger, and sea salt made up 4 percent of total PM_{10} and 2 percent of total $PM_{2.5}$.

Figure 14



Data source: GNS Science, Auckland Council, Greater Wellington Regional Council, Tasman District Council and Environment Canterbury

Note: Particulate matter concentrations have been averaged by month across all years. Shaded area shows 95% confidence interval. PM_{10} – particulate matter 10 micrometres or less in diameter; $PM_{2.5}$ – particulate matter 2.5 micrometres or less in diameter.

Emerging issues with particulate matter pollution

Ultrafine particles have health impacts

Ultrafine particles (UFPs) are particles less than 0.1 µm in diameter and are the smallest subset of PM (see figure 2 for the relative sizes of different types of PM). UFPs are mainly human-generated, especially from vehicle emissions (Chen et al, 2016), but they can also come from other combustion sources, such as home heating and forest fires (Morawska et al, 2008). Concentrations of UFPs tend to be highest in cities because motor-vehicle emissions are the primary source (Kumar et al, 2014).

The very small size of UFPs gives them unique properties compared with the larger-sized PM – they act more like a gas than a particle. Because they can avoid many of the body's defences for PM, a greater proportion of UFPs than larger-sized particles are deposited in the lung (Li N et al, 2016). The small size of UFPs also allows them to cross into the bloodstream where they can be transported throughout the body, resulting in very different health impacts from larger particles; for example, they can cause cellular and genetic damage (Li N et al, 2016). Figure 5 shows how different sizes of PM reach different parts of the body.

Since UFPs have a relatively large surface-area-to-volume ratio, a relatively large amount of hazardous material can attach to them. As a consequence, and due to their increased penetration into the lungs and beyond, UFPs have greater potential to cause injury to cells than larger particles (Li N et al, 2016). Emerging evidence also suggests the small size of UFPs allows them to interfere with the immune response – exposure to UFPs could be a risk factor for developing and exacerbating asthma, as well as for cardiovascular disease (Chen et al, 2016; Li N et al, 2016).

While experimental evidence and short-term studies point to adverse health effects from UFPs due to their size, more work is needed to separate the effects of UFPs from the hazardous materials that can attach to them. Long-term studies on the health effects from exposure to UFPs, and regulatory-grade monitors to measure them, are not available yet, so more research is needed both internationally and in New Zealand before an air quality guideline can be developed.

Gaseous pollutants

This section discusses impacts from gaseous pollutants, sources of gaseous pollutants in New Zealand (or pressures), and concentrations (or state). This section refers to thresholds in legislation and guidelines, which are summarised in Air quality standards: legislation and guidelines.

Gaseous pollutants are potentially harmful substances that exist as gases in the atmosphere. Since there are air quality standards for them, the main gases that are monitored in New Zealand are nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3); but many other gaseous pollutants are present in our air at any given time.

Impacts from gaseous pollutants

Nitrogen dioxide and sulphur dioxide can have negative health impacts

Short-term exposure to high concentrations of nitrogen dioxide causes inflammation of the airways and respiratory problems, and can trigger asthma attacks (US EPA, 2016). Recent evidence suggests exposure may also increase the risk of premature death and trigger heart attacks. Long-term exposure may cause asthma to develop and decreased lung development in children, and may also increase the risk of premature death and certain forms of cancer (US EPA, 2016).

Nitrogen dioxide has also been noted as an important component of brown haze in Auckland, which is also associated with an increase in hospital admissions (see Auckland brown-haze events).

Nitrogen dioxide has other impacts. It can cause injury to plant leaves and subsequent decreased growth in plants that are directly exposed to high levels (US EPA, 2008). In the atmosphere, nitrogen dioxide can combine with water to form nitrate (NO_3), which has been shown to cause acidification and negative effects on freshwater ecosystems. It can also cause biodiversity changes by acting as a nutrient (Payne et al, 2017).

Sulphur dioxide is another gaseous pollutant of concern in New Zealand. When inhaled, sulphur dioxide can affect the respiratory system and breathing, particularly for people with asthma, and especially for children. It may increase the risk of premature death and it is possible that long-term exposure may be a cause of asthma, although more research is needed (US EPA, 2017).

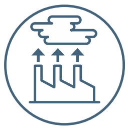
In ecosystems, sulphur dioxide can damage vegetation, reduce plant growth, and acidify water and soil (US EPA, 2008).

Sulphur dioxide can also interact with other compounds in the air to form sulphate PM, a secondary pollutant. Sulphate PM is associated with significant health effects because of its small size, and because it can be acidic (see Health impacts of particulate matter pollution). It is also a cause of haze, which impairs visibility.

Auckland brown-haze events

- Brown haze or smog is a common feature of many urban areas around the world; and when the weather conditions are right, it occurs in Auckland too. In Auckland its occurrence was variable; brown haze events occurred as few as one and as many as 13 times per year from 2001 to 2011 (Salmond et al, 2016).
- Pollutants can build up on cool, calm weekday mornings, mainly during the cooler months – these pollutants are from diesel exhaust and home heating, and include nitrogen oxides, carbon monoxide, and PM.
- Slow-moving, intense anticyclones to the south-east of New Zealand are an important factor for developing brown haze because they tend to draw air from the more populated and industrial areas to the city centre and can deliver cool, humid, and stable conditions (Salmond et al, 2016; Senaratne & Shooter, 2004).
- Hospital admissions for respiratory issues are significantly increased in Auckland following brown haze events. They peak at one and five days following the events for children and five days after the event for senior citizens, but 11 days after for those aged 15–64 years – this may reflect a heightened sensitivity to the pollutants for the young and the elderly (Dirks et al, 2017).
- A new forecast system is being tested, which would alert people when conditions are right for brown haze to form in Auckland.

Gaseous pollutants in New Zealand



See Air pollutant emissions

Gaseous air pollutants are emitted from a variety of sources, in different quantities at various locations. Oxides of nitrogen (nitric oxide and nitrogen dioxide) and sulphur dioxide are of most concern in New Zealand. Their emission sources are discussed below, alongside other gaseous pollutants. The methodology for the emissions inventory was the same as for PM. The gaseous pollutants are discussed under the categories of their main emission sources – motor-vehicle emissions and industrial emissions.

Motor vehicles and gaseous emissions

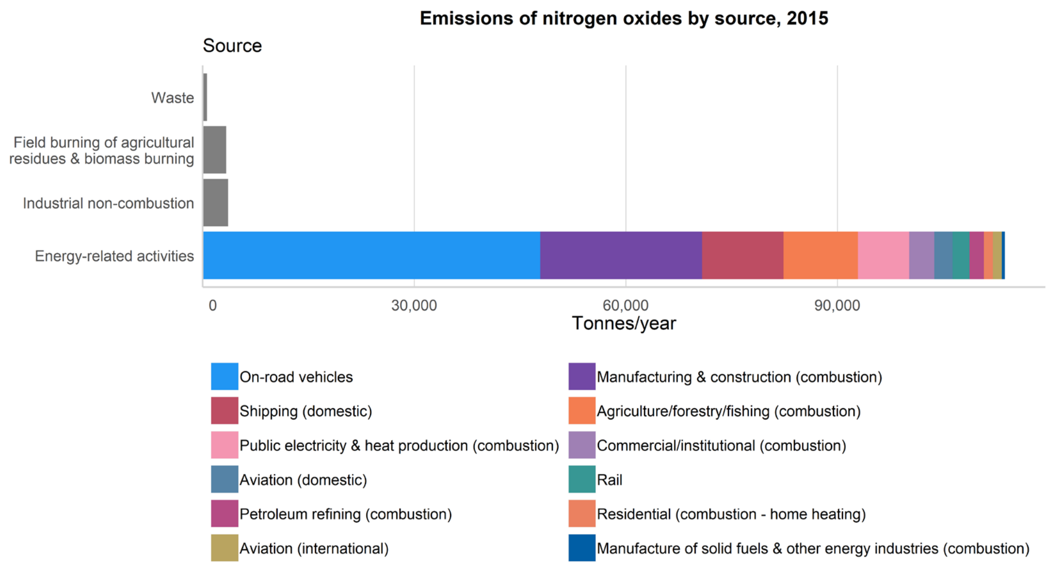
On-road vehicles are the largest source of nitrogen oxides

When vehicles burn fuel they produce a variety of gases and particles that vary depending on the type and quality of fuel used, and the combustion process itself. Many of the most hazardous pollutants are formed from incomplete combustion. Motor-vehicle emissions are made up of these combustion by-products, which enter the air through the exhaust pipe and through evaporative losses of the petrol itself during operation and refuelling.

The main pollutants emitted by the typical car are carbon dioxide, carbon monoxide, volatile organic compounds (VOCs) (as unburned hydrocarbons), and nitrogen oxides. In 2015, on-road vehicle emissions were the main contributor to nitrogen oxides in our air, producing 39 percent (47,800 tonnes) of human-generated emissions (see figure 15), 70 percent of which was from diesel vehicles. Because concentrations of nitrogen oxides are closely associated with vehicle emissions, they are often used as a proxy for all motor-vehicle pollutants.

Note: nitrogen monoxide can be readily transformed to nitrogen dioxide in our air in the presence of oxidants such as ozone.

Figure 15



Data source: Emission Impossible Ltd

Note: Sub-sectors with less than 1% of sector emissions are excluded. Home heating emissions are assumed to be the same as the 2013 national emissions inventory (Wilton et al. 2015) because updated population data were not readily available.

While the main source of emissions for nitrogen oxides in 2015 was on-road vehicles, other emission sources included combustion in manufacturing and construction, which includes off-road vehicles such as construction machinery (19 percent), domestic shipping (10 percent), combustion in primary industries (9 percent), and public electricity and heat production (6 percent).

Monitoring for nitrogen dioxide around New Zealand

The National Environmental Standards for Air Quality (NESAQ) for nitrogen dioxide requires regional councils and unitary authorities to undertake monitoring where it is thought concentrations may approach unhealthy levels, using regulatory-compliant monitors. Because motor-vehicle emissions are the major source of nitrogen dioxide, the New Zealand Transport Agency (NZTA) also operates a network of passive nitrogen dioxide samplers that do not assess compliance with the NESAQ but provide information on concentrations. These types of samplers are less accurate than regulatory monitors, but do allow more widespread and cost-effective data collection.

Nitrogen dioxide levels decrease at traffic-focused monitors

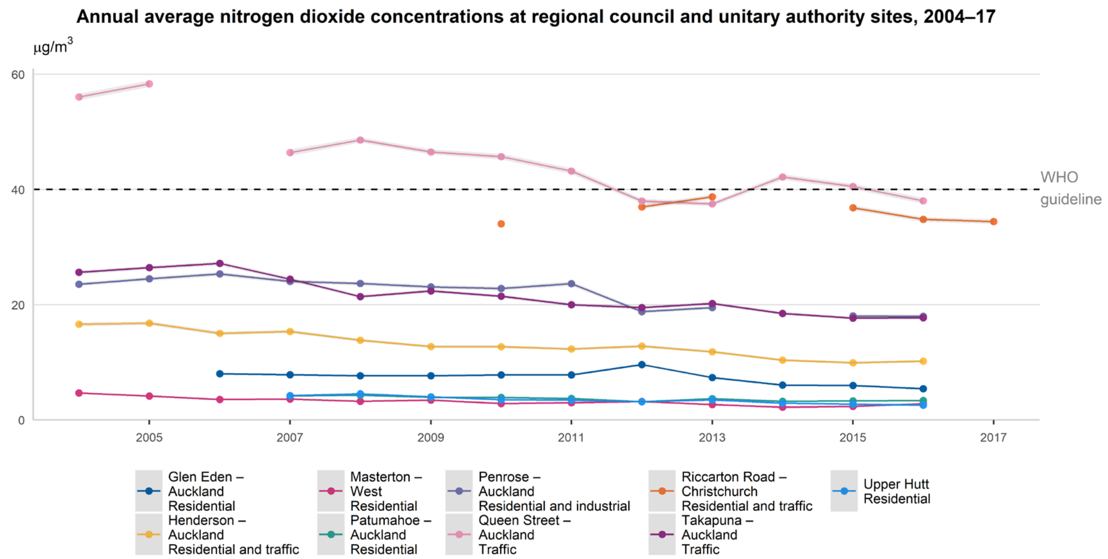
Regulatory monitoring for nitrogen dioxide is not as extensive as for PM_{10}. Regional council and unitary authority nitrogen dioxide data are from 13 sites located in Auckland, the Greater Wellington Region, Hamilton, and Christchurch. These sites include four residential-focused sites, four traffic sites, three residential and traffic sites, one residential and industrial site, and one industrial and traffic site.

See Nitrogen dioxide concentrations

Eight of these sites had enough data to assess trends, three of which included a traffic focus. Monthly average concentrations of nitrogen dioxide slightly decreased (0.52–1.56 µg/m^3 on average per year) at these three sites in Auckland (Queen Street, Takapuna, Henderson) between 2004 and 2016 (see figure 16). The remaining five sites all include a residential focus and showed slightly decreasing trends during this period.

Note: Data for 2017 in figure 16 were only available for some sites.

Figure 16



Data source: Auckland Council, Environment Canterbury, Greater Wellington Regional Council

Note: Dashed line indicates World Health Organization (WHO) long-term (annual) guideline (40 µg/m^3). Shaded area represents 95% confidence intervals. Only sites that met data completeness criteria are displayed.

Remote sensing of vehicle emissions

Roadside remote sensing of vehicle emissions was undertaken in a study for NZTA (Bluett, Smit, & Aguiar, 2016). It found that nitrogen monoxide emitted by light-duty vehicles decreased significantly between 2003 and 2014, mainly because of improved engine technology and fuel-use efficiency – the average light-duty vehicle monitored in Auckland in 2015 emitted about half that emitted in 2003. The decrease in emissions has slowed since 2011, partly as a result of an increased number of light-duty diesel vehicles and older high-emission vehicles on the road.

The study also found that light-duty diesel vehicles emit about 10 times more nitrogen monoxide than similar petrol vehicles, highlighting their important contribution to the concentrations of nitrogen oxides in our air (Bluett et al, 2016).

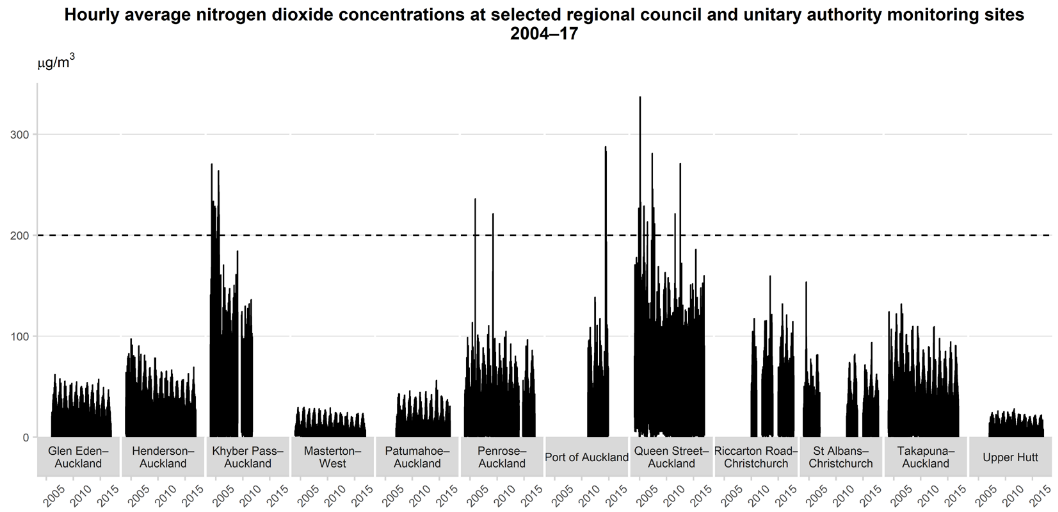
Nitrogen dioxide one-hour average

Between 2004 and 2017, sites that include a traffic or industrial focus had higher one-hour average concentrations of nitrogen dioxide than sites with only a residential focus (see figure 17). All sites that are only residential-focused were less than half the NESAQ and WHO guidelines. This difference reflected the vehicles' contributions to nitrogen dioxide in the air and its localised nature.

Recent data indicate that one site exceeded the **one-hour average** NESAQ for nitrogen dioxide from 2014 to 2016. A temporary monitor at Port of Auckland exceeded the NESAQ 13 times in 2014, but it was not operating during 2015 or 2016.

Four sites in Auckland and one in Hamilton exceeded the NESAQ for nitrogen dioxide between 2004 and 2017, although not all sites had data for the entire period. These sites include the traffic-focused Queen Street – Auckland site, a site subject to heavy traffic and the street canyon effect created by tall buildings. However, no NESAQ exceedances have been recorded at Queen Street since 2012, likely due to a change in traffic patterns and moving bus routes away from the monitor in 2011. Note that data for the Hamilton site (Te Rapa Road) did not have sufficient data to be displayed, and 2017 were only available for some sites. See the table on NESAQ and WHO guidelines for more information.

Figure 17



Data source: Auckland Council, Environment Canterbury, Greater Wellington Regional Council

Note: National Environmental Standards for Air Quality (NESAQ) short-term standard (200 $\mu g/m^3$) shown by horizontal broken line. An exceedance is when hourly concentrations are above 200 $\mu g/m^3$. Nine exceedances over 12 months are allowed. Only sites that met data completeness criteria are displayed.

Queen Street nitrogen dioxide concentrations were also higher than the **annual average** WHO guideline between 2004 and 2016, most recently in 2015. No other monitored sites were higher than the guideline within this period (see figure 16). None of the 15 regional council or unitary authority sites were reported to breach the 1-hour average NESAQ or exceed the WHO guideline for NO_2 in 2012 in the 2014 Air domain report.

Nitrogen dioxide concentrations are highly localised

The NZTA monitoring network for nitrogen dioxide has monitoring stations located in each region, covering all main urban areas. It began capturing monthly data at 48 sites in 2007 and by the end of 2016 had grown to 132 sites covering all towns and cities with populations larger than 45,000 (representing approximately two-thirds of New Zealand's population).

The sites were classified by NIWA as follows.

- **Urban background sites** – intended to provide information on concentrations away from the influence of nearby sources.
- **Roadside sites** – intended to represent typical roadside concentrations in an urban area, with the caveat that such sites record nitrogen dioxide levels that span a wide range of concentrations due to variation in traffic volumes and the sites being different distances from the road.
- **Peak sites** – intended to capture particularly high concentrations of nitrogen dioxide. Often these are located at busy central streets with taller-than-average buildings (street canyons) or major road intersections.

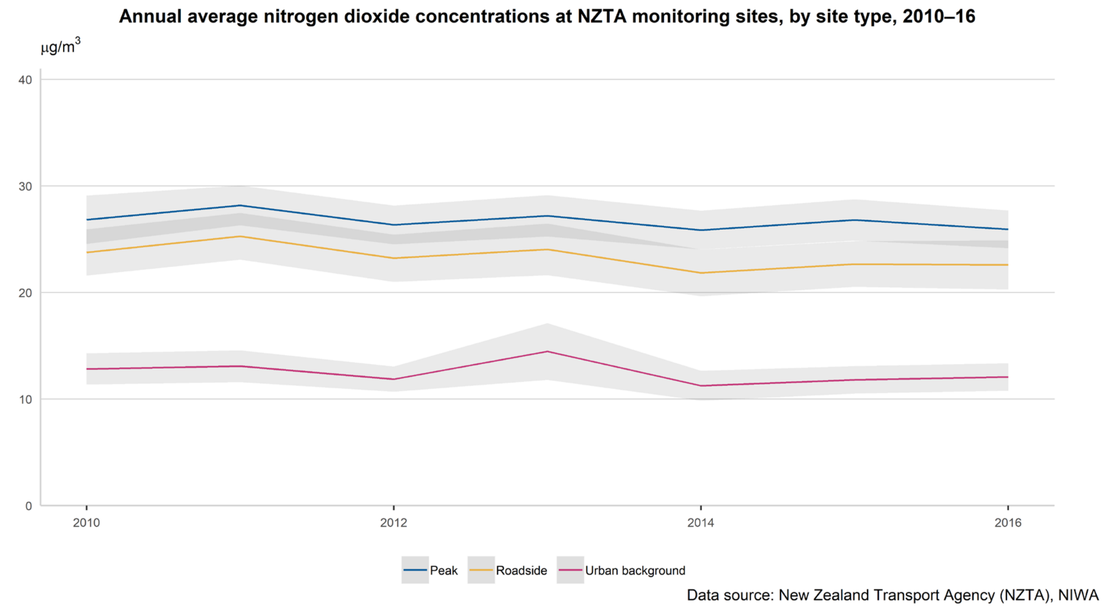
It is important to note that urban background and roadside sites form a continuum and any boundary between them is essentially arbitrary. Similarly, the degree to which sites are representative of all similar sites in New Zealand is somewhat uncertain.

Nitrogen dioxide concentrations can decrease rapidly with distance from source. For example, concentrations at some peak sites represent an extremely localised impact that may extend no more than 10 metres.

Recent data on nitrogen dioxide concentrations measured at NZTA sites indicate that compared with the peak (26.7 $\mu g/m^3$) and roadside (23.3 $\mu g/m^3$) sites, urban background sites (12.5 $\mu g/m^3$) had a lower annual average concentration between 2010 and 2016 (see figure 18). This reflects the highly localised nature of nitrogen dioxide exposure.

In line with regional council data, some NZTA monitors had a slightly decreasing trend. Between 2010 and 2016, 23 monitors in Auckland, Bay of Plenty, Hamilton, Northland and Wellington (out of 92 monitors across the country with enough data to calculate a trend) had decreasing nitrogen dioxide. Three sites (one in Christchurch and two in Wellington) had an increasing trend.

Figure 18



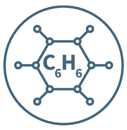
Note: Urban background and roadside are on a continuum so a boundary is arbitrary. Shading shows 95% confidence intervals.

Other pollutants are linked to vehicle emissions

In addition to nitrogen dioxide, many other pollutants are emitted from vehicle exhausts, including benzene, ground-level ozone, and carbon monoxide.

Benzene

Impact – Benzene is a volatile organic compound (VOC) that is normally liquid at ambient temperatures and pressures, but evaporates easily into the air. Its vapours are released from fuel in hot vehicle engines, during vehicle refuelling, or from vehicle exhaust. It is a known carcinogen and has been shown to cause leukaemia (International Agency for Research on Cancer, 2012). Short-term levels (ie acute exposure) are also associated with adverse developmental effects (Office of Environmental Health Hazard Assessment, 2008).



See Benzene concentrations

Concentrations – Of the six residential- and/or traffic-focused monitoring sites in Hamilton with a long-term data record (2003–16), two were measured with benzene levels above the national ambient air quality guideline, but the last recorded exceedance was in 2005. Concentrations at all six sites have decreased over the last monitored decade (2007–16).

Ground-level ozone

Impact – Ozone is a gaseous pollutant at ground level. Exposure to high levels of ozone can increase the incidence and severity of asthma, as well as the risk of premature death from respiratory issues, especially for children and the elderly (US EPA, 2013). Recent studies suggest ozone exposure may also be associated with nervous system, reproductive, and developmental effects (WHO, 2013).

See Ground-level ozone concentrations

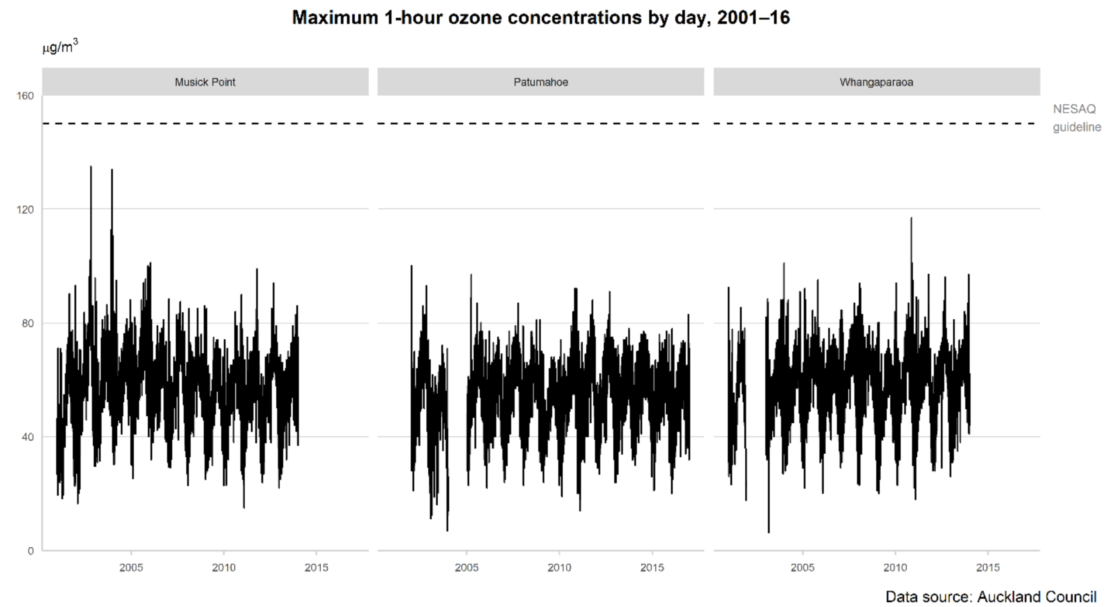
High levels of ground-level ozone can also cause visible damage to vegetation, reduce plant growth (including crop and forest yields), and harm sensitive ecosystems (US EPA, 2013).

Formation – There are no direct emissions of ozone because it is formed when other precursor pollutants (nitrogen oxides and VOCs) react in the air in the presence of sunlight; that is, it is a secondary pollutant. Since vehicles emit large amounts of both VOCs (largely from petrol engines) and nitrogen oxides (largely from diesel engines), they are usually the main 'source' of ozone.

Because sunlight is required for the chemical reaction to form ozone, concentrations are highest in the summer when days are longer. The precursor emissions also need time to mix and react with sunlight, so concentrations are highest in the mid- to late-afternoon; this mixing can also occur tens of kilometres downwind from the source of the original pollutants, sometimes in rural areas.

Concentrations – Ozone concentrations in New Zealand are quite low (relative to the NESAQ and levels recorded in many other countries). Ozone levels are unlikely to exceed standards, so monitoring is usually only undertaken to screen for issues, and long-term measurement is uncommon. Long-term data are only available for three background-focused Auckland sites – Musick Point, Patumahoe, and Whangaparaoa. Ozone concentrations at these sites did not exceed the one-hour NESAQ (see figure 19) or eight-hour WHO guideline between 2001 and 2016, with the exception of Musick point which exceeded the WHO guideline, but not since 2002. Ozone increased at Patumahoe and Whangaparaoa between 2001 and 2016 but no cause has yet been identified for this trend and concentrations remain well below the NESAQ.

Figure 19



Note: The dashed line shows the one-hour National Environmental Standards for Air Quality (NESAQ) standard. Only sites that met data completeness criteria are displayed.

Carbon monoxide

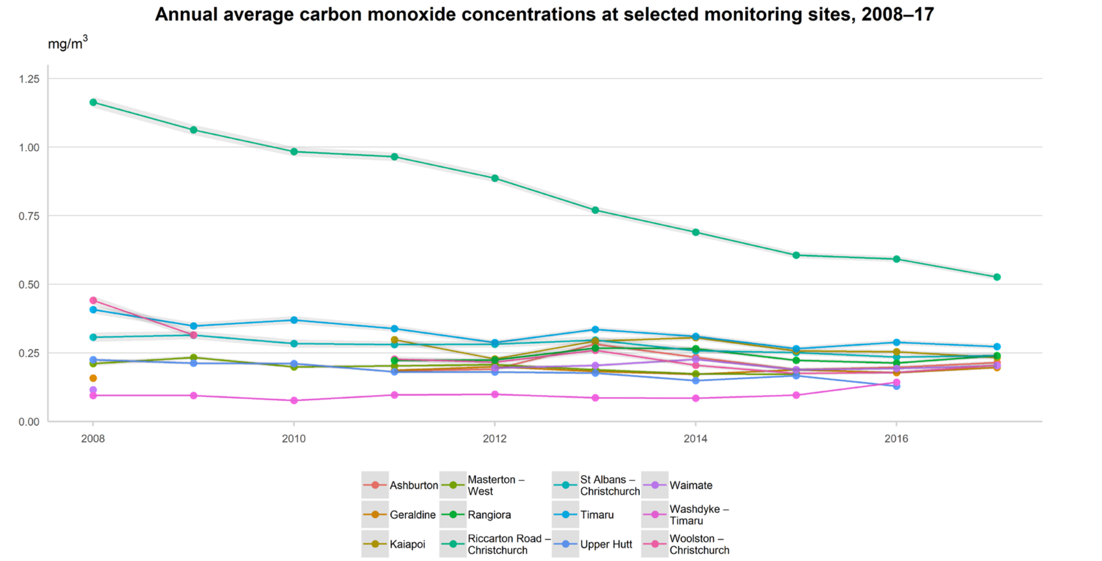
Impact – Carbon monoxide poisoning in confined spaces (eg from gas stoves, unflued gas heaters, and barbequing indoors) can injure or kill. Short-term exposure to high levels of outdoor carbon monoxide can cause a range of health problems, and an increased risk of death due to a reduction in the oxygen-carrying capacity of the blood (US EPA, 2010).

See Carbon monoxide concentrations

Sources – Carbon monoxide emissions from on-road vehicles have decreased in recent years as vehicle emissions have improved (Bluett et al, 2016). Burning wood for home heating is the leading source of human-generated carbon monoxide emissions in New Zealand, responsible for 37 percent of emissions in 2015. On-road vehicles contributed 28 percent.

All 24 monitored sites, a combination of residential-, industrial-, and traffic-focused sites, were far below air quality standards between 2008 and 2017. Note that data for 2017 were only available for some sites. No sites have exceeded the NESAQ since 2006, and in recent years (2014 onwards) all solely residential-focused sites were less than 50 percent of the NESAQ for carbon monoxide. See table 1 on NESAQ and WHO guidelines for more information on thresholds. Over the most recent monitored decade trends could be assessed at 12 sites between 2008 and 2017. One industrial site (Washdyke – Timaru) had an increasing trend. Two sites had a decreasing trend; Riccarton Road – Christchurch had a residential and traffic focus while Woolston – Christchurch had a residential and industrial focus (see figure 20). The remaining nine sites had an indeterminate trend.

Figure 20



Data source: Greater Wellington Regional Council and Environment Canterbury

Note: No health guideline exists for annual average carbon monoxide concentrations. Shaded area shows 95% confidence interval. Only sites that met data completeness criteria are displayed.

Indoor air

- Our greatest exposure to outdoor air may occur inside, because outdoor air infiltrates into buildings – people who live in cities spend around 90 percent of their time indoors either at home, work , or school (Taptiklis & Phipps, 2017).
- Proximity to roadways has been linked with high indoor levels of traffic-related pollutants.
- The proportion of smaller-sized PM in indoor air can be higher, especially in communities with a high number of wood burners, because fine particles are more capable of infiltrating through cracks and gaps.
- In addition to outdoor pollutants that penetrate inside, indoor sources include cooking, building materials, furnishings (eg carpet or furniture), cleaning or personal care products, excess moisture, pets, office equipment, and tobacco products (Kim, Kabir, & Kabir, 2015; US EPA, nd).
- Pollutants likely to be encountered indoors include VOCs (eg benzene or formaldehyde), biological contaminants (eg bacteria or dust mites), PM ranging from coarse to ultrafine in size, and gases such as nitrogen dioxide and carbon monoxide from combustion, and ozone from printers (Taptiklis & Phipps, 2017).
- The main factors that govern our exposure to indoor air pollution include: having the pollutant sources present and how much pollution they emit, the amount of ventilation with outdoors, the time we spend indoors, and our personal behaviour (Kanchongkittiphon et al, 2015).
- Dampness, a particular issue for indoor air quality in New Zealand, can cause asthma in children (Kanchongkittiphon et al, 2015); however, we do not cover the quality of housing in this report.
- The 2018 Census results will contain data on dampness and mould in all New Zealand homes for the first time.

Industrial emissions and gaseous pollutants

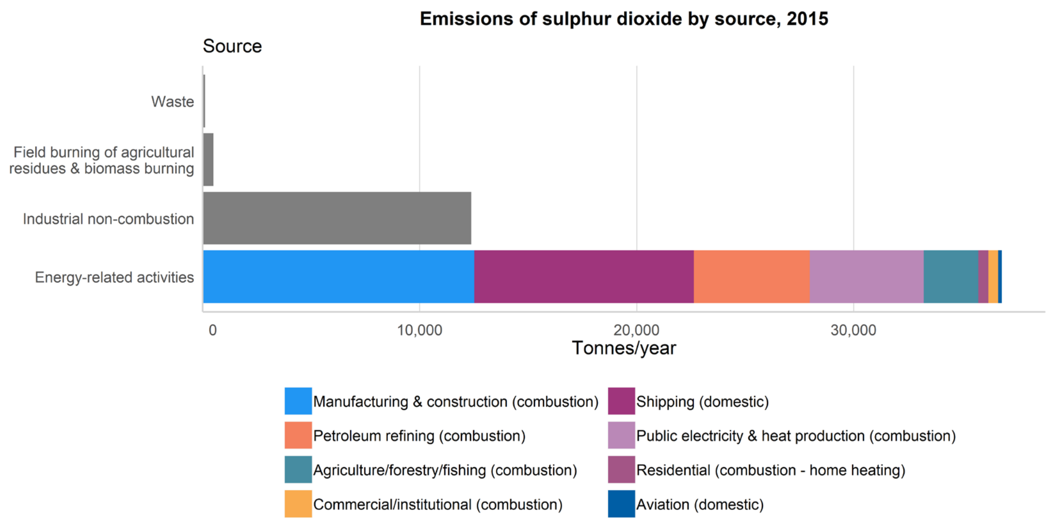
Industry is a significant source of sulphur dioxide in our air

Industrial emissions include pollutants that result from burning fuels to power industrial processes or electricity generation, such as from wood or coal-fired boilers. They also include emissions from industrial processes themselves (eg gases released during the smelting process). Pollutants emitted by industry are as varied as the industries themselves and can include oxides of nitrogen (NO_x), sulphur dioxide, carbon dioxide, VOCs, PM, and heavy metals.

In New Zealand, emissions from industry are an especially important source of sulphur dioxide, although natural sources from volcanic activity can be substantial locally, such as on White Island. Burning coal in manufacturing and construction, and public electricity generation and heat production was the primary source of sulphur dioxide emissions (30 percent) in 2015. Domestic shipping (20 percent), and non-combustion emissions during aluminium production (11 percent) were also large sources (see figure 21).

The emissions inventory used to estimate sulphur dioxide does not include international shipping, a large and growing source (see Shipping and port emissions), so sulphur dioxide (and nitrogen oxides) emissions from shipping are currently underestimated.

Figure 21



Data source: Emission Impossible Ltd

Note: Sub-sectors with less than 1% of sector emissions are excluded. Home heating emissions are assumed to be the same as the 2013 national emissions inventory (Wilton et al. 2015) because updated population data were not readily available.

Sulphur dioxide concentrations exceed air quality standards near industrial sources

Data are available from sulphur dioxide monitoring at nine sites across New Zealand, from 2008 to 2017 (figure 22). Note that data for 2017 were only available for some sites. Six sites include an industrial focus (three of these also have a traffic focus, and three also have a residential focus). Three sites are solely residential-focused. Since sulphur dioxide monitoring is generally aimed at key industrial sources, our knowledge of sulphur dioxide concentrations at other locations around the country is limited.

See Sulphur dioxide concentrations

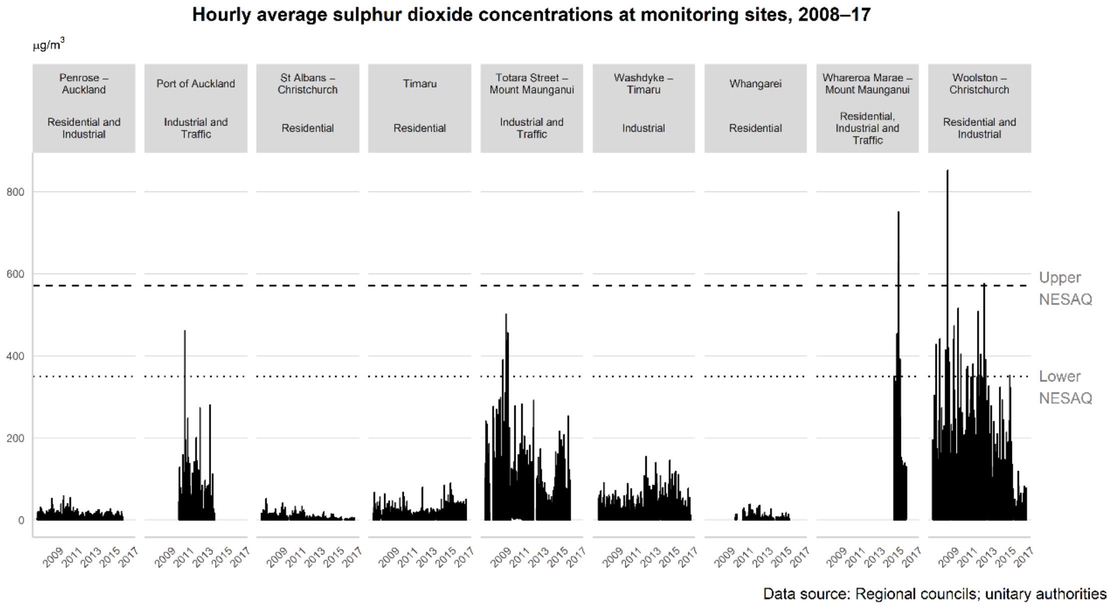
Four thresholds are referred to in discussing sulphur dioxide. One-hour average sulphur dioxide concentrations (see figure 22) are measured against an upper and lower threshold contained in the NESAQ. See table 1 on NESAQ and WHO guidelines for more information on thresholds. Average daily concentrations (see figure 23) are measured against a more stringent WHO guideline, and New Zealand's Ambient Air Quality Guideline (AAQG), which is set at a higher level than the WHO guideline.

One-hour average sulphur dioxide concentrations

Industrial sites, excluding Auckland – Penrose, had the highest **one-hour average** sulphur dioxide concentrations. The industrial sites at Whareroa Marae – Mount Maunganui and Woolston – Christchurch exceeded the (not-to-be-exceeded) upper threshold of 570 μg/m^3 twice, but no other sites exceeded the upper threshold between 2008 and 2017 (see figure 22).

Four of six industrial-focused sites exceeded the lower NESAQ threshold, but no sites exceeded it more than the allowed nine times in 12 months.

Figure 22



Note: Dotted line shows National Environmental Standards for Air Quality (NESAQ) lower (350 μg/m^3) hourly standard and dashed line shows NESAQ upper (570 μg/m^3) hourly standard. Nine exceedances per 12-month period are permitted for the lower standard. No exceedances are permitted for the upper standard.

Daily average sulphur dioxide concentrations

Comparison with the more stringent **24-hour average** WHO guideline reveals that between 2008 and 2017, all six sites that included an industrial-focus were higher than the guideline and had unhealthy sulphur dioxide concentration levels. The remaining three sites with a sole residential-focus did not exceed the guideline (see figure 23). Between 2008 and 2017, the Totara Street – Mount Maunganui site was higher than the WHO guideline for every year monitoring data was available (2008–16), peaking at 151 exceedances in 2009. Woolston was higher than the WHO guideline every year, peaking at 69 exceedances in 2013, although only once in 2017.

The site at Whareroa Marae (which is residential/traffic/industrial-focused, and is located next to a fertiliser works) was higher than the WHO guideline 89 times in 2016, the only year for which complete monitoring data are available. The Port of Auckland recorded the highest

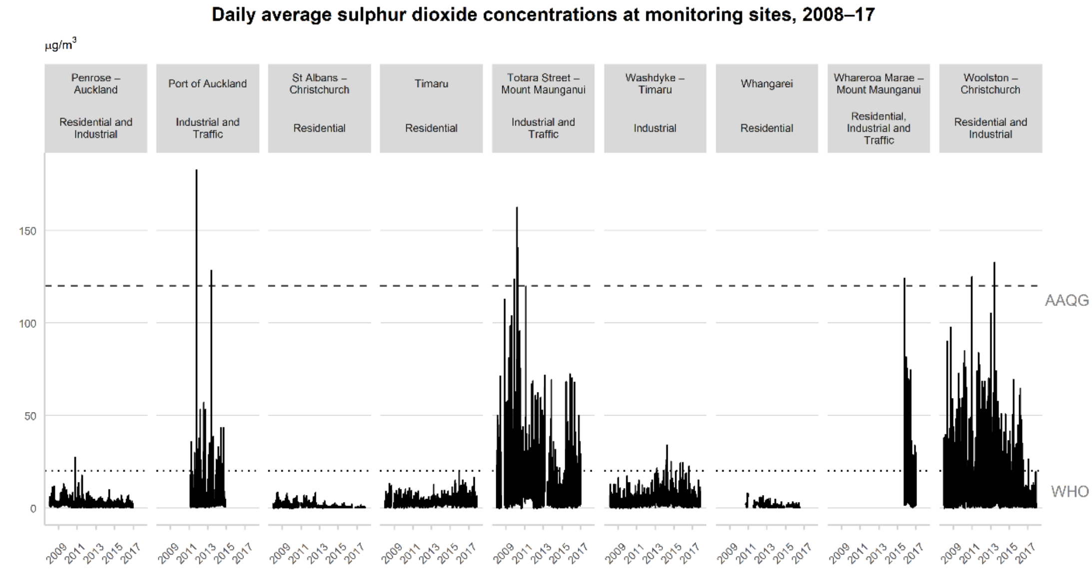
24-hour average concentration between 2008 and 2017, reflecting the large amount of sulphur dioxide that shipping emissions can contribute.

In comparison, only three sites (Port of Auckland, Totara Street, and Woolston) with an industrial focus exceeded the daily AAQG from 2008–17.

The 2014 Air domain report reported that in 2012 three of nine sites exceeded the 24-hour average WHO guideline for sulphur dioxide.

Note that data for 2017 were only available for some sites.

Figure 23



Data source: Regional councils; unitary authorities

Note: Dotted line shows World Health Organization (WHO) guideline (20 µg/m³). Dashed line shows Ambient Air Quality Guidelines (AAQG) guideline (120 µg/m³). Only sites that met data completeness criteria are displayed.

Trends in sulphur dioxide were mixed

Between 2008 and 2017 four sites had enough data to assess trends. **Monthly average** sulphur dioxide concentrations decreased at the residential/industrial sites at Woolston – Christchurch, and Penrose – Auckland between 2008 and 2017.

Two sites had increasing trends during this period. Both were in Timaru (one residential, and one industrial-focused). The sites were well below the lower NESAQ threshold, although the Washdyke – Timaru site was higher than the WHO daily guideline once in 2013, six times in 2014, three times in 2015, and once in 2016.

Note that data for 2017 were only available for some sites.

Other gaseous pollutants in New Zealand

There are other gaseous pollutants that are less prominent in New Zealand.

Persistent organic pollutants (POPs) are chemicals (mainly pesticides) that break down very slowly in the environment. International research shows that exposure to POPs can have serious health consequences. Studies have found that levels of POPs measured in New Zealanders' blood have decreased over the past 15 years and are similar or lower than for other developed countries (Coakley et al , 2018). POPs readily move from the air to water, soil, and plants, and bioaccumulate up the food chain. They can travel long distances and POPs found at pristine alpine sites in the Southern Alps were shown to come from both local and Australian sources (Lavin et al, 2012).

Hydrogen sulphide, which has a rotten egg smell and is emitted by geothermal activity, has few known health effects at concentrations typical of outdoor exposure (Pope et al, 2017). However, in enclosed spaces serious health issues can be associated with exposure to hydrogen sulphide. There can also be quality-of-life impact due to the unpleasant odour.

Emerging issues with gaseous pollutants

Shipping and port emissions

As an island nation, New Zealand has a particular reliance on shipping, and about 99.5 percent of our trade by weight is shipped by sea (Ministry of Transport, 2014). Shipping is economical from a cost per tonne-kilometre perspective, especially for moving bulk materials such as concrete, fertiliser, and fuel (Suckling et al, 2018). In 2016 there were about 7,000 Cook Strait ferry crossings, 2,750 visits by foreign vessels, and 800 visits by cruise ships, in addition to domestic shipping (Maritime New Zealand, 2016).

Emissions from ships make up 70 to 100 percent of port emissions in developed countries (Merk, 2014). The size of the median vessel visiting New Zealand nearly doubled between 2007 and 2013, and is expected to continue to increase, which is significant because larger ships create more emissions. The number and size of cruise ships visiting New Zealand's ports has also grown significantly (Ministry of Business, Innovation and Employment, 2016).

Shipping is an important source of sulphur dioxide because most large vessels use bunker fuel – a poor-quality, high-sulphur-content fuel that results in a much higher concentration of hazardous pollutants than fuel burned by cars, trucks, or trains (Talbot & Reid, 2017). Emissions from shipping also include PM, nitrogen oxides, and carbon monoxide. Nationally, domestic shipping contributed 20 percent of sulphur dioxide in 2015, but only 10 percent of national nitrogen oxides, although it emitted these pollutants in almost equal amounts.

Ship discharging smoke at Wellington port. (Photo: Rob Suisted, Nature's Pic Images, New Zealand)

Studies in Auckland have found that sulphur dioxide concentrations are higher near the waterfront and are highest when the wind comes from the direction of the port (Talbot & Reid, 2017). Tracer studies that can 'fingerprint' emissions from shipping by measuring nickel and vanadium, which are predominantly associated with shipping emissions, found the highest levels near the water. The studies also found a shipping sulphate influence at many of the PM monitoring sites around Auckland, even several kilometres away from the port (Davy et al, 2017).

Shipping has also been identified as the main source of sulphur dioxide emissions in Wellington, and may be of concern at other ports such as Tauranga and Whangarei (Andries, 2010; Iremonger, 2010; Mitchell, 2012).

Many ports in New Zealand are located close to city centres. They can be important sources of urban air pollution from shipping emissions and increased vehicle movements to load and unload ships and move goods.

In addition, some ports use the pesticide methyl bromide to fumigate logs before export. Although localised in nature, methyl bromide has been associated with adverse impacts on human health. It is also a recognised ozone-depleting chemical that has been phased out by most other countries over the past 15 years (Alavanja, Hoppin, & Kamel, 2004; UNEP, 2014). In 2016, there were 13 users of methyl bromide in New Zealand. The highest reported use was 319.6 tons (Northport – Marsden); this was 31 percent more than it used in 2012 (Environmental Protection Authority, 2012, 2016). Annual reports for all users of methyl bromide can be found on the Environmental Protection Authority website.

Ammonia from intensive agriculture

Nitrogen is an essential nutrient for plant growth. It occurs naturally in the environment but is added in agricultural processes (typically as fertiliser) to increase production. When excess nitrogen is not utilised, it can find its way into our waters (see Our fresh water 2017) or be released from animal waste (urine, faeces) as ammonia (NH_3). When it is emitted to the air as ammonia, much of it transforms into ammonium nitrate or ammonium sulphate particles (Parfitt et al, 2012) that can be transported far from its source, potentially affecting ecosystems when it settles from the air or is incorporated in rain drops.

There has been a marked increase in the intensity of farming, especially for dairy, which increased 42 percent in area between 2002 and 2016 (see Our land 2018). Both dairy and increased fertiliser use are known to increase the amount of ammonia emitted to the air. Models indicate it has increased, mainly in Canterbury and Otago where the number of dairy cows has grown (Parfitt et al, 2012).

International research shows that excess nitrogen as ammonia can acidify soil and cause changes in biodiversity by creating nutrient imbalances that favour one species over another, often favouring exotic species over natives (Payne et al, 2017). These effects have been widely observed in areas where nitrogen deposition is high, such as the United States and Europe.

Because soils in New Zealand tend to be naturally low in nitrogen, even small increases have the potential to affect biodiversity and ecosystems negatively (Parfitt et al, 2012; Payne et al, 2017). Increases in livestock numbers and fertiliser use are recent, so it is not known how much excess nitrogen is being emitted to the air and subsequently reaching our natural areas. Data are needed to determine if this is a problem and to categorise the sensitivity of New Zealand’s ecosystems to excess nitrogen.

Air pollution and the climate affect each other

Some types of air emissions not only have an adverse impact on air quality, they can also contribute to global climate change. This report does not cover emissions of greenhouse gases (eg carbon dioxide and methane) and the subsequent impact on our climate (see instead Our atmosphere and climate 2017). However, it is important to acknowledge that changes to the climate system can be caused by air pollutants (that can heat or cool the climate); and in turn, a warming climate can affect pollutants that are already in the air. Black carbon and sulphur dioxide are two such pollutants; their impact and levels are described below.

Because many sources of greenhouse gases also emit PM and gaseous pollutants, there are likely to be significant air quality co-benefits from reductions in greenhouse gas emissions.

Black carbon has multiple negative impacts

Black carbon is gaining prominence as an air pollutant that has negative implications for both human health and our climate. It is a component of fine particulate matter ($PM_{2.5}$) formed through incomplete combustion, and is highly light absorbent. It is commonly known as soot, and it generally comes from vehicle emissions (especially from diesel engines), burning solid fuels (wood or coal) for home heating, or agricultural biomass burn-offs. Inhaling black carbon is associated with health problems, as described in Health impacts of particulate matter pollution.

See Black carbon concentrations

There is growing evidence that black carbon is a problem in New Zealand. Black carbon levels peak here between May and July. Concentrations at three of five sites monitored in Auckland decreased from 2006 to 2016, but were still at high levels when compared internationally. Annual black carbon concentrations ranged from 1.0–4.7 $\mu g/m^3$ in New Zealand urban centres, compared with 1.0–2.9 $\mu g/m^3$ at European / United Kingdom cities, and 0.3–3.0 $\mu g/m^3$ at United States cities (Davy & Trompetter, 2018, US EPA, 2012).

Black carbon also constitutes a relatively high proportion of $PM_{2.5}$ in New Zealand, compared with other countries. Research indicates that 15–45 percent of $PM_{2.5}$ in our towns and cities was composed of black carbon particles, compared with 5–10 percent across a range of urban centres in the US (Li Y et al, 2016). This relatively high proportion of black carbon in $PM_{2.5}$ in New Zealand is mainly due to our heavy reliance on wood burning for home heating and our ageing vehicle fleet (Davy & Trompetter, 2018).

Because of its dark colour, black carbon is very good at absorbing sunlight. In the atmosphere its overall effect is to warm the climate. It is so efficient at this that it is estimated it is second only to carbon dioxide in its contribution to global temperature increases (Bond et al, 2013).

Less is known about the effects of light-absorbing organic PM (known as brown carbon) which comes from biomass burning. It may also contribute to climate warming by absorbing energy; however, more research is needed to understand how it changes in the atmosphere over time.

While carbon dioxide can remain in the atmosphere for hundreds or even thousands of years, black carbon only remains in the atmosphere for about a week before depositing on Earth's surface. Because it is short-lived, reductions in black carbon can more quickly mitigate changes in the climate (Ramanathan & Carmichael, 2008).

Black carbon can also have important climate effects if it is deposited on ice or snow. It decreases Earth's ability to reflect the warming rays of the sun, while absorbing heat and hastening the melt of snow and glaciers, which in turn raises sea level (Ramanathan & Carmichael, 2008). This decreases the reflective quality (albedo) of Earth because bare ground and open water are darker than ice and snow and absorb more energy, which also warms the climate.

Sulphur dioxide has a cooling influence

Sulphur dioxide also affects the climate, and is currently recognised as the most important cooling agent emitted to the atmosphere (Boucher et al, 2013). It can react to form particles of sulphate that scatter incoming sunlight and form clouds, cooling the climate. Most of the sulphate in the atmosphere is from fossil fuel combustion by humans; however, large volcanic eruptions that reach the stratosphere can also add significant amounts that disperse across the globe and cause cooling for months or years at a time (Boucher et al, 2013).

This cooling effect from human-generated emissions is important because it masks some of the warming being caused by increased greenhouse gases in the atmosphere.

Climate change affects air quality

Some air pollutants affect the climate, but some are affected by it. Because ozone is formed through other air pollutants reacting in the presence of sunlight and warmth, an increase in temperature with a warmer climate would speed up the chemical reactions that form ozone and lead to increased concentrations. Ground-level ozone can have serious human health effects (see Gaseous pollutants). An increase would be a particular concern in cities like Auckland, which have high levels of transport emissions that act as precursors to ozone formation (Bolton, 2018).

The additional stress that a warming or drying climate places on ecosystems could increase susceptibility to air pollutants. It may also increase the frequency of wildfires and the amount of wind-blown dust, which would increase the amount of PM in the air.

In contrast, warmer temperatures in winter would likely result in less wood burning for home heating, lowering PM levels in the air (Bolton, 2018).

Quality-of-life impacts

Other impacts of human activities in the air include light pollution, noise pollution, and odours. They are explored in this section. They can have adverse effects on quality of life and human health. Cultural values and ecosystem well-being can also be adversely affected.

Night skies and light pollution

There is increasing awareness of the importance of night skies, alongside growing recognition that this resource is being compromised by light pollution from human activities. Naturally dark night skies are important for multiple reasons, including:

- tikanga Māori (Māori cultural practices)
- unique scenic and scientific values
- the health of native species and ecosystems.

See Artificial night sky brightness

The extent of light pollution

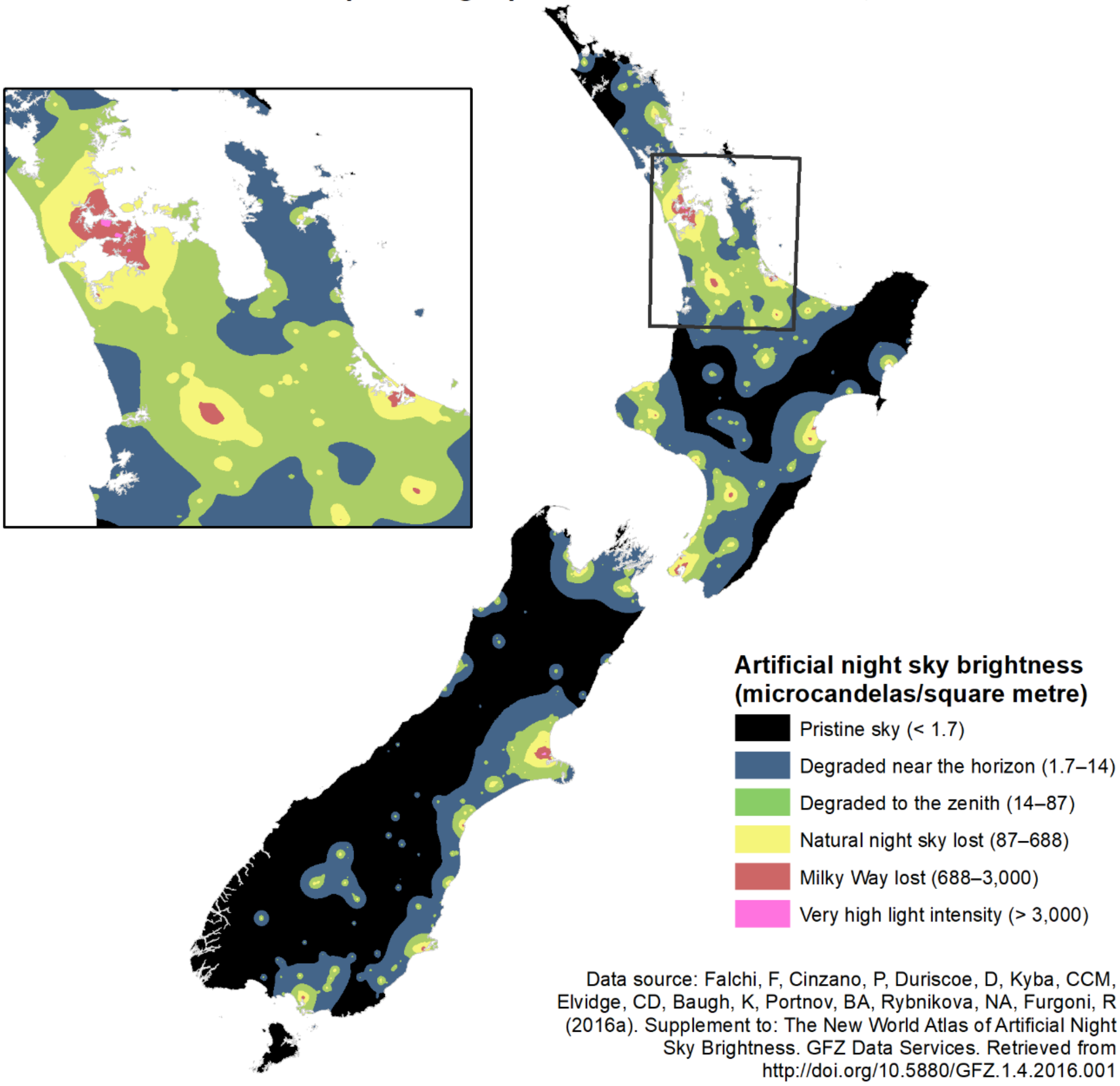
The darkness of night can vary naturally and can also be negatively affected by light pollution. A full moon can be so bright that a torch is not needed, while the faint glow of stars and the Milky Way can be enough to illuminate overturned ponga (silver tree fern) fronds that Māori have traditionally used to mark pathways. Light pollution from artificial lighting is a modern phenomenon that can wash out starlight in the night sky, interfere with astronomical research, disrupt ecosystems, and undermine cultural values.

Light pollution has been estimated for the entire world, including New Zealand. Satellite measurements from six months of observations in 2014 were used to obtain artificial night sky values in microcandelas per square metre (Falchi et al, 2016b). The data indicate that much of New Zealand had little or no light pollution, except for urban areas (see figure 24).

Based on land area, 74 percent of the North Island and 93 percent of the South Island had night skies that were either pristine or only degraded by light pollution near the horizon. However, despite artificial light levels being generally low across much of the country, most New Zealanders live in cities and are therefore disconnected from the night sky. Nearly all parts of all major urban areas had light pollution levels where the natural night sky is lost; it is estimated that over half (56 percent) of New Zealanders are unable to see the Milky Way (Falchi et al, 2016b).

Figure 24

Visual impact of light pollution over New Zealand, 2014



Data source: Falchi, F, Cinzano, P, Duriscoe, D, Kyba, CCM, Elvidge, CD, Baugh, K, Portnov, BA, Rybnikova, NA, Furgoni, R (2016a). Supplement to: The New World Atlas of Artificial Night Sky Brightness. GFZ Data Services. Retrieved from http://doi.org/10.5880/GFZ.1.4.2016.001

Night skies are culturally important

Pacific peoples were, and still are, highly skilled voyagers. They travelled the vast expanses of the Pacific Ocean to settle the many islands of the Pacific using traditional navigation techniques. Māori arrived in Aotearoa during the great waka (canoe) migrations by using expert knowledge that included reading the stars and other elements of the environment. Connections back to these waka are a critical element of Māori identity.

In recent decades there has been a renaissance in traditional navigation practices. Many traditional waka now retrace ancestral voyage routes by using the customary techniques, such as the star compass, for direction. These practices link the present generation to Polynesian ancestral knowledge.

Te Pae Māhutonga (the Southern Cross) is a constellation that is visible low in the night sky and identifies the South Pole. It has long been used to navigate and has been associated with Polynesian and European arrival in New Zealand (Durie, 1999). Matariki was also frequently used in navigation, and was instrumental to the early navigators finding New Zealand (Matamua, 2017).

Celestial bodies are culturally and spiritually significant to Māori. Mātauranga Māori comes from Māori relationships and interactions with the environment developed over thousands of years. Māori observe the stars and moon phases to inform how they apply traditional knowledge. Poor visibility of the night sky affects their ability to use and develop mātauranga and to undertake culturally significant practices.

Knowledge of the stars and Maramataka (the lunar cycle) are both used by Māori as a guide for planting, harvesting, hunting, and gathering food and also for voyaging, building, celebrating, and karakia (prayer) (Matamua, 2017). Each phase of the moon has a different name and indicates whether an activity is suitable or unsuitable for the day ahead. Similarly, tohunga (experts) would look at the position, brightness, colour, and movement of stars to deduce information and rely on it for traditional practices (Matamua, 2017).

Matariki

The Matariki star cluster is also known as Pleiades or the Seven Sisters. Some iwi use other stars to signal the time associated with Matariki, such as Puanga to the east.

Matariki means 'the eyes of god'. A longer form of this name is Ngā mata o te ariki o Tawhirimātea. This name reflects the traditional creation stories shared by some iwi that recall when Tāwhirimātea, enraged at the separation of Papatūānuku (Earth Mother) and Ranginui (Sky Father), ripped out his eyes, crushed them, and threw them to the sky. Hence, Matariki comprises the eyes of Tawhirimatea, who is also known as the blind god, illustrating the character of the winds.

Matariki is a significant time for remembering those who have recently died. During the year, Taramainuku (the captain of the waka-o-Matariki) collects the dead after they make their way along te ara wairua (the spiritual pathway) to Rerenga Wairua (Cape Reinga). They fall as stars at the prow of Taramainuku's waka.

Pōhutakawa is the star associated with the dead, and rises during June. When Matariki rises, Taramainuku releases the hunga mate (those who have passed on) to carry on their journey into the afterlife (Matamua, 2017). This is why Māori lament during the rising of Matariki – it is a time for the last farewell.

Matariki is also a time of renewal and celebrating new life. The rising of Matariki signals the Māori New Year, and indicates what the forthcoming year will look like. There has been a recent revival in Matariki celebrations nationally. Matariki is an example of the significance of the stars, both spiritually and for cultural practice and knowledge, as an intrinsic element of te ao Māori (the Māori world view). Maintaining good visibility of the night sky is crucial to preserve this relationship.

Naturally dark night skies are a scenic and scientific resource

Naturally dark night skies are recognised as a scenic resource in New Zealand for recreational star gazers and astronomical studies. The Mackenzie region, in the centre of the South Island, is recognised as one of the best stargazing sites on Earth, due to very limited light pollution and unusually clear atmospheric conditions. Controls for outdoor lighting were first put into place in the Mackenzie region in the early 1980s to help minimise light pollution.

In 2012, a 4,300 square kilometre area was proclaimed an International Dark Sky Reserve – the largest in the world (International Dark Sky Association, 2012). It also has gold tier status, which is generally reserved for the darkest skies. The astronomical research centre Mount John Observatory lies within this reserve. Around 200,000 people visit each year to see the stars. The Starlight Festival held at Mt Cook is a highlight in the growing astro-tourism industry (International Dark Sky Association, 2017).

The organisers of the International Dark Sky Reserve recognised that the night sky played a critical role for Māori, not only for navigation, but also because astronomy and star lore have become integrated into Māori culture and part of daily life. The reserve seeks to honour this history by recognising that the night sky is an integral part of the area's natural and cultural landscape (International Dark Sky Association, 2012).

Night skies are critical for the well-being of ecological systems

Light pollution can disrupt natural patterns in ecosystems. This is particularly critical for nocturnal species, which are active at night, such as kiwi and native bat species. The absence of light is a key element of their habitat.

International research has revealed numerous connections between light pollution and species disruption. Many species rely on natural patterns of light and dark to navigate, cue behaviours for nesting and mating, and hide from predators or forage for food (Gaston et al, 2013; Rich & Longcore, 2005).

New Zealand night sky in Hawke's Bay. (Photo: Andrew Caldwell, photonewzealand)

Limited information is available on how light pollution affects native species and ecosystems in New Zealand. However, in Nelson and Hawke's Bay unusual nocturnal feeding behaviour has been observed, where groups of karoro (southern black-backed gull) were feeding on swarms of beetles that are attracted to artificial light (Pugh & Pawson, 2016). In Hamilton, a survey of native long-tailed bats found they were detected much less frequently at places with even a small increase in the number of roads and street lights (Le Roux & Le Roux, 2012).

New energy-efficient lighting technologies, such as light emitting diodes (LEDs) may exacerbate light pollution problems by changing the spectrum of light emitted. Low-pressure sodium streetlights, with their familiar orange hue, are being replaced by LED lights in places such as Wellington and Auckland. These LED lights produce a more natural white light made up of a broad spectrum of wavelengths, which is visible to a wider range of species. This can affect circadian rhythms and melatonin production (Gaston et al, 2013). It can also affect night vision in humans (Falchi et al, 2016b). However, many newer lighting systems include better horizontal shielding so less light escapes upwards to pollute the night sky.

Noise pollution

Noise pollution is pervasive in many modern environments. Sometimes it is part of a general background din, such as from a motorway, and sometimes it grabs our attention, such as a police siren, a plane, or a drone flying overhead. Although it is easy to assume that excess noise in the environment is harmless, recent studies have found it can have important effects on both human health and our natural environment.

Exposure to noise can increase levels of stress hormones. In the long term this can cause low-grade inflammation (Halonen et al*,* 2015). In 2011, WHO noted increasing evidence for an association between road traffic and aircraft noise and adverse health outcomes, such as heart attacks. This has been backed up by other studies linking noise to hypertension (van Kempen & Babisch, 2012; WHO, 2011). Recent studies have found a small increase in heart disease, premature death, and especially stroke in the elderly who live in areas with moderate traffic noise (Halonen et al, 2015).

Studies on the health effects of noise on New Zealanders have been limited, although recent work suggests that the impacts on health from noise pollution are independent of effects from air pollution (Shepherd et al, 2016). Other research has found that natural sounds, such as birdsong, can have restorative effects, lowering stress and raising attention levels (Francis et al, 2017).

Noise pollution also has the potential to affect Māori relationships with the environment, due to drowning out birdsong, and the sound of the ocean and forests. The development of mātauranga Māori depends on a close relationship with bio-physical processes, and noise interference can affect this relationship.

The effects of noise pollution are not limited to urban areas. Many animals have hearing that is several times more sensitive than human hearing. As with people, exposure to noise can cause chronic stress if it is perceived as a threat; it may impact where wildlife choose to settle, keeping them out of a suitable habitat (Shannon et al, 2016).

Human-generated noise can interfere with wildlife behaviour by masking the sound of nearby predators, prey, or potential mates, and it can also make it more difficult to maintain territories or care for young (Harbrow, Cessford, & Kazmierow, 2011).

Songbirds in other areas have been shown to change the 'lyrics' of their songs and the frequency at which they sing, but little is known about the response of New Zealand's avian residents (Proppe et al, 2013).

A quiet environment is also a key component of the wilderness experience. Respondents to a Department of Conservation survey noted that aircraft noise had "taken away the feeling of isolation, jolted them out of the wilderness experience… or detracted from the naturalness of the setting" (Shannon et al, 2016). Nine of more than 20 sites where the survey was undertaken were higher than a threshold for annoyance from noise pollution, primarily in Fiordland National Park, but also at Aoraki / Mount Cook and the Franz Joseph Valley. Other studies have noted exceedances on the Abel Tasman coast and the Whanganui River from boats (Harbrow, Cessford, & Kazmierow, 2011).

Odours

Unlike other air pollutants, our response to offensive or unpleasant odours can be highly personalised. In fact, what is termed an odour is not really an air pollutant at all, but is the human olfactory response to one, or more often to a complex mixture of chemicals present in the local atmosphere (Bull, 2014). Because our sense of smell is linked directly to the part of the brain that processes emotions, our response to a particular smell is often influenced more by our experience than by the chemical, or mix of chemicals, in the air. What may be offensive to one person may be acceptable to another (Ministry for the Environment, 2016).

Odorants, in particular organic amines and reduced sulphur gases, have odour thresholds several orders of magnitude lower than their thresholds for irritant (or other toxic) effects (Shusterman, 1992). Despite this apparent margin of safety, unpleasant odours often lead to annoyance or induce stress, and include symptoms such as nausea or headaches. They can become a quality-of-life issue for those who are regularly exposed to the odour. Complaints about offensive odours are among the most common reported to regulatory authorities (Ministry for the Environment, 2016).

Common sources of unpleasant odours include landfills, wastewater plants, or industrial sites such as asphalt plants. To help assess whether an odour is offensive, and therefore must be addressed (often through the Resource Management Act) a framework was developed based on the odour's frequency, intensity, duration, offensiveness, and location (Ministry for the Environment, 2016). This framework is used to assess whether or not an odour is offensive and should be dealt with, for example, by requiring consent under the Act.

Our air – our future

Hau, or breath in this instance, is vital to support the mauri (life force) of people. The sharing of hau is the sharing of mauri. A fundamental part of the tikanga of the hongi (the pressing of noses in greeting) involves the sharing of hau, which is also the sharing of mauri, and connects people together. The hongi comes from the story of when Tāne (the originator of humankind for te ao Māori) breathed life into Hineahuone, the first woman. These stories and perspectives place great importance on the air we breathe for our life force. Ensuring we look after our air is crucial to ensure the well-being of all people both spiritually and physically.

The quality of our air is a result of the cumulative decisions we make as individuals, neighbourhoods, and towns and cities. Since so much of the pollution we are exposed to in New Zealand comes out of our chimneys and the tail pipes of our vehicles, our choices are important to the health of others around us. This is especially true for those most at risk from air pollution, such as the very young, the elderly, and those with pre-existing diseases such as asthma.

Many New Zealanders are already making decisions that have a positive impact on the quality of the air we breathe, including:

- **using high-efficiency heating options**, such as heat pumps, pellet burners, or wood burners designed to have low emissions
- **storing wood under cover and only burning seasoned, dry wood**, using efficient burning techniques that are recommended for their burners
- **not burning treated timber** and, therefore, avoiding release of toxic substances, such as arsenic
- **avoiding outdoor burning** of rubbish and plant matter – instead using appropriate recycling or rubbish disposal facilities, and composting and mulching where possible
- **reducing transport emissions** by cycling, walking, using public transport, or using vehicles with low or no emissions.

Knowledge gaps and data requirements in the air domain

There are knowledge gaps in New Zealand's air domain. The most important ones are listed below.

Currently, monitoring of air pollutants is limited in its coverage over space and time.

- Air pollutant monitoring is limited in its coverage over space and time because it is generally only done where high air quality risks have already been identified. A lack of national monitoring limits our understanding of air quality variations within and between regions and airsheds, populations (eg city, suburban, rural), land use (eg residential, commercial, industrial, agricultural, natural), and changes over time.
- $PM_{2.5}$ monitoring is limited despite increasing international recognition on the seriousness of health effects associated with $PM_{2.5}$.
- Data on methyl bromide and benzo(a)pyrene are limited, which means they have minimal inclusion in this report.

There is currently limited data on health impacts that is specific to New Zealand.

- $PM_{2.5}$ and nitrogen dioxide can have serious health effects as documented in other countries. Our exposure to these pollutants warrants more research to determine their specific impact on the health of New Zealanders.
- New Zealand is one of the few developed countries without an air quality standard for $PM_{2.5}$.
- For sulphur dioxide, WHO guidelines are more stringent than New Zealand's Ambient Air Quality Guidelines.
- The Health and Air Pollution in New Zealand model is currently the best data we have; however, this model relies on a number of assumptions – due to data limitations.

Better data are needed on key air emission sources.

- Estimates of emissions from home heating would be improved with consistent data from either the census or special surveys.
- New Zealand is the only country in the OECD without a pollutant release and tracking register – having one would increase the accuracy of reporting industry emissions, particularly for hazardous air pollutants (eg benzene, methyl bromide, dioxins, and heavy metals).

There is very little data about the impact of air pollutants on natural ecosystems and biodiversity.

- Data are needed to find out if emissions are increasing for pollutants (such as ammonia) that are harmful to natural biodiversity.
- Research is needed to understand the response of our ecosystems to these stresses.

There is limited information on indoor air quality in New Zealand, yet we spend 80 to 90 percent of our time indoors and outdoor air (which could be polluted) makes its way inside.

Acknowledgements

We would like to thank the following people and organisations for their invaluable contribution to *Our air 2018* and Environmental indicators Te taiao Aotearoa: Air.

Data providers

We thank the following for providing data for this report:

Auckland Council, Bay of Plenty Regional Council, Emission Impossible Ltd, Environment Canterbury, Environet, Environment Southland, GNS Science, Greater Wellington Regional Council, Hawke's Bay Regional Council, Manawatu-Wanganui Regional Council (Horizons), Marlborough District Council, Ministry for the Environment, National Institute of Water and Atmospheric Research, New Zealand Transport Agency, Northland Regional Council, Otago Regional Council, Stats NZ, Tasman District Council, Waikato Regional Council.

Peer reviewers

We thank the following people and organisations for reviewing a draft of this report.

Jennifer Salmond – The University of Auckland

Kathleen Kozyniak – Hawke's Bay Regional Council

Technical advisory group

We are very grateful for the assistance of the technical advisory group, who provided advice on potential measures and feedback on draft versions of this report.

Allan Schori – Massey University

Angie Scott – Environment Canterbury

Barry Borman – Massey University, Centre for Public Health Research

Greg Haldane – New Zealand Transport Agency

Haobo Wang – Ministry of Transport

Iain McGlinchy – Ministry of Transport

Ian Longley – NIWA

Janet Petersen

Nick Talbot – Auckland Council

Perry Davy – GNS Science

Rafael Furtado – Ministry of Transport

Sharon Atkins – New Zealand Transport Agency

Suz Halligan – Ministry of Health

Tamsin Mitchell – Greater Wellington Regional Council

Tim Mallett – Environment Canterbury

Glossary

Airshed	An area, formally notified in the New Zealand Gazette, that is likely or known to have unacceptable levels of pollutants, or may require air-quality management.
Anthropogenic	Originating in human activity.
Arsenic	A heavy metal, which in New Zealand comes mainly from burning timber treated with preservative copper-chromate-arsenic. Arsenic can be emitted into the air by burning offcuts of treated timber from building projects for home heating. Some industrial processes also emit arsenic.
Benzene	A volatile organic compound. Motor vehicles and home heating are the main sources, and some industrial activities. Benzene can affect the nervous system and is associated with cancer.
Benzo(a)pyrene (BaP)	A polycyclic aromatic hydrocarbon. Largely emitted from the combustion of fuels (eg wood and coal from home heating), vehicle emissions, and some industrial processes. BaP can irritate the eyes, nose, and throat, and is associated with cancer.
Black carbon	A component of fine particulate matter associated with incomplete combustion. Black carbon has implications for human health and for climate change.
Bunker fuel	A poor-quality, high-sulphur-content fuel used by some large shipping vessels, which results in higher concentration of hazardous pollutants compared with fuel combustion by cars, trucks, or trains.
Carbon monoxide (CO)	A colourless and odourless gas produced by incomplete burning of carbon-containing fuels such as wood, coal, petrol, and diesel.
Combustion	The process of burning, or more technically, the chemical process in which substances mix with oxygen in the air to produce heat and light.
El Niño	El Niño is a negative phase of a naturally occurring global climate cycle. El Niño disrupts normal weather patterns across much of the globe and can lead to intense storms in some places and droughts in others. El Niño and La Niña are opposite phases of a naturally occurring global climate cycle known as the 'El Niño-Southern Oscillation'.
Emission	The release of a pollutant into the atmosphere; its concentration in the air will depend on how the pollutant subsequently disperses in the atmosphere.
Exceedance	Where the concentration of a pollutant exceeds a standard or a guideline.
Exposure	Contact with a chemical, physical, or biological agent that can have either a harmful or beneficial effect.
Heavy metal	Subset of elements that exhibit metallic properties and have relatively high atomic weight. They are naturally occurring within the air, but can be emitted from anthropogenic activities, such as vehicle tyre / brake wear and battery and steelmaking facilities.
Kaitiakitanga	Te ao Māori principle of stewardship, guardianship – particularly for the natural environment.

La Niña	The positive phase of a naturally occurring global climate cycle, which is associated with cooler-than-average sea-surface temperatures in the central and eastern tropical Pacific Ocean. El Niño and La Niña are opposite phases of a naturally occurring global climate cycle known as the 'El Niño-Southern Oscillation'.
Mahinga kai	Traditional food gathering area.
Matariki	Pleiades, The Seven Sisters – an open cluster of many stars in the constellation Taurus.
Mātauranga Māori	Māori knowledge, Māori philosophy.
Mauri	Te ao Māori concept about the essential essence of all being, the life force which is in everything.
Microgram per cubic metre (μg/m^3)	A measuring unit of density used to measure volume in cubic metres to estimate weight or mass in micrograms.
Monitoring site	The site where equipment to sample and/or measure the quality of air is deployed.
NESAQ	National Environmental Standards for Air Quality are regulations made under the Resource Management Act 1991, which aim for a minimum level of health protection for all New Zealanders.
Nitric oxide (NO)	A colourless gas that is generated in combustion engines and in lightning in thunderstorms.
Nitrogen dioxide (NO_2)	A reddish-brown, pungent gas produced mainly from the combustion of fossil fuels (coal, gas, diesel, and oil) and some industrial processes.
Ozone (O_3)	A pale blue gas found in two different layers in the atmosphere. The ozone layer in the stratosphere forms a protective shield, absorbing the ultraviolet wavelengths of sunlight that can have a negative effect on human health. In contrast, ground-level ozone is a pollutant that can have serious effects on human health.
Papatūānuku	Earth Mother in Māori mythology.
Particulate matter (PM)	Small airborne particles composed of solid and/or liquid matter.
Pollutant	Any substance (including gases, odorous compounds, liquids, solids, and micro-organisms) or energy, or heat, that results in an undesirable change to the physical, chemical, or biological environment.
PM_{10}	Airborne particles that are 10 micrometres or less in diameter (about one-fifth of the thickness of a human hair). This includes coarse and fine particulate matter (PM). The sources of PM_{10} include emissions from combustion of wood and fossil fuels, and from various industrial processes. Some PM_{10} comes from natural sources, such as airborne salt and volcanic ash.
$PM_{2.5}$	Fine airborne particles that are 2.5 micrometres (μm) or less in diameter: they mostly come from combustion sources (see PM_{10}). Most particulate matter from natural sources is larger than 2.5 μm in diameter.
Ranginui	Sky Father in Māori mythology.
Sulphur dioxide (SO_2)	A colourless gas with a pungent smell, produced during the combustion of fuels containing sulphur, such as coal and diesel.
Taonga	Te ao Māori concept of a priceless treasure.

Temperature inversion	A layer of warm air that sits over a layer of cooler air near the ground. Because cool air is heavier than warm air, it often remains trapped close to the ground. Air pollution that gets trapped beneath the inversion layer can build up, causing air pollution concentrations to increase.
Te ao Māori	The Māori world view.
Tikanga	Māori cultural practices.
Volatile organic compound (VOC)	Any compound of carbon (excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate) that participates in atmospheric photochemical reactions.
Waiora	Te ao Māori concept about the interconnection of people with their natural environment and how this is important to human well-being.
Whānau	Family, extended family, family connection.

References

Alavanja, MCR, Hoppin, JA, & Kamel, F (2004). Health Effects of Chronic Pesticide Exposure: Cancer and Neurotoxicity. *Annual Review of Public Health*, *25*(1), 155–197. https://doi.org/10.1146/annurev.publhealth.25.101802.123020.

Ancelet, T, Davy, P, & Trompetter, WJ (2013). *Source apportionment of PM_{10} and $PM_{2.5}$ in Nelson Airshed A*.

Ancelet, T, & Davy, P, (2016). *Apportionment of $PM_{2.5}$ and PM_{10} sources in the Richmond airshed, Tasman District*. GNS Science consultancy report 2016/49.

Andries, C (2010). *Air Quality in the Whangarei District*.

Bluett, J, Aguiar, M De, & Gimson, N (2017). *Impacts of exposure to dust from unsealed roads* (Vol. 590).

Bluett, J, Smit, R, & Aguiar, M (2016). Understanding trends in roadside air quality, (September), 171.

Bolton, A (2018). *Climate change and environmental health*. *Client report no: FW17059*.

Bond, TC, Doherty, SJ, Fahey, DW, Forster, PM, Berntsen, T, Deangelo, BJ, … Zender, CS (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research Atmospheres*, *118*(11), 5380–5552. https://doi.org/10.1002/jgrd.50171.

Boucher, O, Randall, D, Artaxo, P, Bretherton, C, Feingold, G, Forster, P, … Zhang, XY (2013). Clouds and aerosols. In TF Stocker, D Qin, GK Plattner, M Tignor, SK Allen, J Boschung, … PM Midgley (Eds), *Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Vol. 9781107057, pp. 571–658). Cambridge, United Kingdom and New York, USA: Cambridge University Press. https://doi.org/10.1017/CBO9781107415324.016.

Bull, M (2014). Guidance on the Assessment of Concrete Bridges, (9).

Cavanagh, JE, Davy, P, Ancelet, T, & Wilton, E (2012). Beyond PM_{10}: benzo (a) pyrene and As concentrations in New Zealand air, *46*(2), 15–24.

Chen, R, Hu, B, Liu, Y, Xu, J, Yang, G, Xu, D, & Chen, C (2016). Beyond $PM_{2.5}$: The role of ultrafine particles on adverse health effects of air pollution. *Biochimica et Biophysica Acta*, *1860*(12), 2844–2855. https://doi.org/10.1016/j.bbagen.2016.03.019.

Coakley, J, Bridgen, P, Bates, MN, Douwes, J, & 't Mannetje, A (2018). Chlorinated persistent organic pollutants in serum of New Zealand adults, 2011–2013. *Science of The Total Environment*, *615*, 624–631. https://doi.org/10.1016/J.SCITOTENV.2017.09.331.

Davy, PK, Ancelet, T, Trompetter, WJ, & Markwitz, A. (2017). *Source apportionment and trend analysis of air particulate matter in the Auckland region*.

Davy, PK, & Trompetter, WJ (2018). *Black Carbon in New Zealand*. Lower Hutt (NZ): GNS Science. 71 p. GNS Science consultancy report 2017/122.

Dirks, K, Scarfe, J, Talbot, NP, Marshall, R, & Salmond, J (2017). A Statistical Analysis of the Relationship between Brown Haze and Surface Air Pollution Levels on Respiratory Hospital Admissions in Auckland, New Zealand. *Climate*, *5*(4), 86. https://doi.org/10.3390/cli5040086.

Durie, M (1999). Te Pae Mahutonga a model for Maori health promotion. In *Health Promotion Forum of New Zealand Newsletter* (Vol. 49, pp. 2–5).

Environmental Health Indicators New Zealand (2015). *Proportion of Households Using Wood and Coal fires as a Source of Home Heating*.

Environmental Protection Authority (2012). Methyl bromide fumigations annual monitoring report: Northport, (Northport), 1–6.

Environmental Protection Authority (2016). Methyl bromide fumigations annual monitoring report: Northport, (December), 1–6.

European Environment Agency (2012). *Particulate matter from natural sources and related reporting under the EU Air Quality Directive in 2008 and 2009*. Copenhagen, Denmark. Retrieved from https://www.eea.europa.eu/publications/particulate-matter-from-natural-sources.

Falchi, F, Cinzano, P, Duriscoe, D, Kyba, CCM, Elvidge, CD, Baugh, K, … Furgoni, R (2016a). Supplement to: The New World Atlas of Artificial Night Sky Brightness. GFZ Data Services. Retrieved from http://doi.org/10.5880/GFZ.1.4.2016.001.

Falchi, F, Cinzano, P, Duriscoe, D, Kyba, CCM, Elvidge, CD, Baugh, K, … Furgoni, R (2016b). The new world atlas of artificial night sky brightness. *Science Advances*, *2*(6), e1600377–e1600377. https://doi.org/10.1126/sciadv.1600377.

Francis, CD, Newman, P, Taff, BD, White, C, Monz, CA, Levenhagen, M, … Barber, JR (2017). Acoustic environments matter: Synergistic benefits to humans and ecological communities. *Journal of Environmental Management*, *203*, 245–254. https://doi.org/10.1016/j.jenvman.2017.07.041.

Gaston, KJ, Bennie, J, Davies, TW, & Hopkins, J (2013). The ecological impacts of nighttime light pollution: A mechanistic appraisal. *Biological Reviews*, *88*(4), 912–927. https://doi.org/10.1111/brv.12036.

Grantz, DA, Garner, JHB, & Johnson, DW (2003). Ecological effects of particulate matter. *Environment International*, *29*(2–3), 213–239. https://doi.org/10.1016/S0160-4120(02)00181-2.

Hales, S, Blakely, T, Woodward, A (2010). Air pollution and mortality in New Zealand: cohort study. Journal of Epidemiology and Community Health, Published Online First: 21 October 2010. doi: 10.1136/jech.2010.112490.

Halonen, JI, Hansell, AL, Gulliver, J, Morley, D, Blangiardo, M, Fecht, D, … Tonne, C (2015). Road traffic noise is associated with increased cardiovascular morbidity and mortality and all-cause mortality in London. *European Heart Journal*, *36*, 2653–2661. https://doi.org/10.1093/eurheartj/ehv216.

Harbrow, MA, Cessford, GR, & Kazmierow, BJ (2011). *The impact of noise on recreationists and wildlife in New Zealand's natural areas: A literature review*. *Science for Conservation*.

Harmsworth, GR, Awatere, S (2013). Indigenous Māori knowledge and perspectives of ecosystems. *Ecosystem services in New Zealand—conditions and trends*. Manaaki Whenua Press, Lincoln, New Zealand, 274-286.

Health Effects Institute (2018). *State of global air 2018. Special Report.* Health Effects Institute, Boston, USA.

International Agency for Research on Cancer (2012). *IARC monographs on the evaluation of carcinogenic risks to humans, volume 100F. Benzene*. *IARC* (Vol. 100F). Lyon, France. Retrieved from http://monographs.iarc.fr/ENG/Monographs/vol100F/mono100F-24.pdf.

International Dark Sky Association. (2012, June 9). New Zealand's Aoraki Mackenzie Named World's Largest International Dark Sky Reserve. *Press Release*.

International Dark Sky Association (2017). *Aoraki Mackenzie International Dark Sky Reserve 2016–2017 Report*.

IPCS (2001). Environmental health criteria on arsenic and arsenic compounds. Environmental Health Criteria Series, No. 224. Arsenic and arsenic compounds, second. WHO, Geneva.

Iremonger, S (2010). *Mount Maunganui ambient sulphur dioxide monitoring* (Vol. Environment).

Kanchongkittiphon, W, Mendell, MJ, Gaffin, JM, Wang, G, & Phipatanakul, W (2015). Indoor Environmental Exposures and Exacerbation of Asthma: An Update to the 2000 Review by the Institute of Medicine. *Environmental Health Perspectives*, *123*(1), 6–20. Retrieved from http://dx.doi.org/10.1289/ehp.1307922%0AIntroduction.

Kim, KH, Kabir, E, & Kabir, S (2015). A review on the human health impact of airborne particulate matter. *Environment International*, *74* (January), 136–143. https://doi.org/10.1016/j.envint.2014.10.005.

Kumar, P, Morawska, L, Birmili, W, Paasonen, P, Hu, M, Kulmala, M, … Britter, R (2014). Ultrafine particles in cities. *Environment International*, *66*, 1–10. https://doi.org/10.1016/j.envint.2014.01.013.

Kuschel, G, Metcalfe, J, Wilton, E, Guria, J, Hales, S, Rolfe, K, & Woodward, A (2012). *Updated Health and Air Pollution in New Zealand Study Volume 1: Summary report* (Vol. 1). Retrieved from http://www.hapinz.org.nz/HAPINZ Update_Vol 2 Technical Report.pdf.

Lai, HK, Berry, SD, Verbiest, MEA, Tricker, PJ, Atatoa Carr, PE, Morton, SMB, & Grant, CC (2017). Emergency department visits of young children and long-term exposure to neighbourhood smoke from household heating – The Growing Up in New Zealand child cohort study. *Environmental Pollution*, *231*, 533–540. https://doi.org/10.1016/j.envpol.2017.08.035.

Lavin, KS, Hageman, KJ, Marx, SK, Dillingham, PW, & Kamber, BS (2012). Using trace elements in particulate matter to identify the sources of semivolatile organic contaminants in air at an alpine site. *Environmental Science and Technology*, *46*(1), 268–276. https://doi.org/10.1021/es2027373.

Le Roux, D, & Le Roux, N (2012). *Hamilton City Bat Survey 2011-2012*. Retrieved from %5C%5Cserver files%5CHamilton City Council%5CBat survey city wide%5Ccity wide survey report_240512.

Li, N, Georas, S, Alexis, N, Fritz, P, Xia, T, Williams, MA, … Nel, A (2016). A work group report on ultrafine particles (AAAAI) why ambient ultrafine and engineered nanoparticles should receive special attention for possible adverse health outcomes in humans. *Journal of Allergy and Clinical Immunology*, *138*(2), 386–396. https://doi.org/10.1097/OGX.0000000000000256.Prenatal.

Li, Y, Henze, DK, Jack, D, Henderson, BH, Kinney, PL, & City, J (2016). Assessing public health burden associated with exposure to ambient black carbon in the United States. *Science of The Total Environment*, *539*, 515–525. https://doi.org/10.1016/j.scitotenv.2015.08.129.Assessing.

Maritime New Zealand (2016). *Maritime New Zealand: Annual Report 2016/17*. Retrieved from https://www.maritimenz.govt.nz/about/annual-reports/documents/MNZ-annual-report-2016-2017.pdf.

Marsden, M (2003). *The woven universe: selected writings of Rev Maori Marsden*. Otaki, NZ, Estate of Rev Maori Marsden.

Matamua, R (2017). *Matariki: the star of the year*. Wellington, NZ, HUIA.

Merk, O (2014). *Shipping Emissions in Ports*. Paris, France, International Transport Forum.

Ministry of Business Innovation and Employment (2016). *Cruise infrastructure*. *Tourism Infrastructure*.

Ministry for the Environment (2002). *Ambient Air Quality Guidelines*. Wellington.

Ministry for the Environment (2016). *Good Practice Guide for Assessing and Managing Odour*. Wellington.

Ministry for the Environment (2017). *New Zealand's Greenhouse Gas Inventory 19902015*. Wellington. Retrieved from http://www.mfe.govt.nz/node/23304/.

Ministry for the Environment and Statistics New Zealand (2014). *New Zealand's Environmental Reporting Series: 2014 Air domain report*. Available from www.mfe.govt.nz and www.stats.govt.nz.

Ministry for the Environment & Statistics New Zealand (2015). *New Zealand's Environmental Reporting Series: Environment Aotearoa 2015*. Available from www.mfe.govt.nz and www.stats.govt.nz.

Ministry for the Environment & Stats NZ (2017a). *New Zealand's Environmental Reporting Series: Our atmosphere and climate 2017*. Retrieved from www.mfe.govt.nz and www.stats.govt.nz.

Ministry for the Environment & Stats NZ (2017b). *New Zealand's Environmental Reporting Series: Our fresh water 2017*. Retrieved from www.mfe.govt.nz and www.stats.govt.nz.

Ministry for the Environment & Stats NZ (2018). *New Zealand's Environmental Reporting Series: Our land 2018*. Retrieved from www.mfe.govt.nz and www.stats.govt.nz.

Ministry of Transport (2014). Future Freight Scenarios Study, (November), 145. Retrieved from http://www.transport.govt.nz/assets/Uploads/Research/Documents/Future-Freight-Scenarios-Study.pdf.

Mitchell, T (2012). Air quality in the Wellington region: State and trends. *Greater Wellington Regional Council.* Publication No. GW/EMI-T-12/137, Wellington.

Mitchell, T (2013). Wainuiomata arsenic in air investigation, 2012. *Greater Wellington Regional Council.* Publication No. GW/ESCI-T-13/39. Wellington.

Morawska, L, Ristovski, Z, Jayaratne, ER, Keogh, DU, & Ling, X (2008). Ambient nano and ultrafine particles from motor vehicle emissions: characteristics, ambient processing and implications on human exposure. *Atmospheric Environment*, *42*, 8113–8138.

New Zealand Government. Resource Management Act 1991 No 69 (as at 11 July 2018), Public Act - New Zealand Legislation (1991). New Zealand. Retrieved from http://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html.

Office of Environmental Health Hazard Assessment. (2008). *Technical supporting document for noncancer RELs, Appendix D1, Updated 2014*.

Parfitt, RL, Stevenson, BA, Dymond, JR, Schipper, LA, Baisden, WT, & Ballantine, DJ (2012). Nitrogen inputs and outputs for New Zealand from 1990 to 2010 at national and regional scales. *New Zealand Journal of Agricultural Research*, *55*(3), 241–262. https://doi.org/10.1080/00288233.2012.676991.

Payne, RJ, Dise, NB, Field, CD, Dore, AJ, Caporn, SJM, & Stevens, CJ (2017). Nitrogen deposition and plant biodiversity: past, present , and future. https://doi.org/10.1002/fee.1528.

Pezza, A, & Mitchell, T (2016). *Influence of climate on air pollution in Masterton 2003 to 2015*. Greater Wellington Regional Council, Report no. GW/ESCI-T-15/169.

Pope, K, So, YT, Crane, J, & Bates, MN (2017). Ambient geothermal hydrogen sulfide exposure and peripheral neuropathy. *Neurotoxicology*, *60*, 10–15. https://doi.org/10.1016/j.neuro.2017.02.006.

Proppe, DS, Sturdy, CB, & St Clair, CC (2013). Anthropogenic noise decreases urban songbird diversity and may contribute to homogenization. *Global Change Biology*, *19*(4), 1075–1084. https://doi.org/10.1111/gcb.12098.

Pugh, AR, & Pawson, SM (2016). Artificial light at night potentially alters feeding behaviour of the native southern black-backed gull (Larus dominicanus). *Notornis*, *63*(1), 37–39.

Querol, X, Alastuey, A, Ruiz, CR, Artiñano, B, Hansson, HC, Harrison, RM, … Schneider, J (2004). Speciation and origin of PM_{10} and $PM_{2.5}$ in selected European cities. *Atmospheric Environment*, *38*(38), 6547–6555. https://doi.org/10.1016/j.atmosenv.2004.08.037.

Ramanathan, V, & Carmichael, G (2008). Global and regional climate changes due to black carbon. *Nature Geoscience*, *1*, 221–227. https://doi.org/10.1038/ngeo156.

Rich, C, & Longcore, T (Eds) (2005). *Ecological consequences of artificial night lighting*. Washington DC: Island Press. Retrieved from https://islandpress.org/book/ecological-consequences-of-artificial-night-lighting.

Salmond, JA, Dirks, KN, Fiddes, S, Pezza, A, Talbot, N, Scarfe, J, & Renwick, J (2016). A climatological analysis of the incidence of brown haze in Auckland , New Zealand. *International Journal of Climatology*, *36 (*October 2015), 2516–2526. https://doi.org/10.1002/joc.4509.

Salomon, V (2015). Ambient concentrations of polycyclic aromatic hydrocarbons (PAHs) and organic markers in Timaru 2012 – 2013. *Environment Canterbury*. Report No R15/5.

Schauer, JJ, Lough, GC, Shafer, MM, Christensen, WF, Arndt, MF, DeMinter, JT, & Park, JS. (2006). *Characterization of metals emitted from motor vehicles. Research report 133*. Boston, MA.

Senaratne, I, & Shooter, D (2004). Elemental composition in source identification of brown haze in Auckland, New Zealand. *Atmospheric Environment*, *38*(19), 3049–3059. https://doi.org/10.1016/J.ATMOSENV.2004.02.046.

Shannon, G, Mckenna, MF, Angeloni, LM, Crooks, KR, Fristrup, KM, Brown, E, … Wittemyer, G (2016). A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews*, *91*, 982–1005. https://doi.org/10.1111/brv.12207.

Shepherd, D, Dirks, K, Welch, D, Mcbride, D, & Landon, J (2016). The Covariance between air pollution annoyance and noise annoyance , and its relationship with health-related quality of life. *International Journal of Environmental Research and Public Health*, *13*, 792. https://doi.org/10.3390/ijerph13080792.

Shusterman, D (1992). Critical review: The health significance of environmental odor pollution. *Archives of Environmental Health*, *47*(1), 76–87. https://doi.org/10.1080/00039896.1992.9935948.

Stats NZ (2017). *Tourism Satellite Account: 2017*. Retrieved from http://www.mbie.govt.nz/info-services/sectors-industries/tourism/tourism-research-data/tourism-satellite-account.

Suckling, I, de Miguel Mercador, F, Monge, JJ, Wakelin, SJ, Hall, PW, & Bennett, PJ (2018). *New Zealand Biofuels Roadmap Technical Report*. Scion.

Talbot, N, & Reid, N (2017). *A Review of Research into the Effects of Shipping on Air Quality in Auckland: 2006-2016* (TR2017/005). Auckland Council technical report.

Taptiklis, P, & Phipps, R (2017). *Indoor Air Quality in New Zealand Homes and Schools*. BRANZ Ltd.

UNEP (2014). *Phasing-out methyl bromide in developing countries*. *Policy*. https://doi.org/10.1002/j.1681-4835.2017.tb00576.x.

United Nations (2017). *Health - United Nations Sustainable Development*. Retrieved 24 July 2018, from https://www.un.org/sustainabledevelopment/health/.

United States Environmental Protection Agency (US EPA) (nd). *Introduction to Indoor Air Quality*. Retrieved 16 May 2018 from https://www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality.

United States Environmental Protection Agency (US EPA) (2008). *Integrated Science Assessment (ISA) for Oxides of Nitrogen and Sulfur - Ecological Criteria (Final Report, Dec 2008)*. Washington, DC. Retrieved from https://www.epa.gov/isa/integrated-science-assessment-isa-oxides-nitrogen-oxides-sulfur-and-particulate-matter.

United States Environmental Protection Agency (US EPA) (2009). *Integrated Science Assessment for Particulate Matter*. https://doi.org/EPA/600/R-08/139F.

United States Environmental Protection Agency (US EPA) (2010). *Integrated Science Assessment for Carbon Monoxide*.

United States Environmental Protection Agency (US EPA) (2012). *Report to Congress on Black Carbon*. https://doi.org/10.1016/j.icrp.2009.12.007.

United States Environmental Protection Agency. (2013). *Integrated science assessment for ozone and related photochemical oxidants*. *Federal Register* (Vol. EPA 600/R-). Research Triangle Park, NC.

United States Environmental Protection Agency (US EPA) (2016). *Integrated Science Assessment for Oxides of Nitrogen – Health Criteria*. Retrieved from https://www.epa.gov/isa/integrated-science-assessment-isa-nitrogen-dioxide-health-criteria.

United States Environmental Protection Agency (US EPA). (2017). *Integrated science assessment for sulfur oxides – Health criteria*. Research Triangle Park, NC. Retrieved from http://cfpub.epa.gov/ncea/isa/ recordisplay.cfm?deid=310044.

van Kempen, E, & Babisch, W (2012). The quantitative relationship between road traffic noise and hypertension. *Journal of Hypertension*, *30*(6), 1075–1086. https://doi.org/10.1097/HJH.0b013e328352ac54.

Varela, Z, López-Sánchez, G, Yáñez, M, Pérez, C, Fernández, JA, Matos, P, … Aboal, JR (2018). Changes in epiphytic lichen diversity are associated with air particulate matter levels: The case study of urban areas in Chile. *Ecological Indicators*, *91* (March), 307–314. https://doi.org/10.1016/j.ecolind.2018.04.023.

World Health Organization (WHO) (2001). Environmental Levels and Human Exposure. In *Environmental Health Criteria 224 Arsenic and arsenic compounds* (pp. 38–40).

World Health Organization (WHO) (2006). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: global update 2005: summary of risk assessment*. *Geneva: World Health Organization*. Geneva. https://doi.org/10.1016/0004-6981(88)90109-6.

World Health Organization (WHO) (2011). *Burden of disease from environmental noise: Quantification of healthy life years lost in Europe*. *World Health Organization*. https://doi.org/10.1080/13504630.2011.629519.

World Health Organization (WHO) (2013). *Review of evidence on health aspects of air pollution – REVIHAAP Project*. Retrieved from http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report.

WHO Regional Office for Europe. (2000). Air quality guidelines for Europe (2nd Ed). *Environmental Science and Pollution Research*, *3*(1), 23–23. https://doi.org/10.1007/BF02986808.

WHO Regional Office for Europe (2016). WHO Expert Consultation: Available evidence for the future update of the WHO Global Air Quality Guidelines (AQGs), (October), 50. Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0013/301720/Evidence-future-update-AQGs-mtg-report-Bonn-sept-oct-15.pdf?ua=1.

Wilton, E (2015). *Napier, Hastings and Havelock North Air Emission Inventory*. Hawke's Bay Regional Council, Report no. RM15-10.

Wilton, E (2016). *Air emission inventory – Tokoroa and Morrinsville 2016*. Waikato Regional Council, technical report 2016/31.

Wilton, E (2017). *Air Emission Inventory – Blenheim 2017*. Marlborough District Council.