Public Health Risks associated with Transport Emissions in NZ:

Part 1 Stocktake and Gap Analysis as at 30 June 2021

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DISCLAIMER

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1. EXECUTIVE SUMMARY

Transportation in New Zealand – which encompasses road, rail, maritime transport and aviation – emits a wide range of air pollutants, many of which present a public health risk. The adverse effects of transport emissions are significant in New Zealand. The social costs of transport-related harmful air pollution are currently estimated at $1.21 billion per annum (in $2019) as a result of New Zealanders dying prematurely, being admitted to hospital or suffering days lost due to illness or poor health. Transport sources also emit direct or indirect climate pollutants. Transport-related greenhouse gas emissions add an additional $1.68 billion in social costs per annum (in $2019) (Kuschel *et al* 2021).

This report is the first step in addressing the research question:

> *"What are the risks to public health associated with road, sea, rail and air travel including vessel emissions, dusty roads and vehicle emissions in New Zealand?"*

A stocktake and gap analysis was undertaken based on the current state of knowledge as at 30 June 2021 for the following sectors:

- On-road vehicles (e.g. light duty passenger cars/vans and heavy duty buses/trucks)
- Rail
- Maritime transport (e.g. ferries and coastal shipping)
- Aviation
- Transport infrastructure (e.g. tunnels, bridges, sealed and unsealed roads)[1]
- Off-road vehicles.

Each sector was assessed in terms of:

- Features that define the sector in New Zealand (i.e. what's special about this sector?)
- Primary contaminants emitted (i.e. what is emitted?)
- Likely spatial distribution of any population exposure (i.e. where are the emissions?)
- Current state (i.e. how much is the likely impact – research/monitoring to date?)
- Trends (i.e. are things improving - historical, now and future?)
- Evaluation of the likely risk posed to public health (qualitative)
- Gaps in our understanding (i.e. what don't we know that would be worth knowing?).

A *qualitative* assessment of risks to public health was then undertaken based on:

- Emissions/concentrations – how high?
- Spatial coverage – where are people are exposed?
- Population exposed – how many people are exposed?
- Exposure duration – how significant is the exposure?

[1] Emissions from transport infrastructure were assessed separately to on-road or rail emissions because different agencies are responsible for managing their impacts.

The top three gaps in our understanding identified from this stocktake are:

1. What are the current health impacts of New Zealanders being exposed to on-road nitrogen dioxide (NO_2) emissions and are they improving?
2. What are the critical factors influencing community exposure to unsealed road particulate matter (PM) emissions?
3. Which characteristics of on-road brake and tyre wear PM emissions present a public health risk?

Note: This stocktake and gap analysis presents the current state as at 30 June 2021. The authors are aware that a number of relevant research reports and policy initiatives which seek to address some of the key gaps identified in this report are now pending. These are new initiatives are highlighted where appropriate but are not included in the analysis as the findings are not yet public.

2. INTRODUCTION

The transport sector - which encompasses road, rail, maritime transport and aviation - emits a broad range of air pollutants, principally through the combustion of fossil fuels.

This chapter outlines the purpose and scope of this report, introduces the important transport-related air pollutants in New Zealand and summarises their health effects. It reviews the factors that contribute to public health risk, how air quality impacts are assessed, outlines the types of options for managing transport emissions and how the qualitative assessment of risks to public health was prepared.

A glossary of technical terms and abbreviations is included at the end, together with all references.

2.1 PURPOSE AND SCOPE

This report is the first step in addressing the research question:

> *"What are the risks to public health associated with road, sea, rail and air travel including vessel emissions, dusty roads and vehicle emissions in New Zealand?"*

We identified the key transport-related air pollutants and their associated health impacts and then summarised the current state of knowledge as at 30 June 2021 for the key sectors in New Zealand in terms of:

- Features that define the transport sector in New Zealand (i.e. what's special about this sector?)
- Primary contaminants emitted (i.e. what is emitted?)
- Likely spatial distribution of any population exposure (i.e. where are the emissions?)
- Current state (i.e. how much is the likely impact – research/monitoring to date?)
- Trends (i.e. are things improving - historical, now and future?)
- Evaluation of the likely risk posed to public health (qualitative)
- Gaps in our understanding (i.e. what don't we know that would be worth knowing?).

The stocktake and gap analysis covers the following transport sectors in New Zealand:

- On-road vehicles (e.g. light duty passenger cars/vans and heavy duty buses/trucks)
- Rail
- Maritime transport (e.g. ferries and coastal shipping)
- Aviation
- Transport infrastructure (e.g. tunnels, bridges, sealed and unsealed roads)[2]
- Off-road vehicles.

[2] Emissions from transport infrastructure were assessed separately to on-road or rail emissions because different agencies are responsible for managing their impacts.

2.2 TRANSPORT-RELATED AIR POLLUTANTS AND THEIR EFFECTS

Air pollution comprises a complex mixture of particles (usually referred to as particulate matter) and gases. The primary air pollutants from transport sources are typically split into harmful air pollutants (which impact locally) and greenhouse gases (which impact globally).

2.2.1 Harmful air pollutants

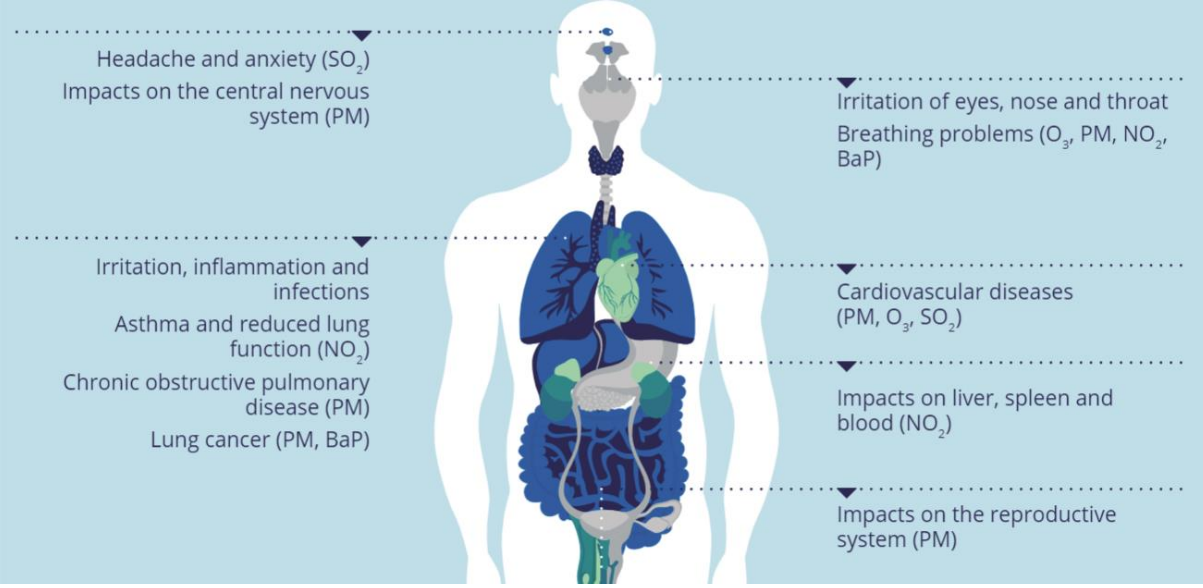
The harmful air pollutants commonly associated with the transport sector include:

- Particulate matter smaller than 10 µm (**PM_{10}**) or smaller than 2.5 µm (**$PM_{2.5}$**) – which arises primarily from diesel fuel combustion, brake/tyre wear and road dust. Combustion-related PM is usually in the $PM_{2.5}$ size range (known as fine particulate) whereas abrasion-related PM is usually in the $PM_{10-2.5}$ size range (known as coarse particulate).
- Nitrogen oxides (**NO_X**), in particular nitrogen dioxide (**NO_2**) – which is emitted primarily from diesel and petrol fuel combustion.
- Sulphur dioxide (**SO_2**) – which is associated with combustion of marine transport fuels (but typically coastal freighters rather than ferries). On-road diesel vehicles used to be a significant source until the sulphur level in motor diesel was reduced to near zero (only 10 ppm) in 2009.
- Volatile organic compounds (**VOC**) – which come from evaporation of fuel in engines and refuelling systems as well as fuel combustion.
- Carbon monoxide (**CO**) – which is associated particularly with the incomplete combustion of petrol. However, concern has reduced now that most petrol vehicles are fitted with catalytic converters.
- Heavy metals – which are emitted from combustion and abrasion processes. On-road vehicles release zinc, copper and iron through brake and tyre wear but iron is also released from abrasion of rail tracks. Nickel and vanadium are present in heavy fuel oils and are typical markers of shipping emissions. Platinum and palladium can also be released in small quantities through degradation of vehicle exhaust treatment systems (e.g. catalytic converters). Lead used to be the main heavy metal of concern in New Zealand because it was added as an octane enhancer in petrol and was ubiquitous in ambient air. In 1996, unleaded fuel became mandatory and levels of lead in ambient air samples have since reduced dramatically.

Harmful air pollutants are so-called because they can cause adverse human health effects ranging from increased **morbidity** (illness, e.g. increased respiratory hospitalisations) to increased **mortality** (loss of life, i.e. premature deaths). The effects depend on the pollutant itself, the concentration and the length of time exposed – **acute** (short-term) or **chronic** (long-term).

Figure 1 illustrates potential health effects associated with harmful air pollution. For more detail on the health effects of transport-related air pollutants, refer to Appendix A.

FIGURE 1: The impact of harmful air pollution on the human body



Source: EEA (2019)

Note: BaP = benzo(a)pyrene; NO_2 = nitrogen dioxide; O_3 = ozone; PM = particulate matter; SO_2 = sulphur dioxide.

2.2.2 Greenhouse gases

The greenhouse gases commonly associated with the transport sector (IPCC 2014) include:

- Carbon dioxide (**CO_2**) – which is released from combustion of all fossil fuels (especially mineral-based petrol and diesel). Combustion of renewable fuels also produces CO_2 but the net effect is considered zero as the CO_2 is then re-captured in the production of the renewable fuels.
- Methane (**CH_4**) – which is associated with incomplete combustion and fuel system leaks in natural gas-fuelled vehicles (not currently common in New Zealand).
- Nitrous oxide (**N_2O**) – which is also associated with fossil fuel combustion.
- Black carbon (**BC**) – which is produced primarily from diesel combustion and is essentially fine particulate matter ($PM_{2.5}$ and smaller).

Greenhouse gases (**GHG**), also known as climate pollutants, are so-called because they contribute to global warming and climate change. GHGs are categorised as short-lived with an atmospheric lifetime of days to ~15 years (e.g. black carbon and methane) or long-lived with an atmospheric lifetime of more than 100 years (e.g. CO_2). For ease of comparison, GHGs are typically expressed as carbon dioxide equivalents (**CO_2e**), which is the amount of CO_2 which would have the equivalent global warming impact.

Note: Several harmful pollutants (especially black carbon) are *direct* climate pollutants. Many of the remaining harmful pollutants (e.g. sulphur dioxide and carbon monoxide) are *indirect* climate pollutants. They do not have a direct warming effect but react with other gases and increase GHG concentrations. Consequently, initiatives which address harmful air pollutants typically yield both health and climate change benefits.

2.3 WIDER IMPACT OF TRANSPORT EMISSIONS ON PUBLIC HEALTH

Air pollution causes serious health effects. However, these impacts are not felt evenly. DANIDA (2000) identifies that people can be more vulnerable if they are:

- more **exposed** to environmental hazards
- more **sensitive** to the effects
- **less resilient** in terms of their ability to be able to **anticipate, cope with, or recover** from the effects.

2.3.1 Exposure

For air pollution risk, the **exposure** is determined largely by external factors, such as the amount of time spent indoors or travelling and where a home/office/school is located relative to transport corridors or a port. Groups with the highest exposure include people who live near busy roads or road canyons with heavy traffic, road users (commuters etc.) and people whose jobs require them to spend a long time on the roads (bus drivers etc.).

There is evidence that young children, adults and households in poverty experience increased exposure to traffic related air pollution (Barnes *et al* 2019). Affordable housing for low socio-economic groups is often located in areas where air quality is poor, such as near highways, in low lying valleys and in more industrialised areas.

Increased air pollution also makes people less likely to engage in physical activity, which of itself has wide ranging public health impacts.

2.3.2 Sensitivity

Sensitivity depends largely on internal factors such as age, health status and genetic makeup. Based on health reviews, there are groups within the New Zealand population who are more affected by air pollution than others (MfE 2011). These susceptible groups include:

- elderly people
- children (including babies, infants and unborn babies)
- people with pre-existing heart or lung disease
- people with respiratory conditions, such as asthmatics
- diabetics
- pregnant women
- Māori and Pacific peoples.

Asthmatics are particularly sensitive to poor air quality. New Zealand has one of the highest prevalence of asthma in the world, with one in seven children aged 2–14 years (107,000 children) and one in nine adults aged over 15 years (389,000 adults) reporting taking current asthma medication (HQSC 2016). The Organisation for Economic Co-operation and Development (**OECD**) indicates New Zealand has the fourth highest hospital admission rates for asthma of OECD countries (OECD 2019).

Māori are 2.9 times and Pacific peoples 3.7 times more likely to be hospitalised for asthma than Europeans or other New Zealanders, and people living in the most deprived areas are 3.2 times more likely to be hospitalised than those in the least deprived areas (Asthma Foundation 2016). There is also evidence of a higher prevalence of medicated asthma among Māori children (MoH 2020).

2.3.3 Resilience

In terms of **ability to cope or recover from health effects** associated with transport emissions, again those in low socio-economic groups are disadvantaged.

In New Zealand, both Māori and Pacific peoples have disproportionately low incomes compared to many other ethnic groups (EHINZ 2021). This means they have fewer options available to them to reduce or avoid air pollution risks.

Note: This report examines the direct impacts of transport emissions on public health. Air quality also affects health outcomes more broadly, such as amenity. These factors sit outside the scope of this paper but are important public health impacts that need to be considered.

2.4 ASSESSING AIR POLLUTION HEALTH IMPACTS

Health impacts of air pollution – whether it be from transport or any sources – can be assessed using either detailed or screening methods as follows.

2.4.1 Detailed assessments

One example of a detailed assessment is the Health and Air Pollution in New Zealand (**HAPINZ**) study, which follows a step-wise process (shown in Figure 2).

For each area under assessment (e.g. a census area unit, CAU), the health impacts are generally calculated as follows:

$$\mathbf{Health\ Effects\ (cases) = Cases\ (total)\ \times\ \ PAF}$$

where:

> **Health effects (cases)** are the number of deaths, hospital admissions or restricted activity days (depending on the health outcome being assessed) due to air pollution.
>
> **Cases (total)** is the total number of health cases (deaths, hospital admissions, or for restricted activity days, population) in the area of interest.
>
> **PAF** (population attributable fraction) is the estimated percentage of total health cases that are attributable to the air pollution exposure.

The PAF is calculated using the exposure–response function (the relative increase in the health effect for every increment of air pollution, e.g. 1.11[3] for every 10 $\mu g/m^3$ of annual average PM_{10}) and the exposure (the average pollution concentration in the area of interest, e.g. an annual average PM_{10} concentration of 15 $\mu g/m^3$).

This approach estimates the health effects that would be prevented if exposure to the pollutant (e.g. PM_{10}) was at the minimum risk level possible, recognising that there is no safe threshold for most air pollutants.

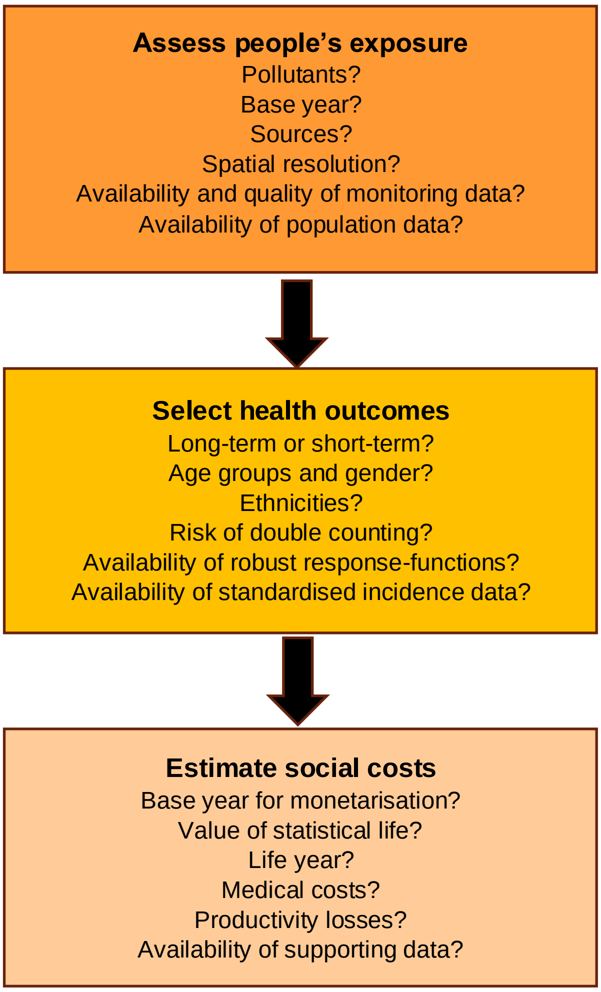
The social costs of air pollution are then calculated as follows:

$$\mathbf{Social\ Costs = Health\ Effects\ (cases) \times\ Cost\ per\ case}$$

In simple terms, we combine the health effects cases estimated as per the previous formula (e.g. the number of premature deaths) with published health-cost data (e.g. the latest value of a statistical life, **VoSL**) to estimate costs.

[3] A relative risk of 1.11 means the risk increases by 11% per pollution increment, in this case per 10 $\mu g/m^3$ of annual average PM_{10}.

FIGURE 2: Typical steps involved in a detailed assessment of air pollution health effects



Source: Kuschel *et al* (2012)

Results can be aggregated and reported for larger urban areas (such as towns and cities) or management areas (such as regions or airsheds) depending on physical and political boundaries.

The most recent HAPINZ study (HAPINZ 2.0) was published in 2012, based on 2006 data (Kuschel *et al* 2012). This study, using PM_{10} as a proxy for all air pollution exposure, estimated that motor vehicle emissions alone were associated with 256 premature deaths and over 352,000 restricted activity days at a cost of $934 million (NZ$2010). However, the authors acknowledged that it was likely that transport emissions-related effects were being significantly under-estimated due to the difficulty in being able to robustly assess NO_2 exposure (insufficient data).

Note: The latest update of HAPINZ (HAPINZ 3.0), which is based on 2016 data, is currently being finalised, but is yet to be published. HAPINZ 3.0 is investigating exposure to both PM and NO_2 and will address many of the gaps in understanding raised in HAPINZ 2.0.

2.4.2 Screening assessments

Detailed assessments are time and resource intensive and are therefore usually undertaken infrequently. A simpler way to estimate air pollution health impacts is to use a screening method, such as damage costs.

Damage costs place a value on emissions to air to enable the benefits to society of a change in policy/operation to be compared with the cost of implementing the change. They can also be used to compare options to identify which will produce the best overall outcome. Damage costs can be developed to capture benefits of emission reductions of both harmful pollutants (e.g. PM_{10}) and greenhouse gases (e.g. CO_2), with costs expressed in $ per tonne. Many agencies publish relevant values to be used in the assessment of costs and benefits of policy options (e.g. Powell *et al* 2019).

In New Zealand, damage costs have been developed from values reported overseas with the PM_{10} costs adjusted using New Zealand-specific health effects from HAPINZ 2.0. The cost per tonne[4] of PM_{10} is derived by matching the HAPINZ 2.0 health effect costs for PM_{10}-related mortality and morbidity to the amount of PM_{10} released to the air (estimated in urban air emissions inventories). This approach assumes emissions are related to concentrations which is a simplification but a reasonable approximation over large urban areas.

The damage costs apply to the pollutant so are independent of source, i.e. one tonne of (say) PM_{10} costs society the same amount, irrespective of whether it has been emitted from transport or domestic fires. However, to date, the application of damage costs in New Zealand has largely been in transport projects, such as assessing environmental outcomes of roading infrastructure projects or comparing the environmental performance of different bus fleets (Kuschel *et al* 2017). Damage costs for harmful pollutant and CO_2 emissions are included in the Monetised Benefits and Costs Manual (**MBCM**) published by Waka Kotahi (NZTA 2021a).

New Zealand damage costs have been revised recently in line with the latest overseas data as part of the Domestic Transport Costs and Charges project commissioned by the Ministry of Transport (Kuschel *et al* 2021). The update provides separate values for urban and rural areas to better reflect the differences in exposure between heavily- and lightly-populated areas in New Zealand. All settlements/areas with more than 1,000 residents were classified as urban areas and all others as rural, in accordance with the StatsNZ Urban Rural 2018 indicator (StatsNZ 2018).

Table 1 presents the revised damage costs for use in New Zealand. These are based on a road safety VoSL of NZ$4.53 million as at the end June 2019 (Kuschel *et al* 2021). All costs are assumed to be additive – i.e. that the impact of double-counting of effects is negligible across the different pollutants.

TABLE 1: New Zealand damage costs in $/tonne in June 2019 prices

POLLUTANT	COSTS IN NZ$/TONNE URBAN	COSTS IN NZ$/TONNE RURAL	VALUE BASE DATE (AT END JUNE)
PM_{10}	$503,346	$38,480	2019
SO_2	$36,491	$2,790	2019
NO_X	$17,887	$1,367	2019
VOC	$1,433	$110	2019
CO_2e	$88	$88	2019
CO	$4.52	$0.35	2019

Source: Kuschel *et al* (2021)

[4] The average density of PM is 1 gram per cubic centimetre (g/cm^3) so 1 tonne of PM would occupy a volume of 1 cubic metre (m^3) – i.e. equivalent to a box with sides of 1 m in all dimensions or alternatively a whole netball court uniformly covered in 2 mm of material.

Note: One of the key deliverables of the HAPINZ 3.0 study (pending) is to develop New Zealand-specific damage costs. Preliminary results suggest there will be little change in the PM_{10} values but that the NO_X values may be considerably higher. As mentioned earlier the HAPINZ 3.0 study is still being finalised, so the values shown in Table 1 are the best available at time of writing.

Screening assessments based on emissions (such as damage costs) are relatively easy to undertake. However, they are **only a proxy for air pollution health effects.** The concentration of a pollutant in ambient air does depend on emissions but is influenced by other factors – such as meteorology, atmospheric chemistry and topography. For example, emissions from vehicles on unsealed roads typically only create public health risks in drier months.

Further, the exposure of an individual also depends on location and duration, in addition to concentration. For example, ship emissions are only a potential public health risk near ports/waterways. Locomotive emissions are only a potential public health risk near rail corridors and likewise tunnel emissions generally only impact workers, users and people living near stacks/portals. Conversely, motor vehicles give rise to long-term and widespread, continuous exposure in urban areas because roads criss-cross our cities and vehicles are used every day.

2.5 OPTIONS FOR MANAGING TRANSPORT EMISSIONS

2.5.1 Target areas

Options to better manage transport emissions and the associated public health impacts typically fall under three main areas – known as the **Avoid-Shift-Improve** approach - as shown in Figure 3.

FIGURE 3: The Avoid-Shift-Improve approach

Source: NZTA (2020a)

In this approach promoted by NZTA (2020a):

- **AVOID/REDUCE** interventions aim to avoid or reduce the need to travel, or the time or distance travelled by car while improving accessibility, e.g. through integrated land use and transport planning for urban form that supports well-connected multi-modal access to local services and employment. This is critical for long term emission reductions at a system level; and brings many other transport, public health and environmental benefits, through reduced air and noise pollution, increased levels of physical activity, reduced congestion, better connected communities and improved safety.

- **SHIFT/MAINTAIN** interventions focus on shifting people who need to travel from cars to more energy efficient modes such as public transport and active or shared modes, e.g. through better provision of low carbon travel options and incentives to choose them.

- **IMPROVE** interventions seek to improve the energy efficiency of motorised vehicles (e.g. through fuel standards or electric vehicle uptake); and optimise transport infrastructure and operations for more efficient vehicle movement. Measures to improve harmful emissions can include initiatives around appropriate maintenance, clean fuels and clean, low emission vehicle technology.

IMPROVE measures related to the emissions and energy efficiency **performance of vehicles** are generally regulated by central government.

In contrast, AVOID/REDUCE and SHIFT/MAINTAIN measures, which influence the **demand for travel**, typically fall within the jurisdiction of transport agencies (national, local and regional) as well as local councils (through integrated transportation and land use planning). Decisions about transport systems, form of urban development and land use all impact each other.

Regardless, reducing the need for travel or making it more efficient reduces emissions of GHGs and harmful air pollutants, while also delivering many other benefits.

Despite the role that government and agencies play, individuals can also have an appreciable influence – especially in their choices around whether, when and how to travel. In terms of options, shifting trips from traditional modes (such as passenger cars) to more active modes (such as walking and cycling) is particularly beneficial as it not only reduces harmful emissions but offers additional public health benefits through increased physical activity/exercise. Waka Kotahi estimates that cycling delivers average public health benefits of $1,300 for each user annually (as at June 2020), with walking even more beneficial at $2,600 (NZTA 2021a).

2.5.2 Milestone actions to date

From a position of being well behind the rest of the world in terms of fuels and emissions standards in 1995, New Zealand has built up momentum to the point where the gap with other developed nations has shrunk considerably. Central government has made major progress in accelerating clean fuels and clean vehicle technology, but less so with encouraging appropriate vehicle maintenance. Across New Zealand, there has been renewed focus and increased expenditure on sustainable transport infrastructure, including improvements to the public transport network and increased provision of cycle infrastructure.

For a summary of major initiatives to date addressing transport emissions in New Zealand, refer to Appendix B.

2.6 QUALITATIVE ASSESSMENT OF PUBLIC HEALTH RISKS

The risk qualifiers shown in Table 2 were used to assess risks to public health.[5].

TABLE 2: Risk qualifiers used to assess each parameter

PARAMETER	DESCRIPTOR	RATING	COMMENT/ASSUMPTION
Emissions or concentrations	Low	L	< 10% regional emissions or guidelines
	Moderate	M	10-50% regional emissions or guidelines
	High	H	> 50% regional emissions or guidelines
Spatial coverage	Discrete	L	Impacts near single locations e.g. ports
	Narrow	M	Impacts along transport corridors
	Widespread	H	Impacts across all regions
Population exposed	Few	L	< 10% population
	Many	M	10-50% population
	Most	H	> 50% population
Exposure duration	Short-term	L	< 30 days per year
	Seasonal	M	90-180 days per year
	Long-term	H	365 days per year
Public health risk rating	Low	≥3L	e.g. low emissions and few people exposed
	Low-Med	2L+1M	
	Medium	2M	In between
	Med-High	2M+1H	
	High	≥2H	e.g. high emissions and many exposed

[5] Based on best available data or expert judgment.

3. ON-ROAD VEHICLES

This chapter reviews the state, trends and public health risks associated with air emissions[6] from on-road vehicles in New Zealand. On-road vehicles include light duty vehicles (e.g. passenger cars and vans) and heavy duty vehicles (e.g. trucks, buses and coaches), as well as motorcycles.

Some definitions:

On-road means on public roads (e.g. state highways) as opposed to private roads (e.g. farm roads).

Duty refers to the gross vehicle mass (**GVM**). Light duty vehicles have a GVM less than 3,500 kg and heavy duty vehicles have a GVM greater than 3,500 kg.

LPV is a light passenger vehicle, **LCV** is a light commercial vehicle, **HCV** is a heavy commercial vehicle.

3.1 CURRENT STATE

3.1.1 What are the key features of this sector?

Key features of the 2019 New Zealand vehicle fleet (MoT 2020) are:

Light vehicles

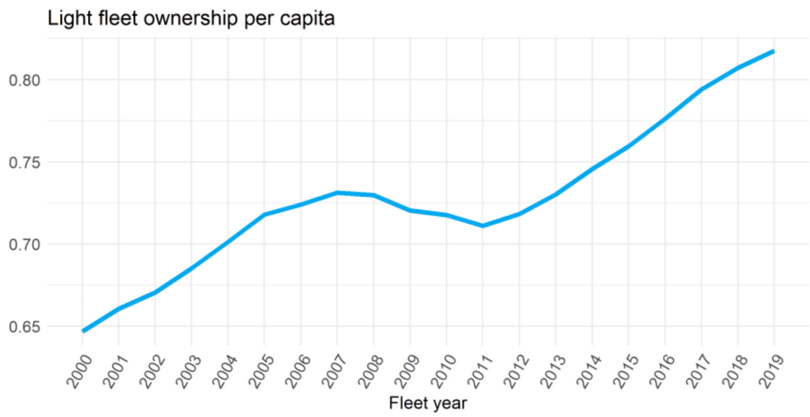
- **High and increasing car ownership** with 0.82 vehicles per capita (see Figure 4) versus 0.78 in Australia (ABS 2020).
- A high **light fleet average age** of 14.1 years versus 10.4 years in Australia.
- **Two relatively equal points of entry** into the light fleet, with 45% of our light vehicles entering as used imports (largely from Japan) versus 55% entering as new.
- **Electric and hybrid** vehicles represent a small proportion (1.7%) of the light fleet.
- A growing **proportion of diesel** vehicles in the light fleet up from 11.8% in 2000 to 19.9% in 2019 (versus 25.6% in Australia). However, light passenger vehicles (**LPVs**) and light commercial vehicles (**LCVs**) are not equally fuelled by petrol and diesel. 91% of the 2019 LPV fleet is petrol-fuelled but 76% of the 2019 LCV fleet is diesel.
- Our vehicles **drive long distances before we get rid of them.** The average odometer of LPVs being scrapped was 204,600 km in 2019 versus 174,000 km in 2001. However, it has been steadily dropping from a high of 217,900 km in 2014.

Heavy vehicles

- Heavy vehicle **travel** (especially for buses) has increased at a greater rate than for LPVs (see Figure 5).
- The **truck fleet has aged steadily** but bus ages have declined (see Figure 6).
- Most heavy vehicles are **diesel fuelled** (98% for both trucks and buses) but the proportion of hybrid or electric buses is increasing (currently 0.9%).

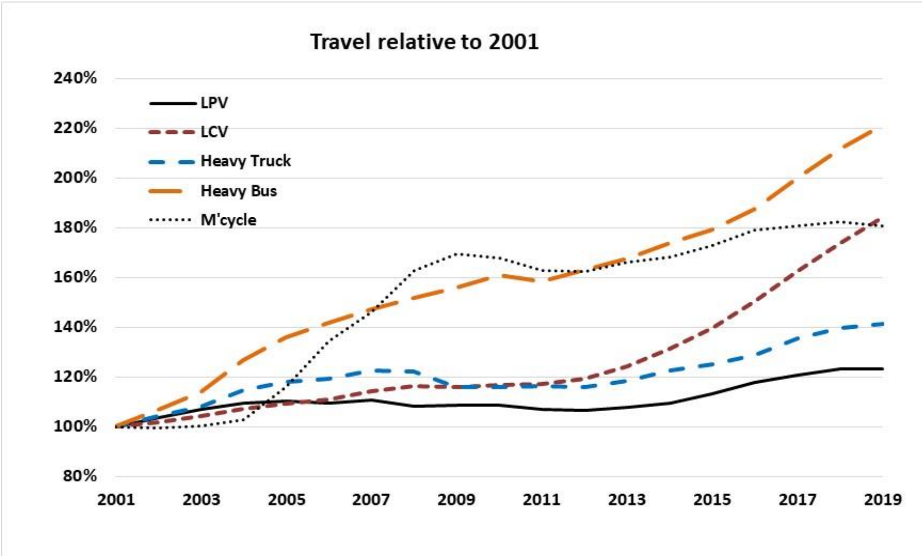
[6] This chapter covers exhaust emissions (i.e. tailpipe) and non-exhaust emissions (e.g. brake and tyre wear). Road dust and emissions released from tunnel portals or stacks are covered in Chapter 7.

FIGURE 4: Light vehicle ownership per 1,000 people since 2000



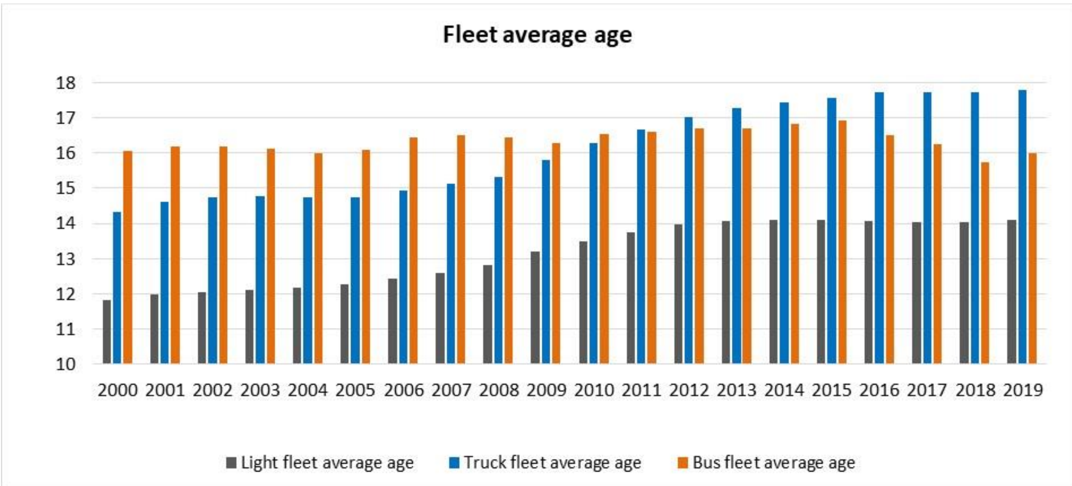
Source: MoT (2020)

FIGURE 5: Growth in vehicle travel since 2001



Source: MoT (2020)

FIGURE 6: National fleet average ages since 2000



Source: MoT (2020)

3.1.2 Which air pollutants are emitted?

The primary pollutants emitted from on-road transport include:

- CO, VOCs, and NO_2 from vehicle exhaust
- PM from vehicle exhaust, typically $PM_{2.5}$ and much smaller
- PM from brake and tyre wear, typically $PM_{10\text{-}2.5}$, which can also include metals such as copper, iron and zinc
- CO_2 from fuel combustion.

On-road transport also generates dust from abrasion of the road surface (typically $PM_{10\text{-}2.5}$) which is discussed in Chapter 7.

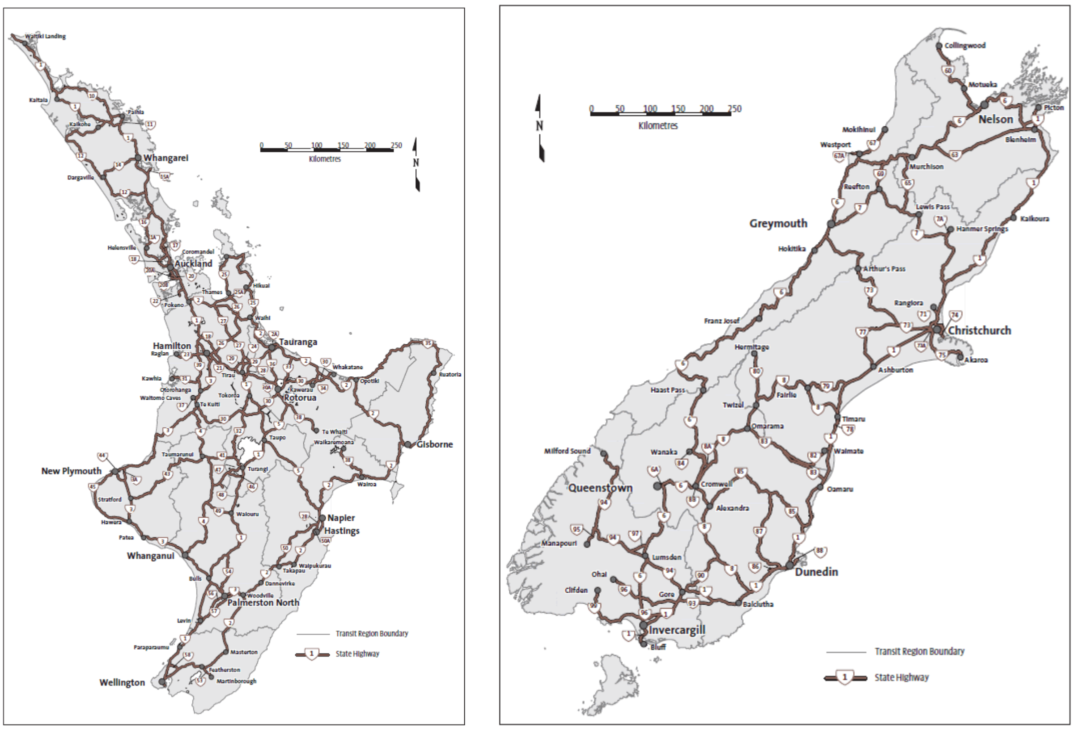
Note: Lead and SO_2 used to be critical pollutants of concern associated with emissions from motor vehicles. However, improvements in petrol and diesel fuel quality starting in 1995 have significantly reduced on-road emissions of these pollutants as evidenced by improvements in ambient air levels (ARC 2010).

Ironically, the decision to make New Zealand's petrol fully unleaded in 1996 initially increased air emissions of benzene (a Group 1 human carcinogen) and other aromatics because they were used in the place of lead as octane enhancers. However, the fuel specifications for these compounds were also tightened reducing the benzene content in petrol in stages from 4% to 3% in 2004, then down to a maximum of 1% in 2006. Ambient levels are no longer elevated in comparison with risk criteria (Wickham *et al* 2017).

3.1.3 Where are the emissions?

Roads are ubiquitous – they traverse our urban and rural settlements and cover the length and breadth of New Zealand (see Figure 7). The length of road per person in New Zealand is one of the highest in the world (NZTA 2021b).

FIGURE 7: The New Zealand state highway network in 2010



Source: OAG (2010)

The state highway network comprises just over 11,000 kilometres of road, with 5,981 km in the North Island and 4,924 km in the South Island. It provides a vital link to almost 83,000 km of local roads – 17,298 km urban and 65,601 km rural. Table 3 summarises the key parameters for the New Zealand public road system.

TABLE 3: The New Zealand public road system

PARAMETER	LOCAL ROADS	STATE HIGHWAYS
Total length	83,000 km	11,000 km
Sealed	61%	100%
Urban : Rural	20% : 80%	-
Responsibility	Local authorities	Transport Agency

Source: NZTA (2021b)

3.1.4 What is the current state of the impact?

On-road transport is estimated to contribute between 71% and 98% of pollutant emissions from all domestic transport sources in New Zealand, except for SO_2 which is dominated by shipping (Kuschel *et al* 2021). Table 4 presents the estimates of on-road emissions for 2018/19.

Note: Road dust generated by on-road transport travelling on sealed and unsealed roads is assigned to transport infrastructure in Chapter 7.

TABLE 4: Emissions from on-road vehicles in New Zealand in 2018/19

EMISSIONS (TONNES)	CO	VOC	NO_X	SO_2	PM_{10} exh	PM10 b&t	CO_2e
Urban	46,733	4,459	17,477	18	707	374	6,127,795
Rural	73,225	7,018	32,303	30	1,308	647	10,581,846
NZ Total	**119,959**	**11,477**	**49,780**	**48**	**2,016**	**1,021**	**16,709,640**

Source: Kuschel *et al* (2021)

Note: exh = exhaust emissions, b&t = brake and tyre emissions
CO_2e emissions shown include upstream (well-to-wheel) as well as downstream (tank-to-wheel) emissions.

The emissions in Table 4 are multiplied by the damage costs from Table 1 to arrive at the estimated social costs (covering both public health and lost productivity) shown in Table 5. As highlighted by the shaded cells, most of the estimated social costs for on-road emissions are associated with CO_2, followed by PM_{10} and NO_X.

TABLE 5: Social costs due to on-road vehicle emissions in New Zealand in 2018/19 (NZ$M at June 2019)

COSTS ($M)	CO	VOC	NO_X	SO_2	PM_{10} exh	PM10 b&t	CO_2e
Urban	0.2	6.4	313	0.6	356	188	539
Rural	0.0	0.8	44	0.1	50	25	931
NZ Total	**0.2**	**7.2**	**357**	**0.7**	**406**	**213**	**1,470**

Source: Kuschel *et al* (2021)

3.2 TRENDS

3.2.1 Emissions

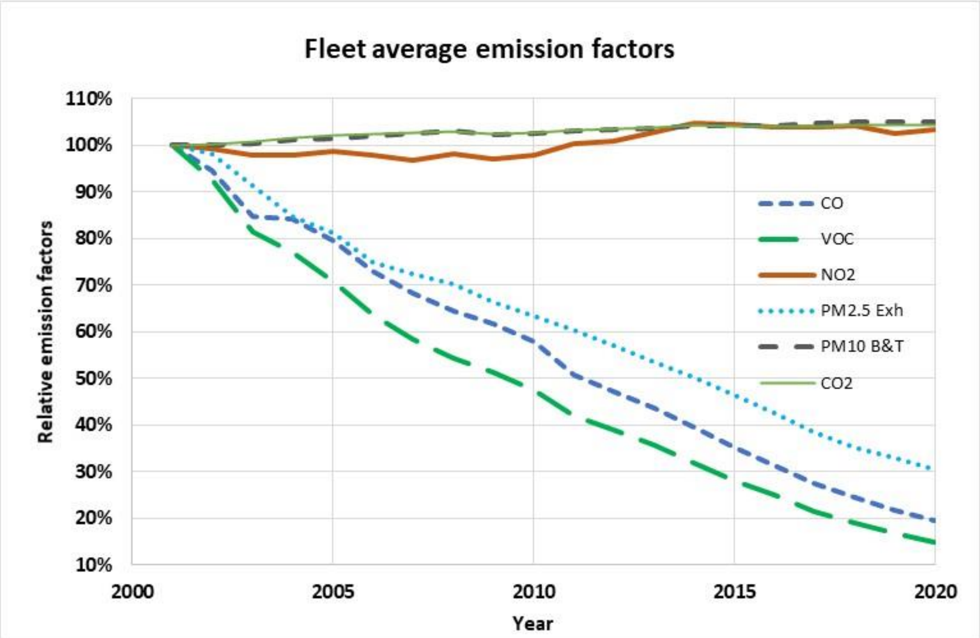
Harmful emissions per driven kilometre (g/km) have reduced appreciably for many pollutants due to the introduction of emissions standards and improvements in vehicle fuel quality.

Figure 8 shows the change in average harmful emission factors for the New Zealand fleet relative to 2001 estimated from the Vehicle Emissions Prediction Model (**VEPM**) developed by Waka Kotahi and Auckland Council (NZTA 2020b). This model (VEPM6.1) predicts significant improvements in fleet average CO, VOC and exhaust $PM_{2.5}$ between 2001 and 2020 but shows plateauing and possible increases for NO_2 and brake and tyre wear PM_{10}. Predicted average CO_2 emissions also increase[7].

Note: Internationally, real-world emissions have been found to be significantly higher than the regulatory limits, especially for NO_X and CO_2 (ICCT 2017). The New Zealand model VEPM6.1 utilises factors developed from international emissions testing, which factors in some influence of real-world behaviour but likely under-estimates the full impact.

Real-world testing has been undertaken in New Zealand on a small number of typical vehicles (Kuschel *et al* 2019) but comprehensive validation of VEPM remains a gap. Waka Kotahi have funded a research project - *Improving our understanding of New Zealand's vehicle fleet greenhouse gas and harmful emissions using measured emissions data* –to inform this, with results from Stage 1 due early 2022.

FIGURE 8: Change in fleet average emissions factors for different pollutants (as predicted by VEPM6.1)



Source: Using VEPM6.1 factors from NZTA (2020b)

The trends in average emissions combined with significant growth in overall vehicle kilometres travelled (**VKT**) mean on-road emissions have significantly increased for CO_2, NO_2, and brake and tyre wear PM_{10}.

[7] Post the stocktake being undertaken in June 2021, Waka Kotahi released a new version of VEPM – VEPM 6.2 (NZTA 2021e). While revisions were made to some of the individual emission factors in the model, the trends shown in Figure 8 for fleet average emission factors are still valid.

Greenhouse gases

As shown in Table 6, road transport CO_2e emissions as at end 2019 have nearly doubled (increased by 96%) over 1990 emissions. This growth accounts for most of the overall growth seen in total transport GHG emissions, shown shaded.

TABLE 6: Total reported greenhouse gas emissions (CO_2e) for transport-related sectors in New Zealand

SECTOR ID	SECTOR	1990	2019	CHANGE
1.A.3	**Transport Total**	**8,772**	**16,208**	**+85%**
1.A.3.a	Aviation	948	1,024	+8%
1.A.3.b	Road	7,475	14,670	+96%
1.A.3.c	Rail	88	141	+61%
1.A.3.d	Domestic shipping	256	332	+30%
1.A.4.c.ii	**Off-road vehicles**	**970**	**1,018**	**+5%**

Source: MfE (2021)

Notes: (1) CO_2e emissions shown here are downstream (tank-to-wheel) only emissions. (2) Emissions from off-road vehicles are shown in bold above as they are reported separately to Transport total emissions.

Nitrogen dioxide

NO_2 from on-road vehicles is of increasing health concern. As discussed in Chapter 1, studies have found stronger associations of long-term exposure with mortality (respiratory, cardiovascular and all cause) as well as for lung carcinogenicity (WHO 2013). Per vehicle NO_2 emissions have not reduced appreciably in recent years despite tightening emissions standards. Increased vehicle engine sizes, greater dieselisation of the fleet and manufacturers cheating on emissions compliance in Dieselgate[8] have all contributed to increased NO_2 emissions.

Despite being mandatory in Europe from September 2015, New Zealand is yet to require Euro 6/VI emissions standard for new vehicles entering the fleet. Once adopted here, this development will significantly improve per vehicle NO_2 emissions for vehicles coming into the fleet. However, scrappage rates for LPVs are currently only 5.0% and for LCVs even lower at 2.9% (MoT 2020) so at current rates an appreciable change in average light vehicle emissions could take 20 years or longer.

Note: The rate of uptake of electric vehicles (**EVs**) is definitely accelerating. However, the current numbers of EVs are still very low (just over 14,000 light vehicles as at end 2019) relative to those using internal combustion engines (just over 4 million) (MoT 2020). EVs will assist with addressing NO_2 but, as with other fleet improvements (e.g. Euro 6), a significant improvement in the average light vehicle emissions will take time. Initiatives are also underway to decarbonise the public transport bus fleet by 2035[9].

PM from brake and tyre wear

As seen in Figure 8, significant improvements have occurred in average per vehicle PM exhaust emissions, but PM brake and tyre wear emissions have increased slightly.

[8] Dieselgate is also known as the Volkswagen emissions scandal but other manufacturers were involved.

[9] https://www.transport.govt.nz/area-of-interest/environment-and-climate-change/public-transport-decarbonisation/

Light duty vehicles have been steadily increasing in gross vehicle mass (GVM) – in particular due to a dramatic rise in popularity of LCVs (e.g. double cab utes) over passenger cars. The rules for heavy duty trucks have changed to permit high productivity motor vehicles to operate above the previous 44 tonne weight limit. The rules for heavy duty buses have also changed to enable double decker and electric buses to operate at weights above what was previously allowed. While electric vehicles release no exhaust PM, they still generate brake and tyre wear PM emissions. These changes, plus likely weight increases associated with further electrification of the road fleet, will result in PM brake and tyre wear emissions eventually dominating all on-road PM and potentially increasing in future (Smit 2020).

Internationally, the contribution of non-exhaust PM (covering both brake and tyre wear and road dust) to total PM from vehicles has risen considerably. Unlike exhaust emissions, non-exhaust emissions are currently unregulated.

In response, the Organisation for Economic Co-operation and Development (**OECD**) released a report in 2020 specifically addressing (OECD 2020):

- What are the causes and impacts of non-exhaust emissions?
- What is the current situation and how will it evolve with the uptake of electric vehicles?
- How should policymakers address non-exhaust emissions?

The authors conclude **there is a need for immediate policy action to reduce non-exhaust emissions** and mitigate their consequences for public health. However, the lack of robust understanding of many aspects of non-exhaust emissions currently hampers development of effective and efficient mitigation measures. They identify that minimising the risk will hinge on advancing the state of knowledge on non-exhaust emissions in critical areas - including their magnitude, better characterisation of their impacts and the effectiveness of mitigation measures. Further research will also be necessary in order to better separate the contributions from road dust resuspension, brake and tyre wear, and road wear, given that their relative toxicity for human health and the potential need for regulations to address them are likely to be different (OECD 2020).

Toxicological findings regarding non-exhaust emissions vary considerably in the published literature. In studies focussing on brake pad PM alone, a recent study suggests the toxicity of brake wear $PM_{2.5}$ on lung alveolar cells is mainly related to copper content (Figliuzzi *et al* 2020). However, an earlier study found no adverse effect for brake pads with low metallic content but significant effects for non-asbestos organic formulated pads (Barasova *et al* 2018).

A review of the human health risk associated with street dust (a category which includes PM from brake and tyre wear as well as road surface dust) found significant variability in measured concentrations of heavy metals in cities worldwide (Aguilera *et al* 2021). However, differences in sampling and analysis techniques made comparisons between locations difficult. Lead and zinc were identified as the heavy metals most commonly found at elevated levels in cities, but these are not emitted from transport sources exclusively as they are also generated by industry. The authors recommend a set of guidelines to improve the robustness of street dust sampling and analyses.

Regardless of composition, it is well established that non-exhaust PM in the smaller size fractions can cause adverse health effects and needs to be mitigated.

Note about COVID-19 impact: Traffic volumes across New Zealand dropped appreciably during the COVID-19 lockdown in 2020. While travel undertaken by private, commercial and freight vehicles has since recovered, public transport patronage remains depressed. For example, Auckland public transport patronage in February 2021 is still only 53% of that for February 2020 (AT 2021). However, the decline in public transport is a worldwide phenomenon. Up to one-third of people in some cities worldwide have stopped using public transport because of the COVID-19 pandemic (Moovit 2021).

3.2.2 Concentrations

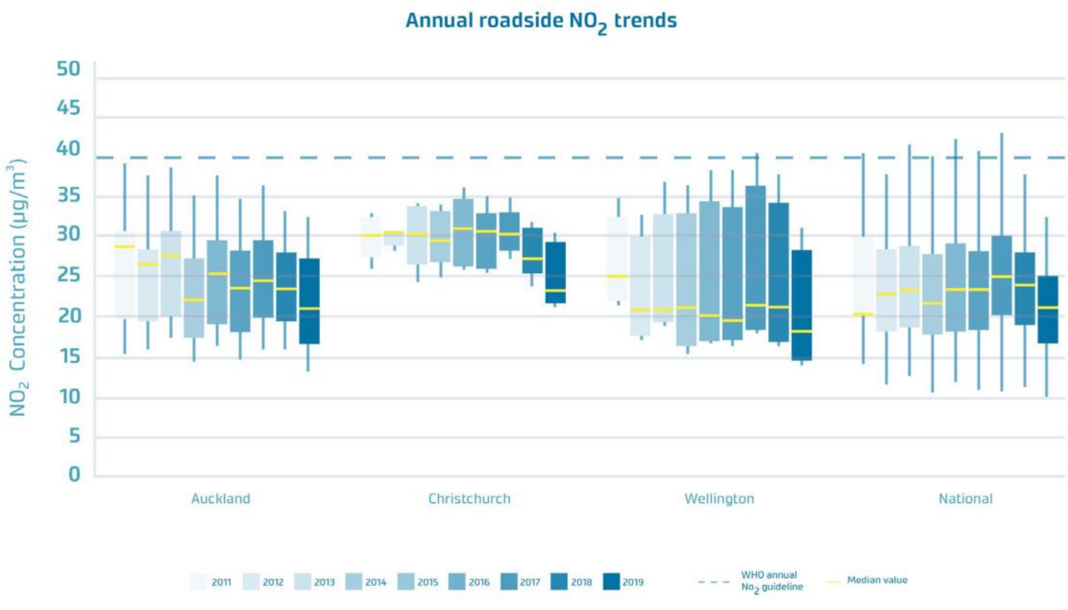
Regional councils monitor air quality in their regions to demonstrate compliance with the national environmental standards for air quality (**NESAQ**). Several councils operate sites that are located near roads, for example Takapuna in Auckland, Willis Street in Wellington and Riccarton Road in Christchurch. Monitoring data at roadside sites across New Zealand show annual PM_{10} concentrations have been decreasing but are now levelling off (LAWA 2021). The trend for $PM_{2.5}$ concentrations is less clear.

Nitrogen dioxide

In 2007, Waka Kotahi established a national ambient air quality network to monitor state highways relative to local roads and background sites. The air quality network adopts NO_2 as a proxy for all motor vehicle pollutants and uses passive samplers[10] to measure concentrations. Passive samplers are a relatively cheap and easy way to measure NO_2 in multiple locations, but they are not as accurate as reference monitoring methods (which are used to assess compliance with ambient air quality standards and guidelines). This means the ability to robustly assess NO_2 exposure in New Zealand is currently limited.

Regardless, passive samplers are useful for assessing trends. The latest monitoring report shows annual concentrations have improved at state highway sites in Auckland, Wellington and Christchurch since 2011 but remain somewhat static overall (see Figure 9). The dashed line in the figure is the annual average NO_2 guideline set by the World Health Organisation (**WHO**) in 2006. In September 2021, WHO reduced this guideline[11] to 10 µg/m^3.

FIGURE 9: Trends in NO_2 concentrations measured at state highway sites 2011-2019



Source: NZTA (2020c)

[10] The passive samplers used by Waka Kotahi are diffusion tubes which, when exposed, react with polluted air. They are deployed at a location for a month then subsequently analysed in a laboratory to provide monthly average concentrations.

[11] https://www.who.int/news/item/22-09-2021-new-who-global-air-quality-guidelines-aim-to-save-millions-of-lives-from-air-pollution

There is emerging evidence that the exposure-response relationships (**ERF**s) for air pollution exposure may be higher at low doses – known as a **supra-linear dose response**[12] (Papadogeorgou *et al* 2019, Chen & Hoek 2020, Yazdi *et al* 2021). Across New Zealand, the population-weighted 2016 annual average for $PM_{2.5}$ is 6.5 µg/m^3 and for NO_2 is 7.8 µg/m^3. These concentrations are well below current New Zealand ambient air quality guidelines or standards – 10 µg/m^3 for $PM_{2.5}$ and 40 µg/m^3 for NO_2 - but do not mean there will be no adverse effects.

Note: As mentioned earlier, in September 2021 WHO reduced the annual NO_2 guideline to 10 µg/m^3. WHO also reduced the annual $PM_{2.5}$ guideline from 10 µg/m^3 to 5 µg/m^3. The Ministry for the Environment is currently reviewing the implications of the latest WHO evidence as part of a review of the National Environmental Standards for Air Quality[13].

PM from brake and tyre wear

Little research has been undertaken in New Zealand to characterise PM from brake and tyre wear. GNS Science has analysed PM samples collected in Auckland between 2006 and 2016 to investigate non-exhaust PM collectively (covering road dust as well as brake and tyre wear). Their results, using elemental copper as a preliminary marker for brake wear emissions, showed statistically significant increases in concentrations at most road sites in Auckland since 2006, consistent with increases in daily traffic flows (Davy & Trompetter 2019).

In late 2020, Waka Kotahi commissioned a research project (TAR 19/17) – *Determining the ecological and air quality impacts of particulate matter from brake and tyre wear and road surface dust*. The research is being undertaken by NIWA, with Stage 1 (the literature review) due to be released by the end of 2021. More sophisticated markers or elemental fingerprints need to be developed to improve our understanding of all the different components of non-exhaust PM. GNS Science holds an archive of PM samples that have been collected from approximately 40 regional council monitoring sites across New Zealand. Stage 2 of the NIWA research will look at analysing these to develop a comprehensive picture of trends.

Note: PM from road dust (sealed and unsealed) is considered separately in Chapter 7 of this report.

3.2.3 Exposure

As at March 2020, the New Zealand population was estimated to be 5,002,100 people. While New Zealand's population density is low compared to most countries, more than 86.6% of New Zealanders live in urban areas or cities (StatsNZ 2020).

Auckland is currently home to just over one-third of New Zealand's population (34%). By 2048, it could make up 37% (StatsNZ 2021a). Children and the elderly are particularly susceptible to the effects of air pollution. More than one third of all children and more than a quarter of the elderly (65 years and over) live in Auckland and these proportions are projected to increase over time.

[12] Dose-response relationships can take many forms. They can be linear (where the slope of the response is constant), supra-linear (where the slope is steeper at low concentrations then flattens at higher concentrations), s-shaped or even a step change. Several harmful air pollutants – notably $PM_{2.5}$ and NO_2 – have shown evidence for supra-linear dose responses.

[13] https://environment.govt.nz/acts-and-regulations/regulations/national-environmental-standards-for-air-quality/

Auckland may have 2 million residents by the early 2030s, but that milestone may come earlier or later depending on levels of migration over the coming years. Accommodating this growth will require more intensification, particularly around transport corridors. This will bring more people potentially into contact with motor vehicle emissions. Other urban areas across New Zealand are also experiencing steady growth and intensification.

3.3 RISKS TO PUBLIC HEALTH

3.3.1 What is the likely risk posed by on-road transport emissions?

The likely risk posed to public health from on-road transport emissions is **currently high** and is likely to **remain high** in future because:

- The road network is ubiquitous, with many people living within 200 m of a major road.
- While emissions of some pollutants have reduced, many improvements have been offset by population growth and intensification along transport corridors.
- There is increasing concern about health effects associated with long-term exposure to NO_2 and $PM_{2.5}$, even at the low levels we see in New Zealand.
- Vehicles are getting heavier, with larger engines and we are travelling more each year.
- Neither EVs (currently only 1.7% of the fleet) or cleaner vehicles (e.g. Euro 6 which is yet to be mandated in New Zealand) are likely to make much impact in the immediate future while our fleet turnover is 5.0% or less per annum.

Table 7 summarises the qualitative public health risk assessment for on-road emissions (overall).

TABLE 7: Qualitative risk assessment for on-road emissions overall

PARAMETER	CURRENT	LIKELY FUTURE
Emissions/concentrations	Moderate (M)	Moderate (M)
Spatial coverage	Widespread (H)	Widespread (H)
Population exposed	Many (M)	Many to most (M-H)
Exposure duration	Long-term (H)	Long-term (H)
Public health risk rating	**High**	**High**

3.3.2 What are the key gaps in our understanding?

The two key gaps in our understanding of public health impacts associated with on-road emissions in New Zealand are:

> **Gap #1**: What are the current health impacts of New Zealanders being exposed to on-road NO_2 emissions and are they improving?

The findings of HAPINZ 3.0 (pending) will assist in bettering our understanding of current health impacts but more work will need to be done to develop effective management strategies. Given that NO_2 has been widely used as a proxy for on-road transport emissions in New Zealand and overseas, care will need to be taken to ensure that policies focussing on reducing NO_2 do not miss addressing other pollutant/s of concern.

Gap #2: Which factors and trends most influence on-road PM brake and tyre wear emissions?

Stage 2 of the Waka Kotahi *Determining the ecological and air quality impacts of particulate matter from brake and tyre wear and road surface dust project* will provide some valuable information about the elemental composition of these emissions but further work will likely be needed on the factors and trends –to inform management strategies.

4. RAIL

This chapter reviews the state, trends and public health risks associated with air emissions from rail transport in New Zealand. Rail locomotives are used for freight transport, long-distance passenger rail and urban public transport.

4.1 CURRENT STATE

4.1.1 What are the key features of this sector?

Key features of the New Zealand rail fleet are:

- **Rail freight is carried by predominantly diesel** locomotives in both islands of New Zealand, with some freight carried by electric locomotives on the main trunk line in the North Island.
- **Long-distance inter-regional passenger** rail is also serviced by diesel locomotives.
- **Urban public transport rail** (Auckland and Wellington only) is largely electric. An analysis of Auckland passenger rail movements in 2014 found these comprised more than 95% of total rail movements in the urban area (EIL 2014).

4.1.2 Which air pollutants are emitted?

The primary pollutants emitted from rail transport include:

- CO, VOCs, and NO_2 from locomotive exhaust
- PM from locomotive exhaust, typically $PM_{2.5}$ and much smaller
- CO_2 from fuel combustion.

Rail transport also generates dust from abrasion of the railway tracks (typically $PM_{10-2.5}$) but this is discussed in Chapter 7.

Note: Successive improvements in diesel fuel quality have dramatically reduced rail transport emissions of sulphur dioxide (the sulphur level in diesel was reduced to near zero, only 10 ppm, in 2009).

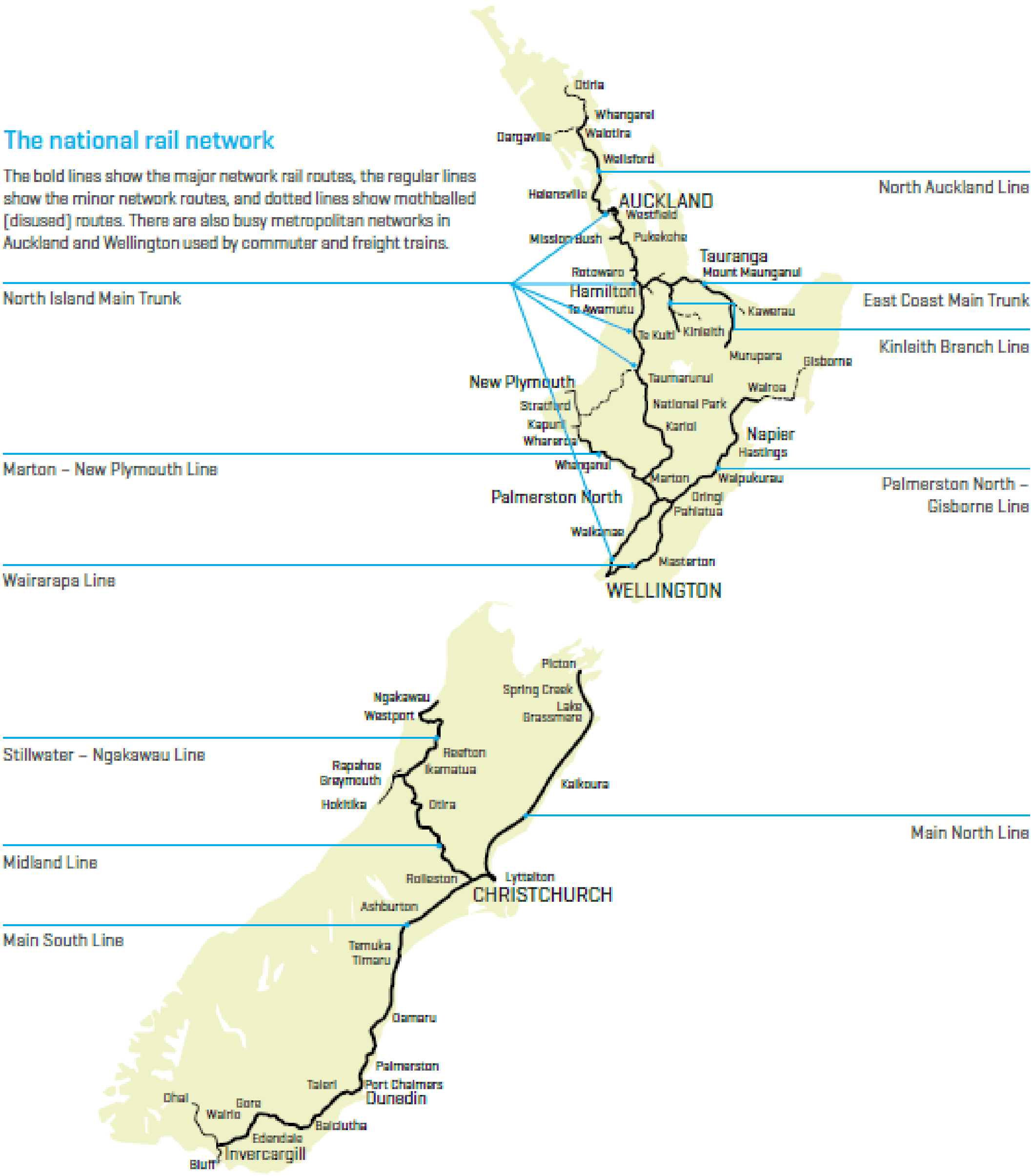
4.1.3 Where are the emissions?

The railway network in New Zealand consists of four main lines (1,842 km), six secondary lines (1,339 km) and numerous short branch lines in almost every region (see Figure 10). It links all major urban centres except Nelson, Taupo, Queenstown, Whakatane and (since 2012) Gisborne. The network is owned and managed by KiwiRail.

KiwiRail operates all freight and a small number of passenger services primarily for tourists on certain routes in both islands.

Transdev operates Auckland Transport AT Metro suburban passenger trains in Auckland and Metlink passenger trains in the Wellington region. Dunedin Railways (formerly Taieri Gorge Railway) operates tourist passenger trains in Dunedin.

FIGURE 10: The New Zealand rail network in 2021



Source: MoT (2021b)

4.1.4 What is the current state of the impact?

Rail is estimated to contribute between 1% and 5% of pollutant emissions from all domestic transport sources in New Zealand (Kuschel *et al* 2021). Table 8 presents the estimates of rail emissions for 2018/19, with the majority (more than 95%) coming from diesel freight locomotives.

The emissions in Table 8 are multiplied by the damage costs from Table 1 to arrive at the estimated social costs (covering both public health and lost productivity) shown in Table 9. As highlighted by the shaded cells, most of the estimated social costs for rail emissions are associated with CO_2 and NO_X, followed by PM_{10}.

TABLE 8: Emissions from rail in New Zealand in 2018/19

EMISSIONS (TONNES)	CO	VOC	NO_X	SO_2	PM_{10} exh	CO_2e
Urban	150	44	550	0	12	42,735
Rural	573	153	2,007	1	38	120,036
NZ Total	**723**	**197**	**2,556**	**1**	**50**	**162,771**

Source: Kuschel *et al* (2021)

Note: exh = exhaust emissions, CO_2e emissions shown include upstream (well-to-wheel) as well as downstream (tank-to-wheel) emissions.

TABLE 9: Social costs due to rail emissions in New Zealand in 2018/19 (NZ$M at June 2019)

COSTS ($M)	CO	VOC	NO_X	SO_2	PM_{10} exh	CO_2e
Urban	0.0	0.1	10	0.0	6.2	3.8
Rural	0.0	0.0	2.7	0.0	1.5	11
NZ Total	**0.0**	**0.1**	**13**	**0.0**	**7.6**	**14**

Source: Kuschel *et al* (2021)

4.2 TRENDS

4.2.1 Emissions

The recently released *New Zealand Rail Plan 2021* signals the intention to move more people and freight onto rail to meet the emissions targets proposed by the Climate Change Commission, reduce congestion and improve road safety (MoT 2021b).

At present, freight carried by rail saves at least 70% of the CO_2 emissions compared to heavy road transport, so each tonne of freight that moves from road to rail makes an appreciable difference to New Zealand's carbon footprint. By 2052, freight tonnage in New Zealand is expected to increase by more than 40% and the rail network will play a role in supporting this growth. Only the section of the North Island Main Trunk (**NIMT**) between Hamilton and Palmerston North is currently electrified. However, other high-volume routes, such as the remainder of the NIMT between Auckland and Wellington and the East Coast Main Trunk (**ECMT**) between Auckland and Tauranga, have been flagged as future potential candidates.

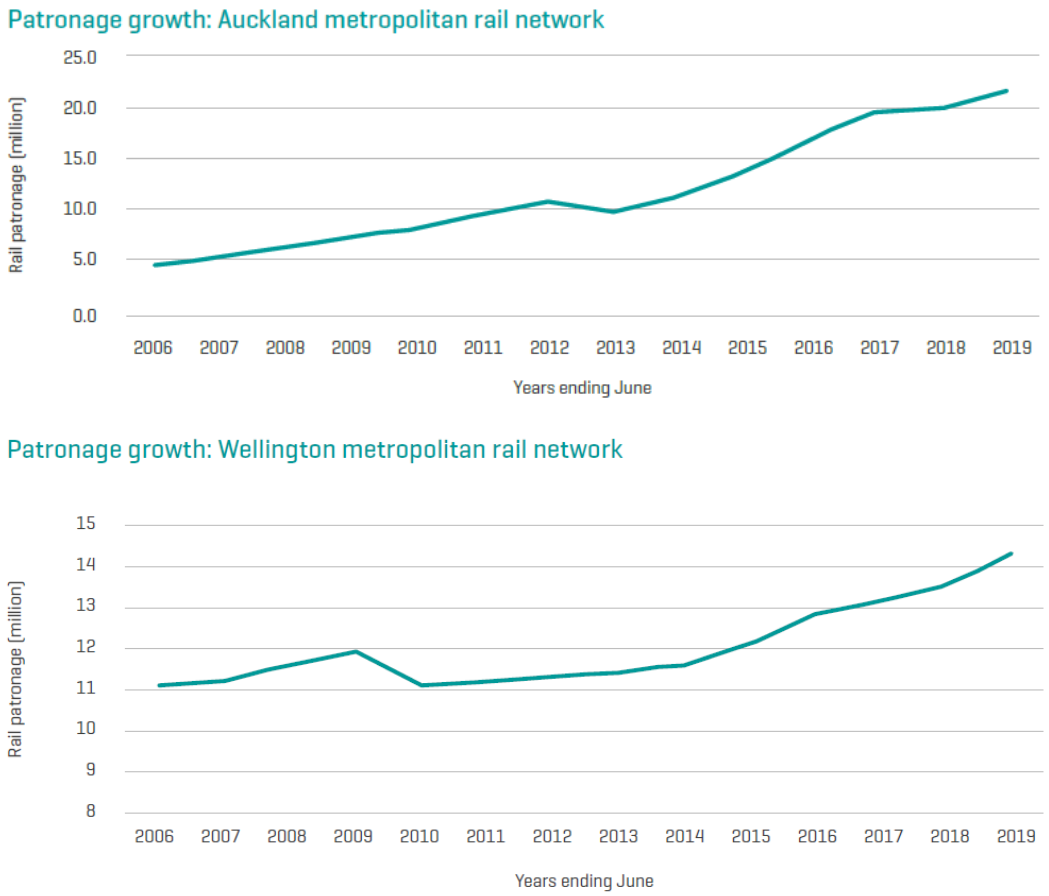
Key rail freight projects underway include:

- Further work on the North Auckland Line to increase freight capacity into Northland
- Construction of the Third Main Line Wiri to Quay Park, due for completion in 2024.

For inter-regional passenger transport, the most recent development is the opening on 6 April 2021 of a new inter-regional passenger service between Hamilton and Auckland (Te Huia). Additional inter-regional routes have been mooted but none is currently scheduled.

Both Auckland and Wellington have seen unprecedented growth in passenger rail transport over the last decade (see Figure 11).

FIGURE 11: Rail patronage growth in Auckland and Wellington



Source: MoT (2021b)

The most significant urban passenger rail project pending is the Central Rail Loop (**CRL**) project in Auckland. This is New Zealand's largest public transport infrastructure project – a $4.4 billion investment jointly funded by Auckland Council and the Crown. CRL is currently under construction and is scheduled to open in late 2024. When operational, it will double capacity on the Auckland rail network, carrying up to 54,000 passengers an hour at peak times through the CRL tunnel. This is the equivalent of three Auckland Harbour Bridges or 16 extra traffic lanes into the city at peak times.

Other urban rail projects include:

- Electrification of the Papakura to Pukekohe line
- Upgrades to the Wellington and Auckland metropolitan networks to increase capacity

Note about COVID-19 impact: Rail volumes across New Zealand also experienced a drop during the COVID-19 lockdown in 2020. As discussed in Chapter 2, rail freight travel has largely recovered but passenger rail services (especially tourist trains such as the TranzAlpine) are still down on historical levels.

4.2.2 Concentrations

Relative to roads, rail transport in New Zealand does not significantly impact ambient air quality.

Recently, poor rail tunnel air quality in Wellington made the news after elevated levels of nitrogen dioxide in the Remutaka Tunnel resulted in passengers on the Capital Connection having to be bussed around (rather than travel through) the tunnel[14]. This issue is related to transport infrastructure (tunnels) so is discussed further in Chapter 7.

4.2.3 Exposure

Current trends show increased intensification of urban areas across most of New Zealand, particularly around transport corridors in major cities. Consequently, more people will be exposed to rail emissions in future. However, the impact is likely to be minimal.

This is because most of the rail movements undertaken in urban environments (where most people live) are by urban passenger trains that are now essentially fully electric with no harmful emissions. Although significant future growth is predicted for rail freight which still relies on diesel locomotives on many lines, the rail network is a lot less dense than the road network and the travel tends to be inter-regional so population exposures will still be relatively minor.

4.3 RISKS TO PUBLIC HEALTH

4.3.1 What is the likely risk posed by rail emissions?

The likely risk posed to public health from rail transport emissions is **currently low** and is likely to **remain low** in future because:

- The rail network is sparse, thereby limiting opportunities for exposure.
- Urban passenger services are essentially fully electric.
- Freight movements are typically long-distance, with much of the journey traversing minimally populated areas.

Table 10 summarises the qualitative public health risk assessment for rail emissions (overall).

TABLE 10: Qualitative risk assessment for rail emissions overall

PARAMETER	CURRENT	LIKELY FUTURE.
Emissions/concentrations	Low (L)	Low (L)
Spatial coverage	Narrow corridors (M)	Narrow corridors (M)
Population exposed	Few (L)	Few (L)
Exposure duration	Long-term (H)	Long-term (H)
Public health risk rating	**Low-Med**	**Low-Med**

4.3.2 What are the key gaps in our understanding?

There are **no obvious gaps** that need addressing currently for the public health risks associated with rail emissions in New Zealand.

[14] https://www.stuff.co.nz/dominion-post/news/wairarapa/125045382/passengers-put-on-bus-after-poisonous-gases-detected-in-remutaka-rail-tunnel

5. MARITIME TRANSPORT

This chapter reviews the state, trends and public health risks associated with air emissions from maritime transport in New Zealand. Maritime transport includes coastal freighters, ocean going vessels, cruise ships, port vessels (tug and pilot boats), ferry boats, commercial fishing vessels as well as recreational boats.

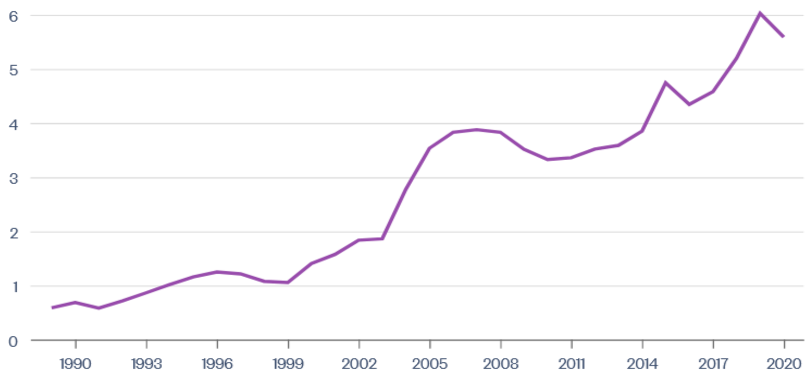
5.1 CURRENT STATE

5.1.1 What are the key features of this sector?

Key features of the New Zealand maritime transport prior to COVID-19 are:

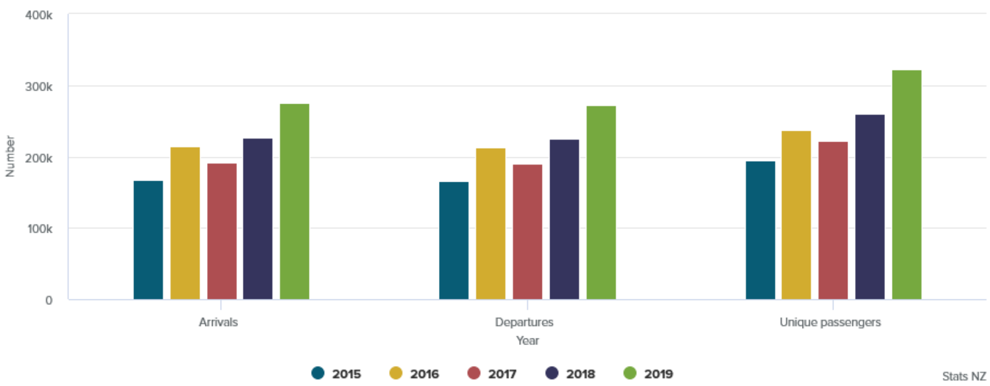
- Strong continued **growth in freight activity** at most ports across New Zealand. Figure 12 shows Port of Tauranga as a typical example.
- Significant **increases in cruise ship visits/passengers** (see Figure 13). Cruise ship passengers visiting New Zealand in the year ended June 2019, were up 24% from 2018 (StatsNZ 2019).
- **High per capita recreational boat use and ownership**. 45% of all New Zealanders partake in boating and we own an estimated 563,932 powered recreational craft (Ipsos 2020).

FIGURE 12: Growth in cargo arriving at Port of Tauranga, year ended June 1989-2020



Source: Figure.nz (2021)

FIGURE 13: Cruise ship passenger counts, year ended June 2015-2019



Source: StatsNZ (2019)

5.1.2 Which air pollutants are emitted?

The primary pollutants emitted from maritime transport include:

- CO, VOCs, NO_2 and SO_2 from ship exhaust
- PM from ship exhaust, typically $PM_{2.5}$ and much smaller
- CO_2 from fuel combustion.

Air emissions are also generated from loading, unloading and fumigation activities at ports but these are considered separate to transport emissions and so are not discussed here.

Note: Annex VI of MARPOL, limiting the sulphur content of maritime fuels, came into force on 1 January 2020. This international treaty has dramatically reduced SO_2 emissions from international vessels, including large container ships, with resulting significant reductions in ambient levels evident at ports around New Zealand. This is discussed in more detail in section 5.2.2.

5.1.3 Where are the emissions?

New Zealand has 13 major seaports handling freight and passenger traffic (see Figure 14). Of these, most are situated in urban areas. The exceptions are Marsden Point, Port Chalmers and South Port which are located more than 2 km from an urban settlement.

FIGURE 14: Locations of main New Zealand seaports

Source: Tenco (2021)

Table 11 shows the number of visits by coastal freighters in 2018/19, indicating the relative activity at each port. The shaded cells indicate the port with the highest activity for that coastal freight type. Picton is not shown as it takes freight in the form of rail locomotives travelling between the North and South Islands on the inter-island ferries.

TABLE 11: Ship visits at ports (by coastal freight type) in 2018/19

PORT	AREA TYPE	NZ CONTAINER	INT'L CONTAINER	NZ BULK/CARGO	NZ TANKER
North Port (Marsden Pt)	Rural	0	0	299	142
Ports of Auckland Ltd	Urban	52	118	121	52
Port of Tauranga	Urban	52	468	78	22
Port of Napier	Urban	0	38	12	9
Port of Taranaki	Urban	0	0	63	2
CentrePort (Wellington)	Urban	0	19	24	11
Port of Nelson	Urban	52	143	57	10
Port of Lyttelton	Urban	52	155	49	13
Port of Timaru	Urban	0	36	83	4
Port Chalmers	Rural	0	56	35	11
South Port (Bluff)	Rural	0	3	5	8
National		**208**	**1,037**	**826**	**284**

Source: Kuschel *et al* (2021)

Note: The ports above are those identified as having substantial movement of *coastal* freight in the *National Freight Demand Study* (MoT 2019). Eastland Port in Gisborne is New Zealand's second largest log exporter but is less significant for coastal freight.

5.1.4 What is the current state of the impact?

Maritime transport (excluding cruise ships and recreational boats) is estimated to contribute between 2% and 5% of most pollutant emissions but **dominates SO_2 emissions (at 79%)** from all domestic transport sources in New Zealand (Kuschel *et al* 2021). Table 12 presents the estimates of maritime transport emissions for 2018/19.

TABLE 12: Emissions from maritime transport (excluding cruise ships and recreational vessels) in New Zealand in 2018/19

EMISSIONS (TONNES)	CO	VOC	NO_X	SO_2	PM_{10} exh	CO_2e
Urban	479	30	932	417	59	77,253
Rural	20	2	55	50	6	916,507
NZ Total	**499**	**32**	**986**	**467**	**64**	**993,760**

Source: Kuschel *et al* (2021)

Notes: (1) The harmful emissions are only for vessels at berth as those at sea are released too far from land to have a discernible impact on urban or rural air quality. (2) SO_2 emissions assume heavy fuel oil contains 2.7% sulphur as at 2018/19. New Zealand was due to become a party to MARPOL Annex VI by the end of 2021 but this was delayed due to COVID-19 disruptions to early 2022. Domestic sulphur fuel reductions will be required shortly after ratification. (3) CO_2e emissions are based on total fuel use and include upstream (well-to-wheel) as well as downstream (tank-to-wheel) emissions.

The emissions in Table 12 are multiplied by the damage costs from Table 1 to arrive at the estimated social costs (covering both public health and lost productivity) shown in Table 13.

As highlighted by the shaded cells, most of the estimated social costs for maritime emissions are associated with CO_2, followed by PM_{10}, NO_X, and SO_2.

TABLE 13: Social costs due to maritime transport emissions (excluding cruise ships and recreational vessels) in New Zealand in 2018/19 (NZ$M at June 2019)

COSTS ($M)	CO	VOC	NO_X	SO_2	PM_{10} exh	CO_2e
Urban	0.0	0.0	17	15	29	7
Rural	0.0	0.0	0	0.1	0	81
NZ Total	**0.0**	**0.0**	**17**	**15**	**30**	**87**

Source: Kuschel *et al* (2021)

5.2 TRENDS

5.2.1 Emissions

Coastal shipping, like rail, offers a lower emissions alternative to road freight so volumes carried by sea are likely to increase in coming years to assist New Zealand to meet its climate obligations.

Regarding international shipping, while the number of ocean-going vessels visiting many ports has dropped, the ships are now larger and air pollution in port areas has been increasing. However, most countries have signed and ratified Annex VI of MARPOL and adopted lower sulphur fuels from 1 January 2020, thereby significantly reducing emissions (of SO_2, which will also reduce formation of secondary particulate). MARPOL limits the sulphur content in maritime fuels to 0.5% (or requires scrubbers to be installed) as well as requiring NO_X controls on vessels built on or after 1 January 2020. Energy efficiency requirements to reduce carbon emissions are due to come into force by 2023. Because almost all ocean-going vessels visiting our ports are registered overseas, these vessels are already required to meet the lower sulphur limits even though New Zealand is yet to ratify Annex VI.

The number of cruise ships visiting New Zealand has significantly increased, with visits to many ports doubling over the last decade. In the year ending June 2019, the New Zealand Cruise Association recorded 176 ship voyages and 981 port calls (including an increasing number of overnights), up from 148 and 707 respectively in the 2018 year (StatsNZ 2019). The ships typically visit during the warmer New Zealand months with most visits in the 1st and 4th quarters of the calendar year. Worldwide, the cruise industry is one of the largest growing sectors in the tourism industry.

Note about COVID-19 impact: As with other sectors, shipping was impacted by COVID-19. Vessels arriving from other countries, such as freight and cruise ships (in particular), were not only subject to tight border controls in New Zealand but also by conditions in their countries of origin.

At time of writing, supply chain issues are still impacting goods arriving by sea and cruise ship visits are not expected to resume until 2022 at the earliest.

5.2.2 Concentrations

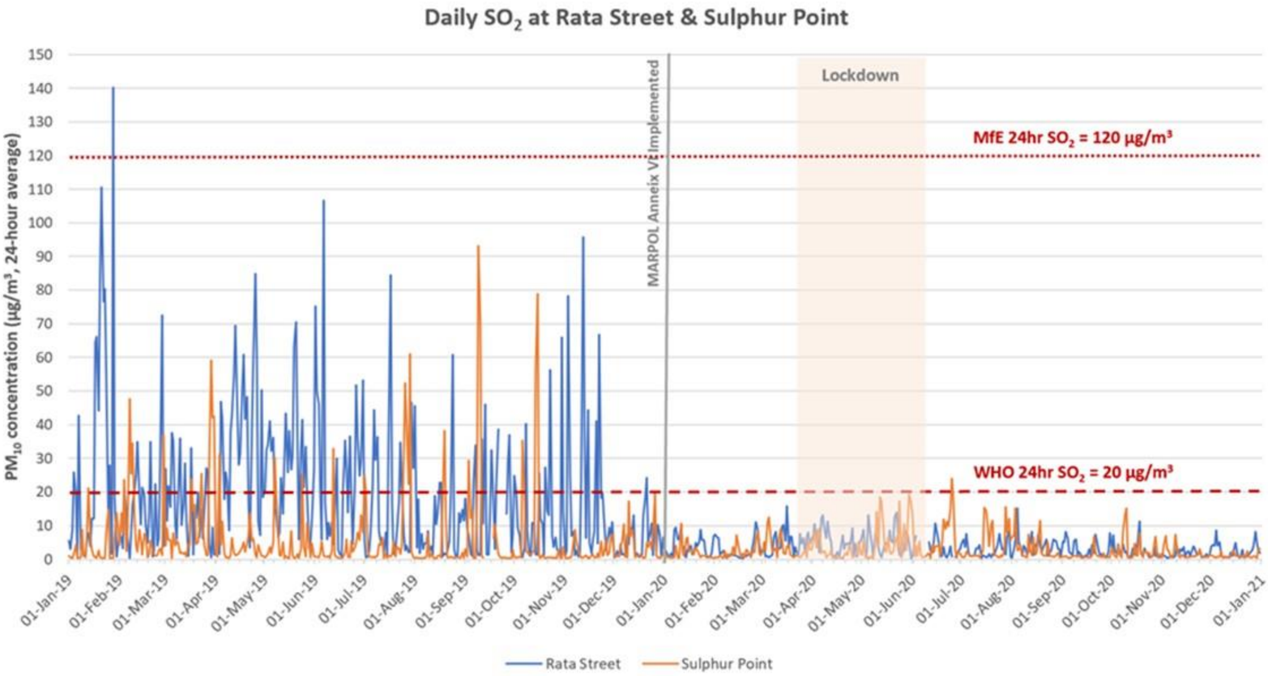
Various air quality monitoring campaigns have been undertaken in or near the Ports of Auckland Ltd starting in 2006 (AC 2017). Elevated levels of SO_2 near the Port of Auckland were first identified in 2007. The port installed an air quality monitoring trailer on site in 2011, which recorded eight exceedances of the 1-hour average SO_2 national environmental standard of 350 µg/m^3 (nine exceedances are permitted) during the 2011 Rugby World Cup. At the time, Auckland was visited by an increased number of vessels, including several cruise ships 'hotelling' at berth. Source apportionment samples collected at Queen Street between 2006 and 2013 were also analysed and found to contain elevated levels of vanadium and nickel (signatures of shipping emissions).

Ports of Auckland commissioned further monitoring in 2018 to establish baseline concentrations prior to Annex VI of MARPOL coming into force internationally (T&T 2020). While SO_2 levels were elevated, no exceedances of the 1-hour average national environmental standard (350 µg/m^3) or New Zealand's 24-hour average guideline (120 µg/m^3) concentrations were recorded. However, 10 exceedances of the WHO 24-hour average guideline (20 µg/m^3) were recorded.

In February 2020, Port Otago announced it would also start to measure air quality at its Port Chalmers base.[15] However, monitoring results are yet to be published and it is possible the campaign has been delayed due to COVID-19.

The most complete, recent dataset available is that for Port of Tauranga. Monitoring has been undertaken by Bay of Plenty Regional Council at multiple locations near the port since late 2018. Figure 15 shows the dramatic reduction in 24-hour average SO_2 concentrations following the implementation of MARPOL Annex VI (Wickham 2021a). The first level 4 national COVID-19 lockdown in New Zealand is also shown but did not result in further significant reductions of SO_2. We anticipate that similar reductions in SO_2 concentrations at other ports across New Zealand would be expected.

FIGURE 15: 24-hour average SO_2 concentrations at Rata Street and Sulphur Point, Mount Maunganui 2019-2020



Source: Wickham (2021a)

5.2.3 Exposure

While many ports have seen significant residential development near their boundaries, the introduction of MARPOL Annex VI fuel improvements in early 2020 has led to significantly reduced exposures to shipping emissions.

[15] https://www.odt.co.nz/news/dunedin/%E2%80%98significant-issues%E2%80%99-prompt-port-measure-air-quality

Note: Air emissions are also generated from loading, unloading and fumigation activities at ports but these are out of scope for this report (which focusses on transport emissions).

5.3 RISKS TO PUBLIC HEALTH

5.3.1 What is the likely risk posed by maritime transport emissions?

The likely risk posed to public health from maritime transport emissions is **currently low** and is likely to **remain low** in future because:

- Ports are located in discrete areas, so exposure is localised.
- MARPOL Annex VI has already proven effective at significantly reducing SO_2 emissions and concentrations at ports.

Table 14 summarises the qualitative public health risk assessment for maritime transport emissions (overall).

TABLE 14: Qualitative risk assessment for maritime transport emissions overall

PARAMETER	CURRENT	LIKELY FUTURE.
Emissions/concentrations	Low (L)	Low (L)
Spatial coverage	Discrete locations (L)	Discrete locations (L)
Population exposed	Few (L)	Few (L)
Exposure duration	Long-term (H)	Long-term (H)
Public health risk rating	**Low**	**Low**

5.3.2 What are the key gaps in our understanding?

There are **no obvious gaps** that need addressing currently for the public health risks associated with maritime transport emissions in New Zealand.

6. AVIATION

This chapter reviews the state, trends and public health risks associated with air emissions from aviation in New Zealand. Aviation includes passenger and freight services, both domestic and international.

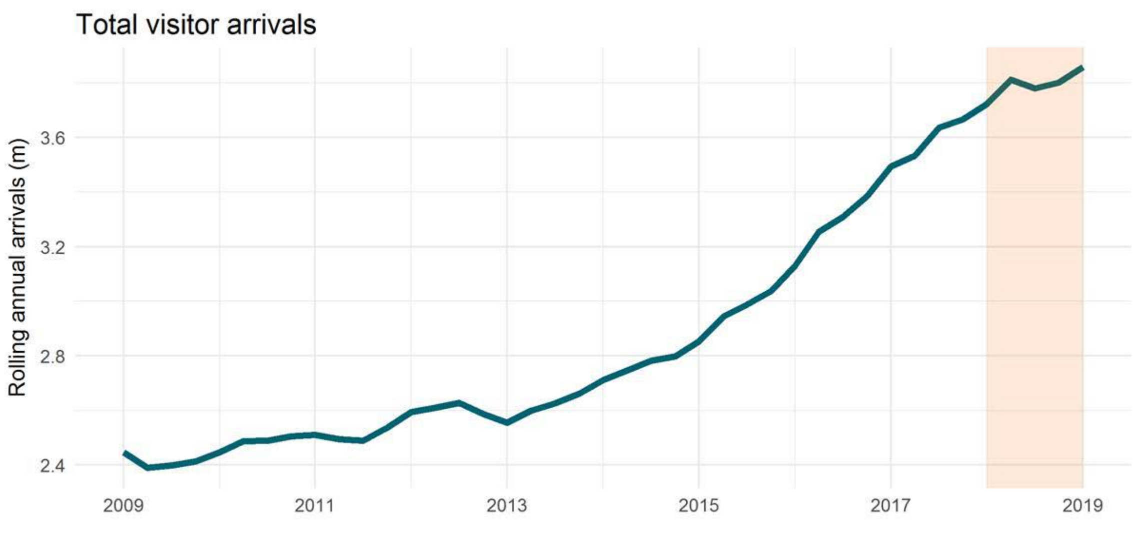
6.1 CURRENT STATE

6.1.1 What are the key features of this sector?

Key features of the New Zealand aviation sector prior to COVID-19 are:

- Strong **growth in international passenger travel** (see Figure 16**)**. Total international passenger movements (arrivals and departures) in 2019 were 14.17 million, up by 25% from 2015 (StatsNZ 2021b). Of the 2019 movements, 74% travelled through Auckland airport.
- Strong **growth in domestic passenger travel**. Auckland airport recorded 9.59 million domestic passenger movements for the year ended June 2019, up by 3.6% from the year ended June 2018 (Auckland Airport 2019).
- Similar strong **growth in air freight**. International air freight through Auckland airport was up 1.6% in year ended June 2019 versus 2018, with domestic air freight increasing by 1.3%.

FIGURE 16: Growth in international visitor arrivals 2009-2019



Source: MBIE (2019)

6.1.2 Which air pollutants are emitted?

The primary pollutants emitted from aviation include:

- CO, VOCs, NO_2 and SO_2 from aircraft exhaust
- PM from aircraft exhaust, typically $PM_{2.5}$ and much smaller
- Lead from small piston engine aircraft which use Avgas, a leaded gasoline fuel
- CO_2 from fuel combustion.

6.1.3 Where are the emissions?

New Zealand has 20 major airports handling freight and passenger traffic (see Figure 17). While only half of these airports are in urban areas (within 2 km of an urban settlement), 78% of aircraft movements occur at airports located in urban areas (Airways Ltd 2021). Except for take-off and landing, however, aircraft emissions are typically emitted at levels elevated well above where people live and breathe.

FIGURE 17: Locations of main New Zealand airports

Source: AirNZ (2021)

Table 15 shows the number of landing and take-off (**LTO**) cycles [16] for 2018/19, indicating the relative activity at each airport. The shaded cells indicate the airports with the highest activity. Timaru and Hokitika are not shown as data were not available.

TABLE 15: Aircraft movements (as LTO cycles) at major regional airports in 2018/19

AIRPORT	AREA TYPE	LTO CYCLES	% OF TOTAL LTO
Auckland	Urban	57,404	25%
Tauranga	Urban	7,192	3.1%
Rotorua	Rural	4,574	2.0%
Christchurch	Urban	34,823	15%
Gisborne	Urban	3,869	1.7%
Napier	Rural	9,255	4.0%
Palmerston North	Urban	8,757	3.8%
Blenheim	Rural	8,348	3.7%

[16] A landing and take-off (LTO) cycle is equivalent to two aircraft movements.

AIRPORT	AREA TYPE	LTO CYCLES	% OF TOTAL LTO
Nelson	Urban	14,196	6.2%
Kerikeri	Rural	1,578	0.7%
Whangarei	Urban	1,762	0.8%
Dunedin	Rural	5,831	2.5%
Queenstown	Urban	6,679	2.9%
Invercargill	Urban	3,420	1.5%
New Plymouth	Rural	6,600	2.9%
Hamilton	Rural	11,776	5.1%
Taupo	Rural	1,688	0.7%
Wellington	Urban	40,938	18%
National		**228,687**	**100%**

Source: Airways Ltd (2021)

6.1.4 What is the current state of the impact?

Aviation (excluding exclusive freight services) is estimated to contribute between 1% and 6% of most pollutant emissions but **13% of SO_2 emissions** from all domestic transport sources in New Zealand (Kuschel *et al* 2021). Table 16 presents the estimates of aviation emissions for 2018/19.

The emissions in Table 16 are multiplied by the damage costs from Table 1 to arrive at the estimated social costs (covering both public health and lost productivity) shown in Table 17. As highlighted by the shaded cells, most of the estimated social costs for aviation emissions are associated with CO_2, followed by NO_X.

TABLE 16: Emissions from aviation (domestic passenger services only) in New Zealand in 2018/19

EMISSIONS (TONNES)	CO	VOC	NO_X	SO_2	PM_{10} exh	CO_2e
Urban	580	74	824	58	3	254,860
Rural	161	21	229	16	1	920,498
NZ Total	**741**	**95**	**1,053**	**75**	**4**	**1,175,358**

Source: Kuschel *et al* (2021)

Notes: (1) The harmful emissions are only for aircraft during take-off and landing as those during cruise are released too high above land to have a discernible impact on urban or rural air quality. (2) CO_2e emissions are based on total fuel use and include upstream (well-to-wheel) as well as downstream (tank-to-wheel) emissions.

TABLE 17: Social costs due to aviation emissions (domestic passenger services only) in New Zealand in 2018/19 (NZ$M at June 2019)

COSTS ($M)	CO	VOC	NO_X	SO_2	PM_{10} exh	CO_2e
Urban	0.0	0.1	15	2.1	1.5	22
Rural	0.0	0.0	0	0.0	0.0	81
NZ Total	**0.0**	**0.1**	**15**	**2.2**	**1.5**	**103**

Source: Kuschel *et al* (2021)

Note: Health effects costs associated with exposure to lead are not included in the above.

6.2 TRENDS

6.2.1 Emissions

Auckland Airport is the primary source of aviation emissions in New Zealand and the best location for showcasing trends. It is the largest airport, handling 21.1 million (11.5 million international and 9.6 million domestic) passengers in the year ended June 2019 (Auckland Airport 2019).

Like ocean-going vessels, planes have increased in size over time. Combined domestic and international passenger movements at Auckland airport have increased by 57% from 2011 to 2019 and freight by 45% but aircraft movements increased by only 16%. The shift towards larger aircraft is particularly evident in domestic travel in 2015 when passenger movements were up 20% over 2011 but aircraft movements actually dropped by 6% (see Figure 18).

FIGURE 18: Growth in passenger, freight and aircraft movements at Auckland airport 2011-2019

Source: Auckland Airport (2021), Auckland Airport (2015)

The trend towards increasing efficiency and productivity is forecast to continue with more airlines opting for larger aircraft (e.g. the Airbus A380 which can carry up to 850 people) to service Auckland.

The International Council for Clean Transportation (**ICCT**) found that although the average fuel consumption of new aircraft improved by 45% between 1968 and 2014, the rate of efficiency improvement varied significantly over time. Average fuel efficiency improved by 2.6% per year during 1980s, while little or no improvement was seen during the 1970s and in the period from 1995 to 2005 (ICCT 2015). More recently, the rate of improvement has returned to historical levels. Despite this progress, manufacturers continue to lag United Nations' fuel efficiency goals for new aircraft. On average, the airline industry is about 12 years behind the 2020 and 2030 fuel efficiency goals established by ICAO, the UN agency that oversees international aviation. This means that emissions (both harmful and greenhouse gas) from aviation are predicted to increase with increasing passenger numbers.

Note about COVID-19 impact: Of all transport sectors, aviation was probably hit the hardest by COVID-19. A review conducted by the International Air Traffic Association (**IATA**) showed passenger demand worldwide in 2020 was down 66%, with international travel down 76%, domestic demand down by 49% and loads falling to 63% relative to 2019 (IATA 2021). As at December 2020, total traffic was 70% below the same month in 2019. IATA's baseline forecast for 2021 is for a 50% improvement on 2020 demand that would bring the industry to 51% of 2019 levels. However, if tight border controls remain to offset the impact of new, more contagious variants of COVID-19, demand improvement could be limited to just 13% over 2020 levels, leaving the industry at 38% of 2019 levels.

At time of writing, quarantine-free air travel was only possible between the Cook Islands and New Zealand.

6.2.2 Concentrations

To date, no air quality monitoring has been undertaken specifically at or near airports in New Zealand. Most of the environmental monitoring has been related to noise. In 2015, Wellington Airport engaged AECOM to undertake an air quality assessment of the proposed runway extension (AECOM 2015). However, this only considered the impact of construction activities – not the operation of the airport itself - and provides no information on existing air quality levels near the airport.

Internationally, an Airport Cooperative Research Program (**ACRP**) was set up in 2003 to assist in solving common operating problems and introducing innovations into the airport industry. The ACRP undertook an extensive review of air quality and public health literature relating to airport emissions in 2015, largely relating to the United States but including a limited number of international studies. The report reviews air quality standards and regulation, airport air quality issues, and provides an overview of air quality health impacts and risk (ACRP 2015). The key findings were:

- Airport contributions to air quality depend on many different factors including airport source types (e.g. aircraft fleet mixes), airport layout and location, geography, and meteorology.
- Fine PM ($PM_{2.5}$) dominates the overall health risks posed by airport emissions but varies significantly between airports.
- Most gases (e.g. CO, NO_2, and SO_2) generated from airports generally tend to result in similar concentrations to background (or urban) levels in surrounding communities.
- Lead is a concern at general aviation airports (civilian airfields that typically do not operate commercially scheduled flights) with smaller private aircraft which use predominantly aviation gasoline (**Avgas**) which has a relatively high lead content. Current studies indicate that lead emissions can persist up to 1,000 m downwind of an airport.

In New Zealand, the major airports are generally located close to the sea or in inland areas that are well-ventilated (i.e. relatively windy).

Large commercial aircraft - jets and turboprops - use Jet A-1 fuel. Jet A-1 is a kerosene type fuel with a maximum sulphur content of 3,000 mg/kg. By comparison, diesel fuel used in on-road vehicles has a maximum sulphur content of only 10 mg/kg.

Small piston engine aircraft in New Zealand use Avgas 100LL, also known as Avgas 100/130 Low Lead. Avgas 100LL is a gasoline fuel with a maximum lead content of 560 mg/l. By comparison, unleaded petrol used in on-road vehicles has a maximum lead content of 5 mg/l.

The movements shown in Table 14 for major airports are for larger commercial aircraft only - data were not available for piston engine aircraft. However, movements by large aircraft are likely to dominate emissions and subsequent concentrations.

6.2.3 Exposure

As mentioned in section 6.1.3, 78% of aircraft movements already occur at airports located in urban areas (Airways Ltd 2021). It is unlikely for the existing urban airports that significant further development will occur, but it is possible for rural airports with pressures on land for housing. In many cases, provisions in local plans are likely to limit the number of people exposed to airport noise and, by association, airport emissions.

However, when (if?) aviation recovers to its previous growth patterns, aircraft emissions and the consequent concentrations may well increase for people already exposed.

6.3 RISKS TO PUBLIC HEALTH

6.3.1 What is the likely risk posed by aviation emissions?

The likely risk posed to public health from aviation emissions is **currently medium** and likely to **remain medium** because:

- Airports are located in discrete areas so exposure is localised. The major airports are generally close to the sea or in inland areas that are well-ventilated (i.e. relatively windy).
- Noise restrictions already limit the number of people in close proximity to the airports (and air emissions) but emissions are projected to increase.
- No air quality monitoring data currently exist to verify a low impact, especially for lead, SO_2 and $PM_{2.5}$ in nearby communities.

Table 18 summarises the qualitative public health risk assessment for aviation emissions (overall).

TABLE 18: Qualitative risk assessment for aviation emissions overall

PARAMETER	CURRENT	LIKELY FUTURE.
Emissions/concentrations	Low to moderate (L-M)	Low to moderate (L-M)
Spatial coverage	Discrete locations (L)	Discrete locations (l)
Population exposed	Few (L)	Few (L)
Exposure duration	Long-term (H)	Long-term (H)
Public health risk rating	**Low-Medium**	**Low-Medium**

6.3.2 What are the key gaps in our understanding?

The key gap in our understanding of public health impacts associated with aviation emissions in New Zealand is:

> **Gap #3**: Is the public health impact from current (and likely future) aviation emissions of lead, SO_2 and $PM_{2.5}$ genuinely low?

Auckland would be a good candidate for a targeted monitoring campaign (post-COVID recovery) as it is home to the largest commercial airport in New Zealand as well as several smaller civilian airfields (such as Ardmore).

7. TRANSPORT INFRASTRUCTURE

This chapter reviews the state, trends and public health risks associated with air emissions from transport infrastructure in New Zealand. Transport infrastructure includes roads (sealed and unsealed), railway tracks, road and rail tunnels and bridges, public transport terminals and depots. Airports and seaports are covered in earlier chapters.

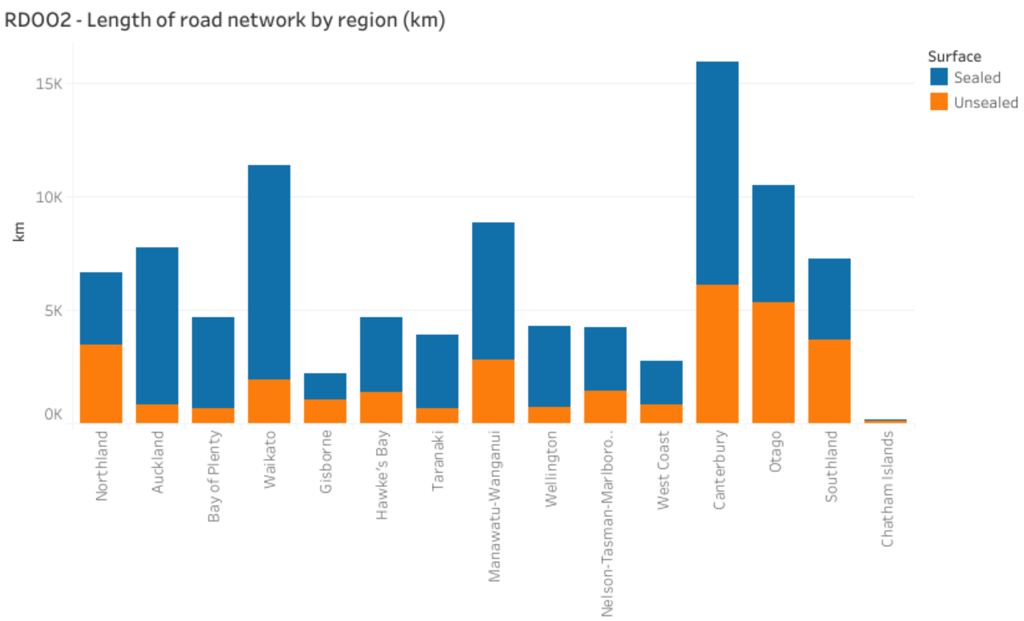
7.1 CURRENT STATE

7.1.1 What are the key features of this sector?

Key features of the transport infrastructure system in New Zealand are:

- A **public road system** spanning more than 96,800 km with seven major (longer than 300m) road tunnels, one major dedicated bus tunnel and nearly 4,200 bridges and large culverts in the state highway network alone.
  - Nearly 65,000 km (66%) are in sealed roads (67%) with 31,860 km (33%) in unsealed roads (NZTA 2021b). However, as seen in Figure 19, the ratio of unsealed to sealed roads varies significantly by region, with Northland, Canterbury, Otago and Southland having the highest proportions.
  - The Waterview Tunnel which opened in 2017 is the longest (2,400 m) and carries three lanes of northbound and southbound traffic as part of Auckland's Western Ring Route.
  - The longest road bridge is the Rakaia River Bridge on State Highway 1 (1,757 m). The oldest bridge is the SH1S Waianakarua South River Bridge, which was built in 1868. There are still 185 single-lane bridges and 14 timber bridges in the state highway network (NZTA 2021c).

FIGURE 19: Length of sealed and unsealed roads by region in New Zealand in 2019/20



Source: NZTA (2021d)

- A **national rail network** consisting of 3,700 km of track and railyards covering 18,000 hectares of land, crossing more than 1,300 bridges and including almost 100 tunnels (MoT 2021b).
- Numerous **metropolitan bus depots, train stations, and ferry terminal**s across New Zealand.
  - Urban public transport buses operate in all regions.
  - However, urban rail only operates in Auckland and Wellington and urban ferry services are only available in Auckland, Wellington and Lyttelton.

7.1.2 Which air pollutants are emitted?

The primary pollutants emitted from transport infrastructure include:

- PM from road dust and railway track wear – road dust may be contaminated with silicon and resuspended exhaust, brake and tyre wear (which contains heavy metals)
- NO_2 from on-road vehicle and locomotive exhausts (which concentrates inside tunnels and gets released through tunnel portals, vents or stacks)

7.1.3 Where are the emissions?

Transport infrastructure spans New Zealand as discussed earlier for on-road vehicles (Chapter 3) and rail transport (Chapter 4).

7.1.4 What is the current state of the impact?

Road dust generated by on-road motor vehicles is estimated to contribute 26% of PM_{10} emissions from all domestic transport sources in New Zealand (Kuschel *et al* 2021). Table 19 presents the estimates of road dust PM_{10} emissions for 2018/19.

The emissions in Table 19 are multiplied by the damage costs from Table 1 to arrive at the estimated social costs (covering both public health and lost productivity) shown in Table 20. The social costs for road dust PM_{10} emissions ($120M), while less than those associated with on-road exhaust PM_{10} emissions ($406M) and on-road brake and tyre wear PM_{10} emissions ($213M) seen in Table 5 (Chapter 3 – On-road vehicles), are still appreciable.

TABLE 19: Emissions from road dust (only) in New Zealand in 2018/19

PM_{10} EMISSIONS (TONNES)	SEALED ROADS	UNSEALED ROADS	TOTAL ROAD DUST
Urban	167	0	**167**
Rural	296	633	**929**
NZ Total	**463**	**633**	**1,096**

Source: Kuschel *et al* (2021)

Note: In the absence of local data, the emissions above were estimated using factors for sealed and unsealed road dust taken from international literature (USEPA 2006, EMEP/EEA 2019). These emission factors have a high degree of uncertainty as road surfaces in Europe and the US are likely to differ from those in New Zealand.

TABLE 20: Social costs due to road dust emissions in New Zealand in 2018/19 (NZ$M at June 2019)

PM_{10} COSTS ($M)	SEALED ROADS	UNSEALED ROADS	TOTAL ROAD DUST
Urban	167	0	**167**
Rural	296	633	**929**
NZ Total	**463**	**633**	**1,096**

Source: Kuschel *et al* (2021)

Note: Estimates of road and rail **tunnel emissions** and costs are a subset of the exhaust and brake and tyre wear emissions estimates in Table 4 (Chapter 3 – On-road vehicles) and Table 8 (Chapter 4 - Rail).

7.2 TRENDS

7.2.1 Emissions

Road dust

Concerns about road dust emissions in New Zealand have increased in recent years.

A number of rural communities have been impacted by significant increases in the number of heavy vehicles using **unsealed** roads to access forestry, quarry or dairying activities in their areas. Climate changes in some regions with a high proportion of unsealed roads are already making road conditions drier for longer periods of time (outside the usual summer peak period), potentially releasing an even higher dust load to surrounding communities. For example, in Northland (the region with the highest percentage of unsealed roads), by 2040 the number of hot days (>25°C) are predicted to increase by 20-30 and spring rainfall is expected to decrease by 5-10% (Pearce 2017). If not addressed through a programme of road sealing or other effective mitigation, unsealed road dust emissions are likely to increase.

In addition, the trends in increased weight for both light duty and heavy duty vehicles mean that **sealed** road dust emissions are also set to increase in future. This is because emissions are directly proportional to the weight of each vehicle (and *inter alia* its speed).

Tunnels

Growing transport infrastructure capacity in urban areas in New Zealand is increasingly reliant on the construction of major tunnels. The most recently completed tunnel was the Waterview Tunnel in Auckland which opened in 2017. Construction of the CRL Tunnel (also in Auckland) is underway for opening in late 2024. Other tunnel projects under consideration include the duplication of the Mt Victoria Tunnel in Wellington and an undersea tunnel for the Auckland Second Harbour Crossing.

While tunnels remove emissions that would have been emitted to near road and rail surroundings, in-tunnel emissions accumulate, requiring use of ventilation and dispersion systems to ensure exposure limits are met inside and outside the tunnel. As an example, the Waterview Tunnel uses 62 jet fans suspended from the roofs to pull fresh air into the tunnels and push it along the tunnel in the same direction as the traffic flow, towards the ventilation buildings. Large axial fans then draw up the polluted air and release it via two 15 m high stacks - one in the north and one in the south.

7.2.2 Concentrations

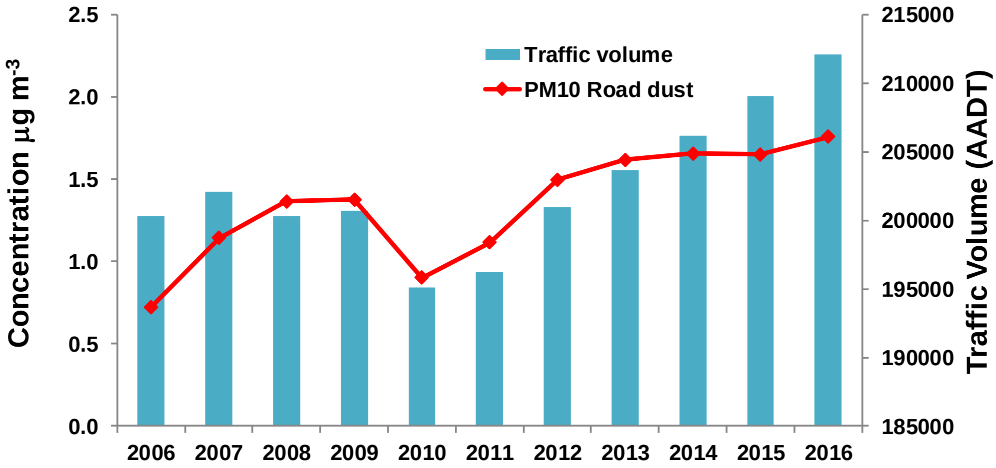
Road dust

To date, only a handful of monitoring campaigns have been undertaken investigating road dust.

As discussed in Chapter 2, GNS Science has analysed PM samples collected in Auckland between 2006 and 2016 to investigate non-exhaust PM collectively, covering road dust as well as brake and tyre wear (Davy & Trompetter 2019). As shown in Figure 20, the authors found a correlation between the PM_{10} fraction attributed to **sealed** road dust (although this likely includes some brake and tyre wear) at Khyber Pass and the annual traffic volumes on the nearby Southern Motorway (NZTA 2019). Road dust is approximately 30-50% of the overall motor vehicle contribution to urban PM_{10} concentrations and is increasing, while the tailpipe emissions component is decreasing.

Note: PM from brake and tyre wear is considered separately in this report (see Chapter 3).

FIGURE 20: Relationship between PM_{10} sealed road dust and traffic volumes at Khyber Pass Road 2006-2016



Source: Davy & Trompetter (2019), NZTA (2019)

By comparison, **unsealed** road dust has been the subject of more research in New Zealand.

Many studies have focussed on mitigation methods, typically involving the use of dust suppressants (Bartley Consultants 1995, Waters 2009, Bluett *et al* 2017). In the most recent study, Bluett *et al* (2017) undertook a two-month monitoring campaign on a section of Mataraua Road, 10 km southwest of Kaikohe in the Far North District, during February, March and April 2015. The results suggested adverse human health impacts may be occurring due to the dust discharged from untreated unsealed roads but that the application of a dust suppressant significantly reduced the impact of dust discharged from the road. The authors developed a framework to assist territorial local authorities in deciding whether to mitigate dust from unsealed roads.

In terms of monitoring short-term air quality, Northland Regional Council (**NRC**) has taken the lead, as most of Northland's road network (61%) is unsealed. Between 2013 and 2020, a PM_{10} monitor was rotated around 40 different sites for periods ranging from several days to several weeks. The results showed that **24-hour average PM_{10}** concentrations exceeded the NESAQ more than 20% of the time, indicating adverse human health impacts may be occurring due to unsealed road dust (NRC 2020).

One (only) study of long-term air quality has been undertaken, again by Northland Regional Council but also in conjunction with Far North District Council. PM_{10} was monitored continuously near an unsealed road (Pipiwai Road) in Northland between 1 June 2017 and 31 May 2018. This enabled **annual average PM_{10}** exposure directly attributable to an unsealed road in New Zealand, and the subsequent health effects, to be quantified for the first time (Metcalfe & Wickham 2019). The monitoring recorded 27 exceedances of 24-hour average PM_{10} NESAQ near unsealed roads and identified that exceedances were more likely when more than 40 trucks travelled the road per day. Previously, the air quality impacts of unsealed roads was modelled using USEPA-derived emissions factors and an NZTA screening dispersion model. However, this modelling was found to significantly under-estimate monitored PM_{10}. Metcalfe and Wickham developed a calibration factor to improve agreement at Pipiwai but noted it was likely site-dependent and recommended additional work to further improve air quality modelling predictions in New Zealand.

Waka Kotahi has commissioned Tonkin & Taylor to develop a national emissions and exposure model for determining community exposure and social costs associated with unsealed roads in New Zealand. The final report is currently due mid-2022.

As mentioned in Chapter 3, Waka Kotahi have commissioned a research project (TAR 19/17) – *Determining the ecological and air quality impacts of particulate matter from brake and tyre wear and road surface dust*. The research is being undertaken by NIWA, with Stage 1 (the literature review) due to be released by the end of 2021.

Tunnels

Prior to the construction of the Waterview Tunnel, Waka Kotahi commissioned NIWA to undertake a desktop review of the five existing road tunnels in the state highway network – Homer, Lyttelton, Mt Victoria, Terrace and Johnstone's Hill (Longley *et al* 2010). The objectives of the review included:

- Establishing existing air quality both within the tunnel and in the vicinity of the tunnel
- Comparing existing levels with current standards and guidelines for external air quality, and a set of proposed guidelines for in-tunnel air quality
- Recommend further assessment, research or analysis to assist in quantifying and reducing the risks presented by the tunnels.

The report reviewed monitoring undertaken between 1980 and 2008 and speculated that there might be a small risk of significant localised impacts at the southern portal of the Terrace Tunnel, the stacks of the Mt Victoria Tunnel (especially the western stack at the adjacent school), and the southern end of the Lyttelton Tunnel. Impacts at the Homer and Johnstone's Hill Tunnels were considered low due to the absence of an exposed population. However, no evidence was found suggesting that the tunnels would lead to local breaches of ambient air quality targets or standards.

Monitoring was later undertaken at the Johnstone's Hill Twin Tunnels in March to July 2010 and all measurements confirmed that air quality met in-tunnel and ambient guidelines (Kuschel & Wickham 2013). While NO_2 levels were close to the WHO annual NO_2 guideline at the northern portal during the three months of monitoring, the authors noted that the nearest potentially sensitive receptors (i.e. residences) were located more than 300 m away so it would be unlikely that any person would be exposed to 'high' NO_2 levels for a full year.

A two-year air quality monitoring campaign was required as a condition of consent for the Waterview Tunnel to ensure ambient air quality met relevant national standards and Auckland Regional air quality targets after opening in July 2017. Monitoring was undertaken at the northern and southern ends of the tunnel to investigate potential adverse effects resulting from the operation of the ventilation system (both stacks and portals), with all results reviewed by a peer review panel. The panel produced two annual summary reports and confirmed the tunnel operation complied with all air quality consent conditions (Kuschel & Simpson 2018, Kuschel & Simpson 2019).

7.2.3 Exposure

In rural locations, many forestry areas are now coming into harvest placing pressure on local, largely unsealed roads. In addition, there is a big push to increase access to natural resources to stimulate regional economic growth. The existing network of unsealed roads is spread throughout New Zealand and therefore exposure will potentially increase in future.

Major tunnels are few in number and in discrete locations. Tunnel air quality effects are relatively well-understood and well-managed in New Zealand. Even with increased population density, the per vehicle emissions for road and rail vehicles travelling through tunnels are improving at such a rate that exposure is likely to reduce in future.

7.3 RISKS TO PUBLIC HEALTH

7.3.1 What is the likely risk posed by infrastructure emissions?

With the public health risk from **major tunnels** considered **low** and likely to decline in future, the key risk associated with transport infrastructure is exposure to road dust.

The likely risk posed to public health from **road dust emissions** is **currently medium** but **may increase to high** in the future because:

- Unsealed roads extend across both the north and south islands of New Zealand and still make up 31,860 km (33%) of the road network.
- There is increasing pressure in rural areas to increase access to natural resources placing pressure on local, largely unsealed roads.
- Exposures appear to be the worst during dry summer months and climate change appears to be extending the duration and frequency of droughts in many areas.

Table 21 summarises the qualitative public health risk assessment for road dust emissions.

TABLE 21: Qualitative risk assessment for infrastructure emissions (road dust only)

PARAMETER	CURRENT	LIKELY FUTURE.
Emissions/concentrations	Moderate (M)	Moderate to high (M-H)
Spatial coverage	Widespread (H)	Widespread (H)
Population exposed	Few (L)	Few (L)
Exposure duration	Short-term (L)	Seasonal (M)
Public health risk rating	**Low-Medium**	**Medium-High**

7.3.2 What are the key gaps in our understanding?

The key gap in our understanding of public health impacts associated with transport infrastructure emissions in New Zealand is:

> **Gap #4**: What are the critical factors influencing community exposure to unsealed road PM emissions?

Monitoring at one location only, has demonstrated that unsealed roads exceed the annual WHO guideline for PM_{10} (Wickham & Metcalfe 2019). There is, however, no current long-term monitoring of PM_{10} being undertaken anywhere in New Zealand.

Current exposure assessment methods rely on international emission factors and screening dispersion models with limited, if any, validation in New Zealand. It is unclear how these relate to New Zealand unsealed road characteristics, e.g. silt content, aggregate composition. Also, given road dust tends to be due to coarse size fraction ($PM_{2.5\text{-}10}$), it would be useful to be able to distinguish health effects from these larger particles from those associated with exhaust PM (typically $PM_{2.5}$ and smaller).

Waka Kotahi has two research projects underway to better understand road dust effects.

The first is being undertaken by Tonkin & Taylor and seeks to deliver a better understanding of the health and social impacts of community exposure to dust from unsealed roads in New Zealand (findings are due for release in mid-2022).

The second is being undertaken by NIWA and focusses on the air quality and ecological impacts of PM arising from vehicle brake and tyre wear and road surface dust (Stage 1 due for release by end 2021).

8. OFF-ROAD VEHICLES

This chapter reviews the state, trends and public health risks associated with air emissions from off-road vehicles in New Zealand. Off-road vehicles include unregistered motorbikes, competition vehicles, farm and forestry vehicles, defence vehicles and equipment used in construction which is not driven on public roads.

8.1 CURRENT STATE

8.1.1 What are the key features of this sector?

As off-road vehicles are not registered or regulated, accurate information on their fleet profile and emissions is largely unknown.

These vehicles are not subject to any emissions regulations in New Zealand, except where they are operating underground or in confined spaces in which exhaust emissions need to be low to protect driver/worker safety.

8.1.2 Which air pollutants are emitted?

The primary pollutants emitted from off-road transport include:

- PM from vehicle exhaust, typically $PM_{2.5}$ and much smaller
- NO_2 from vehicle exhaust
- CO_2 from fossil fuel combustion
- PM from brake and tyre wear, typically $PM_{10-2.5}$.

Off-road transport can also generate dust from road surface abrasion (typically $PM_{10-2.5}$) but this is discussed in Chapter 7.

8.1.3 Where are the emissions?

Where the emissions are released depends on the off-road vehicle purpose.

Those vehicles used in agriculture and forestry tend to operate on private roads or land away from residential settlements while others, such as construction equipment, may be operated on sites within urban settlements (such as in road building or commercial property development).

8.1.4 What is the current state of the impact?

Ministry of Transport estimates that between 30% and 40% of all diesel in New Zealand is used off-road (MoT 2021c). As seen earlier in Table 5 (Chapter 3), off-road vehicles in New Zealand are estimated to emit almost as much CO_2e as domestic aviation in New Zealand (MfE 2021).

Auckland Council estimate that off-road vehicles contributed approximately 9% of PM_{10}, 15% of NO_X, 6% of VOC and 7% of CO_2 emissions from all transport sources in the Auckland region in 2016 (Sridhar & Metcalfe 2019). However, national inventories typically report off-road vehicle emissions outside the transport sector – lumping off-road vehicle activity in with other sectors such as forestry or agriculture.

8.2 TRENDS

8.2.1 Emissions

Most of the sectors in New Zealand which rely on off-road vehicles have experienced significant growth in recent years. For the year ended June 2019, exports of logs and wood increased by 16% over the previous year, with horticulture rising by 13.7% and dairy up 8.4% [17]. Prior to the COVID-19 crisis, the construction industry had been expanding at a healthy rate, growing by 4.6% in real terms in 2019 - up from 4.1% in 2018 - supported by investment in transport infrastructure and commercial and residential projects[18].

Internationally, off-road vehicle emissions are increasing in significance (relative to on-road vehicles) and many jurisdictions are looking at introducing or tightening regulations to address emissions.

In April 2018, the Australian and New South Wales Governments agreed to work together to develop a national approach to manage emissions from non-road diesel engines (such as those used in construction, mining and agricultural equipment) as a priority action under the National Clean Air Agreement[19]. A cost benefit analysis to examine the benefits and costs of various management options for non-road diesel engine emissions commenced in late 2019, following the completion of a market analysis of the sector. The cost benefit analysis is expected to be completed in late 2021, with results and policy options due for consideration in 2022.

The New Zealand government is unlikely to consider any regulations until after the Australian findings are released and made publicly available.

8.2.2 Concentrations

To date, no air quality monitoring has been undertaken specifically looking into the impacts of off-road vehicle emissions in New Zealand. Some construction sites are required to prepare construction air quality management plans, but these tend to focus on managing dust emissions created by vehicle movements, such as trucks.

8.2.3 Exposure

Exposure of the general public to off-road vehicle emissions is likely very low in most locations in New Zealand as the activities are undertaken largely on private land. While the sectors which generate the emissions are growing, it is unclear whether exposure will increase in future.

8.3 RISKS TO PUBLIC HEALTH

8.3.1 What is the likely risk posed by off-road emissions?

The likely risk posed to public health from off-road emissions is **low** but **may increase** in the future because:

- No air quality monitoring data currently exist to verify a low impact.

[17] https://www.stuff.co.nz/business/farming/115831996/new-zealands-primary-sector-exports-reach-a-record-464-billion

[18] https://www.globenewswire.com/news-release/2020/12/31/2152001/0/en/New-Zealand-Construction-Industry-Outlook-to-2024-Growth-Prospects-by-Market-Project-Type-and-Construction-Activity.html

[19] https://www.environment.gov.au/protection/air-quality/national-clean-air-agreement/evaluation-non-road-diesel-engine-emissions

- Off-road vehicles tend to operate on private land limiting the exposure of the general public.
- The sectors which generate off-road emissions are growing.

Table 22 summarises the qualitative public health risk assessment for off-road emissions.

TABLE 22: Qualitative risk assessment for off-road emissions overall

PARAMETER	CURRENT	LIKELY FUTURE.
Emissions/concentrations	Low (L)	Low to moderate (L-M)
Spatial coverage	Discrete locations (L)	Discrete location (L)
Population exposed	Few (L)	Few (L)
Exposure duration	Long-term (H)	Long-term (H)
Public health risk rating	**Low**	**Low-Medium**

8.3.2 What are the key gaps in our understanding?

The key gap in our understanding of public health impacts associated with off-road vehicle emissions in New Zealand is:

> **Gap #5**: What is the emissions profile of the current (and likely future) off-road vehicle fleet?

A better understanding of the current off-road "fleet" in terms of engine emissions standards and activity data (how often and where they operate) would improve our ability to assess whether they pose a significant public health risk.

9. CONCLUSIONS

9.1 RELATIVE PUBLIC HEALTH RISK RATINGS

This report is the first step in addressing the research question:

> *"What are the risks to public health associated with road, sea, rail and air travel including vessel emissions, dusty roads and vehicle emissions in New Zealand?"*

The public health risk ratings associated with different transport emissions sectors in New Zealand, based on the stocktake and gap analyses undertaken in the previous chapters, are summarised in Table 23.

The highest risk ratings are associated with on-road vehicles and transport infrastructure (road dust emissions only) and are shaded.

TABLE 23: Relative public health risk ratings for the different transport emissions sectors

SECTOR	CURRENT	LIKELY FUTURE.
On-road vehicles	High	High
Rail	Low-Medium	Low-Medium
Maritime transport	Low	Low
Aviation	Low-Medium	Low-Medium
Transport infrastructure (road dust emissions only)	Low-Medium	Medium-High
Off-road vehicles	Low	Low-Medium

9.2 KEY GAPS IN OUR UNDERSTANDING

The key gaps in our understanding from this stocktake (prioritised based on the public health risk ratings) are summarised in Table 24.

TABLE 24: Key gaps in our understanding of the public health risks associated with transport emissions in New Zealand

RANK	KNOWLEDGE GAP
1	What are the current health impacts of New Zealanders being exposed to **on-road NO_2 emissions** and are they improving?
2	What are the critical factors influencing community exposure to **PM emissions from unsealed roads**?
3	Which characteristics of on-road **brake and tyre wear PM emissions** present a public health risk?
4	Is the public health impact from current (and likely future) **aviation emissions** of lead, SO_2 and $PM_{2.5}$ genuinely low?
5	What is the **emissions profile of** the current (and likely future) **off-road vehicle fleet**?

Several research projects are already underway looking at the first three gaps.

The HAPINZ 3.0 study, funded by a consortium of government agencies, is investigating exposure to both PM and NO_2 and will assist with gap #1. The final report and other deliverables are due for release in early to mid-2022.

Waka Kotahi has funded two research projects which will assist with gaps #2 and #3. The first seeks to deliver a better understanding of the health and social impacts of community exposure to dust from unsealed roads in New Zealand and is due for release in mid-2022. The second focusses on the air quality and ecological impacts of PM arising from vehicle brake and tyre wear and road surface dust, with Stage 1 due end 2021 and further reporting in 2022. Neither, however, addresses chronic exposure to PM_{10} or $PM_{2.5}$ emissions from unsealed roads. Risks to public health from chronic (i.e. long-term) exposure to transport emissions are significantly greater than those from acute (i.e. short-term) exposure.

GLOSSARY

ABS	Australian Bureau of Statistics
ACC	Accident Compensation Corporation
ACRP	Aviation Cooperative Research Board
Acute	short-term duration but severe
Airshed	a geographic area established to manage air pollution within the area as defined by the NESAQ
ALA	American Lung Association
ALRI	acute lower respiratory infection
As	arsenic
ATAP	Auckland Transport Alignment Project
ATSDR	Agency for Toxic Substances and Disease Registry
BaP	benzo(a)pyrene
BC	black carbon, both a harmful pollutant and a greenhouse gas
CAN	Cycle Action Network
cardiovascular	of, pertaining to, or affecting the heart and blood vessels
CAU	census area unit, a non-administrative geographic area normally with a population of 3,000–5,000 people in an urban area
chronic	long-term duration or constantly recurring
CH_4	methane, a greenhouse gas
CO	carbon monoxide, a harmful pollutant
CO_2	carbon dioxide, a greenhouse gas
CO_2e	carbon dioxide equivalent, a way to express the impact of each different greenhouse gas in terms of the amount of CO_2 that would create the same amount of warming
coarse particulate	particles in the 2.5 µm to 10 µm size range, also known as $PM_{10-2.5}$
COMEAP	Committee on the Medical Effects of Air Pollutants
COPD	chronic obstructive pulmonary disorder
CRL	Central Rail Loop in Auckland
Cu	copper
domestic fire	a solid-fuel heating appliance which is intended primarily to heat a residential dwelling
EEA	European Environment Agency

ECMT	East Coast Main Trunk railway line
EHINZ	Environmental Health Intelligence New Zealand
ELAPSE	Effects of Low-Level Air Pollution: A Study in Europe is a Europe-wide collaboration in a research project investigating mortality and morbidity effects of long-term exposure to low-level $PM_{2.5}$, black carbon, NO_2 and O_3.
ERF	exposure-response function or relative risk function, the increase in risk for every increment in pollution
EV	electric vehicle
fine particulate	particles in the $PM_{2.5}$ fraction
GHG	greenhouse gas
GVM	gross vehicle mass, the maximum the weight of the vehicle can be at any time when fully loaded
GWRC	Greater Wellington Regional Council
HAPINZ	Health and Air Pollution in New Zealand study, based on 2001, undertaken by Fisher *et al* (2007)
HAPINZ 2.0	the first HAPINZ study update, based on 2006, undertaken by Kuschel *et al* (2012)
HAPINZ 3.0	the latest HAPINZ study update, based on 2016, (yet to be published)
harmful pollutant	an air pollutant which causes adverse health effects
HC	hydrocarbon
HCV	heavy commercial vehicle, e.g. all trucks/buses with a GVM greater than 3,500 kg
IARC	International Agency for Research on Cancer
IATA	International Air Traffic Association
ICCT	International Council for Clean Transportation
IPCC	Intergovernmental Panel on Climate Change
LAWA	Land Air Water Aotearoa
LCV	light commercial vehicle, e.g. all goods vans, trucks, utilities, buses and motor caravans with a GVM less than 3,500 kg
LPV	light passenger vehicle, e.g. all cars and vans with a GVM less than 3,500 kg
LTO cycle	landing and take-off cycle, equivalent to two aircraft movements
MBCM	Monetised benefits and costs manual, produced by Waka Kotahi
MBIE	Ministry of Business, Innovation and Employment

meta-analysis	the use of statistical methods to summarise the results of many studies, where those that are statistically similar are combined and analysed as if they were one study
MfE	Ministry for the Environment
MoH	Ministry of Health
MoT	Ministry of Transport
morbidity	ill health or suffering
mortality	death
motor vehicles	vehicles registered to travel on public roads, including cars, light commercial vehicles, trucks, buses and motorcycles
NESAQ	National Environmental Standards for Air Quality
Ni	nickel
NIMT	North Island Main Trunk railway line
NMHC	non-methane hydrocarbon
NO	nitric oxide
NO_2	nitrogen dioxide, a harmful pollutant
NO_X	oxides of nitrogen
N_2O	nitrous oxide, a greenhouse gas
NRC	Northland Regional Council
NZTA	New Zealand Transport Agency, now known as Waka Kotahi NZ Transport Agency or just Waka Kotahi
OAG	Office of the Auditor General
OECD	Organisation for Economic Co-operation and Development
Pacific peoples	indigenous peoples from the Island nations in the South Pacific, and in its narrowest sense Pacific peoples in New Zealand
PAF	population attributable fraction, the estimated percentage of total health cases that are attributable to the air pollution exposure
PAH	polycyclic aromatic hydrocarbon
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 µm in diameter, sometimes referred to as fine particulate – also known as respirable particulate because it deposits deeper in the gas-exchange region, e.g. in the bronchioles and alveoli
PM_{10}	particulate matter less than 10 µm in diameter, includes fine particulate (less than 2.5 µm) and coarse particulate (2.5 µm to 10 µm) – also known as thoracic particulate because it deposits within the lung airways and the gas-exchange region, including the trachea, bronchi, and bronchioles

$PM_{10-2.5}$	particulate matter in the 2.5 µm to 10 µm size range, sometimes referred to as coarse particulate
prevalence	the proportion of a population who have a specific characteristic in a given time period
respiratory	of, pertaining to, or affecting the lungs and airways
REVIHAAP	Review of evidence on health aspects of air pollution
SO_2	sulphur dioxide, a harmful pollutant
Stats NZ	Statistics New Zealand, the public service department charged with the collection of statistics related to the economy, population and society of NZ
UFP	ultrafine particles
µg	microgram, one millionth of a gram
µg/m^3	microgram per cubic metre, a unit of concentration
µm	micrometre, one millionth of a metre
UK	United Kingdom
US	United States of America
US EPA	United States Environmental Protection Agency
V	vanadium
VEPM	Vehicle Emission Prediction Model
VoSL	value of statistical life
VOC	volatile organic compound
Waka Kotahi	Waka Kotahi NZ Transport Agency
WHO	World Health Organization

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APPENDIX A: TRANSPORT-RELATED AIR POLLUTANTS AND THEIR EFFECTS

The critical harmful air pollutants released from transport sources are discussed in more detail in the following subsections.

A.1 PARTICULATE MATTER (PM_{10} AND $PM_{2.5}$)

A.1.1 Sources

Particulate matter (**PM**) emissions typically result from the combustion of fossil fuels (especially diesel) and abrasion processes (such as brake/tyre wear and road dust). Combustion tends to create fine particles (smaller than 2.5 µm, known as **$PM_{2.5}$**) whilst abrasion generates coarse particles (smaller than 10 µm, known as **PM_{10}**).

A.1.2 Size matters

Size matters when it comes to PM. There is considerable evidence that inhaling PM is harmful to human health, particularly smaller fractions such as PM_{10}, $PM_{2.5}$ and finer. PM_{10} is a more inclusive, but less specific, measure of exposure than $PM_{2.5}$. It includes $PM_{2.5}$ plus the coarse $PM_{10\text{-}2.5}$ fraction.

Generally, coarse PM (**$PM_{10\text{-}2.5}$**) deposits in the upper airways whereas fine PM ($PM_{2.5}$ or smaller) lodges in the very small airways deep in the lung. Inhaled ultrafine particulate matter (**UFP**) can even enter the bloodstream and penetrate organs in the body (EFCA 2019).

A.1.3 Composition matters but …

Different sources emit particles with different size distributions and different chemical and biological composition. However, the mechanisms of particle toxicity are complex and still not fully understood. The World Health Organization (WHO) states:

> While both observational and experimental findings imply that particle characteristics are determinants of toxicity, definitive links between specific characteristics and the risk of various adverse health effects have yet to be identified. (WHO 2006)

It is not yet certain which of the several classes of toxic effects observed in laboratory experiments are responsible for specific human health effects (Brook *et al* 2010). Human or animal cells exposed to particles from various sources show a range of inflammatory responses, which vary according to the source and composition of the particles. Particle characteristics such as size, concentration, metal content, potential to cause oxidation and/or immunological responses have all been shown to be important (Steenhof *et al* 2011, Degobbi *et al* 2010).

One of the most comprehensive air pollution epidemiology studies currently being undertaken is the **ELAPSE** project[20] (Effects of Low-Level Air Pollution: A Study in Europe). This project is looking at mortality and morbidity effects of long-term exposure to low concentrations (i.e. within current guidelines) of $PM_{2.5}$, black carbon (**BC**), nitrogen dioxide (**NO_2**) and ozone (**O_3**). Despite downward trends in concentrations in many cities, there is emerging evidence that the exposure-response relationships (**ERF**s) for air pollution exposure may be higher at low doses – known as a supra-linear dose response (Papadogeorgou *et al* 2019, Chen & Hoek 2020, Yazdi *et al* 2021).

[20] http://www.elapseproject.eu/

Effects due to long-term exposure to $PM_{2.5}$ elemental components have also been studied in the ELAPSE project. Chen *et al* (2021) reviewed associations between natural and cause-specific mortality and annual exposures of eight $PM_{2.5}$ components[21] representing major pollution sources as follows:

- copper, iron and zinc representing non-tailpipe traffic emissions
- sulphur representing long-range transport of secondary inorganic aerosols
- nickel and vanadium representing mixed industry/fuel oil combustion
- silicon representing crustal material
- potassium representing biomass burning.

The researchers found an elevated risk of mortality associated with long-term exposure to most $PM_{2.5}$ elemental components in single-pollutant models. However, when $PM_{2.5}$ mass or NO_2 was added in two-pollutant models, the effect estimates (the strength of the risk) reduced for almost all components. After $PM_{2.5}$ and NO_2 adjustment, health risks only remained (almost) significant for K and V. Long term exposures to V - which is a marker for shipping emissions due to heavy fuel oil combustion - was most consistently associated with increased mortality risk (Chen *et al* 2021).

A.1.4 Some exceptions

Although definitive evidence for health effects associated PM composition remains inconclusive, one exception to date is diesel engine exhaust. In 2012, the International Agency for Research on Cancer (**IARC**), which is part of WHO, classified **diesel engine exhaust** as **carcinogenic to humans** (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer (IARC 2012). They also noted a positive **association (limited evidence) with** an **increased risk of bladder cancer** (Group 1).

A year later, IARC announced that it had classified **outdoor air pollution** (irrespective of source and type) as **carcinogenic to humans** (Group 1), based on sufficient evidence that exposure to outdoor air pollution causes lung cancer (IARC 2013). As with diesel exhaust, they also noted a **positive association with an increased risk of bladder cancer** (Group 1). **Particulate matter**, a major component of outdoor air pollution, was evaluated separately and was also classified as **carcinogenic to humans** (Group 1).

A.1.5 Health effects

The health effects of PM are predominantly respiratory and cardiovascular. The impacts range from functional changes (e.g. reduced lung function) to symptoms, impaired activities (e.g. school absenteeism, days off work), doctors' visits through to hospital admissions, reduced life expectancy and death. The social costs due to long-term exposure to PM concentrations are typically much greater than those from short-term exposure.

More people are affected by less severe health effects than the proportion affected by more severe health effects (see Figure 21). While there are a large number of acute/transitory health effects due to PM_{10}, the fewer chronic impacts incur a much greater social cost.

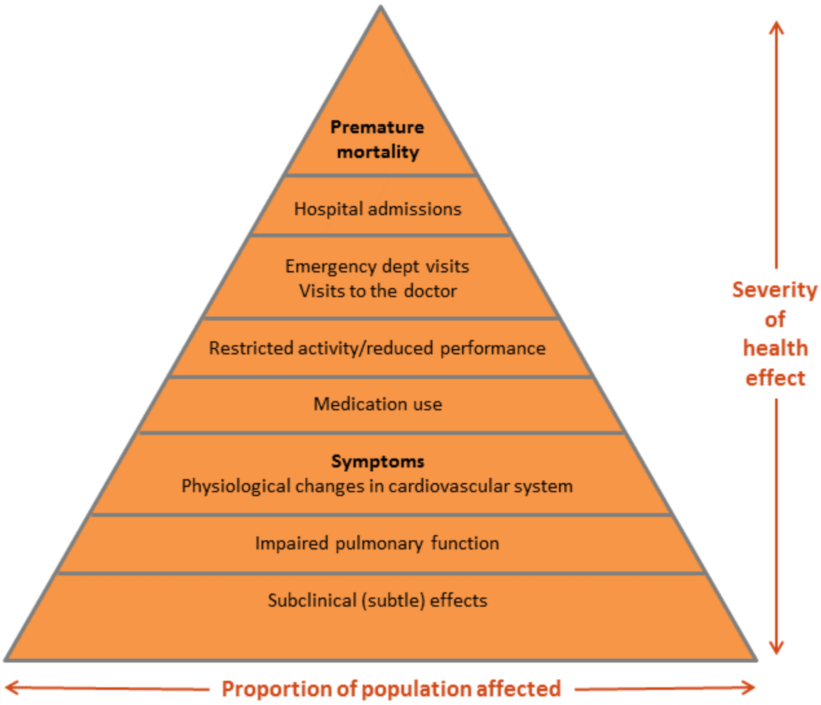
The WHO current *Global Air Quality Guidelines* date back to 2005 (WHO 2006). Since then, the body of science and evidence on air pollution health impacts has significantly expanded. WHO signalled their intention to update the guidelines in 2010 and have been undertaking a comprehensive work program to improve understanding.

The first significant step was the **REVIHAAP** project (Review of evidence on health aspects of air pollution), in which experts reviewed and discussed the newly accumulated scientific

[21] Note motor vehicle exhaust $PM_{2.5}$ is largely organic, e.g. black carbon, so is not included in this list.

evidence on the adverse effects on health of air pollution, formulating science-based answers to the 24 questions (WHO 2013). REVIHAAP found additional support for the effects of short-term exposure to $PM_{2.5}$ on both mortality and morbidity, especially cardiovascular mortality. In addition, long-term exposure to $PM_{2.5}$ was linked to several new health outcomes, including atherosclerosis, adverse birth outcomes and childhood respiratory disease; and emerging evidence suggested possible links between long-term $PM_{2.5}$ exposure and neurodevelopment and cognitive function, as well as other chronic disease conditions, such as diabetes.

FIGURE 21: Pyramid of PM_{10} health effects



Source: WHO (2006)

WHO has recently commissioned a series of systematic reviews and meta-analyses[22] investigating associations between common air pollutants and human health outcomes to assist in the development of updated guidelines.

Evidence of PM effects has been assessed as follows:

- Orellano *et al* (2020) reviewed 196 articles and found positive associations between short-term (24-hour average) PM_{10} and $PM_{2.5}$ exposures and all-cause mortality. PM_{10} and $PM_{2.5}$ were also positively associated with cardiovascular, respiratory, and cerebrovascular mortality. The magnitude of the associations was, as expected, lower than the associations between mortality and the exposure to these same air pollutants in the long-term.
- Chen & Hoek (2020) reviewed 107 cohort studies and found clear evidence that long-term (annual average) exposure to $PM_{2.5}$ and PM_{10} are associated with increased mortality from all causes, cardiovascular disease, respiratory disease and lung cancer.

[22] A systematic review is a type of literature review that answers a defined research question by collecting and summarising all empirical evidence that fits pre-specified eligibility criteria. A meta-analysis is the use of statistical methods to summarise the results of these studies, whereby studies that are statistically similar are combined and analysed as if they were one study.

The associations with $PM_{2.5}$ remained below the current WHO annual average guideline exposure level of 10 µg/m^3 - this means there will be health effects even in locations which meet current guidelines.

Discussion on the implications for New Zealand of the WHO PM health effects findings can be found in Wickham (2021b, 2021c).

A.2 NITROGEN DIOXIDE (NO_2)

A.2.1 Sources

Oxides of nitrogen (**NO_X**) primarily come from combustion sources, when fuels are burnt in the presence of air (which is a mixture of nitrogen and oxygen). The main components of NO_X are nitric oxide (**NO**) and nitrogen dioxide (**NO_2**). NO readily oxidises in the atmosphere to produce NO_2.

A.2.2 Health effects

NO_2 is a gas that causes increased susceptibility to infections and asthma. It reduces lung development in children and has been associated with increasingly more serious health effects, including reduced life expectancy (COMEAP 2015).

There is increasing evidence that traffic-related air pollution is associated with the development of asthma (Khreis *et al* 2017). Another meta-analysis reported associations between air pollution exposure and asthma exacerbations, in both children and adults (Orellano *et al* 2017).

New studies point towards stronger associations of long-term exposure with mortality (respiratory, cardiovascular and all cause) as well as for lung carcinogenicity (WHO 2013). However, there is considerable debate about causality (COMEAP 2018). Although causation between exposure to PM and health outcomes has been demonstrated, it is yet to be fully established for NO_2. Evidence of a causal relationship between short-term NO_2 and respiratory outcomes has strengthened, while remaining suggestive for cardiovascular disease and mortality. However, much of this evidence is based on single pollutant models and the effects recorded for NO_2 may represent those for other pollutants (such as UFP, $PM_{2.5}$, carbon monoxide, black carbon and polycyclic aromatic hydrocarbons) especially in traffic impacted locations (WHO 2016).

The United States Environmental Protection Agency (US EPA) has concluded that there is sufficient evidence of a causal effect of both long- and short-term NO_2 exposure on respiratory diseases, but that:

> evidence is suggestive of, but not sufficient to infer, a causal relationship with cardiovascular effects and diabetes, total mortality, birth outcomes, and cancer. (US EPA 2016)

Evidence of NO_2 effects has been assessed in the recent suite of WHO systematic reviews and meta-analyses as follows:

- Orellano *et al* (2020) found positive associations between short-term (24-hour average) exposure to NO_2 and all-cause mortality, with a high certainty of evidence.

- Zheng *et al* (2021) found short-term (24-hour average) exposure to NO_2 was associated with an increased risk of asthma exacerbation in terms of asthma-associated emergency room visits and hospital admissions, with a high certainty of evidence.

- Huangfu & Atkinson (2020) reviewed 24 studies published up to the end of 2018 and found increased risk of all-cause, respiratory, chronic obstructive pulmonary disorder (**COPD**) and acute lower respiratory infections (**ALRI**) mortality associated with long-term (annual average) exposure to NO_2. The certainty of the associations with mortality was rated low to moderate for each exposure-outcome pair, except for NO_2 and COPD mortality which was rated high.

Discussion on the implications for New Zealand of the WHO NO_2 health effects findings can be found in Wickham (2021b, 2021d, 2021e).

A recent review by Huang *et al* included studies up to February 2020, with analyses undertaken by region (e.g. Asia), and concluded that there is:

> robust epidemiological evidence that long-term exposure to NO_2, a proxy for traffic-sourced air pollutants, is associated with a higher risk of all cause, cardiovascular and respiratory mortality that might be independent of other criteria air pollutants. (Huang *et al* 2021)

It is worth noting that REVIHAAP reported that both short- and long-term studies found associations with adverse effects at concentrations that were at or below the NO_2 limits set in the WHO Global Air Quality Guidelines (WHO 2013). This means there will be health effects even in locations which meet current guidelines.

Note: Exposure to NO_2 has also been implicated in increased mortality and poorer health outcomes in individuals infected with COVID-19 (Konstantinoudis *et al* 2021). Mele *et al* (2021) provide a useful summary of key studies to date that have investigated effects of NO_2 on COVID-19 mortality.

A.3 SULPHUR DIOXIDE (SO_2)

A.3.1 Sources

Sulphur dioxide (SO_2) is a colourless gas with a sharp, irritating odour. It is associated with combustion of fossil fuels (such as diesel and heavy fuel oil used in maritime vessels) and the smelting of mineral ores containing sulphur. On-road diesel vehicles used to be a significant source until the sulphur level in motor diesel was reduced to near zero (only 10 ppm sulphur) in 2009. Similarly, emissions from shipping were a major contributor until Annex VI of MARPOL came into force on 1 January 2020 limiting the sulphur content of maritime fuels[23].

Note: Volcanoes are a significant natural source of SO_2 emissions in New Zealand.

A.3.2 Health effects

SO_2 affects the respiratory system, particularly lung function, and can irritate the eyes. It causes coughing, mucus secretion and aggravates conditions such as asthma and chronic bronchitis. Common symptoms include wheezing, shortness of breath and chest tightness, especially during exercise or physical activity. SO_2 has been linked to cardiovascular disease and mortality.

The US EPA found consistent evidence of association between short-term exposure to ambient SO_2 and all-cause and respiratory morbidity, although the biological mechanism for these outcomes was uncertain (US EPA 2017). REVIHAAP reached a similar conclusion for all-cause and respiratory mortality (WHO 2013).

Evidence of SO_2 effects has been assessed in the recent suite of WHO systematic reviews and meta-analyses as follows:

[23] In December 2019, Cabinet approved (in principle) New Zealand becoming a party to Annex VI, and the Government agreed to an expected implementation date of late 2021. However, this was delayed due to COVID-19 disruptions to early 2022. Domestic sulphur fuel reductions will be required shortly after ratification. See for further https://www.transport.govt.nz/area-of-interest/maritime-transport/marpol/ information.

- Orellano *et al* (2021) found positive associations between short-term (24-hour average) exposure to SO_2 and all-cause and respiratory mortality, with a high certainty of evidence.
- Zheng *et al* (2021) found short-term (24-hour average) exposure to SO_2 was associated with an increased risk of asthma exacerbation in terms of asthma-associated emergency room visits and hospital admissions, with a high certainty of evidence.

Discussion on the implications for New Zealand of the WHO SO_2 health effects findings can be found in Wickham (2021d, 2021f).

A.4 CARBON MONOXIDE (CO)

A.4.1 Sources

Carbon monoxide (CO) is associated with incomplete combustion of fuels, in particular petrol.

Note: Exposure to ambient CO has been dramatically reduced since the advent of emission standards requiring catalytic converters be fitted to petrol-fuelled motor vehicles. Catalytic converters started to make an improvement to New Zealand's air quality in the mid-1990s with the advent of used Japanese imported vehicles being allowed into the market.

A.4.2 Health effects

When inhaled CO enters the blood stream and attaches to haemoglobin molecules, which transport oxygen around the body. This reduces the amount of oxygen that body tissues receive and can have adverse effects on the brain, heart and general health. Exposure to low levels can causes dizziness, weakness, nausea, confusion and disorientation. However, higher levels can cause coma, collapse, loss of consciousness and death.

Evidence of CO effects has been assessed in the recent suite of WHO systematic reviews and meta-analyses as follows:

- Lee *et al* (2020) found positive associations between short-term (in the order of hours up to seven days) exposure to CO and myocardial infarction, with a moderate certainty of evidence.

Discussion on the implications for New Zealand of the WHO CO health effects findings can be found in Wickham (2021g).

A.5 VOLATILE ORGANIC COMPOUNDS (VOCs)

A.5.1 Sources

Volatile organic compounds (**VOC**s) are associated with incomplete combustion of fuels but also come from evaporation of fuels in vehicle fuel delivery systems.

VOC is an umbrella term for the multitude of organic pollutants that can be emitted, ranging from simple chain molecules (e.g. ethane, C_2H_6) to multi-ring compounds (e.g. benzo[a]pyrene, $C_{20}H_{12}$).

Note: VOCs are also referred to as hydrocarbons (**HC**s) – some of which are separated into non-methane hydrocarbons (**NMHC**s) and methane (**CH_4**) to differentiate harmful and greenhouse gases.

A.5.2 Health effects

The health effects of VOCs depend on the individual pollutants present and the length of exposure. Many VOCs are classified as hazardous air pollutants or air toxics because they can cause serious health effects (ALA 2021). Common acute effects include irritation of the eye, nose and throat, dizziness and neurological effects, whilst chronic impacts typically include cancer, genetic defects and birth defects.

For example, benzene – a component in petrol – is carcinogenic to humans (Group 1). It causes acute myeloid leukaemia and is linked to acute and chronic lymphocytic leukaemia, non-Hodgkin's lymphoma and multiple myeloma (WHO 2010). Benzo[a]pyrene (**BaP**) – a PAH often found in vehicle exhaust and heavy fuel oils – is also a known Group 1 human carcinogen (ATSDR 2009a).

A.6 HEAVY METALS

A.6.1 Sources

Heavy metals are emitted from transportation through fuel combustion or abrasion processes.

On-road vehicles release zinc, copper and iron through brake and tyre wear but iron is also released from abrasion of rail tracks. Nickel and vanadium are present in heavy fuel oils and are typical markers of shipping emissions. Platinum and palladium can also be released in small quantities through degradation of vehicle exhaust treatment systems (e.g. catalytic converters).

A.6.2 Health effects

Like VOCs, the health effects of heavy metals depend on the individual pollutant and the length of exposure. Exposure to heavy metals can cause diarrhoea, nausea, abdominal pain, vomiting, shortness of breath, tingling in your hands and feet, chills, weakness, neurological impairment and death (ATSDR 2008a, 2009a, 2009b, 2017).

The main heavy metals emitted into air that threaten human health are lead, mercury and arsenic. However, the last two are more commonly associated with domestic fires or industrial processes rather than transport sources.

Note: Lead used to be the main heavy metal of concern in New Zealand because it was added as an octane enhancer in petrol and ubiquitous in ambient air. In 1996, unleaded fuel became mandatory and levels of lead in ambient air samples have reduced dramatically since. Nowadays, the most common exposure source is dust from old paint which used lead as a whitening agent.

APPENDIX B: MILESTONES IN ADDRESSING TRANSPORT EMISSIONS IN NEW ZEALAND

The critical harmful air pollutants released from transport sources are discussed in more detail in the following subsections.

B.1 CLEAN FUELS

- Banning lead in petrol, allowing catalytic converter technology in motor vehicles (1996).
- Reducing sulphur in diesel, thereby reducing emissions from existing vehicles and allowing cleaner technologies to be adopted in motor vehicles, progressively from 2002 to 2009.
- Electrifying Auckland's passenger rail network. All services were electrified in 2015 except the Papakura to Pukekohe line which is underway and due for completion by 2023.
- Acceding to Annex VI of MARPOL, limiting the sulphur content of maritime fuels (due to be implemented early 2022).

B.2 CLEAN VEHICLE TECHNOLOGY

- Requiring all vehicles entering the New Zealand fleet to have been built to an emissions standard (2004).
- Requiring all light duty vehicles when being sold to display a fuel economy label estimating the annual fuel cost and fuel economy (2006).
- Introducing a set of progressively more stringent rolling exhaust emissions standards for all light and heavy motor vehicles entering the fleet (commenced in 2007).

  Note: From 1 November 2016, all new light and heavy vehicles (irrespective of fuel type) entering the New Zealand fleet have been required to meet Euro 5/V[24] emissions standards. All used import light and heavy vehicles have been required to meet Euro 4/IV since 1 January 2012. The current Vehicle Exhaust Emissions rule **does not** include Euro 6/VI requirements for new vehicles (which were introduced in Europe in 2015) and Euro 5/V requirements for used imports.

- Requiring all urban buses that receive Waka Kotahi public transport funding to meet minimum standards, including emissions standards and age limits (since 2014).
- Offering incentives (such as reduced road user charges and reduced ACC levies) through the Electric Vehicle (**EV**) Programme to encourage uptake to reach a goal of 64,000 EVs in the fleet by end 2021 (commenced in May 2016).

  Note: As at end April 2021, there were 26,723 electric vehicles (including plug-in hybrid vehicles) in the New Zealand fleet, with most of these entering as used imported vehicles from Japan (MoT 2021a).

[24] European exhaust emissions standards use Arabic numerals for light duty vehicle standards (e.g. Euro 5) and Roman numerals for heavy duty vehicle standards (e.g. Euro V).

- Allowing an emissions improvement premium to be awarded to tenderers offering cleaner vehicles operating public transport fleets (since 2017).

  Note: This was developed by Greater Wellington Regional Council (**GWRC**) in 2017 (Kuschel *et al* 2017). GWRC announced in December 2020 that they intend to have a fully electric fleet by 2027.

- Setting CO_2 emissions standards for imported new and used light vehicles entering the New Zealand fleet. The Clean Car Standard was announced in January 2021, with legislation due to be developed by end 2021 to take effect in 2022.

B.3 APPROPRIATE MAINTENANCE

- Raising awareness of need to address transport emissions through the 0800 SMOKEY education campaign which encourage Aucklanders to "dob in" smoky vehicles (2000).
- Prohibiting motor vehicles from emitting visible smoke for 10 or more seconds while being driven on-road (2004).
- Prohibiting the removal of, or tampering with, a vehicle's emissions control equipment and requiring vehicles to pass a five second visible smoke check as part of their warrant of fitness/certificate of fitness inspection (2007).

  Note: While the on-road and warrant of fitness smoke rules exist, non-compliance is rarely recorded, and little enforcement action is taken.

B.4 TRAFFIC AND DEMAND MANAGEMENT

- Local government support for eScooters for short trips through the launch of Lime and other rental operators across New Zealand (launched in Auckland and Christchurch in 2018)
- Encouraging the shift (albeit slowly) from private cars to public transport, walking and cycling mode through projects such as the *Auckland Transport Alignment Project* (**ATAP**). (The latest ATAP funding package was announced in March 2021 and allocates $900 million towards walking and cycling initiatives between 2021 and 2031).

  Note: More investment in recent years has gone into cycling infrastructure for tourist-focussed rail trails than for commuter-oriented cycleways. Nonetheless, experience with these trails and the advent of e-Bikes have fuelled public interest in cycling which has translated to increased urban cycling. About 48,000 people ride to work (about 2.2% of commuters) according to the 2018 Census and commuting by bike is increasing in many cities including Auckland, Wellington and Christchurch (CAN 2021).

- Increasing uptake of teleworking (most recently in response to COVID-19 but also with improved technology such as Zoom and MS Teams) whereby many more people are regularly working from home and are not making as many commuter trips.

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