Public Health Risks associated with Transport Emissions in NZ:

Part 2 Road Transport Emission Trends

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Prepared for ESR by:

Jayne Metcalfe and Gerda Kuschel (Emission Impossible Ltd)

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Management Review	Peer reviewer	Authors
		
Jan Powell	Alistair Woodward	Jayne Metcalfe and Gerda Kuschel
Service Lead	University of Auckland	Director & Senior Air Quality Specialist

DISCLAIMER

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1. EXECUTIVE SUMMARY

In 2021, the Ministry of Health (MoH) funded a stocktake of the state of knowledge (as at June 2021) of the public health risks associated with emissions from the transport sector (Kuschel 2022). That report (Part 1 of the *Public Health Risks Associated with Transport Emissions in New Zealand*) identified critical gaps, with the need to better understand the health impacts of exposure to nitrogen dioxide (NO_2) emissions from on-road motor vehicles at number one.

Following the stocktake, the latest *Health and Air Pollution in New Zealand 2016* (HAPINZ 3.0) was released and confirmed that the health impacts of transport emissions are considerable (Kuschel *et al* 2022a). Air pollution from motor vehicles alone is estimated to result in 2,247 premature deaths, nearly 9,400 hospitalisations, over 13,200 cases of childhood asthma and more than 330,000 restricted activity days each year in Aotearoa New Zealand at a cost of more than $10.5 billion.

In addition to the local air quality impacts, the transport sector is also one of the largest sources of greenhouse gas (GHG) emissions in New Zealand accounting for 18% of Aotearoa's gross carbon dioxide equivalent (CO_2-e) emissions (MfE 2022). Around 90% of transport GHG emissions are from on-road motor vehicles[1]. To achieve current targets and obligations, motor vehicle GHG emissions need to reduce by approximately 41% by 2035 compared with 2019, and the transport sector needs to be largely decarbonised by 2050.

Te hau mārohi ki anamata, Aotearoa New Zealand's first emissions reduction plan (ERP), includes four targets designed to achieve the required GHG emissions reductions for transport, as follows:

Target 1	Reduce total kilometres travelled by the light vehicle fleet by 20% by 2035 through improved urban form and providing better travel options, particularly in our largest cities
Target 2	Increase zero emissions vehicles to 30% of the light fleet by 2035
Target 3	Reduce emissions from freight transport by 35% by 2035
Target 4	Reduce the emissions intensity of transport fuels by 10% by 2035

Targets 1, 2 and 4 are relative to a baseline projection prepared by Te Manatū Waka Ministry of Transport. Target 3 is relative to 2019 levels and includes trucks, rail and ships.[2]

Many initiatives proposed to improve GHG emissions from transport to reduce climate change impacts also result in air quality benefits. Consequently, the aim of this report (Part 2 of the *Public Health Risks Associated with Transport Emissions in New Zealand*) was to estimate the likely improvement in air pollution health impacts associated with meeting the above GHG reduction targets.

The key steps in our assessment were:

- Estimating the air pollution health impacts and social costs of motor vehicle emissions in 2019 to establish current impacts

[1] *New Zealand's Greenhouse Gas Inventory for 2019* reports transport emissions at 14,655 kt CO_2-e, with road tranport emissions at 13,116 kt CO_2-e. https://emissionstracker.environment.govt.nz/

[2] https://www.transport.govt.nz/assets/Uploads/Cabinet-paper-Transport-content-for-the-emissions-reduction-plan.pdf

- Assessing the change in motor vehicle emissions between 2019 and 2035 for business as usual (BAU) and scenarios representing the achievement of the various ERP targets (the scenarios)
- Calculating the associated air pollution health impacts and social costs[3] of motor vehicle emissions in 2035 for BAU and the scenarios.

KEY FINDINGS

Emissions

Estimated total emissions of oxides of nitrogen (NOx) and particulate matter less than 2.5µm ($PM_{2.5}$) from motor vehicles in 2035 reduce appreciably by 2035 for all scenarios - even for BAU which is based on 19% higher vehicle kilometres travelled (VKT) in 2035 versus 2019 - due to gradual uptake in cleaner Euro 6/VI[4] vehicles, as well as electric vehicles (EVs).

However, Scenario 5 (achieving all targets - the ERP pathway) shows substantial additional improvement in NOx and $PM_{2.5}$ emissions compared with BAU, reflecting accelerated adoption of low or zero emission policies.

Health impacts

Similarly, health impacts from motor vehicle air pollution are expected to improve between 2019 and 2035 for all scenarios including BAU.

However, Scenario 5 (the ERP pathway) results in 303 fewer New Zealanders dying prematurely each year by 2035 relative to BAU.

Social costs of motor vehicle air pollution reduce from $10,247 million in 2019 to $5,644 million by 2035 for BAU versus $4,229 million by 2035 for Scenario 5.

In general:

- The greatest NOx emissions reduction benefits result from Scenario 1 (20% reduction in light duty VKT) and Scenario 2 (30% of the light duty fleet being electric).
- The greatest $PM_{2.5}$ emissions reduction benefits result from Scenario 1 (20% reduction in light duty VKT). This is because non-exhaust emissions, which come from both light duty internal combustion engine (ICE) vehicles and EVs, dominate total $PM_{2.5}$ emissions by 2035. Therefore, reducing VKT for all light duty vehicles is the most effective scenario for reducing $PM_{2.5}$ emissions.
- Scenario 3 (reductions in truck VKT) and Scenario 4 (increased electric trucks) deliver fewer benefits compared with Scenarios 1 and 2. This is because the expected VKT

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[3] The air pollution costs are based on damage costs reported in the *Health and Air Pollution in New Zealand 2016* report (Kuschel *et al* 2022a) and reflect the costs to society – i.e. social costs. However, the GHG costs are based on shadow CO_2-e emission values published by the NZ Treasury (2021) in Appendix 5 of their *CBAx Tool User Guidance* and are based on the likely future abatement costs rather than the social costs associated with emissions. Treasury recommends using these shadow values to ensure consistency and comparability across cost-benefit analyses undertaken by government agencies.

[4] Euro 6 and Euro IV are the latest vehicle emission standards for pollution from the use of on-road vehicles sold in Europe and the United Kingdom. Standards denoted using Arabic numerals, e.g. 6, apply to light duty vehicles and those denoted with Roman numerals, e.g. VI, apply to heavy duty vehicles. Since November 2016 all new vehicles (diesel or petrol) entering the New Zealand fleet have been required to meet Euro 5/V (the earlier Euro standards). Euro 6/VI standards are not yet a requirement in New Zealand but we were advised by Te Manatū Waka Ministry of Transport (MoT) staff to assume an implementation date of 2025 in our assessment.

reductions and increases in EVs are smaller for heavy duty vehicles compared with light duty vehicles in 2035.

Policy design

We included an additional scenario – Scenario 6 - to highlight that policy design is critical for achieving the best air quality outcomes. Scenario 6 is the same as Scenario 5 (the ERP pathway) except, instead of the light duty VKT reduction coming from both petrol and diesel vehicles, light duty diesel VKT is largely unaffected by policy.[5]

If light duty petrol and diesel VKT are impacted equally by the policy (Scenario 5), social costs are 25% lower than BAU in 2035. However, if light duty diesel VKT is not impacted (Scenario 6) then the benefit plummets to 11% in 2035, due to an extra 171 premature deaths and an additional $797 million in social costs.

Cumulative total benefits

Achieving the ERP pathway (all targets) could yield net air quality benefits of more than $7 billion (NZ$2019) between 2021 and 2035 due to reduced NOx and $PM_{2.5}$.

However, if light duty vehicles are not impacted, then the net air quality benefits associated with achieving the ERP targets halve from $7 billion to around $3.5 billion (NZ$2019) between 2021 and 2035.

The net benefit of reduced CO_2-e emissions between 2021 and 2035 is around $3.3 billion (NZ$2019), irrespective of the impact on light duty diesel vehicles. In Scenario 6, additional CO_2-e emissions reductions are taken from light duty petrol vehicles to make up the shortfall.

Based on our assessment, the net air quality benefits of achieving the ERP pathway are likely to be at least as significant as the CO_2-e benefits.

Notes: Our assessment of the impact of achieving the ERP targets excludes other co-benefits - such as increased physical activity, reduced noise impacts and improved road safety. These benefits are likely to be considerable, particularly for interventions that reduce VKT for light duty vehicles.

In addition, the assessment of CO_2-e emissions covers exhaust emissions resulting from motor vehicle use only. Significant mode shift away from private vehicles (including EVs) would reduce embodied and operational emissions from transport infrastructure. Reduced car ownership would also reduce life-cycle emissions from the manufacture and disposal of vehicles.

VKT reductions, and their associated air pollution benefits, are applied equally across New Zealand. Realistically, VKT reductions are more likely to be implemented in urban areas where more people are exposed to air pollution and where more transport options exist. This means that the benefits of interventions which reduce VKT are likely to be *under*-estimated.

Our analyses were based on fleet *average* emission factors and did not assess the impact of higher emitting vehicles in each type. Greater air quality benefits could be achieved by implementing policies that target replacement of the most polluting vehicles in the fleet.

We estimated cumulative costs and benefits to 2035. However, the benefits of interventions would extend well beyond 2035.

For full details on the assumptions and calculations, please refer to the accompanying Excel workbook.

[5] The authors strongly recommend applying the policies to both light duty diesel and petrol vehicles and analysed this additional scenario solely to highlight why this is so important.

2. INTRODUCTION

In 2021, the Ministry of Health (MoH) funded a stocktake of the state of knowledge (as at June 2021) of the public health risks associated with emissions from the transport sector (Kuschel 2022). That report (Part 1 of the *Public Health Risks Associated with Transport Emissions in New Zealand*) identified critical gaps, with the need to better understand the health impacts of exposure to nitrogen dioxide (NO_2) emissions from on-road motor vehicles at number one.

Following the stocktake, the latest *Health and Air Pollution in New Zealand 2016* (HAPINZ 3.0) was released and confirmed that the health impacts of transport emissions are considerable (Kuschel *et al* 2022a). Air pollution from motor vehicles alone is estimated to result in 2,247 premature deaths, nearly 9,400 hospitalisations, over 13,200 cases of childhood asthma and more than 330,000 restricted activity days each year in Aotearoa New Zealand at a cost of more than $10.5 billion.

In addition to the local air quality impacts, the transport sector is also one of the largest sources of greenhouse gas (GHG) emissions in New Zealand accounting for 18% of Aotearoa's gross carbon dioxide equivalent (CO_2-e) emissions (MfE 2022). Around 90% of transport GHG emissions are from on-road motor vehicles[6]. To achieve current targets and obligations, motor vehicle GHG emissions need to reduce by approximately 41% by 2035 compared with 2019, and the transport sector needs to be largely decarbonised by 2050. This requires urgent action and system wide changes (MfE 2022).

Te hau mārohi ki anamata, Aotearoa New Zealand's first emissions reduction plan (ERP), includes four targets designed to achieve the required GHG emissions reductions for transport as follows:

Target 1 Reduce total kilometres travelled by the light vehicle fleet by 20% by 2035 through improved urban form and providing better travel options, particularly in our largest cities

Target 2 Increase zero emissions vehicles to 30% of the light fleet by 2035

Target 3 Reduce emissions from freight transport by 35% by 2035

Target 4 Reduce the emissions intensity of transport fuels by 10% by 2035

Targets 1, 2 and 4 are relative to a baseline projection prepared by Te Manatū Waka Ministry of Transport (MoT). Target 3 is relative to 2019 levels and includes trucks, rail and ships.[7]

Achieving these targets will mean that New Zealanders will have better transport choices, cleaner and more efficient vehicles, and a safer and more resilient transport network. It will also have a significant impact on the liveability of our cities and towns, with less congestion and improved air quality (MfE 2022).

2.1 PURPOSE AND SCOPE

Many initiatives proposed to improve GHG emissions from transport to reduce climate change impacts also result in air quality benefits. Consequently, the aim of this report (Part 2

[6] *New Zealand's Greenhouse Gas Inventory for 2019* reports transport emissions at 14,655 kt CO_2-e, with road tranport emissions at 13,116 kt CO_2-e. https://emissionstracker.environment.govt.nz/

[7] https://www.transport.govt.nz/assets/Uploads/Cabinet-paper-Transport-content-for-the-emissions-reduction-plan.pdf

of the *Public Health Risks Associated with Transport Emissions in New Zealand*) was to estimate the likely improvement in air pollution health impacts associated with meeting the GHG reduction targets in *Te hau mārohi ki anamata* (the ERP).

Average emissions from the motor vehicle fleet are expected to reduce with gradual introduction of newer low emission and electric vehicles into the fleet and retirement of older high emission vehicles. However, these reductions could be offset by growth in vehicle kilometres travelled (VKT) and growth in the number of people exposed to air pollution, particularly in urban areas.

The key steps we followed in our assessment involved:

- Estimating the air pollution health impacts and social costs of motor vehicle emissions in 2019 to establish current impacts
- Assessing the change in motor vehicle emissions between 2019 and 2035 for business as usual (BAU) and scenarios representing the achievement of the various ERP transport sector targets (the scenarios)
- Calculating the associated air pollution health impacts and social costs[8] of motor vehicle emissions in 2035 for BAU and the scenarios, based on the changes in emissions and population and health incidence projections.

We also quantified the cumulative benefits of air pollution and GHG emissions reductions from motor vehicles for two key scenarios.

2.2 REPORT STRUCTURE

This report is structured as follows:

- Chapter 3 reviews motor vehicle emissions and their impacts in New Zealand
- Chapter 4 describes the methodology we developed to model current and likely future emissions associated with achieving a range of GHG reduction targets
- Chapter 5 presents the results of the assessment
- Chapter 6 summarises our key findings.

A glossary of terms and abbreviations is included at the end followed by a list of all references.

All data, assumptions and calculations are contained in an Excel workbook, which is available separately.

[8] The air pollution costs are based on damage costs reported in the *Health and Air Pollution in New Zealand 2016* report (Kuschel *et al* 2022a) and reflect the costs to society – i.e. social costs. However, the GHG costs are based on shadow emission values for CO_2-e published by the NZ Treasury (2021) in Appendix 5 of their *CBAx Tool User Guidance* and are based on the likely future abatement costs rather than the social costs associated with emissions. Treasury recommends using these shadow values to ensure consistency and comparability across cost-benefit analyses undertaken by government agencies.

3. VEHICLE EMISSIONS AND IMPACTS

This section reviews motor vehicle emissions and their impact in New Zealand.

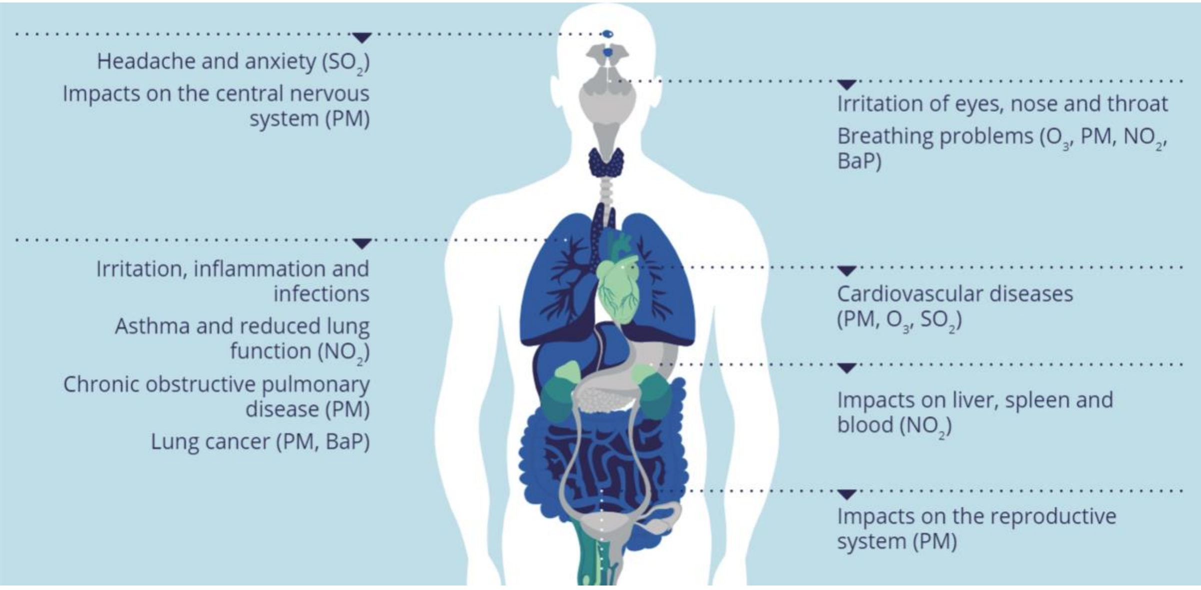
3.1 EMISSIONS FROM MOTOR VEHICLES

Air emissions from vehicles are typically split into harmful air pollutants (which impact locally) and greenhouse gases (which impact globally).

3.1.1 Harmful air pollutants

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.

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



Source: EEA (2020)

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

Air pollution comprises a complex mixture of gases and particles. It is not feasible to measure or assess the effects of all the individual components of air pollution, so the assessment of health impacts is simplified by focusing on key contaminants. These key contaminants may be acting as proxies for the overall air pollution mixture (WHO 2016).

In New Zealand, the pollutants of most concern are:

- 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.

3.1.2 Greenhouse gases

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

New Zealand's *Greenhouse Gas Inventory* (MfE 2022) quantifies emissions of the following gases from motor vehicles, which have direct warming effects:

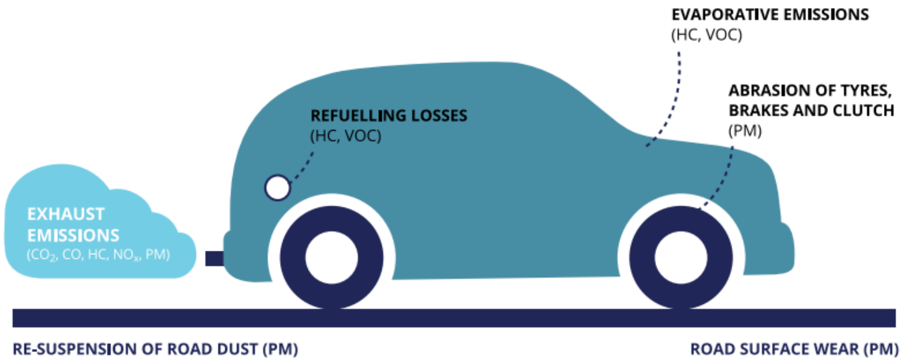
- Carbon dioxide (CO_2) – which is released from combustion of all fossil fuels (especially mineral-based petrol and diesel). Combustion of renewable fuels also produces CO_2 but the net effect is considered zero as the CO_2 is then re-captured in the production of the renewable fuels.
- Methane (CH_4) – 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 (but the major source in New Zealand is agriculture).

Note: Some harmful air pollutants (e.g. NOx) are included in New Zealand's *Greenhouse Gas Inventory* because they are *indirect* climate pollutants. They do not have a direct warming effect but react with other gases and increase GHG concentrations. Consequently, reductions in harmful air pollutants typically yield both health and climate change benefits.

3.1.3 Types of vehicle emissions

Motor vehicles generate different types of air emissions during their operation as shown in Figure 2[9] (EEA, 2016).

FIGURE 2: Different types of emissions from the operation of internal combustion engine vehicles



Source: EEA (2016)

Note: CO_2=carbon dioxide; CO=carbon monoxide; NOx=nitrogen oxides; PM=particulate matter; HC=hydrocarbon; VOC=volatile organic compounds.

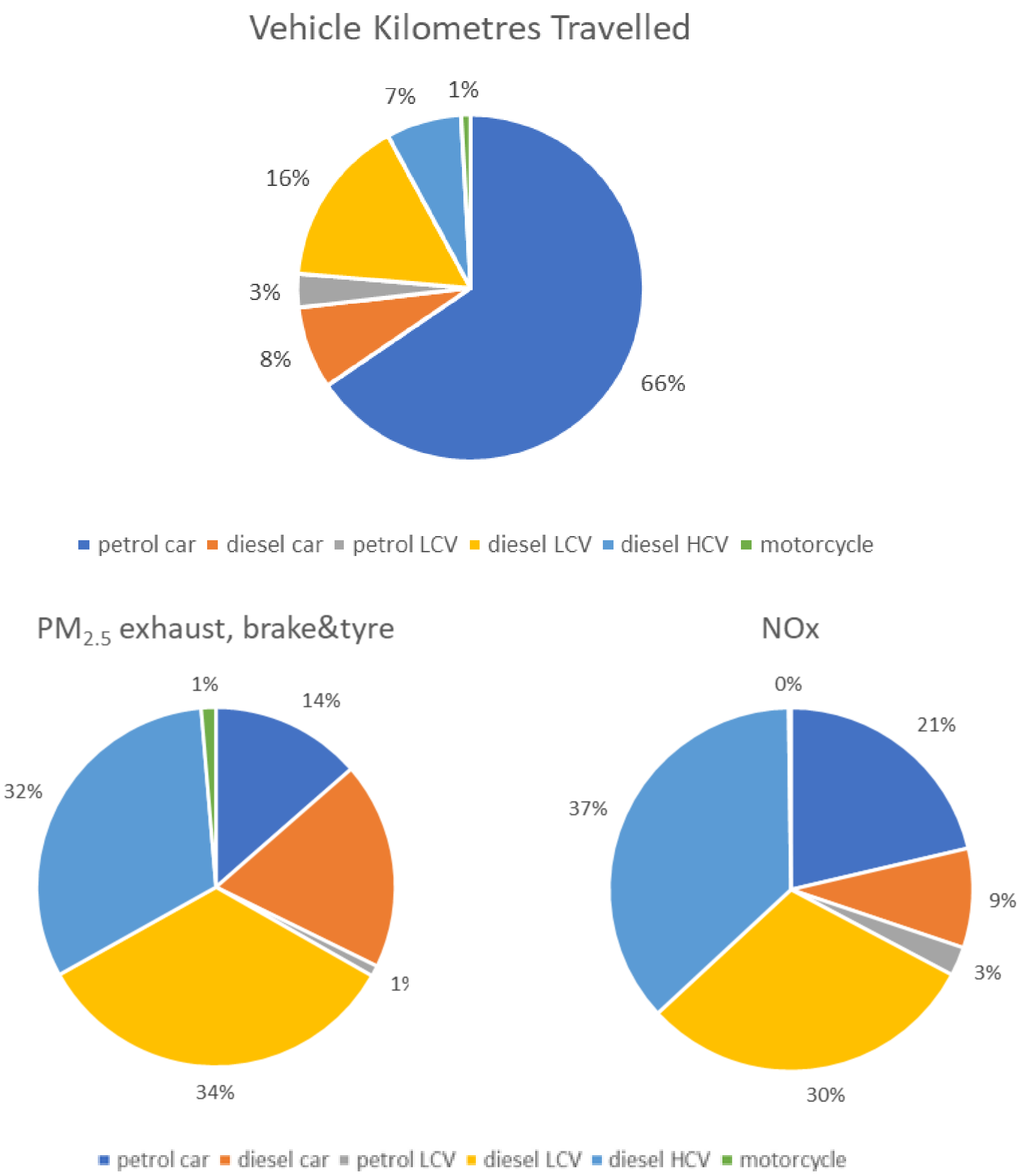
Internal combustion engines emit a range of pollutants via the **exhaust**. The amount of each pollutant released depends on the fuel used (e.g. petrol or diesel) and the engine technology (including emission control equipment). The mechanical **abrasion** of vehicle parts and road surface wear also generates emissions. Abrasion is a key source of emissions of particulate

[9] This figure refers to emissions released during the operating stage only of the full life cycle of vehicles.

matter and some heavy metals. Vapours can escape from vehicle fuel systems via **evaporation** and during **refuelling**, resulting in increased emissions of volatile organic compounds. While electric vehicles have no direct exhaust or evaporative emissions, they still produce abrasion emissions via brake, tyre wear and road surface wear.

Road transport emissions in New Zealand were recently assessed in detail as part of the *Domestic Transport Costs and Charges* (DTCC) project (Kuschel *et al* 2021). This study found that petrol vehicles, while accounting for 69% of VKT, only accounted for 24% of NOx and 15% of $PM_{2.5}$ emissions from all on-road motor vehicles in New Zealand in 2018/19 (Figure 3). Most of the emissions were from diesel heavy commercial vehicles (HCVs) and light commercial vehicles (LCVs) which accounted for only 31% of total VKT.

FIGURE 3: Contribution of different vehicle types to total vehicle kilometres travelled, $PM_{2.5}$ and NOx emissions for the entire New Zealand fleet in 2018/19



Source: DTCC Project (Kuschel *et al* 2021)

Note: Petrol car includes petrol, hybrid and plug-in hybrids. Road surface wear is not included in the $PM_{2.5}$ total.

3.2 AIR POLLUTION IMPACTS OF MOTOR VEHICLES IN NZ

The social costs and health impacts associated with air pollution emissions can be assessed using either detailed or screening methods.

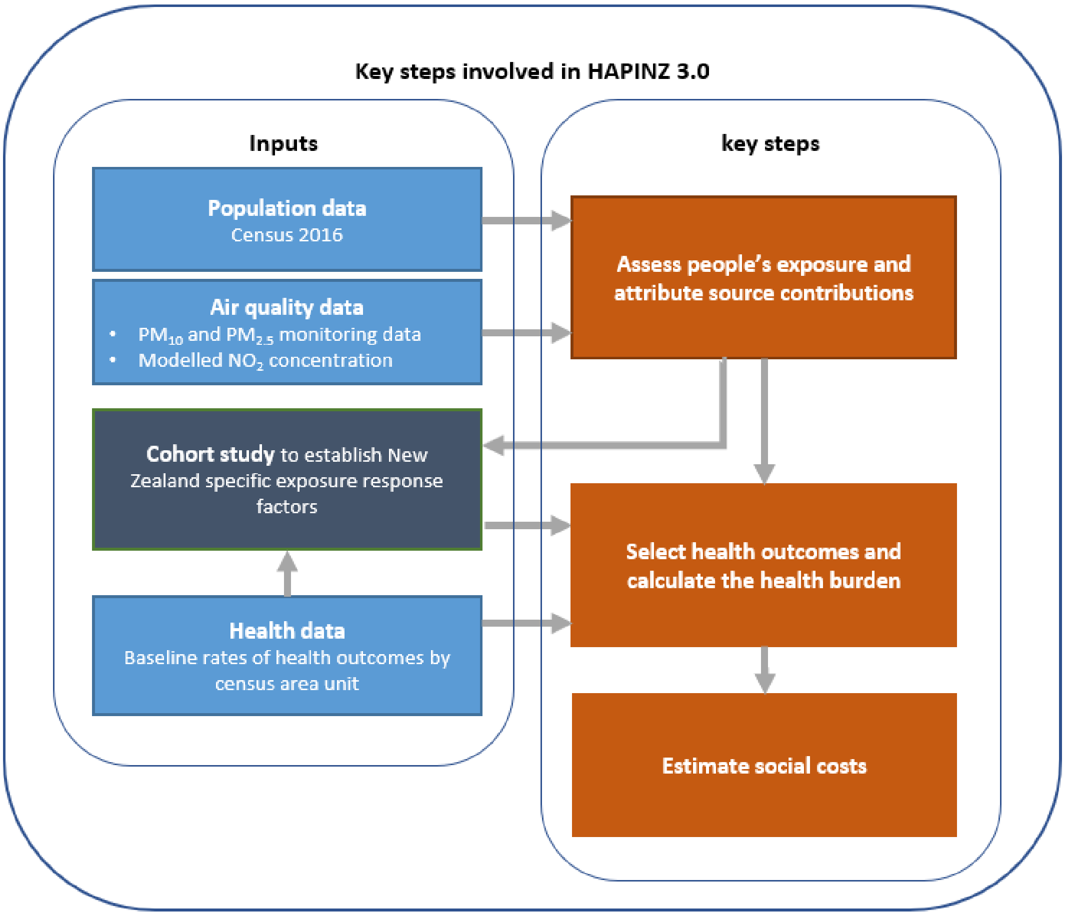
Detailed assessments typically estimate effects at a fine scale then aggregate results to airshed, regional or national totals (a bottom up process). While they provide information that is vital for tailoring local emissions management strategies, detailed assessments are time and resource intensive and are therefore usually undertaken infrequently.

A simpler way to estimate impacts is to use a **screening** method, e.g. damage costs for air pollution health impacts. The social costs associated with changes in harmful air pollution can be calculated by combining the emissions (usually expressed in grams or tonnes of each pollutant) with unit damage costs (expressed in $ per tonne). Damage costs are typically derived from the results of detailed assessments.

3.2.1 The HAPINZ 3.0 study

The *Health and Air Pollution in New Zealand 2016* (HAPINZ 3.0) study is the most recent detailed assessment of air pollution health impacts in New Zealand (Kuschel *et al* 2022a). HAPINZ 3.0 followed the steps shown in Figure 4 to estimate the impacts of exposure to $PM_{2.5}$ and NO_2 air pollution from all sources, based on 2016.

FIGURE 4: Key steps involved in the HAPINZ 3.0 study



As part of HAPINZ 3.0, a cohort study was undertaken to develop New Zealand-specific exposure response functions for $PM_{2.5}$ and NO_2 mortality and morbidity (Hales *et al* 2021).

3.2.2 The HAPINZ 3.0 Health Effects Model

The primary tool developed in HAPINZ 3.0 is a *Health Effects Model* (Sridhar *et al* 2022a). The model is an Excel workbook and allows end-users to output results nationally, regionally, by airshed or by district health board. End-users are also able to run scenarios for comparison with the base case, by selecting from a range of plausible input values of population, exposure and epidemiological exposure-response functions. The scenario option can be used to undertake sensitivity testing to test the effects of different assumptions, evaluate the effects of population and emissions trends, or review the effectiveness of different air quality management options. Instructions for using the model are provided in a *Users' Guide* (Sridhar *et al* 2022b).

Key data and calculations used in the model are summarised in the following sections, with the key features of the study listed in Appendix A. Full details on all data sources, assumptions and methodology are provided in the *HAPINZ 3.0 Volume 2 - Detailed methodology* report (Kuschel *et al* 2022b).

Evaluating exposure

Understanding how much air pollution people are experiencing (exposure) is critical to understanding potential health impacts.

The model includes population data, health data and estimated concentrations of PM_{10}, $PM_{2.5}$ and NO_2 for every census area unit (CAU) in New Zealand for 2016. [10]

- Population data were sourced from Stats NZ for the estimated resident population as at 30 June 2016, based on 2018 census.
- Health data were based on mortality and hospitalisation datasets from the Ministry of Health (MoH) averaged across 2015-2017 with a mid-point of 2016 to reduce inter-annual variability.
- PM_{10} and $PM_{2.5}$ concentrations were based on measured concentrations at ambient monitoring sites averaged across 2015-2017 (where possible) with a mid-point of 2016 to reduce inter-annual variability due to meteorological conditions. Assumptions were made to estimate the concentration of PM_{10} and $PM_{2.5}$ at unmonitored locations based on the concentration at monitored locations.
- NO_2 concentrations were based on estimates generated from Waka Kotahi models, such as the National Vehicle Emissions Dataset (NVED) exposure tool (Jacobs 2016).

Selecting health outcomes and calculating the health burden

The HAPINZ 3.0 model includes a range of mortality and morbidity outcomes (with the primary ones shown in Table 1). For each CAU, the health burden is calculated as follows:

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

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 (i.e. health data based on analysis of MoH mortality and hospitalisations datasets by CAU).

[10] 2016 was chosen as the base year because it was the most recent year for which all the data required were available when HAPINZ 3.0 commenced in 2019

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[11], e.g. 1.105 for every 10 µg/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 µg/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 (i.e. zero), recognising that there is no known safe threshold for most air pollutants.

TABLE 1: Primary health outcomes assessed in HAPINZ 3.0

POLLUTANT	HEALTH OUTCOME
$PM_{2.5}$	Premature deaths from long-term (annual) exposure for all adults 30+ years, all ethnicities
	Cardiovascular hospitalisations from long-term (annual) exposure for all ages, all ethnicities
	Respiratory admissions from long-term (annual) exposure for all ages, all ethnicities
	Restricted activity days from long-term (annual) exposure for all ages, all ethnicities
NO_2	Premature deaths from long-term (annual) exposure for all adults 30+ years, all ethnicities
	Cardiovascular hospitalisations from long-term (annual) exposure for all ages, all ethnicities
	Respiratory admissions from long-term (annual) exposure for all ages, all ethnicities
	Asthma prevalence due to long-term (annual) exposure all children 0-18 years, all ethnicities

Source: Kuschel *et al* (2022b)

Note: The health outcomes shown are independent and therefore the burden for each can be summed to yield a total health burden. **Prevalence** is the proportion of the population or total number of cases of disease *existing* in a population. **Incidence** is the number of *newly diagnosed* cases of a disease in a given period (e.g. 1 year).

Estimating social costs

The model includes costs per case for each type of mortality and morbidity outcome in NZ$ as at June 2019. The social costs of air pollution are then calculated as follows:

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

In simple terms, the health effects cases estimated from the previous formula (e.g. the number of premature deaths) are combined with published health cost data (e.g. the value of a statistical life, VoSL as at June 2019) to estimate costs.

3.2.3 Impacts and costs of motor vehicle air pollution in NZ

HAPINZ 3.0 estimates the total social costs associated with anthropogenic (human-made) air pollution in New Zealand in 2016 to be $15.6 billion or $3,312 per person (Kuschel *et al*

[11] A relative risk of 1.105 means the risk increases by 10.5% per pollution increment, in this case per 10 µg/m^3 of annual average PM_{10}.

2022a). Motor vehicles alone were found to account for 67% of the health effects associated with air pollution from all anthropogenic sources - resulting in 2,160 premature deaths, nearly 9,400 hospitalisations and more than 330,000 restricted activity days each year in New Zealand at a cost of more than $10.5 billion.

Note: The results from HAPINZ 3.0 are significantly different to the previous HAPINZ study undertaken for 2006 (HAPINZ 2.0) which estimated that motor vehicles accounted for 22% of the health impacts associated with anthropogenic sources (Kuschel *et al* 2012).

In HAPINZ 2.0, the total anthropogenic costs were assigned to PM_{10} only (as a proxy for all air pollution) because of limitations in data availability. Because the impacts were assigned to sources based on their contributions to PM_{10} (rather than all) air pollution, the findings prioritised addressing domestic fire emissions over motor vehicle emissions for most locations across New Zealand.

In HAPINZ 3.0, sufficient information meant that both $PM_{2.5}$ and NO_2 were able to be used as the indicators for air pollution, and their effects were found to be independent of one another. Domestic fires were identified as the primary contributor to anthropogenic $PM_{2.5}$ impacts. However, motor vehicles were assigned as the sole source of NO_2 exposure. Exposure to NO_2 accounts for just over 60% of the total social costs associated with anthropogenic air pollution in New Zealand.

3.3 GREENHOUSE GAS EMISSIONS FROM MOTOR VEHICLES IN NZ

The New Zealand government has committed to a 50% reduction in net emissions in our gross 2005 level by 2030 (New Zealand's Nationally Determined Contribution under the Paris Agreement)[12] and achieving net zero emissions of all GHGs other than biogenic methane by 2050 (*Climate Change Response Act*)[13].

The transport sector is one of the largest sources of GHG emissions in New Zealand, accounting for 18% of Aotearoa's gross CO_2-e emissions (MfE 2022). Around 90% of transport emissions are from on-road motor vehicles[14]. To achieve current targets and obligations, motor vehicle GHG emissions need to reduce by approximately 41% by 2035 compared with 2019, and the transport sector needs to be largely decarbonised by 2050. This requires urgent action and system wide changes (MfE 2022).

3.3.1 The Emissions Reduction Plan

Te hau mārohi ki anamata, Aotearoa New Zealand's first emissions reduction plan (ERP) sets out a pathway to achieve our GHG obligations (MfE 2022).

For transport, the approach to GHG emissions reduction is guided by three focus areas:

- reduce reliance on cars and support people to walk, cycle and use public transport
- rapidly adopt low emissions vehicles
- begin work now to decarbonise heavy transport and freight.

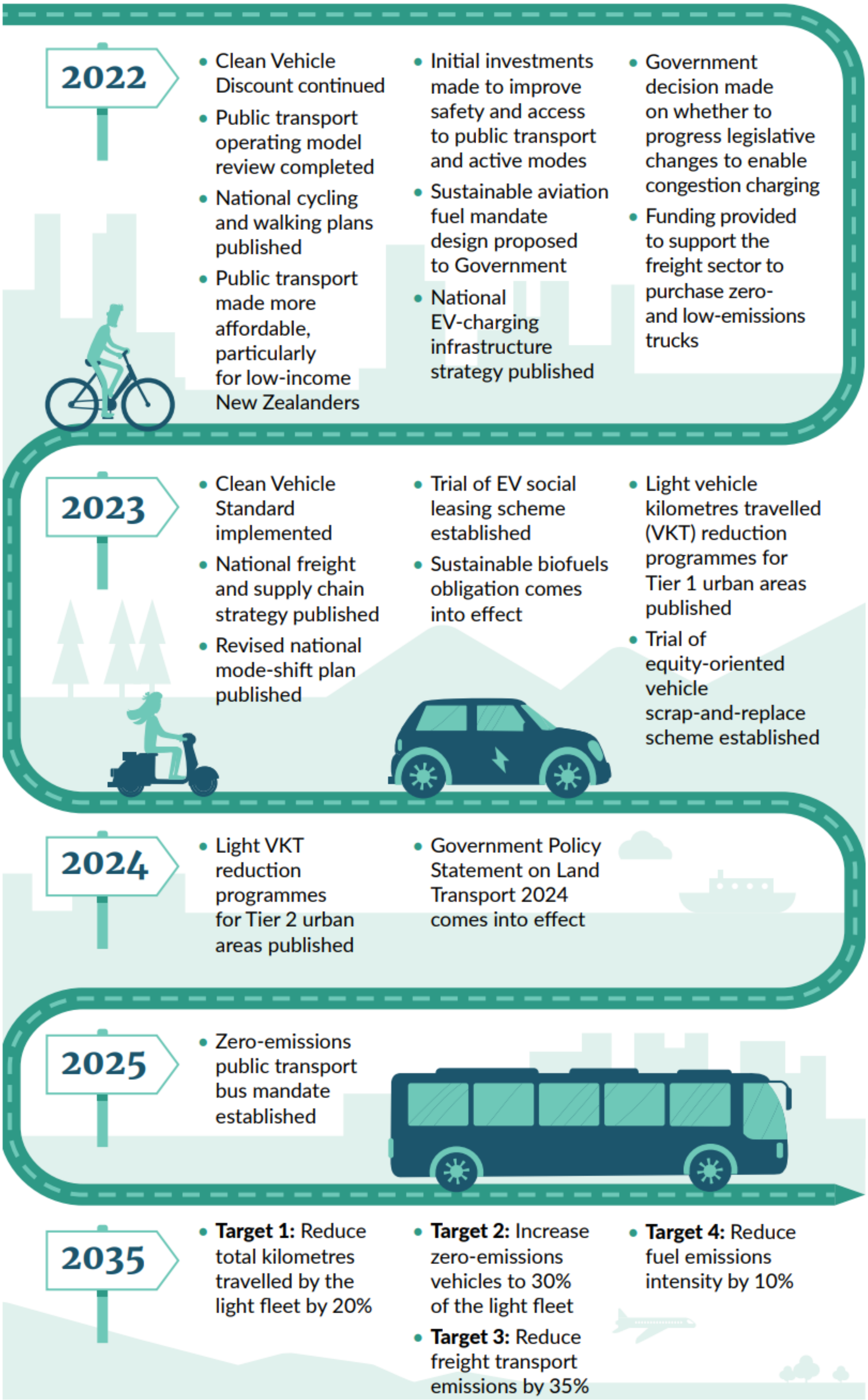
[12] https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/emissions-reduction-targets/greenhouse-gas-emissions-targets-and-reporting/

[13] https://environment.govt.nz/acts-and-regulations/acts/climate-change-response-act-2002/

[14] *New Zealand's Greenhouse Gas Inventory for 2019* reports transport emissions at 14,655 kt CO_2-e, with road tranport emissions at 13,116 kt CO_2-e. https://emissionstracker.environment.govt.nz/

Figure 5 highlights some of the key actions over the next three years in the ERP for achieving the 2035 transport targets.

FIGURE 5: Some key actions to put Aotearoa on track for achieving 2035 transport targets



Source: MfE (2022)

The ERP sets four targets that will support the focus areas and align with achieving the required CO_2-e emissions reductions for transport by 2035, as follows:

Target 1 Reduce total kilometres travelled by the light vehicle fleet by 20% by 2035 through improved urban form and providing better travel options, particularly in our largest cities

Target 2 Increase zero emissions vehicles to 30% of the light fleet by 2035

Target 3 Reduce emissions from freight transport by 35% by 2035

Target 4 Reduce the emissions intensity of transport fuels by 10% by 2035

Targets 1, 2 and 4 are relative to a baseline projection prepared by Te Manatū Waka Ministry of Transport. Target 3 is relative to 2019 levels and includes trucks, rail and ships.[15]

Achieving these targets will mean that New Zealanders will have better transport choices, cleaner and more efficient vehicles, and a safer and more resilient transport network. It will also have a significant impact on the liveability of our cities and towns, with less congestion and improved air quality (MfE 2022).

3.3.2 Treasury shadow emissions values

The costs and benefits associated with greenhouse gas emissions are based on shadow emissions values for CO_2-e (expressed in \$ per tonne) published by the NZ Treasury in Appendix 5 of their *CBAx Tool User Guidance* (Treasury 2021).

These are based on estimates of future costs of emissions reductions (abatement) required to reach New Zealand's domestic emissions targets, as reflected in the Climate Change Commission's final advice, rather than the social costs associated with emissions (which is the case for harmful emissions). Treasury recommends using these shadow values to ensure consistency and comparability across cost-benefit analyses undertaken by government agencies in New Zealand. These values are typically updated annually as knowledge improves on New Zealand's costs of abatement.

[15] https://www.transport.govt.nz/assets/Uploads/Cabinet-paper-Transport-content-for-the-emissions-reduction-plan.pdf

4. METHODOLOGY

This chapter describes the methodology we developed to model current and likely future motor vehicle emissions and their associated air quality impacts resulting from a range of scenarios. These scenarios included business as usual (BAU) trends and the achievement of the various targets (the scenarios) set in *Te hau mārohi ki anamata* (the ERP).

The key steps were:

1. Update the HAPINZ 3.0 health effects model to create an exposure model for 2019 and estimate current air pollution health impacts and social costs of motor vehicle emissions
2. Develop a HAPINZ 3.0 health effects model for 2035 to enable assessment of air pollution health impacts for BAU and the scenarios
3. Estimate fleet weighted emission factors for representative vehicle categories (e.g petrol cars, diesel cars, electric cars etc) between 2019 and 2035
4. Estimate vehicle kilometres travelled by each representative vehicle category between 2019 and 2035 for BAU and the scenarios
5. Combine the emission factors and vehicle kilometres travelled to calculate emissions of NOx and $PM_{2.5}$ for each representative vehicle category between 2019 and 2035
6. Calculate scalars to be applied to the 2019 exposure data, based on the estimated changes in total motor vehicle emissions between 2019 and 2035, for BAU and the scenarios. This assumes that the changes in motor vehicle $PM_{2.5}$ and NO_2 *concentrations* between 2019 and 2035 mirror the estimated changes in motor vehicle $PM_{2.5}$ and NOx *emissions* between 2019 and 2035
7. Apply the scalars to the 2035 HAPINZ projection model (which has 2019 exposure data) to generate the 2035 BAU and scenario exposure estimates to estimate health impacts
8. Estimate the corresponding social costs of motor vehicle emissions in 2035 for BAU and all other scenarios
9. Estimate cumulative total costs between 2021 and 2035 for two key scenarios.

Key steps are described in the following sections. Detailed assumptions and calculations are provided in the accompanying Excel workbook.

4.1 UPDATING THE HAPINZ 3.0 MODEL TO 2019

The HAPINZ 3.0 health effects model was originally established for a base year of 2016.

We updated the model to 2019 to provide the most relevant starting point for this analysis.

Note: 2019 was selected after reviewing scenario modelling undertaken in HAPINZ 3.0 to test the uncertainty of using the population and pollution scalars in the health effects model. The uncertainty analyses identified issues with predictions of health impacts beyond 2019 as COVID-19 border closures and lockdowns severely limited the impact of seasonal influence and other diseases (Kuschel *et al* 2022b). Data for 2020 and 2021 were out of alignment with previous long-term trends.

4.1.1 Population

The HAPINZ 2016 model utilises estimated resident population for 2016 by 2013 CAUs.

For the HAPINZ 2019 model, this information was updated with the estimated resident population as a two-year mean for 2018-19, using population data by 2013 CAUs for 2018 and 2019 provided by Stats NZ[16].

4.1.2 Health data

The HAPINZ 2016 model includes three-year averaged health statistics for mortality and morbidity for a base year of 2016.

For the HAPINZ 2019 model, the following health data were updated:

- Mortality (non-external causes 30+ years) by CAU as a two-year mean for 2018-19 was calculated based on actual mortality data for 2018 and estimated mortality for 2019. Mortality for 2019 was estimated based on 2019 population data (30+ years) and 2016-2018 average mortality rates (30+ years) calculated for each CAU.
- Cardiovascular and respiratory hospitalisations (all ages) by CAU was updated with actual hospitalisation data averaged across 2018-2019 to reduce inter-annual variability.
- Asthma prevalence (0-18 years) was scaled in proportion to population change in each CAU between 2016 and 2018-19 (two-year mean), for the 0-18 year age group.

4.1.3 $PM_{2.5}$ concentrations

The HAPINZ 2016 model estimates exposure to PM_{10} and $PM_{2.5}$ for every CAU in New Zealand based on measured concentrations at ambient monitoring sites with a base year of 2016.

For the HAPINZ 2019 model, ambient air quality concentrations were updated for all monitoring sites in the model where updated data were available. To account for inter-annual variability in meteorology, PM_{10} and $PM_{2.5}$ data were updated using two-year averages, calculated from 2018 and 2019[17].

The assumptions for assigning concentrations in CAU without monitoring data were not reviewed or updated. These assumptions are described in Kuschel *et al* (2022b).

4.1.4 NO_2 concentration

The HAPINZ 2016 model estimates exposure to NO_2 for every CAU in New Zealand using modelling estimates from the NZ Transport Agency *National Vehicle Emissions Dataset* (NVED) exposure tool for 2016 (Jacobs 2016).

For the HAPINZ 2019 model, the 2016 dataset was updated by applying a pollution scalar of 0.9354 to all locations as recommended in Kuschel *et al* (2022b). This scalar was derived based on trends in data recorded for passive NO_2 samplers deployed in the Waka Kotahi national ambient air quality network. The reduction in NO_2 likely reflects improvements in the emissions performance of the vehicle fleet, due to the uptake of cleaner vehicles, despite the growth in VKT that has occurred.[18]

4.1.5 Updated 2019 health impacts

Table 2 and 3 compare the estimates for the HAPINZ 2019 model with those for the HAPINZ 2016 model.

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[16] Source: Stat NZ, customised report and licensed by Stats NZ for re-use under the Creative Commons Attribution 4.0 international licence.

[17] Annual average PM_{10} and $PM_{2.5}$ ambient air quality monitoring data were provided for all available monitoring sites by Stats NZ.

[18] See https://www.nzta.govt.nz/resources/air-quality-monitoring/

As seen in Table 2, population-weighted average concentrations of $PM_{2.5}$ and NO_2 have improved between 2016 and 2019. However, Table 3 shows there is little overall change in impacts and costs. This is most likely due to the air quality improvements being offset by population growth.

TABLE 2: Population and populated-weighted concentrations in the HAPINZ 2019 model versus the HAPINZ 2016 model

PARAMETER	2016	2019
Total population	4,714,055	4,939,965
Population-weighted annual average $PM_{2.5}$	6.5 µg/m^3	6.4 µg/m^3
Population-weighted annual average NO_2	7.8 µg/m^3	7.3 µg/m^3

TABLE 3: Estimated health impacts from the HAPINZ 2019 model compared with the HAPINZ 2016 model – anthropogenic sources only

HAPINZ 3.0 ESTIMATES (ANTHROPOGENIC ONLY)		
EFFECT	2016 CASES/YR	2019 CASES/YR
Cases due to annual $PM_{2.5}$		
Premature mortality (all adults)	1,292	1,275
Cardiovascular hospitalisations (all ages)	2,639	2,746
Respiratory hospitalisations (all ages)	1,985	2,041
Restricted activity days (all ages)	1,745,354	1,771,197
Cases due to annual NO_2		
Premature mortality (all adults)	2,025	1,964
Cardiovascular hospitalisations (all ages)	1,987	2,010
Respiratory hospitalisations (all ages)	6,544	6,440
Asthma prevalence (0-18 yrs)	13,229	12,653
Social costs due to both $PM_{2.5}$ and NO_2		
Social cost ($ million)	$15,613 M	$15,267 M

4.2 PROJECTING THE HAPINZ 3.0 MODEL TO 2035

To estimate impacts of potential air quality improvements in 2035, we created a 2035 version of the HAPINZ 2019 model, based on projected population for 2035.

4.2.1 Population and health data

Population scalars were calculated for each territorial authority and for each Auckland local board area, from the projected % change in population between 2018/19 and 2035 based on:

- Stats NZ subnational population projections[19]

[19] *Subnational population projections, by age and sex, 2018(base)-2048 dataset* downloaded from Stats NZ on 20 June 2022. https://www.stats.govt.nz/information-releases/subnational-population-projections-2018base2048

- The population projection for 2035 was interpolated, assuming a linear rate of change between the Stats NZ projections for 2033 and 2038.
- Population projections were estimated separately for the age groups in the HAPINZ 2019 model (i.e. total population, 30+ years and 0-18 years).
- Projections were developed for 0-18 years age group using 0-14 years + (0.8 * 15-19 years) assuming equal distribution in the 15-19 year age group.

The scalars were applied to calculate 2035 projected population for each CAU.

The scalars (for the relevant age group) were applied to 2018-19 health data to estimate 2035 health data for each CAU for:

- 2035 mortality (non-external causes 30+ years)
- 2035 cardiovascular and respiratory hospitalisation (all ages)
- 2035 asthma prevalence (0-18 years)

Note: The projections for 2035 assume that health incidence (the *number* of new cases) will increase in proportion to population, which is the best assumption we can currently make.

Prior to COVID-19, mortality *rates* had improved since 1970 (due to various changes including improved health care in New Zealand) [20]. However, at the same time, New Zealand's population has grown considerably and the proportion in older age brackets has increased (the median age was 25.6 years in 1970, and 38.0 years in 2020[21]). These demographic changes mean that total number of deaths per year and new cases of disease increase, although age-specific mortality continues to fall. The median age of New Zealand's population is predicted to increase to 41.3 years by 2035.

4.2.2 $PM_{2.5}$ and NO_2 concentrations

Our modelling assessed the impacts of $PM_{2.5}$ and NO_2 – the primary harmful air pollutants in motor vehicle emissions – consistent with the HAPINZ 3.0 health effects model.

Note: The HAPINZ 3.0 study developed exposure-response functions for $PM_{2.5}$ and NO_2 using a two pollutant model, so effects from both pollutants could be considered together (i.e. are additive).

The concentrations of $PM_{2.5}$ and NO_2 were assumed to change in proportion to projected changes in motor vehicle $PM_{2.5}$ and NOx emissions between 2019 and 2035. The method for adjusting $PM_{2.5}$ and NO_2 concentrations in 2035 is described later in Section 4.7.

4.2.3 Scenarios

We developed a range of scenarios representing options to achieve the various targets set in *Te hau mārohi ki anamata* (the ERP) to compare with BAU predictions for 2035. The impact on harmful emissions of achieving the scenarios was assessed individually (for each target) as well as collectively (all targets met in a combined scenario to achieve the ERP pathway).

In addition, for achievement of the overall ERP pathway, we investigated the extent to which improvements could be made to the performance of light duty diesel vehicles – testing a

[20] See https://www.macrotrends.net/countries/NZL/new-zealand/death-rate and Woodward & Blakeley (2014). *The healthy country? A history of life and death in New Zealand*. Auckland University Press 2014

[21] See https://www.statista.com/statistics/436388/average-age-of-the-population-in-new-zealand/

comparable improvement to light duty petrol vehicles (Scenario 5). We looked also at the effects of making no reduction in VKT of light duty diesel vehicles (Scenario 6).

As discussed in Section 3.1.3, diesel vehicles contribute disproportionately to air pollution health impacts in New Zealand. Light duty diesel vehicles, especially diesel vans and utes, tend to be bigger and travel further than typical petrol vehicles (MoT 2021). Commercial vehicles (which are typically diesel vans and utes) are also more likely to undertake trips that cannot be easily replaced by public transport or active modes. However, most trips undertaken by vans/utes are not work-related, and could, potentially, be replaced by other modes.

In the 2015-2018 Household Travel Survey, work-related trips accounted for only a third of VKT in the van/ute category: the proportions of VKT for shopping or personal appointments and social visits were similar to the figures for cars. Currently, there are few options for electrifying these vehicles, which is important because utes are currently the most popular new light vehicle in New Zealand and they are, predominantly, diesel-powered (Woodward *et al* 2021). Scenarios 5 and 6 are intended to provide an indication of the potential impact of policy design with respect to light duty diesel vehicles.

Emissions and social costs were estimated for the ERP baseline and six policy scenarios as shown in Table 4.

TABLE 4: Scenarios developed in relation to ERP targets for transport

SCENARIO DESCRIPTION	EMISSIONS REDUCTION PLAN TARGET
BAU: Business as usual fleet VKT and composition for 2035	*Not applicable as no additional policy interventions*
Scenario 1: Reduce total kilometres travelled by the light fleet by 20% by 2035	**Target 1:** Reduce total kilometres travelled by the light fleet by 20% by 2035
Scenario 2: Increase zero emissions vehicles to 30% of the light fleet by 2035	**Target 2:** Increase zero emissions vehicles to 30% of the light fleet by 2035
Scenario 3: Reduce truck VKT *and* **Scenario 4:** Increase percentage of electric trucks	**Target 3:** Reduce emissions from freight transport by 35% by 2035
Scenario 5: Scenarios 1 to 4 combined, assuming light duty diesel and petrol vehicles impacted equally Or **Scenario 6:** Scenarios 1 to 4 combined, but assuming the BAU VKT of light duty diesel vehicles stays the same	**ERP pathway:** Meet all four targets (including **Target 4:** Reduce the emissions intensity of fuel by 10% by 2035)*

***** We did not assess Target 4 separately as a scenario because the findings from the literature for harmful emissions benefits are mixed and are highly dependent on engine technology and the quality of the conventional fuels being compared against. If the fuels are “drop-in” fuels, with the same properties as conventional fuels, then the harmful emissions will be the same. Consequently, we assumed that there was no air quality benefit from meeting Target 4 but we did include the GHG benefit.

Note: The scenarios are intended to estimate the *relative* impact of key transport outcomes separately. However, relative effects are indicative only because the scenarios ignore potential inter-dependency and synergies between policies.

4.3 ESTIMATING FLEET WEIGHTED EMISSION FACTORS

4.3.1 The vehicle emissions prediction model

We derived exhaust, brake and tyre wear emission factors from the Waka Kotahi *Vehicle Emissions Prediction Model* (VEPM 6.3) [22], with modified assumptions for implementation of Euro 6/VI[23] vehicles as described in the next section.

VEPM predicts real world emission factors for the New Zealand fleet under typical road, traffic, and operating conditions, based on the different vehicle types/technologies present and the relative kilometres travelled by each vehicle class. Fleet-weighted factors are calculated by multiplying the factors in grams per kilometre (g/km) for each vehicle class by the proportion of VKT by that class for any given year. VEPM includes actual registrations and VKT up to the present year and uses predictions about fleet turnover and VKT growth etc. from the MoT *Vehicle Fleet Emission Model*[24] for future years out to 2050.

4.3.2 Modified assumptions in VEPM

VEPM 6.3 assumes that Euro 6/VI standards will be implemented in 2030 and that there are no Euro 6/VI vehicles in the fleet prior to this date.

However, at the time of our analysis, MoT had secured Cabinet approval to propose regulations for the implementation of Euro 6/ VI standards earlier than 2030 – although timeframes were yet to be confirmed. MoT staff recommended the assumed implementation date be brought forward to ensure that the emissions reduction potential of policies was not *over*-estimated. Consequently, a modified version of VEPM 6.3 was created, assuming Euro 6/VI standards would be implemented earlier, in 2025.

4.3.3 Exhaust, brake and tyre wear emission factors

VEPM is an average speed model which means emission factors will vary depending on the speed selected (factors are available for speeds between 10 and 110 km/hour). To simplify our analyses, emission factors were estimated for a single speed for all years and all scenarios. An average speed of 48 km/hr was selected based on previous research, which found that VEPM predicts realistic real world fuel consumption factors for New Zealand (Metcalfe *et al* 2021).

Emission factors for exhaust, brake and tyre wear were generated from the modified VEPM 6.3 using an average speed of 48 km/hour for all years from 2021 to 2035. Default values were used for all other settings in VEPM.

4.3.4 Road wear emission factors

VEPM does not include road wear emission factors. These were derived from the European EMEP/EEA emission inventory guidebook (EMEP/EEA 2019)[25].

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[22] See https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/environment-and-sustainability-in-our-operations/environmental-technical-areas/air-quality/vehicle-emissions-prediction-model/

[23] Euro 6 and Euro IV are the latest vehicle exhaust emission standards required for on-road vehicles sold in Europe and the United Kingdom. Standards with Arabic numerals, e.g. 6, apply to light duty vehicles and those with Roman numerals, e.g. VI, apply to heavy duty vehicles. Since November 2016, all new vehicles (diesel or petrol) entering the New Zealand fleet have been required to meet Euro 5/V (the earlier standards). Euro 6/VI standards are not yet required in New Zealand but we were advised by MoT staff to assume an implementation date of 2025 in our assessment.

[24] See https://www.transport.govt.nz/statistics-and-insights/transport-outlook/sheet/updated-future-state-model-results#element-1535

[25] See Chapter 1.A.3.b vi - *Road Transport: Automobile Tyre and Brake Wear* and Chapter 1.A.3.b vii - *Road Transport: Automobile Road Abrasion*

4.4 ESTIMATING VEHICLE KILOMETRES TRAVELLED

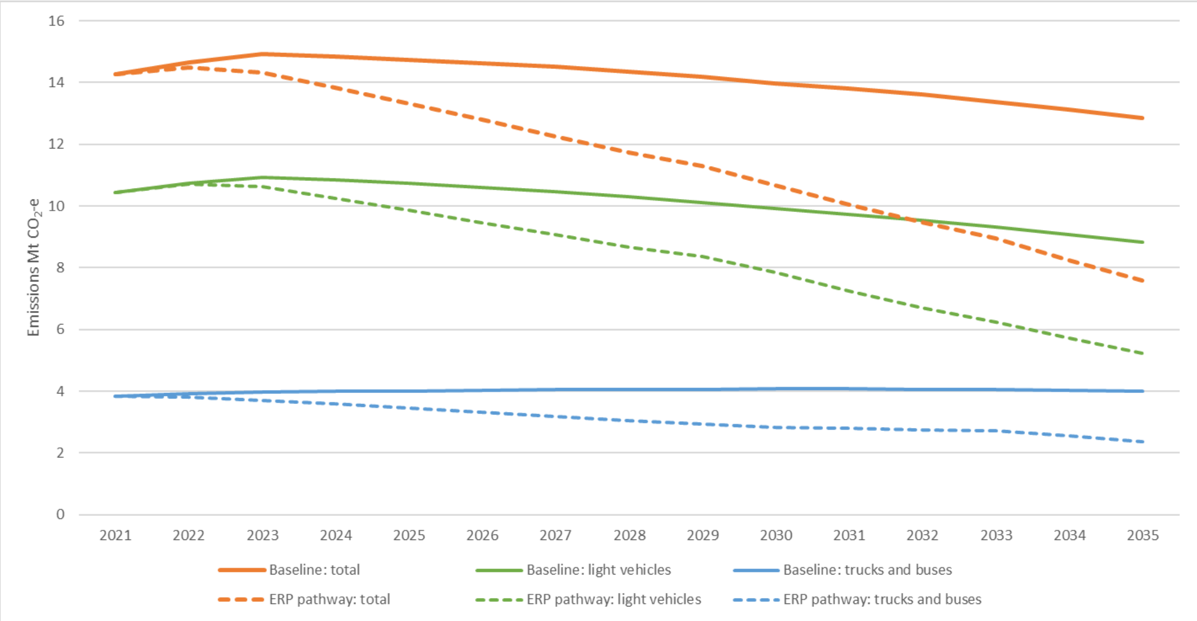
4.4.1 MoT forecasts

All scenarios were based on detailed VKT and fleet data from modelling undertaken by MoT for *Te hau mārohi ki anamata* (the ERP).

All data underpinning the MoT forecasts used in our analyses are included in the accompanying Excel workbook (see *ERP data* worksheet).

Forecasts for on-road vehicle GHG emissions were developed by MoT for BAU and for the pathway adopted in the ERP with all targets achieved (the ERP pathway). Figure 6 compares the predicted CO_2-e emissions resulting from the ERP baseline and the ERP pathway, with emissions from heavy vehicles shown in blue, light vehicles in green, and the total in orange.

FIGURE 6: Forecast CO_2-e emissions from on-road vehicles for the ERP baseline (BAU) and the ERP pathway



Source: MoT forecasts

4.4.2 Fleet profile

The MoT ERP model includes VKT between 2021 and 2035 broken down into internal combustion engine (ICE) or electric vehicles (EV) for the following vehicle types:

- Light vehicles (< 3.5 t)
- Medium truck (3.5 t-10 t)
- Heavy truck (>10 t)
- Bus (> 3.5 t).

Our modelling was undertaken with a base year of 2019 whereas the ERP model has a start year of 2021. For the years 2019 and 2020, we extracted VKT data for these vehicle categories from the *Vehicle Fleet Emissions Model* (VFEM3) [26], which was provided by MoT separately.

For all years from 2019 to 2035, we disaggregated the VKT for each MoT ERP model vehicle category into VEPM subcategories, as shown in Table 5, based on the default fleet profile in VEPM 6.3.

TABLE 5: Vehicle categories in the MoT ERP model and the corresponding VEPM subcategories

MOT ERP MODEL CATEGORY	CORRESPONDING VEPM SUBCATEGORIES
Light duty ICE	• Petrol car • Diesel car • Hybrid car • Plug-in hybrid car • Petrol LCV • Diesel LCV • Hybrid LCV • Plug-in hybrid LCV
Light duty EV	• Electric car • Electric LCV
Medium truck ICE	• Diesel heavy commercial vehicle (<10 t disaggregated by VEPM size categories)
Medium truck EV	• Electric truck (<10 t)
Heavy truck ICE	• Diesel heavy commercial vehicle (>10 t disaggregated by VEPM size categories)
Heavy truck EV	• Electric truck (>10 t)
Bus ICE	• Diesel bus (> 3.5 t disaggregated by VEPM size categories)
Bus EV	• Electric bus (>3.5 t)

4.4.3 BAU and scenario assumptions

The ERP model data provided by MoT includes projected vehicle numbers and VKT for all vehicle categories under BAU. However, under the ERP pathway scenario, data provided includes VKT for the light vehicle fleet only. Vehicle numbers are included for all vehicle categories. MoT also supplied us with separate projections of truck VKT and electric vehicles. Various assumptions were made to estimate VKT for each vehicle category for each scenario based on the data provided by MoT, as summarised in Table 6.

All VKT data and assumptions are available in the accompanying Excel workbook (see the *ERP data* and *MoT truck data* and *VKT* worksheets).

TABLE 6: Summary of VKT and fleet composition assumptions for each scenario

SCENARIO DESCRIPTION	CORRESPONDING VKT AND FLEET COMPOSITION ASSUMPTIONS
BAU: Business as usual fleet VKT and composition for 2035 (no policy interventions)	• Fleet VKT and composition from the BAU projections to 2035, assuming no additional policy intervention

[26] See https://www.transport.govt.nz/statistics-and-insights/transport-outlook/sheet/updated-future-state-model-results

SCENARIO DESCRIPTION	CORRESPONDING VKT AND FLEET COMPOSITION ASSUMPTIONS
Scenario 1: Reduce total kilometres travelled by the light fleet by 20% by 2035	• Total light duty VKT reduces as per MoT projections by approximately 20% versus BAU VKT by 2035 • Total bus VKT calculated based on the number of buses in ERP pathway multiplied by the VKT per bus in BAU. • EV bus VKT based on the proportion of EV buses in the total bus fleet in the ERP pathway multiplied by the revised total bus VKT
Scenario 2: Increase zero emissions vehicles to 30% of the light fleet by 2035	• Total light duty VKT stays the same as BAU • Proportion of EVs in the light fleet increases to 30% in 2035 compared to 14% in BAU • EV light duty VKT increases based on the revised proportion of light duty EVs in the total light duty fleet multiplied by BAU total light vehicle VKT
Scenario 3: Reduce truck VKT	• Truck VKT reduces based on the additional MoT projections • VKT for medium trucks reduces by 14.5% and for heavy trucks by 8.3% relative to BAU total truck VKT in 2035.
Scenario 4: Increase percentage of electric trucks	• Total truck VKT stays the same as BAU • Number of EV trucks taken from the ERP pathway • EV truck VKT based on number of EV trucks in the ERP pathway and the VKT per truck from BAU • Proportion of EVs in the truck fleet increases to 9.2% (medium trucks) and 6.3% (heavy trucks) in 2035 relative to 6.9% (medium) and 3.4% (heavy) in BAU
Scenario 5: Scenarios 1 to 4 combined, assuming the BAU performance of light duty diesel vehicles is influenced (the ERP pathway)	• Combination of Scenarios 1-4 in which the light duty diesel market is part of the ERP pathway • 20% reduction in total light duty VKT as per Scenario 1 • 30% of light duty fleet is electric as per Scenario 2 • Truck VKT and EVs as per Scenarios 3 and 4
Scenario 6: Scenarios 1 to 4 combined, but assuming the VKT of light duty diesel vehicles stays the same as BAU (the ERP pathway but with a constrained market response)	• Combination of Scenarios 1-4 but assuming the light duty diesel market does not comply with the ERP pathway • 20% reduction in total light duty VKT as per Scenario 1 but light duty diesel passenger and commercial VKT unchanged from BAU (the VKT reduction is taken only from light petrol vehicles) • 30% of light duty fleet is electric as per Scenario 2 but light duty diesel VKT unchanged from BAU • Truck VKT and EVs as per Scenarios 3 and 4

4.4.4 Estimated VKT

Figures 7 and 8 present the estimated VKT for BAU and Scenario 5 (the ERP pathway), for different vehicle types – with VKT presented for ICE vehicles and EVs separately.

VKT for all ICE vehicles (light, trucks and buses) essentially does not change between 2019 and 2035 under BAU, with the growth in total VKT reflecting the increase in VKT by EVs.

FIGURE 7: Forecast VKT in the business as usual (BAU) scenario for different vehicle types

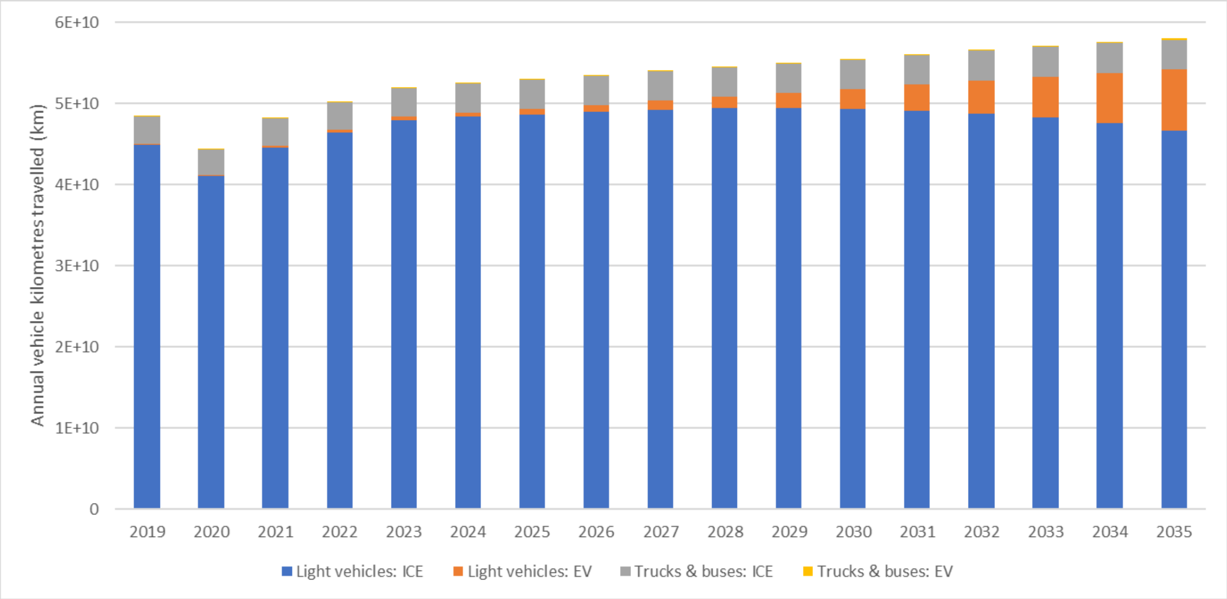


FIGURE 8: Forecast VKT in Scenario 5 (the ERP pathway) for different vehicle types

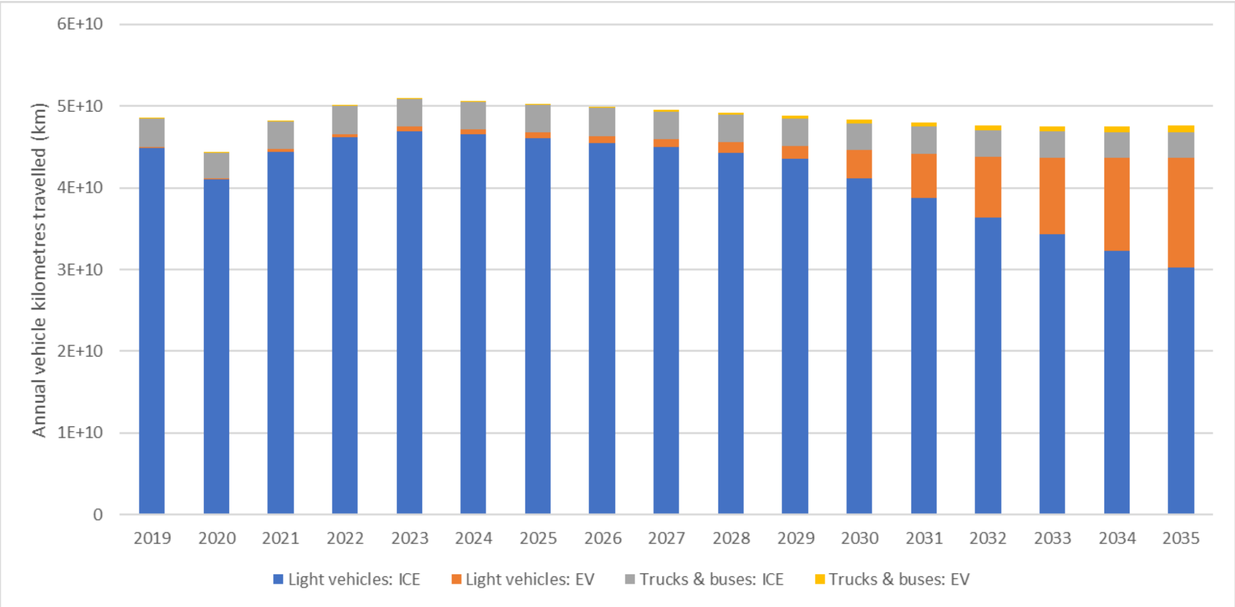


Table 7 summarises the estimated VKT for 2019 and 2035 for BAU and each scenario, with VKT split by ICE vehicles and EVs.

Note: In our modelling of harmful emissions, we estimated VKT for each scenario based on forecasts provided by MoT and based on the assumptions described in this section. Our VKT estimates for different vehicle types may differ from those developed by MoT for other purposes.

TABLE 7: Estimated VKT for 2019 and for BAU and all scenarios in 2035

SCENARIO	VKT (MILLION KM/YR)						
	TOTAL	ICE			EV		
		LIGHT	TRUCK	BUS	LIGHT	TRUCK	BUS
	2019						
BAU	48,427	44,879	3,090	322	134	0	2
	2035						
BAU	58,066	46,643	3,178	430	7,599	146	70
Scenario 1: reduce light duty VKT by 20%	47,911	37,536	3,178	365	6,115	146	571
Scenario 2: increase EV% in light duty fleet to 30%	58,066	37,867	3,178	430	16,375	146	70
Scenario 3: reduce truck VKT	57,735	46,643	2,862	430	7,599	130	70
Scenario 4: increase EV% in truck fleet	58,066	46,643	3,037	430	7,599	286	70
Scenario 5: deliver full ERP pathway (ideal market)*	47,579	30,276	2,706	365	13,375	286	571
Scenario 6: deliver full ERP pathway (constrained market)‡	47,579	30,276	2,706	365	13,375	286	571

***** In Scenario 5, the total light vehicle VKT reduces to 30,276 million km, of which 7,789 million km is undertaken by diesel vehicles and 22,487 million km by petrol and hybrid vehicles.

‡ In Scenario 6, the total light vehicle VKT also reduces to 30,276 million km but the diesel BAU VKT of 12,000 million km is unchanged requiring the petrol and hybrid VKT to reduce to 18,276 million km (a further reduction of nearly 19% over Scenario 5).

4.5 ESTIMATING MOTOR VEHICLE EMISSIONS BETWEEN 2019 AND 2035

The same method was used to estimate emissions for the BAU and for each scenario. Fleet weighted emission factors for each vehicle subcategory, were multiplied by VKT for the corresponding vehicle subcategory to estimate total emissions for:

- All vehicle subcategories
- All years from 2019 to 2035
- NOx and $PM_{2.5}$.

Emissions from electric vehicles included $PM_{2.5}$ from road, brake and tyre wear only.

4.6 CALCULATING MOTOR VEHICLE EMISSION SCALARS

Total emissions of $PM_{2.5}$ and NOx from all vehicle categories were calculated for 2019 and for 2035 for BAU and for each scenario.

Scalars (to be applied to the HAPINZ 2019 model exposure data) were then developed from the ratio of the 2035 emissions to the 2019 emissions for each pollutant for each scenario.

Note: As mentioned earlier, the application of these scalars assumes that changes in motor vehicle $PM_{2.5}$ and NO_2 *concentrations* between 2019 and 2035 mirror the estimated changes in motor vehicle $PM_{2.5}$ and NOx *emissions* in the same period.

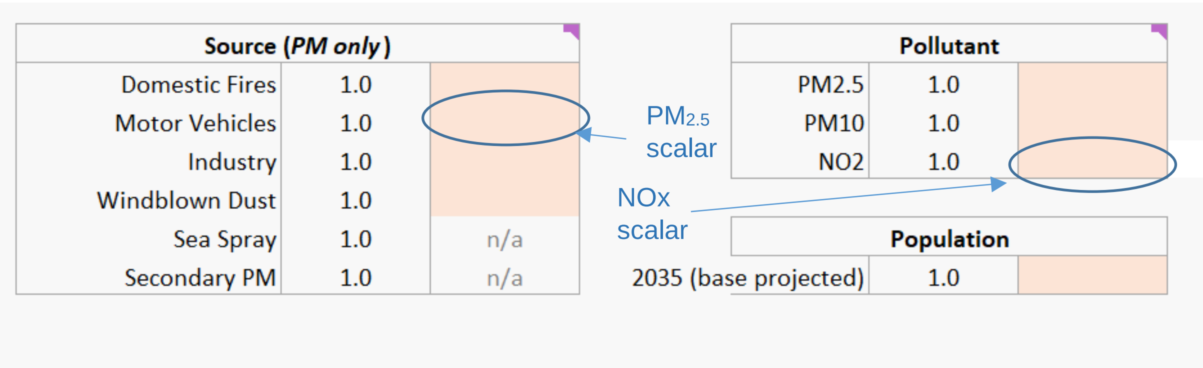
While the concentration of a pollutant in ambient air does depend on emissions, it is influenced by other factors – such as meteorology, atmospheric chemistry, and topography. Nonetheless, this approach is a reasonable approximation and is widely used for policy evaluation.

4.7 ESTIMATING HEALTH IMPACTS

The HAPINZ 3.0 health effects model allows users to adjust concentrations either by pollutant or by source (but for PM_{10} and $PM_{2.5}$ only). Users cannot adjust NO_2 concentration by source because all NO_2 health impacts are assumed to be from motor vehicles only.

We estimated health impacts in 2035 for BAU and all scenarios by applying the relevant scalars in the input sheet (as shown in Figure 9) of the HAPINZ 2035 model (developed for this analysis as discussed in Section 4.2).

FIGURE 9: The location of the emissions scalars in the input data sheet of the HAPINZ 2035 model used to estimate health impacts of motor vehicle emissions from different scenarios



4.8 ESTIMATING SOCIAL COSTS

We estimated social costs of motor vehicle $PM_{2.5}$ and NOx air pollution based on the costs per case (NZ$ as at June 2019) from HAPINZ 3.0 (shown in Table 8).

Air pollution social costs for 2019 and 2035 were estimated from the HAPINZ 2019 and HAPINZ 2035 models for BAU and the scenarios.

TABLE 8: Air pollution social costs per case used in this assessment

OUTCOME	SOCIAL COST (NZ$2019)	
Premature mortality	$4,527,300	per premature death
Cardiovascular hospitalisation	$36,666	per admission
Respiratory hospitalisation	$31,748	per admission
Restricted activity day (RAD)	$89	per RAD
Asthma prevalence	$128	per case

Source: Kuschel *et al* (2022a)

4.9 CUMULATIVE COSTS AND BENEFITS

As described in the previous section, air pollution social costs were estimated for 2019 and 2035.

To estimate the cumulative benefits of emissions reduction policies, we estimated annual social costs of emissions between 2021 and 2035 for BAU and for Scenario 5 (equivalent to the ERP pathway) and Scenario 6 (ERP pathway with no impact on light duty diesel vehicles). Annual shadow costs of CO_2 emissions were also estimated.

4.9.1 Annual social costs

Social costs (in NZ$2019) were estimated for each year between 2019 and 2035, for BAU and Scenarios 5 and 6, as follows:

- The social costs of $PM_{2.5}$ and NO_2 air pollution for 2019 and 2035 were 'normalised' to costs per tonne of $PM_{2.5}$ and NOx emissions in 2019 and 2035 based on the annual emissions estimated for this assessment (as described in section 4.5).
- 'Normalised' costs per tonne of emissions were then developed for the intervening years, assuming a linear rate of change in these costs between 2019 and 2035.
- Social costs for all years between 2019 and 2035 were then estimated from the relevant 'normalised' costs per tonne and the estimated NOx and $PM_{2.5}$ emissions.

Note: The 'normalised' social costs per tonne of $PM_{2.5}$ and NO_X developed for this assessment differ from the $PM_{2.5}$ and NO_X damage costs published in HAPINZ 3.0. This is due to differences in assessment years and emission calculation methodology.

4.9.2 Annual CO_2-e emissions costs

The cost of CO_2-e emissions was calculated based on estimated CO_2-e emissions per annum provided by the MoT for the ERP baseline and the ERP pathway, multiplied by the appropriate shadow CO_2-e emissions values published by Treasury.

The shadow emissions values were based on the 'central' recommended values provided by Treasury, which range from $63 per tonne of CO_2-e in 2021 to $173 per tonne of CO_2-e in 2035 (Treasury 2021). These were converted from NZ$2021 to NZ$2019 for equivalence with HAPINZ 3.0 social cost estimates using the Reserve Bank inflation calculator[27] (see Table 9).

TABLE 9: Shadow emission values per tonne CO_2-e used in this assessment

YEAR	SHADOW COST (NZ$2021)	ADJUSTED SHADOW COST (NZ$2019)
2021	63	60.0
2022	72	68.6
2023	81	77.1
2024	90	85.7
2025	99	94.3
2026	108	102.9
2027	118	112.4
2028	127	121.0
2029	136	129.5
2030	145	138.1
2031	150	142.9
2032	156	148.6

[27] Costs were divided by 1.05 on the basis that $1 in 2019Q2 is equivalent to $1.05 in 2021Q2: Inflation calculator - Reserve Bank of New Zealand - Te Pūtea Matua (rbnz.govt.nz)

YEAR	SHADOW COST (NZ$2021)	ADJUSTED SHADOW COST (NZ$2019)
2033	162	154.3
2034	167	159.0
2035	173	164.8

Source: Treasury (2021)

The ERP pathway CO_2-e estimate was assumed for Scenario 5 (the ERP pathway) and Scenario 6 (as per Scenario 5 but with no impact on light duty diesel vehicles). CO_2-e emissions costs were estimated for each year from 2021 to 2035, multiplied by the relevant shadow emission value in Table 9 (in NZ$2019).

4.9.3 Calculation of cumulative costs and benefits

Social costs of air pollution emissions and shadow costs of CO_2-e emissions were estimated for each year then converted into present values using the Treasury recommended discount rate of 5% for road and other transport projects (Treasury 2021). This meant costs for each scenario could be aggregated to a total covering all years 2021 to 2035 for comparison with BAU.

The net present benefit (NPV) was then calculated for each scenario as the difference between the net present costs of BAU compared with the net present cost of each scenario between 2021 and 2035.

Note: Discounting renders benefits and costs that occur in different time periods comparable by expressing their values in present terms.

The net present value (**NPV**) of a projected stream of current and future benefits and costs relative to the base case is estimated by multiplying the benefits and costs in each year by a discount factor, ***d*** (e.g. 5%), and adding all of the weighted values as shown in the following equation:

$$\mathrm{NPV} = \mathrm{NB}_0 + \mathrm{d}^1\mathrm{NB}_1 + \mathrm{d}^2\mathrm{NB}_2 + \dots + \mathrm{d}^{n-1}\mathrm{NB}_{n-1} + \mathrm{d}^n\mathrm{NB}_n \qquad (1)$$

where $\boldsymbol{NB_t}$ is the net difference between benefits and costs ($\boldsymbol{B_t - C_t}$) that accrue at the end of period ***t***. The discounting weights, $\mathbf{d_t}$, are given by:

$$\mathrm{d}_t = 1/(1+\mathrm{r})^t \qquad (2)$$

where ***r*** is the discount rate. The final period of the policy's future effects is designated as time ***n***.

5. RESULTS

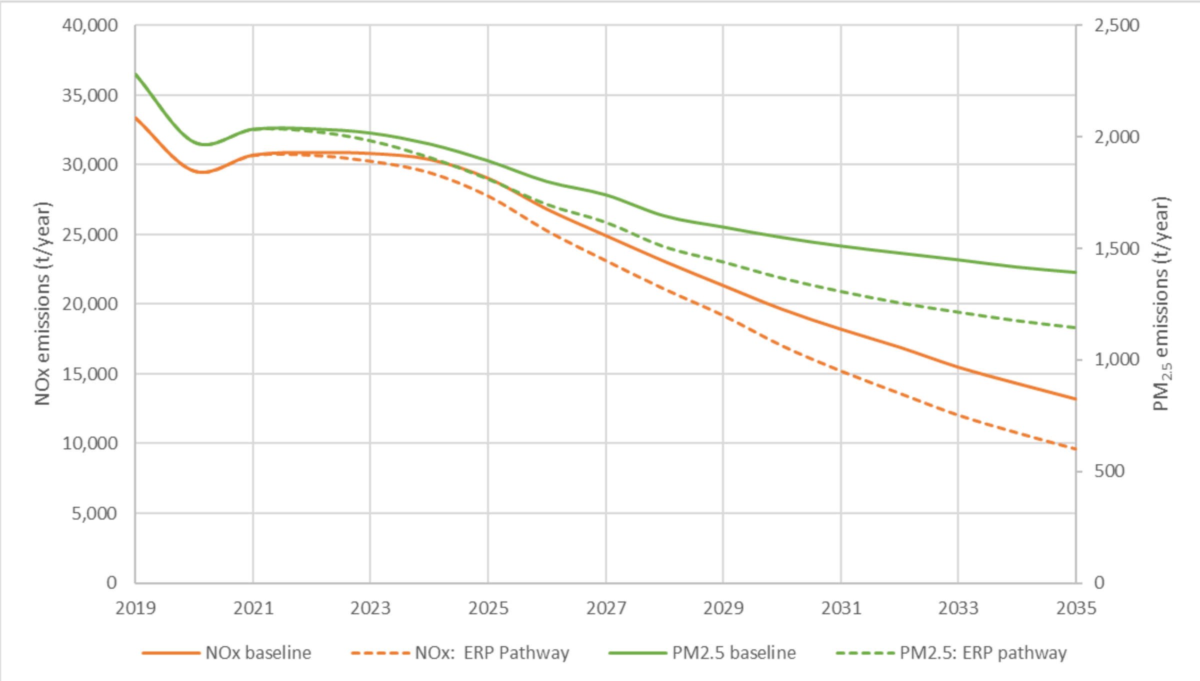
This chapter presents the results of our assessment.

5.1 EMISSIONS AND SCALARS

Figure 10 shows the estimated total emissions of NOx and $PM_{2.5}$ from motor vehicles between 2019 and 2035 for BAU and Scenario 5 (the ERP pathway). Both extremes highlight substantial emissions reductions by 2035, even for BAU which is based on 19% higher VKT in 2035 versus 2019 (see Table 7).

The BAU emissions reductions are due to gradual replacement of vehicles in the fleet with lower emitting Euro 6/VI vehicles, as well as gradual uptake of EVs. However, Scenario 5, which is equivalent to the ERP pathway, shows substantial additional reduction of emissions compared with BAU reflecting accelerated adoption of low emission policies.

FIGURE 10: Total NOx and $PM_{2.5}$ emissions from on-road vehicles for the baseline (BAU) and Scenario 5 (the ERP pathway)



The estimated emissions for all scenarios in 2019 and 2035 are summarised in Table 10, with the relevant pollutant scalars (2035 emissions divided by 2019 emissions) shown in Table 11.

TABLE 10: Total NOx and $PM_{2.5}$ emissions from on-road vehicles for BAU and all scenarios in 2019 and 2035

SCENARIO	EMISSIONS (T/YR)			
	NOx	PM2.5 EXHAUST	PM2.5 NON-EXH	PM2.5 TOTAL
	2019			
BAU	33,337	1,356	923	2,278
	2035			
BAU	13,183	306	1,087	1,393
Scenario 1: light duty VKT reduced by 20%	11,575	275	939	1,215
Scenario 2: 30% light duty fleet is electric	11,634	277	1,084	1,360
Scenario 3: reduce truck VKT	12,796	293	1,066	1,360
Scenario 4: increase % of electric trucks	13,017	300	1,085	1,386
Scenario 5: deliver full ERP pathway	9,624	231	913	1,144

TABLE 11: Vehicle emissions scalars for BAU and all scenarios

SCENARIO	POLLUTANT SCALAR)	
	NOx	PM2.5 TOTAL
	2019	
BAU	-	-
	2035	
BAU	0.40	0.61
Scenario 1: Light duty VKT reduced by 20%	0.35	0.53
Scenario 2: 30% light duty fleet is electric	0.35	0.60
Scenario 3: Reduce truck VKT	0.38	0.60
Scenario 4: Increase % of electric trucks	0.39	0.61
Scenario 5: Deliver full ERP pathway	0.29	0.50

5.2 HEALTH IMPACTS

Table 12 presents the estimated health impacts in 2019 and in 2035 for BAU and Scenario 5 (the ERP pathway). Results for all scenarios are provided in the accompanying spreadsheet.

Health impacts from motor vehicle air pollution are expected to reduce significantly between 2019 and 2035 under BAU, regardless. However, significant further reduction of impacts is predicted under Scenario 5 (the ERP pathway).

For example:

- Exposure to $PM_{2.5}$ and NO_2 pollution from motor vehicles contributed to 2,188 premature deaths in 2019. Mortality is predicted to drop to 1,207 premature deaths in 2035 under BAU and to 904 premature deaths under Scenario 5 (the ERP pathway). This means that achieving all targets in the ERP pathway will mean 303 fewer New Zealanders dying prematurely each year by 2035 relative to BAU. This is equivalent to cutting the number of road crash deaths each year by about 80% (road crash deaths in New Zealand in 2022 = 378).

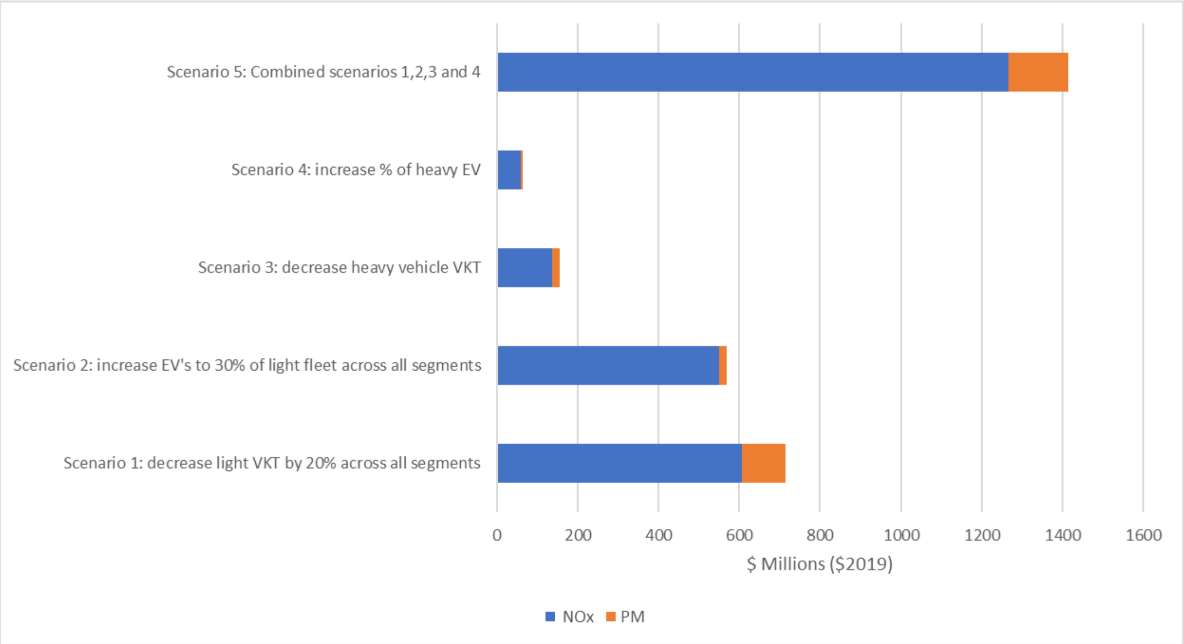
- Social costs of on-road vehicle air pollution are predicted to reduce from $10,247 million in 2019 to $5,644 million by 2035 for BAU. In Scenario 5 (the ERP pathway), social costs reduce to $4,229 million by 2035.

TABLE 12: Health impacts and social costs of on-road vehicle air pollution for BAU and Scenario 5 in 2019 and 2035

HAPINZ 3.0 ESTIMATES (MOTOR VEHICLES ONLY)			
SCENARIO	2019	2035 BAU	2035 SCENARIO 5
Cases per year due to annual $PM_{2.5}$			
Premature mortality (all adults)	224	175	144
Cardiovascular hospitalisations (all ages)	498	357	293
Respiratory hospitalisations (all ages)	390	279	230
Restricted activity days - (all ages)	342,151	245,649	201,761
Cases per year due to annual NO_2			
Premature mortality (all adults)	1,964	1,032	760
Cardiovascular hospitalisations (all ages)	2,010	946	694
Respiratory hospitalisations (all ages)	6,440	3,166	2,340
Asthma prevalence (0-18 yrs)	12,653	5,247	3,874
Social costs per year due to both $PM_{2.5}$ and NO_2			
Social cost ($ million)	$10,247M	$5,644M	$4,229M

The predicted social costs of on-road vehicle air pollution for the ERP pathway at 2035 are $1,416M less than for BAU at 2035. Figure 11 compares the improvements over the 2035 BAU social costs for each scenario at 2035.

Figure 11: Improvements in social costs of on-road vehicle air pollution for each scenario in 2035 relative to BAU



In general:

- NOx emissions reduction benefits are most significant for Scenarios 1 and 2, which significantly reduce kilometres travelled by light duty vehicles and increase the proportion of light duty vehicles that are electric.
- $PM_{2.5}$ emissions reduction benefits are most significant for Scenario 1, which significantly reduces light duty vehicle VKT. This is because non-exhaust emissions dominate total $PM_{2.5}$ emissions by 2035, and the non-exhaust emission factors for EV and ICE vehicles are assumed to be the same. Consequently, significantly reducing VKT for light duty ICE vehicles and EVs is the most effective scenario for reducing $PM_{2.5}$ emissions.
- The impacts of Scenarios 3 and 4, which target heavy duty vehicles, are less significant compared with Scenarios 1 and 2. This is because the expected reduction in VKT and the increase in EVs are smaller for heavy duty vehicles compared with light duty vehicles in 2035.

5.3 SENSITIVITY OF HEALTH IMPACTS TO POLICY DESIGN

As discussed in Section 4.2.3, we analysed an additional scenario to investigate the potential impact of policy design with respect to light duty diesel vehicles. Scenario 6 is the same as Scenario 5 (the ERP pathway) except it assumes light duty diesel VKT is not impacted by policy (and therefore remains the same as in BAU).

Table 13 shows the estimated health impacts in 2035 for Scenario 6. Results for BAU and Scenario 5 (the ERP pathway) are repeated for comparison.

TABLE 13: Health impacts and social costs of on-road vehicle air pollution in 2035 for BAU compared with Scenarios 5 and 6

HAPINZ 3.0 ESTIMATES (MOTOR VEHICLES ONLY)			
SCENARIO	2035 BAU	2035 SCENARIO 5	2035 SCENARIO 6
Cases per year due to annual $PM_{2.5}$			
Premature mortality (all adults)	175	144	**150**
Cardiovascular hospitalisations (all ages)	357	293	**306**
Respiratory hospitalisations (all ages)	279	230	**240**
Restricted activity days - (all ages)	245,649	201,761	**210,931**
Cases per year due to annual NO_2			
Premature mortality (all adults)	1,032	760	**925**
Cardiovascular hospitalisations (all ages)	946	694	**846**
Respiratory hospitalisations (all ages)	3,166	2,340	**2,840**
Asthma prevalence (0-18 yrs)	5,247	3,874	**4,705**
Social costs per year due to both $PM_{2.5}$ and NO_2			
Social cost ($ million)	$5,644M	$4,229M	**$5,026M**
Improvement vs BAU (%)	-	25%	**11%**

If light duty petrol and diesel VKT are impacted equally by the policy (Scenario 5), social costs are 25% lower than BAU in 2035. However, if light duty diesel VKT is not impacted (Scenario 6) then the benefit plummets to 11% in 2035, due to an extra 171 premature deaths and an additional $797 million in social costs.

5.4 CUMULATIVE TOTAL BENEFITS FROM 2021 TO 2035

As described in section 4.9, the estimated cumulative benefit is based on the estimated social costs of NOx and $PM_{2.5}$ emissions and the estimated shadow cost of CO_2-e emissions. The benefit is the difference between the total costs of emissions in BAU compared with the total cost of emissions in each scenario between 2021 and 2035.

Table 14 compares the benefits (as NPV in NZ$2019) associated with reduced emissions for Scenario 5 and Scenario 6 relative to BAU, between 2021 and 2035.

TABLE 14: Benefits of reductions in harmful and CO_2-e emissions for Scenario 5 and Scenario 6 relative to BAU between 2021 and 2035

NPV 2019 TO 2035 RELATIVE TO BAU (NZ$2019 IN MILLION)			
SCENARIO	NOx and $PM_{2.5}$	CO_2-e	Total
Scenario 5: ERP pathway, with equal impact on light duty diesel and petrol vehicles	$7,106M	$3,267M	$10,373M
Scenario 6: ERP pathway, with no impact on light duty diesel vehicles	$3,539M	$3,267M	$6,806M

The results show that:

- Achieving the ERP pathway (all targets) could yield net air quality benefits of more than $7 billion (NZ$2019) between 2021 and 2035 due to reduced NOx and $PM_{2.5}$.
- However, the air quality benefits are sensitive to the impact of policy on light duty diesel vehicles. If light duty vehicles are not impacted, then the net air quality benefits associated with achieving the ERP targets halve from $7 billion to around $3.5 billion (NZ$2019) between 2021 and 2035.
- The net benefit of reduced CO_2-e emissions between 2021 and 2035 is around $3.3 billion (NZ$2019), irrespective of the impact on light duty diesel vehicles.
- Based on our assessment, the net air quality benefits of achieving the ERP pathway are likely to be at least as significant as the CO_2-e benefits.

6. KEY FINDINGS

This chapter summarises our key findings.

6.1 EMISSIONS

Estimated total emissions of NOx and $PM_{2.5}$ from on-road vehicles in 2035 reduce appreciably by 2035 for all scenarios - even for BAU which is based on 19% higher VKT in 2035 versus 2019 - due to gradual uptake in cleaner Euro 6/VI vehicles, as well as EVs.

However, Scenario 5 (achieving all targets in the ERP pathway) shows substantial additional improvement in NOx and $PM_{2.5}$ emissions compared with BAU, reflecting accelerated adoption of low or zero emission policies.

6.2 HEALTH IMPACTS

Similarly, health impacts from on-road vehicle air pollution are expected to reduce significantly between 2019 and 2035 for all scenarios including BAU.

However, Scenario 5 (the ERP pathway) results in 303 fewer New Zealanders dying prematurely each year by 2035 relative to BAU.

Social costs of on-road vehicle air pollution reduce from $10,247 million in 2019 to $5,644 million by 2035 for BAU versus $4,229 million by 2035 for Scenario 5.

In general:

- The greatest NOx emissions reduction benefits result from Scenario 1 (20% reduction in light duty VKT) and Scenario 2 (30% of the light duty fleet being electric).
- The greatest $PM_{2.5}$ emissions reduction benefits result from Scenario 1 (20% reduction in light duty VKT). This is because non-exhaust emissions, which come from both light duty internal combustion engine (ICE) vehicles and EVs, dominate total $PM_{2.5}$ emissions by 2035. Therefore, reducing VKT for all light duty vehicles is the most effective scenario for reducing $PM_{2.5}$ emissions.
- Scenario 3 (reductions in truck VKT) and Scenario 4 (increased electric trucks) deliver fewer benefits compared with Scenarios 1 and 2. This is because the expected VKT reductions and increases in EVs are smaller for heavy duty vehicles compared with light duty vehicles in 2035.

6.3 POLICY DESIGN

We included an additional scenario – Scenario 6 - to highlight that policy design is critical for achieving the best air quality outcomes. Scenario 6 is the same as Scenario 5 (the ERP pathway) except, instead of the light duty VKT reduction coming from both petrol and diesel vehicles, light duty diesel VKT is largely unaffected by policy.[28]

If light duty petrol and diesel VKT are impacted equally by the policy (Scenario 5), social costs are 25% lower than BAU in 2035. However, if light duty diesel VKT is not impacted (Scenario 6) then the benefit plummets to 11% in 2035, due to an extra 171 premature deaths and an additional $797 million in social costs.

[28] The authors strongly recommend applying the policies to both light duty diesel and petrol vehicles and analysed this additional scenario solely to highlight why this is so important.

6.4 CUMULATIVE TOTAL BENEFITS

Achieving the ERP pathway (all targets) could yield net air quality benefits of more than $7 billion (NZ$2019) between 2021 and 2035 due to reduced NOx and $PM_{2.5}$.

However, if light duty diesel vehicles are not impacted, the net air quality benefits associated with achieving the ERP targets halve from $7 billion to around $3.5 billion (NZ$2019) between 2021 and 2035.

The net benefit of reduced CO_2-e emissions between 2021 and 2035 is around $3.3 billion (NZ$2019), irrespective of the impact on light duty diesel vehicles.

Based on our assessment, the net air quality benefits of achieving the ERP pathway are likely to be at least as significant as the CO_2-e benefits.

Notes: Our assessment of the impact of achieving the ERP targets excludes other co-benefits - such as increased physical activity, reduced noise impacts and improved road safety. These benefits are likely to be considerable, particularly for interventions that reduce VKT for light duty vehicles.

In addition, the assessment of CO_2-e emissions covers exhaust emissions resulting from motor vehicle use only. Significant mode shift away from private vehicles (including EVs) would reduce embodied and operational emissions from transport infrastructure. Reduced car ownership would also reduce life-cycle emissions from the manufacture and disposal of vehicles.

VKT reductions, and their associated air pollution benefits, are applied equally across New Zealand. Realistically, VKT reductions are more likely to be implemented in urban areas where more people are exposed to air pollution and where more transport options exist. This means that the potential benefits of interventions which reduce VKT are likely to be *under*-estimated.

Our analyses were based on fleet *average* emission factors and did not assess the impact of higher emitting vehicles in each type. Greater air quality benefits could be achieved by implementing policies that target replacement of the most polluting vehicles in the fleet.

We estimated cumulative costs and benefits to 2035. However, the benefits of interventions would extend well beyond 2035.

For full details on the assumptions and calculations, please refer to the accompanying Excel workbook.

GLOSSARY

acute	short-term duration but severe
BAU	business as usual - relating to the on-road vehicle emissions predicted in 2035 with no additional policy interventions
cardiovascular	of, pertaining to, or affecting the heart and blood vessels
CAU	census area unit
chronic	long-term duration or constantly recurring
CH_4	methane, a greenhouse gas
CO_2	carbon dioxide, a greenhouse gas
CO_2-e	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 $PM_{10-2.5}$
DTCC	the *Domestic Transport Costs and Charges* project, funded by MoT
EEA	European Environment Agency
ERP	*Te hau mārohi ki anamata,* Aotearoa New Zealand's first Emissions Reduction Plan
ERP pathway	the emissions reduction plan pathway - relating to the on-road vehicle emissions predicted in 2035 with all targets achieved
Euro	vehicle emission standards for pollution from the use of on-road vehicles sold in Europe and the United Kingdom, where standards denoted using Arabic numerals (e.g. 6) apply to light duty vehicles and those denoted with Roman numerals (e.g. VI) apply to heavy duty vehicles.,
EV	electric vehicle
fine particulate	particles in the $PM_{2.5}$ fraction
GHG	greenhouse gas
GVM	gross vehicle mass
HAPINZ 2.0	the *Health and Air Pollution in New Zealand* study, based on 2006, undertaken by Kuschel *et al* (2012)
HAPINZ 3.0	the *Health and Air Pollution in New Zealand* study, based on 2016, undertaken by Kuschel *et al* (2022a, 2022b)
harmful pollutant	an air pollutant which causes adverse health effects
HCV	heavy commercial vehicle, e.g. trucks and buses with a GVM greater than 3,500 kg

heavy duty vehicle	an on-road vehicle with a GVM of more than 3.5 tonnes
ICE	internal combustion engine
incidence	the number of newly diagnosed cases of a disease in a population – often expressed as an incidence rate, i.e. the number of new cases divided by the number of persons at risk
LCV	light commercial vehicle, e.g. all goods vans, trucks, utilities, buses and motor caravans with a GVM less than 3,500 kg
light duty vehicle	an on-road vehicle with a GVM of less than 3.5 tonnes
MfE	*Manatū Mō Te Taio*, Ministry for the Environment
MoH	*Manatū Hauora*, Ministry of Health
MoT	*Te Manatū Waka*, 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
NO_2	nitrogen dioxide, a harmful pollutant
NO_X	oxides of nitrogen
N_2O	nitrous oxide, a greenhouse gas
NPV	net present value
NVED	National Vehicle Emissions Dataset
O_3	ozone
PAF	population attributable fraction, the estimated percentage of total health cases that are attributable to the air pollution exposure
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
$PM_{10\text{-}2.5}$	particulate matter in the 2.5 µm to 10 µm size range, sometimes referred to as coarse particulate
prevalence	the proportion of the population or total number of cases of disease existing in a population
respiratory	of, pertaining to, or affecting the lungs and airways

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
µg	microgram, one millionth of a gram
$\mu g/m^3$	microgram per cubic metre, a unit of concentration
µm	micrometre, one millionth of a metre
VEPM	Vehicle Emission Prediction Model, developed by Waka Kotahi to predict air emission and fuel consumption of the New Zealand vehicle fleet
VFEM	Vehicle Fleet Emissions Model, developed by MoT to predict the makeup, travel, energy (fuel and electricity) use and greenhouse gas emissions of the New Zealand vehicle fleet
VKT	vehicle kilometres travelled
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: HAPINZ 3.0 FEATURES

Key features of the HAPINZ 3.0 study are summarised in the table below.

TABLE 15: Key features of the HAPINZ 3.0 study

FEATURE	DETAILS
Base year	2016 for population
Spatial resolution	**Calculations** undertaken using 2013 census area unit boundaries **Results** aggregated by 16 regional councils, 20 district health boards, 67 territorial authorities and 89 airsheds
Population covered	100% of 2016 population
Pollutants	Particulate matter ($PM_{2.5}$ and PM_{10}) Nitrogen dioxide (NO_2)
Exposure assessment	**$PM_{2.5}$ and PM_{10}**: ambient monitoring data typically averaged for 2015-2017 covering the majority of urban areas in New Zealand, with proxy monitoring used in unmonitored areas **NO_2**: modelling estimates from the NZ Transport Agency NVED exposure tool
Source attributions	**$PM_{2.5}$ and PM_{10}**: using source apportionment data and assigned to domestic fires, motor vehicles, industry, windblown dust, sea spray, and secondary PM **NO_2**: no source apportionment data available but assigned to motor vehicles (estimated to contribute approximately 90% of NO_2 exposure in urban areas)
Health endpoints	**Primary health impacts** • **mortality** and years of life lost (YLL) from long-term **$PM_{2.5}$** for all adults 30+ years, all ethnicities and Māori/Pacific peoples • **cardiovascular hospitalisations** from long-term **$PM_{2.5}$** for all ages, all ethnicities • **respiratory admissions** from long-term **$PM_{2.5}$** for all ages, all ethnicities • **restricted activity days** from long-term **$PM_{2.5}$** for all ages, all ethnicities • **mortality** and YLL from long-term **NO_2** for all adults 30+ years, all ethnicities • **cardiovascular hospitalisations** from long-term **NO_2** for all ages, all ethnicities • **respiratory admissions** from long-term **NO_2** for all ages, all ethnicities **Secondary health impacts (for comparison with HAPINZ 2.0)** • **mortality** from long-term **PM_{10}** for all adults 30+ years, all ethnicities and for Māori • **restricted activity days** from long-term **$PM_{2.5}$** for all ages, all ethnicities (also in primary health impacts) **Childhood asthma impacts relevant to NZ** • **asthma/wheeze hospitalisations** due to long-term **NO_2** for all 0-18 years • **asthma prevalence** due to long-term **NO_2** for all 0-18 years

Social costs	**Valuation of mortality costs** • **change** in mortality multiplied by NZ Value of a Statistical Life (**VoSL**) as at June 2019 • change in total life years multiplied by a NZ Value of a Life Year (**VoLY**) as at June 2019 **Valuation of morbidity costs** • cardiovascular and respiratory hospital admissions • restricted activity days • childhood asthma costs from GP visits, medication and hospitalisation **Development of a suite of NZ-specific damage costs** for consistent assessment of benefits to society in reducing harmful emissions and greenhouse gases
Key outputs	Combined **exposure/health effects model** enabling sensitivity/scenario testing and designed to be easily updateable together with a Users' Guide A **set of New Zealand-specific exposure-response functions** for assessing effects of air pollution on mortality and morbidity amongst New Zealanders A **detailed report**, suitable for a technical audience, outlining the methodology adopted and clearly stating all assumptions (Volume 2) A **summary report**, suitable for a more general audience, presenting the key findings and discussing their implications (Volume 1) A **messaging guide** to provide evidence-based dos and don'ts for anyone wanting to communicate the study findings through various channels together with a checklist

Source: Kuschel *et al* (2022b)

Science for Communities

INSTITUTE OF ENVIRONMENTAL
SCIENCE AND RESEARCH LIMITED

Kenepuru Science Centre
34 Kenepuru Drive, Kenepuru, Porirua 5022
PO Box 50348, Porirua 5240
New Zealand
T: +64 4 914 0700 **F:** +64 4 914 0770

Mt Albert Science Centre
120 Mt Albert Road, Sandringham, Auckland 1025
Private Bag 92021, Auckland 1142
New Zealand
T: +64 9 815 3670 **F:** +64 9 849 6046

NCBID – Wallaceville
66 Ward Street, Wallaceville, Upper Hutt 5018
PO Box 40158, Upper Hutt 5140
New Zealand
T: +64 4 529 0600 **F:** +64 4 529 0601

Christchurch Science Centre
27 Creyke Road, Ilam, Christchurch 8041
PO Box 29181, Christchurch 8540
New Zealand
T: +64 3 351 6019 **F:** +64 3 351 0010

www.esr.cri.nz