Health and air pollution in New Zealand 2016 (HAPINZ 3.0)

He rangi hauora he iwi ora

Volume 1 – Findings and implications

Prepared for

Ministry for the Environment
Ministry of Health
Te Manatū Waka Ministry of Transport
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Executive summary

Clean healthy air contributes to New Zealand's quality of life - not only people's health, but also the natural functioning and "*beauty of the natural and physical environment*" (MfE 2007). New Zealand has good air quality in most locations for most of the time. However, exhaust emissions from vehicles and solid fuel (wood and coal) used for domestic heating combine to produce unacceptable air quality in some locations, particularly during winter.

Understanding how much air pollution people are experiencing (exposure) is critical to understanding potential health impacts. This is because the combination of the length of time people are exposed to air pollutants, the concentration of the pollutants and the sensitivity of those people exposed together determine the likelihood and magnitude of resultant health effects. Despite the relatively low levels of pollution in New Zealand versus many other countries, the health burden associated with air pollution is still appreciable.

Air pollution health effects in New Zealand were first comprehensively assessed in the Health and Air Pollution in New Zealand (**HAPINZ 1.0**)[1] study undertaken by Fisher *et al* (2007) for a base year of 2001. This work was later updated by Kuschel *et al* (2012) (**HAPINZ 2.0**) for a base year of 2006 to reflect the more comprehensive monitoring being undertaken across New Zealand in response to the introduction of a national environmental standard for ambient particulate matter (**PM_{10}**) concentrations in September 2005 (MfE 2011).

Since 2012, air quality monitoring has further expanded across New Zealand to include many more locations, pollutants and sources, and exposure-response functions[2] are now available for a greater range of health endpoints. In recognition, the Ministry for the Environment and Waka Kotahi (in partnership with Te Manatū Waka Ministry of Transport and Ministry of Health) commissioned a new update – **HAPINZ 3.0** – in 2019 to better reflect the air pollution health effects experienced by New Zealanders and to update the impacts for 2016[3].

This report (Volume 1 – Findings and implications) presents the health impacts and social costs[4] associated with air pollution in New Zealand for 2016. Full details on the methodology we developed to arrive at these impacts are contained in the separate Volume 2 – Detailed methodology (Kuschel *et al* 2022).

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[1] This report refers to the previous studies of Fisher *et al* (2007) and Kuschel *et al* (2012) as HAPINZ 1.0 and HAPINZ 2.0 respectively to make it easier to differentiate between those studies and this one (HAPINZ 3.0).

[2] An exposure-response function (ERF) is a risk ratio showing the relative increase in health effect for every increment of air pollution. For example, an ERF of 1.105 (per 10 $\mu g/m^3$) for premature mortality due to exposure to long-term $PM_{2.5}$ means the risk of death increases by 10.5% for every 10 $\mu g/m^3$ increase in the $PM_{2.5}$ annual average concentration.

[3] 2016 was selected as the base year for HAPINZ 3.0 because when the study commenced in July 2019 this was the most recent year for which we had suitable population, health and air quality monitoring data.

[4] Costs here are referred to as social costs rather than health costs because they denote the total costs to society of the health effects, which are more than just the costs incurred by the health system.

As air and air quality are both *taonga*[5] and a part of *kaitiakitanga*[6] for Māori, the HAPINZ 3.0 study is also named *He rangi hauora he iwi ora* which translates to healthy air means healthy people.

Key features

This latest update - **HAPINZ 3.0**:

- used population, health and air quality data based on 2016, averaged over 2015-2017 to account for variability between years in meteorological conditions
- assessed the impacts of particulate matter less than 2.5 µm[7] (**$PM_{2.5}$**) and nitrogen dioxide (**NO_2**), which together contribute to most air pollution health effects in New Zealand
- incorporated New Zealand-specific exposure-response functions (**ERFs**) for critical health impacts of air pollution exposure, such as mortality and hospital admissions
- assessed the impacts on childhood asthma using indicators for increased prevalence and exacerbation in the community
- updated the associated social costs (in NZ$ as at June 2019[8]).

HAPINZ 3.0 estimated annual average concentrations of $PM_{2.5}$ and NO_2 by census area unit (**CAU**) across New Zealand and determined health effects and social costs associated with the following *anthropogenic* (human-generated) air pollution sources:

- motor vehicles (exhaust and brake/tyre wear from on-road vehicles)
- domestic fires (wood and coal burning for home heating)
- windblown dust (construction, land use activities and road dust etc.)
- industry

and for the following *natural* air pollution sources:

- sea spray (sea salt)
- secondary particulate matter (atmospheric gases reacting to form particles).

Note: This report focusses on the results for the anthropogenic sources only, because these can be controlled. The results for all sources are presented in the *Health Effects Model*[9].

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[5] A taonga in Māori culture is a treasured thing, whether tangible or intangible.

[6] A kaitiaki is a guardian, and the process and practices of protecting and looking after the environment are referred to as kaitiakitanga.

[7] A µm, also known as a micrometre, is a millionth of a metre, i.e. 0.0000001 m.

[8] HAPINZ 3.0 uses a base year of 2016 because it is the most recent year for which we have a complete set of suitable air quality, population and health data. The social costs, however, are calculated for 2019 to align with the latest road safety Value of Statistical Life (VoSL) used to assess road crash deaths.

[9] Sridhar S *et al* (2022a). *Health and air pollution in New Zealand 2016 (HAPINZ 3.0): Health effects model*. Excel model prepared by S Sridhar, J Metcalfe and K Mason for Ministry for the Environment, Ministry of Health, Ministry of Transport and Waka Kotahi NZ Transport Agency, March 2022.

Key findings

National impacts and costs

The primary health impact resulting from air pollution (in terms of social costs) is premature **mortality** (death) in adults. However, the cost of increased **morbidity** (illness and disease) is also considerable.

Exposure to $PM_{2.5}$ and NO_2 pollution from **anthropogenic sources** in New Zealand in 2016 contributed to:

- the premature deaths of more than 3,300 adult New Zealanders[10]
- more than 13,100 hospital admissions for respiratory and cardiac illnesses, including 845 asthma hospitalisations for children
- over 13,200 cases of childhood asthma
- approximately 1.745 million restricted activity days (days on which people could not do the things they might otherwise have done if air pollution had not been present).

The **social costs** resulting from these anthropogenic health impacts totalled **$15.6 billion** with **$NO_2$ exposure accounting for just over 60% of the total costs**. This was a significant and surprising finding.

Note: The previous study – HAPINZ 2.0 – used PM_{10} as a proxy for all air pollution (based on the data available at the time) but noted that the results likely under-estimated impacts due to NO_2. However, the extent of the NO_2 impacts found in HAPINZ 3.0 was startling. When the HAPINZ 3.0 draft findings first became available (February 2021), no other researchers had published such strong associations between NO_2 and mortality. To ensure the findings were genuine, the HAPINZ 3.0 research team undertook considerable additional analyses to check for bias, and the results were rigorously peer-reviewed before being published internationally (Hales *et al* 2021). This paper has now been referenced by others who have found similarly strong NO_2 impacts.

Sources

The costs of $PM_{2.5}$ pollution from **anthropogenic sources** in New Zealand in 2016 ($6.1 billion) were associated with:

- domestic fires (74%)
- motor vehicles (17%)
- windblown dust (8%)
- and industry (0.1%).

The costs of NO_2 pollution from **anthropogenic sources** in New Zealand in 2016 ($9.5 billion) were assumed to result from motor vehicles alone (100%).

[10] StatsNZ report that 31,179 New Zealanders died in 2016 from all causes, see https://www.stats.govt.nz/topics/births-and-deaths.

Note: Our method for assessing NO_2 exposure used roadside emissions (from motor vehicles only) as well as background concentrations (from all sources) but we were not able to separate other sources. While we defaulted to assigning all effects of NO_2 to motor vehicles, we considered this assumption was reasonable given motor vehicles are likely to be responsible for nearly 90% of all NO_2 exposure in urban areas (Xie *et al* 2019, Sridhar & Metcalfe 2019).

Regional impacts

In all regions, domestic fire impacts dominated the regional $PM_{2.5}$ social costs – with contributions ranging from 59% to 88%. On average, domestic fire impacts were more than four times those of motor vehicles for $PM_{2.5}$ pollution from anthropogenic sources.

However, for the total anthropogenic health costs ($PM_{2.5}$ and NO_2 combined), motor vehicles were the dominant source in most locations across New Zealand (except those with high solid fuel home heating use during winter). On average, motor vehicle impacts were more than twice those of domestic fires for total ($PM_{2.5}$ and NO_2) pollution from anthropogenic sources.

Trends

The methodology used in HAPINZ 3.0 was used to assess the likely air pollution impacts for 2006 to compare how air pollution impacts have changed over time.

While the population-weighted annual average $PM_{2.5}$ concentration from anthropogenic sources improved by more than 21% between 2006 and 2016, the resultant social costs reduced by only 9.4%. The impact of improvements to date (largely due to reductions in domestic fire emissions) have been counteracted by increased population.

In contrast, the population-weighted annual average NO_2 concentration from anthropogenic sources worsened by just over 13% between 2006 and 2016, resulting in an increase in social costs of more than 28%. This is not surprising given the number of diesel vehicles, which are the main source of NO_2, have increased significantly since 2006. Light diesel vehicles have increased by 44% and heavy diesels by 12% (MoT 2021).

Overall, combining $PM_{2.5}$ and NO_2, **the air pollution health burden due to anthropogenic sources increased by 10.2% between 2006 and 2016**. All of this increase is due to increased exposure to NO_2, but the full impact of worsening NO_2 has been lessened by the improvements in $PM_{2.5}$ concentrations.

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1. Introduction

This chapter outlines background on the previous HAPINZ studies, the objectives of the current update (HAPINZ 3.0) and how this Volume 1 report is structured.

1.1 Previous HAPINZ studies

1.1.1 Health effects in 2001 (HAPINZ 1.0)

Air pollution health effects in New Zealand were first comprehensively assessed in the Health and Air Pollution in New Zealand (**HAPINZ 1.0**)[11] study, undertaken by Fisher *et al* (2007).

In HAPINZ 1.0, health effects were evaluated for 67 urban areas based on population and for exposure to a range of air pollutants using monitoring data, using a base year of 2001. The resulting social costs were presented in NZ$ as at June 2004. Air pollution from all sources in New Zealand in 2001 was estimated to cause approximately 1,400 premature deaths, of which 1,100 premature deaths were attributed to **anthropogenic** (human-generated) sources.

The authors found the greatest effect was premature mortality associated with long-term exposure to particulate matter less than 10 micrometres (**µm**) in diameter (**PM_{10}**) from combustion sources. However, mortality effects due to carbon monoxide (**CO**) and various morbidity (non-mortality illness) effects associated with other pollutants were also identified. A separate mortality effect associated with exposure to nitrogen dioxide (**NO_2**) was not determined as the authors assumed NO_2 was strongly correlated with PM_{10}. Therefore, the exposure-response function (**ERF**) for PM_{10} and mortality would capture effects for both pollutants.

1.1.2 Health effects in 2006 (HAPINZ 2.0)

Following HAPINZ 1.0, data availability and the understanding of air pollution health effects improved significantly. Air quality monitoring was implemented in most urban locations in New Zealand – largely due to the introduction in 2005 of national environmental standards for air quality (**NESAQ**), one of which regulated ambient concentrations of PM_{10} (MfE 2011). An update (**HAPINZ 2.0**) was prepared by Kuschel *et al* (2012) to incorporate population data from the 2006 census and the more comprehensive PM_{10} monitoring that was now being undertaken.

HAPINZ 2.0 assessed health effects across all areas of New Zealand, using a base year of 2006. The focus was on exposure to PM_{10} only (single pollutant model), because PM_{10} was assumed to dominate the air pollution health effects, and it was considered a good indicator of the sources and effects of other air pollutants. At the time, little data were available for other pollutants such as particulate matter smaller than 2.5 µm (**$PM_{2.5}$**) and NO_2. The resulting social costs were presented in NZ$ as at June 2010.

[11] This report refers to the previous studies of Fisher *et al* (2007) as HAPINZ 1.0 and Kuschel *et al* (2012) as HAPINZ 2.0 to make it easier to differentiate between those studies and the current one (HAPINZ 3.0).

Air pollution from all sources in New Zealand in 2006 was estimated to cause approximately 2,300 premature deaths, nearly 1,200 hospitalisations and more than 2.9 million restricted activity days at a total cost of NZ$8.4 billion. Approximately half of these effects and costs were associated with *anthropogenic* (human-generated) sources such as domestic fires, motor vehicles, industry and open burning. Domestic fires were identified as the largest contributor to anthropogenic effects but the authors noted that the impact of motor vehicles was likely to be under-estimated as effects due to exposure to NO_2 were not able to be quantified.

1.2 HAPINZ 3.0 objectives

Following HAPINZ 2.0, the database of ambient monitoring across New Zealand expanded even further to include many more locations, pollutants and sources. In addition, exposure-response functions (**ERFs**) became available in the literature to enable quantification of a greater range of health endpoints.

In recognition, the Ministry for the Environment (**MfE**) and Waka Kotahi (in partnership with Te Manatū Waka Ministry of Transport and Ministry of Health) commissioned a new update in 2019 – **HAPINZ 3.0** – to better reflect the air pollution health effects experienced by New Zealanders and update the impacts for 2016[12].

A team of experienced researchers led by Emission Impossible Ltd commenced HAPINZ 3.0 in July 2019. Progress was reported regularly to a Steering Group with international peer review sought at critical stages throughout the project as follows:

- the methodology (completed December 2019, approved March 2020)
- the draft report (completed February 2021)
- additional investigations to confirm the NO_2 findings (completed December 2021)
- the draft final report (completed February 2022)
- the final report (completed March 2022).

Note: While the HAPINZ 2.0 authors and reviewers acknowledged the probable under-estimation of impacts due to using PM_{10} as a proxy for all air pollution, the extent of the NO_2 impacts found in HAPINZ 3.0 was startling. At the time of the HAPINZ 3.0 draft findings being completed, no other researchers had found such strong associations between NO_2 and mortality.

To be assured that the HAPINZ 3.0 findings were robust, the Steering Group commissioned a separate peer review by Professor Bert Brunekreef from Utrecht University in The Netherlands. Prof Brunekreef was leading the *Effects of Low-Level Air Pollution: A Study in Europe* **(ELAPSE)** study at the time so had considerable expertise in low level air pollution health effects. He recommended a suite of comprehensive additional analyses, which the HAPINZ 3.0 team undertook to check for bias, and the results were confirmed to be sound.

[12] 2016 was selected as the base year for HAPINZ 3.0 because when the study commenced in July 2019 this was the most recent year for which we had suitable population, health and air quality monitoring data.

1.3 HAPINZ 3.0 outputs

This report (*HAPINZ 3.0 Volume 1 – Findings and implications*) presents the health impacts and social costs associated with air pollution in New Zealand for 2016. It is intended for a general audience.

The methodology we developed to arrive at these impacts is described in full in the *HAPINZ 3.0 Volume 2 – Detailed methodology*[13] report for readers interested in the technical details.

The reports are complemented by a *Health Effects Model* and a *Messaging Guide*.

The *Health Effects Model*[14], based on an Excel spreadsheet, 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*[15].

The draft *Messaging Guide*[16] provides guidance on how to communicate key messages to improve understanding of the effects of air pollution on health and well-being and mobilise support for actions that build healthier environments.

Together, the HAPINZ 3.0 outputs will be useful for:

- weighing benefits of health improvements against the costs of (various) air pollution reduction initiatives
- evaluating the effectiveness of existing policy initiatives (scenario modelling)
- assessing the likely effects of current population and business as usual trends (forecasting)
- developing targeted strategies for reducing the air pollution exposure of particularly vulnerable groups in the population.

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[13] Kuschel G *et al* (2022). *Health and air pollution in New Zealand 2016 (HAPINZ 3.0): Volume 2 – Detailed methodology*. Report prepared by G Kuschel, J Metcalfe, S Sridhar, P Davy, K Hastings, K Mason, T Denne, J Berentson-Shaw, S Bell, S Hales, J Atkinson and A Woodward for Ministry for the Environment, Ministry of Health, Te Manatū Waka Ministry of Transport and Waka Kotahi NZ Transport Agency, March 2022.

[14] Sridhar S *et al* (2022a). *Health and air pollution in New Zealand 2016 (HAPINZ 3.0): Health effects model*. Excel model prepared by S Sridhar, J Metcalfe and K Mason for Ministry for the Environment, Ministry of Health, Ministry of Transport and Waka Kotahi NZ Transport Agency, March 2022.

[15] Sridhar S *et al* (2022b). *Health and air pollution in New Zealand 2016 (HAPINZ 3.0): Health effects model – Users' guide*. Guide prepared by S Sridhar, G Kuschel and K Mason for Ministry for the Environment, Ministry of Health, Te Manatū Waka Ministry of Transport and Waka Kotahi NZ Transport Agency, March 2022.

[16] Berentson-Shaw J & Bell S (2020). *How to talk about air quality and environmental health*. Draft message guide for Ministry for the Environment, Te Manatū Waka Ministry of Transport and Waka Kotahi NZ Transport Agency prepared by The Workshop, November 2020.

1.4 Report layout

This report presents the findings and implications of the HAPINZ 3.0 work and is structured as follows:

- Chapter 2 summarises the key features of our approach for the steps involved in the assessment of air pollution health effects.
- Chapter 3 discusses our findings overall, by region and by source. We also review the sensitivity of the results to the base assumptions and use our new methodology to assess 2006 to see how air pollution impacts have changed over time.
- Chapter 4 presents our overall conclusions and their implications of our findings and our recommendations for any future updates.

All references are listed at the end followed by a glossary of technical terms and abbreviations.

A series of appendices are also provided as follows:

- Appendix A shows a selection of results at the regional and territorial authority level to show examples of outputs that can be generated by the health effects model.
- Appendix B presents the sensitivity analyses undertaken to indicate how sensitive the HAPINZ 3.0 model results are to the various assumptions made.

2. What did we do?

This chapter summarises the methodology we followed in HAPINZ 3.0 to assess the air pollution health effects in New Zealand for 2016 under the following steps:

1. Evaluating exposure
2. Attributing source contributions
3. Selecting health impacts and calculating the health burden
4. Estimating social costs.

The methodology is presented in full in the *HAPINZ 3.0 Volume 2 – Detailed methodology* (Kuschel *et al* 2022) for readers interested in the technical details.

2.1 Evaluating exposure

Understanding how much air pollution people are experiencing (exposure) is critical to understanding potential health impacts. This is because the length of time people are exposed to air pollutants, the concentration of the pollutants and the sensitivity of people who are exposed combine to determine the likelihood and magnitude of resultant health effects.

2.1.1 Base year

The base year for the exposure assessment was 2016, with data typically averaged over 2015-2017 to account for inter-annual variability in meteorology.

2016 was selected because it was the most recent year for which we had a complete set of suitable air quality, population and health data[17].

Note: At the start of the pandemic, correlations between air pollution levels and COVID-19 outcomes were reported widely. As HAPINZ 3.0 was based on 2016, prior to the pandemic, our assessment is independent of any effects on air pollution levels due to lockdowns or increased health effects due to COVID infections.

Consequently, we highlight in the Volume 2 report that extreme care needs to be taken if end users wish to use the *HAPINZ 3.0 Health Effects Model* to predict mortality and morbidity for any years beyond 2019.

2.1.2 Spatial resolution

We collated and analysed all data by census area units (**CAUs**) to enable the results to then be reported by many different spatial groupings (e.g by airshed or by district health board). To enable alignment of the various population, health and monitoring datasets, the CAUs were based on the 2013 Census boundaries.

[17] Air quality data typically come available within one to two years of the end of the calendar year of interest but health data on hospitalisations and mortality can lag by three or more years.

Results were estimated at the *CAU level* (2,012 in total)[18] but with the ability to be aggregated by:

- airshed (89)
- district health board (20)
- regional council (16)
- territorial authority (67), or
- nationally.

2.1.3 Population data

All population data were sourced from Stats NZ and were for the *estimated resident population* as at 30 June 2016.[19]

2.1.4 $PM_{2.5}$ and PM_{10} exposure

$PM_{2.5}$ was used as a primary indicator of air pollution exposure due to the wealth of monitoring data available and the links to existing exposure-response functions developed from New Zealand and international epidemiological studies. PM_{10} was used to supplement the $PM_{2.5}$ data in areas with limited data and to backcast health effects in earlier years.

Actual monitoring data were used in preference to modelling estimates and averaged for 2015 to 2017 (where possible) to reduce the influence of inter-annual variability in meteorological conditions. The monitored concentration was typically applied to the entire airshed. However:

- For airsheds with more than one monitor, the site(s) most representative of the population exposure was selected.
- For unmonitored areas, annual concentrations were based on comparisons with monitored areas that had similar characteristics (including urban/rural classification, topography, meteorology and emissions).
- In areas where only PM_{10} was monitored, ratios of $PM_{2.5}$ to PM_{10} were derived using an empirical relationship based on PM_{10} monitoring data to estimate $PM_{2.5}$. This method was specifically developed for HAPINZ 3.0 (Davy & Trompetter 2020).

2.1.5 NO_2 exposure

NO_2 was also used as a primary indicator of air pollution exposure due to increasing epidemiological evidence of significant health effects near roadways.

Despite more monitoring data being available than in the past, the coverage was still insufficient to undertake a robust assessment of national exposure using data only.

[18] HAPINZ 3.0 estimates effects at the CAU level but is intended to be used to compare larger population-based health impacts. We do not recommend using HAPINZ 3.0 below the aggregated levels shown, i.e. airshed etc.

[19] The estimated resident population as at June 2016 was 4,714,055. Provisional figures suggest the population has increased by at least 8.7% to 5,122,600 as at June 2021.

Consequently, we relied on modelled estimates of NO_2 exposure in 2016 which were generated from the Waka Kotahi Vehicle Emissions Mapping Tool (**VEMT**) and National Vehicle Emissions Datasets (**NVED**) tool (Jacobs 2016).

2.1.6 Other pollutants

We did not assess exposure to carbon monoxide (**CO**), ozone (**O_3**) or sulphur dioxide (**SO_2**) in HAPINZ 3.0.

Since the widespread introduction of petrol vehicles fitted with catalytic converters into the fleet from 2003, concentrations of CO in New Zealand have declined markedly and are very low compared to recommended health guidelines.

O_3 concentrations are also generally low, with monitoring undertaken at only a few locations across New Zealand - Musick Point, Auckland and Wellington Central.

Elevated levels of SO_2 tend to be localised and there are insufficient data available to assess impacts at a national level. However, the effects of secondary sulphate particulate are captured in the assessment of secondary PM.

Greenhouse gases, such as carbon dioxide, were not assessed in HAPINZ 3.0 because the focus was on pollutants which result in a more direct impact on human health.

2.2 Attributing source contributions

Understanding the contributions that individual sources make to air pollution concentrations or exposure and the associated health effects is vital to tailor management strategies to reduce the health burden associated with air pollution.

2.2.1 $PM_{2.5}$ sources

For $PM_{2.5}$, with the wealth of data now available, we attributed contributions to sources based on already identified source apportionment "fingerprints" [20] as follows:

- **domestic fires** used for home heating – based on a *biomass burning* fingerprint (where available) or an empirical method based on $PM_{2.5}$
- **motor vehicles** encompassing exhaust, brake/tyre wear and re-suspended road dust – based on a *motor vehicle* fingerprint
- **industry** – based on a *local industry* fingerprint (where available)
- **windblown dust** from sources such as construction, land use, industry and the movement of motor vehicles (e.g. road abrasion, suspension and re-suspension of surface material) – based on a *crustal material* fingerprint

[20] HAPINZ 3.0 derives sources of PM from the compositional analysis of samples collected at the same monitoring stations that $PM_{2.5}$ or PM_{10} ambient concentrations are measured. Each source is identified by specific groupings of elements (fingerprints). For example, Na and Cl represent sea spray.

- **sea spray** – based on a *marine aerosol* fingerprint
- **secondary PM** resulting from gases emitted from natural and anthropogenic sources reacting in the atmosphere to form particles – based on a *secondary sulphate* fingerprint.

Open burning of domestic or agricultural waste is now banned, or severely restricted, in most urban areas and source apportionment studies have not identified it as a significant source of pollution. In the few urban areas, where it is still allowed, we estimated the likely contribution to PM exposure based on emissions inventory data (up to 12% but typically no more than 8% of all biomass burning PM). Urban open burning was captured in the domestic fires source.

Due to limited monitoring data, the infrequency of events, and low numbers of people exposed, we were not able to assess open burning in rural areas.

Exposure estimates for other anthropogenic PM sources - especially aviation, shipping, and rail – were not included as they are not recorded consistently in emissions inventories across New Zealand. However, we estimate their contribution is likely to account for less than 5% of exposure at a national level (Kuschel *et al* 2022).

2.2.2 NO_2 sources

NO_2 exposure was based on estimates from the Waka Kotahi NVED tool, which combines estimated *background* concentrations with estimated *roadside* concentrations. While the focus of the NVED tool is on the effect of road transport emissions, the background concentrations are based on the results of monitoring, which may be influenced by other sources of NO_2 for which we have little data in the way of source breakdowns.

Given the limitations of available information, we defaulted to assigning all effects of NO_2 to on-road (registered) motor vehicles. However, we considered this was reasonable given motor vehicles are likely to be responsible for nearly 90% of all NO_2 exposure in urban areas (Xie *et al* 2019). The motor vehicle contribution is dominated by diesel vehicles. For example, for Auckland, the motor vehicle emissions split is 64% diesel versus 36% petrol, with heavy diesel vehicles contributing 61% of emissions while being only 4% of the fleet (Sridhar & Metcalfe 2019).

Note: Forest fires and lightning are natural sources of NO_2, but anthropogenic sources dominate in areas where people are typically exposed.

2.3 Selecting health impacts and calculating burden

Air pollution is a complex and variable mixture of gases and particles. Both short-term exposure and long-term exposure to air pollution are associated with a wide range of negative health impacts, including premature mortality and a range of cardiovascular and respiratory diseases.

Health effects resulting from air pollution depend on the pollutant and the length of exposure – either short-term (*acute*) or long-term (*chronic*). Short–term exposures cover minutes, hours, or days. Long-term exposures are usually over months or years. Depending on the exposure duration and magnitude, the health burden due to chronic exposure to air pollution may be 10 times greater than for acute exposure (WHO 2006). Consequently, we opted for assessing health impacts due to long-term (annual) exposure in HAPINZ 3.0.

We considered the robustness of ERFs by pollutant, the availability of exposure and health data, and the likely public health significance of the exposure in selecting the most relevant health impacts for HAPINZ 3.0.

We developed New Zealand-specific ERFs for PM_{10}, $PM_{2.5}$ and NO_2 *mortality* (death) and *morbidity* (ill health or suffering) as part of a separate cohort study[21]. We also established appropriate indicators to enable assessment of childhood asthma in New Zealand.

2.3.1 Mortality impacts

Mortality impacts were assessed both in terms of premature deaths and years of life lost (**YLL**) for adults (people aged 30 years and over) due to long-term (annual) exposure to $PM_{2.5}$ and NO_2. We developed ERFs for $PM_{2.5}$ and NO_2 using a two pollutant model, which meant that effects from both pollutants could be considered together. This is different to HAPINZ 2.0 which only used a single pollutant model, assuming PM_{10} as a proxy for all air pollution

Note: Multi-pollutant models assume that more than one pollutant may be contributing to the observed effects and generate exposure-response functions based on the combination.

For example, a single pollutant model for $PM_{2.5}$ seeks to explain the change in adverse effects based on $PM_{2.5}$ concentrations *alone* and will likely have a high relative risk factor, e.g. 1.205 per 10 $\mu g/m^3$ $PM_{2.5}$ with wide 95% confidence intervals. However, if part of the observed effect is actually due to NO_2 then a two pollutant model covering $PM_{2.5}$ and NO_2 is better able to explain the changes and will likely reduce the relative risk factor for $PM_{2.5}$, e.g. 1.105 per 10 $\mu g/m^3$ $PM_{2.5}$ with narrower confidence intervals. Because the two pollutant model is based on both pollutants, the effects of each are additive.

We assessed the mortality impacts for all adults[22] in the population, as well as assessing them separately for the subset Māori adult and Pacific adult populations to test for effects associated with ethnicity.

Note: We found no robust differences in any of the ERFs in the two pollutant model when we limited the analyses to specific ethnic groups. The central estimates for some associations were higher for different ethnic groups. However, when combined with the confidence intervals, there was no statistically significant difference between the results. This is similar to what we found in HAPINZ 2.0.

We also assessed premature deaths for all adults in the population due to long-term exposure to PM_{10} to enable comparison with HAPINZ 2.0.

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[21] Hales S *et al* (2021). Long term exposure to air pollution, mortality and morbidity in New Zealand: Cohort study. *Science of Total Environment* **801** (2021) 149660, August. https://doi.org/10.1016/j.scitotenv.2021.149660

[22] Adult (30 years and over) mortality is a typical metric used in air pollution health effects assessment and enables the HAPINZ 3.0 results to be compared with international studies.

2.3.2 Morbidity impacts

Hospitalisations

We assessed hospital admissions for two main categories - cardiovascular disease (**CVHAs**) and respiratory disease (**RHAs**). Both types of admissions were assessed for all ages due to long-term (annual) exposure to $PM_{2.5}$ and NO_2.

Restricted activity days

Restricted activity days (**RADs**) are days when exposure to air pollution causes symptoms which prevent people being able to go to work, school or undertake their usual activities. This impact was assessed in HAPINZ 2.0. We considered RADs were useful to retain as another measure of morbidity in HAPINZ 3.0 and assessed the impact due to long-term (annual) exposure to $PM_{2.5}$.

Childhood asthma

For childhood asthma, we assessed asthma/wheeze hospitalisations for all children (aged 0-18 years). This is a subset of respiratory hospital admissions. We also looked at the prevalence of childhood asthma for all children (0-18 years), because New Zealand has a high prevalence[23] of asthma relative to other countries with one in seven children aged 2-14 years currently taking asthma medication (HQSC 2016).

We assessed both impacts due to long-term (annual) exposure to NO_2.

2.3.3 ERFs for selected health effects

Table 1 summarises the ERFs used to assess the selected health effects in HAPINZ 3.0.

Table 1: ERFs used for the health effects assessed in HAPINZ 3.0

Health effect	ERF	Reference
Due to exposure to annual $PM_{2.5}$		
Premature deaths and YLL (all adults, aged 30 yrs and over)	1.105 (95% CI: 1.065, 1.145) per 10 μg/m³ $PM_{2.5}$	HAPINZ 3.0 cohort study
Premature deaths and YLL (all Māori adults, all Pacific adults)	Same as above	HAPINZ 3.0 cohort study
Cardiovascular hospitalisations (all ages)	1.115 (95% CI: 1.084, 1.146) per 10 μg/m³ $PM_{2.5}$	HAPINZ 3.0 cohort study
Respiratory hospitalisations (all ages)	1.070 (95% CI: 1.021, 1.122) per 10 μg/m³ $PM_{2.5}$	HAPINZ 3.0 cohort study
Restricted activity days (all ages)	0.9 (lower/upper bounds: 0.5, 1.7) per 10 μg/m³ $PM_{2.5}$	ALA 1995 based on Ostro 1987

[23] *Prevalence* is the proportion of a population who *have* a specific characteristic in a given time period. *Incidence* is the proportion of a population who *develop* a specific characteristic in a given time period.

Health effect	ERF	Reference
Due to exposure to annual NO_2		
Premature deaths and YLL (all adults, aged 30 yrs and over)	1.097 (95% CI: 1.074, 1.120) per 10 µg/m³ NO_2	HAPINZ 3.0 cohort study
Cardiovascular hospitalisations (all ages)	1.047 (95% CI: 1.031, 1.064) per 10 µg/m³ NO_2	HAPINZ 3.0 cohort study
Respiratory hospitalisations (all ages)	1.130 (95% CI: 1.102, 1.159) per 10 µg/m³ NO_2	HAPINZ 3.0 cohort study
Asthma/wheeze hospitalisations (all children, aged 0-18 yrs)	1.182 (95% CI: 1.0942, 1.276) per 10 µg/m³ NO_2	HAPINZ 3.0 cohort study
Prevalence of asthma (all children, aged 0-18 yrs)	1.05 (95% CI: 1.02, 1.07) per 4 µg/m³ $PM_{2.5}$	Khreis *et al* 2017
Due to exposure to annual PM_{10}		
Premature deaths (all adults, aged 30 yrs and over)	1.111 (95% CI: 1.089, 1.133) per 10 µg/m³ PM_{10}	HAPINZ 3.0 cohort study
Premature deaths (all Māori adults, all Pacific adults)	Same as above	HAPINZ 3.0 cohort study

2.3.4 Health datasets

As with the air quality monitoring and population data, the health data were analysed at the CAU level (CAU2013) with data averaged across three years to reduce inter-annual variability.

Mortality data

We analysed unit record data from the New Zealand Mortality Collection, provided by the Ministry of Health (**MoH**). The Mortality Collection includes date of birth, date of death, underlying cause of death (using the International Classification of Diseases 10th revision – Australia Modification, **ICD-10 AM** code), ethnic groups and domicile code (which relates to CAU).

Years of life lost for all adults in the population were calculated using the mortality data (above) and life tables[24] for five-year age bands (0, 1–4, 5–9, … 90+ years), for males and females based on age at death and sex of each individual.

Hospital admissions

We analysed unit record data from the National Minimum Dataset (**NMDS**), provided by MoH. The NMDS Collection includes date of birth, date of hospital admission and discharge, primary diagnosis (ICD-10 AM code), ethnic groups and domicile code.

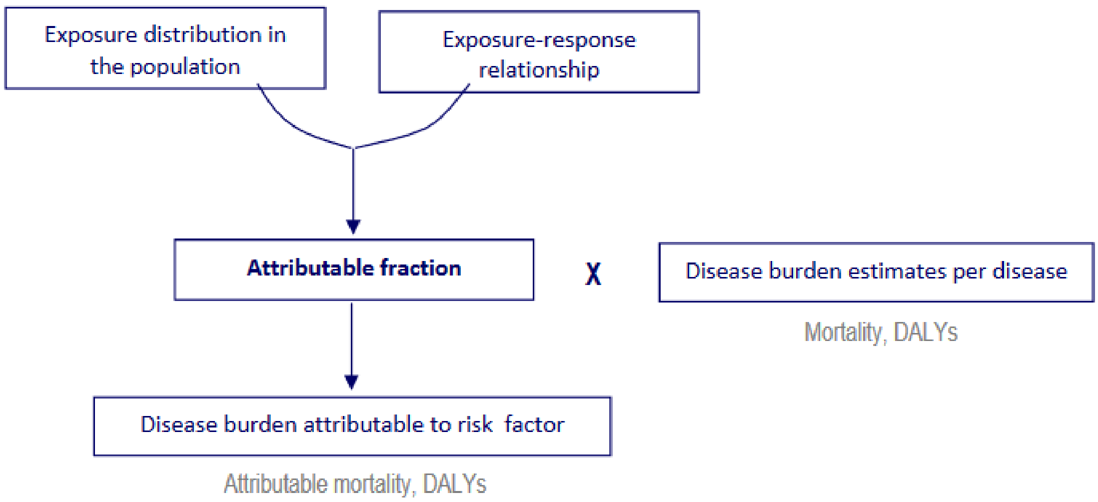
[24] A life table is a table which shows, for each age, what the probability is that a person of that age will die before their next birthday. In other words, it represents the survivorship of people from a certain population.

Data were analysed for the three-year period 2015–2017 to calculate the average nights per hospital stay for the different types of hospital admission – CVHA, RHA and asthma/wheeze in children.

2.3.5 Estimation of the health burden

Our approach to estimating the health burden attributable to air pollution followed the method used in the Environmental Burden of Disease Study (WHO 2018; Prüss-Üstün *et al* 2003) and is summarised in Figure 1. It is also consistent with the approach used in previous HAPINZ studies.

Figure 1: Method for estimating burden of disease



Source: WHO (2018), Burden of Disease methods for ambient air pollution
Note: DALYs= disability-adjusted life years

This method uses the **population attributable fraction** or **PAF (**the proportion of the health burden attributable to a specified risk factor) to estimate the **attributable burden**.

2.4 Estimating social costs

Mortality and morbidity impacts amount to loss of life and life quality for people exposed to air pollution. These costs can be estimated to arrive at a total cost to society (the *social* cost) resulting from exposure to air pollution in New Zealand. Adverse effects resulting from air pollution place a significant burden on society and health systems.

2.4.1 Mortality costs

Two approaches were used for valuing mortality impacts:

- premature deaths and the value of statistical life (**VoSL**)
- life years lost and the value of a life year (**VoLY**).

Under the VoSL approach, the estimated change in the number of premature deaths was multiplied by the current New Zealand-based VoSL based on transport risk (road safety), as was done in HAPINZ 2.0. We used a VoSL of $4,527,300 per death, at June 2019 prices (MoT 2020).

Under the VoLY approach, the change in total life years was multiplied by VoLY. The VoLY was estimated from the VoSL, discounted over 40 years at 5% (the NZ Treasury recommended discount rate). The resulting VoLY was $263,843 (June 2019 prices).

2.4.2 Morbidity costs

Hospital admissions

The social costs of hospital admissions were estimated from the financial costs per hospitalisation (based on the average number of bed nights for each type), productivity losses from time off work or school for those hospitalised, family and friends, and recovery costs after discharge from hospital including any long-term disability (quality of life).

The total costs for cardiac admissions were estimated at $36,666 per case, with respiratory admissions at $31,748 per case.

Restricted activity days

The social costs of RADs ($89 per case) were estimated based on lost average income per day (the same approach as in HAPINZ 2.0) but with an updated value of lost income.

Childhood asthma

Childhood asthma costs included those resulting from GP visits, medication and hospitalisations.

GP visit and pharmaceutical costs were estimated at $128 per case and asthma hospitalisations at $1,822 per case.

2.4.3 Damage costs

Damage costs are a way to value changes in emissions to air to compare the benefits to society of a change in policy/operation with the cost of implementing the change. They can be used to capture benefits of emission reductions of both harmful pollutants (e.g. $PM_{2.5}$) and greenhouse gases (e.g. carbon dioxide, $\mathbf{CO_2}$) and for comparing options to identify which will produce the best overall outcome. Many international government agencies publish relevant values to be used in the assessment of costs and benefits of policy options in their jurisdictions (e.g. Powell *et al* 2019).

In HAPINZ 3.0, we used the *HAPINZ 3.0 Health Effects Model* outputs to match health costs to emissions of $PM_{2.5}$ and NO_X[25] to develop a suite of New Zealand-specific harmful emissions damage costs for areas with different population densities.

For the other harmful pollutants, we started with the damage costs in the *Monetised Benefits and Costs Manual* (**MBCM**) (NZTA 2021), assuming these values were applicable in urban areas, then calculated corresponding rural values using the urban/rural damage cost ratio for $PM_{2.5}$.

Regarding greenhouse gas emissions, the NZ Treasury publishes guidance on undertaking cost benefit analyses, including recommended annual values for CO_2 equivalent (**CO_2e**) emissions for use in policy assessment. These values are based on the likely future *abatement* costs[26] rather than the *social* costs associated with the emissions. However, these are the best figures currently available in New Zealand to value CO_2e emissions and ensure consistency and comparability across cost benefit analyses.

The resultant damage costs for harmful emissions developed from HAPINZ 3.0 are shown in Table 2. For comparison, we include the NZ Treasury (2021) CBAx central value for CO_2e emissions adjusted for June 2019 (which is $88 in all areas).

Table 2: Damage costs developed in HAPINZ 3.0 for harmful emissions and the CBAx costs for greenhouse gases (in 2019 NZ$)

Pollutant	Costs in $/tonne Urban	Costs in $/tonne Rural	Costs in $/tonne New Zealand
$PM_{2.5}$	$622,786	$24,473	$382,524
NO_X	$499,526	$11,296	$186,037
SO_2	$36,491	$1,434	$22,413
VOC	$1,433	$56	$880
CO	$4.52	$0.18	$2.78
CO_2e	$88	$88	$88

[25] As a marker of NO_2 emissions

[26] The emissions values provided 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. These values will be updated annually as knowledge improves on New Zealand's costs of abatement.

2.5 Summary of methodology

The key features of the approach we adopted are summarised in Table 3 below:

Table 3: Key features of the HAPINZ 3.0 update

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	**Priority 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 • **cardiac admissions** 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 • **cardiac admissions** 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

Feature	Details
Social costs	**Valuation of mortality costs** • change in mortality multiplied by current NZ Value of a Statistical Life (**VoSL**) • change in total life years multiplied by a NZ Value of a Life Year (**VoLY**) **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 draft **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

3. What did we find?

This chapter presents our findings related to **anthropogenic air pollution only**. Results for all sources (including natural) are available in the *HAPINZ 3.0 Health Effects Model*[27].

3.1 National impacts

3.1.1 Overall

We estimated (and costed) the health impacts associated with anthropogenic air pollution using **two measures of mortality** – one based on premature deaths and the other based on years of life lost (YLL) – both for adults (aged 30 years and over). Historically in New Zealand, air pollution impacts have been reported based on premature deaths but internationally many jurisdictions also report YLL.

Table 4 summarises the anthropogenic air pollution health impacts for New Zealand in 2016, based on **premature deaths**, for those health effects which are additive.

Exposure to $PM_{2.5}$ and NO_2 pollution from anthropogenic sources contributed to more than 3,300 New Zealanders dying prematurely in 2016. Air pollution exposure also resulted in more than 13,100 hospitalisations for cardiovascular and respiratory illness, over 13,200 cases of childhood asthma and nearly 1.75 million days where people's activities were restricted.

Table 4: Health impacts for New Zealand in 2016 by effect and source due to anthropogenic air pollution (in case numbers)

Health effect	Cases by source (number)				
	Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Cases due to annual $PM_{2.5}$					
Premature deaths (all adults)	962	222	2	106	**1,292**
Cardiovascular hospitalisations (all ages)	1,940	470	4	225	**2,639**
Respiratory hospitalisations (all ages)	1,435	375	3	171	**1,985**
Restricted activity days (all ages)	1,255,711	330,388	2,700	156,555	**1,745,354**
Cases due to annual NO_2					
Premature deaths (all adults)		2,025			**2,025**
Cardiovascular hospitalisations (all ages)		1,987			**1,987**
Respiratory hospitalisations (all ages)		6,544			**6,544**
Asthma prevalence (0-18 yrs)		13,229			**13,229**

[27] Sridhar S *et al* (2022a). *Health and air pollution in New Zealand 2016 (HAPINZ 3.0): Health effects model*. Excel model prepared by S Sridhar, J Metcalfe and K Mason for Ministry for the Environment, Ministry of Health, Ministry of Transport and Waka Kotahi NZ Transport Agency, March 2022.

Health effect	Cases by source (number)				
	Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Cases due to both $PM_{2.5}$ and NO_2					
Premature deaths (all adults)	962	2,247	2	106	**3,317**
Cardiovascular hospitalisations (all ages)	1,940	2,456	4	225	**4,626**
Respiratory hospitalisations (all ages)	1,435	6,919	3	171	**8,529**
Asthma prevalence (0-18 yrs)		13,229			**13,229**
Restricted activity days (all ages)	1,255,711	330,388	2,700	156,555	**1,745,354**

Note: NO_2 exposure and effects were assigned to motor vehicles only, in the absence of data for other sources but also recognising that motor vehicles are the dominant source in urban areas (~90%).

Table 5 presents the associated social costs of anthropogenic air pollution for New Zealand in 2016, based on **premature deaths**, for those health effects which are additive.

The **total social costs** associated with anthropogenic air pollution in New Zealand in 2016 are estimated at **$15.6 billion.** The majority of these result from premature mortality (death) in adults. However, the costs of increased morbidity (illness and disease) are also considerable.

Table 5: Social costs for New Zealand in 2016 by effect and source due to anthropogenic air pollution (in 2019 NZ$)

Health effect	Costs by source ($million)				
	Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Costs due to annual $PM_{2.5}$					
Premature deaths (all adults)	4,357	1,003	7	480	**$5,847**
Cardiovascular hospitalisations (all ages)	71	17	0	8	**$97**
Respiratory hospitalisations (all ages)	46	12	0	5	**$63**
Restricted activity days (all ages)	112	29	0	14	**$155**
Costs due to annual NO_2					
Premature deaths (all adults)		9,168			**$9,168**
Cardiovascular hospitalisations (all ages)		73			**$73**
Respiratory hospitalisations (all ages)		208			**$208**
Asthma prevalence (0-18 yrs)		2			**$2**
Costs due to both $PM_{2.5}$ and NO_2					
Premature deaths (all adults)	4,357	10,171	7	480	**$15,015**
Cardiovascular hospitalisations (all ages)	71	90	0	8	**$170**
Respiratory hospitalisations (all ages)	46	220	0	5	**$271**
Asthma prevalence (0-18 yrs)		2			**$2**
Restricted activity days (all ages)	112	29	0	14	**$155**
Total social costs ($million)	**$4,585**	**$10,512**	**$8**	**$508**	**$15,613**

Looking at the alternative way of valuing mortality, Table 6 summarises the **years of life lost** through exposure to anthropogenic air pollution for New Zealand in 2016. The associated social costs are shown in Table 7.

More than 43,500 years of life were lost for adult New Zealanders due to anthropogenic air pollution in New Zealand in 2016, at cost of $11.5 billion.

Table 6: Years of life lost for New Zealand in 2016 by effect and source due to anthropogenic air pollution (in years)

Health effect	YLLs by source (years)				
	Domestic fires	Motor vehicles	Industry	Windblown dust	Total
YLLs due to annual $PM_{2.5}$					
Years of life lost (all adults)	12,412	2,917	24	1,421	**16,774**
YLLs due to annual NO_2					
Years of life lost (all adults)		26,756			**26,756**
YLLs due to both $PM_{2.5}$ and NO_2					
Years of life lost (all adults)	12,412	29,673	24	1,421	**43,531**

Table 7: Social costs of years of life lost for New Zealand in 2016 by effect and source due to anthropogenic air pollution (in 2019 NZ$)

Health effect	Costs by source ($million)				
	Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Costs due to annual $PM_{2.5}$					
Years of life lost (all adults)	3,275	770	6	375	**$4,426**
Costs due to annual NO_2					
Years of life lost (all adults		7,059			**$7,059**
Costs due to both $PM_{2.5}$ and NO_2					
Years of life lost (all adults	3,275	7,829	6	375	**$11,485**
Total social costs of YLLs ($million)	**$3,275**	**$7,829**	**$6**	**$375**	**$11,485**

Note: The social costs associated with years of life lost at $11.49 billion are less than those based on premature deaths at $15.0 billion because the method used for valuing these impacts is based on a *discounted* value of a life year. Regardless the social costs of mortality using either method are similar and substantial.

3.1.2 Contributions

Table 8 shows the contribution of the pollutants and individual sources to the social costs of anthropogenic air pollution for New Zealand in 2016.

Table 8: Contribution of individual sources to the total social costs of anthropogenic air pollution for New Zealand in 2016 (in 2019 NZ$)

Health effect	Costs by source ($million)				
	Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Costs due to annual $PM_{2.5}$					
Total costs of impacts ($million)	4,585	1,061	8	508	$6,162
Fraction of anthropogenic costs (%)	**74.4%**	**17.2%**	**0.1%**	**8.2%**	**100.0%**
Costs due to annual NO_2					
Total costs of impacts ($million)	-	9,451	-	-	$9,451
Fraction of anthropogenic costs (%)	**0.0%**	**100.0%**	**0.0%**	**0.0%**	**100.0%**
Costs due to both $PM_{2.5}$ and NO_2					
Total costs of impacts ($million)	4,585	10,512	8	508	$15,613
Fraction of anthropogenic costs (%)	**29.4%**	**67.3%**	**0.05%**	**3.3%**	100.0%

By pollutant

The total social costs of $15.6 billion of anthropogenic air pollution are split between $PM_{2.5}$ impacts ($6.2 billion) and NO_2 impacts ($9.5 billion), with **$NO_2$ exposure accounting for just over 60% of the total costs**. This is a significant finding.

The previous study – HAPINZ 2.0 – used PM_{10} as a proxy for all air pollution (based on the data available at the time) but noted that the results likely under-estimated impacts due to NO_2. However, the extent of the NO_2 impacts found in HAPINZ 3.0 was startling. When the HAPINZ 3.0 draft findings first became available (February 2021), no other researchers had published such strong associations between NO_2 and mortality. However, this may have been because they were studying associations in locations with NO_2 concentrations that were much higher than those in New Zealand. To ensure the findings were genuine, the HAPINZ 3.0 research team undertook considerable additional analyses to check for bias, and the results were rigorously peer-reviewed before being published internationally (Hales *et al* 2021). This paper has now been referenced by others who have found similarly strong NO_2 impacts.

As discussed in the *HAPINZ 3.0 Volume 2 – Detailed methodology*[28] report, there is evidence that the ERFs for NO_2 and mortality are *supra-linear*, i.e. the response is more marked at low concentrations and flattens out at higher concentrations. Supra-linearity has been found by other researchers and has contributed to the World Health Organization (**WHO**) significantly tightening many of their guideline values for ambient air quality (WHO 2021). For example, the annual average NO_2 guideline has reduced from 40 μg/m^3 to 10 μg/m^3.

[28] Kuschel G *et al* (2022). *Health and air pollution in New Zealand 2016 (HAPINZ 3.0): Volume 2 – Detailed methodology*. Report prepared by G Kuschel, J Metcalfe, S Sridhar, P Davy, K Hastings, K Mason, T Denne, J Berentson-Shaw, S Bell, S Hales, J Atkinson and A Woodward for Ministry for the Environment, Ministry of Health, Te Manatū Waka Ministry of Transport and Waka Kotahi NZ Transport Agency, March 2022.

By source

As seen in Table 8, the dominant sources to anthropogenic social costs depend on the pollutant.

Domestic fires used for home heating in winter dominate the anthropogenic $PM_{2.5}$ pollution costs (74%) followed by motor vehicles (17%), with lesser contributions from windblown dust (8%) and industry (0.1%).

Motor vehicles dominate (exclusively) the anthropogenic NO_2 pollution costs (100%). As mentioned earlier, other anthropogenic sources will contribute to NO_2 exposure but due to limited information, we defaulted to assigning all effects of NO_2 to on-road (registered) motor vehicles only. Nonetheless, we consider this is reasonable given motor vehicles are likely to be responsible for nearly 90% of all NO_2 exposure in urban areas.

The **combined social costs** associated with both $PM_{2.5}$ and NO_2 anthropogenic air pollution are dominated by motor vehicles (67%) followed by domestic fires (29%), windblown dust (3%) and the balance from industry (0.05%).

Note: The contribution of motor vehicles to overall anthropogenic air pollution health impacts in HAPINZ 3.0 is considerably greater than that reported in HAPINZ 2.0. This is because HAPINZ 2.0 used PM_{10} as a proxy for all air pollution and assigned effects to individual sources based on their estimated contribution to PM_{10} concentrations, which are generally dominated by domestic fires used for winter-time heating. As mentioned, motor vehicles are the dominant source of NO_2 in urban areas but this was not factored into the HAPINZ 2.0 source allocations because the NO_2 impacts were not expected to be so significant.

3.1.2 Population subgroups

We assessed health impacts for a selection of population subgroups relating to ethnicity and age (as outlined in section 2.5). Table 9 presents the health impacts of air pollution in New Zealand in 2016 for population subgroup impacts under the main headings of premature deaths due to annual $PM_{2.5}$ and respiratory hospitalisations due to annual NO_2.

Table 9: Health impacts for New Zealand in 2016 for different population subgroups due to anthropogenic air pollution (in case numbers)

Health effect	Cases by source (number)				
	Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Cases due to annual $PM_{2.5}$					
Premature deaths (all adults)	962	222	2	106	**1,292**
Premature deaths (Māori only adults)	87	20	0	11	**118**
Premature deaths (Pacific only adults)	30	12	0	4	**46**
Cases due to annual NO_2					
Respiratory hospitalisations (all ages)		6,544			**6,544**
Asthma/wheeze hospitalisations (0-18 yrs)		845			845

Note: The unshaded health effects are a sub-group of the shaded categories and should not be added to the health effects or costs as this would be 'double-counting'.

$PM_{2.5}$ premature mortality

Based on our analyses, the number of **premature deaths** due to anthropogenic $PM_{2.5}$ pollution for **different ethnic subgroups closely matched their proportions in the population**.

- Māori adults comprised 9.1% of the total adult premature deaths versus 11.7% of the 2016 adult population.
- Pacific adults comprised 3.7% of the total adult premature deaths versus 5.4% of the 2016 adult population.

Note: The HAPINZ 2.0 results suggested that ethnicity could be a factor in the response of some individuals to air pollution. We investigated this in more detail in HAPINZ 3.0 but found no conclusive proof. While the central estimates for some ERFs were higher for different ethnic groups, when these were combined with the confidence intervals (the error limits), there was no statistically significant difference between them. Consequently, we assigned the same values in the ERFs (regardless of ethnicity) but did combine them with specific health and ambient air quality data relating to specific ethnic groups.

NO_2 respiratory hospitalisations

For the respiratory hospitalisations due to NO_2 exposure, 13% of the cases were for children aged 0 to 18 years presenting with asthma/wheeze. Children aged 0-18 years make up 25.0% of the total 2016 population.

Note: While the asthma/wheeze hospitalisation numbers are a small fraction of the total number of respiratory hospitalisations, this does not mean children are necessarily under-represented overall as there are many more categories of respiratory hospitalisation that will include children.

3.2 Regional impacts

Detailed results by region and territorial authority (**TA**) are summarised in Appendix A. However, a selection of results are presented here to highlight regional variations.

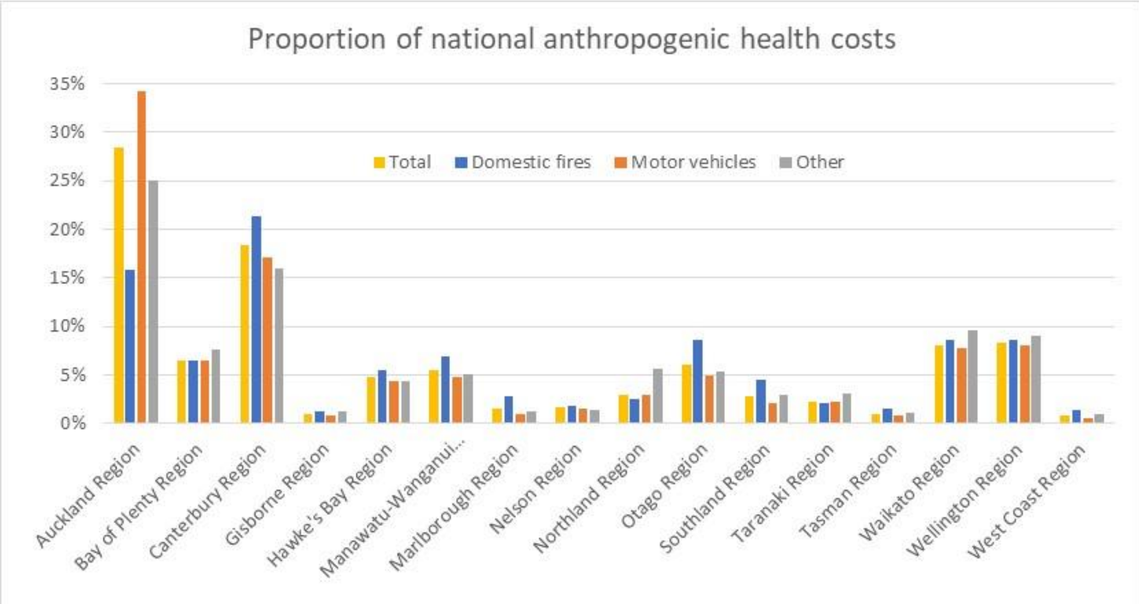
3.2.1 National contributions

Figure 2 shows the contribution of each region to the total anthropogenic air pollution health costs for New Zealand as well as the contribution to the national totals by source.

For example, the Auckland region contributed 29% of all anthropogenic social costs for New Zealand in 2016. However, Auckland contributed more of the motor vehicle social costs (34%) but less of the domestic fire costs (16%) and other anthropogenic (industry and windblown dust) costs (25%). The Auckland region comprised 34% of New Zealand's total population in 2016.

By comparison the Canterbury region contributed 18% of all anthropogenic social costs for New Zealand but more of the domestic fire social costs (21%) and less of the motor vehicle costs (17%) and other anthropogenic costs (16%). The Canterbury region comprised 13% of New Zealand's total population in 2016.

Figure 2: Contribution of individual regions to the total social costs of anthropogenic air pollution for New Zealand in 2016



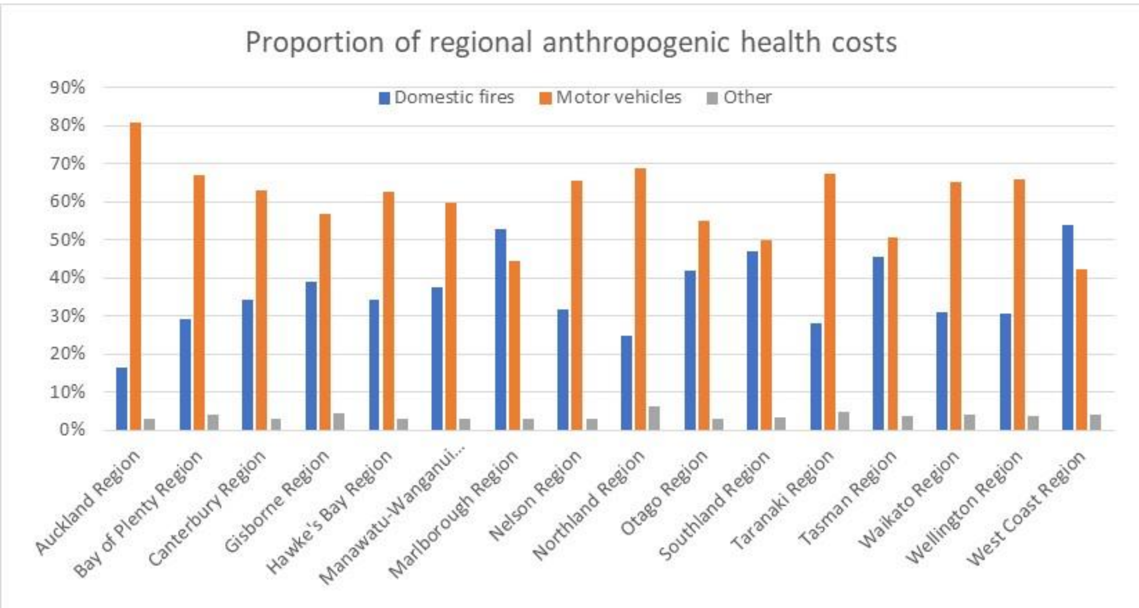
Note: Other includes industry and windblown dust

3.2.1 Relative source contributions

All anthropogenic air pollution

Figure 3 shows the **relative contribution of each source to all anthropogenic** air pollution health costs in each region.

Figure 3: Relative contributions of individual sources to the social costs of all anthropogenic air pollution by region in 2016



Note: Other includes industry and windblown dust

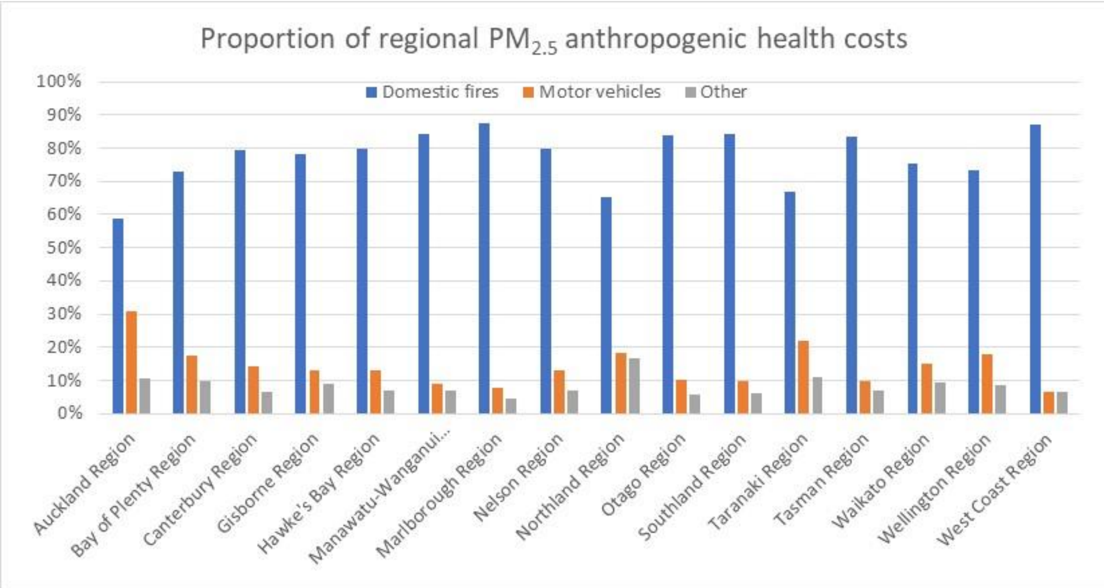
In all but two regions – Marlborough and West Coast – motor vehicles were the single greatest source contributing to anthropogenic air pollution health costs. In most regions in the North Island of New Zealand motor vehicle impacts were at least twice those of domestic fires. In the South Island, the difference between the two sources was markedly reduced.

At the TA level (see Appendix A), **motor vehicles dominated the total ($PM_{2.5}$ and NO_2) anthropogenic health costs in <u>most</u> locations across New Zealand** (except those with high use of solid fuel home heating during winter). On average, **motor vehicle impacts were more than twice those of domestic fires** for total ($PM_{2.5}$ and NO_2) pollution from anthropogenic sources.

$PM_{2.5}$ only anthropogenic air pollution

Figure 4 shows the **relative contribution of each source to all $PM_{2.5}$ only anthropogenic** air pollution health costs in each region.

Figure 4: Relative contributions of individual sources to the social costs of $PM_{2.5}$ anthropogenic air pollution by region in 2016



Note: Other includes industry and windblown dust

In all regions, domestic fire impacts dominated the regional $PM_{2.5}$ social costs – with contributions ranging from 59% to 88%. Regional NO_2 social costs were all assumed to be from motor vehicles (100%) so these are not shown separately.

At the TA level (see Appendix A), **domestic fires dominated the $PM_{2.5}$ anthropogenic health costs in <u>every</u> location across New Zealand.** On average, **domestic fire impacts were more than four times those of motor vehicles** for $PM_{2.5}$ pollution from anthropogenic sources.

3.3 Sensitivity testing

The *HAPINZ 3.0 Health Effects Model* includes a set of default/recommended values which are used to generate the results for the 2016 base case. However, the model also includes ranges of high/low values which generally represent the 95% confidence intervals for each parameter. Appendix B presents the full list of default (base case) parameters with their typical ranges.

Using these ranges, we tested the sensitivity of the model results to the following parameters:

- the exposure-response functions
- the social cost values
- the choice of mortality impact (premature deaths versus life years lost).

Table 10 summarises the results of the sensitivity testing in terms of social costs. Using the high estimates for the social cost values would have the greatest impact (52%) on total anthropogenic social costs.

Table 10: Sensitivity of the HAPINZ 3.0 anthropogenic social costs to different parameters versus the base case (in 2019 NZ$)

Scenario	Social costs ($million)			
	Mortality	Morbidity	Total	vs base case
Base case				
Default values	15,015	597	**$15,613**	-
Exposure-response functions				
Lower bounds of 95% confidence interval	10,863	395	**$11,257**	-28%
Higher bounds of 95% confidence interval	18,972	868	**$19,839**	+27%
Social cost values				
Low estimates	13,435	187	**$13,621**	-13%
High estimates	17,386	6,357	**$23,743**	+52%
Mortality valuation method				
Years of life lost instead of premature deaths	11,485	597	**$12,083**	-23%

3.3.1 Effect of exposure–response values

If the **lower bounds of the confidence intervals** for the exposure-response functions were used, then the impacts would be 28% less than those in the base case.

If the **higher bounds of the confidence intervals f**or the exposure-response functions were used, then the impacts would be 27% higher than those predicted using the base case.

Overall effect: Within these two bounds, anthropogenic air pollution health impacts would be between $11.3 billion and $19.8 billion (relative to the base case of $15.6 billion).

Note: The number of premature deaths for adults due to anthropogenic air pollution would be between 2,399 and 4,191 (relative to the base case of 3,317 deaths).

3.3.2 Effect of social cost values

If the **low estimates** for the social cost values were used, then the impacts would be 13% less than those in the base case.

If the **higher estimates** for the social cost values were used, then the impacts would be 52% higher than those predicted using the base case.

Overall effect: Within these two bounds, anthropogenic air pollution health impacts would be between $13.6 billion and $23.7 billion (relative to the base case of $15.6 billion).

Note: The increase in the high cost estimate scenario is largely due to factoring in loss of life quality from prolonged illness and suffering which is not included in the base case. Many overseas jurisdictions use a specific environmental VoSL which is considerably higher than a transport (road safety) risk VoSL to adequately account for these loss of life quality costs.

3.3.3 Effect of mortality valuation method

The base case uses premature deaths as the primary measure for mortality as outlined in Section 2.4. However, estimates of years of life lost are also available and can be used as an alternative method for valuing mortality.

If **life years lost were used instead of premature deaths,** then the impacts would be 23% lower relative to the base case.

Overall effect: Anthropogenic air pollution health impacts would be $12.1 billion (relative to the base case of $15.6 billion).

3.4 Backcasting and trends

The *HAPINZ 3.0 Health Effects Model* was used to:

- estimate air pollution health effects based on PM_{10} in 2006 and 2016 so we could compare HAPINZ 2.0 with HAPINZ 3.0, using the same methodology (backcasting)
- estimate air pollution health effects based on $PM_{2.5}$ and NO_2 in 2006 and 2016 so we could review changes over time (trends).

HAPINZ 2.0 assessed premature deaths using PM_{10} as a proxy for all air pollution (single pollutant model) whereas HAPINZ 3.0 assessed premature deaths based on $PM_{2.5}$ and NO_2 (two pollutant model). However, in HAPINZ 3.0 we developed a revised mortality ERF for PM_{10} only (single pollutant model) to enable comparison with HAPINZ 2.0 (see section 2.3.3).

3.4.1 Trends in total impacts based on PM_{10}

We assessed changes in premature deaths due to total air pollution by applying the revised ERF for PM_{10} only (single pollutant model) to the base data in HAPINZ 2.0 (2006) and to the base data in HAPINZ 3.0 (2016). We did this to see how the results estimated for PM_{10} only (the basis for HAPINZ 2.0) compared to those estimated for $PM_{2.5}$ and NO_2 (the basis for HAPINZ 3.0) as PM_{10} data are available for backcasting air pollution impacts for years before 2006.[29] Because this analysis used PM_{10} as a proxy for all air pollution, we were not able to split the results into different sources based on their estimated contribution to PM_{10} concentrations. Consequently, we estimated effects due to total air pollution (anthropogenic and natural).

Table 11 compares the HAPINZ 2.0 and HAPINZ 3.0 results for PM_{10} and premature mortality using this method as follows:

- Column 2 shows the results for 2006 using the HAPINZ 2.0 base data with the revised PM_{10} only mortality ERF from a single pollutant model (1.111 per 10 μg/m^3).
- Column 3 shows the results for 2016 using the HAPINZ 3.0 base data with the revised PM_{10} only mortality ERF from a single pollutant model (1.111 per 10 μg/m^3).
- For comparison, the last column shows the results for 2016 using the HAPINZ 3.0 base data with the new $PM_{2.5}$ and NO_2 mortality ERFs from a two pollutant model.

Table 11: Change in premature mortality impacts between 2006 and 2016 based on total (anthropogenic and natural) PM_{10} air pollution

Parameter	2006 HAPINZ 2.0 base data (revised PM_{10})	2016 HAPINZ 3.0 base data (revised PM_{10})	Change relative to 2006	2016 HAPINZ 3.0 base data ($PM_{2.5}$ & NO_2)
Population (all)	4,184,650	4,714,055	+12.7%	4,714,055
Premature deaths for all adults, all sources (number of cases)	3,782	3,821	+1.0%	4,011
Premature deaths for all adults, all sources ($million)	$17,122	$17,299	+1.0%	$18,158
Population-weighted PM_{10} annual average concentration (μg/m^3)	15.3	13.1	-14.4%	n/a

The results show it is reasonable to use the revised mortality ERF based on PM_{10} only for backcasting because it predicts comparable premature death cases and social costs from **all air pollution** for 2016 (column 3) relative to those shown using the two pollutant approach (column 5).

While population-weighted annual average PM_{10} concentrations have reduced by 14.4% from 2006 to 2016, air pollution mortality effects have likely increased slightly (by 1%). This is due to growth in the New Zealand population of nearly 13% which has put more people into contact with air pollution.

[29] There are very few monitoring records available for $PM_{2.5}$ and NO_2 prior to 2006.

3.4.2 Trends in anthropogenic impacts based on $PM_{2.5}$ and NO_2

We assessed overall and anthropogenic air pollution effects between 2006 and 2016, based on exposure to both $PM_{2.5}$ and NO_2, using the *HAPINZ 3.0 Health Effect Model*. We did this to see how the estimated health impacts have changed since 2016. The HAPINZ 3.0 method is more robust for forecasting air pollution impacts beyond 2016 (but can also be used in earlier years where data are available).

We used the HAPINZ 3.0 methodology to create a $PM_{2.5}$ exposure dataset for 2006 to fill in the gaps in the monitoring record and populated the model with actual population and health data for 2006. For NO_2 exposure in 2006, we scaled the 2016 NO_2 exposure values by a factor of 0.8736 using the method described in the *HAPINZ 3.0 Volume 2 – Detailed methodology* report (Kuschel *et al* 2022). The base case in HAPINZ 3.0 was based on 2016 so we already had all the data needed to assess 2016.

Change in concentrations

Table 12 shows the changes in the population-weighted concentrations for $PM_{2.5}$ and NO_2 between 2006 and 2016. The $PM_{2.5}$ annual average due to anthropogenic sources only is estimated using the HAPINZ 3.0 source attribution methodology for $PM_{2.5}$. The NO_2 annual average is the overall concentration but is assumed to be due to anthropogenic sources only (see section 2.2.2).

Population weighted concentrations are used to assess trends in the average concentrations people are likely to be exposed to. The results show that the impact **per person** from anthropogenic $PM_{2.5}$ sources reduced by more than 21% going from 2006 to 2016 (most likely in response to interventions put in place by councils to reduce domestic fire emissions). However, the impact from anthropogenic NO_2 increased by just over 13% (most likely due to the increase in diesel vehicle numbers).

Table 12: Change in population-weighted pollutant concentrations between 2006 and 2016

Population-weighted concentrations	2006 (μg/m³)	2016 (μg/m³)	Change relative to 2006
$PM_{2.5}$ annual average (overall)	7.6	6.5	-14.5%
$PM_{2.5}$ annual average (anthropogenic only)	**5.2**	**4.1**	**-21.2%**
NO_2 annual average (overall)* * but assumed anthropogenic only	6.9	7.8	+13.2%

Change in impacts

Resultant impacts are a function of the change in per person average concentrations combined with changes in population numbers overall (i.e. are more people now exposed?).

Table 13 shows the changes in health impacts due to air pollution from all sources (shown shaded) and from anthropogenic only sources between 2006 and 2016, for those health effects which are additive.

Table 13: Change in health impacts between 2006 and 2016 based on $PM_{2.5}$ and NO_2 air pollution (in case numbers)

Health effect	All sources			Anthropogenic only		
	2006	2016	vs 2006	2006	2016	vs 2006
Cases due to annual $PM_{2.5}$						
Premature deaths (all adults)	1,986	1,986	0.0%	1,424	1,292	-9.3%
Cardiovascular hospitalisations (all ages)	4,564	4,115	-9.8%	3,271	2,639	-19.3%
Respiratory hospitalisations (all ages)	2,707	3,105	14.7%	1,914	1,985	3.7%
Restricted activity days (all ages)	2,865,175	2,770,971	-3.3%	1,953,202	1,745,354	-10.6%
Cases due to annual NO_2						
Premature deaths (all adults)	1,580	2,025	28.2%	1,580	2,025	28.2%
Cardiovascular hospitalisations (all ages)	1,721	1,987	15.5%	1,721	1,987	15.5%
Respiratory hospitalisations (all ages)	4,437	6,544	47.5%	4,437	6,544	47.5%
Asthma prevalence (0-18 yrs)	11,557*	13,229	14.5%	11,557*	13,229	14.5%
Cases due to both $PM_{2.5}$ and NO_2						
Premature deaths (all adults)	3,566	4,011	12.5%	3,005	3,317	10.4%
Cardiovascular hospitalisations (all ages)	6,285	6,102	-2.9%	4,991	4,626	-7.3%
Respiratory hospitalisations (all ages)	7,143	9,649	35.1%	6,351	8,529	34.3%
Asthma prevalence (0-18 yrs)	11,557	13,229	14.5%	11,557	13,229	14.5%
Restricted activity days (all ages)	2,865,175	2,770,971	-3.3%	1,953,202	1,745,354	-10.6%

Note: In the absence of other information, the asthma prevalence cases for 2006 marked by * were estimated by scaling the 2016 case numbers by 0.8736 (using the NO_2 scalar).

Table 14 presents the changes in associated social costs over the same time period.

Table 14: Change in health impacts between 2006 and 2016 based on $PM_{2.5}$ and NO_2 air pollution (in 2019 NZ$)

Health effect	All sources			Anthropogenic only		
	2006	2016	vs 2006	2006	2016	vs 2006
Costs due to annual $PM_{2.5}$						
Premature deaths (all adults)	$8,992	$8,989	0.0%	$6,449	$5,847	-9.3%
Cardiovascular hospitalisations (all ages)	$167	$151	-9.8%	$120	$97	-19.3%
Respiratory hospitalisations (all ages)	$86	$99	14.7%	$61	$63	3.7%
Restricted activity days (all ages)	$255	$247	-3.3%	$174	$155	-10.6%
Total social costs ($million)	**$9,500**	**$9,486**	**-0.2%**	**$6,803**	**$6,162**	**-9.4%**

Health effect	All sources			Anthropogenic only		
	2006	2016	vs 2006	2006	2016	vs 2006
Costs due to annual NO_2						
Premature deaths (all adults)	$7,154	$9,168	28.2%	$7,154	$9,168	28.2%
Cardiovascular hospitalisations (all ages)	$63	$73	15.5%	$63	$73	15.5%
Respiratory hospitalisations (all ages)	$141	$208	47.5%	$141	$208	47.5%
Asthma prevalence (0-18 yrs)	$1	$2	14.5%	$1	$2	14.5%
Total social costs ($million)	**$7,359**	**$9,451**	**28.4%**	**$7,359**	**$9,451**	**28.4%**
Cases due to both $PM_{2.5}$ and NO_2						
Premature deaths (all adults)	$16,146	$18,158	12.5%	$13,602	$15,015	10.4%
Cardiovascular hospitalisations (all ages)	$230	$224	-2.9%	$183	$170	-7.3%
Respiratory hospitalisations (all ages)	$227	$306	35.1%	$202	$271	34.3%
Asthma prevalence (0-18 yrs)	$1	$2	14.5%	$1	$2	14.5%
Restricted activity days (all ages)	$255	$247	-3.3%	$174	$155	-10.6%
Total social costs ($million)	**$16,859**	**$18,936**	**12.3%**	**$14,162**	**$15,613**	**10.2%**

While the population-weighted anthropogenic annual average $PM_{2.5}$ concentration improved by more than 21% between 2006 and 2016 (Table 12), social costs reduced by only 9.4% (Table 14). The impact of improvements to date (largely due to reductions in domestic fire emissions) have been counteracted by increased population.

In contrast, the population-weighted anthropogenic annual average NO_2 concentration worsened by just over 13% between 2006 and 2016, resulting in an increase in social costs of more than 28%. This is not surprising given the considerable growth in diesel vehicles, which are the main source of NO_2, in that time. The number of light diesel vehicles in the fleet has increased by 44% and heavy diesels by 12% since 2006 (MoT 2021).

Overall, combining $PM_{2.5}$ and NO_2, the air pollution health burden due to anthropogenic sources increased by 10.2% between 2006 and 2016. This increase was driven by increased exposure to NO_2, but there was some offset due to improvements in $PM_{2.5}$ exposure over the same period.

4. What do the results mean for improved air quality in future?

4.1 Conclusions

4.1.1 National impacts and costs

The primary health impact resulting from air pollution (in terms of social costs) is premature **mortality** (death) in adults. However, the cost of increased **morbidity** (illness and disease) is also considerable.

Exposure to $PM_{2.5}$ and NO_2 pollution from **anthropogenic sources** in New Zealand in 2016 contributed to:

- the premature deaths of more than 3,300 adult New Zealanders[30]
- more than 13,100 hospital admissions for respiratory and cardiac illnesses, including 845 asthma hospitalisations for children
- over 13,200 cases of childhood asthma
- approximately 1.745 million restricted activity days (days on which people could not do the things they might otherwise have done if air pollution had not been present).

The **social costs** resulting from these anthropogenic health impacts totalled **$15.6 billion** with **$NO_2$ exposure accounting for just over 60% of the total costs**. This was a significant and surprising finding.

Note: The previous study – HAPINZ 2.0 – used PM_{10} as a proxy for all air pollution (based on the data available at the time) but noted that the results likely under-estimated impacts due to NO_2. However, the extent of the NO_2 impacts found in HAPINZ 3.0 was startling. When the HAPINZ 3.0 draft findings first became available (February 2021), no other researchers had published such strong associations between NO_2 and mortality. To ensure the findings were genuine, the HAPINZ 3.0 research team undertook considerable additional analyses to check for bias, and the results were rigorously peer-reviewed before being published internationally (Hales *et al* 2021). This paper has now been referenced by others who have found similarly strong NO_2 impacts.

4.1.2 Sources

The costs of $PM_{2.5}$ pollution from **anthropogenic sources** in New Zealand in 2016 ($6.1 billion) were associated with:

- domestic fires (74%)
- motor vehicles (17%)

[30] StatsNZ report that 31,179 New Zealanders died in 2016 from all causes, see https://www.stats.govt.nz/topics/births-and-deaths.

- windblown dust (8%)
- and industry (0.1%).

The costs of NO_2 pollution from **anthropogenic sources** in New Zealand in 2016 ($9.5 billion) were assumed to result from motor vehicles alone (100%).

Note: Our method for assessing NO_2 exposure used roadside emissions (from motor vehicles only) as well as background concentrations (from all sources) but we were not able to separate other sources. While we defaulted to assigning all effects of NO_2 to motor vehicles, we considered this assumption was reasonable given motor vehicles are likely to be responsible for nearly 90% of all NO_2 exposure in urban areas (Xie *et al* 2019, Sridhar & Metcalfe 2019).

4.1.3 Regional impacts

In all regions, domestic fire impacts dominated the regional $PM_{2.5}$ social costs – with contributions ranging from 59% to 88%. On average, domestic fire impacts were more than four times those of motor vehicles for $PM_{2.5}$ pollution from anthropogenic sources.

However, for the total anthropogenic health costs ($PM_{2.5}$ and NO_2 combined), motor vehicles were the dominant source in most locations across New Zealand (except those with high solid fuel home heating use during winter). On average, motor vehicle impacts were more than twice those of domestic fires for total ($PM_{2.5}$ and NO_2) pollution from anthropogenic sources.

4.1.4 Trends

The methodology used in HAPINZ 3.0 was used to assess the likely air pollution impacts for 2006 to compare how air pollution impacts have changed over time.

While the population-weighted annual average $PM_{2.5}$ concentration from anthropogenic sources improved by more than 21% between 2006 and 2016, the resultant social costs reduced by only 9.4%. The impact of improvements to date (largely due to reductions in domestic fire emissions) have been counteracted by increased population.

In contrast, the population-weighted annual average NO_2 concentration from anthropogenic sources worsened by just over 13% between 2006 and 2016, resulting in an increase in social costs of more than 28%. This is not surprising given the number of diesel vehicles, which are the main source of NO_2, have increased significantly since 2006. Light diesel vehicles have increased by 44% and heavy diesels by 12% (MoT 2021).

Overall, combining $PM_{2.5}$ and NO_2, **the air pollution health burden due to anthropogenic sources increased by 10.2% between 2006 and 2016**. All of this increase is due to increased exposure to NO_2, but the full impact of worsening NO_2 has been lessened by the improvements in $PM_{2.5}$ concentrations.

4.2 Policy implications

Air quality management can only realistically address anthropogenic sources.

In HAPINZ 2.0, the total anthropogenic costs were assigned to PM_{10} only (as a proxy for all air pollution). 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, we used $PM_{2.5}$ and NO_2 as the indicators and found the total impacts were split between $PM_{2.5}$ impacts ($6.1 billion) and NO_2 impacts ($9.5 billion), with NO_2 exposure accounting for just over 60% of the total impacts ($15.6 billion). This finding shows air quality management strategies need to focus at least equally (if not more so) on addressing motor vehicle emissions, given they are estimated to be responsible for 67% of the national air pollution health burden from anthropogenic sources at an estimated social cost of $10.5 billion.

Since 2006, considerable improvements have occurred in domestic fire emissions in response to the introduction of the woodburner standards in the NESAQ and various insulation and clean heat retrofit programmes. As a consequence, most airsheds that were exceeding the **NESAQ** in winter-time are now in compliance. Despite these considerable improvements, domestic fires are estimated to be responsible for 29% of the national air pollution health burden from anthropogenic sources at an estimated social cost of $4.6 billion.

Significant and genuine improvements were made in fuel quality and vehicle emissions standard requirements between 2001 and 2006. However, little further regulation of motor vehicle emissions has occurred since. The Volkswagen Emissions Scandal – also known as "Dieselgate" – uncovered significant discrepancies between real-world vehicle emissions performance and regulated emissions standards in 2015. At time of writing, New Zealand is yet to adopt Euro 6 emissions standards for new vehicles entering the fleet. The New Zealand fleet (excluding motorcycles) currently comprises 4.22 million vehicles, with an average age over 14 years. Between 2006 to 2016, vehicle travel increased by 12% and the number of light diesel vehicles, a major contributor to NO_2 emissions, increased by 44% (MoT 2021).

Moving forward from HAPINZ 3.0, more attention will need to go on addressing harmful emissions from motor vehicles - from in-service vehicles as well as those entering the fleet. Because on road vehicles are also an important source of greenhouse gas emissions, there are significant opportunities to secure benefits for both air quality and climate change. The suite of damage costs developed in this update for harmful emissions will enable improved assessment of costs/benefits of any emissions reduction strategy.

The *Health Effects Model* developed for this update will be a useful tool to assist policy makers with designing and evaluating effective air quality management programmes.

4.3 Recommendations for future work

This health effects assessment was based on $PM_{2.5}$ and NO_2.

For many locations covered in HAPINZ 3.0, $PM_{2.5}$ exposure is based on PM_{10} monitoring results. There would be considerable value in **continuing to extend and expand the $PM_{2.5}$ monitoring network. However, ideally this will not replace PM_{10} monitoring**. The coarse PM fraction - $PM_{10-2.5}$ – is likely to remain an issue for the future (especially due to road dust which will still be emitted by electric vehicles if the fleet becomes decarbonised). As part of HAPINZ 3.0, we developed a three-pollutant model for New Zealand (covering $PM_{10-2.5}$, $PM_{2.5}$ and NO_2). However, we could not determine robust relationships for all three pollutants so reverted to the two pollutant model ($PM_{2.5}$ and NO_2) in the HAPINZ 3.0 assessment. Measurements of $PM_{2.5}$ and/or PM_{10} concentrations were unavailable for some CAUs, and not available at finer geographic scale. In many areas, estimates of $PM_{10-2.5}$ concentrations relied on extrapolated $PM_{2.5}$ to PM_{10} ratios. For these reasons, it is possible that the results of models including coarse PM were affected by exposure misclassification. Additional monitoring of PM_{10} and $PM_{2.5}$ would provide valuable data to re-visit a three-pollutant model in future.

Due to the significant proportion of air pollution health effects now attributed to NO_2 exposure, there would be value in further **extending NO_2 monitoring and investigating source apportionment options**. Currently, all NO_2 effects are assigned to motor vehicles which means contributions from other anthropogenic sources are being under-estimated. Forest fires and lightning are natural sources of NO_2, but anthropogenic sources dominate in areas where people are typically exposed.

One of the critical parameters identified in the sensitivity testing that affects the outcome of any air pollution health impacts assessment is the value of statistical life (VoSL). In the absence of appropriate data, this update uses a published transport safety risk-based VoSL for the **environmental risk-based VoSL**. Given the likelihood that the environmental risk VOSL should be valued much higher to reflect the suffering and loss of life quality caused by air pollution (as it is in many overseas countries), we recommend that a study be carried out to estimate the relativity between these two types of VoSL specifically for New Zealand.

Glossary

Term	Definition
acute	short-term duration but severe
airshed	a geographic area established to manage air pollution within the area as defined by the NESAQ
anthropogenic	generated by human activities, such as the combustion of fuels or processing of raw materials
cardiac	of, pertaining to, or affecting the heart
cardiovascular	of, pertaining to, or affecting the heart and blood vessels
CAU	census area unit, a non-administrative geographic area normally with a population of 3,000–5,000 people in an urban area
CAU2013	census area unit based on the 2013 Census boundaries
CBAx	cost-benefit analysis tool, provided by NZ Treasury
chronic	long-term duration or constantly recurring
CI	confidence interval – a measure of the certainty that a value falls within a given range, e.g. a 95% CI is the range within which there is a 95% probability that the value we are interested in actually sits
CO	carbon monoxide, a harmful pollutant
CO_2	carbon dioxide, a greenhouse gas
CO_2e	carbon dioxide equivalent, a way to express the impact of each different greenhouse gas in terms of the amount of CO_2 that would create the same amount of warming
CVD	cardiovascular disease
CVHA	cardiovascular hospital admission
DALY	disability-adjusted life year is a measure of years in perfect health lost
domestic fires	burning of wood in appliances used for heating homes in winter – considered anthropogenic in HAPINZ 3.0 and assessed using the biomass burning fingerprint
ERF	exposure-response function or relative risk function, the increase in risk for every increment in pollution
HAPINZ	Health and Air Pollution in New Zealand
HAPINZ 1.0	the original HAPINZ study for 2001, undertaken by Fisher *et al* (2007)
HAPINZ 2.0	the first HAPINZ update for 2006, undertaken by Kuschel *et al* (2012a)
HAPINZ 3.0	the current HAPINZ update for 2016, undertaken by Kuschel *et al* (2022)
harmful pollutant	an air pollutant which causes adverse health effects
ICD-10 AM	International Classification of Diseases 10th revision – Australian Modification
incidence	the proportion or rate of persons who *develop* a condition during a particular time period

industry	activities generating emissions as part of the manufacturing of products or in the generation of energy - considered anthropogenic in HAPINZ 3.0 and assessed using the industry fingerprint (where available)
kaitiakitanga	in Māori culture, a kaitiaki is a guardian, and the process and practices of protecting and looking after the environment are referred to as kaitiakitanga
sea spray	particulate matter (primarily salt) released to air through the action of wind and waves - considered natural in HAPINZ 3.0 and assessed using the marine aerosol fingerprint
MBCM	Monetised Benefits and Costs Manual, produced by Waka Kotahi
MfE	Ministry for the Environment
MoH	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 - considered anthropogenic in HAPINZ 3.0 and assessed using the motor vehicle fingerprint
natural	generated by natural activities, such as sea spray, sand storms, vegetation, animals or volcanoes
NESAQ	The Resource Management (National Environmental Standards for Air Quality) Regulations 2004 include a suite of air quality standards, including one for ambient levels of PM_{10} (50 mg/m^3 as a 24-hour average)
NO_2	nitrogen dioxide, a harmful pollutant
NO_X	oxides of nitrogen
NMDS	National Minimum Dataset, which holds data on date of birth, date of hospital admission and discharge, primary diagnosis (ICD-10AM code), ethnic groups, domicile code (CAU), and other useful information
NVED	National Vehicle Emissions Dataset
NZTA	Waka Kotahi NZ Transport Agency
O_3	ozone, a harmful pollutant
open burning	burning of biomass (e.g. crops or garden trimmings) and waste in the outdoors - considered anthropogenic in HAPINZ 3.0 but included in the biomass burning fingerprint and assigned to domestic fires
Pacific peoples	indigenous peoples from the Island nations in the South Pacific, and in its narrowest sense Pacific peoples in New Zealand
PAF	population attributable fraction, the estimated percentage of total health cases that are attributable to 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 including the respiratory bronchioles and alveoli
$PM_{2.5}$ / PM_{10} ratio	the fraction of $PM_{2.5}$ (by concentration or weight) in PM_{10}

PM_{10}	particulate matter less than 10 µm in diameter, includes fine particulate (less than 2.5 µm) and coarse particulate (2.5 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
population-weighted average concentration	where the average air pollution concentration is calculated by multiplying the averages for smaller areas (e.g. CAUs) by their individual populations, summing them to a total and then dividing by the total population
prevalence	the proportion of a population who *have* a specific characteristic in a given time period
RAD	restricted activity day, a day on which people cannot do the things they might otherwise have done if air pollution was not present
respiratory	of, pertaining to, or affecting the lungs and airways
RHA	respiratory hospital admission
secondary PM	particulate matter created when gases combine and react in the atmosphere – considered natural in HAPINZ 3.0 and assessed using the secondary sulphate fingerprint
SO_2	sulphur dioxide, a harmful pollutant
solid fuel	coal and wood (including wood pellets)
Stats NZ	Statistics New Zealand, the public service department charged with the collection of statistics related to the economy, population and society of NZ
taonga	in Māori culture, a taonga is a treasured thing, whether tangible or intangible
TA	Territorial Authority, such as city or district council
µg	microgram, one millionth of a gram
µg/m^3	microgram per cubic metre, a unit of concentration
µm	micrometre, one millionth of a metre
UK	United Kingdom
VoLY	value of a life year
VoSL	value of statistical life
VOC	volatile organic compound
Waka Kotahi	Waka Kotahi NZ Transport Agency
WHO	World Health Organization
windblown dust	particulate matter from construction, landuse activities, etc. - considered anthropogenic in HAPINZ 3.0 and assessed using the crustal material fingerprint
YLL	year of life lost

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Appendix A: Results tables

This appendix summarises the HAPINZ 3.0 model results for anthropogenic only air pollution for the 16 regions and 67 territorial authorities (TAs) across New Zealand. Results can also be output for each of the 89 airsheds and 20 district health board areas but these are not presented here.

A.1 Air pollution health costs by region

A.1.1 Total anthropogenic health costs by source

Table 15: Costs of all anthropogenic air pollution by region in 2016 (in 2019 NZ$)

Region	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Auckland	1,589,815	724	3,597	1	128	**$4,451**
Bay of Plenty	301,485	296	679	2	37	**$1,014**
Canterbury	601,860	980	1,800	1	81	**$2,863**
Gisborne	48,745	60	87	1	6	**$154**
Hawke's Bay	166,885	254	466	0	23	**$743**
Manawatū-Whanganui	241,060	317	506	-	26	**$849**
Marlborough	47,095	128	109	-	7	**$244**
Nelson	51,355	81	167	1	7	**$255**
Northland	176,390	114	317	1	28	**$460**
Otago	223,020	393	517	0	27	**$938**
Southland	99,005	209	221	0	15	**$445**
Taranaki	118,465	99	236	0	16	**$351**
Tasman	51,895	72	81	0	6	**$159**
Waikato	452,725	393	824	0	50	**$1,267**
Wellington	510,695	396	852	0	47	**$1,295**
West Coast	32,920	67	53	-	5	**$125**
Area Outside	*640*	*0*	-	-	*0*	**$0**
National	**4,714,055**	**$4,585**	**$10,512**	**$8**	**$508**	**$15,613**

16 in total (in 2016)

A.1.2 $PM_{2.5}$ anthropogenic health costs by source

Table 16: Costs of $PM_{2.5}$ anthropogenic air pollution by region in 2016 (in 2019 NZ$)

Region	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Auckland	1,589,815	724	381	1	128	**$1,234**
Bay of Plenty	301,485	296	70	2	37	**$406**
Canterbury	601,860	980	175	1	81	**$1,237**
Gisborne	48,745	60	10	1	6	**$77**
Hawke's Bay	166,885	254	41	0	23	**$318**
Manawatū-Whanganui	241,060	317	33	-	26	**$376**
Marlborough	47,095	128	11	-	7	**$147**
Nelson	51,355	81	13	1	7	**$101**
Northland	176,390	114	32	1	28	**$176**
Otago	223,020	393	49	0	27	**$470**
Southland	99,005	209	24	0	15	**$248**
Taranaki	118,465	99	33	0	16	**$148**
Tasman	51,895	72	9	0	6	**$87**
Waikato	452,725	393	78	0	50	**$521**
Wellington	510,695	396	97	0	47	**$540**
West Coast	32,920	67	5	-	5	**$77**
Area Outside	*640*	0	-	-	0	**$0**
National	**4,714,055**	**$4,585**	**$1,061**	**$8**	**$508**	**$6,162**

16 in total (in 2016)

A.1.3 NO_2 anthropogenic health costs by source

Table 17: Costs of NO_2 anthropogenic air pollution by region in 2016 (in 2019 NZ$)

Region	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Auckland	1,589,815		3,216			**$3,216**
Bay of Plenty	301,485		608			**$608**
Canterbury	601,860		1,626			**$1,626**
Gisborne	48,745		77			**$77**
Hawke's Bay	166,885		425			**$425**
Manawatū-Whanganui	241,060		473			**$473**
Marlborough	47,095		97			**$97**
Nelson	51,355		154			**$154**
Northland	176,390		285			**$285**
Otago	223,020		469			**$469**
Southland	99,005		197			**$197**
Taranaki	118,465		203			**$203**
Tasman	51,895		72			**$72**
Waikato	452,725		746			**$746**
Wellington	510,695		755			**$755**
West Coast	32,920		48			**$48**
Area Outside	*640*		-			-
National	**4,714,055**		**$9,451**			**$9,451**

16 in total (in 2016)

A.2 Air pollution health costs by territorial authority

A.2.1 Total anthropogenic health costs by source

Table 18: Costs of all anthropogenic air pollution by TA in 2016 (in 2019 NZ$)

TA	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Ashburton District	33,895	60	53	-	4	**$117**
Auckland	1,589,815	724	3,597	1	128	**$4,451**
Buller District	10,305	20	17	-	2	**$39**
Carterton District	9,055	7	14	-	1	**$22**
Central Hawke's Bay District	14,140	13	20	-	2	**$35**
Central Otago District	20,210	56	25	-	2	**$83**
Chatham Islands Territory	*640*	*0*	-	-	*0*	**$0**
Christchurch City	374,600	640	1,466	1	54	**$2,161**
Clutha District	17,735	39	23	-	2	**$65**
Dunedin City	128,395	167	407	0	19	**$593**
Far North District	64,880	42	94	0	11	**$146**
Gisborne District	48,745	60	87	1	6	**$154**
Gore District	12,700	31	29	-	2	**$62**
Grey District	13,845	32	23	-	2	**$57**
Hamilton City	160,770	98	363	-	14	**$475**
Hastings District	81,645	144	219	0	10	**$373**
Hauraki District	19,675	19	36	-	3	**$59**
Horowhenua District	32,945	60	89	-	5	**$154**
Hurunui District	12,710	7	10	-	2	**$19**
Invercargill City	54,935	168	168	0	9	**$346**
Kaikoura District	3,950	6	6	-	1	**$12**
Kaipara District	22,180	12	30	-	4	**$46**
Kapiti Coast District	53,520	70	129	-	8	**$207**
Kawerau District	7,120	6	17	1	1	**$25**
Lower Hutt City	105,740	61	188	0	10	**$259**
Mackenzie District	4,715	2	3	-	0	**$5**
Manawatu District	30,095	33	45	-	3	**$81**
Marlborough District	47,095	128	109	-	7	**$244**
Masterton District	25,370	72	62	-	4	**$138**

TA	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Matamata-Piako District	34,150	29	55	-	5	**$89**
Napier City	62,415	88	212	0	9	**$310**
Nelson City	51,355	81	167	1	7	**$255**
New Plymouth District	80,940	71	174	0	11	**$256**
Opotiki District	9,295	6	14	-	2	**$21**
Otorohanga District	10,135	4	9	-	1	**$14**
Palmerston North City	86,410	94	172	-	7	**$273**
Porirua City	56,755	48	72	-	5	**$125**
Queenstown-Lakes District	36,050	43	22	-	1	**$66**
Rangitikei District	15,125	14	20	-	2	**$35**
Rotorua District	72,285	132	142	0	8	**$282**
Ruapehu District	12,670	15	17	-	1	**$34**
Selwyn District	56,450	27	32	-	3	**$62**
South Taranaki District	28,115	20	44	-	4	**$68**
South Waikato District	24,125	57	43	0	3	**$103**
South Wairarapa District	10,415	8	15	-	1	**$25**
Southland District	31,370	10	24	-	3	**$37**
Stratford District	9,555	8	18	-	1	**$27**
Tararua District	18,090	22	30	-	2	**$54**
Tasman District	51,895	72	81	0	6	**$159**
Taupo District	36,835	52	67	-	4	**$124**
Tauranga City	131,130	103	380	1	16	**$499**
Thames-Coromandel District	29,110	34	61	-	5	**$100**
Timaru District	46,995	140	118	0	8	**$267**
Upper Hutt City	43,825	43	93	-	5	**$141**
Waikato District	72,575	40	76	-	7	**$123**
Waimakariri District	58,715	84	98	-	7	**$189**
Waimate District	8,065	15	14	-	1	**$30**
Waipa District	52,185	46	98	-	6	**$150**
Wairoa District	8,590	9	14	-	2	**$25**
Waitaki District	22,390	88	42	-	3	**$133**
Waitomo District	9,585	13	14	-	1	**$28**
Wanganui District	45,565	80	134	-	6	**$219**
Wellington City	206,005	86	280	0	13	**$379**

TA	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Western Bay of Plenty District	49,380	28	70	-	6	**$103**
Westland District	8,770	16	12	-	1	**$29**
Whakatane District	35,950	23	58	-	5	**$86**
Whangarei District	89,330	60	193	1	14	**$268**
Area Outside	*30*	*0*	-	-	*0*	**$0**
National	**4,714,055**	**$4,585**	**$10,512**	**$8**	**$508**	**$15,613**

67 in total (in 2016)

Note: Anthropogenic fractions for Chatham Island Territory and Area Outside are unreliable as they are based on a very small number of health effects so they are shown in *italics*

A.2.2 $PM_{2.5}$ anthropogenic health costs by source

Table 19: Costs of $PM_{2.5}$ anthropogenic air pollution by TA in 2016 (in 2019 NZ$)

TA	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Ashburton District	33,895	60	8	-	4	**$72**
Auckland	1,589,815	724	381	1	128	**$1,234**
Buller District	10,305	20	1	-	2	**$23**
Carterton District	9,055	7	1	-	1	**$10**
Central Hawke's Bay District	14,140	13	2	-	2	**$17**
Central Otago District	20,210	56	2	-	2	**$61**
Chatham Islands Territory	*640*	0	-	-	0	**$0**
Christchurch City	374,600	640	138	1	54	**$833**
Clutha District	17,735	39	2	-	2	**$43**
Dunedin City	128,395	167	39	0	19	**$225**
Far North District	64,880	42	8	0	11	**$61**
Gisborne District	48,745	60	10	1	6	**$77**
Gore District	12,700	31	4	-	2	**$37**
Grey District	13,845	32	2	-	2	**$36**
Hamilton City	160,770	98	33	-	14	**$144**
Hastings District	81,645	144	18	0	10	**$172**
Hauraki District	19,675	19	4	-	3	**$26**
Horowhenua District	32,945	60	6	-	5	**$71**

TA	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Hurunui District	12,710	7	1	-	2	**$9**
Invercargill City	54,935	168	19	0	9	**$196**
Kaikoura District	3,950	6	1	-	1	**$7**
Kaipara District	22,180	12	2	-	4	**$18**
Kapiti Coast District	53,520	70	14	-	8	**$92**
Kawerau District	7,120	6	4	1	1	**$12**
Lower Hutt City	105,740	61	22	0	10	**$93**
Mackenzie District	4,715	2	0	-	0	**$3**
Manawatu District	30,095	33	3	-	3	**$40**
Marlborough District	47,095	128	11	-	7	**$147**
Masterton District	25,370	72	6	-	4	**$82**
Matamata-Piako District	34,150	29	6	-	5	**$40**
Napier City	62,415	88	21	0	9	**$118**
Nelson City	51,355	81	13	1	7	**$101**
New Plymouth District	80,940	71	24	0	11	**$106**
Opotiki District	9,295	6	1	-	2	**$8**
Otorohanga District	10,135	4	1	-	1	**$6**
Palmerston North City	86,410	94	10	-	7	**$110**
Porirua City	56,755	48	10	-	5	**$63**
Queenstown-Lakes District	36,050	43	2	-	1	**$46**
Rangitikei District	15,125	14	1	-	2	**$17**
Rotorua District	72,285	132	15	0	8	**$155**
Ruapehu District	12,670	15	1	-	1	**$18**
Selwyn District	56,450	27	2	-	3	**$33**
South Taranaki District	28,115	20	6	-	4	**$30**
South Waikato District	24,125	57	5	0	3	**$64**
South Wairarapa District	10,415	8	1	-	1	**$11**
Southland District	31,370	10	1	-	3	**$14**
Stratford District	9,555	8	3	-	1	**$12**
Tararua District	18,090	22	2	-	2	**$26**
Tasman District	51,895	72	9	0	6	**$87**
Taupo District	36,835	52	6	-	4	**$63**
Tauranga City	131,130	103	36	1	16	**$155**
Thames-Coromandel District	29,110	34	6	-	5	**$44**

TA	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Timaru District	46,995	140	15	0	8	**$164**
Upper Hutt City	43,825	43	9	-	5	**$57**
Waikato District	72,575	40	8	-	7	**$54**
Waimakariri District	58,715	84	9	-	7	**$99**
Waimate District	8,065	15	1	-	1	**$17**
Waipa District	52,185	46	10	-	6	**$62**
Wairoa District	8,590	9	1	-	2	**$12**
Waitaki District	22,390	88	4	-	3	**$95**
Waitomo District	9,585	13	1	-	1	**$16**
Wanganui District	45,565	80	9	-	6	**$94**
Wellington City	206,005	86	34	0	13	**$133**
Western Bay of Plenty District	49,380	28	7	-	6	**$41**
Westland District	8,770	16	1	-	1	**$18**
Whakatane District	35,950	23	7	-	5	**$34**
Whangarei District	89,330	60	21	1	14	**$96**
Area Outside	*30*	0	-	-	0	**$0**
National	**4,714,055**	**$4,585**	**$1,061**	**$8**	**$508**	**$6,162**

67 in total (in 2016)

Note: Anthropogenic fractions for Chatham Island Territory and Area Outside are unreliable as they are based on a very small number of health effects so they are shown in *italics*

A.2.3 NO_2 anthropogenic health costs by source

Table 20: Costs of NO_2 anthropogenic air pollution by TA in 2016 (in 2019 NZ$)

TA	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Ashburton District	33,895		45			**$45**
Auckland	1,589,815		3,216			**$3,216**
Buller District	10,305		16			**$16**
Carterton District	9,055		13			**$13**
Central Hawke's Bay District	14,140		18			**$18**
Central Otago District	20,210		23			**$23**
Chatham Islands Territory	*640*		-			**-**

TA	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
Christchurch City	374,600		1,328			**$1,328**
Clutha District	17,735		21			**$21**
Dunedin City	128,395		368			**$368**
Far North District	64,880		86			**$86**
Gisborne District	48,745		77			**$77**
Gore District	12,700		25			**$25**
Grey District	13,845		21			**$21**
Hamilton City	160,770		331			**$331**
Hastings District	81,645		202			**$202**
Hauraki District	19,675		32			**$32**
Horowhenua District	32,945		82			**$82**
Hurunui District	12,710		10			**$10**
Invercargill City	54,935		149			**$149**
Kaikoura District	3,950		5			**$5**
Kaipara District	22,180		27			**$27**
Kapiti Coast District	53,520		115			**$115**
Kawerau District	7,120		12			**$12**
Lower Hutt City	105,740		166			**$166**
Mackenzie District	4,715		3			**$3**
Manawatu District	30,095		41			**$41**
Marlborough District	47,095		97			**$97**
Masterton District	25,370		56			**$56**
Matamata-Piako District	34,150		49			**$49**
Napier City	62,415		192			**$192**
Nelson City	51,355		154			**$154**
New Plymouth District	80,940		150			**$150**
Opotiki District	9,295		13			**$13**
Otorohanga District	10,135		8			**$8**
Palmerston North City	86,410		162			**$162**
Porirua City	56,755		62			**$62**
Queenstown-Lakes District	36,050		20			**$20**
Rangitikei District	15,125		18			**$18**
Rotorua District	72,285		127			**$127**
Ruapehu District	12,670		16			**$16**
Selwyn District	56,450		29			**$29**

TA	Population	Social costs by source ($million)				
		Domestic fires	Motor vehicles	Industry	Windblown dust	Total
South Taranaki District	28,115		38			**$38**
South Waikato District	24,125		38			**$38**
South Wairarapa District	10,415		14			**$14**
Southland District	31,370		23			**$23**
Stratford District	9,555		15			**$15**
Tararua District	18,090		27			**$27**
Tasman District	51,895		72			**$72**
Taupo District	36,835		61			**$61**
Tauranga City	131,130		344			**$344**
Thames-Coromandel District	29,110		56			**$56**
Timaru District	46,995		103			**$103**
Upper Hutt City	43,825		84			**$84**
Waikato District	72,575		68			**$68**
Waimakariri District	58,715		89			**$89**
Waimate District	8,065		12			**$12**
Waipa District	52,185		88			**$88**
Wairoa District	8,590		13			**$13**
Waitaki District	22,390		38			**$38**
Waitomo District	9,585		12			**$12**
Wanganui District	45,565		125			**$125**
Wellington City	206,005		246			**$246**
Western Bay of Plenty District	49,380		62			**$62**
Westland District	8,770		11			**$11**
Whakatane District	35,950		51			**$51**
Whangarei District	89,330		172			**$172**
Area Outside	*30*		-			-
National	**4,714,055**		**$9,451**			**$9,451**

67 in total (in 2016)

Note: Anthropogenic fractions for Chatham Island Territory and Area Outside are unreliable as they are based on a very small number of health effects so they are shown in *italics*

Appendix B: Default values used in the model

Table 21 presents the default values used in the *HAPINZ 3.0 Health Effects Model* for the base case, together with the recommended 95% confidence intervals or low/high values.

Table 21: Default values, plus their associated ranges, used in the HAPINZ 3.0 Health Effects Model (costs in 2019 NZ$)

Health effect	Relative risk default (*range*)		Social cost value default (*range*)	
$PM_{2.5}$				
Premature deaths (all adults, all Māori adults, all Pacific adults)	1.105 *(1.065 - 1.145)*	per 10 µg/m³	$4,527,300 *($4,050,742 - $5,242,137)*	per death
Years of life lost (all adults, all Māori adults, all Pacific adults)	1.105 *(1.065 - 1.145)*	per 10 µg/m³	$263,843 *($62,187 - $305,502)*	per YLL
CVD hospitalisations (all ages)	1.115 *(1.084 - 1.146)*	per 10 µg/m³	$36,666 *($10,809 - $473,294)*	per admission
Respiratory hospitalisations (all ages)	1.070 *(1.021 - 1.122)*	per 10 µg/m³	$31,748 *($5,891 - $462,770)*	per admission
Restricted activity days (all ages)	0.9 *(0.5 – 1.7)*	per 10 µg/m³	$89 *($49 - $125)*	per RAD
NO_2				
Premature deaths (all adults)	1.097 *(1.074 - 1.120)*	per 10 µg/m³	$4,527,300 *($4,050,742 - $5,242,137)*	per death
Years of life lost (all adults)	1.097 *(1.074 - 1.120)*	per 10 µg/m³	$263,843 *($62,187 - $305,502)*	per YLL
CVD hospitalisations (all ages)	1.047 *(1.031 - 1.064)*	per 10 µg/m³	$36,666 *($10,809 - $473,294))*	per admission
Respiratory hospitalisations (all ages)	1.130 *(1.102 - 1.159)*	per 10 µg/m³	$25,372 ($5,725 - $462,411)	per admission
Asthma/wheeze hospitalisations (all children, 0-18 yrs)	1.182 *(1.094 - 1.276)*	per 10 µg/m³	$1,822 *($911 - $2,733)*	per admission
Asthma prevalence (all children, 0-18 yrs)	1.05 (1.02 – 1.07)	per 4 µg/m³	$128 *($64 - $192)*	per case
PM_{10}				
Premature deaths (all adults)	1.111 *(1.089 - 1.133)*	per 10 µg/m³	$4,527,300 *($4,050,742 - $5,242,137)*	per death