TE MANATŪ WAKA
MINISTRY OF TRANSPORT

Domestic Transport Costs and Charges Study

Working Paper D4
Air quality and greenhouse gas emissions

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In association with Ian Wallis Associates Ltd
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Disclaimer

This Working Paper is one of a series that has been prepared as part of the New Zealand Domestic Transport Costs and Charges (DTCC) Study. A consultant team led by Ian Wallis Associates Ltd was contracted by Te Manatū Waka Ministry of Transport to carry out this Study.

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Research, Economics and Evaluation

The Research, Economics and Evaluation team operates within the System Performance and Governance Group of Te Manatū Waka Ministry of Transport. The team supports the Ministry's policy teams by providing the evidence base at each stage of the policy development.

The team is responsible for:

- Providing sector direction on the establishment and use of the Transport Evidence Base (see below) – including the collection, use, and sharing of data, research and analytics across the transport sector and fostering the development of sector research capabilities and ideas.
- Leading and undertaking economic analyses, appraisals and assessment including providing economic input on business cases and funding requests.
- Performing the evaluation function for Te Manatū Waka, including designing monitoring and evaluation frameworks and approaches, developing performance metrics and indicators, and designing, conducting and procuring evaluations.

The Transport Evidence Base

The Transport Evidence Base Strategy creates an environment to ensure data, information, research and evaluation play a key role in shaping the policy landscape. Good, evidence-based decisions also enhance the delivery of services provided by both the public and private sectors to support the delivery of transport outcomes and improve wellbeing and liveability in New Zealand.

The Domestic Transport Costs and Charges study aims to fill some of the research gaps identified in the 2016 Transport Domain Plan (Recommendation R6.2), which forms part of the Transport Evidence Base.

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For more information

For more information about this project and associated report, please contact: info@transport.govt.nz.

Executive summary

Overview

The Domestic Transport Costs and Charges (**DTCC**) study aims to identify all costs imposed by the domestic transport system on the wider New Zealand economy, including costs (financial and non-financial) and charges borne by the transport user. The Study, funded by the Ministry of Transport, is an important input to achieving a quality transport system for New Zealand that improves wellbeing and liveability. Its outputs will improve our understanding of the economic, environmental, and social costs imposed by different transport modes and the extent to which those costs are currently being offset by charges paid by transport users.

The DTCC work is divided into a number of modal topics – roads, rail, sea and air – and various impact topics – congestion, safety, health and environment.

This draft working paper presents **the air quality and greenhouse gas emissions impacts** resulting from the following modes of domestic transport in New Zealand:

- Road transport (excluding public transport)
- Rail
- Domestic aviation
- Coastal shipping
- Public transport.

We also show the estimated net emissions benefits that arise from substituting an average urban trip by car with the same journey by each of the following alternative modes:

- Walking and cycling
- Ride-hailing
- Micro-mobility.

The impacts outlined in this working paper are for a base year of 2018/2019 (July to June), with all costs in New Zealand dollars as at 30 June 2019. Impacts are expressed in emissions (and associated social costs) per vehicle kilometre as well as being normalised per passenger-kilometre (**PK**) and net tonne (freight)-kilometre (**NTK**). Upstream greenhouse gas emissions from energy production are included in the estimates.

We estimated all the costs in this report using damage costs (social costs per tonne of pollutant) developed from international literature that were applicable for New Zealand conditions. Damage costs are a way to value changes in air emissions to enable the benefits to society of a change in policy/operations to be compared against the cost of implementing the change.

New Zealand-specific damage costs are currently being developed as part of the latest Health and Air Pollution in New Zealand (**HAPINZ 3.0**) study and we had intended to use these values in the final version of our working paper. However, HAPINZ 3.0 has been delayed by several months due to data access issues resulting from COVID-19. At the time when finalising this working paper, these values were not yet available.

Summary of results

The following tables summarise the estimated air quality and greenhouse gas emissions impacts in 2018/19. The first table presents the total costs by mode (in $million) and the second shows the normalised costs by mode (in c/PK or c/NTK). Results are split by mode type – i.e. passenger versus freight – as well as spatially – i.e. urban versus rural and nationally.

Table ES.1 Total air quality and greenhouse gas emissions costs for all transport modes in New Zealand in 2018/19. All costs in June 2019 prices.

Mode	Urban			Rural			National		
	AQ	GHG	Total	AQ	GHG	Total	AQ	GHG	Total
Passenger transport ($M)	**$486 M**	**$380 M**	**$867 M**	**$68 M**	**$604 M**	**$672 M**	**$555 M**	**$984 M**	**$1,539 M**
Passenger car	$385	$333	$718	$64	$508	$572	$449	$841	$1,289
Coach	$2.4	$0.8	$3.2	$0.6	$2.9	$3.5	$3.0	$3.7	$6.7
Other bus	$4.4	$1.7	$6.1	$1.2	$5.8	$7.0	$5.6	$7.5	$13
Motorcycle	$9.4	$1.4	$11	$1.4	$2.2	$3.6	$11	$3.6	$14
Long-distance rail	$0.18	$0.03	$0.2	$0.06	$0.13	$0.2	$0.2	$0.2	$0.4
Domestic aviation	$18	$22	$41	$0.4	$81	$81	$19	$103	$122
Urban bus	$51	$16	$68	-	-	-	$51	$16	$68
School bus	-	-	-	$0.8	$3.9	$4.8	$0.8	$3.9	$4.8
Urban rail	$1.0	$1.0	$2.0	-	-	-	$1.0	$1.0	$2.0
Urban ferry	$14	$3.7	$18	-	-	-	$14	$3.7	$18
Freight transport ($M)	**$559 M**	**$192 M**	**$751 M**	**$93 M**	**$500 M**	**$592 M**	**$652 M**	**$691 M**	**$1,343 M**
LCV	$327	$120	$447	$43	$183	$226	$370	$303	$673
MCV	$33	$11	$43.6	$9	$37	$45.8	$42	$48	$89
HCV	$137	$55	$192	$36	$189	$225	$173	$244	$417
Electric locomotive	$0	$0.02	$0.02	$0	$0.1	$0.1	$0	$0.1	$0.1
Diesel locomotive	$15	$2.7	$18	$4.2	$10	$15	$19	$13	$32
Coastal freighter	$47	$3.1	$50	$0.4	$81	$81	$48	$84	$131
Total all ($M)	**$1,045 M**	**$572 M**	**$1,617 M**	**$161M**	**$1,103 M**	**$1,265 M**	**$1,206 M**	**$1,676 M**	**$2,882 M**

Table ES.2 Normalised air quality and greenhouse gas emissions costs for all transport modes in New Zealand in 2018/19. All costs in June 2019 prices.

Mode	Urban			Rural			National		
	AQ	GHG	Total	AQ	GHG	Total	AQ	GHG	Total
Passenger transport - ave (c/PK)	**1.6**	**1.3**	**2.9**	**0.2**	**1.6**	**1.8**	**0.8**	**1.5**	**2.3**
Passenger car	1.7	1.5	3.3	0.2	1.5	1.7	0.8	1.5	2.3
Coach	2.0	0.7	2.7	0.2	0.7	0.9	0.6	0.7	1.3
Other bus	1.6	0.6	2.3	0.1	0.6	0.8	0.5	0.6	1.1
Motorcycle	5.8	0.9	6.6	0.5	0.9	1.4	2.5	0.9	3.4
Long-distance rail	0.9	0.1	1.0	0.1	0.1	0.2	0.2	0.1	0.3
Domestic aviation	0.3	0.4	0.7	0.02	5.1	5.2	0.3	1.4	1.7
Urban bus	5.0	1.6	6.6	-	-	-	5.0	1.6	6.6
School bus	-	-	-	0.2	1.0	1.2	0.2	1.0	1.2
Urban rail	0.2	0.2	0.3	-	-	-	0.2	0.2	0.3
Urban ferry	15.7	4.1	19.9	-	-	-	15.7	4.1	19.9
Freight transport – ave (c/NTK)	**4.5**	**1.6**	**6.1**	**0.3**	**1.8**	**2.2**	**1.7**	**1.8**	**3.4**
LCV	18.0	6.6	24.6	1.6	6.6	8.2	8.1	6.6	14.7
MCV	6.5	2.2	8.7	0.5	2.2	2.7	1.9	2.2	4.0
HCV	2.6	1.0	3.6	0.2	1.0	1.2	0.7	1.0	1.8
Electric locomotive	0.0	0.1	0.1	0.0	0.07	0.07	0.00	0.07	0.07
Diesel locomotive	2.3	0.4	2.7	0.1	0.3	0.5	0.5	0.4	0.9
Coastal freighter	1.2	0.1	1.3	0.0	6.5	6.6	0.9	1.6	2.5

Note:

1. Air quality and greenhouse gas emissions released by domestic aviation during landing and take-off and by coastal freighters at berth are assigned to urban/rural based on port location.
2. Greenhouse gas emissions released by domestic aviation while at altitude (cruise) and by coastal freighters at sea are assigned to rural areas only.

Chapter 1 Introduction

1.1 Background

The Domestic Transport Costs and Charges (DTCC) study aims to identify all the costs associated with the domestic transport system and its impacts on the wider New Zealand economy, including costs (financial and non-financial) and charges borne by transport users.

The Study is an important input to achieving a quality transport system for New Zealand that improves wellbeing and liveability. Its outputs will improve our understanding of the economic, environmental and social costs associated with different transport modes - including road, rail, public transport and coastal shipping - and the extent to which those costs are currently offset by charges paid by transport users.

The DTCC is intended to support the wider policy framework of Te Manatū Waka, in particular the Transport Outcomes Framework (TOF). The TOF seeks to make clear what government wants to achieve through the transport system under five outcome areas:

- Inclusive access,
- Economic prosperity,
- Healthy and safe people,
- Environmental sustainability, and
- Resilience and security.

Underpinning the outcomes in these areas is the guiding principle of mode neutrality. In general, outputs of the DTCC study will contribute to the TOF by providing consistent methods for (a) estimating and reporting economic costs and financial charges; and (b) understanding how these costs and charges vary across dimensions that are relevant to policy, such as location, mode, and trip type.

Robust information on transport costs and charges is critical to establishing a sound transport policy framework. The Study itself does not address future transport policy options; but the study outputs will help inform important policy development in areas such as charging and revenue management, internalising externalities, and travel demand management.

The Study was undertaken for Te Manatū Waka by a consultant consortium headed by Ian Wallis Associates Ltd. The Study has been divided into a number of topic areas, some of which relate to different transport modes (including road, rail, urban public transport and coastal shipping), and others to transport-related impacts or externalities (including accidents, congestion, public health, emissions, noise, biodiversity and biosecurity).

Working papers (25) have been prepared covering each of the topic areas. Their titles, topic areas and specialist authors are listed in Appendix D.

However, the scope of the DTCC is considerably wider than that of STCC; in addition to road and rail, the DTCC covers a wider selection of transport modes/segments, including:

- domestic air passenger transport
- domestic sea freight transport
- active travel modes – walking, cycling
- other road-based transport modes not covered in STCC – ride-hailing (including taxis) and micro-mobility (scooters etc)

Further, and complementary to this wider selection of transport modes, the consideration of economic costs will be widened in two main respects:

- a more detailed assessment of environmental costs; and
- the inclusion of the relative health cost implications of the different transport modes.

1.2 Costing Practices

The focus of DTCC is on NZ transport operations, economic costs, financial costs and charges for the year ending 30 June 2019 (FY 2018/19). Consistent with this focus, all economic and financial cost figures are given in NZ$2018/19 (average for the 12-month period) unless otherwise specified.

All financial costs include any taxes and charges (but exclude GST); while economic costs exclude all taxes and charges.

The DTCC economic and financial analyses comprise essentially single-year assessments of transport sector costs and charges for FY 2018/19. Capital charges have been included in these assessments, with annualised costs based on typical market depreciation rates plus an annualised charge (derived as 4% p.a., in real terms, of the optimised replacement costs of the assets involved).

1.3 Purpose and scope of study

The original STCC study generated a working paper[1] covering a broad range of environmental impacts – noise, water, air quality and climate change – resulting from road and rail (only) transport for a base year of 2001 (January to December).

This working paper presents the environmental and public health impacts of air quality and greenhouse gas emissions resulting from various modes of domestic transport in New Zealand. The methodology follows international and local best practice for assessing air emissions from the various modes, with a combination of bottom-up or top-down approaches used (depending on data availability).

Air quality and greenhouse gas emissions are calculated from activity data and relevant emission factors and reported as national totals as well as broken down by urban/rural locations (where possible). Emissions are multiplied by damage cost figures to arrive at total external costs of air pollution per transport mode. These

[1] Booz Allen Hamilton (2005). *Surface* Transport *Costs and Charges Study – Environmental Impacts Working Paper.* Report prepared for Ministry of Transport, January 2005.

figures are then normalised to allocate average costs per passenger-kilometre and net tonne-kilometre per mode.

1.4 Report structure

The report is structured as follows:

- Chapter 2 describes the overall methodology used to assess the air quality and greenhouse gas impacts for the various modes in terms of emissions and subsequent costs
- Chapter 3 presents the results for road transport (including freight and long-distance passenger services but excluding buses used for public transport and school services)
- Chapter 4 presents the results for rail (including freight and long-distance passenger services but excluding rail used for public transport)
- Chapter 5 presents the results for domestic air travel (passenger only)
- Chapter 6 presents the results for coastal shipping (including freight but excluding cruise ships and ferries used for public transport)
- Chapter 7 presents the results for public transport (including buses, rail, and ferries)
- Chapter 8 presents the results for alternative modes (including walking and cycling, ride-hailing and micro-mobility)
- Chapter 9 summarises our findings and recommends where further work could be applied to address key data gaps.

A glossary of terms and abbreviations is included (Appendix A) and all references are listed at the end of the report (Appendix B).

Supporting information is included in a technical appendix (Appendix C).

Chapter 2 Methodology

This chapter describes the overall methodology used to assess the air quality and greenhouse gas impacts for the various modes in terms of emissions and related costs. It covers:

- Which air pollutants are associated with domestic transport emissions and why are they of concern?
- What are the typical steps involved in assessing the environmental and public health impacts of air emissions?

The specific methodologies used to assess the impact of emissions for each mode are covered in more detail in later chapters.

2.1 Air pollutants associated with domestic transport emissions

The domestic transport sector - which encompasses road, rail, marine and aviation - generates air emissions, principally through the combustion of fossil fuels. These emissions are typically split into air quality pollutants (which impact locally) and greenhouse gases (which impact globally).

2.1.1 Air quality pollutants

Air quality pollutants (also known as “harmful pollutants”) include:

- Particulate matter smaller than 10 µm (**PM_{10}**) or smaller than 2.5 µm (**$PM_{2.5}$**) – which arises primarily from diesel fuel combustion, brake/tyre wear and road dust.
- Nitrogen oxides (**NO_X**), in particular, nitrogen dioxide (**NO_2**) – which is emitted primarily from diesel and petrol fuel combustion.
- Sulphur dioxide (**SO_2**) – which is associated with combustion of marine transport fuels (but typically coastal freighters rather than ferries). On-road diesel vehicles used to be a significant source until the sulphur level in motor diesel was reduced to near zero (only 10ppm) in 2009.
- Volatile organic compounds (**VOCs**) – which come from evaporation of fuel in engines and refuelling systems as well as fuel combustion.
- Carbon monoxide (**CO**) – which is associated particularly with the incomplete combustion of petrol. However, concern has reduced now that most petrol vehicles are fitted with catalytic converters.

Air quality pollutants cause adverse human health effects ranging from increased *morbidity* (illness, e.g. increased respiratory hospitalisations) to increased *mortality* (loss of life, e.g. premature deaths). The effects depend on the pollutant, its concentration and the length of time a person is exposed to it – either acute (short-term) or chronic (long-term).

The air quality pollutants assessed in this working paper include CO, VOCs, NO_X, SO_2 and PM_{10}. Particulate matter in exhaust emissions is typically in the smaller size fraction ($PM_{2.5}$) while particulate matter from road dust and brake/tyre wear is typically in the larger size fraction (PM_{10}). Therefore, accounting for PM_{10} accounts for both.

2.1.2 Greenhouse gases

Greenhouse gases (also known as “climate pollutants”) include:

- Carbon dioxide (**CO_2**) – which is released from combustion of all fossil fuels (especially mineral-based petrol and diesel). Combustion of renewable fuels also produces CO_2, but the net effect is considered zero as the CO_2 is then re-captured in the production of the renewable fuels.
- Methane (**CH_4**) – which is commonly associated with incomplete combustion and fuel system leaks in natural gas-fuelled vehicles.
- Nitrous oxide (**N_2O**) – which is also associated with fossil fuel combustion.
- Black carbon (**BC**) – which is produced primarily from diesel combustion and is essentially fine particulate matter ($PM_{2.5}$ and smaller).

Greenhouse gases (**GHGs**) are so-called because they contribute to global warming and climate change. GHGs are categorised as short-lived with an atmospheric lifetime of days to 15 years (e.g. BC and CH_4) or long-lived with an atmospheric lifetime of more than 100 years (e.g. CO_2). For ease of comparison, GHGs are typically expressed as CO_2 equivalents (**CO_2e**), which is the amount of CO_2 which would have the equivalent global warming impact over 100 years.

Note: Several air quality pollutants (especially BC) are direct climate pollutants. Many of the remaining air quality pollutants (e.g. SO_2 and CO) are indirect climate pollutants. They do not have a direct warming effect but react with other gases and increase GHG concentrations. Therefore, initiatives which address air quality pollutants typically yield both health and climate change benefits.

The greenhouse gases assessed in this working paper include CO_2, CH_4 and N_2O – collectively referred to as CO_2e. The greenhouse effect of BC is not assessed but the local air quality effect is captured in the PM_{10} size fraction.

2.2 Assessing impacts of transport-related air emissions

Assessing the impacts of transport-related air emissions requires:

- Estimating the emissions (e.g. tonne per pollutant per mode)
- Applying cost factors (e.g. health damage costs in NZ$ per tonne per pollutant)
- Allocating the output (e.g. average costs per passenger-km or net tonne-km)
- Considering whole of life impacts (e.g. well to wheel emissions)

2.2.1 Estimating emissions

There are two common approaches to estimating emissions – bottom-up and top-down. The method used depends on data availability, resources and the resolution required for the assessment. In practice, a combination is often used to reality-check results.

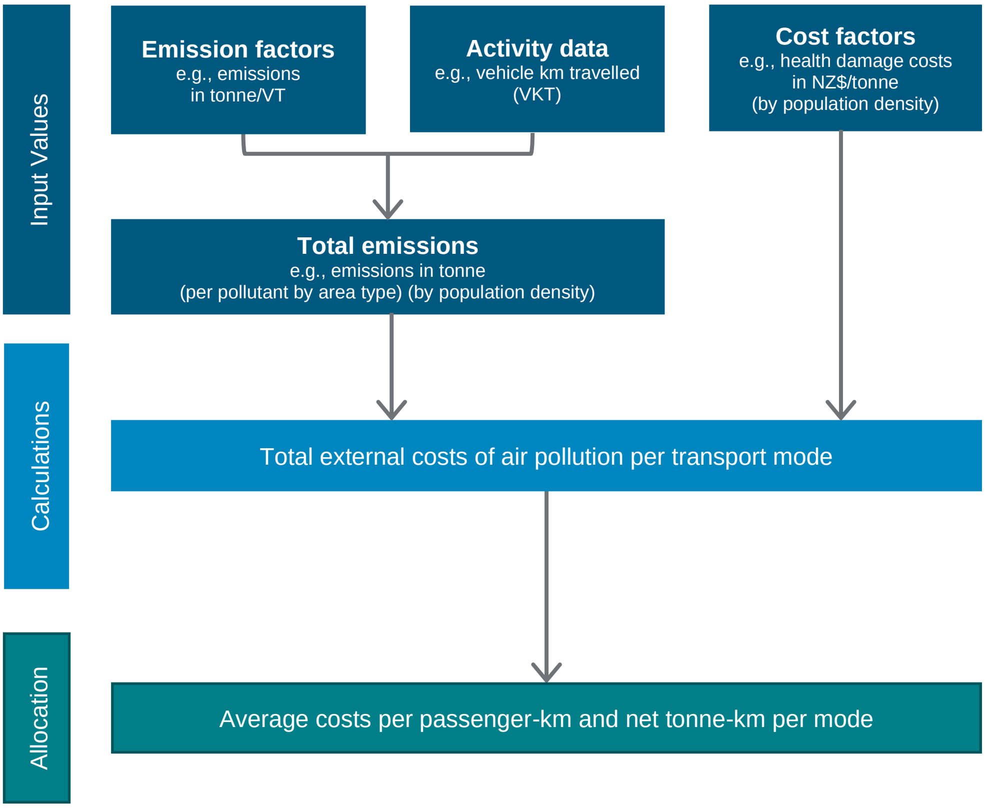
Bottom-up approaches

Bottom-up approaches utilise detailed local data in calculations and then aggregate emissions from the local level (the “bottom”) to provide regional or national totals (the “top”). These approaches yield accurate results but are very time consuming and resource intensive. In addition, suitably detailed information for the critical inputs is not always readily available.

The European Commission recommends a generic bottom-up approach for calculating total and average costs of air pollution and GHG emissions (as shown in Figure 2.1) in their 2019 *Handbook on External Costs of Transport* (Essen et al 2019)[2].

Emissions are calculated by combining emission factors (which will be a function of the vehicle technology, fuel type, duty, speed, and load including gradient) with activity data.

Figure 2.1 Generic methodology for calculating total and average costs of air pollution (Essen et al 2019)



Note: A similar methodology is used for GHG emissions

Top-down approaches

Top-down approaches take aggregate data typically at a national level (e.g., total annual diesel use) and then disaggregate the numbers using other metrics (e.g., population or length of road network) to estimate the local contribution (the “bottom”). These approaches are much easier and faster to undertake but typically yield less accurate results. However, in some instances data are only available at the national/aggregate level, leaving no option but the top-down approach.

[2] Essen et al (2019). *Handbook on the external costs of transport, Version 2019*. Report prepared for European Commission, Directorate-General for Mobility and Transport, January 2019.

Estimated emissions from the New Zealand transport sector were previously reported in the *National Air Emissions Inventory for 2015* (Metcalfe & Sridhar 2018) [3]. This national inventory provides estimated emissions of PM_{10}, $PM_{2.5}$ (a subset of PM_{10}), CO, NO_X, and SO_X for road transport, aviation, coastal shipping, and rail. Similarly, estimates of greenhouse gas emissions for the transport sector are available in *New Zealand's Greenhouse Gas Emissions Inventory 1990-2018* (MfE 2020)[4]. Both inventories draw mostly from national data to provide estimated emissions at a national level only.

Spatial and temporal resolution

The impacts outlined in this working paper are assessed for a **base year** of 2018/2019 (July to June). All costs are in New Zealand dollars (**NZ$**) as at 30 June 2019 (June 2019 prices).

Emissions and costs are estimated **spatially** at a regional or finer scale level (where possible) but reported for urban areas, rural areas and nationally across New Zealand. Where regional data are available, they have been included in the appendices to indicate the variation across New Zealand.

The decision to report urban versus rural rather than by region in this working paper is two-fold:

- **Consistency**: Although suitable regional data exist for some of the modes, comparable information is not available for all modes being assessed.
- **Exposure**: The separation between urban and rural is particularly important for air quality impacts which depend on the population exposed in a given area. The type of area is more important (generally) than the region.

Statistics New Zealand (**StatsNZ**) defines urban areas[5] to be:

> … statistically defined areas with no administrative or legal basis. They are characterised by high population density with many built environment features where people and buildings are located close together for residential, cultural, productive, trade, and social purposes.

Urban areas typically contain an estimated resident population of more than 1,000 people and usually have a population density of more than 400 residents or 200 address points per square kilometre.

The StatsNZ Urban Rural 2018 indicator (StatsNZ 2018) further classifies urban areas by the size of their estimated resident population:

- major urban area – 100,000 or more residents
- large urban area – 30,000–99,999 residents
- medium urban area – 10,000–29,999 residents
- small urban area – 1,000–9,999 residents.

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[3] Metcalfe & Sridhar (2018). *National Air Emissions Inventory 2015*. Report prepared for Ministry for the Environment by Emission Impossible Ltd, October 2018. https://www.mfe.govt.nz/publications/air/national-air-emissions-inventory
[4] MfE (2020). *New Zealand's Greenhouse Gas Inventory 1990-2018*. Ministry for the Environment, Wellington, April 2020. https://www.mfe.govt.nz/climate-change/state-of-our-atmosphere-and-climate/new-zealands-greenhouse-gas-inventory
[5] StatsNZ (2018). *Urban Rural 2018 V1.0.0 Classification*. Statistics New Zealand. http://aria.stats.govt.nz/aria/?_ga=2.36874984.934161582.1606679968-909068172.1605493681#ClassificationView:uri=http://stats.govt.nz/cms/ClassificationVersion/qqn46tSGdZlUV4fU

In our analyses, we classify all settlement/areas with more than 1,000 residents as urban areas and all others as rural.

2.2.2 Applying cost factors

Emissions to air, either air quality or greenhouse gas, cause an impact on society through increased medications use, lost productivity through illness, increased hospitalisations, death and extremes in climate. The social costs associated with changes in air quality pollutants and greenhouse gases can be calculated by combining the emissions (usually expressed in grams or tonnes of each pollutant) with unit damage costs (expressed in $ per tonne).

Damage costs are a way to value changes in air emissions so that the benefits to society of a change in policy/operation can be compared against the cost of implementing the change. They can also be used to compare a range of options to see which will yield the best overall outcome.

Many overseas governmental agencies publish relevant values to be used in the assessment of costs and benefits of various policy options in their jurisdictions (e.g. DEFRA 2020)[6]. These are often expressed as an overall national average as well as by population density, with higher damage costs assigned to high density urban areas (e.g. £52,587 per tonne for road transport NO_X in inner London in 2017) and significantly lower in lower density locations (e.g. £3,166 per tonne for road transport NO_X in rural United Kingdom in 2017).

Current damage costs for New Zealand (MBCM)

Damage costs are published by Waka Kotahi NZ Transport Agency (**Waka Kotahi**) for use in transport project evaluations in New Zealand.

A suite of values covering the main road transport-related air pollutants was developed originally for the *Economic Evaluation Manual* (**EEM**) released in 2013 (NZTA 2013)[7]. These were based on overseas values published by Austroads (2012)[8] and DEFRA (2015)[9]. However, results from the *Updated Health and Air Pollution in New Zealand Study* (Kuschel et al 2012)[10] were used to calibrate the PM_{10} damage costs for New Zealand conditions.

[6] DEFRA (2020). *Air quality appraisal: damage cost guidance*. Report prepared by UK Department for Environment Food and Rural Affairs, July 2020. https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance

[7] NZTA (2013). *Economic Evaluation Manual*. Effective from October 2013. https://www.nzta.govt.nz/resources/economic-evaluation-manual

[8] Austroads (2012). *Guide to Project Evaluation Part 4: Project Evaluation Data.* Austroads, 6 August 2012. https://austroads.com.au/publications/economics-and-financing/agpe04-12

[9] DEFRA (2015). Valuing impacts on air quality: Updates in valuing changes in emissions of Oxides of Nitrogen (NO_X) and concentrations of Nitrogen Dioxide (NO_2). UK Department for Environment Food and Rural Affairs, September 2015. http://qna.files.parliament.uk/qna-attachments/419202/original/676%20-%20HL2275%20Air-quality-econanalysis-nitrogen-interim-guidance.pdf

[10] Kuschel et al (2012). *Updated Health and Air Pollution in New Zealand Study*. Prepared by Emission Impossible and others for Health Research Council of New Zealand, Ministry of Transport, Ministry for the Environment and NZ Transport Agency, March 2012. https://www.mfe.govt.nz/publications/air/updated-health-and-air-pollution-new-zealand-study-2012-summary-report

The EEM was superseded by the *Monetised Benefits and Costs Manual* (**MBCM**) in 2020 (NZTA 2020a) [11]. Costs were updated for a value base date of 2016 using the change in the road safety Value of Statistical Life (**VoSL**) figure (Te Manatū Waka 2017) [12]. The current values (shown in

Table 2.1) are based on estimates of impacts in urban areas.

Table 2.1 Damage costs for use in project evaluations in $/tonne in the MBCM (NZTA 2020a)

Pollutant	Costs in NZ$/tonne	Value base date (at end June)
PM_{10}	$460,012	2016
NO_X	$16,347	2016
VOC	$1,310	2016
CO_2e	$65.58	2016
CO	$4.13	2016

Note:

1. The value shown for CO_2e has no relationship to the level of carbon tax or carbon price that the government might consider as a policy instrument to restrain CO_2e emissions. It is intended to reflect the social cost of these emissions.
2. All costs are based on a road safety VoSL of $4.140 million (NZ$) at end June 2016 and can be updated to future years using the VoSL ratios.

Revised damage costs for New Zealand (DTCC)

While the MBCM damage costs are useful, there are potential limitations in the applicability of overseas data and a need to provide more spatially representative values (i.e. both urban and rural). In response, one of the key objectives of the latest Health and Air Pollution in New Zealand (**HAPINZ 3.0**) study, which is still underway, is to develop New Zealand-specific damage costs.

The HAPINZ 3.0 study has been undertaken in parallel with the DTCC study and the original timelines were synchronised to enable the HAPINZ 3.0 damage costs to be used in our final DTCC working paper. Unfortunately, due to COVID-19, the HAPINZ 3.0 team could not gain access to critical datasets in time so the final values were not available to be incorporated into this final working paper. Nonetheless, while we were not able to use the HAPINZ 3.0 *values* we were able to apply some of the HAPINZ 3.0 preliminary *findings*[13] (especially regarding the likely urban versus rural costs ratio and supporting stronger health impacts due to NO_2) to revise the Waka Kotahi MBCM values to reflect the New Zealand situation more accurately.

The steps we followed to develop the revised damage costs for the DTCC study (shown in Table 2.2) were as follows:

1. The MBCM values from Table 2.1 were used as the starting point for urban damage costs for the following air quality pollutants – PM_{10}, NO_X, VOC, and CO.

[11] NZTA (2020a). *Monetised benefits and costs manual*. Effective from August 2020. https://www.nzta.govt.nz/resources/monetised-benefits-and-costs-manual/
[12] Te Manatū Waka (2017). *The Social Costs of Road Crashes and Injuries 2016 Update*. Ministry of Transport, March 2017. https://www.transport.govt.nz/mot-resources/road-safety-resources/roadcrashstatistics/social-cost-of-road-crashes-and-injuries/
[13] The HAPINZ 3.0 project is being undertaken by the same team members involved in the preparation of this DTCC working paper, ie Gerda Kuschel, Jayne Metcalfe and Surekha Sridhar.

2. The costs were then updated to June 2019 based on the 2019 road safety VoSL from *The Social Costs of Road Crashes and Injuries 2019 Update* (Te Manatū Waka 2020)[14].
3. The SO_2 urban damage cost (which was not developed for the MBCM) was estimated from the ratio of SO_2 urban to NO_X urban costs in the *Air quality appraisal: damage cost guidance* (DEFRA 2020)[15].
4. The CO_2e urban damage cost was estimated from the *CBAx Tool User Guidance* (Treasury 2020)[16], with the value used being the average of the low ($58) and high ($118) values in Appendix 4 of the Guidance, in June 2019.
5. The rural damage costs for all air quality pollutants were estimated using the ratio of PM damage costs for central London versus those for rural in the DEFRA (2020) guidance. This yields an urban to rural ratio of 13.1 which is broadly comparable to the preliminary findings from HAPINZ 3.0. The health impacts of air quality pollutants depend on local exposure, which will be lower in rural areas due to fewer people exposed even if the concentrations or emissions are the same. Rural damage costs for all air quality pollutants were estimated by dividing the relevant urban damage costs by 13.1.
6. The rural damage cost for CO_2e was assigned the same value as the urban damage cost because CO_2e has a global impact.

The values shown in Table 2.2 are those that were used in the assessment of costs for all modes (in Chapters 3 to 8). The marginal costs were assumed to be equal to the average costs for application of all emission costs rates. **All costs were assumed to be additive** – i.e. that the impact of double-counting of effects was negligible. The justification for this is discussed in more detail in the next section.

[14] Te Manatū Waka (2020). *The Social Costs of Road Crashes and Injuries - June 2019 Update.* Ministry of Transport, August 2020. https://www.transport.govt.nz/about-us/news/social-cost-of-road-crashes-and-injuries-2019-update/
[15] DEFRA (2020). *Air quality appraisal: damage cost guidance*. Report prepared by UK Department for Environment Food and Rural Affairs, July 2020. https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance
[16] Treasury (2020). *CBAx Tool User Guidance*. NZ Treasury, December 2020. https://treasury.govt.nz/publications/guide/cbax-tool-user-guidance

Table 2.2 Revised damage costs used in the DTCC study in $/tonne in June 2019 prices

Pollutant	Costs in NZ$/tonne Urban	Costs in NZ$/tonne Rural	Value base date (at end June)
PM_{10}	$503,346	$38,480	2019
SO_2	$36,491	$2,790	2019
NO_X	$17,887	$1,367	2019
VOC	$1,433	$110	2019
CO_2e	$88	$88	2019
CO	$4.52	$0.35	2019

Note: All costs are based on a road safety VoSL of $4.530 million (NZ$) at end June 2019 by multiplying the 2016 damage costs (Table 2.1) by 1.094 (=4.530/4.140) to derive these 2019 urban values.

Issues associated with applying damage costs

Concerns that need to be considered in applying damage costs include:

1. Lagged effects/benefits
2. Non-linearity of exposure-response functions
3. Potential double-counting

There is a **lag between a change in air pollution and a health benefit/impact**. Consequently, studies of the costs and benefits of air pollution typically use lagged benefits. The approaches used are still developing and there is increased focus on testing the extent of lag. Some US studies suggest a significant proportion of the benefit is gained soon after a reduction in emissions (Lepeule et al 2012) [17].

The **exposure-response functions**, used in the development of subsequent damage costs, are **not linear**. The increment in health effect per unit increase in concentration (e.g. per 10 µg/m^3 increase in annual average PM_{10}) tends to be higher at lower concentrations than at higher concentrations, i.e. the effect tapers off.

Double counting of effects can arise. The World Health Organisation (**WHO**) states[18] that:

> …for any particular health outcome and exposure period (long-term or short-term exposure), estimated impacts of the three pollutants should not be added without recognising that this will, in most practical circumstances, lead to some overestimation of the true impact. Impacts estimated for one pollutant only will, on the other hand, underestimate the true impact of the pollution mixture, if other pollutants affect that same health outcome independently.
> (WHO, 2013)

[17] Lepeule J et al (2012). Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities Study from 1974 to 2009. *Environmental Health Perspectives*, 120(7): 965-97

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

These concerns are addressed in the revised damage costs used in the DTCC study (Table 2.2) as follows.

1. The existing MBCM damage costs (and HAPINZ 3.0) are **based on lagged benefit models** so this is already accounted for. In the case of CO_2e, the damage costs have been developed from marginal abatement cost (**MAC**) curves developed by the Ministry for the Environment to estimate the marginal cost of emission reduction to meet current and proposed future limits.
2. New Zealand's air quality is good relative to other countries (i.e. at the lower end of concentration ranges) and therefore the exposure-response functions are **essentially linear over the range of values we typically encounter**. Also the effects are likely to be higher per unit of pollution than in more heavily polluted countries.
3. The pollutants most likely to overlap in effects are PM and NO_2. While not yet publicly available, the HAPINZ 3.0 study uses functions **derived from multi-pollutant models** which take into account the effect of long-term exposure to both PM_{10} and NO_2 (meaning the impacts and subsequent costs can be added). The HAPINZ 3.0 preliminary findings indicate a much higher impact from NO_2 than has been recognised previously or is reflected in the damage costs in Table 2.2. Therefore, adding the effects of different pollutants is unlikely to lead to double-counting - if anything, the revised values may be under-estimates, but they are the best currently available.

2.2.3 Allocating air pollution costs

Impacts are expressed in emissions (and subsequent social costs) per vehicle kilometre as well as normalised per passenger-kilometre (**PK**) and net tonne (freight)-kilometre (**NTK**).

2.2.4 Considering whole of life impacts

Typically, the assessment of impacts is limited to those air quality and greenhouse gas emissions resulting from the *direct use* (only) of the various modes on their typical routes - in other words fuel combustion, brake and tyre wear, and road abrasion (dust from sealed and unsealed roads). However, there are other upstream and downstream processes directly related to transport that also led to negative external effects. Taking a *life-cycle view*, the energy production, the vehicle and infrastructure production, maintenance and 'end of life' disposal (scrappage) all lead to the emission of air pollutants and greenhouse gases.

Given the paucity of relevant data, life-cycle assessments commonly focus on well-to-wheel (**WTW**) greenhouse gas emissions only as information is usually more readily available for a broader range of sources and sectors. A WTW approach captures both tailpipe emissions (tank-to-wheel or **TTW**) and the emissions associated with generating a fuel or energy vector (well-to-tank or **WTT**) to enable a fair comparison of all technologies and fuels, e.g., an electric bus has no tailpipe emissions but there are emissions produced in the generation and transmission of the electricity it uses to charges its batteries.

WTW greenhouse gas emissions factors are reported annually for different New Zealand fuel types (Barber & Stenning 2019)[19]. In addition, MfE publish guidance on the relevant emission factors to use for combustion of liquid transport fuels and the use of electricity (MfE 2019) [20]. Taken together, these enable the full WTW greenhouse gas emissions to be compared with those for fuel combustion (TTW) emissions. The upstream production (WTT) emissions can then be estimated by difference. Table 2.3 summarises the factors for relevant New Zealand transport fuels and energy in 2019. These factors can be applied directly to the fuel or electricity usage for each transport mode.

Table 2.3 Life cycle emission factors for New Zealand transport fuels/energy in 2019

Fuel type	Unit	WTW GHG (gCO_2e/unit) Barber & Stenning	TTW GHG (gCO_2e/unit) MfE	WTT GHG (gCO_2e/unit) by difference
Petrol (default)	litres	2,760	2,452	308 (=2,760-2,452)
Diesel	litres	3,147	2,694	453 (=3,147-2,694)
Heavy fuel oil	litres	3,539	3,039	500 (=3,539-3,039)
Aviation gasoline	litres	2,634	2,312	322 (=2,634-2,312)
Jet fuel	litres	2,949* (=2,627+322)	2,627	322* (same as av gas)
Electricity (2017)	kWh	121.2	0	121.2 (=121.2-0)

Source: WTW factors Barber & Stenning (2019); TTW factors MfE (2019);WTT calculated from the difference.
Notes:

1. All CO_2e emissions are based on global warming potentials of CH_4=25 and N_2O=298 taken from the IPCC Fourth Assessment report (2007) [21].
2. Marine diesel is the same as road transport diesel in New Zealand. Fishing vessels and recreational vessels use automotive gas oil, i.e. diesel fuel available at service stations that goes in trucks and cars. The New Zealand refinery does not supply a separate marine diesel oil.
3. A jet fuel WTW value was not reported in Barber & Stenning (2019) so the WTT emissions (marked with a *) were assumed to be the same as those for aviation gasoline (i.e. 322 gCO_2e/litre) and then added to the MfE (2019) TTW value to derive the WTW value (also marked with a *).
4. The value shown for electricity is the average for 2017 based on the mix of generation at that time and is the most current value available, taken from Barber & Stenning (2019).

Other whole of life impacts exist but they are poorly understood and difficult to quantify. Whilst not accounting for all impacts, WTW emissions capture an appreciable proportion of the total (at least for greenhouse gas emissions). For example, Del Pero et al (2018) [22] estimate that WTW greenhouse gas emissions represent 85% of the total life-cycle greenhouse gas emissions for light duty petrol or diesel vehicles in Europe.

[19] Barber & Stenning (2019). *New Zealand fuel and electricity total primary energy and life cycle greenhouse gas emission factors 2019.* Agrilink New Zealand Ltd, September 2019. http://agrilink.co.nz/wp-content/uploads/2019/09/Fuel-LCA-emission-factors-2019-2.pdf
[20] MfE (2019). *Measuring Emissions: 2019 Emission Factors Workbook*. Ministry for the Environment, May 2019. https://www.mfe.govt.nz/publications/climate-change/measuring-emissions-guide-organisations-2019-detailed-guide
[21] IPCC (2007). *Fourth Assessment Report (AR4): The physical science basis*. Intergovernmental Panel on Climate Change, June 2007. https://www.ipcc.ch/assessment-report/ar4/
[22] Del Pero et al (2018). Life Cycle Assessment in the automotive sector: a comparative case study of Internal Combustion Engine (ICE) and electric car. *Procedia Structural Integrity* **12** (2018): 521-537

2.3 Detailed methodology by mode

The emission factors and activity data used depend on the mode being assessed. In some instances, New Zealand data are only available top-down so information needs to be disaggregated spatially.

The detailed methodology undertaken for each mode is discussed in the relevant following chapters.

As noted earlier, emissions and costs are estimated for 2018/19 (1 July 2018 to 30 June 2019) at a regional or finer scale level (where possible). These are then reported for urban areas, rural areas and nationally (overall). Where regional data are available, they have been included in the appendices to indicate the variation across New Zealand.

Chapter 3 Road transport

This chapter assesses the air quality and greenhouse gas emission impacts for transport travelling on New Zealand's road network covering:

- All road transport, including freight and long-distance passenger buses
- But **excluding** buses used in public and school transport (which are covered in Chapter 7)

This chapter discusses the detailed methodology used in the assessment of this mode including the fleet profile, the relevant emission factors and the activity rate data.

Results are presented as emissions and associated costs and are disaggregated spatially and by fuel type. Upstream greenhouse gas emissions from energy production are also assessed.

3.1 Methodology

Air quality and greenhouse gas emissions were estimated for a range of vehicle types (dependent on fuel and duty) in the road transport fleet as follows:

$$E = EF \times VKT \qquad \text{Equation 3.1}$$

Where:

E = emission of a pollutant (g/yr)

EF = emission factor (**EF**) of the pollutant by speed for vehicle type (g/km)

VKT = total vehicle kilometres travelled (**VKT**) by vehicle type on the network (km/yr).

Emissions were estimated bottom-up, using speed and VKT data for regions across New Zealand as well as urban/rural splits. Estimates were then aggregated to provide national emissions.

3.1.1 Road fleet profile

The New Zealand road fleet profile in 2018/19 (in terms of VKT) was taken from the *Vehicle Emissions Prediction Model* (**VEPM**). VEPM utilises fleet data and projections from the *Vehicle Fleet Emissions Model* (**VFEM**). The latest version of VEPM - VEPM6.1 - covers years from 2001 to 2050 and is populated with actual fleet data to the end of 2017.

The Vehicle Fleet Emissions Model (VFEM)

VFEM, developed by Te Manatū Waka , predicts the makeup of future vehicle **fleets** and their kilometres travelled, energy (fuel and electricity) use and greenhouse gas emissions (Te Manatū Waka 2019a)[23].

23 Te Manatū Waka (2019a). *Transport Outlook Vehicle Fleet Emissions Model (VFEM3).* Ministry of Transport, July 2019. https://www.transport.govt.nz/assets/Import/Uploads/Research/Documents/4e03a96a14/Vehicle-Fleet-Emissions-Model-Documentation-20190719.pdf

The latest version of VFEM – VFEM3 – incorporates the results of the updated electric vehicle uptake model and real-world fuel use study. The model estimates the fleet profile for historic years (since 2001) and projected years (up to 2055), with data broken down by vehicle type, vehicle age, fuel type, New Zealand-new or used import, and engine size (light duty vehicles) or gross vehicle mass (trucks and buses).

The Vehicle Emissions Prediction Model (VEPM)

VEPM, developed by Auckland Council and Waka Kotahi, predicts air **emissions** and fuel consumption from vehicles in the New Zealand fleet under typical road, traffic and operating conditions (NZTA 2020b).[24] VEPM has undergone considerable development since first being developed in 2008 and is based on the latest available international emissions databases. The critical factors that affect emissions are the exhaust emission standard that a vehicle is manufactured to, the speed (or average speed) that the vehicle is traveling and the extent to which real-world driving has been factored in. The emission factors predicted by VEPM compensate for all these factors, with much of the recent development focussing on improving the real-world estimates.

VEPM is an average speed model and provides tailpipe exhaust emission factors for CO, HC, NO_X, PM and fuel consumption, as well as PM from brake and tyre wear. It does not currently estimate evaporative or crank case emissions. The emissions factors used for average speed models are based on the results of thousands of empirical tests. These tests use drive cycles representing real life driving conditions rather than the cycles used for regulatory compliance. The cycles have a wide range of different operating conditions, i.e. acceleration rates, maximum speeds, periods of idle etc, and hence a similarly wide range of average speeds. For example, a low average speed is typical of driving in congested traffic.

The majority of the **New Zealand new** fleet is manufactured to European emission standards. For these vehicles, emission factors are taken from the European Computer Model to Calculate Emissions from Road Transport (**COPERT**). This is a model that has been under development since the 1990s for the creation of national emissions inventories for EU countries. It is used extensively worldwide and a version of COPERT is in use in Australia. COPERT emission factors are published in an excel spreadsheet in the *EMEP/EEA Air pollutant emission inventory guidebook* (EMEP/EEA 2019)[25].

The substantial remainder of the New Zealand fleet is second hand **used imported** vehicles, most of which were manufactured to the Japanese vehicle emission standards applicable at the time. Available emissions data are currently insufficient to be able to develop a comprehensive model based on Japanese data. For these vehicles, VEPM assigns each Japanese vehicle class to the closest equivalent European emission factor, an approach which is in accordance with international best practice[26].

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[24] NZTA (2020b). *Vehicle emissions prediction model (VEPM6.1)*. Waka Kotahi NZ Transport Agency, September 2020. https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/air-quality-climate/planning-and-assessment/vehicle-emissions-prediction-model/

[25] EMEP/EEA (2019). *Air pollutant emission inventory guidebook 2019*. European Environment Agency Report No 13/2019, October 2019. https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

[26] The developers of COPERT used a similar process to develop emission factors for Cyprus where the vehicle fleet is also dominated by Japanese used imports.

VEPM reports the fleet profile in terms of the proportion of VKT in each category for four-wheeled vehicles (motorcycles are excluded).

Table 3.1 shows the default fleet profile for the 2018/19 road fleet we used in our assessment.

Table 3.1 Road transport VKT profile for 2018/19 from VEPM6.1 (NZTA 2020b)

Vehicle type	Fuel type	2018/19 %VKT
Passenger Car	Petrol <3.5t	64.82%
	Diesel <3.5t	7.77%
	Hybrid <3.5t	1.04%
	Plug-in hybrid <3.5t	0.08%
	Electric <3.5t	0.18%
Light commercial vehicle (LCV)	Petrol <3.5t	3.15%
	Diesel <3.5t	15.86%
	Hybrid <3.5t	0.00%
	Plug-in hybrid <3.5t	0.00%
	Electric <3.5t	0.02%
Medium commercial vehicle (MCV)	Diesel 3.5-7.5t	1.28%
	Diesel 7.5-10t	0.54%
	Electric <10t	0.00%
Heavy commercial vehicle (HCV)	Diesel 10-20t	0.77%
	Diesel 20-25t	0.87%
	Diesel 25-30t	1.35%
	Diesel >30t	1.64%
	Electric >10t	0.00%
Coach	Diesel <18t	0.08%
Bus	Diesel <15t	0.22%
	Diesel 15-18t	0.33%
	Electric >3.5t	0.01%
Total for all four-wheel VKT		100.00%

3.1.2 Emission factors

Various sources were used to obtain emission factors for air quality and greenhouse gas emissions.

VEPM6.1 was used to generate **fuel combustion** (exhaust) emissions factors for an average speed of 40 km/h (assumed for urban areas) and 80 km/h (assumed for rural areas) for:

- CO, fuel consumption (**FC**), VOC, NO_X, and PM_{10}[27] –in g/km or l/100 km for FC
- SO_2 – from the FC combined with the sulphur content of the fuel (see Appendix C.1)

[27] All exhaust PM is in the $PM_{2.5}$ or smaller size fraction but this is a subset of PM_{10}.

- The FC values were aggregated to get fuel totals which were compared with national totals from the latest greenhouse gas emissions inventory (MfE 2020). The national actuals were used to adjust the VEPM FC and combustion-related emission factors to compensate for any gradient effects due to New Zealand's terrain. The revised FC figures were then multiplied by the relevant TTW factor from Table 2.3 to get CO_2e.

VEPM6.1 was also used to generate PM_{10} emission factors for brake and tyre wear.

A Tier 1 EMEP/EEA methodology was used to estimate emissions for motorcycles, based on VKT, because a detailed motorcycle fleet profile was not available (EMEP/EEA 2019) [28].

A Tier 1 EMEP/EEA methodology was used to estimate PM_{10} emissions from sealed road abrasion (EMEP/EEA 2019)[29]. USEPA methodology for public roads was used to estimate PM10 emissions from unsealed road abrasion (USEPA 2006)[30].

The life cycle emission factors outlined in Table 2. 1 (from Barber & Stenning 2019 and MfE 2019) were used to derive upstream emissions in CO_2e for road transport based on petrol, diesel and electricity use.

Table 3.2 summarises the sources used for the road transport emission factors.

Table 3.2 Summary of sources used for the road transport emissions factors

Process	Upstream	Fuel combustion	Brake & tyre wear	Road abrasion
Air quality				
CO		VEPM		
VOC		VEPM		
NOx		VEPM		
PM_{10}		VEPM (as $PM_{2.5}$)	VEPM	EMEP/EEA + USEPA
SO_2		Fuel S content + FC		
Greenhouse gases				
FC		VEPM (checked vs MfE 2020)		
CO_2e	WTT	Revised VEPM FC + Fuel CO_2e		

Note:

1. All PM exhaust emissions are in the size fraction $PM_{2.5}$ (which is a subset of PM_{10})
2. SO_2 factors were estimated based on the FC and the fuel sulphur content.
3. FC estimates from VEPM were aggregated to total fuel use and compared with MfE greenhouse gas inventory estimates (MfE 2020). VEPM results were scaled where necessary to match and then CO_2e factors applied to the fuel use based on the MfE (2019) factors.

[28] See Chapters 1.A.3.b.i, 1.A.3.b.ii, 1.A.3.b.iii, 1.A.3.b.iv Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motor cycles

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

[30] USEPA (2006). *AP42 Miscellaneous Sources, Unpaved Roads (section 13.2.2).* Office of Air Quality Planning & Standards, US Environmental Protection Agency, 2016. https://www3.epa.gov/ttn/chief/ap42/ch13/final/c13s0202.pdf

3.1.3 Activity rates

VKT data

The primary activity rate data used for road transport were annual VKT. **National VKT** figures were taken from the *2019 New Zealand Vehicle Fleet Statistics* (Te Manatū Waka 2020b)[31]. The annual VKT figures for 2018 and 2019 were averaged to yield 2018/19 VKT values.

Note: VKT done by public transport buses and school buses was subtracted from the national total before undertaking any regional disaggregation as these modes are reported separately in Chapter 7.

Using the Waka Kotahi *Vehicle Use* dataset[32], VKT were further disaggregated into:

- local roads and state highways
- heavy versus light travel
- road seal (sealed or unsealed)

VKT were also assigned to **urban and rural areas** consistent with the StatsNZ definitions based on population (Paling 2020) [33] rather than the Waka Kotahi definitions. Vehicles were assumed to travel at average speeds of 40 km/h on local roads and 80 km/h on state highways.

Table 3.3 presents the annual VKT breakdowns for road transport (excluding public transport buses and school buses) in 2018/19.

Table 3.3 Annual VKT for road transport (including motorcycles but excluding public transport buses and school buses) by area and road surface in 2018/19

Area	Local road VKT (million km)	State highway VKT (million km)	Total VKT (million km)
Urban			
Light	9,209	8,694	17,903
Heavy	205	530	735
Total	9,414	9,224	18,638
Rural			
Light	14,045	13,260	27,305
Heavy	700	1,811	2,511
Total	14,745	15,071	29,816
National			
Light	23,254	21,954	45,208

[31] Te Manatū Waka (2020b). *2019 New Zealand Vehicle Fleet Statistics*. Ministry of Transport, October/November 2020. https://www.transport.govt.nz/mot-resources/vehicle-fleet-statistics/

[32] https://nzta.govt.nz/planning-and-investment/learning-and-resources/transport-data/statistics-on-mode-of-transport/

[33] Paling R (2020). *Estimate for urban/rural road kilometre splits*. Email from Richard Paling, Richard Paling Consulting Ltd, pers comm, 6 October 2020.

Area	Local road VKT (million km)	State highway VKT (million km)	Total VKT (million km)
Heavy	904	2,342	3,246
Total	24,159	24295	48,454
Road surface			
Sealed	23,601	24,423	48,025
Unsealed	608	2	610
% unsealed	2.5%	0.0%	1.3%

Fuel and energy consumption

Typical electric vehicle energy consumption was taken to be the following, based on relevant international data as indicated:

- 0.20 kWh/km for electric cars and LCVs[34]
- 1.3 kWh/km (range 1.15-1.44 kWh/km) for large battery electric long-haul trucks[35], with battery electric MCVs assumed to be less at 1.0 kWh
- 1.2 kWh/km (range 1.0 to 1.4 kWh/km) for battery electric buses and coaches[36]

Passenger-kilometres and net-tonne kilometres travelled

Passenger kilometres travelled (PK) were estimated for each passenger transport category as follows:

- Passenger car occupancy was based on the *New Zealand Household Travel Survey, 2011-2014* (Te Manatū Waka 2015)[37], assuming a mean occupancy rate based on the ratio of driver to passenger distance travelled occupancies (McSaveney 2020) [38]. In the absence of more recent data, vehicle occupancy in 2018/19 was assumed to be the same as for the earlier period yielding an average national occupancy figure of 1.56 in 2018/19 (see Appendix C.2 for the detailed data). The 2018/19 passenger car VKT was then multiplied by the average occupancy to derive passenger car PK.
- In the absence of more recent information, coach data were taken from the previous STCC study (Booz Allen Hamilton et al 2005). We assumed the same ratio between coach PK in 2005 (320 million) and coach VKT in 2005

[34] USEPA/DOE (2020). *Model Year 2017 Fuel Economy Guide*. US Environmental Protection Agency and US Department of Energy, updated 16 July 2020. https://www.fueleconomy.gov/feg/pdfs/guides/FEG2017.pdf

[35] Earl et al (2018). Analysis of long-haul battery electric trucks in EU: Marketplace and technology, economic, environmental, and policy perspectives. Paper presented at 8th Commercial Vehicle Workshop, Graz, 17-18 May 2018. https://www.transportenvironment.org/sites/te/files/publications/20180725_T%26E_Battery_Electric_Trucks_EU_FINAL.pdf

[36] https://www.sustainable-bus.com/news/electric-bus-range-focus-on-electricity-consumption-a-sum-up/

[37] Te Manatū Waka (2015). *New Zealand Household Travel Survey 2011-2014*. Ministry of Transport, 2015. https://www.transport.govt.nz/area-of-interest/public-transport/new-zealand-household-travel-survey/

[38] McSaveney J (2020). *Estimate of per km mean occupancy rate based on the ratio of driver to passenger distance travelled*. Email from Jennifer McSaveney, Ministry of Transport, pers comm, 25 September 2020.

(24 million) and applied this ratio to the 2018/19 coach VKT to derive coach PK.

- We applied the same coach ratio to derive other bus PK.
- For motorcycles, we assumed an average occupancy of 1.0 and applied this to the 2018/19 motorcycle VKT to derive motorcycle PK.

Table 3.4 summarises the VKT and PK by the different passenger transport categories in 2018/19. The national passenger transport PK values were segregated into urban and rural according to the splits shown in Table 3. 3 (i.e. 38.6%/61.4%).

Table 3.4 Vehicle-kilometres and passenger-kilometres travelled by passenger road transport in 2018/19

Passenger transport category	Urban (million km)		Rural (million km)		National (million km)	
	VKT	PK	VKT	PK	VKT	PK
Passenger car	14,106	22,005	21,505	33,547	35,610	55,552
Coach	9	119	31	407	39	526
Other bus	20	267	68	911	88	1,178
Motorcycle	164	164	261	261	424	424

Note: The ‘Other bus’ category does not include PT buses and school buses.

Net-tonne kilometres travelled (**NTK**) were estimated for each freight transport category as follows:

- While Te Manatū Waka (2020b) report average tonnes carried per heavy vehicle in New Zealand (8.26 t per truck on average over 2018/19), this is not broken down into MCV and HCV size categories. In addition, no data exist for LCV average tonnes carried.
- To estimate freight averages, we used data on typical payloads (t) recorded at seven Weigh in Motion (**WiM**) sites across New Zealand (Paling & King 2020) [39] and matched the values to the comparable categories in the New Zealand fleet. These were then weighted by VKT to yield the average freight tonnes carried by each commercial vehicle type as shown in Appendix C.3.
    - Some of the loads carried by the heaviest vehicles are transported in ISO containers and consequently the values shown will, in principle, overestimate the actual weight of the commodities carried. However, a review of container weights versus freight suggests that the estimated container tonne-km will be only about 0.5 per cent of the total freight moved and can therefore be considered negligible.
    - Very minor adjustments were made to some values to get the predicted overall heavy fleet average and predicted NTK overall to match the reported figures in the *2019 New Zealand Vehicle Fleet Statistics* (Te Manatū Waka 2020b).
- We applied the consequent average loadings per freight vehicle (LCV, MCV and HCV) to 2018/19 VKT to derive NTK.

[39] Paling R & King M (2020). *Defining average payloads for DTCC study*. Memo by Richard Paling and Murray King, 4 December 2020.

Table 3.5 summarises the VKT and NTK by the different freight transport categories overall in 2018/19. The national freight transport NTK values were segregated into urban and rural according to the splits shown in Table 2.3 (i.e. 38.6%/61.4%).

Table 3.5 Vehicle-kilometres and net tonne-kilometres travelled by road freight transport in 2018/19

Freight transport category	Urban (million km)		Rural (million km)		National (million km)	
	VKT	NTK	VKT	NTK	VKT	NTK
LCV	3,634	1,817	5,540	2,770	9,173	4,587
MCV	200	503	683	1,719	882	2,222
HCV	506	5,325	1,729	18,184	2,236	23,509

Note: The combined NTK for all heavy vehicles shown (MCV and HCV) equates to 25,731 million NTK which compares favourably with a figure of 25,344 million NTK averaged from the 2018 and 2019 values reported in the 2019 New Zealand Vehicle Fleet Statistics (Te Manatū Waka 2020b).

3.1.4 Damage cost factors

The damage cost factors shown in Table 2.2 were applied to the emissions estimated for urban and rural areas. All costs shown are in June 2019 prices.

3.2 Emissions and costs

The air quality and greenhouse gas emissions impacts of road transport are presented as:

- Total tonnes emitted nationally and split by urban and rural areas
- Relative emission rates by different vehicle types for urban and rural areas

3.2.1 Air quality

Urban versus rural emissions

Table 3.6 summarises the air quality emissions and costs for road transport in urban areas, rural areas and nationally in 2018/19.

Table 3.6 Air quality emissions and costs for road transport in New Zealand in 2018/19

Area	Air quality emissions (t)							Costs ($M)
	CO	VOC	NO_X	SO_2	PM_{10} exh	PM_{10} B&T	PM_{10} road dust	
Urban total	46,308	4,406	16,081	17	664	366	167	$898
Rural total	73,149	7,009	32,058	30	1,300	645	929	$155
National overall	119,457	11,415	48,139	47.5	1,964	1,011	1,096	$1,053 M

Relative emissions rates by vehicle type

Table 3.7 and Table 3.8 summarise the relative air quality emissions and costs per km for different road vehicles in **urban areas** and **rural areas**, respectively.

Note: The relative emissions rates (in milligrams per kilometre, mg/km) are essentially identical for urban and rural areas (except for road dust) because the split between local roads and state highways is the same for both (see Table 2.3). However, the relative costs are quite different.

Table 3.7 Relative air quality emission rates and costs for different road vehicles in urban areas

Vehicle type	Relative urban emission rates (mg/km)							Urban costs (c/km)
	CO	VOC	NO_X	SO_2	PM_{10} exh	PM_{10} B&T	PM_{10} road dust	
Fleet weighted average*	2,465	236	993	1.0	41	21	8.9	5.4
Passenger car								**2.7**
Petrol <3.5t	2,910	237	329	0.7	1.8	16	8.9	2.0
Diesel <3.5t	235	46	1,139	1.0	119	16	8.9	9.3
Hybrid <3.5t	36	0.8	15	0.3	0	16	8.9	1.3
Plugin hybrid <3.5t	17	0.4	7	0.2	0	16	8.9	1.3
Electric <3.5t	0	0	0	0	0	16	8.9	1.3
Light commercial vehicle								**9.0**
Petrol <3.5t	6,931	505	819	0.9	2.1	25	8.9	3.4
Diesel <3.5t	548	74	1,913	1.0	99	25	8.9	10.1
Hybrid <3.5t	36	0.8	15	0.3	0	16	8.9	1.3
Plugin hybrid <3.5t	17	0.4	7	0.2	0	16	8.9	1.3
Electric <3.5t	0	0	0	0	0	16	8.9	1.3
Medium commercial vehicle								**16.1**
Diesel 3.5-7.5t	764	118	2,925	1.4	116	21	8.9	12.6
Diesel 7.5-10t	1,571	208	5,349	2.4	233	48	8.9	24.2
Electric <10t	0	0	0	0	0	21	8.9	1.5
Heavy commercial vehicle								**26.7**
Diesel 10-20t	1,632	235	5,454	2.6	219	62	8.9	24.4
Diesel 20-25t	1,898	230	6,615	3.0	265	70	8.9	29.2
Diesel 25-30t	1,925	179	6,088	3.3	236	77	8.9	27.2
Diesel >30t	2,221	138	6,177	3.8	206	85	8.9	26.2
Electric >10t	0	0	0	0	0	51	8.9	3.0
Other								
Coach, Diesel >3.5t	1,751	218	6,645	2.9	225	51	8.9	26.3
Other bus*, Diesel >3.5t	1,629	198	5,297	2.6	197	39	8.9	21.8
Other bus*, Electric >3.5t	0	0	0	0	0	21	8.9	1.5
Motorcycle	17,420	4,599	232	7.5	77	6	8.9	5.8

* The fleet weighted average is for four-wheeled plus vehicles and excludes motorcycles (which are shown separately) as well as PT and school buses (covered later in Chapter 7).

Note: The road dust emission factor is the same for all vehicle types as road dust is calculated top-down and does not differentiate by weight/duty.

Table 3.8 Relative air quality emission rates and costs for different road vehicles in rural areas

Vehicle type	Relative rural emission rates (mg/km)							Urban costs (c/km)
	CO	VOC	NO_X	SO_2	PM_{10} exh	PM_{10} B&T	PM_{10} road dust	
Fleet weighted average*	2,465	236	993	1.0	41	21	31.1	0.5
Passenger car								**0.3**
Petrol <3.5t	2,910	237	329	0.7	1.8	16	31.1	0.2
Diesel <3.5t	235	46	1,139	1.0	119	16	31.1	0.8
Hybrid <3.5t	36	0.8	15	0.3	0	16	31.1	0.2
Plugin hybrid <3.5t	17	0.4	7	0.2	0	16	31.1	0.2
Electric <3.5t	0	0	0	0	0	16	31.1	0.2
Light commercial vehicle								**0.8**
Petrol <3.5t	6,931	505	819	0.9	2.1	25	31.1	0.3
Diesel <3.5t	548	74	1,913	1.0	99	25	31.1	0.9
Hybrid <3.5t	36	0.8	15	0.3	0	16	31.1	0.2
Plugin hybrid <3.5t	17	0.4	7	0.2	0	16	31.1	0.2
Electric <3.5t	0	0	0	0	0	16	31.1	0.2
Medium commercial vehicle								**1.3**
Diesel 3.5-7.5t	764	118	2,925	1.4	116	21	31.1	1.0
Diesel 7.5-10t	1,571	208	5,349	2.4	233	48	31.1	1.9
Electric <10t	0	0	0	0	0	21	31.1	0.2
Heavy commercial vehicle								**2.1**
Diesel 10-20t	1,632	235	5,454	2.6	219	62	31.1	1.9
Diesel 20-25t	1,898	230	6,615	3.0	265	70	31.1	2.3
Diesel 25-30t	1,925	179	6,088	3.3	236	77	31.1	2.2
Diesel >30t	2,221	138	6,177	3.8	206	85	31.1	2.1
Electric >10t	0	0	0	0	0	51	31.1	0.3
Other								
Coach, Diesel >3.5t	1,751	218	6,645	2.9	225	51	31.1	2.1
Other bus*, Diesel >3.5t	1,629	198	5,297	2.6	197	39	31.1	1.8
Other bus*, Electric >3.5t	0	0	0	0	0	21	31.1	0.2
Motorcycle	17,420	4,599	232	7.5	77	6	31.1	0.5

* The fleet weighted average is for four-wheeled plus vehicles and excludes motorcycles (which are shown separately) as well as PT and school buses (covered later in Chapter 7).

Note: The road dust emission factor is the same for all vehicle types as road dust is calculated top-down and does not differentiate by weight/duty. It is higher in rural areas than in urban areas due to typically higher speeds and a higher proportion of unsealed roads.

3.2.2 Greenhouse gas

Urban versus rural emissions

Table 3.9 compares the greenhouse gas emissions and costs for road transport in urban areas, rural areas and nationally in 2018/19.

Table 3.9 Greenhouse gas emissions and costs for road transport in New Zealand in 2018/19

Area	Greenhouse gas emissions (kt) CO2e	Costs ($M)
Urban total	5,943	$523
Rural total	10,537	$927
National overall	16,480	$1,450 M

Note: The totals above include upstream CO_2e emissions from energy production.

Relative emissions rates by vehicle type

Table 3.10 summarises the relative greenhouse gas emissions and costs for different road vehicles in both urban and rural areas. Greenhouse gas costs per km are identical for urban and rural areas so only one table is presented here.

Table 3.10 Relative greenhouse gas emission rates and costs for different road vehicles in urban or rural areas

Vehicle type	Relative CO_2e emission rates (g/km)		Urban or rural costs (c/km)
	Energy production (WTT)	Fuel combustion (TTW)	
Fleet weighted average*	43	297	3.0
Passenger car			2.4
Petrol <3.5t	29	232	2.3
Diesel <3.5t	51	305	3.1
Hybrid <3.5t	14	111	1.1
Plugin hybrid <3.5t	7	53	0.5
Electric <3.5t	24	0	0.2
Light commercial vehicle			3.3
Petrol <3.5t	37	297	2.9
Diesel <3.5t	55	328	3.4
Hybrid <3.5t	14	111	1.1
Plugin hybrid <3.5t	7	53	0.5
Electric <3.5t	24	0	0.2
Medium commercial vehicle			5.4
Diesel 3.5-7.5t	73	433	4.5
Diesel 7.5-10t	127	753	7.7
Electric <10t	121	0	1.1
Heavy commercial vehicle			10.9
Diesel 10-20t	140	833	8.6
Diesel 20-25t	163	971	10.0
Diesel 25-30t	177	1,054	10.8
Diesel >30t	206	1,225	12.6
Electric >10t	158	0	1.4
Other			
Coach, Diesel >3.5t	154	918	9.4
Other bus*, Diesel >3.5t	141	839	8.6
Other bus*, Electric >3.5t	145	0	1.3
Motorcycle	11	86	0.9

* The fleet weighted average is for four-wheeled plus vehicles and excludes motorcycles (which are shown separately) as well as PT and school buses (covered later in Chapter 7).

3.3 Summary

The impacts of air quality and greenhouse gas emissions from road transport are presented as:

- Total costs nationally
- Normalised costs by passenger-km and net tonne-km.

3.3.1 Total costs

Table 3.11 summarises the **total costs** of air quality and greenhouse gas impacts in New Zealand in 2018/19 for road passenger and road freight services.

Table 3.11 Total costs of air quality and greenhouse gas impacts for road transport in New Zealand in 2018/19

Road passenger impact	Urban costs ($M)	Rural costs ($M)	Total costs, $M (June 2019 prices)
Air quality	$400.9	$67.1	$468.0
Greenhouse gas	$337.0	$518.7	$855.7
Combined	$737.9 M	$585.8 M	$1,323.7 M
Road freight impact	**Urban costs ($M)**	**Rural costs ($M)**	**Total costs, $M (June 2019 prices)**
Air quality	$496.7	$88.2	$584.9
Greenhouse gas	$186.0	$408.6	$594.6
Combined	$682.7 M	$496.8 M	$1,179.5 M

3.3.2 Normalised costs

Table 3.12 and Table 3.13 summarise the **normalised air quality costs** and **normalised greenhouse gas costs**, respectively, for different road transport vehicles in urban and rural areas of New Zealand in 2018/19.

Table 3.12 Normalised costs of air quality impacts for road transport in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Passenger car	2.7	1.7	0.3	0.2	1.3	0.8
Coach	26.6	2.0	2.1	0.2	7.6	0.6
Other bus	21.9	1.6	1.7	0.1	6.3	0.5
Motorcycle	5.8	5.8	0.5	0.5	2.5	2.5
Freight transport category	**Urban**		**Rural**		**National average**	
	c/VKT	**c/NTK**	**c/VKT**	**c/NTK**	**c/VKT**	**c/NTK**
LCV	9.0	18.0	0.8	1.6	4.0	8.1
MCV	16.4	6.5	1.3	0.5	4.7	1.9
HCV	27.0	2.6	2.1	0.2	7.7	0.7

Table 3.13 Normalised costs of greenhouse gas impacts for road transport in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Passenger car	2.4	1.5	2.4	1.5	2.4	1.5
Coach	9.4	0.7	9.4	0.7	9.4	0.7
Other bus	8.5	0.6	8.5	0.6	8.5	0.6
Motorcycle	0.9	0.9	0.9	0.9	0.9	0.9
Freight transport category	**Urban**		**Rural**		**National average**	
	c/VKT	**c/NTK**	**c/VKT**	**c/NTK**	**c/VKT**	**c/NTK**
LCV	3.3	6.6	3.3	6.6	3.3	6.6
MCV	5.4	2.2	5.4	2.2	5.4	2.2
HCV	10.9	1.0	10.9	1.0	10.9	1.0

Chapter 4 Rail

This chapter assesses the air quality and greenhouse gas emission impacts for rail in New Zealand covering:

- Long-distance passenger and freight
- But excluding urban rail (which is covered in Chapter 7)

This chapter discusses the detailed methodology used in the assessment of this mode including the fleet profile, the relevant emission factors and the activity rate data.

Results are presented as emissions and associated costs and are disaggregated spatially and by fuel type. Upstream greenhouse gas emissions are also assessed.

4.1 Methodology

Air quality and greenhouse gas emissions were estimated for a range of locomotive types (dependent on fuel and duty) in the rail transport fleet as follows:

$$E = EF \times FC \qquad \text{Equation 4.1}$$

Where:

E = emission of a pollutant (g/yr)

EF = emission factor (**EF**) of the pollutant by fuel type (kg/tonne fuel)

FC = total fuel consumption by that vehicle type on the network (t/yr).

Emissions were estimated top-down, using fuel consumption data for New Zealand and split for urban/rural accordingly.

4.1.1 Rail fleet profile

While some information was available on the different locomotive types in service, it was insufficient for us to be able to assess emissions at a bottom-up level as we were able to for road transport in Chapter 3. Consequently, rail fleet emissions were assessed by energy use, using rail fleet profiles based on fuel type only.

Rail freight is carried by predominantly diesel locomotives in both islands of New Zealand, with some freight carried by electric locomotives on the main trunk line in the North Island. These services are operated by KiwiRail.

Our assessment of long-distance **passenger rail** includes:

- the Capital Connection service which offers a commuter service between Palmerston North and Wellington each weekday using diesel-electric DC locomotives
- the Coastal Pacific, TranzAlpine and Northern Explorer services which are scenic journeys largely utilised by tourists.

The Wairarapa Connection, which operates between Masterton and Wellington, is included in the urban rail section of public transport (Chapter 7) as it is an intra-urban service contracted by Greater Wellington Regional Council.

4.1.2 Emission factors

Various sources were used to obtain emission factors for air quality and greenhouse gas emissions.

For diesel or diesel-electric locomotives, we used a Tier 1 EMEP/EEA methodology to estimate air quality emissions resulting from fuel combustion, based on fuel use (EMEP/EEA 2019) [40]. The diesel fuel use totals for freight and long-distance passenger rail were cross-checked against the latest greenhouse gas emissions inventory (MfE 2020).

The life cycle emission factors outlined Table 2.3 (from Barber & Stenning 2019 and MfE 2019) were then used to calculate the upstream emissions in CO2e for rail transport based on diesel and electricity use.

4.1.3 Activity rates

Rail freight fuel use and net-tonne kilometres travelled

The rail freight fleet profile in terms of energy use and NTK was sourced from KiwiRail (2020)[41]. This information was only available in terms of North Island (**NI**) - South Island (**SI**) splits as shown in Table 4.1.

Table 4.1 Energy use and freight carried by rail freight categories in 2018/19 (KiwiRail 2020)

Rail freight category	Energy use	Energy units	Million NTK
Electric locomotive - NI	11,321,747	kWh electricity	181
Diesel locomotive – NI	29,344,858	litres diesel	2,484
Diesel shunt - NI	1,085,340		
Diesel locomotive – SI	16,164,926	litres diesel	1,182
Diesel shunt - SI	595,852		
National			**3,846**

Note: The NTK figures above exclude the weight of third-party containers. The figure with containers is 4,406 million NTK which (if used) would decrease the normalised costs for rail transport by approximately 13% (3,846/4,406).

All diesel shunt emissions were assigned to urban (assuming all shunting yards are in urban areas). All locomotive emissions (diesel or electric) were split with 18% being assigned to urban areas and 82% being assigned to rural areas based on train kilometres (King 2020)[42].

Diesel NTK was split between the different shunt and locomotive types for the North and South Islands using relative fuel use.

[40] See Chapter 1.A.3.c *Railways*.

[41] KiwiRail (2020). *Data for North Island and South Island Freight Services in 2018/19.* Provided by Andrew Fookes/Malia Vehikite from KiwiRail via Murray King, 26 June to 2 July 2020.

[42] King (2020). *Estimate for urban/rural rail kilometre splits*. Email from Murray King, King & Small Consultants, pers comm, 12 October 2020.

Long distance passenger rail fuel use and passenger-kilometres travelled

Long-distance passenger rail patronage was sourced from KiwiRail (2020b)[43].

In the absence of data, the long-distance passenger rail fuel use was **based on diesel only**, assuming the same fuel consumption (in litres per km travelled) for the comparable Papakura to Pukekohe urban rail service (provided by Auckland Transport in Chapter 7). The resultant diesel fuel use, VKT and PK are shown in Table 4.2.

All long-distance passenger rail emissions were split with 18% being assigned to urban areas and 82% being assigned to rural areas based on train kilometres (King 2020).

Table 4.2 Fuel use and travel by long-distance passenger rail services in 2018/19 (KiwiRail 2020b)

Passenger rail category	Diesel use (litres)	VKT	Million PK
Northern Explorer - NI	261,341	212,472	25.5
Capital Connection - NI	86,986	70,720	13.6
Coastal Pacific - SI	129,268	105,096	9.9
Kiwi TranzAlpine - SI	200,232	162,790	65.5
National	**677,826**	**551,078**	**114.5**

Note: These services do not include urban PT trains

4.1.4 Damage cost factors

The damage cost factors shown in Table 2.2 were applied to the emissions estimated for urban and rural areas. All costs shown are in June 2019 prices.

4.2 Emissions and costs

The air quality and greenhouse gas emissions impacts of rail freight and long-distance passenger rail are presented as:

- Total tonnes emitted nationally and split by urban and rural areas
- Relative emission rates by different locomotive types for urban and rural areas.

4.2.1 Air quality

Urban versus rural emissions

Table 4.3 summarises the air quality emissions and costs for rail transport in urban areas, rural areas and nationally in 2018/19.

Table 4.3 Air quality emissions and costs for rail freight and long-distance passenger rail in New Zealand in 2018/19

[43] KiwiRail (2020b). *Data for Long-Distance Passenger Rail Services in 2018/19.* Provided via Murray King, 12 October 2020.

Area	Air quality emissions (t)					Costs ($M)
	CO	VOC	NO_X	SO_2	PM_{10}	
Urban total	141	40	517	0.2	11	$15.0
Rural total	573	153	2,007	0.6	38	$4.2
National overall	714	193	2,524	0.8	50	$19.3 M

Note: All rail emissions (except shunt emissions) are assigned to urban and rural areas according to an 18%/82% split based on train km.

Relative emissions rates by locomotive type

Table 4.4 and Table 4.5 summarise the relative air quality emissions and costs per litre of diesel used for different locomotive types in **urban areas** and **rural areas**, respectively.

Table 4.4 Relative air quality emission rates and costs for different locomotive types in urban areas

Locomotive type	Relative urban emission rates (g/l diesel)					Urban costs (c/l diesel)
	CO	VOC	NO_X	SO_2	PM_{10}	
Long distance passenger rail (average)						**146.2**
Diesel-electric DC locomotive	15.1	4.0	53.0	0.01	1.0	146.2
Rail freight (average)						**150.5**
Electric locomotive	0	0	0	0	0	0
Diesel locomotive	15.1	4.0	53.0	0.0	1.0	146.2
Diesel shunt	9.1	3.9	45.7	0.0	1.8	171.3

Note: All shunt emissions are assigned to urban areas.

Table 4.5 Relative air quality emission rates and costs for different locomotive types in rural areas

Locomotive type	Relative rural emission rates (g/l diesel)					Rural costs (c/l diesel)
	CO	VOC	NO_X	SO_2	PM_{10}	
Long distance passenger rail (average)						**11.2**
Diesel-electric DC locomotive	15.1	4.0	53.0	0.01	1.0	11.2
Rail freight (average)						**11.2**
Electric locomotive	0	0	0	0	0	0
Diesel locomotive	15.1	4.0	53.0	0.0	1.0	11.2
Diesel shunt	0	0	0	0	0	0

Note: All shunt emissions are assigned to urban areas.

4.2.2 Greenhouse gas

Urban versus rural emissions

Table 4.6 compares the greenhouse gas emissions and costs for rail in urban areas, rural areas and nationally in 2018/19.

Table 4.6 Greenhouse gas emissions and costs for rail freight and long-distance passenger rail in New Zealand in 2018/19

Area	Greenhouse gas emissions (kt) CO_2e	Costs ($M)
Urban total	32	$2.8
Rural total	120	$10.6
National overall	152	$13.4 M

Note: The totals above include upstream CO_2e emissions from energy production**.**

Relative emissions rates by locomotive type

Table 4.7 summarises the relative greenhouse gas emissions and costs for different locomotive types in urban or rural areas.

Table 4.7 Relative greenhouse gas emission rates and costs for different locomotive types in urban or rural areas

Locomotive type	Relative CO_2e emission rates (g/l diesel)		Urban or rural costs (c/l or Wh)
	Energy production (WTT)	Fuel combustion (TTW)	
Long distance passenger rail			27.7
Diesel-electric DC locomotive	453	2,694	27.7
Diesel freight			27.7
Diesel locomotive	453	2,694	27.7
Diesel shunt	453	2,694	27.7
Electric freight per 1000kWh			1.1
Electric locomotive	121	0	1.1

Note: There are no differences between urban and rural damage costs for greenhouse gas emissions. However, the electric locomotive emission rates are per Wh electricity instead of per l diesel.

4.3 Summary

The impacts of air quality and greenhouse gas emissions from rail transport are presented as:

- Total costs nationally
- Normalised costs by passenger-km and net tonne-km.

4.3.1 Total costs

Table 4.8 summarises the **total costs** of air quality and greenhouse gas impacts in New Zealand in 2018/19 for long distance rail passenger and rail freight services.

Table 4.8 Total costs of air quality and greenhouse gas impacts for rail in New Zealand in 2018/19

Rail passenger impact	Urban costs ($M)	Rural costs ($M)	Total costs, $M (June 2019 prices)
Air quality	$0.18	$0.06	$0.24
Greenhouse gas	$0.03	$0.13	$0.16
Combined	$0.2 M	$0.2 M	$0.4 M
Rail freight impact	**Urban costs ($M)**	**Rural costs ($M)**	**Total costs, $M (June 2019 prices)**
Air quality	$14.9	$4.2	$19.0
Greenhouse gas	$2.8	$10.4	$13.2
Combined	$17.6 M	$14.6 M	$32.2 M

4.3.2 Normalised costs

Table 4.9 and Table 4.10summarise the **normalised air quality costs** and **normalised greenhouse gas costs**, respectively, for rail locomotive types in urban and rural areas of New Zealand in 2018/19.

VKT data for rail freight locomotives were not available at the time of writing this report.

Table 4.9 Normalised costs of air quality impacts for rail in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Diesel-electric DC locomotive	179.8	0.9	13.7	0.1	43.6	0.2
Freight transport category	**Urban**		**Rural**		**National average**	
	c/VKT	**c/NTK**	**c/VKT**	**c/NTK**	**c/VKT**	**c/NTK**
Freight locomotive (average)	n/a	2.1	n/a	0.1	n/a	0.5
Electric locomotive	n/a	0	n/a	0	n/a	0
Diesel locomotive	n/a	2.3	n/a	0.1	n/a	0.5

Note: 'n/a' means data not available

Table 4.10 Normalised costs of greenhouse gas impacts for rail in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Diesel-electric DC locomotive	34.1	0.2	34.1	0.2	34.1	0.2
Freight transport category	**Urban**		**Rural**		**National average**	
	c/VKT	**c/NTK**	**c/VKT**	**c/NTK**	**c/VKT**	**c/NTK**
Freight locomotive (average)	n/a	0.4	n/a	0.3	n/a	0.3
Electric locomotive	n/a	0.1	n/a	0.1	n/a	0.1
Diesel locomotive	n/a	0.4	n/a	0.3	n/a	0.4

Note: 'n/a' means data not available

Chapter 5 Domestic aviation

This chapter presents the air quality and greenhouse gas emission impacts for domestic aviation in New Zealand:

- Covering domestic passenger travel on scheduled services only
- But excluding domestic air freight (which is not assessed)

This chapter discusses the detailed methodology used in the assessment of this mode including the fleet profile, the relevant emission factors and the activity rate data.

Results are presented as emissions and associated costs and are disaggregated spatially and by fuel type. Upstream greenhouse gas emissions are also assessed.

5.1 Methodology

Air quality and greenhouse gas emissions were estimated for a range of aircraft types (dependent on fuel and duty) in the domestic aviation fleet as follows:

E = EF x LTO Equation 5.1

Or

E = EF x FC Equation 5.2

Where:

E = emission of a pollutant (g/yr)

EF = emission factor of the pollutant by aircraft type (kg/LTO) for the landing and take-off phases or by FC (g/l fuel) for the climb, cruise and descent phases

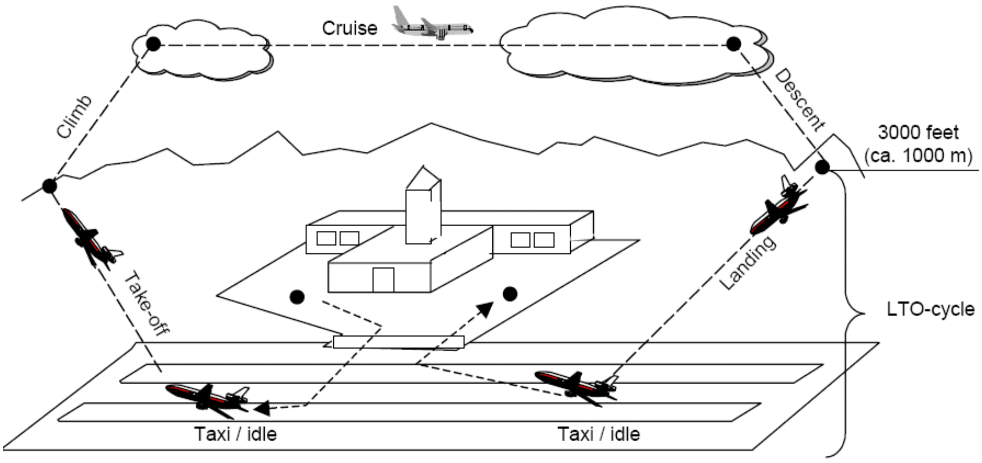
FC = total fuel consumption by that aircraft type (l/yr)

LTO = number of landing and take-off movements for the type of aircraft per year.

Emissions were estimated using a combination of bottom-up and top-down approaches.

An aircraft movement includes several phases of a flight including taxi out, take-off, climb, cruise, descent, approach, landing and taxi-in (as shown in Figure 5. 1).

Figure 5. 1 Typical phases of flight (EMEP/EEA 2019)



Phases that take place below a height of 3,000 feet (915 metres) are reported together as the "landing and take-off" (**LTO**) cycle. LTO emissions were calculated bottom-up, using aircraft movement data for a selection of domestic airports and split for urban/rural accordingly.

Phases that take place above 3,000 feet are reported together as "climb, cruise and descent" (**CCD**). CCD emissions were calculated top-down, from the difference between the overall aircraft fuel use and the LTO cycle fuel use, and then assigned to regions based on LTO cycles but as rural. **For the CCD phase, only greenhouse gas emissions were reported and costed, because CCD air quality emissions are too far above ground to affect local areas.**

5.1.1 Aviation fleet profile

While some information was available on the different aircraft types in service, it was insufficient for us to be able to assess emissions at a bottom-up level as done for road transport in Chapter 3. Consequently, domestic aviation emissions were assessed by aircraft movements based on Air New Zealand's domestic fleet shown in Table 5.1 (AirNZ 2020)[44].

Table 5.1 Engine type, aircraft numbers and passenger capacity by domestic aviation categories in 2018/2019

Aircraft	Engine type	No. in fleet	Passenger capacity
A320	Jet	17	171 seats
ATR72	Turboprop	27	68 seats
Q300	Turboprop	23	50 seats

Note: Small piston-engine aircraft were not assessed as details for these types of aircraft were not available. However, the air emissions resulting from these are likely to be minimal relative to jet and turboprop aircraft.

[44] AirNZ (2020). *Operating fleet as at 29 February 2020.* Air New Zealand, 2020. https://www.airnewzealand.com/fleet

5.1.2 Emission factors

Various sources were used to obtain emission factors for air quality and greenhouse gas emissions.

For the LTO phase, the EMEP/EEA Aviation 1 Master Emissions Calculator was used to obtain emission factors for the respective aircraft types listed in Table 5.1 based on LTO cycles (EMEP/EEA 2019) 45. Since specific aircraft movements by each aircraft type were not available, a fleet-weighted average emission factor was calculated using the proportion of each aircraft type in Air New Zealand's fleet. Using a fleet-weighted average accounts for any variations in the size and fuel consumption across all aircraft types operating in the domestic passenger aviation sector.

For the CCD phase, emission factors were based on fuel use. CCD fuel use was estimated by subtracting the jet fuel used in the LTO phase from the national jet fuel total in the latest greenhouse gas emissions inventory (MfE 2020).

The life cycle emission factors outlined in Table 2.3 (from Barber & Stenning 2019 and MfE 2019) were then used to calculate the upstream emissions in CO2e for domestic aviation based on jet fuel use.

5.1.3 Activity rates

Aircraft movements

Domestic aircraft movements at selected airports were obtained from Airways Ltd (Airways Ltd 2020) 46. Airports were selected based on Air New Zealand's domestic and regional network (Air NZ Group 2020)47. Timaru and Hokitika airports were not assessed because aircraft movements were not available. The airports included are listed in Appendix C.4.

Only movements based on instrument flight rules were included as these cover the large commercial services which utilise jet fuel. Smaller services which use aviation gasoline were not assessed.

Domestic aviation fuel use and passenger-kilometres travelled

Passenger-km were calculated from Air New Zealand's data for revenue passenger kilometres (**RPK**) multiplied by their market share of 82% (Air NZ Group 2020). The domestic aviation fuel use (assumed to be Jet A1 fuel only) was sourced from the Ministry of Business, Innovation and Employment's (**MBIE**) *Oil Statistics* (MBIE 2020) [48]. This information was available as a national total only. The resultant jet fuel use and PK are shown in Table 5.2 Aircraft kilometres travelled were not available at the time of writing this report.

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[45] See Chapter 1.A.3.a Aviation 1 Master emissions calculator.

[46] Airways Ltd (2020). *Air traffic movements to March 2020*. Airways Ltd. https://www.airways.co.nz/assets/Airways-air-traffic-movements-to-March-2020.pdf

[47] AirNZ Group (2020). *Air New Zealand Databook 2019*. Air New Zealand, 2020. https://www.airnewzealand.com/databook

[48] MBIE (2020). *Oil Statistics*. Ministry of Business, Innovation and Employment, 2020. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/oil-statistics/

Table 5.2 Fuel use and passenger-kilometres for domestic aviation in New Zealand in 2018/19

Passenger aviation category	Jet fuel use (million litres)	Million PK
All aircraft types	398.6	7,265
National	**398.6**	**7,265**

Note: Total fuel use and PK were apportioned to urban/rural based on the relative number of LTO cycles.

Domestic aviation air quality emissions were assigned to the rural and urban classification based on the location of the airport in the region but only for the LTO cycles. Emissions for the CCD phase were assumed to be too far above ground to affect local air quality.

Greenhouse gas emissions from LTO cycles were also assigned to the same rural or urban classification based on location of the airport. However, emissions from the CCD phase were assigned to rural only.

Damage cost factors

The damage cost factors shown in Table 2.2 were applied to the emissions estimated for urban and rural areas. All costs shown are in June 2019 prices.

5.2 Emissions and costs

The air quality and greenhouse gas emissions impacts of domestic aviation are presented as:

- Total tonnes emitted nationally and split by urban and rural areas for all airports included in Air New Zealand's domestic and regional network (Air NZ Group 2020)
- Relative emission rates by different aircraft types for urban and rural areas

5.2.1 Air quality

Urban versus rural emissions

Table 5.3 summarises the air quality emissions and costs for domestic aviation in urban areas, rural areas and nationally in 2018/19. LTO air quality emissions were assigned to urban or rural areas based on the airport location. CCD air quality emissions were assumed to be negligible because they were emitted too far above land for people to be reasonably exposed.

Table 5.3 Air quality emissions and costs for domestic aviation in New Zealand in 2018/19

Area	Air quality emissions (t)					Costs ($M)
	CO	VOC	NO_X	SO_2	PM_{10}	
Urban total	580	74	824	58	3.0	$18.5
Rural total	161	21	229	16	0.8	$0.4
National overall	741	95	1,053	75	3.8	$18.9 M

Note: Air quality emissions and costs are only from aircraft during take-off and landing. Emissions from aircraft at cruise altitudes are released too high above land to have a discernible air quality impact on urban or rural areas.

Relative emissions rates by aircraft type

Table 5.4 and Table 5.5summarise the relative air quality emissions and costs for the **LTO phase only** for different aircraft types in urban and rural areas, respectively.

The air quality emission rates per LTO for urban and rural areas are identical but the costs depend on the population exposed.

Table 5.4 Relative air quality emission rates and costs for different aircraft types in urban areas

Aircraft type	Relative urban emission rates (kg/LTO)					Urban costs ($/LTO)
	CO	VOC	NO_X	SO_2	PM_{10}	
A320 jet	8.25	1.64	11.28	0.69	0.07	262
ATR7 turboprop	1.54	0.00	2.34	0.20	0.00	49
Q300 turboprop	1.54	0.00	2.33	0.20	0.00	49
Aviation fleet average	**3.24**	**0.42**	**4.60**	**0.33**	**0.02**	**103**

Note: These are relative emissions for landing and take-off movements only.

Table 5.5 Relative air quality emission rates and costs for different aircraft types in rural areas

Aircraft type	Relative rural emission rates (kg/LTO)					Rural costs ($/LTO)
	CO	VOC	NO_X	SO_2	PM_{10}	
A320 jet	8.25	1.64	11.28	0.69	0.07	20
ATR7 turboprop	1.54	0.00	2.34	0.20	0.00	3.8
Q300 turboprop	1.54	0.00	2.33	0.20	0.00	3.8
Aviation fleet average	3.24	0.42	4.60	0.33	0.02	7.9

Note: These are relative emissions for landing and take-off movements only.

5.2.2 Greenhouse gas

Urban versus rural emissions

Table 5.6 summarises the greenhouse gas emissions and costs for domestic aviation in urban areas, rural areas and nationally in 2018/19. LTO emissions were assigned to urban or rural based on the airport location. CCD emissions were assigned to rural only because they are released at altitude.

Table 5.6Greenhouse gas emissions and costs for domestic aviation in New Zealand in 2018/19

Area	Greenhouse gas emissions (kt)	Costs ($M)
	CO_2e	
Urban total	255	$22.4
Rural total	920	$81.0
National overall	1,175	$103.4 M

Note: The totals above include upstream CO_2e emissions from energy production.

Relative emissions rates by aircraft type

Table 5.7 summarises the relative greenhouse gas emissions and costs for the **LTO phase only** for different aircraft types in both urban and rural areas.

Greenhouse gas costs per LTO are identical for urban and rural areas so only one table is presented.

Table 5.7 Relative greenhouse gas emission rates and costs for different aircraft types in urban or rural areas

Aircraft type	Relative CO_2e emission rates (kg/LTO)		Urban or rural costs ($/LTO)
	Energy production (WTT)	Fuel combustion (TTW)	
A320 jet	327	2,667	263
ATR7 turboprop	109	784	79
Q300 turboprop	109	782	78
Aviation fleet average	**155**	**1,268**	**$125**

5.3 Summary

The impacts of air quality and greenhouse gas emissions from domestic aviation are presented as:

- Total costs nationally
- Normalised costs by passenger-km.

5.3.1 Total costs

Table 5.8 summarises the **total costs** of domestic aviation air quality and greenhouse gas impacts in New Zealand in 2018/19.

Table 5.8 Total costs of air quality and greenhouse gas impacts for domestic aviation in New Zealand in 2018/19

Domestic aviation impact	Urban costs ($M)	Rural costs ($M)	Total costs, $M (June 2019 prices)
Air quality	$18.5	$0.4	$18.9
Greenhouse gas	$22.4	$81.0	$103.4
Combined	**$40.9 M**	**$81.4 M**	**$122.3 M**

5.3.2 Normalised costs

Tables 5.9 and 5.10 summarise the **normalised air quality costs** and **normalised greenhouse gas costs**, respectively, for an average domestic aircraft in urban and rural areas of New Zealand in 2018/19.

VKT data for domestic passenger aircraft were not available at the time of writing this report.

Table 5.9 Normalised costs of air quality impacts for domestic aviation in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Domestic aircraft (average)	n/a	0.3	n/a	0.02	n/a	0.3

Note:

1 Total fuel use and PK were apportioned to urban/rural based on LTO cycles.
2 Emissions for the CCD phase were assumed to be too far above ground to affect local air quality.
3 Domestic air freight was not assessed.
4 'n/a' means data not available.

Table 5.10 Normalised costs of greenhouse gas impacts for domestic aviation in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Domestic aircraft (average)	n/a	0.4	n/a	5.1	n/a	1.4

Note:

1 Total fuel use and PK were apportioned to urban/rural based on LTO cycles.
2 All greenhouse gas emissions associated with the CCD phase were apportioned to rural.
3 Domestic air freight was not assessed.
4 'n/a' means data not available.

Chapter 6 Coastal shipping

This chapter presents the air quality and greenhouse gas emission impacts for coastal shipping[49] in New Zealand covering:

- Freight only
- But excluding passenger ferries (which are covered in Chapter 7) and cruise ships

This chapter discusses the detailed methodology used in the assessment of this mode including the fleet profile, the relevant emission factors and the activity rate data.

Results are presented as emissions and associated costs and are disaggregated spatially and by fuel type. Upstream greenhouse gas emissions are also assessed.

6.1 Methodology

Air quality and greenhouse gas emissions were estimated for a range of freight vessels used for domestic shipping as follows:

E = EF x PV Equation 6.1

Or

E = EF x FC Equation 6.2

Where:

E = emission of a pollutant (g/yr)

EF = emission factor of the pollutant by vessel type (kg/PV) for the at-berth phase or by FC (g/litre fuel) for the at-sea phase

FC = total fuel consumption by that vessel type (l/yr)

PV = port visits for the type of vessel per year.

Emissions were estimated using a combination of bottom-up and top-down approaches.

Coastal shipping releases air quality and greenhouse gas emission while in port (at berth) and while steaming between ports (at sea).

Emissions **at berth** were calculated bottom-up using port visits and assigned to urban/rural depending on the location of the seaport.

Emissions **at sea** were calculated top-down, from the difference between the overall domestic shipping fuel use and the at-berth fuel use, and then assigned to regions based on port visits but as rural. **Only at-sea greenhouse gas emissions were**

[49] New Zealand only transports freight on vessels via the sea (coast) and does not utilise inland waterways.

reported and costed because at-sea air quality emissions are released too far from land to affect local areas.

6.1.1 Coastal shipping fleet profile

Our assessment used the definition of coastal shipping in the *National Freight Demand Study* (**NFDS**) (Te Manatū Waka 2019b) [50] – meaning all domestic movements of the following freight types by coastal vessel:

- limestone, cement and fertiliser (assumed by bulk/cargo)
- retail and manufacturing (assumed by container)
- petroleum (assumed by tanker).

Coastal shipping fleet data (e.g. emissions rates, average gross tonnages etc) were taken from *Auckland Air Emissions Inventory 2016 - Sea Transport* (Peeters 2018)[51)]. While this inventory focussed on Auckland, the vessels listed (being coastal freighters) visit many if not all of the New Zealand seaports so the Auckland coastal fleet can be assumed to be representative of all coastal shipping in New Zealand waters.

Table 6.1 lists the vessel categories used in our assessment of coastal shipping, based on the Auckland data.

Table 6.1 Average gross tonnages for coastal shipping vessels in 2018/19 (Peeters 2018)

Vessel	Average gross tonnages
Bulk/Cargo	5,348
Container ship	26,592
Tanker	9,645

6.1.2 Emission factors

Various sources were used to obtain emission factors for air quality and greenhouse gas emissions.

For vessels **at berth**, we derived average emission factors for each vessel type listed in Table 6.1 based on the *Auckland Air Emissions Inventory 2016 - Sea Transport* (Peeters 2018). We calculated a kg/visit emission factors for each pollutant by vessel type based on the total emissions and the associated number of visits registered at Ports of Auckland Ltd in 2016.

For vessels at sea, emission factors were based on fuel use. At-sea fuel use was estimated by subtracting the fuel oil used at berth from the national fuel oil total in the latest greenhouse gas emissions inventory (MfE 2020) and then allocating emissions by the number of port visits.

[50] Te Manatū Waka (2019b). *National Freight Demand Study 2017/18*. Ministry of Transport, October 2019. https://www.transport.govt.nz/mot-resources/freight-resources/nationalfreightdemandsstudy/

[51] Peeters (2018). *Auckland Air Emissions Inventory 2016 - Sea Transport*. Technical report 2018/017 prepared for Auckland Council, July 2018. https://knowledgeauckland.org.nz/publications/auckland-air-emissions-inventory-2016-sea-transport/

The life cycle emission factors outlined in Table 2.3 (from Barber & Stenning 2019 and MfE 2019) were then used to calculate the upstream emissions in CO2e for domestic shipping based on heavy fuel oil use.

6.1.3 Activity rates

Port visits

Coastal shipping operates out of many seaports across New Zealand. For our assessment we selected those ports identified by the National Freight Demand Study (Te Manatū Waka 2019b) as having substantial movements of coastal freight. The 11 seaports included are listed in Appendix C.5. Data on the type of ships visiting each port were provided by Rockpoint (Stone 2020)52. International ships visiting New Zealand are permitted to carry freight domestically and transport a significant proportion of the container volumes (around 82%).

For our assessment, only bulk/cargo, container ships, and tanker vessels were considered as these aligned with the three freight categories in section 6.1.1.

Freight fuel use and net tonne-kilometres travelled

Coastal shipping NTK data were provided by Stone (2020) with estimates made of the number of international container vessels carrying domestic freight.

The domestic shipping fuel use (assumed to be heavy fuel oil - also known as domestic navigation fuel oil only) was sourced from the Oil Statistics (MBIE 2020). This information was available as a national total only and was therefore scaled by the relative fuel consumption of a typical container vessel to derive an international fuel use total. This was added to the domestic total to account for all fuel used to transport coastal freight.

The resultant NTK for each coastal shipping freight/vessel type and the national heavy fuel oil use are shown in Table 6.2.

Table 6.2 Fuel use and net-tonne kilometres for coastal shipping in 2018/19 (Stone 2020; MBIE 2020)

Vessel type	Coastal freight type	Heavy fuel oil use (million litres)	Million NTK
NZ Bulk/Cargo	Limestone, cement, & fertiliser	41.3*	516
NZ Container	Manufacturing & retail	31.8*	413
NZ Tanker	Petroleum	37.3*	2,399
NZ Vessels only	Total	110.4	3,328
Int Container	Manufacturing & retail	158.4‡	1,880
All Vessels	Total	268.8	5,207

Note: The fuel totals shown by * were estimated from the MBIE total based on relative fuel consumption of the different vessels. The international container vessel fuel use shown by ‡ was estimated by scaling up the NZ container vessel total based on the number of vessels.

[52] Stone (2020). *Ship Visits to NZ Ports*. Data provided by Chris Stone, Rockpoint, 17 September 2020.

Air quality emissions from domestic shipping at berth were assigned to urban or rural areas depending on location. Emissions generated when the ships were at sea were assumed to be too far from land to affect local air quality.

Greenhouse gas emissions from domestic shipping at berth were also assigned to urban areas. However, emissions generated when the ships were at sea were assigned to rural only.

6.1.4 Damage cost factors

The damage cost factors shown in Table 2.2 were applied to the emissions estimated for urban and rural areas. All costs shown are in June 2019 prices.

6.2 Emissions and costs

The air quality and greenhouse gas emissions impacts of coastal shipping are presented as:

- Total tonnes emitted nationally and split by urban and rural areas based on the location of seaports
- Relative emission rates by different vessel types for urban and rural areas

6.2.1 Air quality

Urban versus rural emissions

Table 6.3 summarises the air quality emissions and costs for coastal shipping in urban areas, rural areas and nationally in 2018/19. At-berth air quality emissions were assigned to urban or rural areas based on the seaport location. At-sea air quality emissions were assumed to be negligible because they were released too far from land for people to be reasonably exposed.

Table 6.3 Air quality emissions and costs for coastal shipping in New Zealand in 2018/19

Area	Air quality emissions (t)					Costs ($M)
	CO	VOC	NO_X	SO_2	PM_{10}	
Urban total	350	14	421	417	49	$47.2
Rural total	20	1.7	55	50	5.7	$0.4
National overall	370	16	476	467	54	$47.6 M

Note:

1. Air quality emissions and costs are only from shipping at berth. Emissions from shipping at sea are released too far from land to have a discernible air quality impact on urban or rural areas.
2. For the DTCC study base year (2018/19) the average sulphur content of heavy fuel oil is 2.7 wt% (see Appendix C.1) resulting in appreciable SO_2 emissions. In June 2020, the NZ government announced they would be acceding to Marpol Annex VI, which will significantly reduce fuel sulphur levels to 0.5 wt% by 2022.

Relative emissions rates by vessel type

Table 6.4 and Table 6.5 summarise the relative air quality emissions and costs while **at berth only** for different vessel types in urban and rural areas, respectively.
The air quality emission rates per visit for urban and rural areas are identical but the costs depend on the population exposed.

Table 6.4 Relative air quality emission rates and costs for different vessel types in urban areas

Vessel type	Relative urban emission rates (kg/visit)					Urban costs ($/visit)
	CO	VOC	NO_X	SO_2	PM_{10}	
Bulk/Cargo	7	3	95	81	9	$9,258
Container	292	10	314	316	37	$35,783
Tanker	2	1	23	22	2	$2,389
Shipping fleet average	157	7	202	198	23	$22,450

Note: These are relative emissions for at-berth emissions only

Table 6.5 Relative air quality emission rates and costs for different vessel types in rural areas

Vessel type	Relative rural emission rates (kg/visit)					Rural costs ($/visit)
	CO	VOC	NO_X	SO_2	PM_{10}	
Bulk/Cargo	7	3	95	81	9	$708
Container	292	10	314	316	37	$2,736
Tanker	2	1	23	22	2	$1,839
Shipping fleet average	157	7	202	198	23	$1,716

Note: These are relative emissions for at-berth emissions only

6.2.2 Greenhouse gas

Urban versus rural emissions

Table 6.6 summarises the greenhouse gas emissions and costs for coastal shipping in urban areas, rural areas and nationally in 2018/19. At-berth emissions were assigned to urban or rural areas based on the seaport location. At-sea emissions were assigned to rural only because they were released far from land.

Table 6.6 Greenhouse gas emissions and costs for coastal shipping in New Zealand in 2018/19

Area	Greenhouse gas emissions (kt)	Costs ($M)
	CO_2e	
Urban total	35	$3.1
Rural total	917	$80.7
National overall	951	$83.7 M

Note: The totals above include upstream CO_2e emissions from energy production.

Relative emissions rates by vessel type

Table 6.7 summarises the relative greenhouse gas emissions and costs while **at berth only** for different vessel types in both urban and rural areas.

Greenhouse gas costs are identical for urban and rural areas so only one table is presented.

Table 6.7 Relative greenhouse gas emission rates and costs for different vessel types at berth in urban or rural areas

Vessel type	Relative CO_2e emission rates (kg/visit)		Urban or rural costs ($/visit)
	Energy production (WTT)	Fuel combustion (TTW)	
Bulk/Cargo	1,114	6,773	$694
Container	3,409	20,718	$2,123
Tanker	2,932	17,821	$1,826
Shipping fleet average	2,546	15,476	$1,586

Note: These are relative emissions for at-berth emissions only.

6.3 Summary

The impacts of air quality and greenhouse gas emissions from coastal shipping are presented as:

- Total costs nationally
- Normalised costs by net tonne-km.

6.3.1 Total costs

Table 6.8 summarises the **total costs** of coastal shipping air quality and greenhouse gas impacts in New Zealand in 2018/19.

Table 6.8 Total costs of air quality and greenhouse gas impacts for coastal shipping in New Zealand in 2018/19

Coastal shipping impact	Urban costs ($M)	Rural costs ($M)	Total costs, $M (June 2019 prices)
Air quality	$47.2	$0.4	$47.6
Greenhouse gas	$3.1	$80.7	$83.7
Combined	$50.3 M	$81.1 M	$131.4 M

6.3.2 Normalised costs

Table 6. 9 and Table 6.10summarise the **normalised air quality costs** and **normalised greenhouse gas** costs, respectively, for an average coastal vessel in urban and rural areas of New Zealand in 2018/19.

VKT data for coastal shipping vessels were not available at the time of writing this report.

Table 6.9 Normalised costs of air quality impacts for coastal shipping in New Zealand in 2018/19

Freight transport category	Urban		Rural		National average	
	c/VKT	c/NTK	c/VKT	c/NTK	c/VKT	c/NTK
Coastal vessel (average)	n/a	1.2	n/a	0.03	n/a	0.9

Note:

1 Total fuel use and NTK were apportioned to urban/rural based on port visits.
2 At-sea air quality emissions were assumed to be released too far from land to affect local air quality.
3 'n/a' means data not available.

Table 6.10 Normalised costs of greenhouse gas impacts for coastal shipping in New Zealand in 2018/19

Freight transport category	Urban		Rural		National average	
	c/VKT	c/NTK	c/VKT	c/NTK	c/VKT	c/NTK
Coastal vessel (average)	n/a	0.1	n/a	6.5	n/a	1.6

Note:

1 Total fuel use and NTK were apportioned to urban/rural based on port visits.
2 All at-sea greenhouse gas emissions were assigned to rural.
3 'n/a' means data not available.

Chapter 7 Public transport

This chapter presents the air quality and greenhouse gas emission impacts for urban public transport and school buses in New Zealand covering:

- Urban buses, urban rail and urban ferries as well as school buses

This chapter discusses the detailed methodology used in the assessment of this mode including the fleet profiles, the relevant emission factors and the activity rate data.

Results are presented as emissions and associated costs and are disaggregated spatially and by fuel type. Upstream greenhouse gas emissions from energy production are also assessed.

7.1 Methodology

Air quality and greenhouse gas emissions were estimated for a range of public transport vehicles (on road, rail and sea) as follows:

E = EF x VKT Equation 7.1

Or

E = EF x FC Equation 7.2

Where:

E = emission of a pollutant (g/yr)

EF = emission factor of the pollutant by speed for buses (g/km) or fuel type for rail and ferries (g/litre fuel)

VKT = total vehicle kilometres travelled by that bus type on the public transport network (km/yr)

FC = total fuel consumption by that vehicle type on the public transport network (l/yr).

Bus emissions were estimated bottom-up, using speed and VKT data for regions across New Zealand. Estimates were then aggregated to provide national emissions. All urban public transport bus emissions were assigned to urban. In the absence of data, all school bus emissions were assigned to rural.

Rail and ferry emissions were estimated bottom-up, based on data for Auckland pro-rated by activity for relevant regions across New Zealand. All urban public transport rail and ferry emissions were assigned to urban.

7.2 Public transport fleet profiles

We contacted councils and the Ministry of Education to get information on the public transport service fleets in operation. Unfortunately, detailed and consistent data were not available for all regions. Rather than using individual regional public transport fleets, we developed a series of generic fleet profiles for the various forms of public transport. However, we did combine these generic fleet profiles with region-specific activity data to get regional emissions.

Urban buses and school buses operate in most regions across New Zealand. Councils operate urban bus services (which may include urban school buses) whereas the Ministry of Education (MoEd) manages rural school bus services.

The urban bus fleet and school bus fleet profiles in 2018/19 were taken from the Vehicle Emissions Prediction Model (NZTA 2020b) and are broken down by the following bus categories:

- Diesel buses <=15t, which equates to medium diesel buses
- Diesel buses 15 – 18t, which equates to large and double-decker diesel buses

The urban bus fleet profile also includes:

- Electric buses > 3.5t, which equates to medium to large electric buses

However, this electric category is not included in the school bus fleet profile, as school buses are typically older and therefore built to earlier emissions standards than urban buses.

Urban rail operates in only two regions - Auckland and Wellington. The Auckland urban rail fleet profile, covering diesel multiple unit (**DMU**) and electric multiple unit (**EMU**) trains, was provided by Auckland Transport (AT 2020)[53]. The Wellington urban rail fleet profile, covering diesel-electric and EMU trains, was sourced from Wikipedia[54].

Urban ferries operate in three regions – Auckland, Wellington and Christchurch. The Auckland urban ferry fleet profile was provided by Auckland Transport (AT 2020). The Wellington and Christchurch fleet operate catamarans, but further details on the vessels were not available.

Table 7.1 shows the categories of public transport we used in our assessment.

Table 7.1 Typical passenger numbers, dead running and VKT for public transport in 2018/19

Public transport category	Typical passenger numbers per vehicle	Dead running	National annual VKT (million km) with dead running
Urban bus			133.3
Diesel medium bus	<35 max	15%	
Diesel large+dble-deck bus	>36	15%	
Electric large bus	>36	15%	
Rural school bus			47.0
Diesel medium bus	<35 max	69%	

[53] AT (2020). *Data for Auckland Public Transport Services in 2018/19.* Provided by Manoj Pokhrel from Auckland Transport, 26 June 2020.

[54] Wikipedia (2020). *Public transport in the Wellington Region.* Accessed from Wikipedia on 10 August 2020. https://en.wikipedia.org/wiki/Public_transport_in_the_Wellington_Region#Rolling_stock

Public transport category	Typical passenger numbers per vehicle	Dead running	National annual VKT (million km) with dead running
Diesel large bus	>36	69%	
Urban rail			7.9
Diesel-electric+DMU train	132-250	-	
Electric EMU train	500-1000	-	
Urban ferry			1.6
Diesel ferry (average)	100-200	-	

Note: Dead running is the percentage extra applied to the in service VKT to reflect when a vehicle travels without carrying or accepting passengers, e.g. when coming from a garage to begin its first trip of the day or when returning empty to the depot to restart a route during peak periods. Table 7. 1 shows the assumed dead running applied to the urban bus and school bus VKT. The figure for school buses is the average across all services.

7.2.1 Emission factors

Various sources were used to obtain emission factors for air quality and greenhouse gas emissions.

Urban buses and rural school buses

VEPM6.1 was used to generate **fuel combustion** (exhaust) emissions factors for an average speed of 24 km/h (assumed for buses in urban areas) and 60 km/h (assumed for school buses in rural areas) for:

- CO, FC, VOC, NO_X, and PM_{10}[55] –in g/km or l/100km for FC
- SO_2 –from the FC combined with the sulphur content of the fuel (see Appendix C.1)
- The FC values were aggregated to get fuel totals which were compared with national totals from the latest greenhouse gas emissions inventory (MfE 2020). The national actuals were used to adjust the VEPM FC and combustion-related emission factors to compensate for any gradient effects due to New Zealand's terrain. The revised FC figures were then multiplied by the relevant TTW factor from Table 2.3 to get CO_2e.

VEPM6.1 was also used to generate PM_{10} emission factors for **brake and tyre wear**.

A Tier 1 EMEP/EEA methodology was used to estimate PM_{10} emissions from **sealed road abrasion** (EMEP/EEA 2019)[56]. USEPA methodology for public roads was used to estimate PM_{10} emissions from **unsealed road abrasion** (USEPA 2006).

The life cycle emission factors outlined in Table 2.3 (from Barber & Stenning 2019 and MfE 2019) were used to derive **upstream emissions** in CO_2e for road transport based on diesel and electricity use.

[55] All exhaust PM is in the $PM_{2.5}$ or smaller size fraction but this is a subset of PM_{10}.

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

Urban rail

For diesel or diesel-electric locomotives, we used a Tier 1 EMEP/EEA methodology to estimate air quality emissions resulting from **fuel combustion**, based on fuel use (EMEP/EEA 2019) [57]. The diesel fuel use was estimated from rail fuel consumption data provided by Auckland Transport (AT 2020). AT also provided electricity usage data for the EMU trains. The Auckland urban rail fuel and energy consumption data were applied to the relevant Wellington trains to estimate their fuel use.

The life cycle emission factors outlined in Table 2.3 (from Barber & Stenning 2019 and MfE 2019) were then used to calculate the **upstream emissions** in CO_2e for rail transport based on diesel and electricity use.

Urban ferry

For urban ferries, we derived fleet average emission factors based on the vessel types listed in Table 2.3 using the *Auckland Air Emissions Inventory 2016 - Sea Transport* (Peeters 2018). We calculated a kg/t fuel use emission factor for each pollutant based on the total emissions and the estimated fuel use. The diesel fuel use for Auckland was cross-checked against the total estimated by AT of approximately 12 million litres/yr (AT 2020).

Emissions for ferries in Wellington and Christchurch were based on the average fuel consumption for Auckland ferries multiplied by the respective service kilometres taken from the *PT Performance* spreadsheet by region (NZTA 2020c).

The life cycle emission factors outlined in Table 2.3 (from Barber & Stenning 2019 and MfE 2019) were then used to calculate the **upstream emissions** in CO_2e for urban ferries based on diesel use.

7.2.2 Activity rates

The primary activity rate data used for public transport were annual VKT and PK.

Activity rates for council services for **all modes of urban public transport** were obtained from the Waka Kotahi *PT Performance* spreadsheet by region (NZTA 2020c)[58]. Urban public transport services were assumed to operate in urban areas only. VKT and PK data were reported in the PT performance data, with dead running for urban buses taken from Auckland Transport data (AT 2020).

Data for **school buses** were provided by the Ministry of Education (MoEd 2020)[59] but only the following services were able to be assessed – daily bus, technology bus and direct-resourced. School bus services were assumed to operate in rural areas only. In service data from MoEd (2020), together with assumptions about dead running and occupancy provided by Wallis (2021) [60], were used to estimated dead running VKT and PK (as shown in Appendix C.6).

[57] See Chapter 1.A.3.c *Railways*.

[58] NZTA (2020c). *Performance of public transport services*. Data spreadsheet, Waka Kotahi NZ Transport Agency, accessed July 2020. https://www.nzta.govt.nz/planning-and-investment/learning-and-resources/transport-data/data-and-tools/

[59] MoEd (2020). *Data for National School Bus Services in 2018/19.* Provided by Steve Guiney from Ministry of Education, 17 July 2020.

[60] Wallis (2021). *Estimate of dead running and occupancy for school bus services*. Email from Ian Wallis, Ian Wallis Associates Ltd, pers comm, 18 January 2021.

Note: Insufficient information was available for the specialised education school transport assistance and Māori medium school bus services – many of which rely on forms of road transport other than buses, e.g. vans. Although they were not able to be identified separately, emissions and impacts from unassessed school bus services were still accounted for in the road transport assessment.

Appendix C.7 lists the public transport activity rates by region and nationally.

7.2.3 Damage cost factors

The damage cost factors shown in Table 2.2 were applied to the emissions estimated for urban and rural areas. All costs shown are in June 2019 prices.

7.3 Emissions and costs

The air quality and greenhouse gas emissions impacts of public transport are presented in:

- Total tonnes emitted nationally and split by urban and rural areas
- Relative emission rates by different public transport types for urban and rural areas

7.3.1 Air quality

Urban versus rural emissions

Table 7.2 summarises the air quality emissions and costs for public transport in urban areas, rural areas and nationally in 2018/19. All urban public transport emissions were assigned to urban. In the absence of data, all school bus emissions were assigned to rural.

Table 7.2 Air quality emissions and costs for public transport in New Zealand in 2018/19

Area	Air quality emissions (t)					Costs
	CO	VOC	NO_X	SO_2	PM_{10}	($M)
Urban total	563	73	1,940	0.61	63	$66.7
Rural total	76	9	245	0.12	13	$0.8
National overall	**639**	**82**	**2,184**	**0.73**	**76**	**$67.5 M**

Note: All MoEd school bus emissions are assigned to rural areas. All other public transport is assigned to urban.

Relative emissions rates by public transport vehicle

Table 7.3 and Table 7.4 summarise the relative air quality emissions and costs per thousand VKT for different public transport categories in **urban areas** and **rural areas**, respectively.

Table 7.3 Relative air quality emission rates and costs for different public transport modes in urban areas

Public transport mode	Relative urban emission rates (mg/km)							Urban costs (c/km)
	CO	VOC	NO_X	SO_2	PM_{10} exh	PM_{10} B&T	PM_{10} road dust	
Urban bus								38.6
Diesel medium bus	3,190	30.3	8,622	3	253	33	8.9	30.3
Diesel large+dble-deck bus	3,252	45.0	11,949	4	378	82	8.9	45.0
Electric large bus	0	0	0	0	0	33	8.9	2.1
Urban rail								13.1
Diesel-electric+DMU train	11,172	131.8	41,273	10	1,138	0	0	131.8
Electric EMU trains	0	0.0	0	0	0	0	0	0.0
Urban ferry								884.4
Diesel ferry (average)	80,139	884.4	318,482	70	6,218	0	0	884.4

Note: All MoEd school bus emissions are assigned to rural areas. All other public transport is assigned to urban.

Table 7.4 Relative air quality emission rates and costs for different public transport modes in rural areas

Public transport mode	Relative rural emission rates (mg/km)							Rural costs (c/km)
	CO	VOC	NO_X	SO_2	PM_{10} exh	PM_{10} B&T	PM_{10} road dust	
Rural school bus								1.7
Diesel medium bus	1,660	180	4,291	2.2	158	25	31	1.4
Diesel large bus	1,601	203	5,841	2.8	211	60	31	2.0

7.3.2 Greenhouse gas

Urban versus rural emissions

Table 7.5 summarises the greenhouse gas emissions and costs for public transport in urban areas, rural areas and nationally in 2018/19. All urban public transport emissions were assigned to urban. In the absence of data, all school bus emissions were assigned to rural.

Table 7.5 Greenhouse gas emissions and costs for public transport in New Zealand in 2018/19

Area	Greenhouse gas emissions (kt) CO_2e	Costs ($M)
Urban total	238	$20.9
Rural total	45	$3.9
National overall	283	$24.9 M

Note: The totals above include upstream CO_2e emissions from energy production.

Relative emissions rates by public transport vehicle

Table 7.6 summarises the relative greenhouse gas emissions and costs for different public transport categories in both urban and rural areas.

Greenhouse gas costs are identical for urban and rural areas so only one table is presented.

Table 7.6 Relative greenhouse gas emission rates and costs for different public transport modes in urban or rural areas

Public transport category	Relative CO_2e emission rates (g/km)		Urban or rural costs (c/km)
	Energy production (WTT)	Fuel combustion (TTW)	
Urban bus			12.2
Diesel medium bus	168	998	10.3
Diesel large+dbl-deck bus	225	1,338	13.8
Electric large bus	0.15	0	0.001
Rural school bus			8.4
Diesel medium bus	119	709	7.3
Diesel large bus	150	889	9.1
Urban rail			12.3
Diesel-electric+DMU train	557	3,314	34.1
Electric EMU trains	1,127	0	9.9
Urban ferry			232.0
Diesel ferry (average)	3,795	22,569	232.0

7.4 Summary

The impacts of air quality and greenhouse gas emissions from public transport are presented as:

- Total costs nationally
- Normalised costs by passenger-km.

7.4.1 Total costs

Table 7.7 summarises the **total costs** of air quality and greenhouse gas impacts in New Zealand in 2018/19 for public transport.

Table 7.7 Total costs of air quality and greenhouse gas impacts for public transport in New Zealand in 2018/19

Public transport impact	Urban costs ($M)	Rural costs ($M)	Total costs, $M (June 2019 prices)
Air quality	$66.7	$0.8	$67.5
Greenhouse gas	$20.9	$3.9	$24.9
Combined	$87.6 M	$4.8 M	$92.4 M

7.4.2 Normalised costs

Table 7.8 and Table 7.9 summarise the **normalised air quality costs** and **normalised greenhouse gas** costs, respectively, for public transport in urban and rural areas of New Zealand in 2018/19.

Table 7.8 Normalised costs of air quality impacts for public transport in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Urban bus (average)	38.6	5.0	-	-	38.6	5.0
Rural school bus (average)	-	-	1.7	0.2	1.7	0.2
Urban rail (average)	13.1	0.2	-	-	13.1	0.2
Urban ferry (average)	884.4	15.7	-	-	884.4	15.7

Table 7.9 Normalised costs of greenhouse gas impacts for public transport in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Urban bus (average)	12.2	1.6	0.0	0.0	12.2	1.6
Rural school bus (average)	0.0	0.0	8.4	1.0	8.4	1.0
Urban rail (average)	12.3	0.2	0.0	0.0	12.3	0.2
Urban ferry (average)	232.0	4.1	0.0	0.0	232.0	4.1

Chapter 8 Alternative modes

This chapter estimates the net emissions benefits that arise from substituting an average urban trip by car with the same journey by each of the following alternative modes:

- Walking and cycling
- Ride-hailing
- Micro-mobility.

8.1 Methodology

The assessment was undertaken using the same principles outlined in the earlier section but **focussing on urban travel only**. Air quality and greenhouse gas emissions resulting from the alternative modes were estimated and then compared to the emissions resulting from the same type of trip using an average car (see Chapter 3).

8.1.1 Alternative mode profiles

Walking and cycling were assessed for three options - walking, cycling and e-cycling. Data on the typical energy consumption of e-bikes were taken from the Wellington Electric Bikes website[61].

Ride-hailing (including taxis, Uber, Lyft etc) was assumed to be undertaken by hybrid (only) vehicles in the New Zealand fleet. This assumption is likely to result in a more optimistic (i.e. lower emissions) assessment of the impact of these vehicles, therefore a sensitivity analysis was also undertaken based on an average petrol car. The fleet profile in the *Vehicle Emission Prediction Model* (see section 3.1.1) was used to develop factors for an average hybrid and an average petrol car. Data on vehicle occupancies were provided by Veitch Lister (Bruce 2020)[62]. Dead running of 100% was assumed for these vehicles based on overseas findings (OECD/ITF 2020) [63].

Micro-mobility was assessed for privately owned e-scooters separate to rental e-scooters to recognise the additional emissions burden associated with the latter from collection and redistribution. Data on the typical energy consumption of e-scooters were taken from the Electric Scooter Guide website[64]. Data on collection and redistribution associated with rental scooters were taken from Chester Energy and Policy (2019) [65].

[61] Wellington Electric Bikes (2020). *Technical Details.* Accessed from their website on 16 August 2020. https://www.wellingtonelectricbikes.co.nz/technical-details/
[62] Bruce (2020). *Typical ride-hailing occupancies*. Data provided by Oliver Bruce, Veitch Lister, 30 June 2020.
[63] OECD/ITF (2020). *Good to Go? Assessing the Environmental Performance of New Mobility*. Organisation for Economic Co-operation and Development/International Transport Forum, 17 September 2020. https://www.itf-oecd.org/good-go-assessing-environmental-performance-new-mobility
[64] Electric Scooter Guide (2020). *Ultimate guide to electric scooters.* Accessed from their website on 16 August 2020. https://electric-scooter.guide/guides/definitive-guide-electric-scooters/
[65] Chester Energy (2019). *Life cycle analysis of electric scooters.* Accessed from their website on 16 August 2020. https://chesterenergyandpolicy.com/2019/01/28/its-a-bird-its-a-lime-its-dockless-scooters-but-can-these-electric-powered-mobility-options-be-considered-sustainable-using-life-cycle-analysis/

Table 8.1 summarises the key assumptions made regarding occupancy and dead running for the alternative modes assessed and the base case of the average passenger car.

Table 8.1 Typical occupancy, dead running and energy consumption for alternative modes in 2018/19

Category	Typical occupancy	Dead running	Average energy consumption
Average passenger car	1.56	0%	9.55 l/100km
Walking and cycling			
Walking	1.0	0%	-
Cycling	1.0	0%	-
E-cycling	1.0	0%	0.010 kWh/km
Ride-hailing			
Hybrid <3.5t	2.2	100%	4.54 l/100km
Petrol car <3.5t *	2.2	100%	9.46 l/100km
Micro-mobility			
E-scooter (private)	1.0	0%	0.016 kWh/km
E-scooter (rental)	1.0	0%	0.016 kWh/km

Note:

1. Dead running is when a vehicle operates without carrying or accepting passengers, e.g. when coming from a garage to begin its first trip of the day or when returning empty to the depot to restart a route during peak periods. The assumed dead-running applied to the ride hailing VKT was based on overseas data (OECD/ITF 2020).
2. In the absence of suitable data, all ride-hailing vehicles were assumed to be hybrids. This assumption is likely to result in a more optimistic (i.e. lower emissions) assessment of the impact of these vehicles, therefore a sensitivity analysis was also undertaken based on an average petrol car (marked with a *).

8.1.2 Emission factors

Various sources were used to obtain emission factors for air quality and greenhouse gas emissions.

Walking and cycling

The life cycle emission factors outlined in Table 2.3 (from Barber & Stenning 2019 and MfE 2019) were used to derive **upstream emissions** in CO_2e for e-bikes based on electricity use.

Ride-hailing

VEPM6.1 was used to generate **fuel combustion** (exhaust) emissions factors for an average speed of 40 km/h (assumed for urban areas) as outlined in section 3.1.2 for an average hybrid and an average petrol car.

VEPM6.1 was also used to generate PM_{10} emission factors for **brake and tyre wear**.

A Tier 1 EMEP/EEA methodology was used to estimate PM_{10} emissions from **sealed road abrasion** (EMEP/EEA 2019). USEPA methodology for public roads was used to estimate PM_{10} emissions from **unsealed road abrasion** (USEPA 2006).

The life cycle emission factors outlined in Table 2.3 (from Barber & Stenning 2019 and MfE 2019) were used to derive **upstream emissions** in CO_2e for hybrids based on petrol use.

Micro-mobility

The life cycle emission factors outlined in Table 2.3 (from Barber & Stenning 2019 and MfE 2019) were used to derive **upstream emissions** in CO_2e for e-scooters based on electricity use.

For rental scooters, the emissions from collection and redistribution were estimated assuming a typical passenger car was used to transport 10 scooters at a time an average distance of 8 km - the “medium” scenario outlined in Chester Energy (2019).

8.1.3 Activity rates

Air quality and greenhouse gas emissions for each mode were normalised per VKT and per PK, based on typical occupancies and dead running shown in Table 8. 1.

8.1.4 Damage cost factors

The damage cost factors shown in Table 2.2 were applied to the emissions estimated for urban and rural areas. All costs shown are in June 2019 prices.

8.2 Emissions and costs

The air quality and greenhouse gas emissions impacts of alternative modes versus an average passenger car are presented as relative emission rates by different alternative modes for urban only areas.

Note: The results for ride-hailing are very dependent on the assumption of the vehicle used. If a trip by an average passenger car is replaced with a hybrid ride-share then there is a positive benefit but this reduces to zero if the ride-share is undertaken with a petrol car. Regardless, the active modes of walking and cycling (including e-cycling) result in net benefits for both air quality and greenhouse gas impacts.

8.2.1 Air quality

Relative emissions rates by vehicle type

Table 8.2 compares the relative air quality emissions and costs per km for different alternative modes versus an average passenger car in **urban** areas in 2018/19.

Table 8.2 Relative air quality emission rates and costs for different alternative modes in urban areas in 2018/19

Vehicle mode	Relative urban emission rates (mg/km)							Urban costs (c/km)
	CO	VOC	NO_X	SO_2	PM_{10} exh	PM_{10} B&T	PM_{10} road dust	
Passenger car	2,579	213	409	0.7	14	16	8.9	2.7
Walking and cycling								
Walking	0	0	0	0	0	0	0	0
Cycling	0	0	0	0	0	0	0	0
E-cycling	0	0	0	0	0	0	0	0
Ride hailing (per km of ride)*								
Hybrid <3.5t	71	1.6	30	0.7	0.0	32.3	17.8	2.6
Petrol car <3.5t *	5,821	473	658	1.4	3.7	32.3	17.8	4.0
Micro-mobility								
E-scooter (private)	0	0	0	0	0	0	0	0.0
E-scooter (rental) **	129	10.6	20.4	0	0.7	0.8	0.4	0.1

Note: * emission rates doubled due to 100% dead running, ** emission rates include collection and redistribution

8.2.2 Greenhouse gas

Relative emissions rates by vehicle type

Table 8.3 compares the relative greenhouse gas emissions and costs for different alternative modes versus an average passenger car in **urban** areas in 2018/19.

Table 8.3 Relative greenhouse gas emission rates and costs for different alternative modes in urban areas in 2018/19

Vehicle mode	Relative CO_2e emission rates (g/km)		Urban costs (c/km)
	Energy production (WTT)	Fuel combustion (TTW)	
Passenger car	31.2	237.2	2.4
Walking and cycling			
Walking	0	0	0
Cycling	0	0	0
E-cycling	1.2	0	0.01

Vehicle mode	Relative CO_2e emission rates (g/km)		Urban costs (c/km)
	Energy production (WTT)	Fuel combustion (TTW)	
Ride hailing (per km of ride)*			
Hybrid <3.5t	28.0	222.7	2.2
Petrol car <3.5t *	58.3	463.8	4.6
Micro-mobility			
E-scooter (private)	1.9	0.0	0.02
E-scooter (rental) **	3.5	11.9	0.13

Note: * emission rates doubled due to 100% dead running, ** emission rates include collection and redistribution

8.3 Summary

The impacts of air quality and greenhouse gas emissions from alternative modes are presented as normalised costs and net benefits (relative to an average passenger car).

8.3.1 Normalised costs

Table 8.4 summarises the **normalised air quality costs** for different alternative modes (relative to an average passenger car) in **urban** areas of New Zealand in 2018/19.

Table 8.4 Normalised air quality costs and net benefits (relative to an average passenger car) of different alternative modes in urban areas of New Zealand in 2018/19

Vehicle mode	Urban air quality costs		Net benefits	
	c/VKT	c/PK	c/VKT	c/PK
Walking and cycling				
Walking	0	0	2.7	1.8
Cycling	0	0	2.7	1.8
E-cycling	0	0	2.7	1.8
Ride hailing (per km of ride)				
Hybrid <3.5t	2.6	2.1	0.2	-0.4
Petrol car <3.5t	4.0	3.3	-1.2	-1.5
Micro-mobility				
E-scooter (private)	0	0	2.7	1.8
E-scooter (rental)	0.1	0.1	2.6	1.6

Note: The ride-hailing costs per PK include costs associated with 100% dead running. A negative benefit is a cost.

Table 8.5 summarises the **normalised greenhouse gas costs** for different alternative modes (relative to an average passenger car) in **urban** areas of New Zealand in 2018/19.

Table 8.5 Normalised greenhouse gas costs and net benefits (relative to an average passenger car) of different alternative modes in urban areas of New Zealand in 2018/19

Vehicle mode	Urban greenhouse gas costs		Net benefits	
	c/VKT	c/PK	c/VKT	c/PK
Walking and cycling				
Walking	0	0	2.4	1.5
Cycling	0	0	2.4	1.5
E-cycling	0.01	0.01	2.4	1.5
Ride hailing (per km of ride)				
Hybrid <3.5t	2.2	1.0	0.2	-0.3
Petrol car <3.5t	4.6	2.1	-2.2	-2.3
Micro-mobility				
E-scooter (private)	0.02	0.02	2.3	1.5
E-scooter (rental)	0.1	0.1	2.2	1.4

Note: The ride-hailing costs per PK include costs associated with 100% dead running. A negative benefit is a cost.

Chapter 9 Summary and recommendations

This chapter summarises the air quality and greenhouse gas impacts overall and recommends next steps for further work to address gaps.

9.1 Overall summary

The impacts of air quality and greenhouse gas emissions resulting from different modes of domestic transport in New Zealand are summarised in:

- Total costs nationally
- Normalised costs of different passenger transport vehicles by passenger-km and different freight transport vehicles by net tonne-km

9.1.1 Total costs

Table 9.1 summarises the **total costs** of **air quality** impacts resulting from different modes of domestic transport in New Zealand in 2018/19.

Table 9.1 Total costs of domestic transport air quality impacts in New Zealand in 2018/19

Mode	Urban costs ($M)	Rural costs ($M)	Total costs, $M (June 2019 prices)
Road transport	$897.6	$155.3	$1,052.9
Rail	$15.0	$4.2	$19.3
Domestic aviation	$18.5	$0.4	$18.9
Coastal shipping	$47.2	$0.4	$47.6
Public transport	$66.7	$0.8	$67.5
All modes	$1,045 M	$161 M	$1,206 M

Table 9.2 summarises the **total costs** of **greenhouse gas** impacts resulting from different modes of domestic transport in New Zealand in 2018/19.

Table 9.2Total costs of domestic transport greenhouse gas impacts in New Zealand in 2018/19

Mode	Urban costs ($M)	Rural costs ($M)	Total costs, $M (June 2019 prices)
Road transport	$523	$927.3	$1,450.3
Rail	$2.8	$10.6	$13.4
Domestic aviation	$22.4	$81.0	$103.4
Coastal shipping	$3.1	$80.7	$83.7
Public transport	$20.9	$3.2	$24.2
All modes	$572 M	$1,103 M	$1,675 M

9.1.2 Normalised costs for domestic passenger transport

Table 9.3 summarises the **normalised air quality costs** for different passenger transport vehicles in New Zealand in 2018/19.

Table 9.3 Normalised costs of air quality impacts for domestic passenger transport vehicles in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Passenger car	2.7	1.7	0.3	0.2	1.3	0.8
Coach	26.6	2.0	2.1	0.2	7.6	0.6
Other bus	21.9	1.6	1.7	0.1	6.3	0.5
Motorcycle	5.8	5.8	0.5	0.5	2.5	2.5
Long-distance rail	179.8	0.9	13.7	0.1	43.6	0.2
Domestic aviation	n/a	0.3	n/a	0.02	n/a	0.3
Urban bus	38.6	5.0	-	-	38.6	5.0
School bus	-	-	1.7	0.2	1.7	0.2
Urban rail	13.1	0.2	-	-	13.1	0.2
Urban ferry	884.4	15.7	-	-	884.4	15.7

Note: Emissions and costs for urban bus, urban rail and urban ferry were only assigned to urban, whereas emissions for rural school buses were only assigned to rural. VKT data for aviation were not available.

Table 9.4 summarises the **normalised greenhouse gas costs** for different passenger transport vehicles in New Zealand in 2018/19.

Table 9.4 Normalised costs of greenhouse gas impacts for domestic passenger transport vehicles in New Zealand in 2018/19

Passenger transport category	Urban		Rural		National average	
	c/VKT	c/PK	c/VKT	c/PK	c/VKT	c/PK
Passenger car	2.4	1.5	2.4	1.5	2.4	1.5
Coach	9.4	0.7	9.4	0.7	9.4	0.7
Other bus	8.5	0.6	8.5	0.6	8.5	0.6
Motorcycle	0.9	0.9	0.9	0.9	0.9	0.9
Long-distance rail	28.6	0.1	28.6	0.1	28.6	0.1
Domestic aviation	n/a	0.4	n/a	5.1	n/a	1.4
Urban bus	12.2	1.6	-	-	12.2	1.6
School bus	-	-	8.4	1.0	8.4	1.0
Urban rail	12.3	0.2	-	-	12.3	0.2
Urban ferry	232.0	4.1	-	-	232.0	4.1

Note: Emissions and costs for urban bus, urban rail and urban ferry were only assigned to urban, whereas emissions for rural school buses were only assigned to rural. VKT data for aviation were not available.

9.1.3 Normalised costs for domestic freight transport

Table 9.5summarises the **normalised air quality costs** for different freight transport vehicles in New Zealand in 2018/19.

Table 9.5 Normalised costs of air quality impacts for domestic freight transport vehicles in New Zealand in 2018/19

Freight transport category	Urban		Rural		National average	
	c/VKT	c/NTK	c/VKT	c/NTK	c/VKT	c/NTK
LCV	9.0	18.0	0.8	1.6	4.0	8.1
MCV	16.4	6.5	1.3	0.5	4.7	1.9
HCV	27.0	2.6	2.1	0.2	7.7	0.7
Electric locomotive	n/a	0.0	n/a	0.0	n/a	0.0
Diesel locomotive	n/a	2.3	n/a	0.1	n/a	0.5
Coastal freighter	n/a	1.2	n/a	0.03	n/a	0.9

Note: Domestic air freight was not assessed. VKT data were not available for freight locomotives and coastal vessels.

Table 9.6 summarises the **normalised greenhouse gas costs** for different freight transport vehicles in New Zealand in 2018/19.

Table 9.6Normalised costs of greenhouse gas impacts for domestic freight transport vehicles in New Zealand in 2018/19

Freight transport category	Urban		Rural		National average	
	c/VKT	c/NTK	c/VKT	c/NTK	c/VKT	c/NTK
LCV	3.3	6.6	3.3	6.6	3.3	6.6
MCV	5.4	2.2	5.4	2.2	5.4	2.2
HCV	10.9	1.0	10.9	1.0	10.9	1.0
Electric locomotive	n/a	0.1	n/a	0.1	n/a	0.1
Diesel locomotive	n/a	0.4	n/a	0.3	n/a	0.4
Coastal freighter	n/a	0.1	n/a	6.5	n/a	1.6

Note: Domestic air freight was not assessed. VKT data were not available for freight locomotives and coastal vessels.

9.2 Recommendations for future work

We recommend future work focusses on addressing the following data gaps:

Road transport

- Improve road dust (sealed and unsealed) emission factors

  We note that Waka Kotahi released an RFP for a research project looking into this issue in July 2020- ART 19-18 Unsealed road dust exposure

- Obtain/record actual average loads for commercial vehicles

  We note that an update of VEPM is currently underway to improve truck loadings in the model and that the Climate Change Commission and others are trying to improve their modelling of road freight fuel consumptions etc

- Improve motorcycle exhaust emission factors

  Currently we rely on top-down assessment based on fuel use and have few details on the motorcycle fleet. However, this source likely contributes little to impacts in most locations.

Shipping

- Obtain/record better data on domestic shipping fuel use and separation of international/domestic ship visits for coastal shipping

Public transport

- Improve resolution and utility of school bus data (especially regarding PK estimates)

General

- Improve consistency in the way all transport modes record key metrics (e.g. VKT, NTK and PK)
- Update all costs, if necessary, once HAPINZ 3.0 is publicly released

Appendix A: Glossary

$M	millions of dollars
ATAP	Australian Transport Assessment and Planning
AUD	Australian dollars
BC	black carbon, both an air quality pollutant and a greenhouse pollutant
c	cents
CCD	cruise, climb and descent phases of an aircraft flight
CH_4	methane, a greenhouse gas
CO	carbon monoxide, an air quality 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
COPERT	the European Computer Model to Calculate Emissions from Road Transport
dead running	when a vehicle operates without carrying or accepting passengers, e.g. when coming from a garage to begin its first trip of the day or when returning empty to the depot to restart a route during peak periods
DEFRA	UK Department for Environment Food and Rural Affairs
DMU	diesel multiple unit, a two or three passenger car set in which one car is diesel powered
downstream emissions	the average GHG emissions associated with energy use and end-of-life processes, including scrappage in the case of vehicles
DTCC	Domestic Transport Costs and Charges
EEM	Economic Evaluation Manual, published by Waka Kotahi NZ Transport Agency but superseded by the Monetised Benefits and Costs Manual (MBCM) in 2020
EIL	Emission Impossible Ltd
EMU	electric multiple unit, a two or three passenger car set in which one car is electrically powered
EU	European Union
FC	fuel consumption
g	gram, a unit of mass
GHG	greenhouse gas

GVM	gross vehicle mass
HAPINZ	Health and Air Pollution in New Zealand, a study of the air pollution impacts and associated social costs
HCV	heavy commercial vehicle, a commercial vehicle with a GVM >10 tonnes
ICCT	International Council on Clean Transportation
km	kilometre
kt	kilotonne
LCV	light commercial vehicle, a commercial vehicle with a GVM < 3.5 tonnes
light duty vehicle	a vehicle with a GVM < 3.5 tonnes
LTO	landing and take-off cycle of an aircraft
M	million
MBCM	Monetised Benefits and Costs Manual, published by Waka Kotahi NZ Transport Agency in 2020 replacing the Economic Evaluation Manual (EEM)
MBIE	Ministry of Business, Innovation and Employment
MCV	Medium commercial vehicle, a commercial vehicle with a GVM between 3.5 and 10 tonnes
MfE	Ministry for the Environment
mg	milligram, one thousandth of a gram
MoEd	Ministry of Education
Te Manatū Waka	Ministry of Transport
NI	North Island
NO_X	oxides of nitrogen
NO_2	nitrogen dioxide, an air quality pollutant
N_2O	nitrous oxide, a greenhouse gas (not to be confused with NO_2 which is an air quality pollutant)
NTK	Net tonne-km, the unit of measure of measurement representing the transport of one tonne of goods by a given transport mode (road, rail, air, sea, etc) over a distance of one kilometre
NZ$	New Zealand dollars
NZTA	Waka Kotahi NZ Transport Agency
PK	passenger-km, the unit of measurement representing the transport of one passenger by a defined mode of transport (road, rail, air, sea, etc) over one kilometre
PM	particulate matter, an air quality pollutant
$PM_{2.5}$	particulate matter smaller than 2.5 µm in diameter

PM_{10}	particulate matter smaller than 10 µm in diameter
SI	South Island
SO_2	sulphur dioxide, an air quality pollutant
STCC	Surface Transport Costs and Charges study, the previous study undertaken in 2005
t	tonne, a unit of mass
TTW emissions	tank-to-wheel emissions, the average GHG emissions associated with the operation (driving) of a vehicle
$\mu g/m^3$	microgram per cubic metre, a unit of air pollution concentration
µm	micrometre, one millionth of a metre
upstream emissions	the average GHG emissions associated with the production, processing and delivery of a fuel or energy vector
VEPM	Vehicle Emissions Prediction Model, developed by Waka Kotahi to predict air emissions and fuel consumption for the New Zealand fleet
VFEM	Vehicle Fleet Emissions Model, developed by Te Manatū Waka to predict the makeup, travel, energy (fuel and electricity) use and greenhouse gas emissions of the future New Zealand vehicle fleet
VKT	vehicle kilometres travelled
VOC	Volatile organic compounds
Waka Kotahi	Waka Kotahi NZ Transport Agency
WHO	World Health Organization
WiM	weight in motion, devices designed to capture and record the axle weights and gross vehicle weights as vehicles drive over a measurement site
WTT emissions	well-to-tank emissions, the average GHG emissions associated with the production, processing and delivery of a fuel or energy vector
WTW emissions	well-to-wheel emissions, the combined GHG emissions associated with the production, processing, delivery and use of a fuel or energy vector, i.e. WTW=WTT+TTW.

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Appendix C: Supporting data

This appendix lists supporting data used in the assessment of emissions and subsequent costs.

Appendix C1. Sulphur content of New Zealand transport fuels

Table C. 1 Sulphur content of New Zealand transport fuels in 2019

Fuel type	Sulphur concentration	Sulphur content (g/kg)	Fuel density (kg/litre)	Sulphur content (g/litre)
Diesel	10ppm	0.01	0.84	0.008
Petrol (regular)	10ppm	0.01	0.75	0.008
Marine diesel oil	10ppm	0.01	0.84	0.008
Heavy fuel oil*	2.7wt%	27	0.95	25.65
Jet fuel	0.05wt%	0.5	0.80	0.40

* The sulphur contents are all based on the relevant NZ petroleum fuels specifications except for heavy fuel oil which is based on the *Auckland Air Emissions Inventory 2016 - Sea Transport* (Peeters 2018)

Appendix C2. Average passenger vehicle occupancy

Table C. 2 Average light 4-wheeled vehicle occupancy (people/km) by region (TV010 indicator from Te Manatū Waka 2015)

Region	2009-2013	2010-2014
Auckland	1.51	1.51
Bay of Plenty	1.60	1.62
Canterbury	1.60	1.59
Gisborne	1.76	1.55
Hawkes Bay	1.60	1.53
Manawatu/Whanganui	1.55	1.55
Nelson/Marlborough	1.57	1.65
Northland	1.74	1.75
Otago	1.64	1.58
Southland	1.65	1.56
Taranaki	1.73	1.81
Waikato	1.66	1.67
Wellington	1.59	1.58
West Coast	1.69	1.64
National	1.59	1.58

Using the 2011-2014 data, based on the ratio of driver to passenger distance travelled, the average distance weighted occupancy comes out at 1.56 (McSaveney 2020).

Appendix C3. Average load per commercial vehicle category

C3.1 Defining average payloads

Average payloads by the main vehicle types were estimated for the DTCC paper (WP 5) on vehicle operating costs (Paling & King 2020). These are based on the average laden weights recorded at the seven Weigh in Motion (WiM) sites across the country and assumptions partly based on WIM data on the typical vehicle tare weights. These typical payloads are set out in Table C. 3.

Table C. 3 Typical pay loads by vehicle type

Vehicle type	GVW (t)	Tare (t)	Average payload (t)
Courier van			0.5
2 axle rigid	6.3	3.5	2.8
3 axle rigid	14.2	8.5	5.7
4 axle rigid	17.5	11	6.5
44T 8 axle truck and trailer	34.4	20	14.4
50 MAX	39.3	22	17.3

C3.2 Impact of containers

Some of the loads carried by the heaviest vehicles are transported in ISO containers and as a result the payloads set out in Table A.3 above include the weight of the container and would therefore, in principle, overestimate the actual weight of the commodities carried. However, the weight of containers and the constraints imposed by their fixed size mean that these are not in general an efficient way to transport freight on a journey entirely by road. While containers are moved by road as part of intermodal trips, this is mainly made up of short-distance movements, and their use for long distance movements is very limited.

A review of container weights versus freight suggests that the estimated container tonne-kms would be only about 0.5 per cent of the total freight moved and can therefore be considered negligible (Paling & King 2020).

C3.3 Assigning values to comparable fleet categories

The road transport types shown Table C. 3 (based on WiM data) were then matched to comparable categories in the New Zealand fleet to produce the average load per vehicle estimates shown in Table A.4 for the emissions assessment.

The MCV diesel 7.5-10t average payload in Table C. 4 was based on the 2-axle rigid payload in Table C. 3. For the HCV categories, averaging was undertaken across values in the size ranges shown in Table C. 3. For example, the HCV diesel 25-30t average payload in Table C. 4 was the average of the 4-axle rigid and 44T 8-axle truck and trailer in Table C. 3.

Very minor adjustments were made to get the predicted overall heavy fleet average and the predicted NTK overall to match the figures in the 2019 New Zealand Vehicle Fleet Statistics (Te Manatū Waka 2020b).

Table C. 4 Average load per commercial vehicle category based on Paling & King (2020)

Size	Type	VEPM Fleet VKT%	Average Freight (t) per LCV	Average Freight (t) per MCV	Average Freight (t) per HCV
LCV	Petrol <3.5t	3.15%	0.5		
	Diesel <3.5t	15.86%	0.5		
	Hybrid <3.5t	0.00%	0.5		
	Plugin hybrid <3.5t	0.00%	0.5		
	Electric <3.5t	0.02%	0.5		
MCV	Diesel 3.5-7.5t	1.28%		2.4	
	Diesel 7.5-10t	0.54%		2.8	
	Electric <10t	0.00%		2.6	
HCV	Diesel 10-20t	0.77%			4.25
	Diesel 20-25t	0.87%			6.1
	Diesel 25-30t	1.35%			10.45
	Diesel >30t	1.64%			15.85
	Electric >10t	0.00%			6.9
VKT weighted average			0.50	2.52	10.51
Overall average load 8.26 t per heavy vehicle (MCV+HCV)*					

* This matches the average of 8.26 t per heavy vehicle for 2018/19 reported by Te Manatū Waka (2020b)

Appendix C4. Domestic airports assessed

Table C. 5 Regional airports assessed in the domestic aviation impacts chapter with their urban/rural category for assignation of LTO emissions. Data taken from Airways Ltd (2020).

Region	Airport	Area	LTO* cycles
Auckland	Auckland	Urban	57,404
Bay of Plenty	Rotorua	Rural	4,574
	Tauranga	Urban	7,192
Canterbury	Christchurch	Urban	34,823
Gisborne	Gisborne	Urban	3,869
Hawkes Bay	Napier	Rural	9,255
Manawatu/Whanganui	Palmerston North	Urban	8,757
Nelson/Marlborough	Blenheim	Rural	8,348
	Nelson	Urban	14,196
Northland	Kerikeri	Rural	1,578
	Whangarei	Urban	1,762
Otago	Dunedin	Rural	5,831
	Queenstown	Urban	6,679
Southland	Invercargill	Urban	3,420
Taranaki	New Plymouth	Rural	6,600
Waikato	Hamilton	Rural	11,776
	Taupo	Rural	1,688
Wellington	Wellington	Urban	40,938
National			228,687

* LTO movements are for instrument flight rules movements only as these represent the large commercial services which use jet fuel.

Timaru and Hokitika airports, which are part of Air New Zealand's network, are not included here and were not assessed because aircraft movements were not available.

Airports are classified as urban based on their proximity to the urban area (i.e. within 2 km). This means that airports located on the city fringe are classified as *urban* (e.g. Christchurch), while the remaining airports are classified as *rural*.

Appendix C5. Domestic seaports assessed

Table C. 6 Regional seaports assessed in the domestic shipping chapter with their urban/rural category for assignation of at-berth emissions. The number of visits at each port by vessel type for 2019 from Stone (2020).

Region	Port Name	Area	Ship Visits to NZ Ports			
			NZ Container	Int'l Container	NZ Bulk/Cargo	NZ Tanker
Auckland	Ports of Auckland Ltd	Urban	52	118	121	52
Bay of Plenty	Port of Tauranga	Urban	52	468	78	22
Canterbury	Port of Lyttelton	Urban	52	155	49	13
Canterbury	Port of Timaru	Urban	0	36	83	4
Hawkes Bay	Port of Napier	Urban	0	38	12	9
Nelson/Marlborough	Port of Nelson	Urban	52	143	57	10
Northland	North Port (Marsden Pt)	Rural	0	0	299	142
Otago	Port Chalmers	Rural	0	56	35	11
Southland	South Port (Bluff)	Rural	0	3	5	8
Taranaki	Port of Taranaki	Urban	0	0	63	2
Wellington	CentrePort	Urban	0	19	24	11
National			208	1,037	826	284

The ports above are those identified by the *National Freight Demand Study* (Te Manatū Waka 2019b) as having substantial movements of coastal freight.

Appendix C6. School bus activity data

Table C. 7 School bus activity data and assumptions 2018/19 (MoEd 2020, Wallis 2021)

School bus service	In service VKT* (million)	Dead running %	VKT with dead running (million)	No of routes	Average daily km/route*	Average passenger numbers	Occupancy %	Average passengers per route	Annual PK* (million)
Daily bus	17.142	70%	29.14	1,455	61.36	34.65	40%	13.86	237.58
Technology bus	0.665	35%	0.90	629	5.50	31.85	100%	31.85	21.17
Direct-resourced	9.986	35%	16.98	558	88.45	35.68	40%	14.27	135.24
Total	27.793		47.02						394.00

* the values in these columns are calculated based on in service VKT only (ie without dead running)

Note: The assumptions for dead running and occupancy were provided by Wallis (2021). All other data shown were provided by MoEd (2020).

Appendix C7. Public transport activity rates by region

Table C. 8 Public transport activity rates by region 2018/19 (NZTA 2020c, MoEd 2020)

Region	Urban bus VKT (million)	Urban bus PK (million)	School bus VKT (million)	School bus PK (million)	Urban rail VKT (million)	Urban rail PK (million)	Urban ferry VKT (million)	Urban ferry PK (million)
Auckland	71.27	567.83	n/a	n/a	4.34	260.58	1.46	87.40
Bay of Plenty	7.21	25.90	n/a	n/a	-	-	-	-
Canterbury	18.29	134.25	n/a	n/a	-	-	0.05	0.45
Gisborne	0.13	1.01	n/a	n/a	-	-	-	-
Hawkes Bay	1.18	7.99	n/a	n/a	-	-	-	-
Manawatu/Whanganui	1.85	15.37	n/a	n/a	-	-	-	-
Nelson/Marlborough	0.60	3.56	n/a	n/a	-	-	-	-
Northland	0.61	5.46	n/a	n/a	-	-	-	-
Otago	6.22	23.49*	n/a	n/a	-	-	-	-
Southland	0.35	2.37	n/a	n/a	-	-	-	-
Taranaki	0.92	8.30	n/a	n/a	-	-	-	-
Waikato	7.27	41.14	n/a	n/a	-	-	-	-
Wellington	17.29	186.69	n/a	n/a	3.59	339.53	0.10	2.20
West Coast	0.15	1.14*	n/a	n/a	-	-	-	-
National	133.34	1,024.49	47.02	394.00	7.93	600.11	1.60	90.05

* Urban 2018/19 PK data for Otago and West Coast were missing from the *PT Performance* spreadsheet so Otago was estimated from the PK/VKT ratio in the previous year (3.775) and West Coast was assumed to have the same PK/VKT ratio as Gisborne.

Note: All VKT data shown includes dead running. School bus data were only available as national totals and were not broken down by region and are therefore marked as 'n/a'.

Appendix C8. Total and normalised emissions costs for New Zealand in 2018/19

Table C. 9 Total air quality and greenhouse gas emissions costs for all transport modes in New Zealand in 2018/19. All costs in June 2019 prices.

Mode	Urban			Rural			National		
	AQ	GHG	Total	AQ	GHG	Total	AQ	GHG	Total
Passenger transport ($M)	**$486 M**	**$380 M**	**$867 M**	**$68 M**	**$604 M**	**$672 M**	**$555 M**	**$984 M**	**$1,539 M**
Passenger car	$385	$333	$718	$64	$508	$572	$449	$841	$1,289
Coach	$2.4	$0.8	$3.2	$0.6	$2.9	$3.5	$3.0	$3.7	$6.7
Other bus	$4.4	$1.7	$6.1	$1.2	$5.8	$7.0	$5.6	$7.5	$13
Motorcycle	$9.4	$1.4	$11	$1.4	$2.2	$3.6	$11	$3.6	$14
Long-distance rail	$0.18	$0.03	$0.2	$0.06	$0.13	$0.2	$0.2	$0.2	$0.4
Domestic aviation	$18	$22	$41	$0.4	$81	$81	$19	$103	$122
Urban bus	$51	$16	$68	-	-	-	$51	$16	$68
School bus	-	-	-	$0.8	$3.9	$4.8	$0.8	$3.9	$4.8
Urban rail	$1.0	$1.0	$2.0	-	-	-	$1.0	$1.0	$2.0
Urban ferry	$14	$3.7	$18	-	-	-	$14	$3.7	$18
Freight transport ($M)	**$559 M**	**$192 M**	**$751 M**	**$93 M**	**$500 M**	**$592 M**	**$652 M**	**$691 M**	**$1,343 M**
LCV	$327	$120	$447	$43	$183	$226	$370	$303	$673
MCV	$33	$11	$43.6	$9	$37	$45.8	$42	$48	$89
HCV	$137	$55	$192	$36	$189	$225	$173	$244	$417
Electric locomotive	$0	$0.02	$0.02	$0	$0.1	$0.1	$0	$0.1	$0.1
Diesel locomotive	$15	$2.7	$18	$4.2	$10	$15	$19	$13	$32
Coastal freighter	$47	$3.1	$50	$0.4	$81	$81	$48	$84	$131
Total all ($M)	**$1,045 M**	**$572 M**	**$1,617 M**	**$161M**	**$1,103 M**	**$1,265 M**	**$1,206 M**	**$1,676 M**	**$2,882 M**

Table C. 10 Normalised air quality and greenhouse gas emissions costs for all transport modes in New Zealand in 2018/19. All costs in June 2019 prices.

Mode	Urban			Rural			National		
	AQ	GHG	Total	AQ	GHG	Total	AQ	GHG	Total
Passenger transport - ave (c/PK)	**1.6**	**1.3**	**2.9**	**0.2**	**1.6**	**1.8**	**0.8**	**1.5**	**2.3**
Passenger car	1.7	1.5	3.3	0.2	1.5	1.7	0.8	1.5	2.3
Coach	2.0	0.7	2.7	0.2	0.7	0.9	0.6	0.7	1.3
Other bus	1.6	0.6	2.3	0.1	0.6	0.8	0.5	0.6	1.1
Motorcycle	5.8	0.9	6.6	0.5	0.9	1.4	2.5	0.9	3.4
Long-distance rail	0.9	0.1	1.0	0.1	0.1	0.2	0.2	0.1	0.3
Domestic aviation	0.3	0.4	0.7	0.02	5.1	5.2	0.3	1.4	1.7
Urban bus	5.0	1.6	6.6	-	-	-	5.0	1.6	6.6
School bus	-	-	-	0.2	1.0	1.2	0.2	1.0	1.2
Urban rail	0.2	0.2	0.3	-	-	-	0.2	0.2	0.3
Urban ferry	15.7	4.1	19.9	-	-	-	15.7	4.1	19.9
Freight transport – ave (c/NTK)	**4.5**	**1.6**	**6.1**	**0.3**	**1.8**	**2.2**	**1.7**	**1.8**	**3.4**
LCV	18.0	6.6	24.6	1.6	6.6	8.2	8.1	6.6	14.7
MCV	6.5	2.2	8.7	0.5	2.2	2.7	1.9	2.2	4.0
HCV	2.6	1.0	3.6	0.2	1.0	1.2	0.7	1.0	1.8
Electric locomotive	0.0	0.1	0.1	0.0	0.07	0.07	0.00	0.07	0.07
Diesel locomotive	2.3	0.4	2.7	0.1	0.3	0.5	0.5	0.4	0.9
Coastal freighter	1.2	0.1	1.3	0.0	6.5	6.6	0.9	1.6	2.5

Note:

1. Air quality and greenhouse gas emissions released by domestic aviation during landing and take-off and by coastal freighters at berth are assigned to urban/rural based on port location.
2. Greenhouse gas emissions released by domestic aviation while at altitude (cruise) and by coastal freighters at sea are assigned to rural areas only.

Appendix D: Listing of DTCC Working Papers

The table below lists the working papers prepared as part of the DTCC study, together with the consultants responsible for their preparation.

Ref	Topic/working paper title	Principal Consultants	Affiliation
	MODAL TOPICS		
C1.1	Road Infrastructure – Marginal Costs	David Lupton	David Lupton & Associates
C1.2	Road Infrastructure – Total & Average Costs	David Lupton	David Lupton & Associates
C2	Valuation of the Road Network	Richard Paling	Richard Paling Consulting
C3	Road Expenditure & Funding Overview	Richard Paling	Richard Paling Consulting
C4	Road Vehicle Ownership & Use Charges	Richard Paling	Richard Paling Consulting
C5	Motor Vehicle Operating Costs	Richard Paling	Richard Paling Consulting
C6	Long-distance Coaches	David Lupton	David Lupton & Associates
C7	Car Parking	Stuart Donovan	Veitch Lister Consulting
C8	Walking & Cycling	Stuart Donovan	Veitch Lister Consulting
C9	Taxis & Ride-hailing	Stuart Donovan	Veitch Lister Consulting
C10	Micromobility	Stuart Donovan	Veitch Lister Consulting
C11.2	Rail Regulation	Murray King	Murray King & Francis Small Consultancy
C11.3	Rail Investment	Murray King	Murray King & Francis Small Consultancy
C11.4	Rail Funding	Murray King	Murray King & Francis Small Consultancy
C11.5	Rail Operating Costs	Murray King	Murray King & Francis Small Consultancy
C11.6	Rail Safety	Murray King	Murray King & Francis Small Consultancy
C12	Urban Public Transport	Ian Wallis & Adam Lawrence	Ian Wallis Associates
C14	Coastal Shipping	Chris Stone	Rockpoint Corporate Finance
C15	Cook Strait Ferries	Chris Stone	Rockpoint Corporate Finance
	SOCIAL AND ENVIRONMENTAL IMPACT TOPICS		
D1	Costs of Road Transport Accidents	Glen Koorey	ViaStrada
D2	Road Congestion Costs	David Lupton	David Lupton & Associates
D3	Health Impacts of Active Transport	Anja Misdrak & Ed Randal	University of Otago (Wellington)
D4	Air Quality & Greenhouse Gas Emissions	Gerda Kuschel	Emission Impossible
D5	Noise	Michael Smith	Altissimo Consulting
D6	Biodiversity & Biosecurity	Stephen Fuller	Boffa Miskell

Note: The above listing incorporates a number of variations from the initial listing and scope of the DTCC working papers as set out in the DTCC Scoping Report (May 2020).

Domestic Transport Costs and Charges Study

Working Paper D4

Air quality and GHG emissions

transport.govt.nz

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