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Carbon Emission Baseline Recommendations for New Zealand Infrastructure Projects

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Waka Kotahi Carbon Baselines Project

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Carbon Emission Baseline Recommendations for New Zealand Infrastructure Projects

Client: Waka Kotahi

Co No.: N/A

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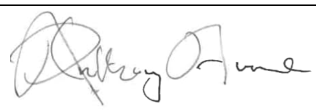
1	27-July-2023	Draft	Anthony Hume Practice Lead - Sustainability and Resilience	
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Executive Summary

This study has collected data from a range of sources to enable the creation of carbon emission baselines for land-based infrastructure projects, and to compare emissions from New Zealand projects with projects internationally. The carbon emissions baselines recommended in this document, alongside the footprint data collected for this study, are intended to be used to assess current and future infrastructure-related emissions and will support understanding of the transport sector's contribution to New Zealand's emissions.

This study considers greenhouse gas emissions across the life cycle of the infrastructure project including construction, operation, and maintenance. Additional analysis has been provided in some cases to improve understanding of the data and results.

Carbon Emission Baselines

Carbon emission baselines have been recommended based on analysis of the collected datasets. Where possible, baselines have been recommended based on projects in New Zealand and Australia only as these best represent the likely emissions from New Zealand projects.

Table 1 Summary of infrastructure construction emission baseline recommendations.

Project Category	Infrastructure Type	Footprints included	Emissions baseline recommendation (tCO_2e/lane km)	Level of confidence
Road	Road/Busway/Path	28	2,320	Moderate
	Road/Busway/Path – Bridge Only	4	9,080	Low
	Road/Busway/Path – Tunnel Only	4	7,720	Low
	Intersection Improvements – without major structures or earthworks *	39	2,740	High
	Intersection Improvements – with major structures or earthworks *	6	6,280	Low
	Safety and Traffic flow improvements *	29	1,270	High
Shared Path	Shared Path – without major structures or earthworks *	2	40	Very Low
	Shared Path – with major structures or earthworks	2	5,970	Very Low
Rail	Rail route	14	9,610	Moderate
	Rail – Tunnel Only	2	40,000	Low

* 'Footprints included' contains UK and Ireland footprints (not just Australia and New Zealand footprints)

Table 2 Summary of infrastructure operation and maintenance emissions baseline recommendations

Project Category	Infrastructure Type	Footprints included	Emissions baseline recommendation (tCO_2e/lane km/year)	Level of confidence
Road	Road/Busway/Path – without major structures or earthworks *	4	30	Low
	Road/Busway/Path – with major structures or earthworks *	21	70	Moderate
	Road/Busway/Path – Tunnel Only	3	840	Low
	Intersection Improvements *	2	90	Low
Shared Path	Shared Path – without major structures or earthworks	1	8	Very Low
Rail	Rail route	13	290	Low
	Rail – Tunnel Only	2	560	Very Low

* 'Footprints included' contains UK and Ireland footprints (not just Australia and New Zealand footprints)

- Further data collection, especially of projects in New Zealand will be required to enable more confident recommendations for New Zealand-specific baselines. Any future work to update the recommended baselines will have to consider the limitations of this work. A larger sample of footprints for all categories and greater detail into the inputs and results of each footprint would improve the reliability and accuracy of the results.

Additional Findings:

Data availability

- Through the collection of footprint data, it was discovered that carbon emissions footprints for infrastructure projects were not widely available. This is reflected in the low number of footprints within some project categories.
- Collected footprint data was not all reported using the same criteria (e.g., inclusions and exclusions, and calculation methodologies), this created issues of comparability between differently reported footprints. This has been considered throughout.
- Insufficient data availability for road area (m^2), and limitations in estimating this data have meant that emissions per road area (tCO_2e/m^2) calculations did not produce a usable and comparable result.

Comparison of New Zealand infrastructure emission footprints to footprints internationally

- When using comparable metrics such as tCO_2e/lane km, New Zealand land-based transport infrastructure emissions construction footprints are similar to footprints from the UK, Australia and Ireland. New Zealand operation and maintenance footprints are similar to UK footprints and generally smaller than footprints from Australia.
  - One exception to this is for road/busway/shared path construction where UK projects tend to have higher per lane km emissions than New Zealand projects.

Impact of major structures and earthworks on emissions

- The presence of structures (such as bridges), and significant earthworks (such as tunnels and major cuttings) results in higher emissions per lane km when compared to projects without.

Road construction emission sources

- Embodied emissions from construction materials represents the largest source of road construction emissions (65%), followed by on-site fuel and energy use (21%) and 'other' emissions (8%). Due to the use of averages, the sum of these proportions does not add to 100%.

Correlation of project cost and emissions

- There is a strong correlation between project cost and emissions for projects in this dataset. An average of 190 tCO_2e/ $1M NZD (all projects) and 130 tCO_2e/ $1M NZD (New Zealand and Australia projects only) was found. These rates can be used to estimate emissions at a very early project stage with a high level of uncertainty.

1.0 Introduction

Waka Kotahi NZ Transport Agency (Waka Kotahi) commissioned AECOM to develop carbon emissions baselines for the construction, operation, and maintenance of land-based transport infrastructure. These baselines can be used to benchmark the emissions impact of infrastructure projects and estimate emissions in the absence of measured data.

Under the Government Policy Statement for Land Transport 2021, climate change is a strategic priority and Waka Kotahi has a key role to play through prioritising investment decisions funded by the National Land Transport Fund to support the transition to a low carbon land transport system[1]. Further, Waka Kotahi has direction to reduce emissions from vehicles and infrastructure from the Emissions Reduction Plan[2] and Carbon Neutral Government Programme[3].

The carbon emissions baselines recommended in this document, alongside the footprint data collected for this study, are intended to be used to assess current and future infrastructure-related emissions and will support understanding of the transport sector's contribution to New Zealand's construction and operation and maintenance emissions. This work will also support the development of the Waka Kotahi resource efficiency work programme[4], which includes an update to the Project Emissions Estimation Tool (PEET) developed and supported by AECOM for Waka Kotahi, Auckland Transport, and Kiwirail.

The analysis and results presented here builds on, and supersedes, the "Carbon Emissions Baseline Recommendations for NZ Infrastructure Projects" report published in January 2022, and the "Carbon Emissions Baseline Addendum" published in November 2022. This update includes additional data collected since the previous publication and focusses baseline recommendations on emissions footprints from New Zealand and Australia.

2.0 Project Scope

The purpose of this project is to:

- Establish carbon emission baselines for different categories of land-based infrastructure projects in New Zealand covering construction phase emissions, and operation and maintenance emissions, so that Waka Kotahi has information to benchmark the emissions of their projects against in the absence of measured data
- Use the carbon baselines and dataset informing them to update high level estimates within the Project Emissions Estimation Tool (PEET)
- Update the previous 'Carbon Baselines' work (published January 2022) with additional data collected, and to focus baseline recommendations on emissions footprints from New Zealand and Australia.

The work considers greenhouse gas emissions across the design/construction, operation, and maintenance life cycle stages. Not included in the scope of this study are end-of-life demolition and decommissioning emissions and emissions produced by vehicles using the infrastructure.

The emissions baseline results presented in this document should not be used as a replacement for a detailed emissions inventory for infrastructure, but rather as a starting point for further understanding of the emissions related to infrastructure. The results should be treated with caution if used as supporting evidence for investment decision making.

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[1] https://www.nzta.govt.nz/about-us/about-waka-kotahi-nz-transport-agency/environmental-and-social-responsibility/transport-transition/
[2] https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/emissions-reduction-plan/
[3] https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/carbon-neutral-government-programme/
[4] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/environment-and-sustainability-in-our-operations/environmental-technical-areas/resource-efficiency-and-waste-minimisation/

3.0 Background Information

3.1 Carbon Emission Footprints for Land Transport Infrastructure

Calculating greenhouse gas emissions through carbon emission footprints is used to understand the potential climate change effect of infrastructure projects. Footprints can be calculated during the design or construction stage (predicted emissions) or measured after completion of the project (actual emissions). Due to the limited number of actual emissions footprints in the dataset, no distinction between predicted and actual emissions are analysed in this study.

Greenhouse gases such as Methane (CH_4) and Nitrous Oxide (N_2O) contribute to infrastructure emissions footprints. However, Carbon Dioxide (CO_2) is by far the largest greenhouse gas produced in relation to infrastructure projects due to its presence in fossil fuels (such as diesel) and the embodied emissions of construction materials. Infrastructure emissions footprints report emissions in Carbon Dioxide Equivalent (CO_2e) units which combines all greenhouse gases into an equivalent unit.

Emission reduction strategies have tended to focus on emissions arising from the use of the infrastructure or simply on fuel and energy used in construction. However, efforts to address greenhouse gas emissions from buildings and infrastructure are increasingly considering whole-of-life emissions including embodied carbon.

The two categories of carbon emission footprints used in this study are:

- **Construction Emissions –** emissions related to the production of materials used for construction (capital or embodied emissions), transportation of materials required for construction, fuel or electricity used on site and disposal of materials removed from the site during construction. The construction emissions category relates to Life Cycle Assessment (LCA) modules A1-A5 (product and construction stages).
- **Operation and Maintenance Emissions –** ongoing emissions during the service life of the asset relating to electricity demands (e.g., for lighting) and maintenance (e.g., embodied material emissions and fuel use for resurfacing and repair work). The operation and maintenance emissions category relates to LCA modules B1-B7 (use stage).

Major emission sources for land-based transport infrastructure projects are:

- the embodied emissions of construction materials (especially concrete, steel and to a lesser extent asphalt)
- the embodied emissions of maintenance materials (e.g., asphalt, aggregates)
- fuel consumption (e.g., for vehicles and plant on site)
- electricity consumption (e.g., used for lighting, ventilation, and tools on site)[5][6]
- fuel or energy consumption for the transport of materials (e.g., by road, rail, or ship)

An unpublished preparatory AECOM study of carbon footprints for New Zealand infrastructure projects[7], found that fuel, concrete, steel, and aggregate were responsible for between 83% and 99% of the total emissions of the construction phase of projects in New Zealand[8].

Operation and maintenance emissions are an important aspect of whole of life emissions from a project. Literature suggests that the main operation and maintenance emissions sources are electricity used for lighting (and ventilation in tunnels), embodied emissions from materials used for maintenance and fuel used for maintenance[9][10]. The dataset collected for this study backs up these findings.

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[5] Trunzo, Moretti and D'Andrea, Life Cycle Analysis of Road Construction and Use (2019)
[6] Highways England, Highways England Carbon Tool Guidance (2020)
[7] provided to Waka Kotahi in March 2020
[8] AECOM, Carbon Footprint Stocktake - Transport Projects / Assets (2020)
[9] Trunzo, Moretti and D'Andrea, Life Cycle Analysis of Road Construction and Use (2019)
[10] European Commission, Comprehensive life cycle approach (LCA) tool applied to road construction (2013)

Emissions produced by vehicles using the infrastructure, and emissions related to the decommissioning of infrastructure, are not included in the scope of this study.

3.2 Carbon Emission Baselines for Land Transport Infrastructure

Carbon footprint baselines are used to compare, understand, and assess emissions produced by infrastructure projects. Waka Kotahi aims to use baselines from this study as a benchmark to aid assessment of the relative significance of measured and predicted emissions from different infrastructure projects and project designs.

Increased understanding and assessment of emissions from construction and operation and maintenance of infrastructure can assist Waka Kotahi in targeting emissions reductions from infrastructure activities. Research into sustainable design practices stresses the importance of addressing carbon at the earliest stage of the design process, when the most influential design decisions are made[11]. Reducing the embodied and operational carbon associated with infrastructure projects has the added benefits of reducing costs, unlocking innovation, driving better solutions in the market, and driving resource efficiency[11][12].

Alongside assessing and reporting total emissions from infrastructure projects, it is important to look at emissions in relation to the size of the project to enable comparison between projects of varying sizes[13]. For this reason, a per-lane-kilometre figure is used as the basis for this assessment.

3.3 Carbon Emission Baselines and the Project Emissions Estimation Tool (PEET)

PEET is a tool developed by AECOM, Waka Kotahi, Auckland Transport, and Kiwirail used to calculate high-level estimates of GHG emissions based on industry research and standard design examples. It uses data from various aspects of a project lifecycle including:

- construction (for road and rail projects)
- operations and maintenance (for road and rail)
- enabled emissions from vehicle use
- avoided emissions from use of public transport or active modes.

AECOM worked alongside Waka Kotahi the New Zealand Transport Agency, Auckland Transport, and Kiwirail to develop the tool. The information from PEET can be used to inform decisions throughout the business case process and can also be used to compare the emissions profiles of different design options, during optioneering phases.

The carbon baselines and the dataset collected for this study are used to inform the first order estimates in PEET as well as estimations for fuel used in material transport and the construction of site works. This revision will be used to update values in the next version of PEET to enhance the accuracy of the PEET tool.

[11] Urban Insight, Carbon Cost in Infrastructure (2020)
[12] HM Treasury, Infrastructure Carbon Review (2013)
[13] Future Cities, Building Canada's Low-Carbon Approach to Infrastructure Investments (2017)

4.0 Approach and Method

This section describes key aspects of the approach and method, including data collection sources and calculation methodology. Limitations and assumptions are described in section 9.0.

4.1 Data Collection

For this project, comparable carbon footprints were required to calculate a reliable emissions baseline. Data collection focused on infrastructure footprints in New Zealand, Australia, the UK, Ireland, and the USA. These countries were chosen because construction and maintenance standards, construction materials, and other aspects of construction and use were determined to be largely comparable to New Zealand infrastructure projects. The differences between infrastructure projects and emissions reporting between these countries are outlined in the limitations and assumptions section (section 9.0). Where possible, the analysis focusses on emissions footprints from New Zealand and Australia.

Data was collected for construction carbon footprints, and operation and maintenance carbon footprints for infrastructure projects in the period from 2000 to 2023. These projects were classified by ‘project type’ in line with the definitions in Table 3, with the acknowledgment that many infrastructure projects will include elements of multiple ‘project types’. Where this was the case, projects were classified in line with the ‘project type’ which describes the majority or core purpose of the project. Projects were also classified as to whether they included major structures or earthwork. The effect of having ‘major structures or earthworks’ is likely to increase the emissions footprint significantly due to increased steel, concrete or fuel use compared to at-grade designs.

The nature of infrastructure construction projects that have historically completed carbon assessments tend to be large-scale, high cost, infrastructure initiatives which have particular social or political importance. Therefore, these types of projects are common in the database used in this analysis, and smaller scale projects with a lower cost and scale of construction (and therefore lower carbon impact) are underrepresented. Projects that use a lower cost and carbon impact approach by repurposing existing assets through road space allocation are not well represented in this database, this is especially true of projects than involve the creation of on road bus lanes, on road cycle paths and shared use spaces. Lower carbon impact approaches, such as utilising existing assets, should be considered ahead of carbon-intensive options such as fully new infrastructure.

Table 3 Infrastructure classification descriptions

Project Category	Infrastructure Type	Definition
Road	Road/Busway/Path	Refers to projects that cover the construction of new roads, busways and road widening projects and projects that include paths. If there was no obvious category to allocate projects to, they were allocated to the Road/Busway/Path infrastructure type. If most of the project is a bridge or tunnel, then classify as bridge only or tunnel only.
	Road/Busway/Path Bridge Only	Refers to projects where most of the footprint involves the construction of a bridge
	Road/Busway/Path Tunnel Only	Refers to projects where most of the footprint involves the construction of a tunnel
	Intersection improvements	Refers to junction improvements. This includes changes to roundabouts, signalised intersections, and flyovers.
	Safety and traffic flow improvements	Refers to projects which include installation of smart motorways, safety barriers and lane layout/widening
Rail	Rail improvements	Refers to projects with light treatments such as electrification, signalling upgrades, re-sleepering, turnout replacements
	Rail intersection improvements	Refers to junction improvements. This includes changes to roundabouts, signalised intersections, and flyovers.
	Rail route	Refers to projects that cover the construction of new rail routes. If much of the project is a bridge or tunnel, then classify as bridge only or tunnel only.
Shared Path	Shared Path Only	Refers to projects that include walking and/or cycling paths where isolated from other road construction works

A summary of data sources is found in Table 4.

Table 4 Summary of data sources by country

Source Country	Data Sources

New Zealand	• AECOM in New Zealand
	  o Existing New Zealand footprints collected by AECOM for a previous project with Waka Kotahi
	  o Footprints calculated by AECOM for Waka Kotahi
	• Greenroads International
	• Infrastructure Sustainability Council (ISC)

Australia	• AECOM in Australia • Infrastructure Sustainability Council (ISC) • Additional footprints sourced where publicly available
UK and Ireland	• AECOM in the UK • Highways England • CEEQUAL
USA	• AECOM in the USA

Differences in footprint reporting standards meant that some footprints included both construction and in-use emissions in the footprint. In these cases, construction and operation and maintenance (in-use) emissions have been separated into different footprints.

Some footprint data was produced as aggregated figures due to commercial sensitivity; these have been separated into separate footprints based on the number of footprints and known total lane kilometres. Where this is significant to the analysis in this report, this has been noted.

Estimations and assumptions used to fill data gaps are outlined in the limitations and assumptions section (Section 9.0).

4.2 Calculation

The calculation and analysis methodology involved collating data into comparable categories, calculating comparable emissions measurements and finding average emissions measurements for each category. The calculations methodology is further outlined below.

Calculation methodology for construction, and operation and maintenance carbon footprint baselines:

- Data from each carbon footprint was designated into a category that aligns with the high-level groupings of Waka Kotahi activity classes. The categories and some of the relevant work categories that are applicable to them are listed below.
  - Public Transport
    - PT information, PT Infrastructure development, PT infrastructure maintenance & Renewal, PT Services, Total Mobility
  - Walking and Cycleway
    - Walking and cycling facilities, low-cost low-risk improvements
  - Road Improvements
    - Bridges structures replacement, minor improvements, new roads and bridges, property purchase, resilience improvements, road reconstruction, traffic management
  - Road Maintenance
    - Corridor operational traffic management, traffic services renewals, traffic services maintenance, level crossing warning devices, cycle path maintenance, emergency reinstatement, routine drainage maintenance, environmental maintenance, drainage renewals, environmental renewals, footpath maintenance, pavement and seal maintenance, structures maintenance
- The footprints were then labelled based on the life cycle covered as either construction, operations and maintenance, operations, or maintenance. When a footprint covered multiple phases of a life cycle it was separated out appropriately.
- The footprints were then assigned a project category and infrastructure type in alignment with Table 3 above.
- Footprints were checked for comparability, and data gaps or differences were filled where possible (refer section 9.0).
- Footprint data for operation and maintenance was converted to a per-year figure to enable comparisons where differing timeframes had been used.
- Some of the data was provided at an aggregated level which included total emissions, project length and number of lanes. An estimate of per-project emissions was made using this data and included in the dataset.

- Lane number and road length information was estimated where it was not included in the data. From these figures, emissions per lane km (tCO_2e/lane km) were calculated for each project. For operation and maintenance, these figures were calculated per year.

Mean and median average emissions per lane kilometre were then calculated for each project type and infrastructure category, and by country.

5.0 Results

Analysis of carbon emission footprints has been conducted for the two life cycle phases of construction, and operation and maintenance footprints. An insufficient number of projects were collected to develop meaningful results for operations only, or maintenance only. Within the life cycle phases, data has been split into road, shared path, and railway project types. Road projects include road creation, widening, and junction improvements. Rail projects include new route creations, improvements and bridges or tunnels. Shared paths include walking and cycling paths.

The results presented in this section are used to inform the creation of carbon emissions baselines for infrastructure construction and infrastructure operation and maintenance. The results presented here also offer a chance to discover and discuss other findings relating to infrastructure and carbon emissions from the dataset collected.

The analysis focusses on the per lane km metric as this is the most applicable and comparable for projects across a range of scales. To take account of differences between carbon footprint reporting and to compare results for New Zealand footprints against other countries, the results have been reported by country and for the entire dataset of the category.

Discussion of the results and recommendations for carbon emission baselines is presented in Section 6.0.

5.1 Construction Emissions

5.1.1 Road Construction Emissions

The road construction emissions category contained 145 road construction carbon footprints. Road construction footprints included road/busway/path construction footprints, tunnel only construction footprints, bridge only construction footprints, intersection improvement footprints, and safety and traffic flow improvements (or similar outside of New Zealand).

Table 5 Average and range of emissions per lane km for road construction emissions, by country

	Number of Footprints	Mean average emissions per lane km (tCO_2e/km)	Median average emissions per lane km (tCO_2e/km)	Smallest emissions per lane km (tCO_2e)	Largest emissions per lane km (tCO_2e)
New Zealand	21	3,013	1,699	105	9,226
Australia	23	3,163	985	985	11,099
UK	98	3,317	2,231	364	13,265
Ireland	3	6,088	3,164	1,761	13,337
Entire Dataset	**145**	**3,314**	**2,231**	**105**	**13,337**

The New Zealand dataset contained 21 footprints, and within this there were a wide range in emissions per lane km, from 105 tCO_2e/lane km to 9,226 tCO_2e/lane km.

The entire road construction footprint dataset contained 145 footprints. The mean average of emissions per lane km from the entire dataset was 3,314 tCO_2e/lane km.

5.1.1.1 Road Construction Emissions and the Impact of Major Structures or Earthworks

Road construction footprints have been classified as either “with major structures or earthworks,” or “without major structures or earthworks.” Road structures include bridges and flyovers, while earthworks include large cuttings and tunnel construction. Footprints have been classified as ‘with major structures or earthworks” when they contain a structure or earthworks component which represents a significant proportion of the construction works.

Table 6 Average and range of emissions per lane km road construction emissions for footprints that include, or do not include, major structures or earthworks.

	Number of Footprints	Mean average emissions per lane km (tCO_2e/lane km)	Median average emissions per lane km (tCO_2e/lane km)	Smallest emissions per lane km (tCO_2e/lane km)	Largest emissions per lane km (tCO_2e/lane km)
With Major Structures or Earthworks	44	4,353	3,574	985	13,337
Without Major Structures or Earthworks	101	2,850	2,231	105	13,265
Entire Dataset	**145**	**3,306**	**2,231**	**105**	**13,337**

Of the 145 footprints in the dataset, 44 footprints were deemed to include major structures or earthworks and 101 footprints were deemed to not include major structures or earthworks.

The mean and median average emissions per lane kilometres for projects with major structures or earthworks is higher than for projects without major structures or earthworks.

5.1.1.2 Road Construction Emissions by Infrastructure Type

Within the road construction project category there are several different infrastructure types, from the construction of entirely new roads to construction of intersection improvements and safety and traffic improvements.

The Road/Busway/Shared Path infrastructure type covers the construction of new roads and road widening projects. All other categories cover specific road infrastructure project types. Where a road construction project included elements of multiple infrastructure project types, the project was allocated to the most relevant infrastructure type. If there was no obvious category to allocate projects to, these projects were allocated to the Road/Busway/Path infrastructure type.

Table 7 Average and range of emissions per lane km, by infrastructure type, for road construction footprints.

Infrastructure Type	Number of Footprints	Mean average emissions per lane km (tCO_2e/ lane km)	Median average emissions per lane km (tCO_2e/lane km)	Smallest emissions per lane km (tCO_2e/lane km)	Largest emissions per lane km (tCO_2e/lane km)
Road/Busway/Shared Path *(excluding tunnel and bridge-only projects)*	63	3,774	3,415	105	13,337
Road/Busway/Shared Path - Bridge Only	4	9,078	7,472	3,047	18,322
Road/Busway/Shared Path - Tunnel Only	5	8,408	7,751	6,014	11,163
Intersection Improvements - without major structures or earthworks	39	2,743	2,231	364	7,853
Intersection Improvements - with major structures or earthworks	6	6,283	5,234	2,140	12,171
Safety and Traffic Flow Improvements	29	1,272	1,063	335	3,860
Entire Dataset	**145**	**3,409**	**2,231**	**105**	**18,322**

The largest mean average emissions per lane km for these infrastructure types were for Road/Busway/Shared Path – Tunnels Only at 8,408 tCO_2e/lane km. The lowest mean average emissions per lane km were for Safety and traffic flow improvements at 1,272 tCO_2e/lane km.

Due to the differences in road construction and specifications used internationally versus within Australia and New Zealand the results for just Australian and New Zealand projects are shown below. The largest mean average per lane km continues to be the Road/Busway/Shared Path – Tunnels Only infrastructure type at 7,719 tCO_2e/lane km. Generally, the emissions per lane km from Australian and New Zealand projects is lower than the other international projects analysed in this study.

Table 8 Average and range of emissions per lane km, by infrastructure type, for road construction footprints in New Zealand and Australia.

Infrastructure Type	Number of Footprints	Mean average emissions per lane km (tCO_2e/ lane km)	Median average emissions per lane km (tCO_2e/lane km)	Smallest emissions per lane km (tCO_2e/lane km)	Largest emissions per lane km (tCO_2e/lane km)
Road/Busway/Shared Path *(excluding tunnel and bridge-only projects)*	28	2,317	1,023	105	5,714
Road/Busway/Shared Path - Bridge Only	4	9,078	7,472	3,047	18,322
Road/Busway/Shared Path - Tunnel Only	4	7,719	6,882	6,014	11,099
Intersection Improvements	6	3,298	2,244	974	7,548
Safety and Traffic Flow Improvements	3	831	459	335	1,699
Entire Dataset	**45**	**3,430**	**1,699**	**105**	**18,322**

5.1.2 Shared Path Construction Emissions

Only 3 shared path construction carbon footprints were included in this study, all of which were in New Zealand. Shared paths are assumed to be one ‘lane’ wide (approximately 5m).

Table 9 Average and range of emissions per lane km, for shared path construction emissions for footprints that include, or do not include, major structures or earthworks

	Number of Footprints	Mean average emissions per km (tCO_2e/ km)	Median average emissions per km (tCO_2e/ km)	Smallest emissions per km (tCO_2e/ km)	Largest emissions per km (tCO_2e/ km)
Shared path only – with major structures or earthworks	2	5,965	5,965	1,577	10,353
Shared path only - without major structures or earthworks	2	43	43	25	60
Entire Dataset	**4**	**3,004**	**819**	**25**	**10,353**

Shared path construction emissions per km range from 25 tCO_2e/km to 10,353 tCO_2e/km. The entire shared path construction footprint dataset contained 4 footprints with a mean average emissions per km of 3,004 tCO_2e/km. The data has been presented showing the results for shared paths with and without major structures or earthworks due to the large range. The two footprints with major structures or earthworks include bridges and earthworks along the route whereas the footprint without major structures or earthworks travels across relatively flat ground and does not contain any bridges or major earthworks.

5.1.3 Railway Construction Emissions

There were 16 railway footprints in this dataset and all footprints were from Australia and New Zealand. Many footprints were from three sets of aggregated data which means that it is likely that the range in results within the analysis is likely to be greater than reported here. There was insufficient information in the data provided to determine a per km rate for intersection improvements.

5.1.3.1 Rail Construction Emissions and the Impact of Major Structures or Earthworks

Rail construction footprints have been classified as either “with major structures or earthworks,” or “without major structures or earthworks.” Rail structures include bridges and flyovers, while earthworks include large cuttings and tunnel construction. Footprints have been classified as ‘with major structures or earthworks” when they contain a structure or earthworks component which represents a significant proportion of the construction works.

Table 10 Average and range of emissions per km, for railway construction footprints that include, or do not include, major structures or earthworks.

	Number of Footprints	Mean average emissions per km (tCO_2e/ km)	Median average emissions per km (tCO_2e/ km)	Smallest emissions per km (tCO_2e/ km)	Largest emissions per km (tCO_2e/ km)
Rail - With major structures or earthworks	12	16,809	15,049	5,889	58,939
Rail - Without major structures or earthworks	4	3,217	3,217	3,217	3,217
Entire Dataset	**16**	**13,411**	**11,776**	**3,217**	**58,939**

The mean averages are the only reliable figures within these results due to the issues of aggregated data. The mean average emissions per km for rail with major structures was 16,809 tCO_2e/ km. This figure is much higher than the mean average for the 4 projects without major structures or earthworks, at 3,217 tCO_2e/ km.

5.1.3.2 Rail Construction Emissions by Infrastructure Type

Within the rail construction project category there are several different infrastructure types, from the construction of entirely new routes to construction of intersection improvements.

The rail route infrastructure type covers the construction of new railways. All other types cover specific rail infrastructure project types. Where a rail construction project included elements of multiple infrastructure project types, the project was allocated to the most relevant category. If there was no obvious category to allocate projects to, these projects were allocated to the rail route type.

Table 11 Average and range of emissions per lane km, by infrastructure type, for rail construction footprints in New Zealand and Australia.

	Number of Footprints	Mean average emissions per km (tCO_2e/ km)	Median average emissions per km (tCO_2e/ km)	Smallest emissions per km (tCO_2e/ km)	Largest emissions per km (tCO_2e/ km)
Rail route	14	9,611	8,503	3,217	15,049
Rail tunnel only	2	40,008	40,008	21,077	58,939
Entire Dataset	**16**	**13,411**	**11,776**	**3,217**	**58,939**

Due to the non-linear nature of rail intersection and rail improvements the footprints have not been included in the per km results above. The total project emissions are reported below however the variation in project size makes it difficult to establish a baseline without a common metric. Insufficient data was provided to determine a per km rate for intersection improvements.

Table 12 Average and range of overall emissions for the construction of rail improvements in Australia.

	Number of Footprints	Mean average emissions (tCO_2e)	Median average emissions (tCO_2e)	Smallest emissions (tCO_2e)	Largest emissions (tCO_2e)
Rail intersection improvements	13	33,276	39,595	12,215	39,595
Rail Improvements	1	4,211	4,211	4,211	4,211
Entire Dataset	**14**	**31,200**	**39,595**	**4,211**	**39,595**

5.2 Operation and Maintenance Emissions

5.2.1 Road Operation and Maintenance Emissions

The road operation and maintenance emissions analysis contained 30 road operation and maintenance carbon footprints. Road operation and maintenance projects include included road/busway/path construction footprints, tunnel only construction footprints, bridge only construction footprints, intersection improvement footprints, and safety and traffic flow improvements (or similar outside of New Zealand). Due to the use of aggregated data in the Australian dataset, a median figure for the dataset is not a useful measure.

Table 13 Average and range of emissions per lane km per year, by country, for road operation and maintenance footprints.

	Number of Footprints	Mean average emissions per lane km (tCO_2e/lane km/year)	Median average emissions per lane km (tCO_2e/lane km/year)	Smallest emissions per lane km (tCO_2e/lane km/year)	Largest emissions per lane km (tCO_2e/lane km/year)
New Zealand	1	6	6	6	6
Australia	22	179	25	25	1,026
UK	6	48	19	3	146
Ireland	1	20	20	20	20
Entire Dataset	**30**	**142**	**25**	**3**	**1,026**

The entire road operation and maintenance footprint dataset contained 30 footprints. The mean average of emissions per lane km per year from the entire dataset was 142 tCO_2e/lane km/year.

5.2.1.1 Road Operation and Maintenance Emissions by Project Type

Within the road operations and maintenance project category there are several different project types, from the operation and maintenance of entire roads, tunnels, or intersections.

The Road/Busway/Shared Path infrastructure type covers the operation and maintenance of roads and road widening projects. All other categories cover specific road infrastructure project types. The ‘Road/Busway/Shared Path – with major structures and earthworks’ category here does not include the tunnel only projects.

Where a road operation and maintenance project included elements of multiple infrastructure project types, the project was allocated to the most relevant category. If there was no obvious category to allocate projects to, these projects were allocated to the Road/Busway/Path infrastructure type.

Table 14 Average and range of emissions per lane km, by infrastructure type, for road operation and maintenance footprints.

Infrastructure Type	Number of Footprints	Mean average emissions per lane km (tCO_2e/ lane km/year)	Median average emissions per lane km (tCO_2e/lane km/year)	Smallest emissions per lane km (tCO_2e/lane km/year)	Largest emissions per lane km (tCO_2e/lane km/year)
Road/Busway/Shared Path – without major structures or earthworks	4	31	15	3	90
Road/Busway/Shared Path – with major structures or earthworks	21	69	25	6	161
Road/Busway/Shared Path – tunnel only	3	838	1,026	462	1,026
Intersection Improvements – with major structures or earthworks	2	86	86	27	146
Entire Dataset	**30**	**142**	**25**	**3**	**1,026**

Footprints in the 'Road/Busway/Shared Path – without major structures or earthworks' category ranged from 3 tCO_2e/lane km/year to 90 tCO_2e/lane km/year and had mean average emissions of 31 tCO_2e/lane km/year. Footprints in the 'Road/Busway/Shared Path – with major structures or earthworks' category ranged from 6 tCO_2e/lane km/year to 161 tCO_2e/lane km/year and had mean average emissions of 69 tCO_2e/lane km/year.

Notably, 'tunnel only' projects had by far the highest emissions per lane kilometre, ranging from 462 tCO_2e/lane km/year to 1,026 tCO_2e/lane km/year with mean average emissions of 838 tCO_2e/lane km/year. This is likely due to high operational energy demand for lighting, ventilation, and signage per lane km. All three of these projects are from Australia so may not be representative of tunnel projects in New Zealand where electricity is generated by a higher proportion of renewable generation.

5.2.2 Shared Path Operation and Maintenance Emissions

One shared path footprint was included in this dataset. This footprint had operation and maintenance emissions of 8 tCO_2e per km per year.

Table 15 Carbon emissions from the one footprint in the shared path operation and maintenance dataset including total and per km emissions per year.

	Number of Footprints	Total Emissions (tCO_2e/year)	Emissions per km/year (tCO_2e/km/year)
Entire Dataset	1	84	8

5.2.3 Railway Operation and Maintenance Emissions

There were 15 railway footprints in this dataset. Of the 15 footprints, 13 footprints were from Australia and all of the footprints from Australia were from three sets of aggregated data. The aggregated data means that it is likely that the range in results within the analysis is likely to be greater than reported here. The two remaining footprints were for New Zealand projects.

Table 16 Average and range of emissions per track km per year, by infrastructure type, for railway operation and maintenance footprints.

	Number of Footprints	Mean average emissions per km (tCO_2e/ km/year)	Median average emissions per km (tCO_2e/ km/year)	Smallest emissions per km (tCO_2e/ km/year)	Largest emissions per km (tCO_2e/ km/year)
Rail route	13	290	205	76	455
Railway – Tunnel Only	2	563	563	13	1,113
Entire Dataset	**15**	**327**	**205**	**13**	**1,113**

The mean averages are the only reliable figures within these results due to the issues of aggregated data. The mean average emissions per km for rail routes was 290 tCO_2e/km/year. This figure is lower than the mean average for the tunnel projects, at 563 tCO_2e/ km/year.

6.0 Discussion and Recommendations

This section presents a discussion of the analysis and provides recommendations for carbon emission baselines for New Zealand land-based infrastructure construction and operation to be used by Waka Kotahi. The results within the dataset for each category and infrastructure type is included in section 5.0.

For the recommendation of a baseline, the mean average is used due to the provision of some aggregated datasets as part of the data collected for this study. An aggregated dataset can significantly skew the median. Where the dataset of projects was too small, or where significant anomalies exist which may prevent the calculation of an accurate or usable baseline, these limitations have been stated with the recommendation as a level of confidence. For transparency we recommend stating the levels of confidence, and the limitations and assumptions presented in this report, when using these baselines.

All baselines have been recommended rounded to the nearest 10 tCO_2e.

6.1 Construction Emissions

6.1.1 Road Construction Emissions

Road Construction Emissions by Country (all infrastructure types)

The dataset for road construction emissions was made up of 145 footprints, including 21 footprints from New Zealand and 23 footprints from Australia.

Due to the different standards and specifications used in different countries the carbon footprint of similar infrastructure varies. For example, we have observed the footprint of infrastructure is often higher in the United Kingdom per lane km due to the specification standards used. Where possible based on the sample size, carbon baselines have been recommended based on the mean average of footprints from New Zealand and Australia, with the entire baseline average provided for reference and context.

Figure 1 shows the road construction footprints in the dataset and the mean average for the New Zealand footprints. It is important to note the range in emissions per lane km. Analysis of the results found that design and construction factors result in these large differences between footprints per lane km. For example, bridges tend to require significantly more concrete and steel (materials with relatively high embodied emissions) per lane km than stretches of road that do not require significant structural components, and tunnels require more fuel for earthworks and higher material-related embodied emissions than for other stretches of road. It is for this reason that our carbon baseline recommendations are based on the type of road project and elements within the project (e.g., major structures, tunnels, and bridges).

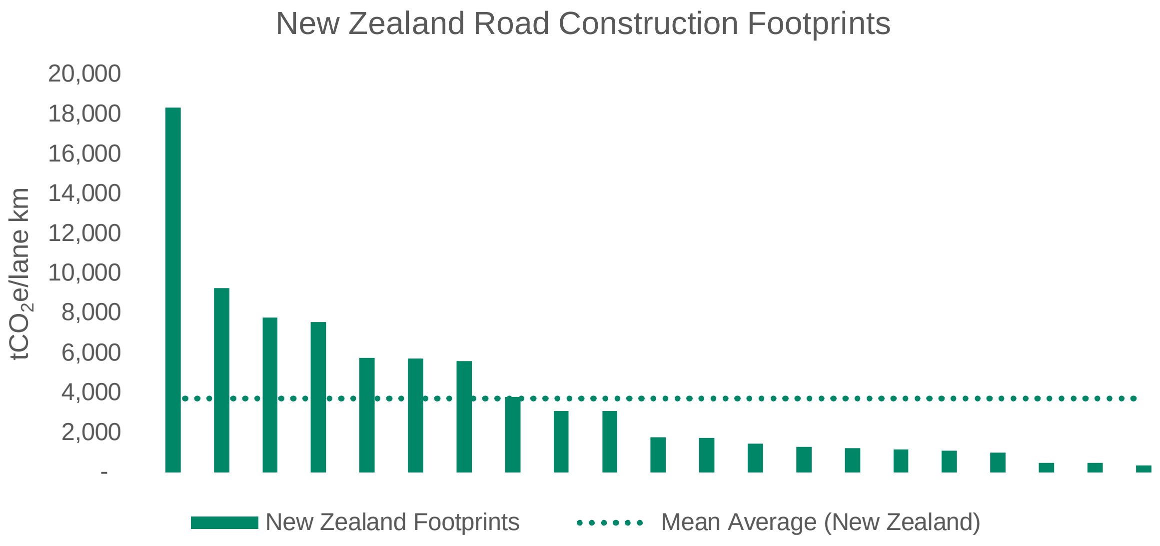

Figure 1 **New Zealand road construction footprints compared to the mean average for New Zealand projects**

6.1.1.1 Road Construction Emissions and the Impact of Major Structures or Earthworks (all infrastructure types)

We looked at the impact of structures (e.g., bridges and tunnels) and major earthworks (e.g., cuttings) on emissions from road construction projects (see Figure 2). The dataset for this analysis contained 145 footprints with 44 footprints classed as including major structures or earthworks and 101 without major structures or earthworks. Footprints which include major structures or earthworks had mean average emissions of 4,353 tCO_2e/lane km, compared to 2,850 tCO_2e/lane km for footprints without major structures or earthworks and 3,306 tCO_2e for the entire dataset. This illustrates the impact of major structures or earthworks on emissions from road construction projects.

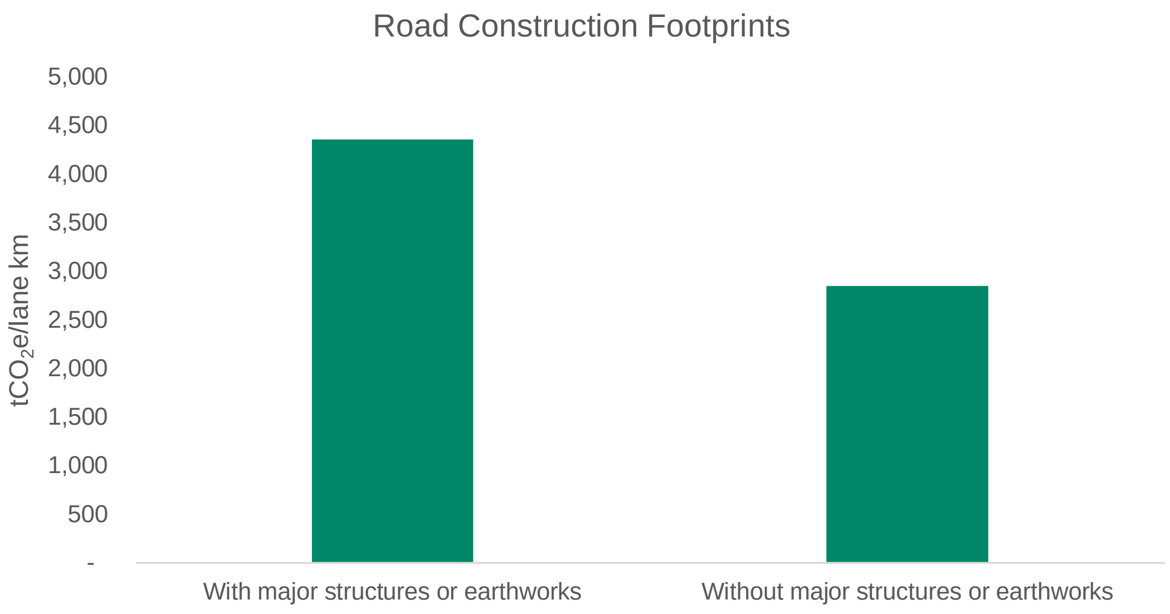

Figure 2 **Mean average carbon emissions by road type per lane km for road construction footprints which include major structures or earthworks and footprints which do not include major structures or earthworks.**

6.1.1.2 Road Construction Emissions by Infrastructure Type

Road Construction: Road/Busway/Shared Path

This infrastructure type contained 72 footprints and the mean average emissions per lane km was 4,390 tCO_2e/lane km. To create more detailed baselines, this infrastructure type was split into three subcategories:

- projects where most of the footprint involves construction of a bridge (i.e., Road/Busway/Shared Path - Bridge Only),
- projects where the vast majority of the footprint involves construction of a tunnel (i.e., Road/Busway/Shared Path - Tunnel Only).
- All other Road/Busway/Shared Path projects

Figure 3 shows the mean average per lane kilometre emissions for these infrastructure types for the entire dataset and for just New Zealand and Australian footprints. The differences between these infrastructure types shows the importance of creating three separate baselines for road/busway/share path construction.

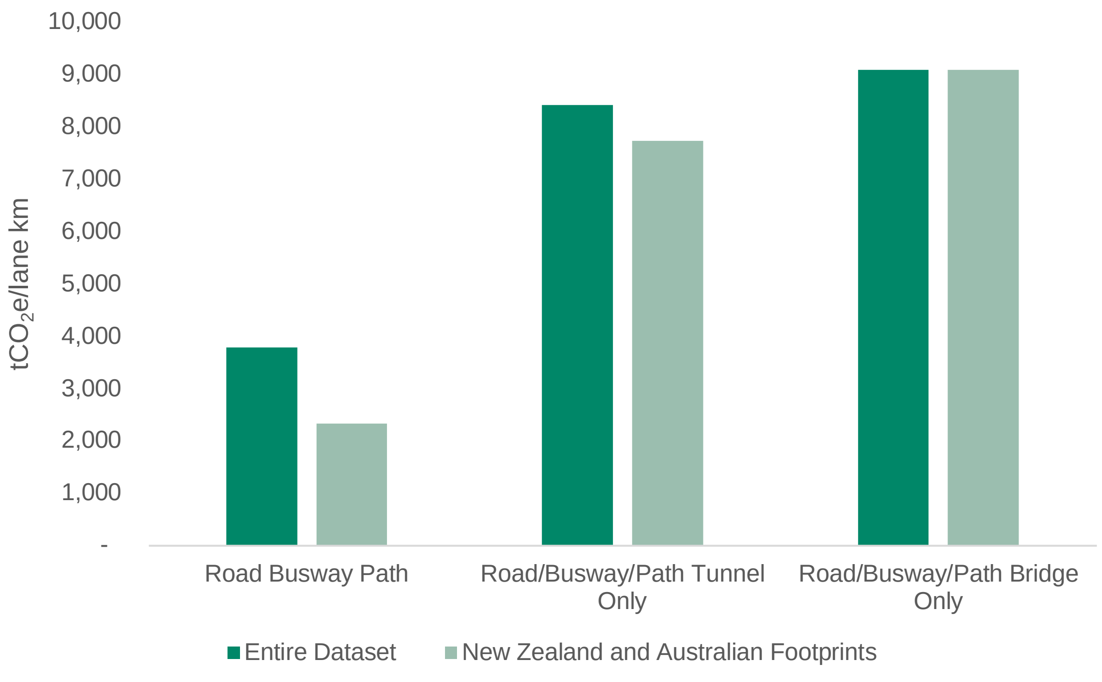

Figure 3 Mean average carbon emissions per lane km for road/busway/shared path construction footprints by infrastructure type.

For road/busway/shared path construction of bridges and tunnels only, the comparison of the entire dataset mean average per lane kilometre and the mean average for projects from New Zealand and Australia are very similar. Due to this factor and the aim to make the baseline as applicable to New Zealand, the mean average for projects from New Zealand and Australia is recommended to be used as the baseline for these infrastructure types. For New Zealand and Australian tunnel only projects, the mean average emissions per lane km was 7,719 tCO_2e/lane km. The bridge-only data base contains only footprints from New Zealand and Australia. For bridge only projects, the mean average emissions per lane km was 9,078 tCO_2e/lane km, this is the highest average emissions by project type. The tunnel and bridge averages are much higher than for other road construction infrastructure types, reflecting the greater number of materials, and the scale of the works per km required.

For road/busway/shared path construction excluding bridge and tunnel only projects, there is a large difference between the entire dataset mean average emissions per lane kilometre and the mean average for projects from New Zealand and Australia. This is due to generally higher per lane km emissions from road construction in the UK due to the specification standards used (e.g., a larger proportion of the road network construction is asphalt) and also the higher proportion of energy generation from fossil fuel sources. For this reason, the mean average for footprints from New Zealand and Australia is recommended to be used as the baseline for this infrastructure type.

Baseline recommendations for Road/Busway/Shared Path projects:

- Road/Busway/Shared Path *(excluding bridge-only and tunnel-only projects)*
  - 2,320 tCO_2e/lane km
  - Based on 28 New Zealand and Australian footprints
  - Recommended with a moderate level of confidence
- Road/Busway/Shared Path - Bridge Only
  - 9,080 tCO_2e/lane km
  - Based on 4 New Zealand and Australian footprints
  - Recommended with a low level of confidence
- Road/Busway/Shared Path - Tunnel Only
  - 7,720 tCO_2e/lane km
  - Based on 4 New Zealand and Australian footprints
  - Recommended with a low level of confidence

Road Construction: Intersection Improvements

Intersection improvements have an average emissions per lane km of 3,438 tCO_2e/lane km. Out of the intersection improvements dataset (45 projects), only 6 included major structures or earthworks. Figure 4 shows the difference in the mean average emissions per lane km for intersection improvements with and without major structures or earthworks, for the entire dataset. This difference reflects the finding that the presence of major structures or earthworks increases emissions per lane km for road construction projects.

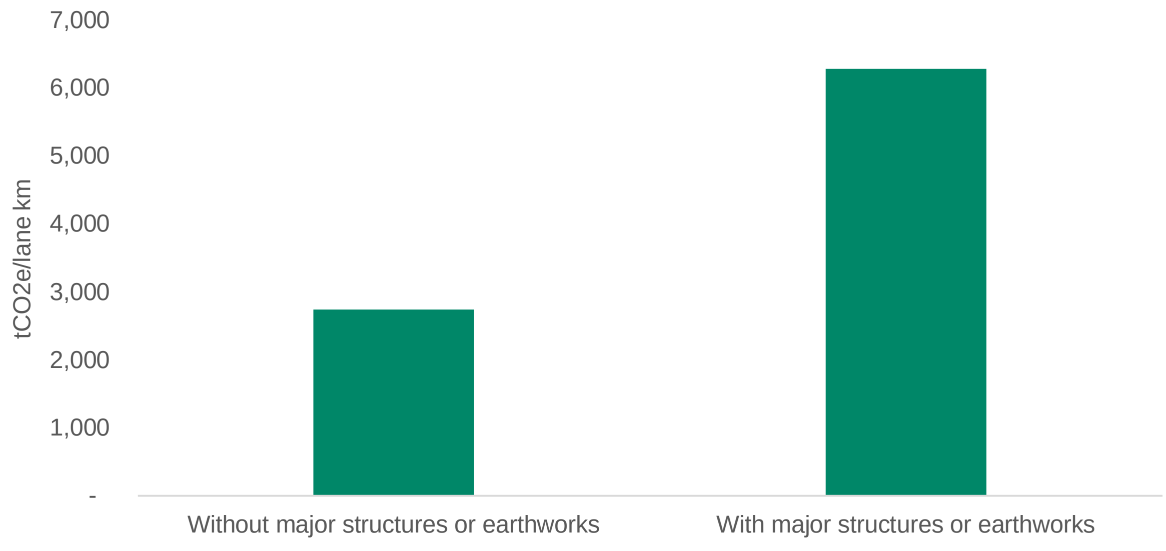

Figure 4 Mean average carbon emissions per lane km for intersection improvement footprints.

There are only 6 New Zealand footprints in the dataset, with no footprints from Australia, and only one New Zealand footprint with major structures or earthworks. Therefore, it is recommended that the mean average emissions per lane km for the entire dataset, split by categorisation of with/without major structures or earthworks, is used as the carbon baseline for these project type categories.

Note that the use of the per lane km unit to measure intersection improvements is used for consistency based on the project data received. The number or size of intersections could be a better unit of measurement however this information was not provided in the project data available.

Baseline recommendations for Intersection Improvement projects:

- Intersection Improvement - without major structures or earthworks
  - 2,740 tCO_2e/lane km
  - Based on 39 UK and New Zealand footprints
  - Recommended with a high level of confidence
- Intersection Improvement - with major structures or earthworks
  - 6,280 tCO_2e/lane km
  - Based on 6 UK and New Zealand footprints
  - Recommended with a low level of confidence

Road Construction: Safety and traffic flow improvements

There are 29 safety and traffic flow improvements projects in the dataset. This includes a number of UK 'Smart motorway' projects. For safety and traffic flow improvements projects, the mean average emissions per lane km was 1,272 tCO_2e/lane km. This is the smallest average emissions by infrastructure type for road projects.

As there are only 3 New Zealand Projects, and no projects from Australia, the entire dataset mean average emissions per lane km is recommended as the carbon baseline.

Baseline recommendation for Safety and Traffic Flow Improvement projects:

- Safety and Traffic Flow Improvement
  - 1,270 tCO_2e/lane km
  - Based on 29 UK and New Zealand footprints
  - Recommended with a high level of confidence

6.1.2 Shared Path Construction Emissions

There are only 4 shared path construction projects in the dataset, 3 of which are New Zealand footprints. The project emissions vary considerably from 25 tCO_2e/km to 10,353 tCO_2e/km. Due to the large impact of having major structures or earthworks, the split of categorisation is recommended with baselines provide with a very low level of confidence.

Baseline recommendation for Shared Path construction projects:

- Shared Path – without major structures or earthworks
  - 40 tCO_2e/ km
  - Based on 1 New Zealand footprint and 1 UK footprint
  - Recommended with a very low level of confidence
- Shared Path – with major structures or earthworks
  - 5,970 tCO_2e/ km
  - Based on 2 New Zealand footprints
  - Recommended with a very low level of confidence

6.1.3 Railway Construction Emissions

6.1.3.1 Rail Construction Emissions and the Impact of Major Structures or Earthworks (all infrastructure types)

We looked at the impact of structures (e.g., bridges and tunnels) and major earthworks (e.g., cuttings) on emissions from rail construction projects (see Figure 5). The dataset for this analysis contained 16 footprints with 12 footprints classed as including major structures or earthworks and 4 without major structures or earthworks. Footprints which include major structures or earthworks had mean average emissions of 16,810 tCO_2e/ km, compared to 3,200 tCO_2e/lane km for footprints without major structures or earthworks and 13,400 tCO_2e for the entire dataset. This illustrates the impact of major structures or earthworks on emissions from rail construction projects.

6.1.3.2 Rail Construction Emissions by Infrastructure Type

Four rail construction infrastructure type were used in the database. These are as follows,

- the construction of new rail routes
- tunnel projects where the vast majority of the footprint involves construction of a rail tunnel
- rail intersection improvement projects where most of the footprint involves construction of an intersection (i.e., level crossing removals, flyovers)
- rail improvement projects with light treatments (i.e., electrification, signalling upgrades, re-sleepering, turnout replacements)

The figure below shows the mean average per kilometre and per project emissions for these infrastructure types. Note that all projects are from New Zealand and Australia and the intersection improvements and rail improvements are per project not per km.

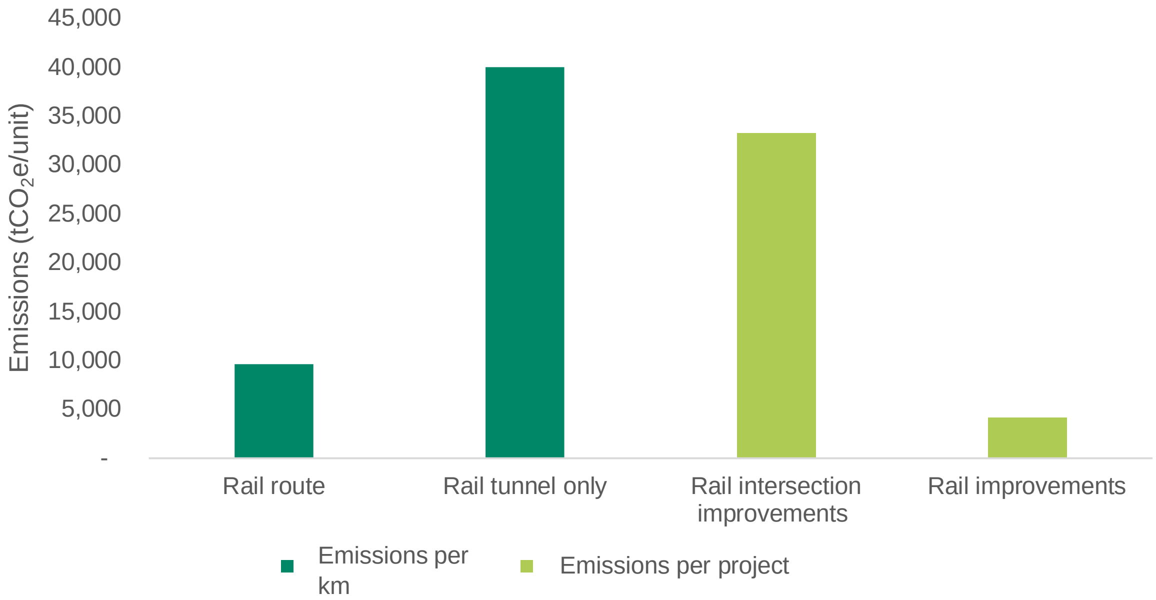

Figure 5 Rail project construction emissions by infrastructure type

The rail route category consists of 14 Australian footprints, with all but two projects categorised as containing major structures or earthworks. The range within this category is from 3,217 tCO_2e/ km to 15,049 tCO_2e/ km, with mean emissions of 9,611 tCO_2e/ km. The mean emissions per km is recommended as a baseline however the lack of New Zealand projects should be taken into account when using this baseline.

For tunnel only rail route projects, the dataset consists of only 2 footprints, both related to one major urban project in New Zealand. The range of emissions is from 21,077 tCO_2e/ km to 58,939 tCO_2e/ km, with mean emissions of 40,008 tCO_2e/ km. The mean average is recommended as the baseline with a low level of confidence due to the small number of footprints and the large range of emissions per km. However, this baseline can still be used to understand the potential scale of tunnel only rail route projects, with a mean average emissions per km six times larger than for the rail route category (even with the rail route category consisting of mostly projects with major structures or earthworks). Rail tunnel projects in a non-urban environment may have lower emissions per km than indicated here.

For rail intersection improvements and rail improvements, insufficient data was collected to recommend baselines per km. However, we have looked at the total emissions per footprint for these projects to hopefully provide some context to New Zealand's rail improvement projects. For the 13 Australian rail intersection improvement projects the range of total footprint emissions is from 12,215 tCO_2e to 39,595 tCO_2e, with mean emissions of 33,279 tCO_2e. For the one rail improvement project with minor treatments the total emissions are 4,221 tCO_2e. More data, including information on the size of these projects would be required to provide useable baselines.

Baseline recommendations for Rail projects:

- Rail route
  - 9,610 tCO_2e/ km
  - Based on 14 Australian footprints
  - Recommended with a moderate level of confidence
- Rail route - Tunnel Only
  - 40,000 tCO_2e/ km
  - Based on 2 New Zealand footprints
  - Recommended with a low level of confidence
- Rail intersection improvements
  - Not applicable
- Rail improvements
  - Not applicable

6.2 Operation and Maintenance Emissions

Analysis of operation and maintenance emissions focusses on per year emissions for ease of comparability. The recommendation of baselines in this analysis are presented per year. It is understood that emissions per year will likely change over time as new technologies, materials, and practices take place, however these recommended baselines can still be used as a starting point for understanding land infrastructure operation and maintenance emissions

6.2.1 Road Operation and Maintenance Emissions

The entire road operation and maintenance footprint dataset contained 30 footprints, with only 1 New Zealand footprint. A larger sample size of New Zealand footprints is required to assess whether emissions from New Zealand projects are comparable to those from other countries, especially Australia. Recommended baselines may be a conservative estimate for the New Zealand context, in particular, electricity use emissions for New Zealand projects is likely to be lower than for projects from Australia and the UK due to the high proportion of renewable energy generation in New Zealand. This would particularly affect operational lighting and ventilation energy consumption.

Entire Dataset Plus Additional Maintenance-only Footprints

In addition to the 30 footprints which contained data on both operation and maintenance emissions, there were 3 footprints that only reported maintenance emissions and one that only reported operations emissions. By isolating operation and maintenance emissions from the dataset, where possible, we can examine if information from these additional footprints provides more confidence in the median average recommended baseline as advised above.

Within the maintenance-only dataset of 3 footprints, emissions per lane km per year ranged from 0.2 tCO_2e/lane km/year to 14 tCO_2e/lane km/year. Within the operation-only dataset, emissions per lane km per year was 113 tCO_2e/lane km/year. By adding the mean and median averages from the operation-only and maintenance-only footprints we can compare these to the results of the analysis of combined operation and maintenance emissions. The results are similar and provides confidence in the combined operation and maintenance baseline.

Road Operation and Maintenance Emissions by Project Type

The full dataset for each project type is used to provide the carbon baseline recommendations.

For Road/Busway/Shared Path operation and maintenance projects the range was from 3 tCO_2e/lane km/ year to 161 tCO_2e/lane km/ year. This reflects the different demands of different project types, for example where some projects may need more lighting or more regular surface replacement due to different demands. Different countries may also have differing standards for maintenance or operation considerations. Due to the large variance between projects with and without major structures and earthworks separate baselines have been recommended.

Tunnel only projects had much higher operation and maintenance emissions per year than the other projects, ranging from 462 tCO_2e/lane km/ year to 1,026 tCO_2e/lane km/ year, with an average of 838 tCO_2e/lane km/ year. This reflects the greater energy use during operation for tunnels for lighting, ventilation, and signage.

There were only 2 footprints in the Intersection Improvements category with mean average emissions of 86 tCO_2e/lane km/ year. This is higher than for Road/Busway/Shared Paths likely reflecting the greater energy use for intersections than for stretches of road.

Note that operation and maintenance emissions are likely to change over time especially over the expected service life of infrastructure, so these baselines will require review in the future.

Baseline recommendation for road operation and maintenance projects:

- Road/Busway/Shared Path – without major structures or earthworks
  - 30 tCO_2e/lane km/ year
  - Based on 4 Australia, Ireland, and UK projects
  - Recommended with a low level of confidence
- Road/Busway/Shared Path – with major structures or earthworks
  - 70 tCO_2e/lane km/ year
  - Based on 21 Australia, UK, and New Zealand projects
  - Recommended with a moderate level of confidence
- Tunnel only
  - 840 tCO_2e/lane km/ year
  - Based on 3 Australian projects
  - Recommended with a low level of confidence
- Intersection improvements
  - 90 tCO_2e/lane km/ year
  - Based on 2 UK footprints
  - Recommended with a low level of confidence

6.2.2 Shared Path Operation and Maintenance Emissions

Only one footprint was included in this dataset with emissions of 8 tCO_2e/km/year. This may be used as a carbon emissions baseline given the lack of data available, however it is recommended with a very low level of confidence and will be updated as further data comes available.

6.2.3 Railway Operation and Maintenance Emissions

There are 15 rail operation and maintenance projects in the dataset, all of which are from New Zealand (2) and Australia (13). The projects include both rail route and rail tunnel infrastructure types. These emission footprints relate to operation and maintenance of the infrastructure only and do not include energy consumed by trains during use.

The emissions for the 13 Australian rail route projects vary considerably from 13 tCO_2e/km/year to 455 tCO_2e/km/year, with average emissions of 290 tCO_2e/km/year. New Zealand footprints would be required to assess the similarity of projects and emissions from New Zealand and Australia, and therefore the applicability of using Australian footprints for a carbon baseline.

Of the two New Zealand rail tunnel footprints the range in emissions is from 13 tCO_2e/km/year to 1,113 tCO_2e/km/year. Due to the limited number of projects for different rail infrastructure types, the baselines are recommended with a low level of confidence.

Baseline recommendation for rail operation and maintenance projects:

- Rail route
  - 290 tCO_2e/km/year
  - Based on 13 Australian footprints
  - Recommended with a low level of confidence
- Rail – Tunnel Only
  - 560 tCO_2e/km/year
  - Based on 2 New Zealand footprints
  - Recommended with a very low level of confidence

7.0 Infrastructure Construction GHG Impact by Emission Source 2023 (Using Carbon Baseline Database)

There were 41 projects in the database that included data which split the overall construction emissions into emissions from materials (LCA modules A1-A3), transport of materials (A4) and the fuel and energy used to construct the assets on site (A5). Only projects that had data for all three of these emission sources were included in this analysis. Using this data, the percentage of each emission source for each project was averaged so that an average for each infrastructure type could be determined. Note that because they are average results, the total of the emission source percentages does not equal 100%.

The results below in Table 17 show that for most types of infrastructure the embodied emissions from materials make up the largest contribution of emissions during the construction phase (approximately 65% of construction emissions). Fuel and energy usage is the next largest source (21%) followed by transport of materials (8%). There is some variability between different infrastructure types but due to the limited number of projects only the total average across all infrastructure types is recommended.

Table 17 Contributions of emissions sources for different infrastructure types

Infrastructure Type	No. of Projects	Material (A1-A3)	Transport (A4)	Fuel & Energy (A5)
Intersection improvements	2	76%	12%	9%
Rail intersection improvements	10	63%	4%	29%
Rail route	8	66%	5%	28%
Rail tunnel only	2	88%	5%	6%
Road/Busway/Path	16	66%	9%	15%
Road/Busway/Path Tunnel Only	2	44%	6%	39%
Shared Path Only	1	47%	49%	4%
Total Average	**41**	**65%**	**8%**	**21%**

The impact of major structures or earthworks on the contribution of emissions sources can also be considered as shown below in Table 18. The results show that for projects with major structures and earthworks, the fuel and energy usage make up a larger proportion of construction emissions. This is expected due to the increased number of plant or machinery, larger plant or machinery and longer duration of construction required for complex projects that have major structures or earthworks.

Table 18 Contributions of emissions sources from projects with or without major structures or earthworks

With or without major structures or earthworks	No. of Projects	Material (A1-A3)	Transport (A4)	Fuel & Energy (A5)
With major structures or earthworks	34	63%	8%	23%
Without major structures or earthworks	7	75%	8%	13%
Total Average	**41**	**65%**	**8%**	**21%**

The impact of the location of projects on the contribution of emissions sources is considered below in Table 19. The results show that projects in rural areas tend to have a higher proportion of emissions from transporting materials and that urban projects have higher fuel and energy emissions. These results are anticipated due to the longer freight distances for materials in rural areas and the more intensive fuel and energy required to construct complex urban projects.

Table 19 Contributions of emission sources from project in rural or urban areas

Rural or Urban	No. of Projects	Material (A1-A3)	Transport (A4)	Fuel & Energy (A5)
Rural	11	68%	12%	9%
Urban	30	65%	7%	26%
Total Average	**41**	**65%**	**8%**	**21%**

The results in the tables above prove that the database is functioning appropriately to create results that align with expectations. Using the database, it would be possible to find the emissions contributions for a particular infrastructure type, with major structures or earthworks in an urban or rural location. This would provide a more detailed result but due to the size of the database currently is not recommended (only the total average is recommended). As more projects are added to the database this functionality could be developed.

The total average results in this section are used in the second order of PEET to estimate the transport and fuel and energy emissions.

8.0 Project Cost and Emissions

International literature suggests a strong correlation between the cost of a project and the emissions footprint. In most cases, the relationship is approximately proportionate – measures to reduce carbon tend to reduce cost. These measures include material savings, energy demand reduction, and delivering operational efficiencies. This correlation is supported by this dataset which includes 50 projects where the capital cost of the project and the total construction footprint (in tCO_2e) is included in the data (see Figure 6). A correlation coefficient of 0.86 means there is a strong positive correlation between the capital cost of the project and the total construction emissions footprint. This correlation is related to the size of the project, the quantity of earthworks and structures involved in the project, and the amount of fuel, electricity and materials used in the project. Actions to reduce cost or emissions tends to also reduce the other.

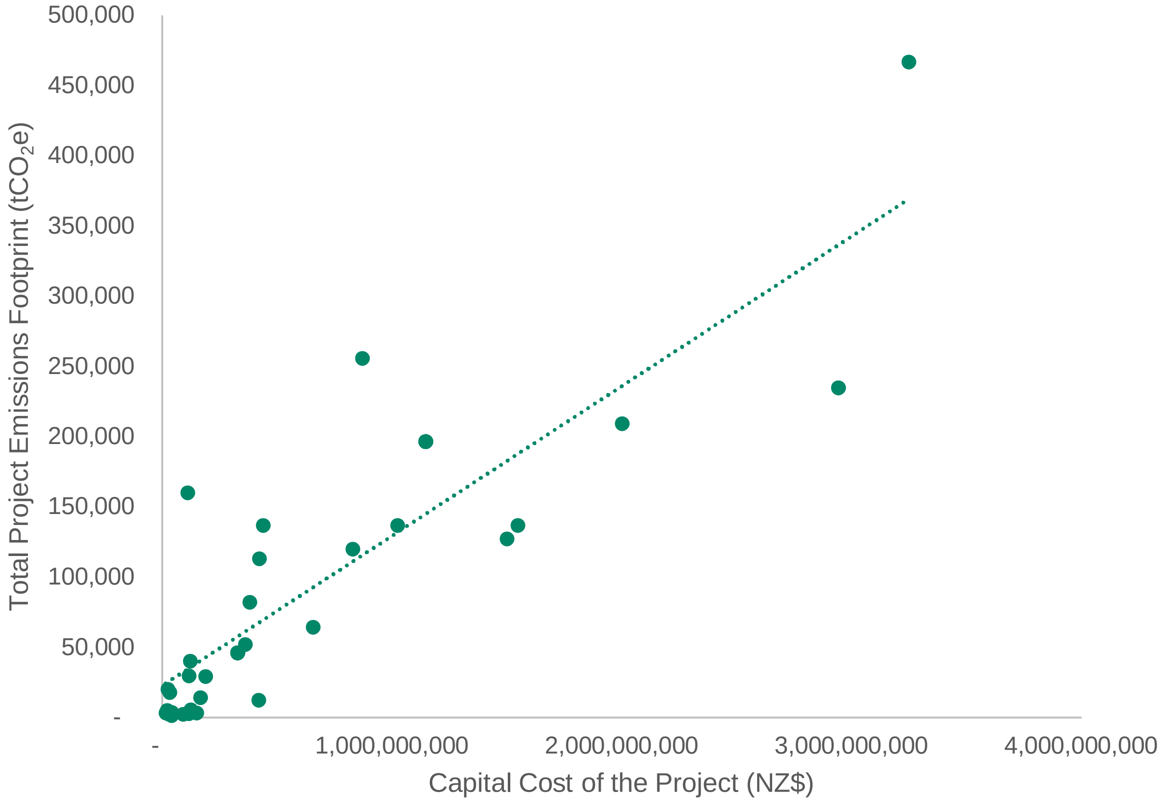

Figure 6 Graph showing the correlation of project capital cost and project construction emissions

From the dataset included in this project we can examine construction emissions per $1m of project contract cost. The mean average for emissions per project cost from the entire dataset was 190 tCO_2e/$1m for all 50 projects in the database and 130 tCO_2e/$1m for projects from Australia and New Zealand.

The strong correlation of cost and emissions enables the emissions per cost metric to be used as an initial screening method for the emissions produced by a project at the early design stage. However, this method is indicative only and depending on the project type, risks and location, the capital cost may provide an inaccurate prediction of the emissions.

9.0 Assumptions and Limitations

This section describes important assumptions and limitations involved in data collection, calculation, and analysis within this work. A discussion of whether the emissions baseline can be effectively used as a benchmark for understanding the emissions of projects is included in the limitations section.

9.1 Assumptions

When collecting and collating data from carbon emissions footprints, assumptions have been used to fill data gaps and account for differences in footprints. For example, to minimise the impact of the use of different reporting standards.

Based on an understanding of the different reporting standards and differences in construction, operation and maintenance between countries, results are provided by country. Emissions from major sources included in carbon footprints such as from concrete, steel and liquid fuel use show small differences between countries (especially between New Zealand, Australia, and the UK). Other differences in reporting standards exist in the emission factors used, inclusion/exclusion of emission sources (e.g., vegetation clearing/planting) and the carbon intensity of electricity. Significantly, New Zealand has a relatively low carbon intensity of electricity, especially when compared to Australia. Despite these differences, emissions from major sources included in footprints, such as from concrete and steel, present similar results and so enable reasonable comparability between footprints.

Where there were gaps in the data, assumptions have been used to fill in those gaps. Particularly of note was for footprints where the number of lanes or lane widths was not known. For footprints with variable numbers of lanes along their length, for example on stretches of motorway with junctions, an estimate of the average number of lanes across the length of the project was made, based on drawings and information available. Where the works did not contain easily defined lanes, such as for junction improvements or smart-motorway improvements, an assumption has been made based on the approximate road area included in the works.

It is assumed that all footprints report CO_2e and not just CO_2. Generally, emissions footprints cover all major greenhouse gas emissions and report CO_2e. Any footprints only reporting CO_2 would be underestimating emissions, however, CO_2 is the largest contributor to CO_2e in infrastructure footprints so these footprints would still be comparable.

Data for several footprints were provided by both AECOM in the UK and by Highways England. Where the data differed, the AECOM figure was used as the footprint detail provided was higher.

Data for some footprints from Australia was provided in aggregated form by the Infrastructure Sustainability Council. An estimate of per-project emissions has been made using this data. Some projects provided material emissions from construction and operations and maintenance in a combined value. The emissions have been separated using an assumption that construction materials account for 40% of emissions and maintenance materials account for 60% of emissions over a 100-year lifetime. This assumption is based on a high-level analysis using the Waka Kotahi Project Emissions Estimation Tool (PEET).

Summary of key assumptions:

- Emissions produced by vehicles using the infrastructure, and emissions related to the decommissioning of infrastructure, are not included in the scope of this study.
- Carbon footprints using different reporting standards are comparable for the purposes of this calculation, however, it is important that these differences are considered during analysis
- Where the number of lanes included in a footprint is unclear, an estimation has been made based on drawings and other information available (such as by work type)
- It is assumed that all footprints report CO_2e and not just CO_2.

9.2 Limitations

Due to the wide range of data sources used in this study and the relative lack of cohesive data, there are several limitations to results of this study.

As mentioned in the assumptions section, one of the major limitations of this study is that footprint data comes from several countries, and that these countries have different emissions reporting standards, and that they have been produced in different years. This means that caution should be taken when comparing the footprints in this dataset. Differences exist in emission factors, materials used, boundaries, and reporting requirements (e.g., which emissions sources are included or excluded).

Footprints calculated between 2000 and 2022 have been included in this study. Over time the knowledge, protocols, emission factors, and tools available to measure project and asset-based emissions have developed. This impacts the total reported emissions from the project.

Most of the footprints in this study are 'predicted' emission footprints which is where emissions have been estimated for projects before completion of the project. 'Actual' emission footprints refer to calculations that have been made after completion of the project with knowledge of the actual quantities of fuel, materials and energy used for the project. Predicted emission footprints tend to be less accurate than actual emission footprints.

For certain footprint categories (e.g., shared path and railway footprints) there were only a small number of footprints in our dataset. This has been noted in the results where relevant alongside advice to treat results and baselines in these categories with a low level of confidence.

Within each emissions footprint category dataset there was a large range within the results, both in total emissions and using comparable metrics, such as emissions per km. This range is dependent on the type and scale of the project, for example high emissions per km exist for projects that include major earthworks or structure construction (e.g., for tunnels or bridges). The large range combined with smaller datasets for some categories presents a risk of the averages being skewed higher or lower than may be realised with a larger dataset.

Aggregated data was provided by the Infrastructure Sustainability Council for some projects from Australia. For this data, the range within the data and project specific information was not available. Where this aggregated data represented a large proportion of a dataset (e.g., for railway baselines) the applicability of the baseline to specific projects in New Zealand is unclear. There may be significant differences between projects within this category that are unknown.

Summary of key limitations:

- Differences in footprint standards and requirements, especially between countries. These differences exist predominantly in emission factors, materials used and emission source inclusions/exclusions.
- Footprints produced in different years. The year in which the footprint was calculated affects the emission factors used and which emission sources are included or excluded in the calculation.
- Small sample-size of datasets for certain categories. This is especially true for shared path and railway footprints.
- Use of predicted emission footprints which may not accurately represent the actual emissions footprints of the projects.
- Wide range of results within each category, especially impacted by the earthworks or structures included in the project.
- Where aggregated data represented a large proportion of a dataset (e.g., for railway baselines) the applicability of the baseline to specific projects in New Zealand is unclear.

Any use of this work, and future work to update the recommended baselines will have to consider the limitations of this work. A larger sample of footprints for all categories and greater detail into the inputs and results of each footprint would improve the reliability and accuracy of the results.

10.0 AECOM Limitations

AECOM New Zealand Limited (AECOM) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Waka Kotahi (New Zealand Transport Agency) and only those third parties who have been authorised in writing by AECOM to rely on these calculations.

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