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Carbon Emission Baseline Recommendations for New Zealand Infrastructure Projects

17-Jan-2022
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

Prepared by

AECOM New Zealand Limited
8 Mahuhu Crescent, Auckland 1010, PO Box 4241, Auckland 1140, New Zealand
T +64 9 967 9200 F +64 9 967 9201 www.aecom.com

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1.0 Introduction

Waka Kotahi NZ Transport Agency (Waka Kotahi) engaged AECOM to help develop carbon emissions baselines for construction, and operation and maintenance emissions from land-based transport infrastructure. These baselines will be used to benchmark projects against 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 a long term outcome of net zero land transport GHG gas emissions by 2050, as set out in Toitū Te Taiao Our Sustainability Action Plan[1].

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 project will also support the development of Waka Kotahi resource efficiency benefit measures[2].

The results of this study draw on existing carbon footprints from New Zealand compiled by AECOM in previous work for Waka Kotahi. They also draw on international footprints from land-based transport infrastructure projects in Australia, the United States, Ireland, and the United Kingdom.

2.0 Project Scope

The purpose of this project is to:

- Establish a carbon emissions baseline for infrastructure projects in New Zealand covering construction 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.
- Build on the previous work completed by AECOM for Waka Kotahi in 2020 that investigated the most important emissions for construction in state highway projects in New Zealand.

The work considers greenhouse gas emissions across the life-cycle of the infrastructure project including design/construction, operation and maintenance. Due to a lack of data end-of-life demolition and decommissioning emissions are excluded from the scope of this project.

Most of the footprints analysed were road construction and improvement projects. However, where data was available, other types of projects including shared paths and railways have been analysed. Separate footprint baselines have been created for these categories.

Scope of services:

- Review existing work completed by AECOM on New Zealand carbon footprint / Greenhouse Gas (GHG) inventories.
- Review international GHG footprints completed for construction, and operation and maintenance emissions.
- Develop an agreed service life for asset maintenance, and timeframes for reporting in-use emissions (for operation and maintenance).
- Provide a dataset of reported emissions for infrastructure projects in New Zealand and internationally to enable informed comparison of emissions from Waka Kotahi's projects.

[1] Waka Kotahi, Toitū Te Taiao Our Sustainability Action Plan (2020)
[2] https://www.nzta.govt.nz/planning-and-investment/planning-and-investment-knowledge-base/201821-nltp/monitoring-and-reporting-on-investments/benefits-management-approach/investment-performance-measurement/list-of-investment-performance-measures/

- Calculate an infrastructure carbon emissions baseline for construction footprints, and operations and maintenance footprints, from the dataset using standard metrics (e.g. emissions per lane km and emissions per m^2).
- Provide additional detail on high emitting sources such as concrete and cement, steel, aggregate, fuel (mainly diesel), and waste management.
- Produce a report outlining the literature review, international context, calculation methods used, key assumptions, the results of carbon baseline calculations, and discussion of whether the emissions baseline can be effectively used as a benchmark for understanding the emissions of projects.

Additional analysis has been provided in some cases to improve understanding of the data and results.

3.0 Background Information

3.1 Carbon Emission Footprints for 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).

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

- **Construction Emissions –** emissions related to the production of materials used for construction (embodied emissions), transportation of materials required for construction, fuel or electricity used on site and disposal of materials removed from the site during construction.
- **Operation and Maintenance Emissions –** ongoing emissions relating to both the electricity demands (e.g. for lighting) and maintenance during the service life of the asset, including resurfacing and repair work.

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 combine all greenhouse gases into an equivalent unit.

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

Major emission sources for land-based transport infrastructure construction projects are;

- the embodied emissions in materials used (especially concrete, steel and to a lesser extent asphalt),
- fuel consumption (e.g. for construction vehicles on site), and;
- electricity consumption (e.g. used for lighting and tools on site)[3][4].

A previous AECOM study of carbon footprints for New Zealand infrastructure projects[5] , found that fuel, concrete, steel, and aggregate were responsible for between 83% and 99% of the total emissions of the construction phase of projects[6].

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

[3] Trunzo, Moretti and D'Andrea, Life Cycle Analysis of Road Construction and Use (2019)
[4] Highways England, Highways England Carbon Tool Guidance (2020)
[5] provided to Waka Kotahi in March 2020
[6] AECOM, Carbon Footprint Stocktake - Transport Projects / Assets (2020)

lighting (and ventilation in tunnels), embodied emissions from materials used for maintenance and fuel used for maintenance[7][8]. The dataset collected for this study backs up these findings.

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 Transport Infrastructure

Carbon footprint baselines are used to compare, understand, and assess emissions produced by infrastructure projects. Waka Kotahi aim 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 use of infrastructure can assist Waka Kotahi in achieving its emissions reduction targets. 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[9]. 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[9][10].

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[11].

Various metrics are used to report carbon emissions and to create baselines, commonly these are:

- Total emissions (tCO_2e)
- Total emissions per kilometre (tCO_2e/km)
- Total emissions per lane kilometre (tCO_2e/lane km)
- Total emissions per area (tCO_2e/m^2)
- Total emissions per project cost (tCO_2e/$1m).

[7] Trunzo, Moretti and D'Andrea, Life Cycle Analysis of Road Construction and Use (2019)
[8] European Commission, Comprehensive life cycle approach (LCA) tool applied to road construction (2013)
[9] Urban Insight, Carbon Cost in Infrastructure (2020)
[10] HM Treasury, Infrastructure Carbon Review (2013)
[11] 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 the Appendix.

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 8.0).

Data was collected for construction carbon footprints, and operation and maintenance carbon footprints for motorways, state highways, shared paths, and railways in the period from 2000 to 2021. Differences in footprint reporting standards meant that some footprints included both construction and in-use emissions in the footprint. In these cases, we have separated construction and in-use emissions into separate footprints.

For New Zealand infrastructure carbon footprints, we examined existing carbon footprint data collected by AECOM for previous work with Waka Kotahi and collected data from carbon footprints that AECOM have subsequently delivered.

To collect international data, we contacted AECOM specialists in Australia, the UK, Sweden, and the USA. These teams were able to provide confidential data for carbon footprints where AECOM had delivered the footprint.

Infrastructure sustainability rating schemes such as Greenroads, CEEQUAL and the Infrastructure Sustainability Council of Australia (ISCA) and Highways England also provided additional data.

Additional information from a study of relevant literature and publicly available carbon footprints was added to the footprint dataset.

A summary of data sources is found in Table 1.

Table 1 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

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

For each footprint, a data collection template was completed to enable comparison with other footprints. A copy of the data collection template can be found in the supplementary information provided with this report.

Estimations and assumptions used to fill data gaps are outlined in the limitations and assumptions section (section 8.0).

Key information recorded from each footprint included:

- Description of the project and significant work types (e.g. bridges or tunnels)
- Country
- Infrastructure type – motorway, state highway, local road, shared path, or railway
- Road length (km)
- Number of lanes
- Road area (m^2)
- Total carbon emissions footprint
- Carbon footprint reporting protocol followed (e.g. the GHG Protocol)
- Carbon footprint completion date
- Key omissions, exclusions, or limitations.

Optional additional information from each footprint (not all listed):

- Location – rural or urban
- Footprint emissions by scope
- Top three footprint emission sources
- Emission factors used.

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 split into the two emissions categories of: construction, and operation and maintenance. Within these categories, footprints were split into roads, shared paths and railways.
- Footprints were checked for comparability, and data gaps or differences were filled where possible (refer section 8.0).
- Footprint data for operation and maintenance was converted to a per-year figure to enable comparisons where differing timeframes had been used. A timeframe for reporting in-use emissions in New Zealand (operation, maintenance) of 60 years has been used to represent the service life of an infrastructure project.
- Some of the Australian 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 and road area information was estimated where it was not included in the data. From these figures, emissions per km (tCO_2e/km), emissions per lane km (tCO_2e/lane km), and emissions per road area (tCO_2e/m^2) were calculated for each project. For operation and maintenance, these figures were calculated per year and per 60-year service life.

- Mean and median average emissions per kilometre, per lane kilometre and per road area were then calculated for each category (e.g. for road construction emissions) and for each country within that category.
- To develop a recommendation for a carbon baseline for each category, an assessment of the data and calculation limitations has been made to determine the most applicable figure to use.

5.0 Results

Analysis of carbon emission footprints has been conducted for the two emissions categories of construction, and operation and maintenance footprints. Within these categories, data has been split into subcategories for road, shared path, and railway projects. Road projects include road creation, widening, and junction improvements. 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. These baselines can then be used by Waka Kotahi to assess project designs, and measured emissions, with the goal of reducing carbon emissions from infrastructure. 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 are presented in section 4.2.

5.1 Construction Emissions

Construction footprint results are provided for:

- Road Construction (tCO_2e and tCO_2e per lane km)
  - All road construction footprints, by country
  - All road construction footprints, with and without major structures or earthworks
  - Road construction footprints by project type:
    - Road/Busway/Path construction footprints
    - Road/Busway/Path construction footprints, with and without major structures or earthworks
    - Tunnel only construction footprints
    - Bridge only construction footprints
    - Intersection improvement footprints, at grade and grade separated
    - Safety and traffic flow improvement footprints
- Road Construction (tCO_2e/$1M project cost)
  - All road construction footprints, by country
- Shared path construction (tCO_2e and tCO_2e per km)
  - All shared path construction footprints, with and without major structures or earthworks
- Railway construction (tCO_2e and tCO_2e per track km)
  - All railway construction footprints, by country

5.1.1 Road Construction Emissions

The road construction emissions analysis contained 137 road construction carbon footprints. Road construction projects included motorways and state highways (or similar outside of New Zealand). Table 2 shows the data collected for this study, including the number of footprints, average total emissions, and range of total emissions by country. Due to the use of aggregated data in the Australian dataset, a median figure for the dataset is not a useful measure.

Table 2 Average and range of total emissions, by country, for road construction footprints.

	Number of Footprints	Mean average total emissions (tCO_2e)	Median average total emissions (tCO_2e)	Smallest footprint in range (tCO_2e)	Largest footprint in range (tCO_2e)
New Zealand	21	56,651	5,570	603	238,690
Australia	17	292,535	176,663	125,007	2,020,000
UK	97	80,571	24,884	4,220	2,031,607
Ireland	1	4,050	4,050	4,050	4,050
USA	1	19,000	19,000	19,000	19,000
Entire Dataset	137	102,198	28,860	603	2,031,607

Table 3 presents the average and range of emissions per project lane km's.

Table 3 Average and range of emissions per lane km, by country, for road construction footprints.

	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	3,569	1,699	105	18,322
Australia	17	4,110	2,964	2,964	11,099
UK	97	3,230	2,231	513	13,265
Ireland	1	1,761	1,761	1,761	1,761
USA	1	7	7	7	7
Entire Dataset	137	3,357	2,231	7	18,322

The New Zealand dataset contained 21 footprints, and within this there was a wide range in emissions per lane km, from 105 tCO_2e/lane km to 18,322 tCO_2e/lane km.

The UK dataset contained 97 footprints. There was also a wide range of results, with a handful of particularly large emissions footprints per lane km, including three projects over 10,000 tCO_2e/lane km. Within this dataset, 68% of UK footprints had emissions per lane km between 1,000 tCO_2e/lane km and 4,000 tCO_2e/lane km.

The Australian dataset contained two individually reported footprints and 15 footprints calculated from aggregated data. Of the individually reported Australian footprints, one footprint represented one of the highest emissions per lane km in the study at 11,099 tCO_2e/lane km. The remaining footprints ranged from 2,964 tCO_2e/lane km to 4,745 tCO_2e/lane km. It is important to note that there is likely to be a much wider range in emissions within the aggregated data as the calculation uses the mean average to estimate footprint size.

The entire road construction footprint dataset contained 137 footprints. The mean average of emissions per lane km from the entire dataset was 3,357 tCO_2e/lane km.

The five footprints with the highest emissions per lane km in the dataset (> 10,000 tCO_2e/lane km) stand out when compared to the rest of data. These footprints include one footprint that only includes the bridge elements of a new motorway, two footprints with major motorway tunnel constructions and two projects with major changes to junction layouts including flyovers.

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

Road construction footprints have been classified as either “including major structures or earthworks”, “not including major structures or earthworks”, or are unclassifiable due to lack of data. There were 123 footprints which can be classified, with 17 footprints including major structures or earthworks and 106 footprints not including major structures or earthworks.

Road structures include bridges and flyovers, while earthworks include large cuttings and tunnel construction. Footprints have been classified as ‘including major structures or earthworks” when they contain a structure or earthworks component which represents a significant proportion of the construction works.

Table 4 Average and range of road construction emissions for footprints that include, or do not include, major structures or earthworks.

	Number of Footprints	Mean average total emissions (tCO_2e)	Median average total emissions (tCO_2e)	Smallest footprint in range (tCO_2e)	Largest footprint in range (tCO_2e)
With Major Structures or Earthworks	17	400,762	124,855	3,133	2,031,607
No Major Structures or Earthworks	106	44,914	21,597	603	304,549

Table 5 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	17	7,193	6,976	1,267	18,322
No Major Structures or Earthworks	106	2,733	2,231	7	13,265

Footprints which included major structures or earthworks ranged from 1,267 tCO_2e/lane km to 18,322 tCO_2e/lane km and had mean average emissions of 7,193 tCO_2e/lane km.

Footprints without major structures or earthworks ranged from 7 tCO_2e/lane km to 13,265 tCO_2e/lane km and had mean average emissions of 2,733 tCO_2e/lane km.

5.1.1.2 Road Construction Emissions by Project Type

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

We have broken down the road construction category into the following project types:

- Road/Busway/Path
- Intersection improvements – at grade
- Intersection improvements – grade separated
- Tunnel only

- Bridge only
- Safety and traffic flow improvements.

To categorise projects using these new categories, a process was developed where projects were allocated to the most relevant category. The Road/Busway/Shared Path category 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 category. If there was no obvious category to allocate projects to, these projects were allocated to the Road/Busway/Path category.

Table 6 Average and range of total emissions, by infrastructure type, for road construction footprints.

	Number of Footprints	Mean average total emissions (tCO_2e)	Median average total emissions (tCO_2e)	Smallest footprint in range (tCO_2e)	Largest footprint in range (tCO_2e)
Road/Busway/Path	57	135,903	113,016	2,256	981,432
Intersection improvements – at grade	41	21,615	9,145	603	176,686
Intersection improvements – grade separated	4	46,093	20,938	5,570	136,928
Bridge only	3	59,713	29,430	3,133	146,576
Tunnel only	3	1,420,290	2,020,000	209,264	2,031,607
Safety and traffic flow improvements	29	25,659	22,048	2,752	87,237

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

	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/Path	57	3,875	3,256	105	13,265
Intersection improvements – at grade	41	2,937	2,231	558	9,848
Intersection improvements – grade separated	4	6,137	4,651	3,074	12,171
Bridge only	3	9,029	5,717	3,047	18,322
Tunnel only	3	10,004	11,099	7,751	11,163
Safety and traffic flow improvements	29	1,261	1,063	7	3,860

The largest mean average emissions per lane km for these categories were for tunnels at 10,004 tCO_2e/lane km. The lowest mean average emissions per lane km were for safety and traffic flow improvements at 1,340 tCO2e/lane km.

Data was available to separate the Road/Busway/Path category into two subcategories covering footprints which do and do not include major structures or earthworks for 42 of the 57 projects. The results of this analysis are presented in the tables below.

Table 8 Average and range of total emissions, by subcategory, for road/busway/path construction footprints.

	Number of Footprints	Mean average total emissions (tCO_2e)	Median average total emissions (tCO_2e)	Smallest footprint in range (tCO_2e)	Largest footprint in range (tCO_2e)
Road/Busway/Path – with major structures or earthworks	5	343,119	136,826	52,179	981,432
Road/Busway/Path – no major structures or earthworks	37	86,562	51,948	2,256	304,549

Table 9 Average and range of emissions per lane km, by subcategory, for road/busway/path construction footprints.

	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/Path – with major structures or earthworks	5	4,486	3,763	1,267	8,443
Road/Busway/Path – no major structures or earthworks	37	3,883	3,279	105	13,265

Road/Busway/Path projects with major structures or earthworks had mean average emissions of 4,486 tCO_2e/lane km. Road/Busway/Path projects without major structures or earthworks had mean average emissions of 3,873 tCO_2e/lane km.

5.1.1.3 Road Construction Emissions and Cost

Table 10 shows the results of emissions per project cost analysis of road construction projects.

Table 10 Average and range of road construction emissions per project cost, by country.

	Number of Footprints	Mean average emissions per project cost (tCO_2e/$1m)	Median average emissions per project cost (tCO_2e/$1m)	Smallest emissions per project cost (tCO_2e/$1m)	Largest emissions per project cost (tCO_2e/$1m)
New Zealand	15	136	133	23	292
Australia	1	189	N/A	189	189
UK	44	179	129	22	994
Entire Dataset	60	168	133	22	994

Within the road construction dataset there were 60 footprints where information about both the capital cost of the project and the total construction footprint (in tCO_2e) was included in the data. Within this group, the total capital cost ranged from under $15,000,000 up to above $13,000,000,000.

The mean and median averages for emissions per project cost from the dataset were 168 tCO_2e/$1m and 133 tCO_2e/$1m respectively.

5.1.1.4 Road Construction Emissions by Emission Source

Table 11 shows the results of emission source analysis of road construction projects.

Table 11 Average emissions per lane km and average proportion of road construction emissions.

	Average emissions per lane km (tCO_2e/lane km)	Proportion of total emissions (%)
Materials (Embodied Carbon)	2,890	73%
Fuel and Energy Use	781	20%
Other	270	7%

Within the road construction dataset there were 45 footprints where information about emission sources (in tCO_2e) was included in the data. Emissions from different sources was categorised into Materials, Fuel and Energy Use, and Other, for comparison.

Within this dataset, Material embodied carbon emissions made up 73% of total footprint emissions, with Fuel and Energy Use contributing 20% and Other emissions contributing 7% of total footprint emissions.

5.1.2 Shared Path Construction Emissions

Only 5 shared path construction carbon footprints were included in this study. Table 12 shows the data collected for this study, including the number of footprints, average total emissions, and range of total emissions by country.

Table 13 shows the emissions per km results for the dataset. Shared paths are assumed to be one 'lane' wide (approximately 5m) so the emissions per kilometre and per lane kilometre are the same. This allows comparison of the shared path construction emissions per kilometre figure with the road construction emissions per lane km figure.

Table 12 Average and range of total carbon emissions, by country, for shared path construction footprints.

	Number of Footprints	Mean average total emissions (tCO_2e)	Median average total emissions (tCO_2e)	Smallest footprint in range (tCO_2e)	Largest footprint in range (tCO_2e)
New Zealand	4	17,222	9,545	102	49,696
Ireland	1	2,537	N/A	2,537	2,537
Entire Dataset	5	14,285	2,537	102	49,696

Table 13 Average and range of carbon emissions per km, by country, for shared path construction footprints.

	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)
New Zealand	4	3,621	2,053	25	10,353
Ireland	1	60	N/A	60	60
Entire Dataset	5	2,909	1,577	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 five footprints with a mean average emissions per km of 2,909 tCO_2e/km.

Data was available to separate the shared path category into two subcategories covering footprints which do and do not include major structures or earthworks. The results of this analysis are presented in the tables below.

Table 14 Average and range of total emissions, by subcategory, for shared path only construction footprints.

	Number of Footprints	Mean average total emissions (tCO_2e)	Median average total emissions (tCO_2e)	Smallest footprint in range (tCO_2e)	Largest footprint in range (tCO_2e)
Shared path only – with major structures and Earthworks	3	22,928	16,561	2,528	49,696
Shared path only - no major structures or earthworks	2	1,319	1,319	102	2,537

Table 15 Average and range of emissions per km, by subcategory, for shared path only construction footprints.

	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 and Earthworks	3	4,820	2,528	1,577	10,353
Shared path only - no major structures or earthworks	2	43	43	25	60

Shared path projects with major structures or earthworks had mean average emissions of 4,820 tCO_2e/ km. Shared path projects without major structures or earthworks had mean average emissions of 43 tCO_2e/km.

5.1.3 Railway Construction Emissions

There were 18 railway footprints in this dataset. All footprints were for Australian projects and 17 of the footprints were from 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. Information on the type of projects included in the aggregated data was not available. This is important to note, as the type of project can have a large impact on construction emissions (e.g. underground vs overground railways, or urban vs rural railways).

Table 16 Average and range of total emissions, by country, for railway construction footprints.

	Number of Footprints	Mean average total emissions (tCO_2e)	Median average total emissions (tCO_2e)	Smallest footprint in range (tCO_2e)	Largest footprint in range (tCO_2e)
Entire Dataset	18	186,431	196,516	149,806	388,667

Table 17 presents the average and range of emissions per project track km's.

Table 17 Average and range of emissions per track km, by country, for railway construction footprints.

	Number of Footprints	Mean average emissions per track km (tCO_2e/track km)	Median average emissions per track km (tCO_2e/track km)	Smallest emissions per track km (tCO_2e/track km)	Largest emissions per track km (tCO_2e/track km)
Entire Dataset	18	9,388	9,388	2,944	9,398

The one individually reported footprint had emissions per lane km of 2,944 tCO_2e/lane km. These figures are both much lower than the mean average for the 17 projects based on aggregated data (9,338 tCO_2e/lane km). Due to the use of aggregated data, the median average is not reliable.

5.2 Operation and Maintenance Emissions

Operation and maintenance footprint results are provided for:

- Road Operation and Maintenance (tCO_2e and tCO_2e per lane km)
  - All road operation and maintenance footprints, by country
  - All road operation-only footprints
  - All road maintenance-only footprints
  - All road operation and maintenance footprints, with and without major structures or earthworks
- Railway construction (tCO_2e and tCO_2e per track km)
  - All railway construction footprints, by country
- Shared path construction (tCO_2e and tCO_2e per lane km)
  - All shared path construction footprints

5.2.1 Road Operation and Maintenance Emissions

The road operation and maintenance emissions analysis contained 25 road operation and maintenance carbon footprints. Road operation and maintenance projects include motorways and state highways (or similar where not in New Zealand). Table 18 shows the data collected for this study, including the number of footprints, average total emissions, and range of total emissions by country. Due to the use of aggregated data in the Australian dataset, a median figure for the dataset is not a useful measure.

Table 18 Average and range of total emissions per year, by country, for road operation and maintenance footprints.

	Number of Footprints	Mean average total emissions (tCO_2e/year)	Median average total emissions (tCO_2e/year)	Smallest footprint (tCO_2e/year)	Largest footprint (tCO_2e/year)
New Zealand	2	2,259	2,259	186	4,333
Australia	16	8,816	N/A	3,395	84,000
UK	6	634	395	145	1,640
Ireland	1	45	45	45	45
Entire Dataset	25	5,977	3,395	45	84,000

Table 19 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	2	23	23	6	40
Australia	16	97	N/A	68	462
UK	6	48	19	3	146
Ireland	1	20	20	20	20
Entire Dataset	25	76	68	3	462

The New Zealand dataset contained two operation and maintenance footprints, with emissions per lane km per year of 6 tCO_2e/lane km/year and 40 tCO_2e/lane km/year.

The UK dataset contained six operation and maintenance footprints. The mean average for UK road operation and maintenance footprints was 48 tCO_2e/lane km/year and the median average was 19 tCO_2e/lane km.

There were 16 Australian footprints in this dataset, however only one is reported individually while the others were sourced from aggregated data. The one individually reported Australian footprint represented the highest level of emissions per lane km in the dataset at 462 tCO_2e/lane km/year. The mean average for the Australian footprints based on aggregated data was 72 tCO_2e/lane km/year.

The mean average of emissions per lane km per year from the entire dataset was 76 tCO_2e/lane km/year.

Table 20 shows the averages for footprints where only an operation *or* maintenance footprint was available, or where they were able to be separated. Within the dataset there were 10 operation-only and 15 maintenance-only footprints. We have removed 1 operation-only and 2 maintenance-only footprints from the analysis due to significant anomalies.

Table 20 Mean, mean without anomalous result, and median averages, of only operation or maintenance emissions per lane km per year for road projects, for all countries where there were relevant footprints.

	Number of Footprints	Mean average emissions per lane km (tCO_2e/lane km/year)	Mean average emissions per lane km (tCO_2e/lane km/year) Without anomalies	Median average emissions per lane km (tCO_2e/lane km/year)
Operation-only	9	61	12	9
Maintenance-only	13	77	20	5
Operation + Maintenance		139	32	15

Within the operation-only dataset, emissions per lane km per year ranged from less than 1 tCO_2e/lane km/year to 456 tCO_2e/lane km/year. The mean average operation emissions per lane km per year was 61 tCO_2/lane/km/year while the median average was 9 tCO_2/lane/km/year.

Within the maintenance-only dataset (excluding 2 anomalous footprints), emissions per lane km per year ranged from 1 tCO_2e/lane km/year to 767 tCO_2e/lane km/year. The mean average maintenance

emissions per lane km per year was 77 tCO_2e/lane/km/year while the median average was 5 tCO_2e/lane/km/year.

5.2.1.1 Road Operation and Maintenance Emissions and the Impact of Major Structures or Earthworks

Road operation and maintenance footprints were classified as either “including major structures or earthworks”, “not including major structures or earthworks”, or are unclassifiable due to lack of data. There were 9 footprints which could be classified, with 5 footprints including major structures or earthworks and 4 footprints not including major structures or earthworks.

Road structures include bridges and flyovers, while earthworks include large cuttings and tunnel construction. Footprints have been classified as ‘including major structures or earthworks” when they contain a structure or earthworks component which is significantly larger than for standard stretches of road.

Table 21 Average and range of road operation and maintenance emissions for footprints that include, or do not include, major structures or earthworks.

	Number of Footprints	Mean average total emissions (tCO_2e/year)	Median average total emissions (tCO_2e/year)	Smallest footprint in range (tCO_2e/year)	Largest footprint in range (tCO_2e/year)
With Major Structures or Earthworks	5	18,152	1,640	210	84,000
No Major Structures or Earthworks	4	137	159	45	186

Table 22 Average and range of emissions per lane km road operation and maintenance emissions for footprints that include, or do not include, major structures or earthworks.

	Number of Footprints	Mean average emissions per lane km (tCO_2e/km/year)	Median average emissions per lane km (tCO_2e/km/year)	Smallest emissions per lane km (tCO_2e/year)	Largest emissions per lane km (tCO_2e/year)
With Major Structures or Earthworks	5	137	40	11	462
No Major Structures or Earthworks	4	10	8	3	20

Footprints which included major structures or earthworks ranged from 11 tCO_2e/lane km/year to 462 tCO_2e/lane km/year and had mean average emissions of 137 tCO_2e/lane km/year.

Footprints without major structures or earthworks ranged from 3 tCO_2e/lane km/year to 20 tCO_2e/lane km/year and had mean average emissions of 10 tCO_2e/lane km.

5.2.2 Railway Operation and Maintenance Emissions

The railway operation and maintenance emissions analysis contained 17 railway operation and maintenance carbon footprints. Table 23 shows the data collected for this study, including the number of footprints, average total emissions, and range of total emissions by country.

Table 23 Average and range of total emissions per year, by country, for railway operation and maintenance footprints.

	Number of Footprints	Mean average total emissions (tCO_2e/year)	Median average total emissions (tCO_2e/year)	Smallest footprint (tCO_2e/year)	Largest footprint (tCO_2e/year)
Entire Dataset	17	5,663	6,372	4,866	6,372

Table 24 presents the average and range of emissions per project lane km's.

Table 24 Average and range of emissions per track km per year, by country, for railway operation and maintenance footprints.

	Number of Footprints	Mean average emissions per track km (tCO_2e/track km/year)	Median average emissions per track km (tCO_2e/track km/year)	Smallest emissions per track km (tCO_2e/track km/year)	Largest emissions per track km (tCO_2e/track km/year)
Entire Dataset	17	307	305	305	311

All the footprints in this dataset were derived from the mean averages of two sets of aggregated data from Australian projects. It is likely that there is a much wider range in results than reported here, however, we do not have access to sufficient data to report this. Information on the type of projects included in the aggregated data was not available. This is important to note, as the type of project can have a large impact on construction emissions (e.g. underground vs overground railways, or urban vs rural railways).

The mean and median averages for this dataset were very similar for emissions per track km at 307 tCO_2e/track km/year and 305 tCO_2e/track km/year.

5.2.3 Shared Path Operation and Maintenance Emissions

One shared path footprint was included in this dataset. This footprint had total operation and maintenance emissions of 84 tCO_2e per year and emissions per km per year of 8 tCO_2e/km/year.

Table 25 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

6.0 Discussion and Recommendations

This section presents a discussion of the analysis and provides recommendations for carbon emission baselines to be used by Waka Kotahi. The results and recommendations from this study offer a foundation for Waka Kotahi to make decisions around the baseline for carbon emission footprints of infrastructure projects.

A description of the dataset of footprints in each category is included in section 4.2. The analysis focusses on the per lane km metric as this is the most applicable and comparable for projects across a range of scales. Where relevant, the results have been broken down further in this section to explore differences within categories (e.g. by type of road).

For the recommendation of a baseline to be used by Waka Kotahi, the median average is generally recommended where there is a large dataset and the mean average recommended with a smaller dataset. 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.

6.1 Construction Carbon Emission Baselines

6.1.1 Road Construction Emissions

Analysis of the results found that some road construction elements result in particularly high emissions. For example, bridges tend to require significantly more concrete and steel (materials with particularly 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.

New Zealand Road Construction Footprints

In the NZ dataset, there was one footprint which had significantly higher emissions per lane km than the others. This particularly high emissions per lane km footprint skews the mean average to 26% the mean average for New Zealand road footprints without this footprint. The mean average without this footprint was 2,831 tCO_2e/lane km. This is similar to the median average for the entire dataset (at 2,231 tCO_2e/lane km) and suggests that in general, emissions produced from New Zealand projects are comparable with those emitted in other countries (especially the UK where the vast majority of footprints in this dataset are from).

Other Road Construction Footprints

A similar observation was made with footprints from other countries, where each dataset contains a small number of very high emission footprints. For this reason, the median average is preferable to use as a baseline.

Entire Dataset of Road Construction Footprints

Within the entire dataset, 44 footprints were higher than the mean average emissions per lane km and 92 footprints were lower. This suggests that using the median average (2,231 tCO_2e/lane km) may be a more accurate representation of a standard road construction footprint. Removing the five highest and lowest emissions per lane km footprints gives a mean average of 3,092 tCO_2e/lane km which is still substantially higher than the median average but lower than the mean average from the entire dataset. If using the entire dataset to create a single baseline for road construction projects, we recommend that the median average from the entire dataset is used as the baseline.

Due to the wide variation within the dataset, and the possibility for further analysis due to the large sample size, we have conducted further analysis to assess the possibility of multiple baselines specific to different project types.

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

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 1). The dataset for this analysis contained 123 footprints with 17 footprints classed as including major structures or earthworks.

Footprints which include major structures or earthworks had mean average emissions of 7,193 tCO_2e/lane km, compared to 2,733 tCO_2e/lane km for footprints without major structures or earthworks and 3,357 tCO_2e for the entire dataset. These differences are even greater when using the median averages. This illustrates how large an impact major structures or earthworks are on emissions from road construction projects. This is something that should be considered when assessing footprints against a baseline calculated from the entire dataset.

It is recommended that a specific baseline for road construction project types which do, or do not, include major structures or earthworks is included in the baseline recommendations below.

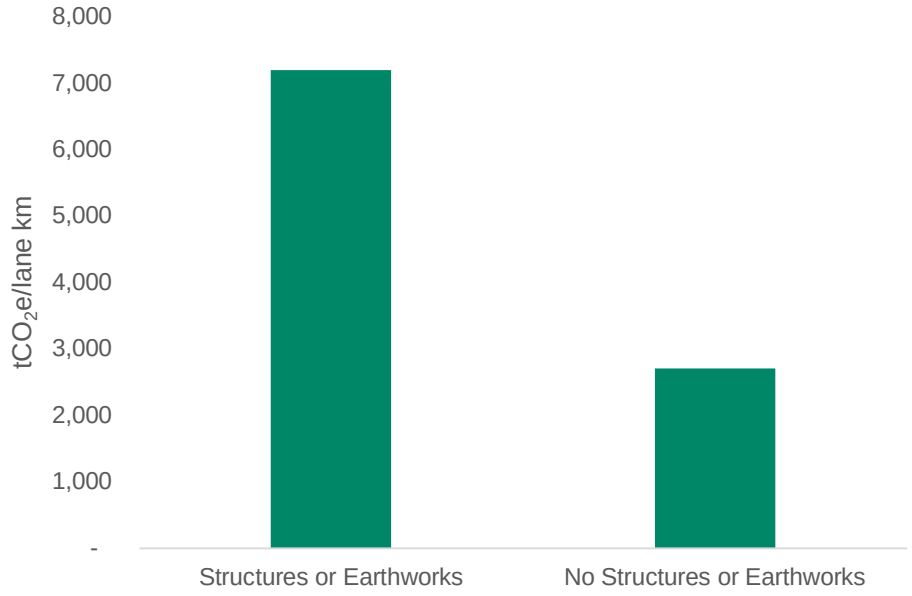

Figure 1 Mean average carbon emissions by road type per lane km for road construction footprints which include major structures or earthworks and footprints which do not include major structures or earthworks.

6.1.1.2 Road Construction Emissions by State Highway or Motorway

We also looked at the difference in emissions per km and per lane km for motorway and state highway projects. The road construction dataset contained 71 footprints classified as motorways and 66 footprints classified as state highways (state highways include A-roads in the UK). Examination of the mean averages for these road types shows that emissions per kilometre tend to be higher for motorways, but emissions per lane kilometre tend to be higher for state highways (see Figure 2). The differences are less distinct when using the median measure.

This is a consideration that Waka Kotahi may wish to consider when assessing which metric to use for a baseline, emissions per km or emissions per lane km, and when assessing footprints for future road project designs against the benchmarks. However, due to the relatively small differences between emissions from motorway and state highway projects, and to enable greater simplicity of use, we have not recommended a baseline specific to motorway and state highway projects.

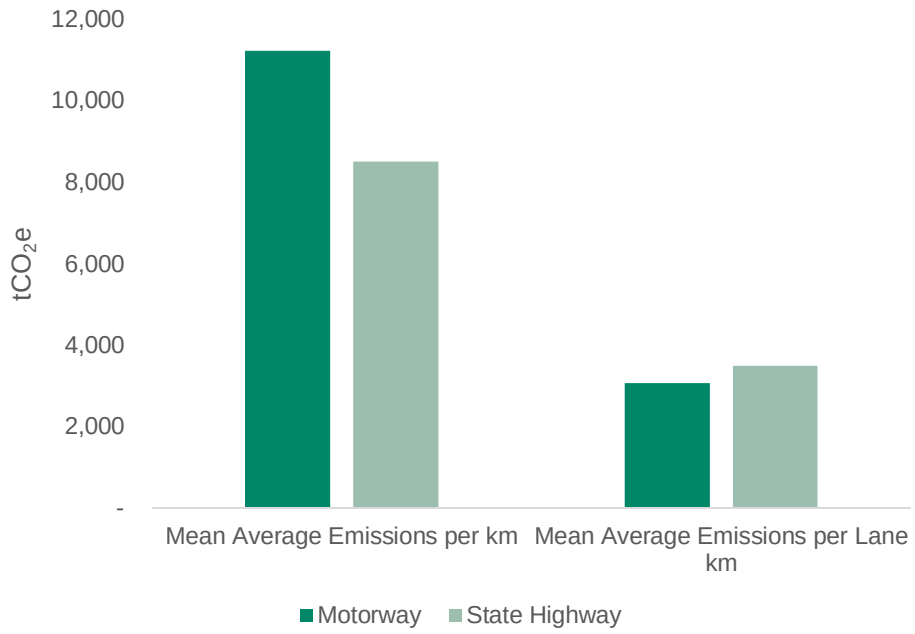

Figure 2 Mean average carbon emissions by road type per km and per lane km for motorway and state highway road construction footprints.

6.1.1.3 Road Construction Emissions by Project Type

Road/Busway/Path

This project type category contained 57 footprints. For this category, the mean average emissions per lane km was 3,882 tCO_2e/lane km. The median average emissions per lane km was 3,256 tCO_2e/lane km.

To create more usable baselines, this project type category was split into two subcategories for those projects where this information was available: road/busway/path with major structures or earthworks (5 projects), and road/busway/path without major structures or earthworks (37 projects). For road/busway/paths with major structures or earthworks, the mean average emissions per lane km was 4,486 tCO_2e/lane km. For road/busway/paths without major structures or earthworks, the mean average emissions per lane km was 3,883 tCO_2e/lane km; this is almost exactly the same as the mean average 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. However, the difference is less stark, due to the separation of the other project types from this analysis, for example, intersection and safety improvements, and projects which contain a bridge or tunnel only, are not included here.

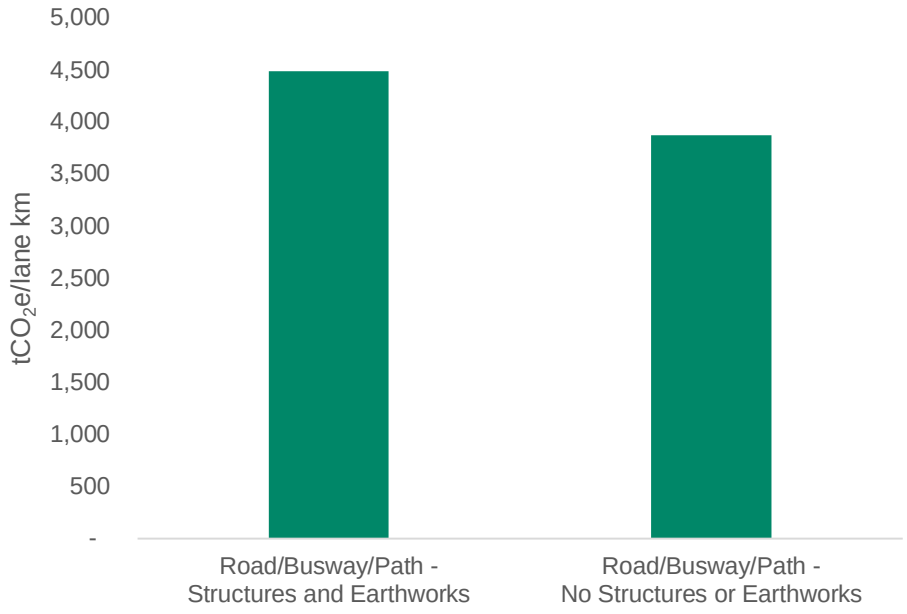

Figure 3 Mean average carbon emissions for road/busway/path construction footprints which include major structures or earthworks, and footprints which do not include major structures or earthworks.

Intersection improvements – grade separated, and at grade

Intersection improvements are split into two categories: at grade (41 projects), and grade separated (4 projects). 'At grade' refers to junction improvements at ground level, whereas 'grade separated' refers to junction improvements where sections of the junction are above ground level (e.g. a flyover).

By their nature, grade separated intersection improvements contain major structures. For intersection improvements at grade, the mean average emissions per lane km was 2,937 tCO_2e/lane km. For intersection improvements grade separated, the mean average emissions per lane km was 6,137 tCO_2e/lane km. This difference reflects the finding that the presence of major structures or earthworks increases emissions per lane km for road construction projects.

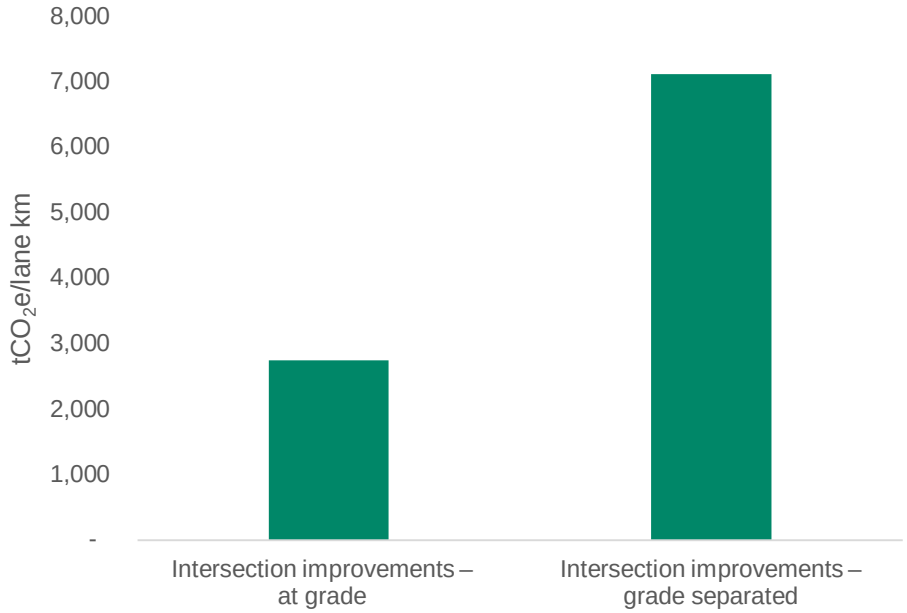

Figure 4 Mean average carbon emissions for intersection improvement construction footprints at grade, and grade separated.

Tunnels and Bridges only

Where the majority of a construction project footprint involved construction of a tunnel or bridge, these projects have been classified as either tunnel only (3 projects), or bridge only (3 projects).

For tunnel only projects, the mean average emissions per lane km was 10,004 tCO_2e/lane km, this is the highest average emissions by project type. For bridge only projects, the mean average emissions per lane km was 9,029 tCO_2e/lane km. Both of these averages are much higher than for other road construction infrastructure types, reflecting the greater amount of materials, and the scale of the works per km required.

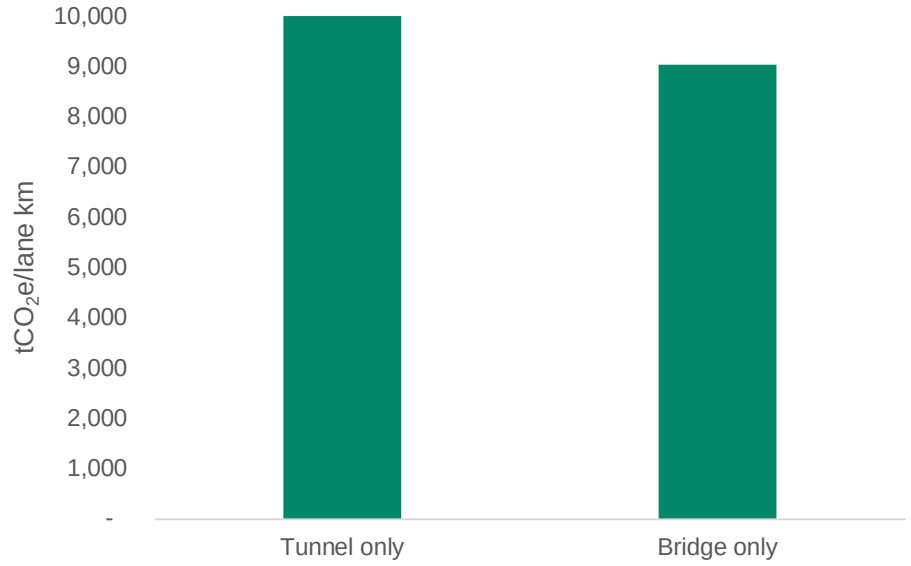

Figure 5 Mean average carbon emissions for tunnel only, and bridge only, construction footprints.

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 1,261 tCO_2e/lane km. This is the smallest average emissions by infrastructure type for road projects.

Recommendation for road construction carbon baselines per lane km

- Three sets of construction emissions baselines are recommended here, based on the level of detail available for the project. These baseline sets are:
    - All roads
    - All roads, with and without major structures or earthworks
    - Roads, by project type.
- Due to the wide range of emissions per lane km for different types of road construction projects, the project type emissions baselines are recommended as the primary baselines. The all roads, and all roads with and without major structures or earthworks baselines are also presented here.
- Baselines use the mean average from the category unless stated otherwise.
- For roads, by project type:

    - For road/busway/paths which contain major structures or earthworks, a carbon emissions baseline of **4,486 tCO_2e/lane km** is recommended.
    - For road/busway/paths which do not contain major structures or earthworks, a carbon emissions baseline of **3,883 tCO_2e/lane km** is recommended.
    - For intersection improvements at grade, a carbon emissions baseline of **2,937 tCO_2e/lane km** is recommended.
    - For intersection improvements grade separated, a carbon emissions baseline of **6,137 tCO_2e/lane km** is recommended.
    - For tunnel only projects, a carbon emissions baseline of **10,004 tCO_2e/lane km** is recommended.
    - For bridge only projects, a carbon emissions baseline of **9,029 tCO_2e/lane km** is recommended.
    - For safety and traffic flow improvement projects, a carbon emissions baseline of **1,261 tCO_2e/lane km** is recommended.
- For all roads, based on the **median average** from the entire dataset, a carbon emissions baseline of **2,231 tCO_2e/lane km** is recommended.
- For all roads, with and without major structures or earthworks:
    - For road projects which contain major structures or earthworks, a carbon emissions baseline of **7,193 tCO_2e/lane km** is recommended.
    - For road projects which do not contain major structures or earthworks, a carbon emissions baseline of **2,733 tCO_2e/lane km** is recommended.
- The range of emissions per lane km within the entire road construction dataset is from 7 tCO_2e/lane km to 18,322 tCO_2e/lane km.
- Due to the large number of footprints in the all roads dataset, the all roads baseline recommendation is presented with a higher level of confidence. Baselines for road/busway/path, intersection improvements at grade, and safety and traffic flow improvements, are also presented with a higher level of confidence. Consideration should be taken when using the other recommended baselines due to the smaller sample-size in these datasets.

Figure 6 shows the emissions per lane km for New Zealand infrastructure project footprints against the all roads baseline recommended by this study. Of the 21 footprints from New Zealand, 11 exceeded the all roads baseline while 10 footprints were lower than the baseline.

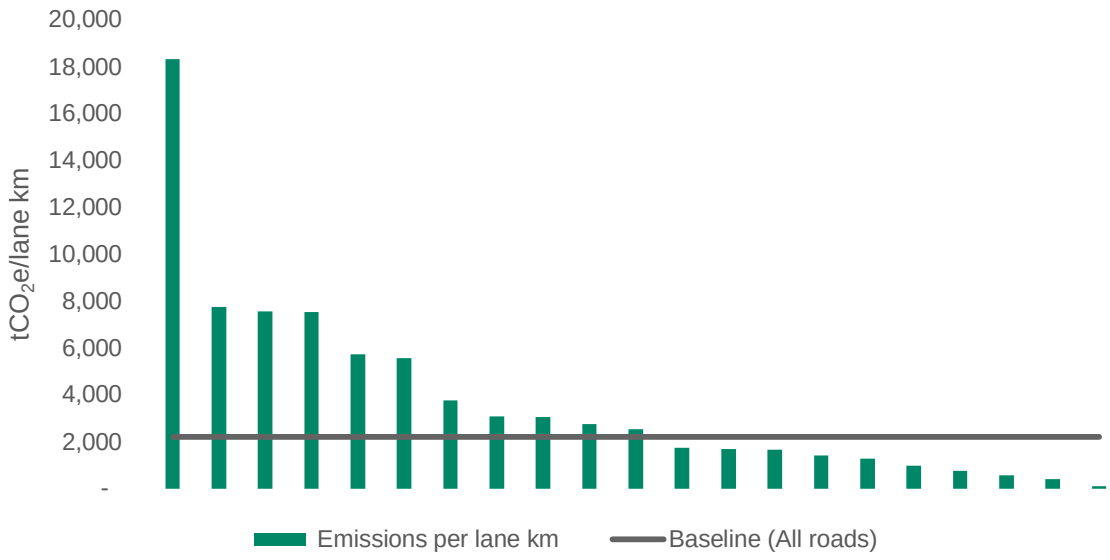

Figure 6 Emissions per lane km for road construction projects in New Zealand only, compared to the all road baseline.

6.1.2 Shared Path Construction Emissions

The entire shared path construction footprint dataset contained just five footprints. Due to the very small sample-size in the dataset, caution should be taken with drawing conclusions from the analysis, especially from any averages.

This dataset contains two footprints with emissions per km below 100 tCO_2e/km and three footprints significantly higher from 1,577 tCO_2e/km to 10,353 tCO_2e/km. Of these high emitting footprints, one includes a large amount of civil works and the other two includes the construction of significant bridges. The other shared paths do not involve significant structures or earthworks. This likely accounts for the large difference in emissions from these projects. It is recommended that a baseline for shared paths without additional construction works is calculated by excluding this footprint from the calculation.

Two baselines are recommended, for shared paths that do and do not include major structures or earthworks. However, additional footprints are required to create an accurate or reliable baseline for shared path construction emissions.

Recommendation for shared path construction carbon baselines

- The mean average from the two footprints in each category (shared paths that do or do not include major structures or earthworks) was chosen as the basis for the carbon emissions baseline recommendations for shared path construction projects.
- A carbon emissions baseline for shared path construction projects without major structures or earthworks of **43 tCO_2e/km** is recommended.
- A carbon emissions baseline for shared path construction projects with major structures or earthworks of **2,528 tCO_2e/km** is recommended.
- These baselines are provided with a very low level of confidence due to the small number of footprints in the dataset. Consideration of the extremely small sample size should be taken when using this recommended baseline.

Figure 7 and Figure 8 shows the two footprints in each shared path construction emissions subcategory against the recommended baseline. Note the difference in scale between these figures.

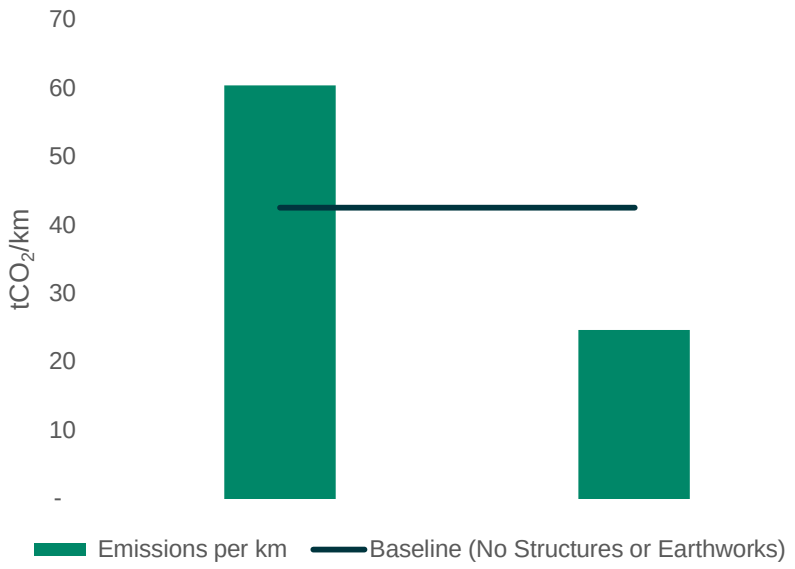

Figure 7 Emissions per lane km for the two shared path construction projects without major structures or earthworks compared to the recommended baseline (mean average from the two projects).

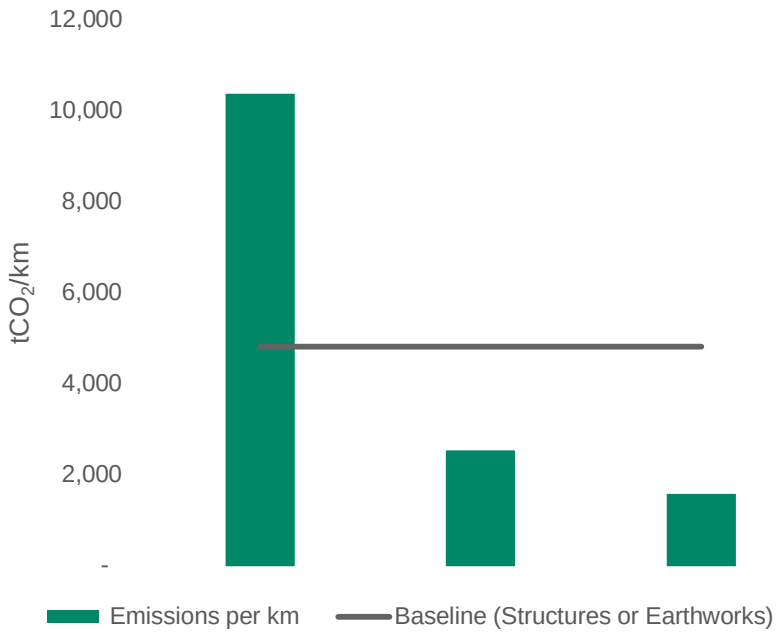

Figure 8 Emissions per lane km for the three shared path construction projects with major structures or earthworks compared to the recommended baseline (mean average from the three projects).

6.1.3 Railway Construction Emissions

The railway construction dataset contained one individually reported footprint and 17 footprints derived from aggregated data. All footprints are for projects in Australia. Emissions for railways are reported per track km.

Emissions per track km for the only individually reported railway construction footprint in the dataset sat between the mean and median averages for road construction footprints in this study (at 2,944 tCO_2e/track km). However, emissions reported from the footprints derived from aggregated data have higher emissions per track km than most road construction projects (at over 9,300 tCO_2e/track km).

It is difficult to draw conclusions relating to New Zealand projects from this data. Only data from Australia is available and it is impossible to know the true range of emissions footprints within the data. The context of the railway lines was also unknown, for example whether the rail lines were in urban or rural, or hilly or flat, areas. Construction emissions may be significantly higher in urban areas where there are many bridges and railway crossings compared to rural areas. There may also be significant differences between construction requirements for passenger and freight railway lines. Without this information it is difficult to assess the usability of this data for a New Zealand carbon emissions baseline.

The mean average is recommended as a baseline due to the lack of data regarding the range of emissions in this dataset.

Recommendation for a railway construction carbon baseline

- The mean average from the entire dataset was chosen as the basis for the carbon emissions baseline recommendation for railway construction projects, as described above.
- A carbon emissions baseline for railway construction projects of **9,398 tCO_2e/track km** is recommended.
- The range of emissions per lane km within the entire dataset was from 2,944 tCO_2e/track km to 9,398 tCO_2e/track km.

Consideration of the limitations of this data should be taken when using this recommended baseline.

6.2 Operation and Maintenance Carbon Emission Baselines

The recommendation of baselines in this analysis is presented per year and per the service life of the project. Analysis of operation and maintenance emissions focusses on per year emissions for ease of comparability. A 60-year service life timeframe has been recommended in a draft method paper provided by AECOM to Waka Kotahi and is based on international best practice and steering from Waka Kotahi. This timeframe is used for the service life emissions baseline.

6.2.1 Road Operation and Maintenance Emissions

New Zealand Road Operation and Maintenance Footprints

Both New Zealand footprints had relatively low emissions per km per year compared to the other footprints in the dataset but sat within the expected range of emissions per km per year for the dataset.

Of these two footprints, the footprint with the smallest emissions per lane km per year was a stretch of road on relatively flat land, while the larger footprint contained many structures (e.g. bridges) and cuttings which added to the maintenance emissions related to fuel use and embodied emissions in materials.

Australian Road Operation and Maintenance Footprint

The Australian dataset contained one individually reported footprint and 15 footprints derived from aggregated data.

The individually reported Australian footprint represented the highest emissions per lane km in the study at 462 tCO_2e/lane km/year. This project included a tunnel which required vastly higher electricity consumption for lighting and ventilation than non-tunnel stretches of road. This footprint stands out as an anomaly, with the next highest emissions per lane km per year at 146 tCO_2e/lane km/year and the remaining 23 footprints all lower than 90 tCO_2e/lane km/year.

Entire Dataset of Road Operation and Maintenance Footprints

The entire road operation and maintenance footprint dataset contained 25 footprints. The mean average of emissions per lane km per year from the entire dataset was 76 tCO_2e/lane km/year. Due to one particularly high emission per lane km per year footprint, the mean average was skewed upwards. The median average was 68 tCO_2e/lane km.

It is notable that 16 of the 18 highest emitting footprints in the dataset are Australian. One possible reason for this is the high carbon intensity of electricity due to use of non-renewable generation sources in Australia. When excluding the Australian footprints, the mean average emissions per lane km from the dataset was 39 tCO_2e/lane km, this is less than half than when including Australian projects.

We recommend using the median average from the entire dataset as the baseline for road operation and maintenance emissions footprints. 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. The available New Zealand footprints for analysis are smaller than the median average of the entire dataset, so this baseline recommendation may be a conservative estimate for the New Zealand context.

Entire Dataset Plus Additional Maintenance-only Footprints

In addition to the 25 footprints which contained data on both operation and maintenance emissions, there were four footprints that only reported maintenance 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 13 footprints, emissions per lane km per year ranged from 1 tCO_2e/lane km/year to 767 tCO_2e/lane km/year, however only one footprint in the dataset had emissions per lane km per year above 100 tCO_2e/lane km/year. The largest emissions per lane km per year footprint in this dataset was a footprint that only included the bridges within a stretch of motorway. The maintenance emissions for bridges are generally much higher due to the embodied emissions from construction materials used for maintenance such as concrete and steel. Without this high emissions footprint, the mean average maintenance emissions per lane km per year was just 20 tCO_2e/lane km/year, much closer to the median average of 6 tCO_2e/lane km/year.

Within the operation-only dataset, emissions per lane km per year ranged from less than 1 tCO_2e/lane km/year to 456 tCO_2e/lane km/year. The mean operation emissions per lane km per year was 61tCO_2/lane/km/year. However, all but one footprint had lower emissions per lane km than the mean average for the dataset. The largest emissions per lane km per year footprint in this dataset was a project which included a tunnel requiring a large amount of electricity use for lighting and ventilation. Without this particularly high emission footprint, the mean average for operation emissions per lane km per year was 12 tCO_2e/lane km/year, much closer to the median average of 9 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. Due to the existence of anomalously high emissions per lane km per year for both operation and maintenance emissions, the mean average of the dataset was skewed higher than most footprints. Using the mean average excluding the anomalous footprints provides a more accurate representation of an average footprint. Using this method, a carbon emissions baseline of 30 tCO_2e/lane km/year would be recommended, this is less than half the baseline recommended above but is very similar to averages of carbon emissions baselines without the Australian footprints.

Road Operation and Maintenance Emissions by Project Type

We looked at the impact of structures (e.g. bridges and tunnels) and major earthworks (e.g. cuttings) on emissions from road operation and maintenance projects (see Figure 1). The dataset for this analysis contained just 9 footprints with 5 footprints classed as including major structures or earthworks and 4 footprints without major structures or earthworks.

Footprints which include major structures or earthworks had mean average emissions of 137 tCO_2e/lane km/year, compared to 10 tCO_2e/lane km/year for footprints without major structures or earthworks and 76 tCO_2e/lane km/year for the entire dataset. The mean average is used due to the extremely small sample-size. This difference illustrates the impact major structures or earthworks are on emissions from road operation and maintenance projects. This is something that should be considered when assessing footprints against a baseline calculated from the entire dataset.

A specific baseline for projects which do, or do not, include major structures or earthworks is included in the baseline recommendations below based on the mean average from each dataset.

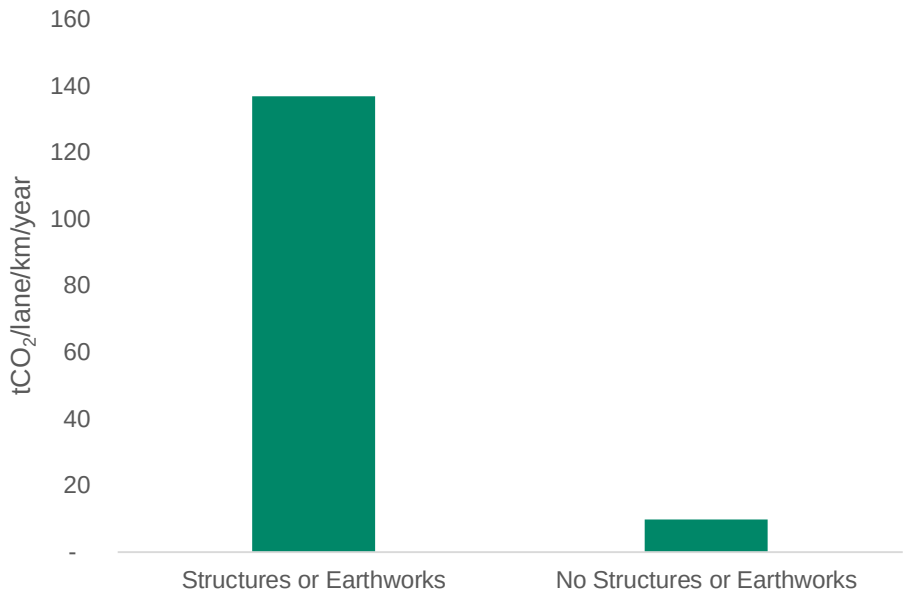

Figure 9 Mean average carbon emissions by road type per lane km for road operation and maintenance footprints which include major structures or earthworks and footprints which do not include major structures or earthworks.

Recommendation for a road operation and maintenance carbon baseline

- The median average from the entire dataset was chosen as the basis for the carbon emissions baseline recommendation for road operation and maintenance projects as described above. Additional baselines for road operation and maintenance footprints for projects which do, and do not, include major structures and earthworks are also presented.
- For all roads:
    - Based on the **median average** from the entire dataset, a carbon emissions baseline of **68 tCO_2e/lane km/year** is recommended.
    - Alternatively, a carbon emissions baseline for a 60-year service life of an asset of **4,102 tCO_2e/lane km** is recommended.
- For roads which do and do not involve major structures or earthworks:
    - For projects which contain major structures or earthworks, a carbon emissions baseline of **137 tCO_2e/lane km/year** is recommended (or **8,220 tCO_2e/lane km** for a 60-year service life).
    - For projects which do not contain major structures or earthworks, a carbon emissions baseline of **10 tCO_2e/lane km/year** is recommended (or **600 tCO_2e/lane km** for a 60-year service life).
- The range of emissions per lane km within the entire dataset was from 3 tCO_2e/lane km to 462 tCO_2e/lane km.
- Due to the small number of New Zealand footprints (two) and the small number of projects where detail of structures and earthworks was available, caution should be taken when using these baselines for New Zealand projects.
- Operation and maintenance emissions may change over time due to changes in emission factors and reporting standards, especially over a 60-year service life, so the baseline will need updating in the future.

6.2.2 Railway Operation and Maintenance Emissions

The railway operation and maintenance emissions dataset contained 17 footprints. All these footprints were Australian and derived from aggregated data. Due to this, we are not able to look at the range, or median average, of emissions in this category. The context of the railway lines was also unknown, for example whether the rail lines were located in urban or rural, or hilly or flat, areas. Operation and maintenance emissions may be significantly higher where lighting is required in urban areas or where there are many bridges and railway crossings. There may also be significant differences between passenger and freight railway lines and due to the frequency of track usage. Without this information it is difficult to assess the usability of this data for a New Zealand carbon emissions baseline.

Emissions for railways are reported per track km. The mean average emissions per track km for railway operation and maintenance footprints was 307 tCO_2e/track km/year. It is recommended that this is used as the baseline.

Caution should be taken when applying the findings of this analysis on New Zealand projects, especially due to the difference in carbon intensity of electricity generation between Australia and New Zealand, and the lack of information about these railway lines.

Recommendation for a railway operation and maintenance carbon baseline

- The mean average for the dataset was used as the basis for the carbon emissions baseline recommendation for railway operation and maintenance projects.
- A carbon emissions baseline for railway operation and maintenance projects of **307 tCO_2e/track km/year** is recommended.
- Alternatively, a carbon emission baseline for a 60-year service life of the asset of **18,449 tCO_2e/track km** is recommended.

Consideration of the limitations of using an Australian dataset should be taken when using this recommended baseline.

6.2.3 Shared Path Operation and Maintenance Emissions

A shared path is determined to consist of one standard lane (approximately 5m wide) so an emissions per lane km figure would be the same as the emissions per km figure.

Emissions per kilometre per year for the only shared path operation and maintenance footprint were lower than all but two of the road operation and maintenance footprints per lane km per year. This suggests that shared path projects are comparable by these metrics to road projects and may be smaller in general than road footprints. However, a larger sample size is required to draw any reliable conclusions.

Shared path operation and maintenance carbon baseline (one footprint)

- The one shared path operation and maintenance footprint produced **8 tCO_2e/km/year**.
- This may be used as a carbon emissions baseline given the lack of data available, however it is recommended that a new baseline is calculated when further data is available.

6.3 Additional Analysis

6.3.1 Road Construction Emissions and Cost

International literature suggests a strong correlation between the cost of a project and the emissions footprint[12][13]. 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. There are both environmental and financial incentives to minimise

[12] Urban Insight, Carbon Cost in Infrastructure (2020)
[13] HM Treasury, Infrastructure Carbon Review (2013)

carbon emissions. This correlation is supported by the dataset AECOM has collected which includes 60 projects where the capital cost of the project and the total construction footprint (in tCO_2e) is included in the data (see Figure 10). A correlation coefficient of 0.84 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.

From the dataset included in this project we can examine emissions per $1m of project contract cost. The mean and median averages for emissions per project cost from the entire dataset were 168 tCO_2e/$1m and 133 tCO_2e/$1m respectively.

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 should not be used as the only method to estimate emissions as it does not necessarily lead to emissions reductions.

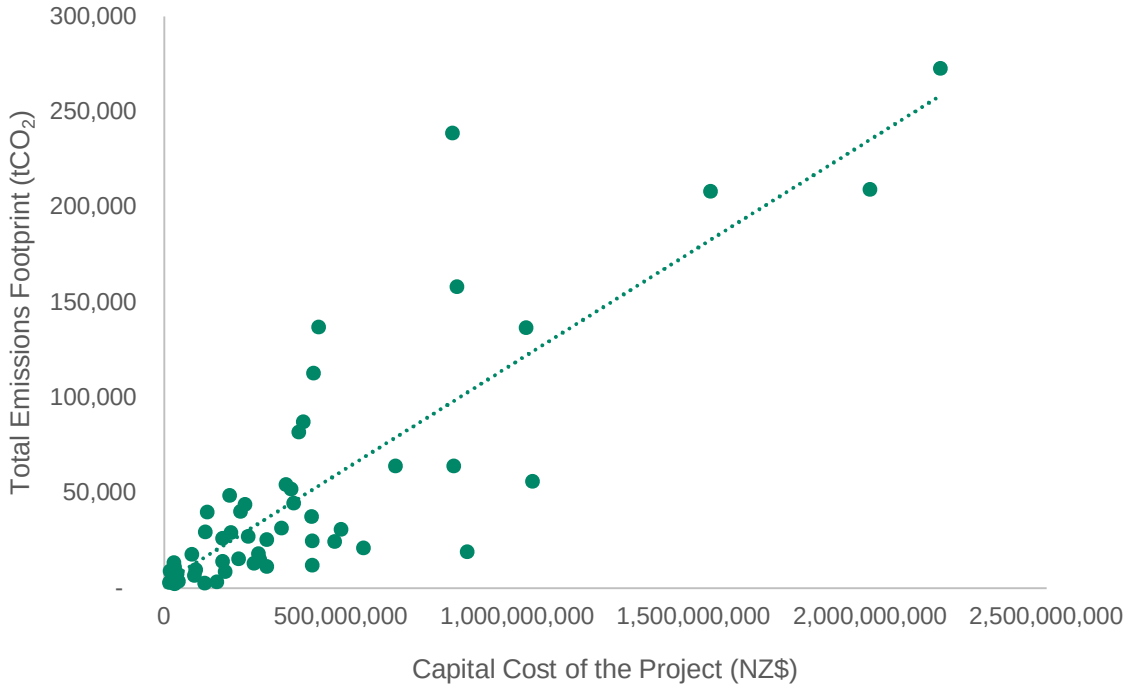

Figure 10 Graph showing the correlation of project cost and project emissions footprint for road construction projects

6.3.2 Road Construction Emissions by Emission Source

The road construction dataset contained 45 footprints where information on emissions from different emission sources was included in the data. Examination of the mean average emissions per lane km for embodied emissions from materials, fuel and energy use, and other emissions was possible with this data (see Figure 11).

Within this dataset, embodied emissions from materials represented 73% of total emissions while on-site fuel and energy use and 'other' emissions represented the remaining 20% and 7% respectively. On average, 2,890 tCO_2e/lane km are caused by embodied emissions from construction materials and 781 tCO_2e/lane km are produced by on-site fuel and energy use. 'Other' emissions represent the remaining emissions per lane km.

The results of this analysis should be taken with caution due to the potential for overlap between these categories, for example, transport of materials to and from the site may be allocated to different

categories in different footprints. It is also important to note that this dataset contains a wide range of different types of project and the level of detail available was variable between footprints.

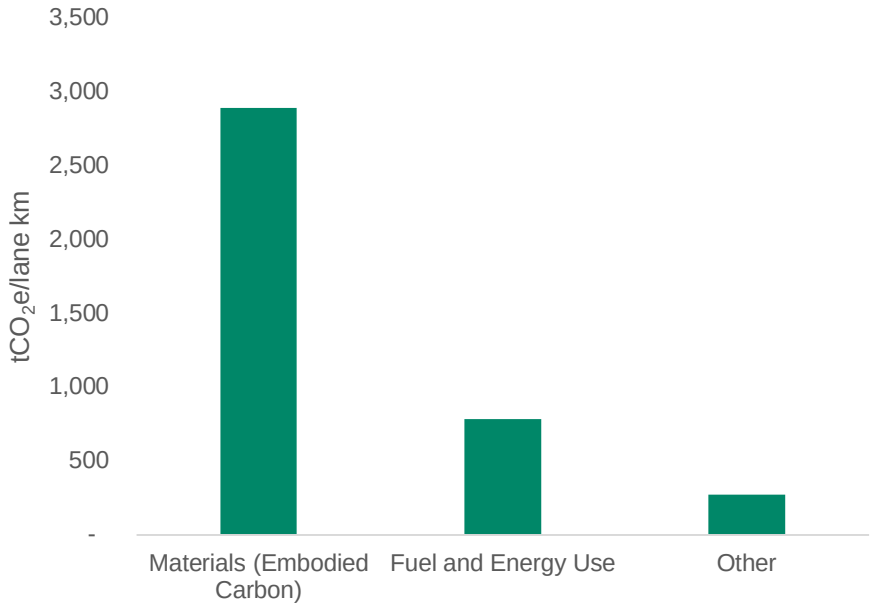

Figure 11 Mean average emissions per lane km from emission sources for road construction footprints

7.0 Summary of Findings

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.

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

This section outlines the key findings from this study.

Development of an agreed service life for infrastructure assets

- A service life of 60 years has been adopted based on common international use.

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 baseline 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 UK, Australian and Irish footprints. New Zealand operation and maintenance footprints are similar to UK footprints and generally smaller than Australian footprints.

Impact of major structures and earthworks on emissions

- The presence of structures (such as bridges), and significant earthworks (such as tunnels and major cuttings) have a major impact on construction, and operation and maintenance emissions.
- Where major structures and earthworks are present in a project footprint, emissions per lane km are significantly higher.

Carbon Emission Baselines

- The emissions per lane km metric has been chosen as the metric for carbon emissions baselines as it enables the greatest level of comparability between different footprints.
- Within each category dataset there is generally a large range of both total emissions and comparable metrics (such as emissions per lane km).
- Due to the wide range of emissions per lane km for different types of road construction projects, the project-type emissions baselines are recommended as the primary baselines. The all roads, and all roads with and without major structures or earthworks baselines are also presented here.
- The recommended baselines are presented in Table 26 with alternative 'all road' baselines presented in Table 27. Operation and maintenance emissions baselines per 60 year service life are presented in Table 28. Recommendations are rounded to the nearest 10 tCO_2e/lane km here.

- The following baselines have been recommended with a higher degree of confidence.
    - All road construction footprints
    - All road construction footprints without major structures or earthworks
    - Road/busway/path construction footprints without major structures or earthworks
    - Intersection improvement at grade footprints
    - Safety and traffic flow improvement footprints
- The following baselines have been recommended with a lesser degree of confidence due to small sample sizes.
    - All road construction footprints with major structures or earthworks
    - Road/busway/path construction footprints with major structures or earthworks
    - Intersection improvement grade separated footprints
    - Tunnel construction footprints
    - Bridge construction footprints
    - Shared path construction footprints with major structures or earthworks
    - Shared path construction footprints without major structures or earthworks
    - Railway construction footprints
    - All road operation and maintenance footprints
    - Road operation and maintenance footprints with major structures or earthworks
    - Road operation and maintenance footprints without major structures or earthworks
    - Railway operation and maintenance footprints
    - Shared path operation and maintenance footprints

Table 26 Summary of infrastructure construction emission baseline recommendations.

Category	Subcategory	Footprints in study	Emissions Baseline Recommendation (tCO_2e/lane km)	Level of Confidence in Baseline
Road/Busway/Path Construction	With major structures or earthworks	5	4,490	Low
	No major structures or earthworks	37	3,880	High
Intersection improvements – at grade		41	2,980	High
Intersection improvements – grade separated		4	6,140	Low
Tunnel Construction		3	10,000	Low
Bridge Construction		3	9,030	Low
Safety and traffic flow improvements		29	1,260	High
Railway Construction		18	9,400 (track km)	Low
Shared Path Construction	With major structures or earthworks	3	4,820	Low
	No major structures or earthworks	2	40	Low

Table 27 Summary of alternative 'all road' construction emission baseline recommendations.

Category	Subcategory	Footprints in study	Emissions Baseline Recommendation (tCO_2e/lane km)	Level of Confidence in Baseline
All Road		137	2,230	High
All Road	With major structures or earthworks	17	7,190	Low
	No major structures or earthworks	106	2,730	High

Table 28 Summary of infrastructure operation and maintenance emission baseline recommendations.

Category	Subcategory	Footprints in study	Emissions Baseline Recommendation (tCO_2e/lane km per 60-year service life)	Level of Confidence in Baseline
Road Operation and Maintenance		25	4,100	Low
Road Operation and Maintenance	With major structures or earthworks	5	8,220	Low
	No major structures or earthworks	4	600	Low
Shared Path Operation and Maintenance		1	480	Low
Railway Operation and Maintenance		17	18,450 (track km)	Low

- 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.
- Refer to section 6.0 for detailed discussion of the level of confidence for each recommended baseline.

Road construction emission sources

- Embodied emissions from construction materials represents the largest source of road construction emissions (73%), followed by on-site fuel and energy use (20%) and 'other' emissions (7%). On average, 2,890 tCO_2e/lane km are caused by embodied emissions from construction materials and 781 tCO_2e/lane km are produced by on-site fuel and energy use.

Correlation of project cost and emissions

- There is a strong correlation between project cost and emissions for projects in this dataset. This could be a way to highlight high emitting projects at an early design stage.

8.0 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.

8.1 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 used in this study, 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 Australian footprints was provided in aggregated form. An estimate of per-project emissions has been made using this data.

Summary of key assumptions:

- 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.

8.2 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 2020 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 Australian data was provided by ISC. 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 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.

9.0 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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