RISSB
RAIL INDUSTRY SAFETY AND STANDARDS BOARD

NATIONAL RAIL CARBON FOOTPRINT STUDY

June 2022

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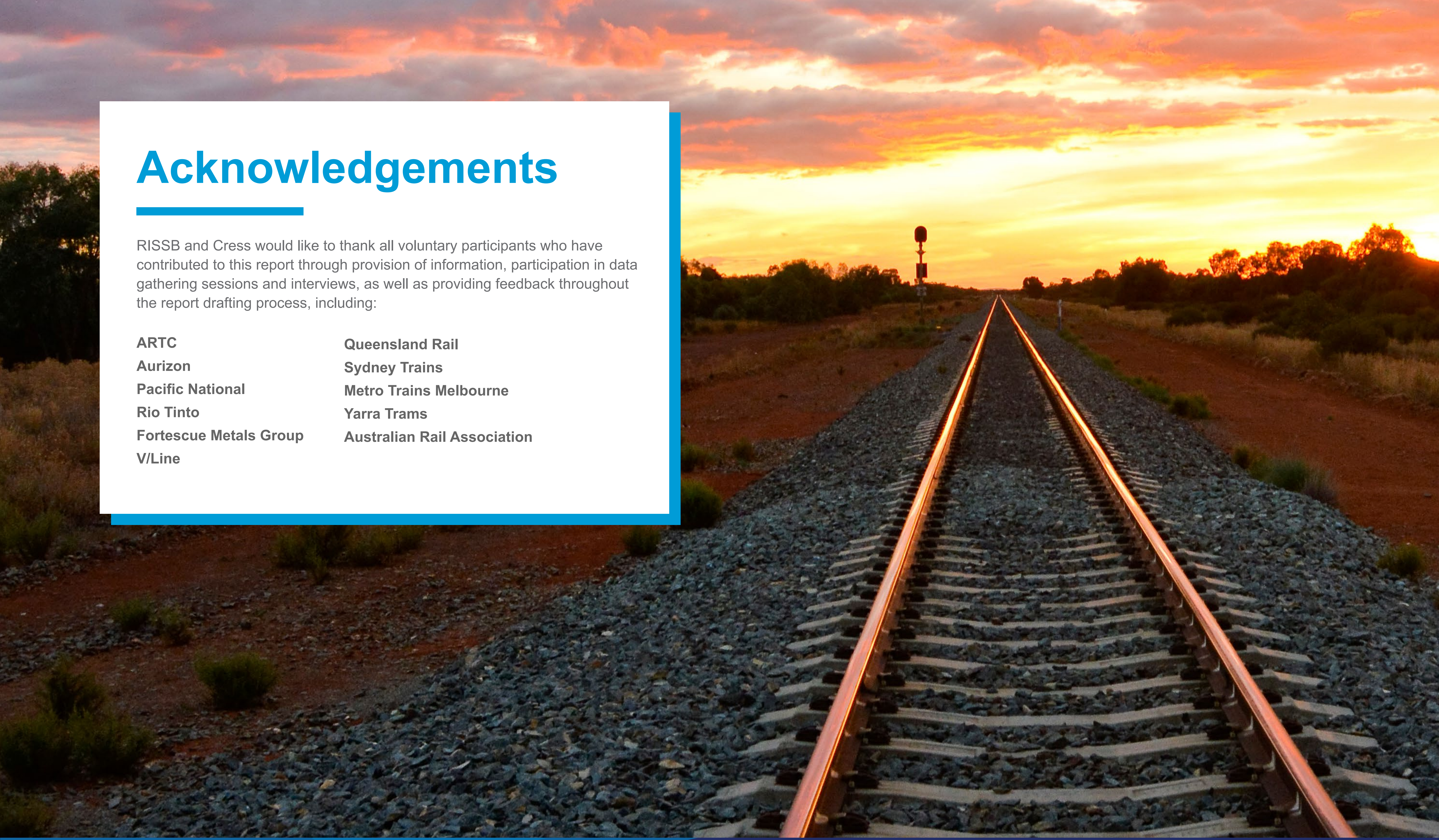
Glossary of Terms

BITRE	Bureau of Infrastructure and Transport Research Economics
CO2-e	Carbon dioxide equivalent
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
NGER	National Greenhouse and Energy Reporting
PPA	Power Purchase Agreements
RE	Renewable electricity
RIM	Rail Infrastructure Managers
RISSB	Rail Industry Safety and Standards Board
RSO	Rolling Stock Operators
RTO	Rail Transport Operators



Acknowledgements

RISSB and Cress would like to thank all voluntary participants who have contributed to this report through provision of information, participation in data gathering sessions and interviews, as well as providing feedback throughout the report drafting process, including:

ARTC
Aurizon
Pacific National
Rio Tinto
Fortescue Metals Group
V/Line
Queensland Rail
Sydney Trains
Metro Trains Melbourne
Yarra Trams
Australian Rail Association

Executive summary

The Rail Industry Safety and Standards Board, RISSB has commissioned this study to estimate carbon emissions associated with the Australian national rail network. Although many rail organisations report on greenhouse gas emissions there are no published data on the national rail footprint.

This work has been produced with consideration of global and national climate change ambitions and from the basis of:

- A convincing case to limit global temperature increase to less than 1.5°C above pre-industrial levels,
- The substantial gap between the current emissions reduction trajectory and the reduction required to achieve global temperature increase to less than 1.5°Cabove pre-industrial levels,
- The Australian Government target of achieving net zero emissions by 2050.

The transport sector accounts for 17% of Australia's national emissions. Despite moving 57% of national freight and 4% of passenger traffic, the national rail network accounts for just 4% of the transport sector's emissions. Road is responsible for 86% of transport emissions with air (7%) and sea (2%) accounting for the remainder. The rail industry has an important role to play in the decarbonisation of the transport sector as a whole. Although there is considerable focus on electric road vehicles as the primary driver of transport emissions reduction, vehicle transition alone is insufficient to achieve net zero emissions. A range of levers are available to policy makers and road transport network operators to support a trajectory to lower emissions, including the shift of transport tasks to other modes with lower emissions intensity[1], such as rail. At the same time, rail may risk losing its transport efficiency and lower emissions competitive position if its rate of emissions reduction is outpaced by the road sector.

This study found good quality data for scope 1 emissions (direct emissions from diesel for example) and indirect emissions from purchased electricity, heat, cooling and steam (scope 2). Sufficient data was unavailable for indirect emissions in the industry's value chain (scope 3). This study extrapolates data from 14 major RTOs representing approximately 85% of the national rail network to provide RISSB with an estimated national rail carbon footprint. It is intended to provide RISSB with a starting point to inform RISSB's own annual workplan development as well as informing the national rail network participants of the emissions estimates, the main emission sources and the key levers to achieve net zero by 2050. The findings will assist in the review and update of existing RISSB standards, as well as provide a quantitative position to support rail industry advocates.

[1] *Austroads (2020) Decarbonisation of Road Transport Network Operations in Australia and New Zealand*

The findings presented in this report should be used to underpin transport sector emissions reduction strategies and potential decarbonisation pathways.

The study explores the impacts of a changing climate on rail infrastructure and assets, such as an increasing need for maintenance and the importance of developing climate resilient networks that both adapt to the impacts of climate change and mitigate emissions to achieve a safe and reliable rail network.

The FY20-21 national rail carbon footprint scope 1 and 2 is estimated to be 6.9 MtCO2-e in steady state operations and maintenance.

90% of emissions are related to rail traction; the diesel used in freight locomotives & electricity consumed in passenger rolling stock are the most significant emission sources in the industry. 95% of scope 1 emissions are related to the diesel consumption for rail traction and 85% of scope 2 emissions are electricity consumed to power rolling stock.

Efforts to decarbonise scope 1 and 2 emissions concerning traction energy offer the greatest opportunities for reductions at a national level.

Two decarbonisation future scenarios have been estimated, a Low Uptake Scenario and a High Uptake Scenario.

The Low Uptake Scenario relies on substantial volume of carbon offsets to reach net zero by 2050. It assumes limited diesel minimisation or renewable electricity initiatives, the absence of regulatory change, no significant modal shift from road or air to rail, no network expansion, and a low level of rail-focused investment.

Conversely, the High Uptake Scenario explores a decarbonisation pathway accounting for effective industry collaboration leading to significant adoption of low and/or zero emissions technologies, such as sustainable biofuels, battery-electric, regenerative braking, and green hydrogen. It also asserts that modal shift, supported by policy setting, government support, investment, behavioural change and urban planning, is crucial to decarbonise the transport sector, and key in the decarbonisation of the rail sector. It also discusses energy efficiency and renewables, as well as carbon offsets.

This report also discusses the importance of more comprehensive carbon footprint studies that consider scope 3 emissions. These will improve the accuracy of the outcomes of this study and strengthen the identification of decarbonisation opportunities. Scope 3 is anticipated to represent a significant portion of the total emissions profile but was unable to be confidently estimated.

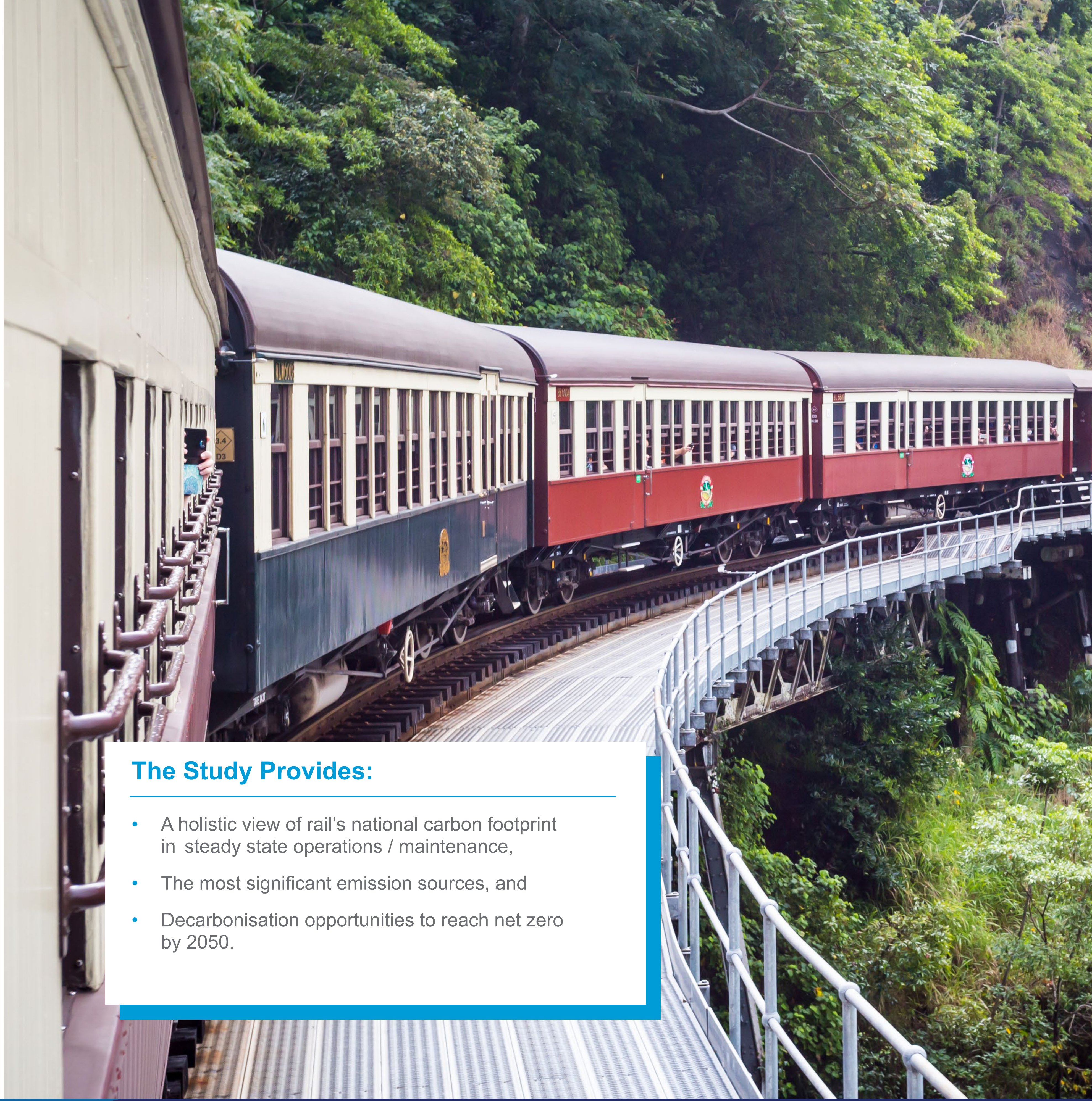
2 Introduction

2.1 Purpose of this study

The purpose of this study is to estimate the national rail network's carbon emissions in steady state operations and maintenance. It does not consider the embodied emissions of the existing infrastructure or assets, nor does it include any new or under construction projects. The study relies primarily on published data and other available information. It aims to quantitatively guide emissions reduction strategies, ensuring that rail plays its part as the sector rapidly decarbonises. The study underlines that rail has an important part to play in Australia's push for net zero by 2050, and that decarbonisation will strengthen its share of Australian transport into the future.

RISSB exists to support management of the safety and efficiency of Australian rail through standardisation, interoperability, and harmonisation. The research and insights from this study aim to fill a knowledge gap, providing RISSB with the information necessary to assist and coordinate the collaboration of rail infrastructure managers and operators and turn research and policy into harmonised industry practice.

The study will inform RISSB's activities including any review of existing standards and may contribute to managing and achieving safety outcomes, reducing costs, increasing productivity and efficiency. Additional RISSB responsibilities such as training and advice, events, safety data and risk analysis models are other elements of potential benefit from the scope of this study.



The Study Provides:

- A holistic view of rail's national carbon footprint in steady state operations / maintenance,
- The most significant emission sources, and
- Decarbonisation opportunities to reach net zero by 2050.

2.2 The rail sector needs to further build climate resilience

Australia is already experiencing the impacts of climate change, and these impacts are projected to become more extreme in the future. The Intergovernmental Panel on Climate Change (IPCC) has highlighted that limiting global warming to 1.5°C would substantially reduce projected losses related to climate change in human systems and ecosystems. To keep global warming to below 1.5°C, emissions must halve by 2030 and reach net zero by 2050.

Climate change risks such as extremely high temperatures, extreme weather events, heavy rainfall leading to flooding, more severe storms and harsher fire seasons can seriously impact rail transport assets, infrastructure, people, supply chains, and communities. Physical risks include increasing delays, derailments, and repairs to track, and other infrastructure in the rail industry. Climate change also poses transitional risks, such as failure to meet the decarbonisation goals of the rail industry, difficulty in complying with future legislation on emissions, the shift from road to rail overwhelming the public transport and freight systems, and skills shortages in servicing and operating new transport technologies.

Emissions from the rail industry, and transport sector generally, are contributing to climate change. However, the rail industry also has a major role to play in the climate change mitigation agenda, in terms of its contribution to support reduction of transport emissions; its decarbonisation ensures no emissions shift between transport sectors. This cannot happen without increased resilience and mitigation against climate change. Understanding climate projections, and potential risks / impacts, is essential to inform the integration of climate change thinking into long-term railway strategic planning, design, investment, decision-making and management processes.

Section 9.1 in the Appendix outlines a summary of climate projections for 2050 of each Australian state and territory, and the physical and transitional risks and adaptation opportunities specific to the rail industry.

2.3 Rail has an important part to play in Australia's 'net zero by 2050 goal'

The transport sector is the third largest contributor of direct carbon emissions in Australia. 86% of transport emissions are from road, 7% from air, 2% sea and 4% are from rail. While rail is considered highly efficient compared to road, as the road sector begins to decarbonise primarily through vehicle electrification, there is pressure on the rail industry to demonstrate it remains a crucial part of Australia's sustainable future.

In October 2021 the Australian Government released the "Australia's long-term emissions reduction plan"[2], highlighting road infrastructure battery charging and hydrogen refuelling stations as priority technologies for the transport sector. While not the dominant source of emissions, the rail sector presents an opportunity to decarbonise transport by attracting more freight and passenger traffic. Defining the best way to decarbonise the rail industry will ensure it plays its part as the transport sector rapidly decarbonises.

The rail industry in Australia is complex and involves many different aspects and organisations with different purposes and objectives. The rail sector services freight, resources and passenger transport across electrified and diesel driven networks via a mix of private and public ownership and management. It is recognised that Australia's railways are comprised of around 200 accredited Rail Transport Operators (RTO), including Rail Infrastructure Managers (RIM) and Rolling Stock Operators (RSO) and many that are both. Collaboration between RTOs is essential, particularly with regards to unified decarbonisation efforts.

The rail sector faces additional challenges that need to be addressed, such as:

- Rail infrastructure requires widespread decarbonisation coordination,
- Road infrastructure is already far more extensive and accessible than rail,
- The lifespan of rolling stock assets is much longer (>30 years)[3] than road assets (approx. 10.6 years)[4], requiring a long-term transition strategy to halve industry emissions by 2030 and achieve net zero by 2050 and
- Rail infrastructure such as steel rail and concrete sleepers, has a longer lifespan than roads and is expected to operate at full capacity for more than 50 years (and even longer, for some installations).

There is a significant amount of development planned for both freight and passenger railways over the coming decade, with up to $155Bn of Government funding planned. Rail enjoys positive green credentials however this advantage could erode as more and more road vehicles convert to battery power. In 2021, the Bureau of Infrastructure and Transport Research Economics (BITRE) reported a 52% investment disparity (total government and public non-financial corporations) between road and rail spending, in favour of road[5]. This underlines the importance for the rail industry to demonstrate its appetite for decarbonisation and take action in the sector.

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[2] *Commonwealth of Australia (2021) Australia's long-term emissions reduction plan, https://www.industry.gov.au/data-and-publications/australias-long-term-emissions-reduction-plan*

[3] *Commonwealth of Australia, Bureau of Infrastructure and Transport Research Economics (BITRE) (2022) Rail Trainline 9*

[4] *Australian Bureau of Statistics (2021) Motor Vehicle Census, Australia*

[5] *Commonwealth of Australia, Bureau of Infrastructure and Transport Research Economics (BITRE) (2021) Australian Infrastructure and Transport Statistics Yearbook 2021*

2.4 Methodology of this study

The carbon footprint was completed following the GHG Protocol principles, methodology, and guidance. The GHG Protocol establishes comprehensive global standardised frameworks to measure and manage greenhouse gas (GHG) emissions from private and public sector operations, value chains and mitigation actions. The study used the GHG Protocol – A Corporate Accounting and Reporting Standard, Scope 2 Guidance and Corporate Value Chain (Scope 3) Accounting and Reporting Standard to determine the emissions boundaries, attributable processes and guide the completion of the carbon footprint estimation. The following outlines the steps followed to complete the study.

i The purpose and scope of the study was reviewed and refined with RISSB.

ii The study defined the rail network elements included in the emissions boundary based on the National Rail Safety Register[6]. The national rail network comprises Rail Infrastructure Managers (RIMs) and Rolling Stock Operators (RSOs) managing and operating freight (bulk and non-bulk) and passenger (heavy and light rail) networks.

iii The study identified the reporting boundary. This involved identifying direct and indirect emissions sources and choosing the scope of the accounting estimation based on data availability and accuracy.

iv The study intended to estimate scope 1, 2 and 3 emissions in steady state operations and maintenance, however, high confidence data were available only for scope 1 and 2. Confidence is low for scope 3 and therefore not included in the footprint at this stage. However, based on the data that has been reviewed, it is likely that scope 3 emission sources will be significant and it is suggested that a scoping exercise be undertaken to better identify emission sources. An initial analysis of major rail operators and managers was completed to identify data sources and select the calculation approach.

v The calculation approach was desktop research to gather relevant information and fill the gaps in the available data using statistical methods and extrapolation. Estimations were based on fourteen rail operators and managers representing approximately 85% of the industry. The remaining 15% was calculated by extrapolating from this data taking into account national total of 33,326 route-kilometres of operational heavy and light railway[7], 58,229 passenger and freight full-time equivalent (FTE) workers, and 29.8 billion contribution to GDP[8]. The study intended to use train kilometres of operations for passenger and freight transport and billion tkm or million tonnes for freight transport, however national data was unavailable. The use of efficiency factors for passenger transport was avoided for extrapolation.

vi The calculation approach for scope 3 estimations included the same extrapolation, based on data that represents 20% of the network. Activity replacement data and selection of emissions factors for steel track, sleepers and ballast was completed to estimate purchased materials carbon emissions.

vii Data sourced from the industry included greenhouse gas emissions in operations and maintenance, emission sources, annual variation of GHG emissions, representation of RTOs in the industry, carbon reduction opportunities, climate change impacts and sustainability issues.

viii The data from the range of selected RTOs was extrapolated under kilometres of track maintained, number of employees and total revenue to represent the national rail carbon footprint. This process was designed from the remaining Australian RTOs.

ix The study identified the most significant carbon emission sources in operations and maintenance to inform decarbonisation opportunities and target carbon hot spots.

x Two decarbonisation scenarios for the rail industry were analysed to reach net zero by 2050. This process was supported by operators' and managers' decarbonisation strategies, international case studies, academic papers and international railways.

xi The draft findings were reviewed with the engaged RTOs & RISSB.

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[6]Office of the National Rail Safety Regulator (ONRSR) (2022) National Rail Safety Registers, https://www.onrsr.com.au/publications/national-rail-safety-register

[7]Commonwealth of Australia, Bureau of Infrastructure and Transport Research Economics (BITRE) (2022) Rail Trainline 9

[8]Australasian Railway Association (2020) Value of Rail 2020

2.5 Carbon emissions in steady state operations and maintenance

Figure 1 illustrates the emissions boundary of the study. It identifies emissions inside the boundary with scope 1 and 2 estimated with high confidence and scope 3 estimated with low confidence, because sufficient scope 3 data were unavailable. The figure also illustrates emissions outside the boundary.

Carbon emissions inside and outside the study are listed in table 1.

Inside Emissions Boundary			Outside emissions boundary
Estimated (high confidence)		Estimated (low confidence)	
Scope 1	Scope 2	Scope 3	Scope 3
• Passenger rolling stock diesel consumption • Freight locomotives diesel consumption • Road fleet diesel and gasoline consumption • Miscellaneous fuel consumption (e.g., stationary energy, greases, oil and fugitive emissions)	• Passenger rolling stock electricity consumption • Freight locomotives electricity consumption • Purchased electricity for facilities (e.g., offices, centres, depots and stations) and signalling systems	• Purchased goods and services • Capital goods • Fuel-and energy-related activities • Upstream transport and distribution • Waste generated • Business travel • Employee commuting	• Embodied emissions of existent railway • New, ongoing or future railway expansion projects • End-of-life of assets

Table 1. Emissions boundary of the National Rail Carbon Footprint study

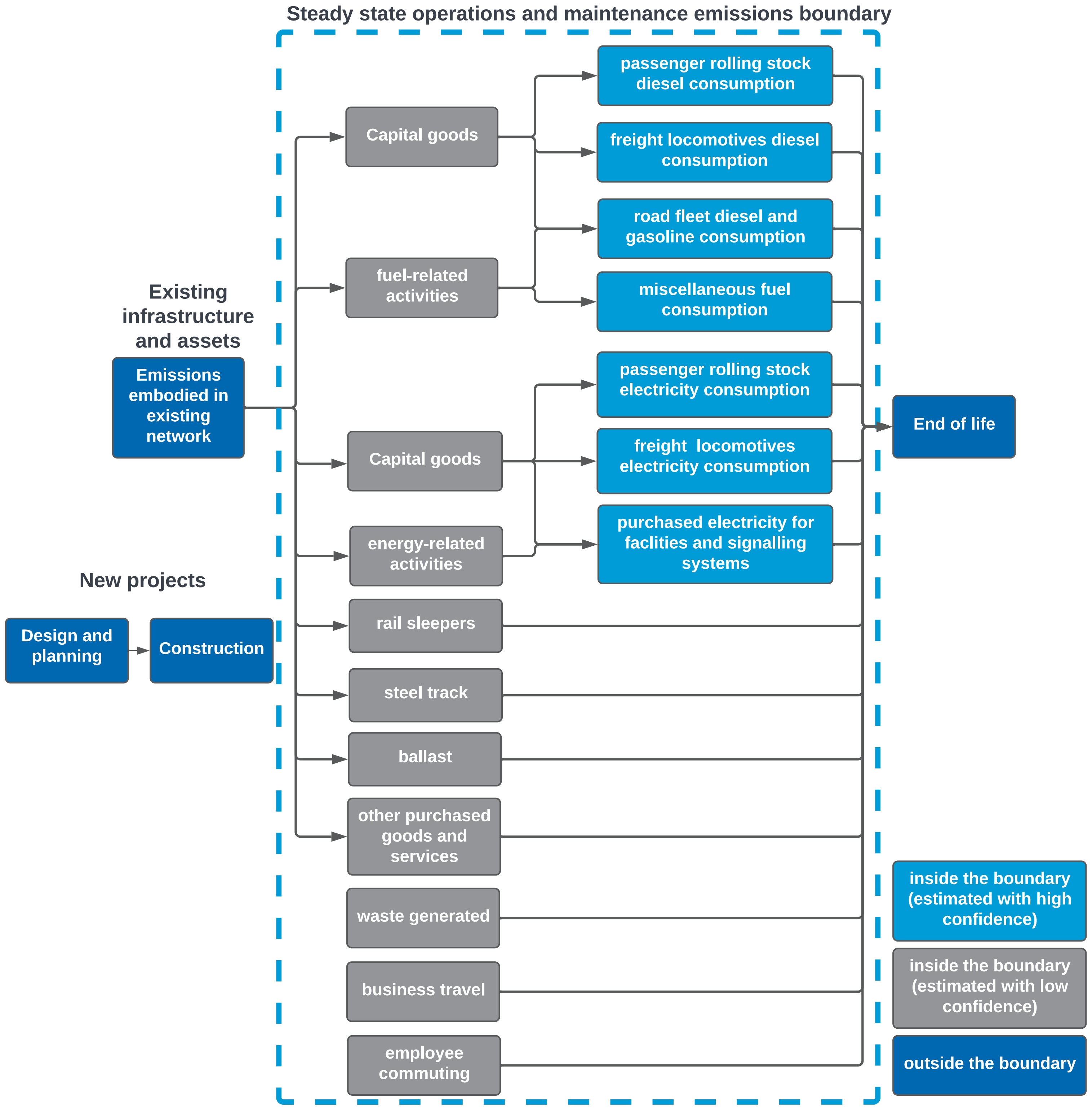


Figure 1. Emissions Boundary of the estimations

2.6 Data sources, assumptions and limitations of the study

Carbon footprint estimations were based on high confidence scope 1 and 2 emissions data from a range of Australian industry operators and managers reporting to NGER and/or available through sustainability and ESG reports. Other main sources used for the completion of this study, included:

- IPCC reports,
- Bureau of Meteorology and CSIRO data,
- Bureau of Infrastructure and Transport Research Economics (BITRE) Rail Trainline 9 (2022) and Yearbook 2021
- Various national[9] and international[10] transport decarbonisation studies and
- International rail industry carbon footprint and decarbonisation strategies e.g., UK[11] and India[12].

The study required several assumptions due to inherent limitations, summarised in table 2:

Assumptions

- The data collected represents 85% of national operations and maintenance
- Data provided by RTOs is accurate and calculated correctly
- COVID did not substantially impact GHG emissions from the majority of RTOs studied
- Carbon emissions calculations will become more accurate over time
- Annual emissions to increase by 0.91% annually based on BITRE estimations
- Low and/or zero emissions technologies will become available by 2050
- RTOs will meet their public decarbonisation strategies
- Decarbonisation of road transport requires transport task shift to other modes with lower emissions intensity[13], such as rail
- Urban rail passenger share to increase 3 times by 2050, from about 4% (pre-COVID) to 11% from industry action and supported journal papers[14]
- Freight road to rail modal shift estimated at 7% by 2050, based on RTOs increased capacity plans and associated emissions
- The rail industry will adopt technologies as they emerge and become available
- The fourteen contributing RTOs are representative of the rail industry-wide carbon profile

Limitations

- Unviable to collect carbon emissions data from every RTO (time, effort, data availability & accuracy)
- Inconsistent carbon inventory boundaries across RTOs
- Some technology for decarbonisation is not yet developed nor commercially available.
- Some maintenance emissions are untracked & excluded from carbon inventories
- Non unified operational criteria across the industry
- There is limited confidence in industry scope 3 carbon emissions and available data sources

Table 2. List of main assumptions and limitations

[9] KPMG, Roads Australia, Australasian Railway Association and Infrastructure Sustainability Council (2022) The journey to net zero, https://roads.org.au/wp-content/uploads/Journey-to-net-zero_Final_ForWeb.pdf Australian National University (2020) On track to 2040

[10] International Energy Agency (2019) The Future of Rail, https://iea.blob.core.windows.net/assets/fb7dc9e4-d5ff-4a22- ac07-ef3ca73ac680/The_Future_of_Rail.pdf

[11] Rail Safety and Standards Board (RSSB) (2010) Whole life carbon footprint of the rail industry

[12] Climate Action Tracker (2020) Decarbonising the Indian transport sector pathways and policies, https://climateactiontracker.org/documents/832/CAT_2020-12- 09_Report_DecarbonisingIndianTransportSector_Dec2020.pdf

[13] Austroads (2020) Decarbonisation of Road Transport Network Operations in Australia and New Zealand

[14] International Energy Agency (2019) The Future of Rail, https://iea.blob.core.windows.net/assets/fb7dc9e4-d5ff-4a22-ac07-ef3ca73ac680/The_Future_of_Rail.pdf Stanleya, J., Ellison, R., Loader, C. and Hensher, D. (2018) Reducing Australian motor vehicle greenhouse gas emissions, Transportation Research Part A, vol 109, pp. 76-88

3 National rail carbon footprint

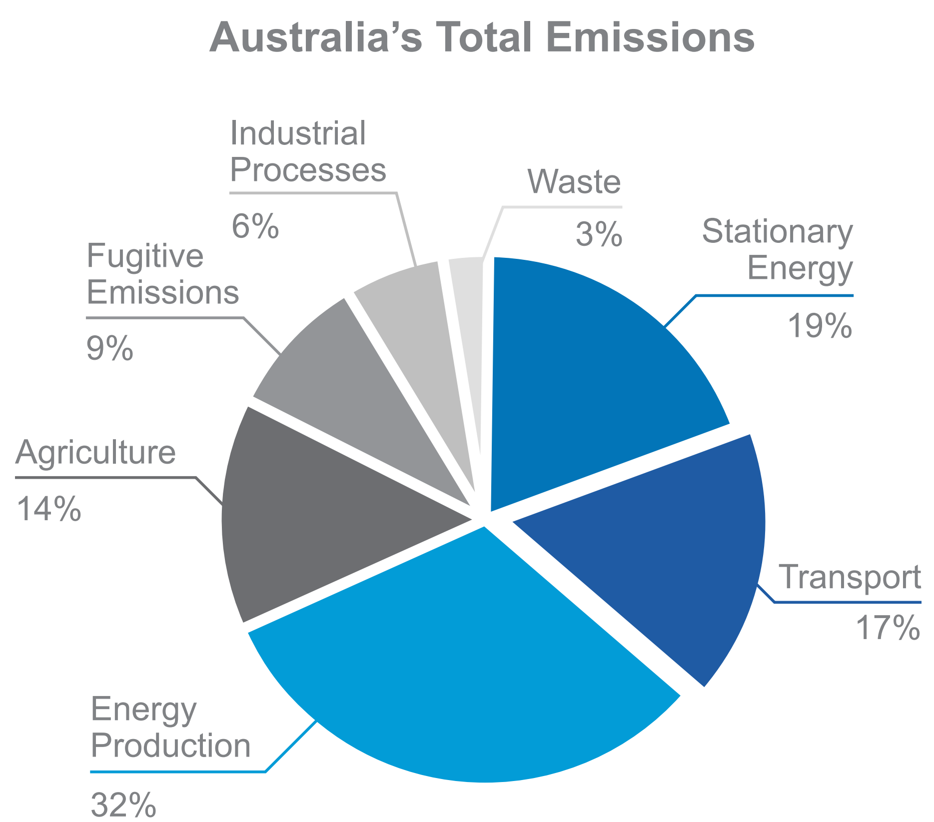
3.1 The national rail network accounts for just 4% of the transport sector's emissions

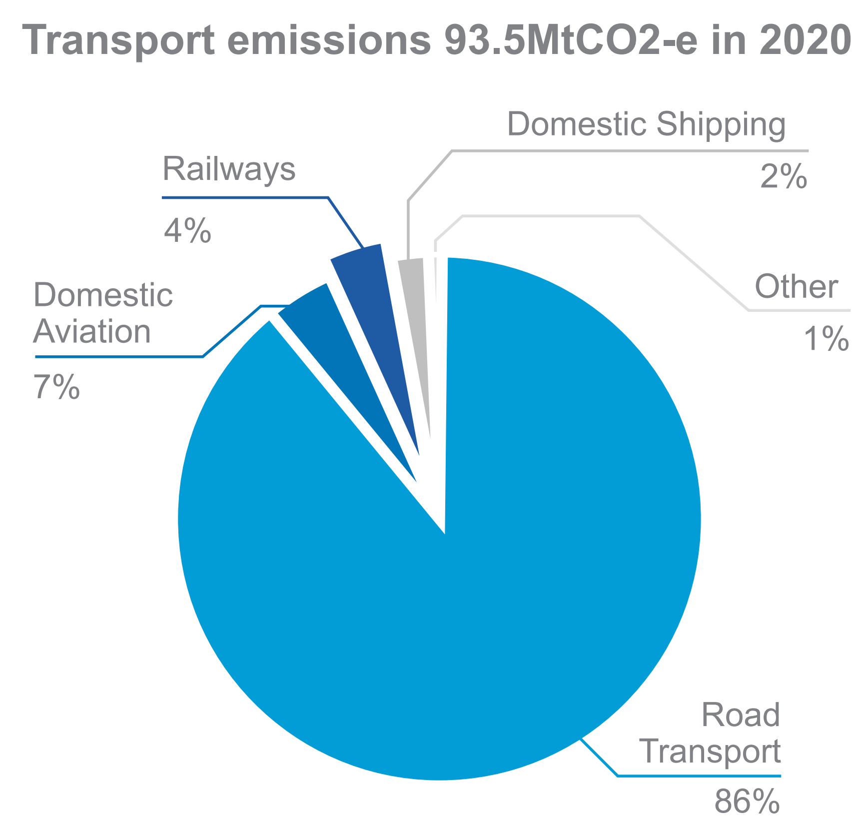
The transport sector contributed 93.5 MtCO2-e or 17% of Australia's GHG emissions in 2020. Road transport was the most significant emission source, responsible for 86% of transport emissions. Road / passenger represented 45% of transport emissions and rigid and articulated trucks represented 22% of transport emissions, the remaining carbon comes from light commercial vehicles, buses and motorcycles, representing 17%, 2% and 0.3% respectively. Domestic aviation was the second largest contributor to transport emissions with 7%, followed by rail at 4% and sea and 'other' comprising the remaining 3% total transport emissions[15].

Rail offers the potential to reduce national transport emissions by shifting additional passengers and freight to a more emissions-efficient mode of transport. This shift could lower traffic congestion, reduce road accidents and fatalities, provide health benefits by reducing air pollution, and can produce economic benefits through agglomeration effects[16].

[15] Commonwealth of Australia (2022) National Inventory Report 2020.

[16] Australasian Railway Association (2020) Value of Rail 2020





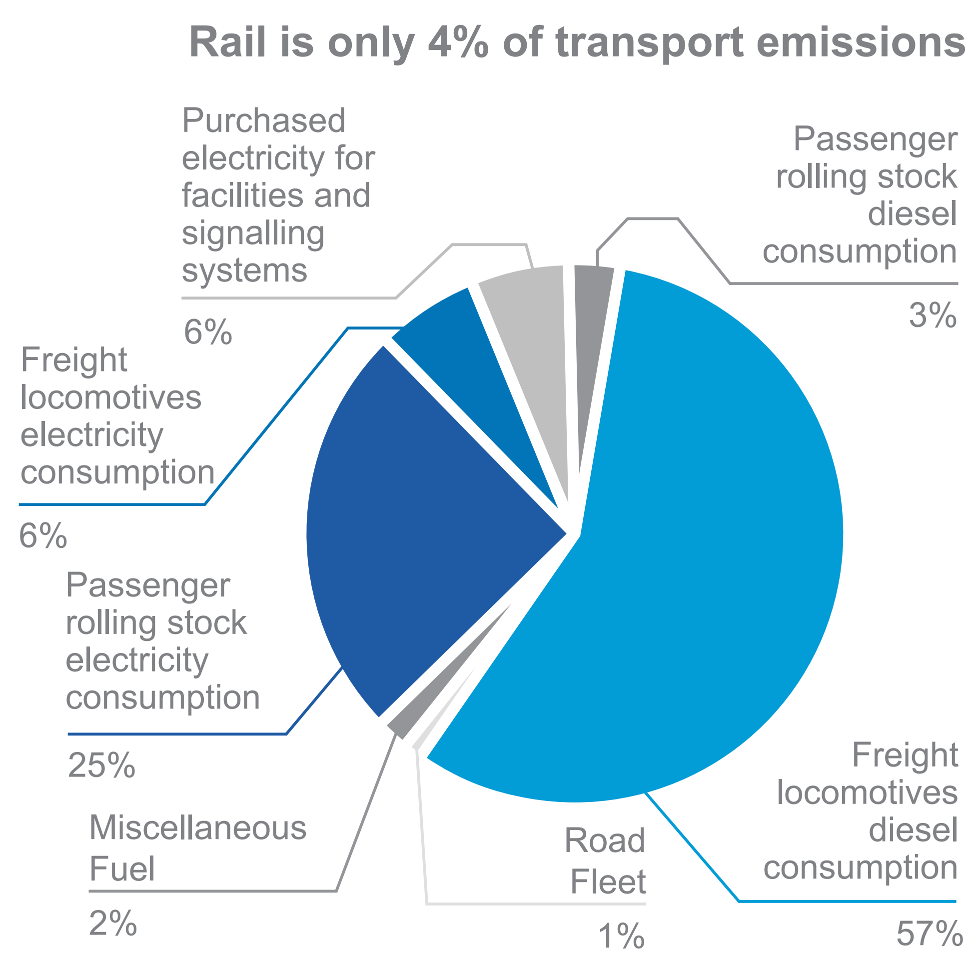


Figure 2. Australia's transport emissions

3.2 Modal shift from road to rail is key to decarbonise the transport sector

Decarbonising the transport sector primarily relies on road vehicle electrification but a number of other levers are needed including shifting more of the transport task to more efficient modes. Despite 57% of national domestic freight being moved by rail[17], rail freight only represents 3% of the national transport emissions. The freight task for trucks is about half of the rail freight task, yet roads contribute over 7 times more emissions than rail. Rail freight represents 4.6 MtCO2-e, based on this study and trucks contribute 21 MtCO2-e[18].

73% of national passengers travel by car, representing 45% of transport emissions. However, only 4% of passengers travel by rail[19], representing 1% of transport emissions. Passenger rail represents 2.3 Mt CO2-e emissions, and car passenger represents 41.7 MtCO2-e[20].

Table 3 shows a summary of the passenger and freight transport task by road and rail in FY20-21,and emissions associated.

To achieve transport sector decarbonisation, road torail modal shift is an important strategy. A decarbonised rail industry will ensure it remains an important part of the Australian transport sector into the future, particularly as the world moves toward net zero by 2050.

Understanding the decarbonisation challenges faced by the rail industry and developing a forward-looking strategy to halve industry emissions by 2030 and achieve net zero by 2050, will support the national transport sector. Without decarbonisation the rail industry's efficiency advantages will narrow compared to road transport, threatening its competitiveness.

[17] *Commonwealth of Australia, Bureau of Infrastructure and Transport Research Economics (BITRE) (2021) Australian Infrastructure and Transport Statistics Yearbook 2021*

[18] *Commonwealth of Australia (2021) Australia's emissions projections 2021*

[19] *Commonwealth of Australia, Bureau of Infrastructure and Transport Research Economics (BITRE) (2021) Australian Infrastructure and Transport Statistics Yearbook 2021*

[20] *Commonwealth of Australia (2021) Australia's emissions projections 2021*

FY20-21	Road		Rail	
Passenger	45% of transport emissions are car passenger (41.7 Mt CO2-e) OR 52% of road transport emissions	73% (COVID year) 64% of passenger travel (pre-COVID)	1% of transport emissions OR 34% of rail transport emissions. This study estimated 2.3 Mt CO2-e	4% (COVID year) 5% of passenger travel (pre-COVID)
Freight	22% of transport emissions are articulated and rigid trucks (21.0 Mt CO2-e) OR 13% of road transport emissions	29% of domestic freight	3% of transport emissions OR 66% of rail transport emissions. This study estimated 4.6 Mt CO2-e	57% of domestic freight
TOTAL	86% of transport emissions equivalent to 80 Mt CO2-e		4% of transport emissions equivalent to 4 Mt CO2-e based on the government, 6.9 Mt CO2-e based on this study	

Table 3. Passenger and freight task and emissions for road and rail transport [19 20]

3.3 Scope 1 and 2 emissions in steady state operations & maintenance

3.3.1 Scope 1 and 2 emissions and sources estimated with high confidence

This study estimated the FY20-21 national rail carbon footprint to be 6.9 MtCO2-e for rail operations and maintenance. Direct GHG emissions (scope 1) from sources that are owned or controlled by rail operators and managers represented 63% of total emissions. Indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling (scope 2) were 37%. These emissions occur at sources not owned or controlled by rail operators and managers.

Diesel consumption from freight locomotives was found to be the most significant emission source, making up 57% of total scope 1 and 2 emissions; passenger rolling stock electricity consumption represented a further 25%.

As 91% of emissions stem from traction energy consumption, this is where decarbonisation efforts are best focussed. Other less significant emission sources included:

- Purchased electricity to power facilities such as offices, centres, depots and train stations, and electricity used for signalling systems,
- Miscellaneous fuel consumption such as stationary energy (e.g., fuel used to power generators, plant and equipment, greases, oils) and fugitive emissions and
- Road fleet diesel and gasoline consumption.

This study identified operational emissions as being more significant than maintenance emissions in scope 1 and 2. In order to quantify this statement with confidence, the industry would need to measure, record and report operations and maintenance associated emissions (e.g., energy consumption) as separate items. Figure 3 shows the national rail industry scope 1 and 2 carbon emissions in steady state operations and maintenance broken down by emission sources. This chart helps visualise the emissions distribution across each scope 1 and 2 emissions source.

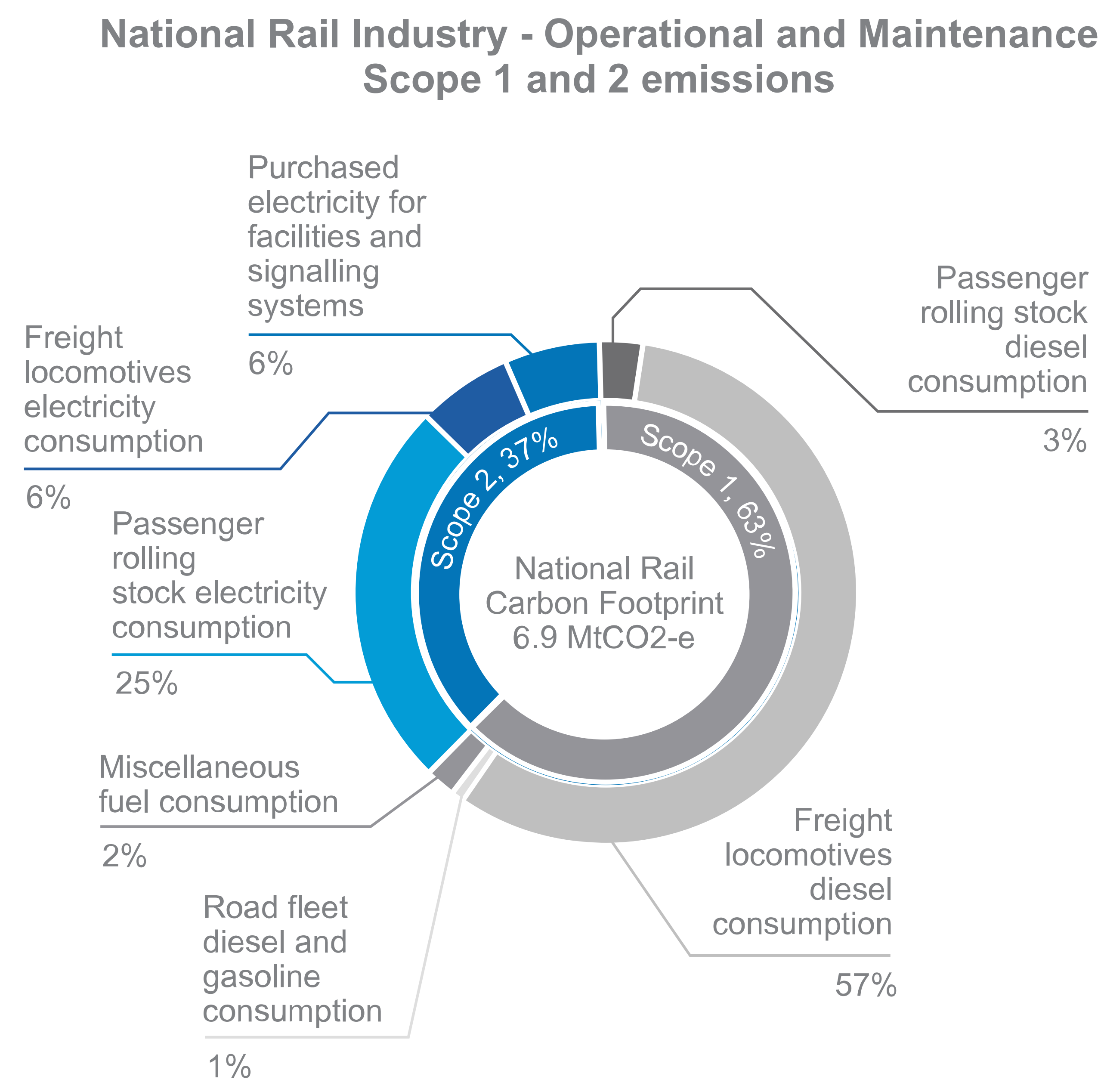


Figure 3. National Rail Carbon Footprint

This study categorised emission sources into traction, staffing and services and subsystems, as below:

Rail Industry Elements										
Traction		Staffing & Services		Subsystems						
Diesel	Electricity	Staff & offices	Services	Track	Rolling stock	Stations	Depots and other buildings	Structures	Electrification systems	Train control systems

Figure 4. Rail Industry Elements

Categorising scope 1 and 2 emissions sources by the rail industry elements above underlines traction energy as the largest emissions source (see Figure 5). As scope 3 emissions become available in the future, a complete and more accurate breakdown of emission sources will be able to be developed to improve granularity of subsystem emissions sources (e.g., track renewal, rolling stock and train control systems) and guide decarbonisation efforts accordingly.

This study also estimated the national rail carbon footprint, following the GHG Protocol market-based methodology[21]. This estimation considered current decarbonisation efforts related to renewable electricity from grid-imported electricity usage and rail operators and infrastructure managers' power purchase agreements (PPA). See Appendix 9.2 for more information.

[21] *World Resources Institute (2015) GHG Protocol Scope 2 Guidance, https://ghgprotocol.org/scope_2_guidance*

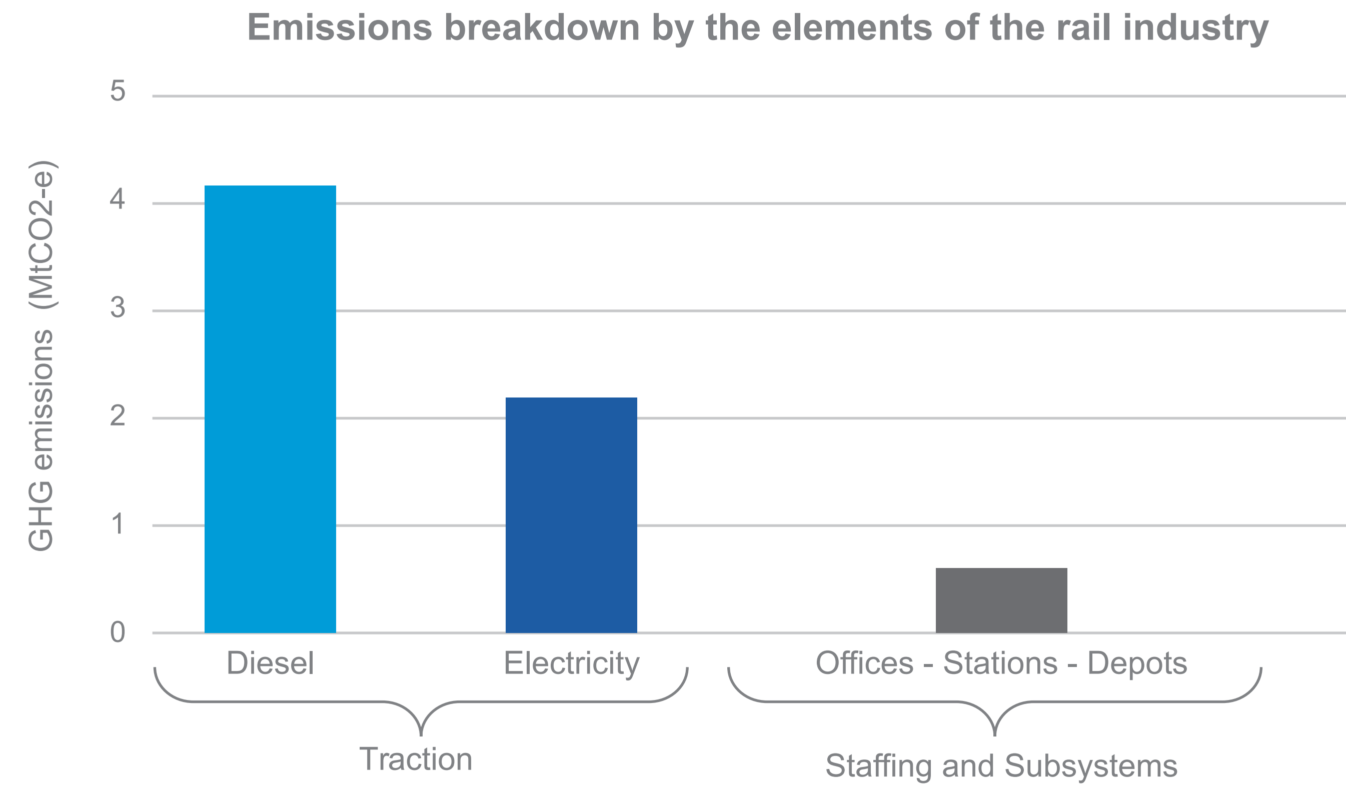


Figure 5. GHG emissions sources by the elements of the rail network

3.3.2 Traction energy is the most significant emission source across all freight and passenger rail

The most significant emission source varies for freight and passenger RTOs, depending on the energy source. Diesel consumption to run freight locomotives and electricity consumption to run passenger rolling stock are still the main emission sources across the groups. Emissions reductions opportunities for traction are where decarbonisation efforts are best focussed.

- For national freight bulk and non-bulk rail, about 73% of GHG emissions are from locomotive diesel consumption.
- For operators and managers transporting only iron ore, rail related emissions were estimated to be 96% from locomotive diesel consumption.
- For urban heavy and light passenger rail, 82% of GHG emissions were estimated to be from electricity consumption to run rolling stock, and 16% to power facilities.
- For non-urban passenger rail, about half of the emissions are from the purchasing of electricity to run rolling stock, and about 30% from rolling stock diesel consumption.

This data is displayed in Figure 6:

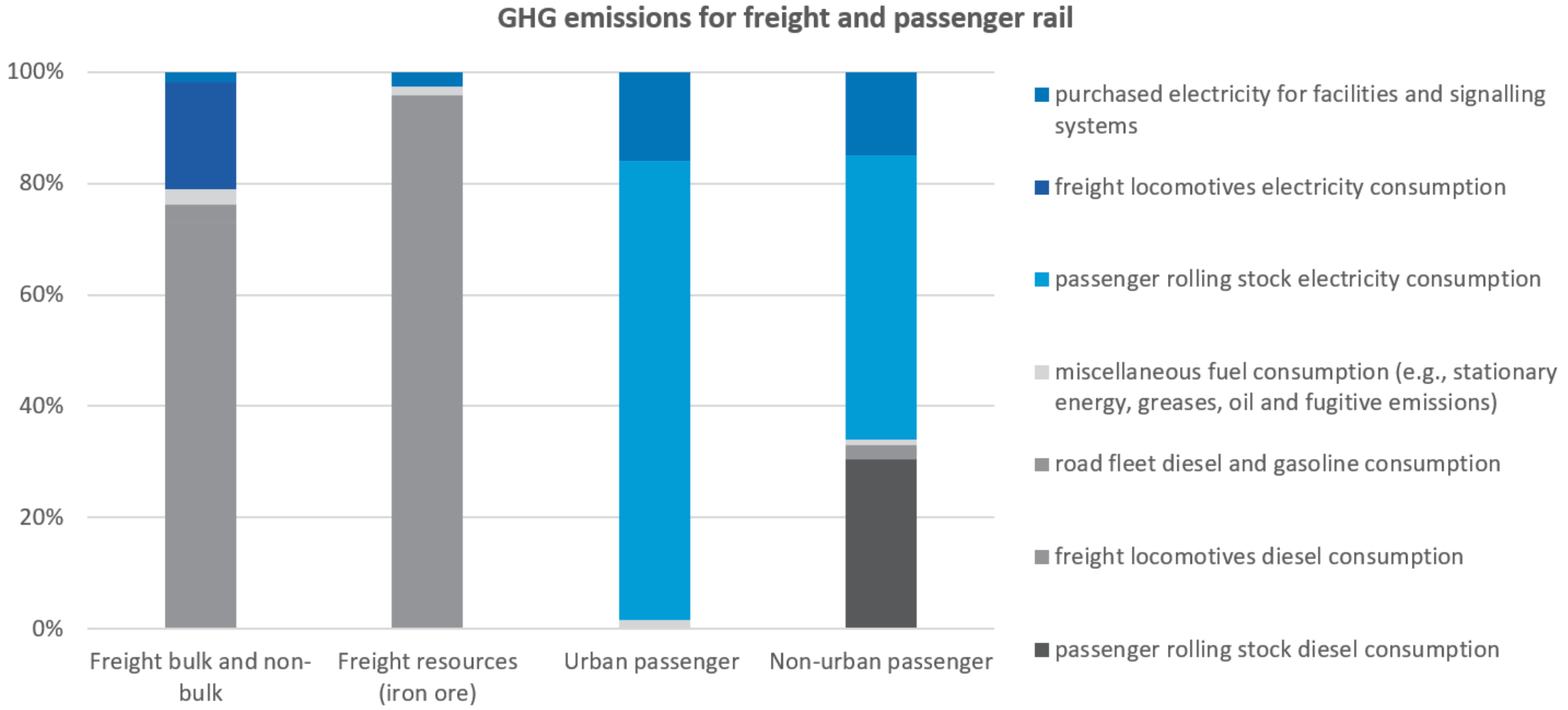


Figure 6. GHG emissions for freight and passenger rail operators and managers

4 Emission Reduction Trajectory to 2050 and Decarbonisation Pathway

4.1 Rail's role to get transport to net zero

This study has developed two high-level decarbonisation pathway scenarios: the Low Uptake Scenario and High Uptake Scenario. The Low Uptake Scenario shows GHG emissions reduction based on current initiatives in the industry, limited energy efficiency improvement, limited adoption of low emissions technologies, and a high dependency on carbon offsets to reach net zero by 2050.

Conversely, the High Uptake Scenario shows a decarbonisation pathway to halve emissions by 2030 and reach net zero by 2050 driven by five decarbonisation strategies:

1. Regulatory change and modal shift to rail
2. Energy efficiency in traction and facilities
3. Adoption of low and/or zero emissions emerging technologies
4. Electricity from renewable sources
5. Carbon offsetting

Decarbonisation of the Australian rail industry requires accelerated collaboration to drive these five categories. This, coupled with rail's inherent efficiency advantages over road transport, offers a distinct opportunity to reduce energy use, GHG emissions and air pollution in the transport sector.

Indicative examples of the Low Uptake Scenario and the High Uptake Scenario are illustrated below.

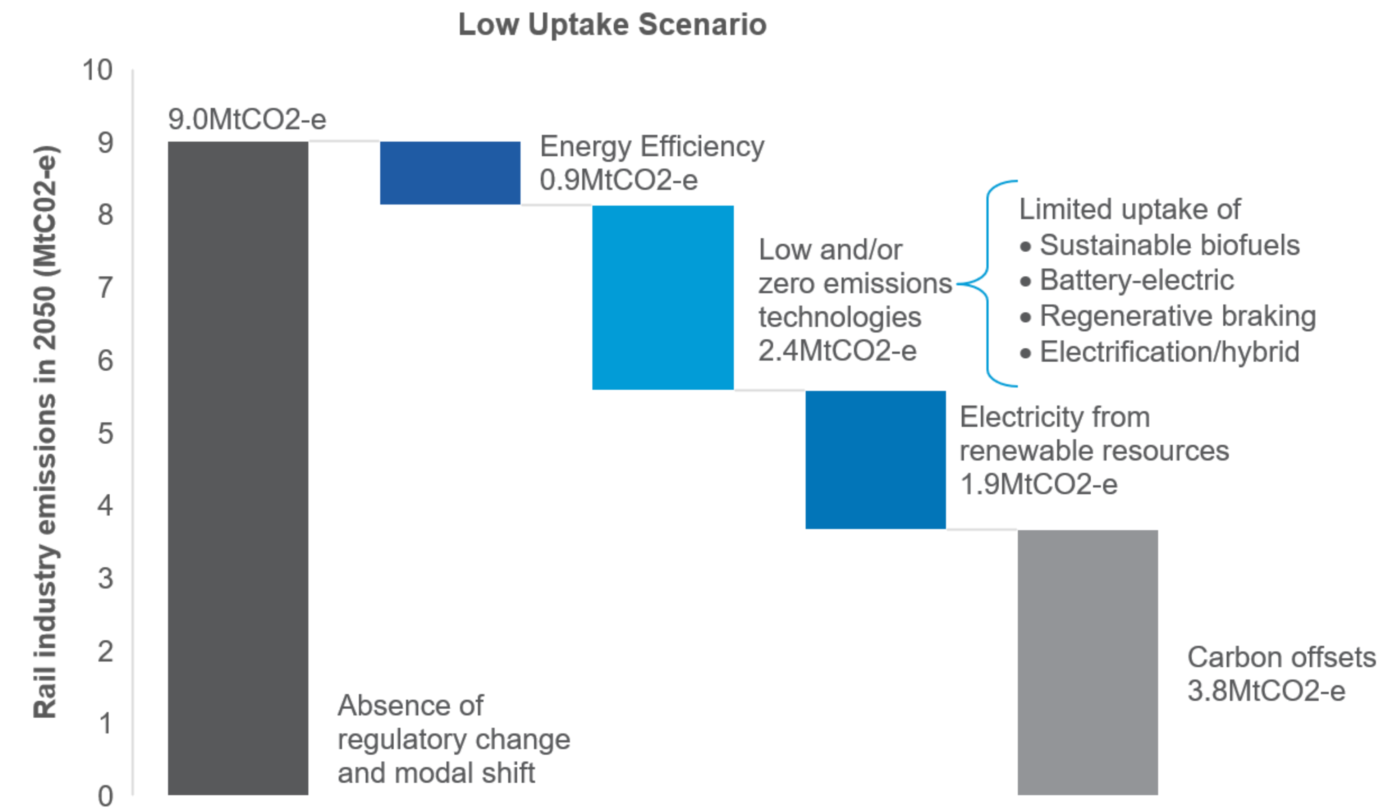


Figure 7. Low Uptake Scenario

A collaborative and coordinated industry effort to define and adopt decarbonisation strategies was identified as crucial to achieving net zero by 2050.

The High Uptake Scenario requires greater effort to find ways to maximise energy efficiency, whole industry adoption of low and/or zero emissions technology (when proven and available), greater electrification and the generation of electricity from renewable resources.

Figure 9 illustrates rail industry emissions if no action is undertaken, compared to the Low Uptake Scenario and High Uptake Scenario. 'No action' shows a continuous increase of emissions to 2050; the Low Uptake Scenario shows major emissions reductions in 2050 - achieved by purchasing a large number of carbon offsets. The high Uptake Scenario shows a more consistent emission reduction, achieving 50% reduction by 2030 and net zero by 2050.

These preliminary scenarios were defined based on existing decarbonisation strategies from rail operators and infrastructure managers, and information in the latest IPCC Sixth Assessment Report (AR6), journals and industry research. More work is needed to refine potential pathways, drive further carbon emissions reductions and define the mix of strategies in the rail industry.

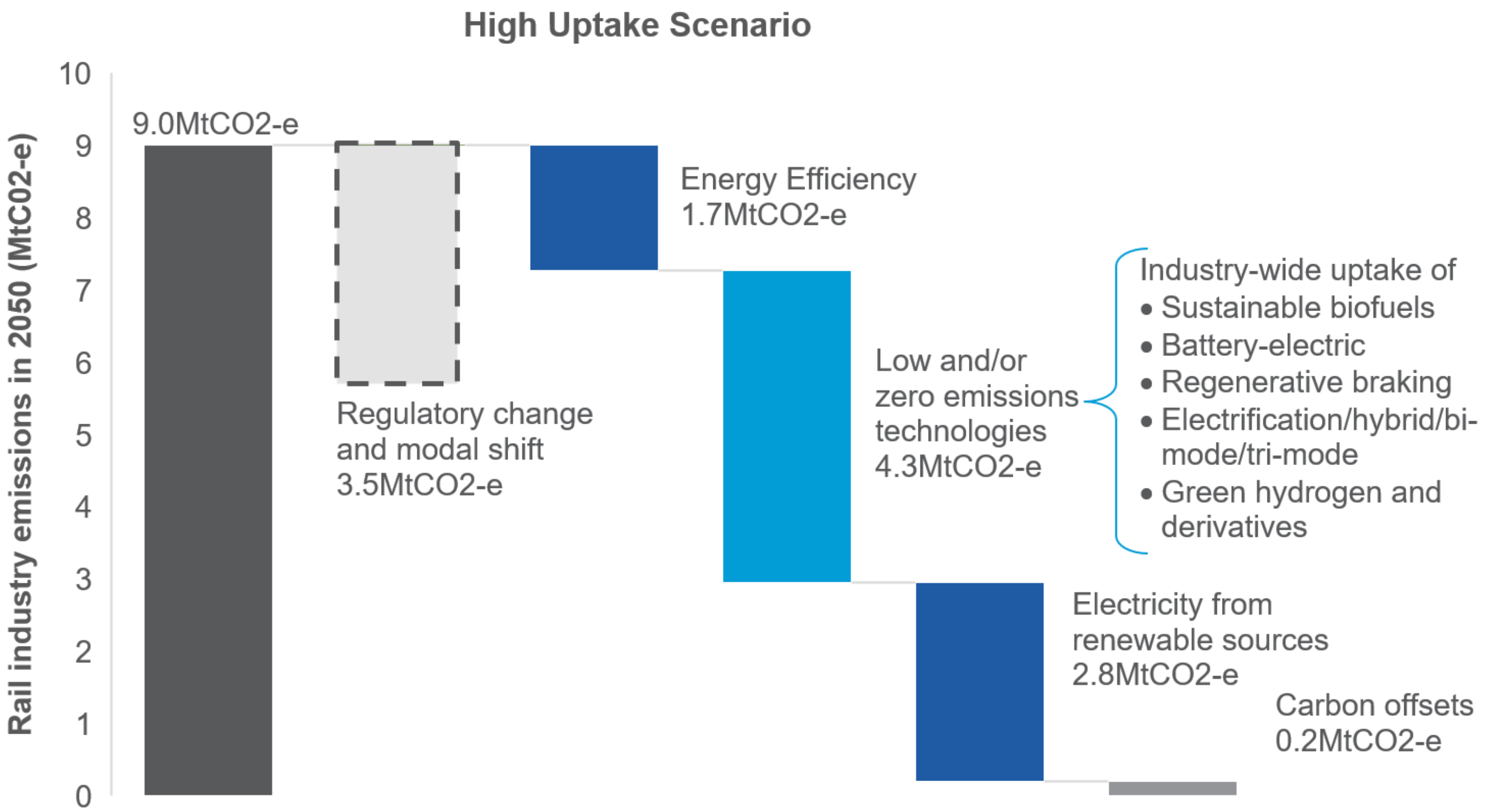


Figure 8. High Uptake Scenario

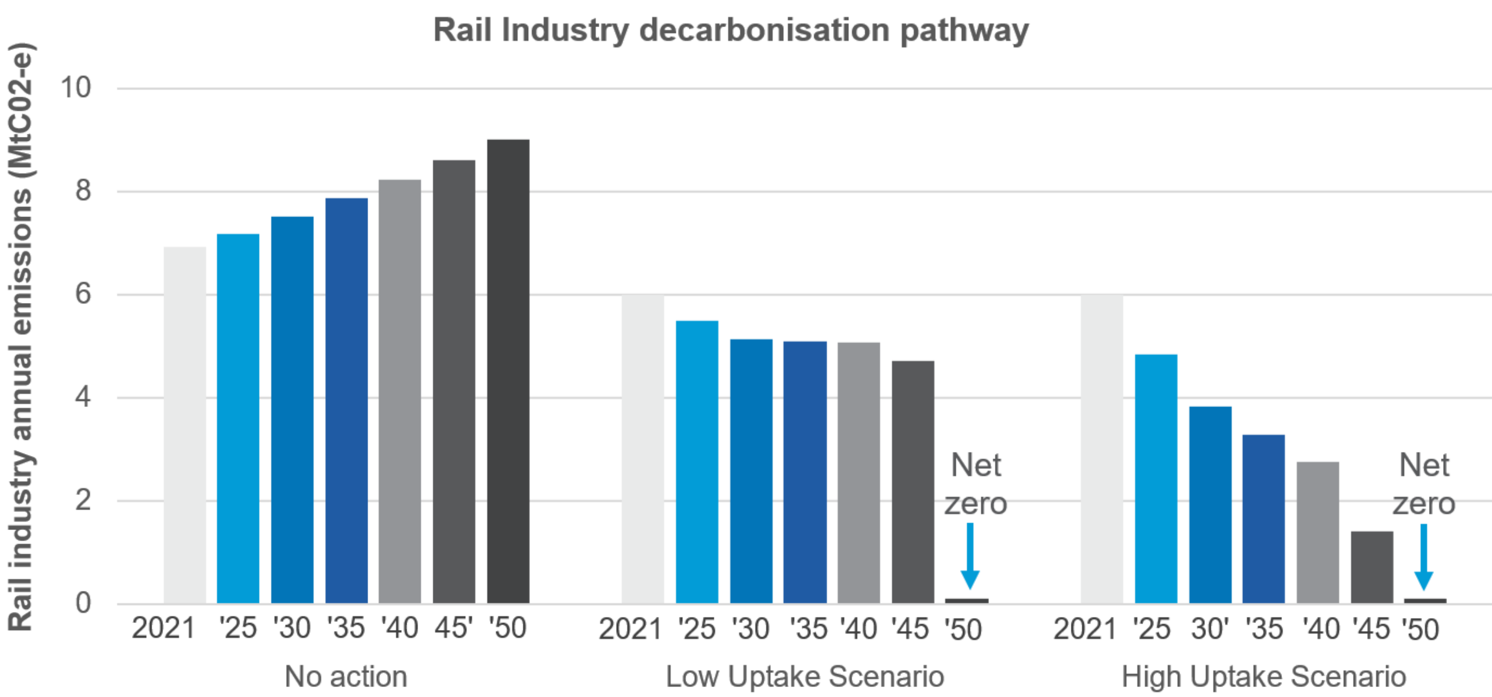


Figure 9. National Rail Annual Decarbonisation Scenarios

4.2 A note on setting targets

The Science-Based Targets Initiative (SBTi)[22] drives ambitious climate action in the private sector by enabling organisations to set science-based emissions reduction targets. The SBTi is a partnership between the CDP, the United Nations Global Compact, World Resources Institute (WRI) and the World Wide Fund for Nature (WWF). By offering a range of target-setting resources and guidance, SBTi shows organisations how much and how quickly they need to reduce GHG emissions to prevent the worst effects of climate change. Science-based targets provide scientifically appropriate and realistic targets to help keep global temperature rise well-below 2°C / 1.5°C. The SBTi is developing transport sector guidance that offers technical resources to model targets for direct and indirect emissions in the sector. The SBTi transport sector development project is led by WWF and provides guidance for land transport, including passenger urban and non-urban rail[23], and freight rail . Guidance is expected to be available mid-2023 and should be used by the rail industry to define appropriate emissions reduction targets.

Section 4.3 below describes decarbonisation strategies in the High Uptake Scenario.

4.3 Collaboration and industry-wide uptake of decarbonisation strategies are required to reach net zero

4.3.1 Regulatory change and modal shift

'Modal shift' describes the emissions reduction from passenger and freight tasks switching from road to rail, though this study did not quantify the increased emissions associated with greater rail traffic. The study assumed that the urban rail passenger task share will be three times greater by 2050 than 2021[24]. That represents an increase in the rail passenger task from about 4% (pre-COVID) to 11% by 2050. The study also estimated carbon emissions savings from road to rail, based on increased containerised freight rail capacity in Australia. Freight road to rail modal shift was estimated at a 7% share increase by 2050, based on RTOs expansion plans and associated emissions. It was assumed that bulk freight would not significantly change as it depends on commodities, mining exploration, exports and economics.

This analysis was informed by various studies, including IEA (2019) 'The Future of Rail' study[25],ARA (2020) 'Value of Rail'[26], Climate Action Tracker (2020) 'Decarbonising the Indian transport sector pathways and policies' study[27], IPCC (2022) report and Stanley et al. (2018)[28]. Further studies modelling the elements of regulatory change and modal shift from other transport sectors (e.g., domestic aviation) are recommended as the industry defines further targets and strategies associated with this transition. Under a high shift approach to transport spending where investment is directed towards rail and away from road infrastructure and parking, aClimate Council (2017) study found that overall transport spending can be reduced while dramatically reducing GHG emissions[29].

Shifting transport modes requires many enablers, including:

- Policy settings
- Government incentives and subsidies to facilitate the low and/or zero emissions technologies uptake,
- Transport spending away from road infrastructure & parking,
- Heightened investment in rail expansion services and infrastructure,
- Strategic urban planning and changes in urban form,
- Build train capacity and reliability of existing services and growth areas and
- Programmes that encourage customer behaviour change.

[22] Science-Based Targets https://sciencebasedtargets.org/

[23] Science-Based Targets (n.d.) Guidance for the transport sector, https://sciencebasedtargets.org/sectors/transport

[24] International Energy Agency (2019) The Future of Rail, https://iea.blob.core.windows.net/assets/fb7dc9e4-d5ff-4a22-ac07-ef3ca73ac680/The_Future_of_Rail.pdf

[25] International Energy Agency (2019) The Future of Rail

[26] Australasian Railway Association (ARA) (2020) Value of Rail 2020

[27] Climate Action Tracker (2020) Decarbonising the Indian transport sector pathways and policies, https://climateactiontracker.org/documents/832/CAT_2020-12-09_Report_DecarbonisingIndianTransportSector_Dec2020.pdf

[28] Stanley, J., Ellison, R., Loader, C. and Hensher, D. (2018) Reducing Australian motor vehicle greenhouse gas emissions, Transportation Research Part A, vol 109, pp. 76-88

[29] Climate Council (2017) Factsheet Transport Emissions: driving down car pollution in cities.

4.3.2 Energy efficiency

Another decarbonisation strategy is improved energy efficiency related to rolling stock and facilities. This study assumed an industry-wide uptake of energy efficiency improvements to achieve a 10% energy efficiency increase by 2030 and continual improvement to 2050. Assumptions were based on various freight and passenger RTOs with decarbonisation commitments. For example, Aurizon has set an emissions intensity reduction target of 10% by 2030[30], Pacific National has an investment strategy in new fuel-efficient locomotives that produce 9% fewer emissions per annum[31] and Sydney Trains' target to reduce emissions by 10% by scheduled train kilometres by 2025[32]. Various other rail decarbonisation studies have concluded that to reduce emissions in line with the Paris Agreement to keep global warming below 1.5°C, shifting road and air modes to rail needs to be complemented byenergy efficiency and fuel switching measures to reduce the carbon intensity[33].

Other recent studies in the Australian transport sector suggest decarbonisation opportunities, including the adoption of low and/or zero emissions technologies and fuel efficiency standards to assist in the transition to low emission vehicle uptake[34]. Energy efficiency can also be related in scope 3 emissions to resource efficiencies, for example, with the use of low-embodied materials with high recycled content.

Traction energy GHG emissions reduction could be achieved through improving driving behaviour and operations, improved design, driver assistance systems, route and locomotive optimisation analysis and regenerative braking[35 36]. Passenger locomotives could improve efficiencies by additives and exhaust recirculation, driver advice systems, assessing energy to be recovered from braking trains and reviewing HVAC and stabling mode improvement opportunities. In addition, robust building performance frameworks and standards should be applied to rail facilities, depots and stations.

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[30] *Aurizon (2020) Climate Strategy and Action Plan*

[31] *Pacific National (2021) ESG Report 2021*

[32] *Transport for NSW (2020) Future Energy Action Plan 2020-2025*

[33] *International Energy Agency (2019) The Future of Rail, https://iea.blob.core.windows.net/assets/fb7dc9e4-d5ff-4a22-ac07-ef3ca73ac680/The_Future_of_Rail.pdf*

[34] *KPMG, Roads Australia, Australasian Railway Association and Infrastructure Sustainability Council (2022) The journey to net zero, https://roads.org.au/wp-content/uploads/Journey-to-net-zero_Final_ForWeb.pdf*

[35] *Pacific National (2021) ESG Report*

One Rail Australia (2019) Sustainability Report

[36] *Australian National University (2020) On track to 2040*

4.3.3 Adoption of low and/or zero emissions technologies

According to the IPCC, the International Energy Agency, research and trials from Australian RTOs and industry research, the most promising low and/or zero emissions technologies in the rail industry to target diesel consumption (the main emission source) are[37]:

- **Sustainable biofuels,**
- **Battery-electric and regenerative braking and**
- **Green hydrogen and derivatives (including synthetic fuels and green ammonia).**

The accelerated uptake of these technologies and the expansion of electrified rail systems can support rail decarbonisation in Australia. This study assumed an industry-wide uptake of low and/or zero emissions technologies based on the short-term uptake of biofuels, such as B5 and B20. Battery-electric technologies and electrification in the short-medium term and green hydrogen and derivatives in the long term. The study assumed that low and/or zero emissions technologies will become available by 2050 and the rail industry will adopt technologies as they emerge and become available.

Sustainable biofuels, blended or unblended with fossil fuels, can provide short and medium-term carbon reduction opportunities. Advances in battery technologies for locomotives and the capability to generate additional energy through regenerative braking will contribute to decarbonisation of the locomotives. The manufacturing of batteries requires addressing challenges related to resource availability, circularity and costs. Green hydrogen represents a long-term opportunity for the rail industry[38]. Green hydrogen fuel cell technology can complement battery-electric trains for services requiring low-speed, long-distance and low-frequency utilisation[39]. Other electrification efforts include bi-mode, tri-mode and hybrid trains. Trains can connect to overhead power on electrified lines or use batteries, reducing reliance on diesel consumption.

The rail industry's challenges are complex regarding driving range, capital and operating costs, commercialisation and infrastructure availability and capacity. These challenges hinder adoption of low and/or zero emissions technologies and require further research, innovation and development, and substantial collaboration within and between sectors. This will facilitate the reduction of technical and implementation uncertainties of introducing low and/or zero emissions technologies and speed up the transition to sustainable fuels.

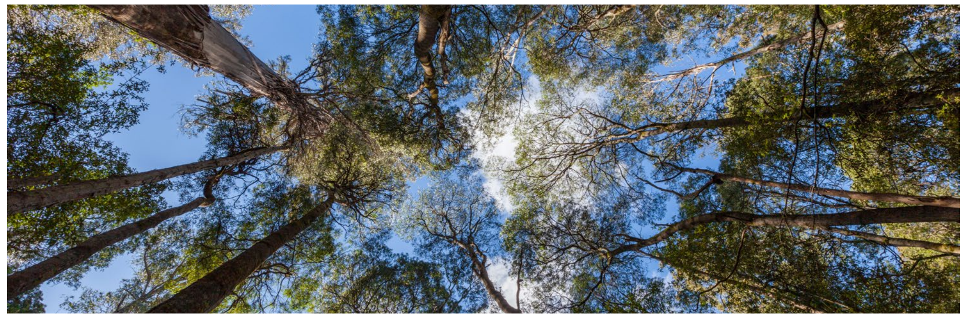
4.3.4 Electricity from renewable sources

As the rail industry increases its efforts to electrify, the adoption of renewable power is essential. Renewable electricity efforts include state government commitments to decarbonise the grid, on site or on the ground power generation by RTOs, conserving energy usage and contractual instruments to purchase renewable power electricity, such as Power Purchase Agreements. This study considered current Power Purchase Agreements by freight and heavy and light rail railway RTOs and the state government uptake of renewable electricity in the decarbonisation pathway. The study assumed a gradual increase of power generation using renewable resources by the rail industry to offset all remaining emissions from electricity consumption by 2050. Solar photovoltaics (PV) and wind continue to be the cheapest sources of new electricity generation capacity in Australia[40]. Increasing the power generation from renewable resources on site or on the ground, could avoid electricity cost fluctuations and reduce the load the industry places on the electricity grid.

4.3.5 Carbon offsets

After all avoidable emissions have been minimised, the remaining emissions of the rail industry could be 'cancelled out' by purchasing or generating carbon credits. An increased number of sectors intend to achieve net zero by 2050 and carbon credits are in high demand. This presents a climate-related opportunity for the industry to participate in the carbon market.

See 9.3 in the Appendix for more information on decarbonisation opportunities.



[37] [38] Jaramillo, P., S. Kahn Ribeiro, P. Newman, S. Dhar, O.E. Diemuodeke, T. Kajino, D.S. Lee, S.B. Nugroho, X. Ou, A. Hammer Strømman, J. Whitehead (2022) Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.012

[39] Arup (2020) Transformative Rail, https://www.arup.com/perspectives/what-does-emission-free-rail-look-like

[40] Graham, P., Hayward, J., Foster J. and Havas, L. 2021, GenCost 2020-21: Final report, Australia, https://www.csiro.au/-/media/EF/Files/GenCost2020-21_FinalReport.pdf

5 Scope 3 Emissions and Decarbonisation Efforts

5.1 Initial scope 3 emissions and sources estimated with low confidence

Initial estimations of the FY20-21 rail industry carbon footprint including scope 1, 2 and 3 emissions, based on limited data available, was 14MtCO2-e. The study recognises that to prepare indicative estimations of the national rail industry's carbon footprint, a scope 3 assessment and scoping exercise is required.

This is the first attempt at the national rail industry level to estimate scope 3 emissions, and should not be relied upon. Scope 3 emissions data are based on a representative data sample size of just 20%, and is therefore classified as low confidence, non-indicative, and subject to change. Notwithstanding that, this study identified potential emission sources in the value chain of railoperations and management include:

- Purchased goods and services (e.g., purchased materials),
- Upstream transport and distribution of purchased goods and services and,
- Capital goods (e.g., locomotives, plant and fleet).

Other carbon emission sources and decarbonisation opportunities should be assessed, such as the maintenance and replacement of rolling stock, track, tunnels, bridges, signalling, and electrification systems, fuel and energy related activities, waste generated, business travel and employee commuting (more information in Appendix 9.2).

While the confidence of scope 3 estimations is low, potential emission sources have been identified to illustrate the importance of further understanding the value chain emissions impacts. As such, efforts should focus on the largest GHG reduction opportunities, leading to more sustainable decisions from RTOs with regards to the use and purchase of products and services.

Embodied carbon emissions of construction materials for maintaining and replacing rail infrastructure (e.g., track, sleepers, and ballast) were categorised under 'track' below. The initial results show a potentially significant emissions source relating to cement production and steel, each responsible for roughly 8% of global emissions[41 42].

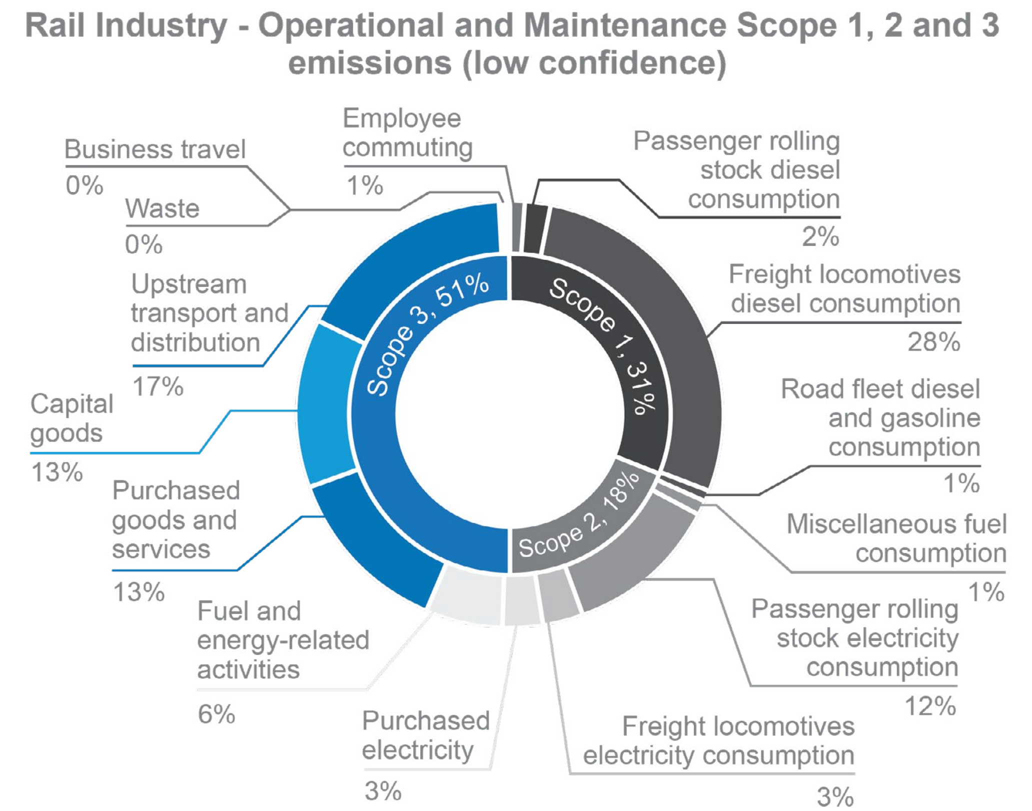


Figure 10. Emissions sources including scope 1, 2 and 3 emissions (low confidence)

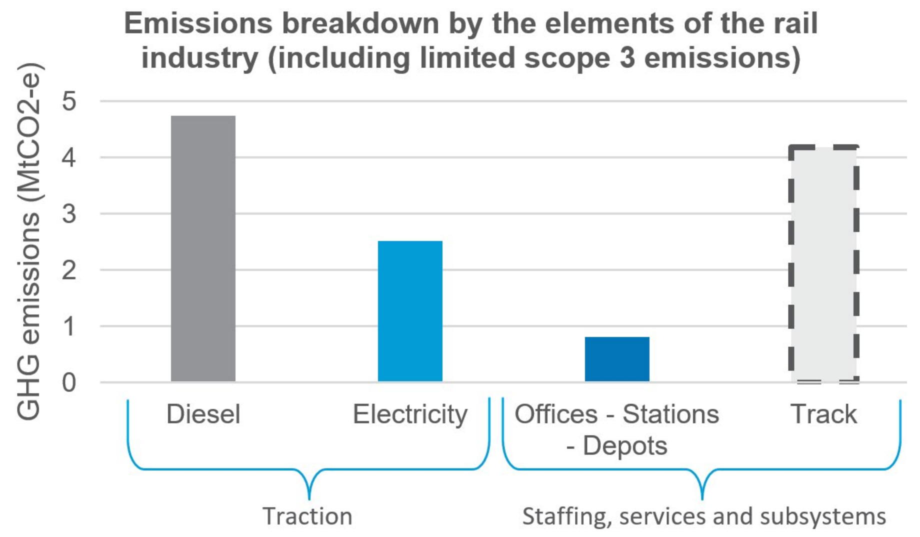


Figure 11. Emissions breakdown by rail industry element, including limited and low confidence scope 3 emissions.

[41] World Steel Association, https://worldsteel.org/publications/policy-papers/climate-change-policy-paper/

[42] OECD (2019) Low and zero emissions in the steel and cement industries

5.2 Scope 3 emissions scoping and calculation is needed to identify indirect decarbonisation opportunities

Developing a scope 3 emissions inventory will strengthen the rail industry's understanding of the overall emissions profile of its upstream and downstream activities. Identifying and assessing scope 3 emissions would help the rail industry go beyond the focus of its own operations and gain insights around associated risks and opportunities in the industry's value chain. This is likely to be helpful when planning for potential regulations, making sustainable procurement decisions, and striving for low-carbon design.

Decarbonisation opportunities in the supply chain could include procurement practices aligned with international ISO 20400 Sustainable Procurement guidance, prioritisation of sustainable materials, whole-of-life thinking, & circularity. The industry should also engage key suppliers and stakeholders to collaborate and identify innovative and emerging solutions to reduce embodied carbon of transport infrastructure and meet net zero transport goals by 2050. A recent report from KPMG, Roads Australia, the Australasian Railway Association and Infrastructure Sustainability Council, highlighted that while the control of embodied emissions may be limited by cost, technology availability and supply chain constraints, transport infrastructure expenditure could be large enough that procurement preferences can transform supply chain activities[43] and therefore minimise scope 3 emissions.

Cement and steel represent major embodied emission sources for rail industry construction materials[44] and track renewals[45]. Innovative structural design and sustainable selection criteria such as reducing the need of replacement, reuse and the use of recycled materials and supplementary cementitious materials (e.g., fly ash, slag, and silica fume)[46] could all reduce emissions and ensure safety standards compliance. Steel emissions could be greatly reduced by extending the life of the track and minimising annual renewals, depending on safety implications and the associated impact of increased maintenance. Recycled materials could be also maximised, such as repurposing steel for other projects. Green steel continues to develop with advances in green hydrogen-based ironmaking technologies.

Ambitious recovery, reuse and recycling of concrete, steel and timber from deconstructed structures in the rail network and other infrastructure will support the reduction of emissions. Alternative materials, optimised design, prioritisation of electrified road transport in the value chain, repurposing expired trains and consideration of other environmental, social and economic aspects are only examples of potential actions in the value chain.

Industry solutions include Victoria's innovative approach to using recycled materials in composite rail sleepers for maintenance and infrastructure[47]. Other solutions in the industry include Holcim Australia concrete range that reduces embodied carbon by 30-60% and provides the opportunity to offset any remaining embodied carbon, as well as purchase of certified carbon neutral ready-mix concrete[48].

The rail industry should set science-based targets for its scope 3 emissions, following available guidance for companies in the transport sector[49]. For example, Network Rail in the UK is the first railway organisation in the world to set science-based targets. Network Rail has found that scope 3 emissions are the most significant emission source for its network, with 97% of total emissions. The largest contributors were related to 33% capital goods and services, 33% purchased goods and services and 25% diesel locomotive traction. Network Rail has committed to achieving net zero carbon emissions by 2050; it has developed national targets for Scope 1 and 2 emissions to staying within a 1.5˚C rise above pre-industrialisation levels, and Scope 3 aligned to staying well below a 2°C rise[50].

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[43] *KPMG, Roads Australia, Australasian Railway Association and Infrastructure Sustainability Council (2022) The journey to net zero, https://roads.org.au/wp-content/uploads/Journey-to-net-zero_Final_ForWeb.pdf*

[44] *Clean Energy Finance Corporation (2021) Australian buildings and infrastructure: Opportunities for cutting embodied carbon*

[45] *Rail Safety and Standards Board (RSSB) (2010) Whole life carbon footprint of the rail industry*

[46] *Holcim Australia (2019) ViroDecs EPD Ready-mix concrete. New South Wales and the Australian Capital Territory*

[47] *Ecologiq (2020) Recycled Materials in Rail Infrastructure Reference Guide*

[48] *Holcim (n.d.) ECOPact – Low carbon concrete*

[49] *Science-Based Targets (n.d.) Guidance of the transport sector, https://sciencebasedtargets.org/sectors/transport#sectoral-decarbonization-approach-sda-transport*

[50] *Network Rail (2020) Our ambition for a low-emission railway 2020 – 2050*

6 Conclusion

The purpose of this study is to estimate the national rail network carbon emissions in steady state operations and maintenance. It does not consider the embodied emissions of the existing infrastructure or assets, nor does it include any new or under construction projects.

The study relies primarily on published data and other available information. It aims to quantitatively guide emissions reduction strategies, ensuring that rail plays its part as the sector rapidly decarbonises. The study underlines that rail has an important part to play in Australia's push for net zero by 2050, and that decarbonisation will strengthen its share of Australian transport into the future.

The study found that the FY20-21 national rail carbon footprint is 6.9 MtCO2-e, extrapolated from data representing 85% of RTOs reporting to NGER, and available sustainability/ESG data.91% of the national rail scope 1 and 2 carbon footprint is in the traction of rolling stock, withfreight locomotive diesel consumption being the largest emissions source therein. Electricity consumption from passenger rolling stock represents the second largest contribution to this total.

Key decarbonisation strategies for the rail industry include regulatory change and modal shift, energy efficiency, adoption of low and/or zero emissions technologies, electricity from renewable sources, and carbon offsetting.

Climate change presents a series of physical and transitional risks to the Australian rail network. Developing climate resilient networks that mitigate emissions, adapt to the impacts of climate change, and realise opportunities to produce renewable energy or carbon offsets should be included in sustainability and carbon management strategies to further build industry resilience.

This study is intended to provide RISSB with a starting point to inform RISSB's own annual workplan development as well as informing the national rail network participants of the emissions estimates, the main emission sources and the key levers to achieve net zero by 2050. This report aims to fill a knowledge gap, allowing RISSB to assist and coordinate the collaboration of rail infrastructure managers and operators and turn research and policy into harmonised industry practice. The findings will assist in the review and update of existing RISSB standards, as well as provide a quantitative position to support rail industry advocates.

A key element of this study is to underline rail's importance as a part of the Australian transport network into the future, particularly as the world moves towards net zero by 2050. Rail's inherent mechanical efficiency grants it an advantage over road, presenting an opportunity to decarbonise the transport sector by attracting more freight and passenger traffic. 57% of national freight is moved by rail, yet it constitutes 3% of total emissions. Regulatory change and government support are critical in catalysing the modal shift from road to rail, and proportionate efforts are required to effect this change. Shifting transport modes requires many enablers, including policy settings, investment, network expansion, incentives, smart urban planning, national strategy, research, development and infrastructure for low and/or zero emissions technologies. Without decarbonisation, the rail industry's efficiency advantages will narrow compared to road transport, threatening its competitiveness.

The availability of scope 3 emissions data is a key limitation at this point in the study. Scope 3 emissions should be further analysed to identify significant emissions sources in the supply chain and decarbonisation opportunities, with particular focus on upstream emissions. With early estimations suggesting that scope 3 could be about 51% of the total carbon footprint, it is imperative that the industry scope these emissions and gain an overall understanding of its emissions profile.

Rail offers a substantial emissions reductions pathway to the entire transport network, but only if it can effectively and collectively decarbonise to halve emissions by 2030, and to achieve net zero by 2050.

7 Recommendations

The five key recommendation areas can be summarised as follows:

1. **Work with RISSB members to complete a scope 3 emissions scoping exercise and calculate scope 3 emissions to assist greater understanding of the value chain emissions profile.** This will improve the accuracy of the industry carbon profile and identify indirect decarbonisation opportunities. Understanding the emissions intensity of upstream and downstream activities could help the industry go beyond the focus of its own operations and maintenance and gain insights around associated risks and opportunities in the industry's value chain. This will inform sustainable procurement decisions, pursuit of circularity, low-carbon preferences, and supply chain engagement.

2. **Work in partnership with RISSB members to set science-based targets** to keep global temperature rise well-below 2°C / 1.5°C. The Science-Based Targets Initiatives are developing a transport sector guidance to model scientifically appropriate and realistic targets for direct and indirect emissions in the sector.

3. **Partner with relevant rail organisations to build climate resilience in the rail industry** by supporting the understanding of climate change hazards and associated safety risks and opportunities. This will enable more rail operators and managers to consider climate change in their decision making and strategic management, building collective climate resilience.

4. **Assess the amendment and expansion of relevant existing standards** to assist the rail industry achieve net zero by 2050. This study offers RISSB a starting point to identify possible integration with existing standards aligned with carbon emissions hot spots and 30-year national technical strategy. Integrations and additions may include rolling stock improved efficiency, electricity efficiency and power generation, guidance materials for sustainable procurement, approach to offsets, and national climate change trends and risks to the rail network.

5. **Partner with rail industry organisations, ISC and others to facilitate industry coordination in adopting decarbonisation opportunities** and achieve net zero by 2050. RISSB should use this study in its capacity to provide training, advice and events, to assist the industry understand carbon emissions hot spots, and focus decarbonisation strategies on traction energy.

8 Glossary of Terms

Adaptation:
The process of adjusting to actual or expected changes in climate to reduce or avoid climate impacts, or exploit beneficial opportunities.

Carbon emissions:
Are the result of human activities creating carbon dioxide and other greenhouse gases (GHG), which are emitted into the atmosphere.

Carbon inventory:
Represents a true and fair account of an organisation carbon emissions, through the use of standardised approaches and principles.

Carbon offsets:
After emissions reduction, any remaining emissions may be ‘cancelled out’ by purchasing or generating accredited carbon credits to achieve net zero. One offset equals one tonne of greenhouse gas emissions that is avoided or reduced elsewhere.

Decarbonisation:
Refers the process by which countries, individuals or other entities aim to achieve zero fossil carbon existence.

Direct GHG emissions:
Emissions from sources that are owned or controlled by the company.

Downstream emissions:
Indirect GHG emissions from sold goods and services. It also includes emissions from products that are distributed but not sold.

Emissions boundary:
The inventory boundary determines which emissions are accounted and reported. It can have several dimensions, such as organisational, operational, geographic, business unit, and target boundaries.

Fugitive emissions:
emissions that are not physically controlled but result from the intentional or unintentional releases of GHGs. They commonly arise from the production, processing transmission storage and use of fuels.

GHG Protocol:
most widely used greenhouse gas accounting standard establishes comprehensive standardised frameworks for private and public sector operations to measure and manage greenhouse gas emissions

Greenhouse gas (GHG):
the release of any substance known to exacerbate the process of global warming.

Indirect GHG emissions:
are a consequence of the activities of the company that occur at sources owned and controlled by another company.

Location-based method:
based on the location in which a business operates; electricity emissions are calculated according to the emissions intensity of the electricity grid that serves the business in that location.

Market-based method:
electricity emissions are based on the electricity purchases of a business, and its investments in electricity products and markets.

Mitigation:
The action we take to limit changes in global climate caused by human activities.

National Greenhouse and Energy Reporting (NGER):
Is a single national framework for reporting and disseminating company information about greenhouse gas emissions, energy production, energy consumption and other information specified under NGER legislation

Net zero:
Means that carbon emissions generated are offset to achieve no net negative impact to the climate.

Resilience:
The capacity of communities, environments and economies to cope with a hazardous event or disturbance, while maintaining essential functions and structure.

Scope 1 emissions:
Direct emissions released to the atmosphere from owned or controlled sources, e.g., fuels combustion (petrol, diesel and gas) and generation of electricity, heat or steam.

Scope 2 emissions:
The emissions released from the indirect consumption of energy from purchased electricity heat, cooling and steam that occurs at sources owned and controller by another organisation.

Scope 3 emissions:
Indirect emissions that occur in a company's value chain. Scope 3 emissions are the result of activities from assets not owned or controlled by the reporting organisation, e.g., purchased goods and services, capital goods and transportation & distribution.

Scope:
Defines the operational boundaries in relation to indirect and direct GHG emissions.

Stationary energy:
Relates to fuel combustion to generate electricity, steam, heat or power in stationary equipment such as power generators and plants, that do not involve transport energy purposes.

Traction energy:
Energy required to operate trains.

Upstream emissions:
Indirect GHG emissions from purchased or acquired goods and services, transport, capital goods, fuel-and energy related activities, waste, business travel, employee commuting and leased assets.

Value chain emissions:
Emissions from the upstream and downstream activities associated with the operations of the reporting company.

9 Appendix

9.1 Climate change projections, impacts and adaptation

The Intergovernmental Panel on Climate Change (IPCC) has highlighted that limiting global warming to close to 1.5°C would substantially reduce projected losses related to climate change in human systems and ecosystems. To keep global warming to below 1.5°C, emissions must be reduced by half by 2030 and reach net zero by 2050.

Emissions from the rail industry and transport sector are contributing to climate change. Future proofing rail infrastructure requires understanding climate hazard projections, impacts and defining adaptation management strategies to build a resilient network. The rail industry has also a major role to play in the climate change mitigation agenda, in terms of its contribution to support reduction of transport emissions while its decarbonisation ensures no emissions shift between transport sectors.

Climate change impacts such as extremely high temperatures, heavy rainfall leading to flooding, more intense severe storms and harsher fire seasons can seriously impact rail transport infrastructure, operations and mobility. Studies show that serious challenges are increasing, with consequent delays, damage to infrastructure etc, likely to be affected to some extent.

9.1.1 Climate change 2050 projections Australia states

Australia's weather and climate are changing in response to a warming global climate. The average annual temperatures across Australian have increased by 1.44 ± 0.24°C since 1910, with the greatest rise occurring in South Australia, followed by Queensland and the Northern Territory. Australia will continue to experience the impacts of climate change. Australia is expected to get hotter, experiencing:

- More extremely hot days and fewer cool days[51],
- Longer fire season and more dangerous fire weather days,
- Heavy rainfall to become more intense,
- Further rise sea level and
- More frequent and longer-lasting marine heatwaves.

Nation-wide, Australia is already experiencing the impacts of climate change, and these impacts are projected to become more extreme before 2050. According to climate change models, Australia will experience hotter and drier conditions and increasingly severe weather events over the coming decades. There are many climate hazards that are currently occurring in varying degrees across the country, including:

- Australia's national climate has warmed on average by 1.44 ± 0.24°C since national records began in 1910, resulting in an increase in the frequency of extreme heat events[52]
- Sea levels are rising at higher rates than the global average in recent decades[53]
- Ocean acidification around Australia is increasing, due to higher levels of carbon dioxide dissolved in the ocean. Additionally, oceans have warmed by around 1 °C since 1910, leading to more frequent and longer marine heatwaves.
- Heat extremes have increased, specifically severe fire weather conditions and the duration of the fire season.
- Rainfall has increased across most of northern Australia since the 1970s but has decreased around 12-16% in Australia's south-east and west. Heavy rainfall events are also more intense, with higher rates of flash flooding.

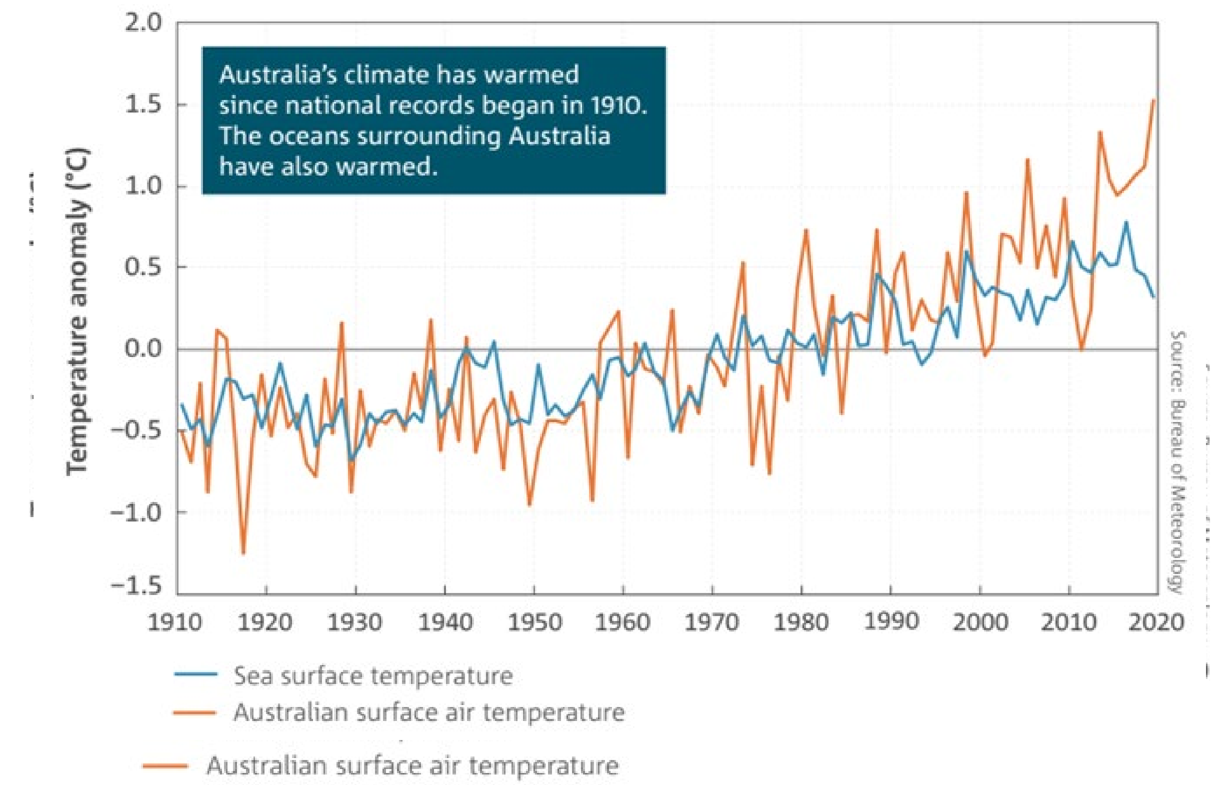

Figure 12. Australia surface and sea temperature anomaly Source: CSIRO and BOM (2020) [54]

[51] *Climate Change in Australia (2021) National Climate Statement, https://www.climatechangeinaustralia.gov.au/en/changing-climate/national-climate-statement/*

[52] *CSIRO and Bureau of Meteorology (2020) State of the Climate, http://www.bom.gov.au/state-of-the-climate/documents/State-of-the-Climate-2020.pdf*

[53] *Intergovernmental Panel on Climate Change (2020) Regional Fact Sheet – Australasia*

[54] *CSIRO and Bureau of Meteorology (2020) State of the Climate, http://www.bom.gov.au/state-of-the-climate/documents/State-of-the-Climate-2020.pdf*

Climate projections are used to understand how increasing greenhouse gas concentrations can affect the global climate. The table below summarise climate trends and projected changes by 2050 under high emissions scenario (RCP8.5 - Representative Concentration Pathways developed by the IPCC) for Australia states where rail infrastructure is located.

State	Climate projections
New South Wales & Australian Capital Territory	• 40% increase in high fire danger days. • Longer and more frequent heatwaves, with over 10 more heatwave days per year.[55] • Increase in rainfall extremes that can cause riverine and flash flooding. • 27 cm sea level rise along the NSW coast. • Greater temperature increases in inland regions compared to the coastal regions.[56]
Northern Territory	• 43-48 days per year with temperatures exceeding 40°C (increase from 7-14 days). • Longer fire seasons. • Intensification of wet and dry season. • 24 cm sea level rise along the coast.[57]
Queensland	• 8-14 days per year with temperatures exceeding 35°C (increase from 2-4 days). • Increased intensity of wet (summer) and dry (winter) seasons. • 26 cm sea level rise along the coast. • Heightened ocean acidification that is proportional to emissions growth.[58]
Victoria	• Temperature increases of up to 2.4°C compared to the 1986-2005 average. • Double as many days per year exceeding 40°C.[59] • 60% increase in extremely high fire danger days. • Reduction in annual rainfall, particularly during the cool season. 35-75% reduction in alpine snowfall. • Heightened intensity of extreme rainfall events, particularly flash flooding. • 24 cm sea level rise.
Tasmania	• Overall reduction in annual rainfall. • Heighted intensity of extreme rain event. • 40% increase in high fire danger days. • 26 cm rise along the coast.
South Australia	• 6-46 days per year with temperatures exceeding 40°C (increase from 2-24 days). • 1.4°C increase in average annual temperatures. • Heightened disparity between wet and dry seasons rainfall. • 24 cm sea level rise along coast.
Western Australia	• 2°C increase in average annual temperatures . • 5 days per year in Perth with temperatures exceeding 40°C (increase from 1.5 days). • 16 days per year in Broome with temperatures exceeding 40°C (increase from 6). • 40% increase in very high fire danger days. • 24 cm seal level rise along coast. • Fewer tropical cyclones, yet the intensity of cyclones will increase.

Table 4. Climate change projections in Australia states by 2050

[55] Office of Environment and Heritage, NSW Government (n.d.) Climate Change in NSW Fact Sheet,

[56] Climate Change in Australia (2021) States/Territories Climate Statements, https://www.climatechangeinaustralia.gov.au/en/changing-climate/state-climate-statements/

[57] CoastAdapt (2017) Sea-level rise and future climate information for coastal councils, https://coastadapt.com.au/sea-level-rise-information-all-australian-coastal-councils

[58] State of Queensland (2019) Climate Change in Queensland v.1,

[59] Victoria State Government (2019) Victoria's Climate Science Report

[60] Department of Premier and Cabinet (n.d.) Climate Change in Tasmania, https://www.dpac.tas.gov.au/divisions/climatechange/adapting_to_climate_change_in_tasmania/appendix_1_predicted_changes_to_tasmanias_climate

[61] Government of Western Australia (2021) Western Australian climate projections, https://www.wa.gov.au/system/files/2022-01/Western_Australian_Climate_Projections_Summary.pdf

9.1.2 Climate change risks and impacts

Climate change risks pose a threat to passenger and freight rail assets, infrastructure, people, supply chain and communities. Physical risks related to infrastructure and operational and supply chain disruption, asset damage and resource availability from increased severe weather events, a hotter and drier climate, flooding, erosion and bushfires. Key physical risks and rail impacts include[62]:

1. Increased temperature and severity of extreme weather events such as unusually hot days, heatwaves, and bushfires may cause heat stress and asset damage, leading to operational disruptions to the service and supply chain, increase cost for repairs and impacting the health and wellbeing of workers.
2. Increased rainfall intensity and flash flooding risk may cause damage to assets and infrastructure accompanied by disruptions to transport services and increase maintenance costs.
3. Rising sea levels and increased risk of storm surge inundation and erosion may cause damage to coastal transport assets and infrastructure and affect intermodal operations.

Transitional risks relate to a wide set of changes in policy, law, markets, technology, and prices that are necessary to achieve the transition to a low-carbon economy and can impact reputation. Some transitional risks include:[63]

- Failure of rail transport to achieve net zero by 2050,
- Policy and regulatory changes not promptly up-taken by rail operators and managers,
- Rail industry not being able to comply with future legislation on emissions,
- Policies preferring investment in road transport, resulting in lower investment in rail decarbonisation solutions,
- The shift from road to rail overwhelming the public transport system and freight system,
- Technical challenges may impact the abilit to decarbonise,
- Skills shortage to service and operate new transport technologies, and
- Reputational damage if the rail industry doesn't increase its effort to decarbonise.

The rail industry could also take advantage of climate-related opportunities. These could include:

- Integrating climate change measures such as carbon emissions reduction, into strategic planning,
- Strengthen future operational resilience,
- Understanding and measuring carbon emissions,
- Industry collaboration to identify main emission sources and accurately estimate scope 3 emissions,
- Keeping pace with road transport sector decarbonisation,
- Adopt emerging low-emissions technologies to phase out the use of fossil fuels and future proof the rail industry,
- Build and increase either the purchase or generation of electricity from renewable sources and
- Assess opportunities to build a carbon offset portfolio with environmental and social co-benefits.

Key enablers for the climate change adaptation and resilience include industry-wide capacity building and partnerships, governance and strategic planning, sustainable adaptation finance and leadership and innovation.

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[62] *Erika J. Palin,Irina Stipanovic Oslakovic,Kenneth Gavin,Andrew Quinn (2021) Implications of climate change for railway infrastructure, WIREs Climate Change*

[63] *The State of Victoria Department of Transport (2022) Transport Climate Change Adaptation Action Plan 2022–2026*

9.1.3 Climate resilient railway infrastructure

The railway represents an energy efficient transport mode with a comparatively small greenhouse gas emissions impact, which puts rail in a favourable light in the implementation of any long-term decarbonisation transport strategy. The rail industry has also potential to mitigate climate change through strategic growth resulting in a reduction in transport emissions overall. However, this potential can onlybe realised if railways are adapted to withstand impacts associated with climate change.

Being able to respond to severe weather events, to demonstrate resilience of key assets/operations as well as the effectiveness of incident preparation, management and recovery processes, are all becoming increasingly important to rail operators and infrastructure managers to provide a safe and efficient future-proof service.

Understanding climate projects and potential impacts of climate change for the rail industry, how these affect operators, network managers, supply chains and communities, and integrating these into long-term railway strategic planning, design, investment, decision-making and management processes, is important to build resilience in the rail industry.

It is essential that the rail industry identify climate change impacts and define actions to adapt assets, people, and operations for the impacts of climate change. Risk management measures in the rail industry could include[64]:

- Incorporate climate change projections into design infrastructure for the long term, ensuring they are fit-for-purpose and resilient to withstand these climate impacts,
- Utilise real-time temperature monitoring systems to inform operational response to hot weather,
- Establish emergency management plans,
- Install spare and emergency capacity for the safety and operational systems to back up the capacity affected by extreme weather,
- Vegetation management to reduce bushfire risks such as removing ground fuel ahead of the season.
- Ensure proactive maintenance and asset improvement initiatives,
- Collaborate within the industry and other sectors to facilitate knowledge sharing and
- Support trials and pilot projects that test transformational adaptation approaches.

[64] *State of Victoria Department of Transport (2022) Transport Climate Change Adaptation Action Plan 2022–2026*

9.2 Further carbon footprint considerations

9.2.1 Scope 2 emissions considerations

Scope 2 emissions were initially estimated using the market-based scenario, following the GHG Protocol Scope 2 Guidance. GHG Protocol presents two scope 2 accounting methods, location-based and market-based method which impact how the industry assesses its performance and what mitigation actions are incentivized. The location-based method provides a picture of the electricity emissions in the context of its location, and the emissions intensity of the electricity grid it relies on. It reflects the average emissions intensity of the electricity grid in the location (State) in which energy consumption occurs and does not allow for any claims of renewable electricity from grid-imported electricity usage.The market-based method provides a picture of the electricity emissions in the context of its renewable energy investments. It reflects the emissions intensity of different electricity products, markets and investments.

Analysis has been carried out considering decarbonisation efforts of renewable electricity from grid-imported electricity usage and operators and managers purchasing electricity from renewable sources. To improve the accuracy of the estimations and meet requirements under GHG Protocol market-based scope 2 methodology, RTOs could report scope 2 emissions on both location-based and market-based methods[65].

When current Power Purchase Agreements (PPA) held by some RTOs and state electricity generation from renewable energy sources were considered in the estimations, scope 2 emissions reduced about 44%. Using the market-based methodology, freight locomotives diesel consumption will then be responsible of 66% of total emissions (57% in the location-based scenario as shown in the section 3.3.1). The national rail carbon footprint would then be 5.8MtCO2-e under this consideration, already included in the decarbonisation scenarios.

[65] World Resources Institute (2015) GHG Protocol Scope 2 Guidance, https://ghgprotocol.org/scope_2_guidance

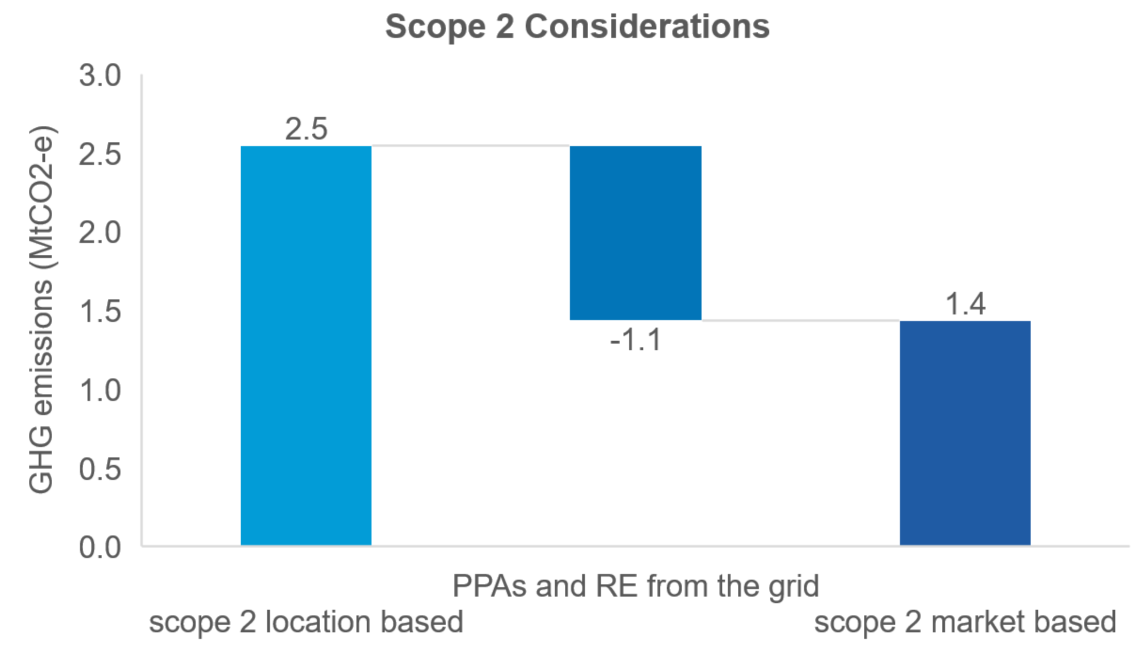

Figure 13. Scope 2 location-based and market-based considerations

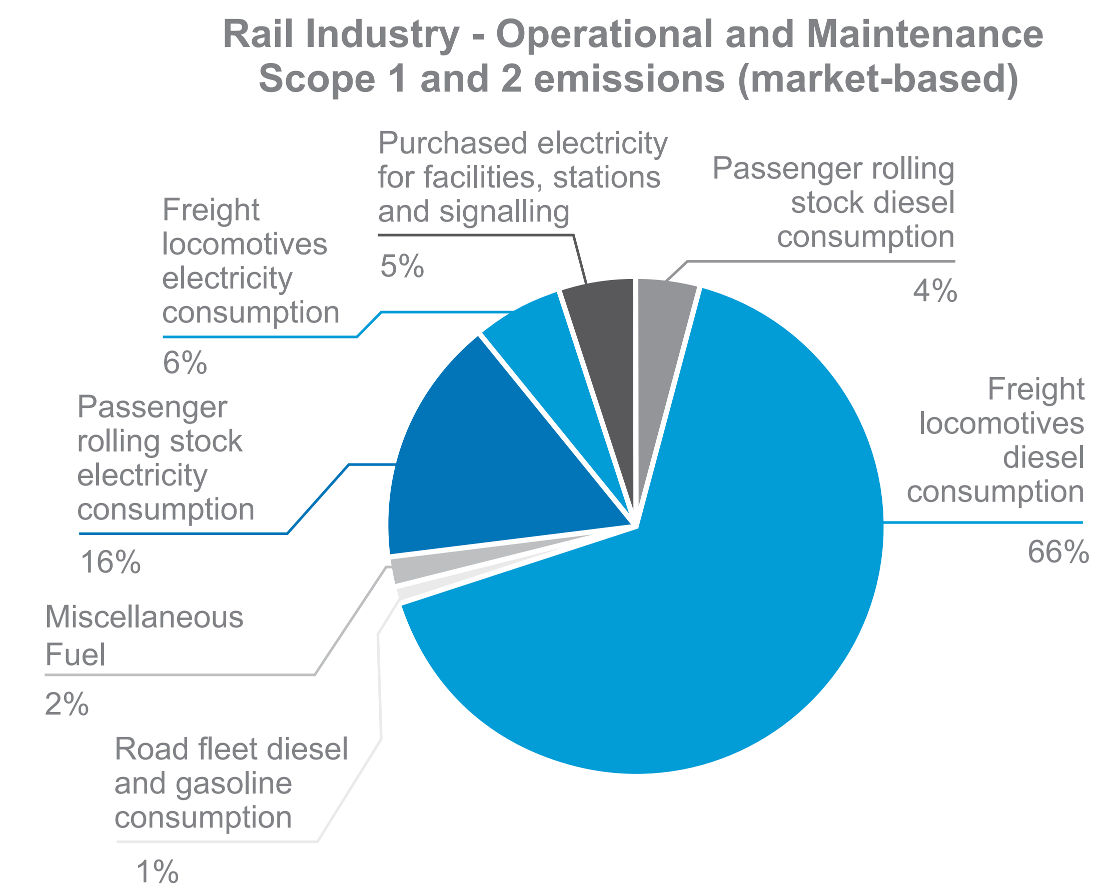

Figure 14. National Rail Carbon Footprint using market-based method

9.2.2 Carbon footprint per freight and passenger group

The most significant emission source varies for freight and passenger railways, depending on the primary energy source. Rolling stock energy consumption is the highest emissions source across all passenger and freight groups. Graphs below show emission sources breakdown for bulk and non-bulk freight, urban and non-urban passenger rail. Urban rail includes national heavy and light rail operations and maintenance. This is presented to provide a high-level understanding of emissions to start identifying decarbonisation focus areas and thereby contribute to decarbonisation.

As the rail industry understands and improves its carbon footprint over the years, the above estimations will also improve and increase in accuracy.

The national rail carbon footprint estimated in this study is larger than that reported by the Australian Government[66] because this study includes additional rail transport emissions such as those associated with privately owned and operated resource industry rail infrastructure and assets, that might otherwise be reported in other sectors.

[66] Commonwealth of Australia (2022) National Inventory Report 2020.

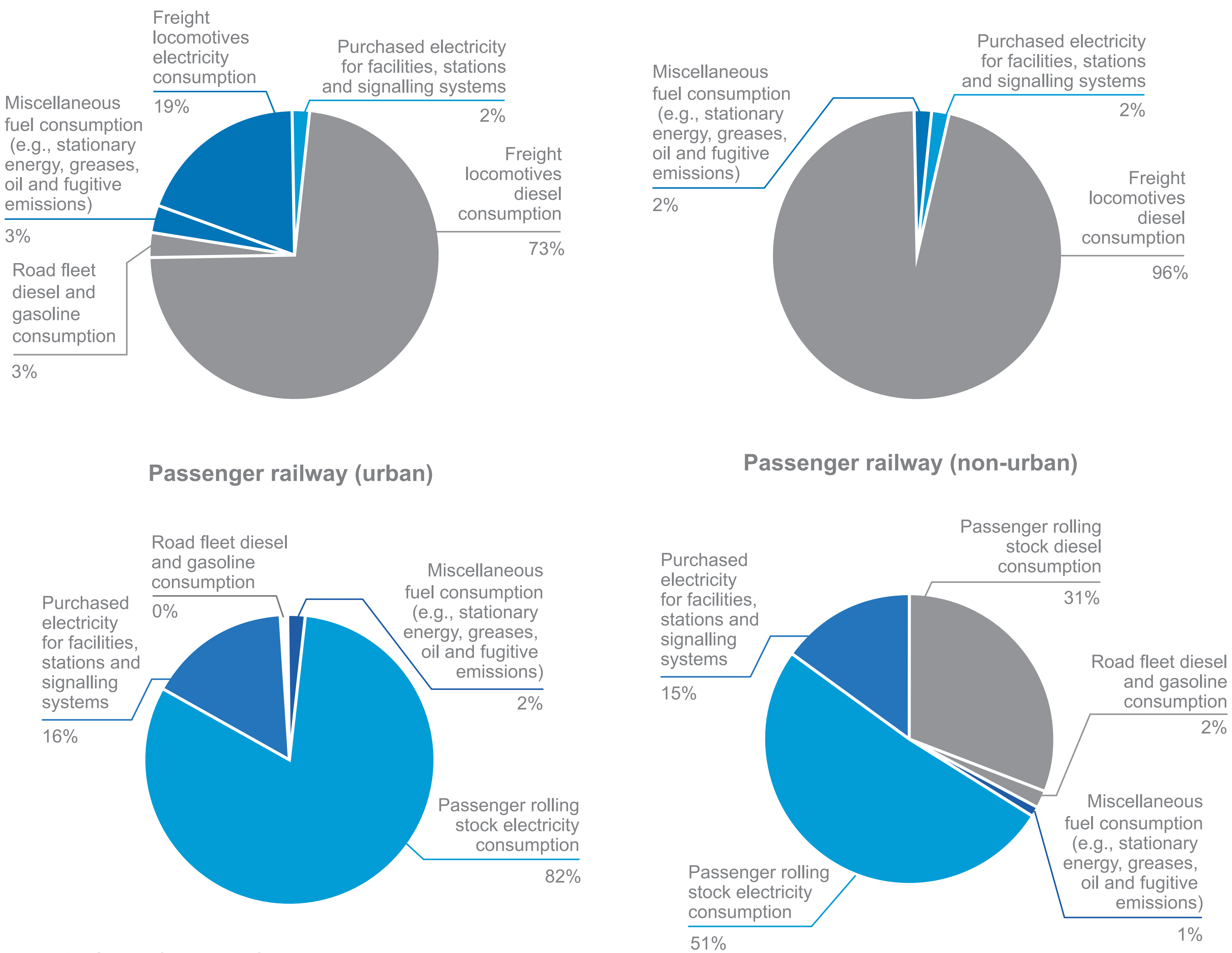

Figure 15. Carbon footprint by freight and passenger national rail network

9.2.3 Carbon footprint further studies

Further analysis will improve accuracy of estimations as the rail operators and infrastructure managers report carbon footprints in a consistent industry-wide way. GHG Protocol establishes GHG accounting and reporting principles of relevance, completeness, consistency, transparency and accuracy.

For a complete analysis, the following would be needed:

1. Rail managers and operators to quantify and report annual scope 1, 2 and 3 emissions and emission sources aligned with international standards such as the GHG Protocol
2. Consideration of tracking data and emissions from replaced rail main components annually (e.g., concrete/timber/steel sleepers, rail track, ballast, bridges, culverts, electrification system, signalling)
3. Rail managers and operators to quantify and report emissions from contractors for the maintenance of the rail network (e.g., diesel consumption)
4. Rail managers and operators to measure and report its absolute operational contribution to the rail industry by a unified criteria (e.g., kilometres travelled by train, total tonnage transported annually)
5. Rail infrastructure managers and operators to estimate and report the emissions contribution of the rail transport part of a wider portfolio of services (when applicable) as distinct from other transport services, logistics, and other sectors such as mining and construction.
6. Rail managers and operators to define emission reduction targets, strategies and timeframes to achieve decarbonisation and net zero by 2050.
7. Rail managers and operators to analyse ways to improve and increase capacity to accommodate and estimate road to rail modal shift.

[67] World Business Council for Sustainable Development and World Resources Institute (2004) The Greenhouse Gas Protocol, A Corporate Accounting and Reporting Standard

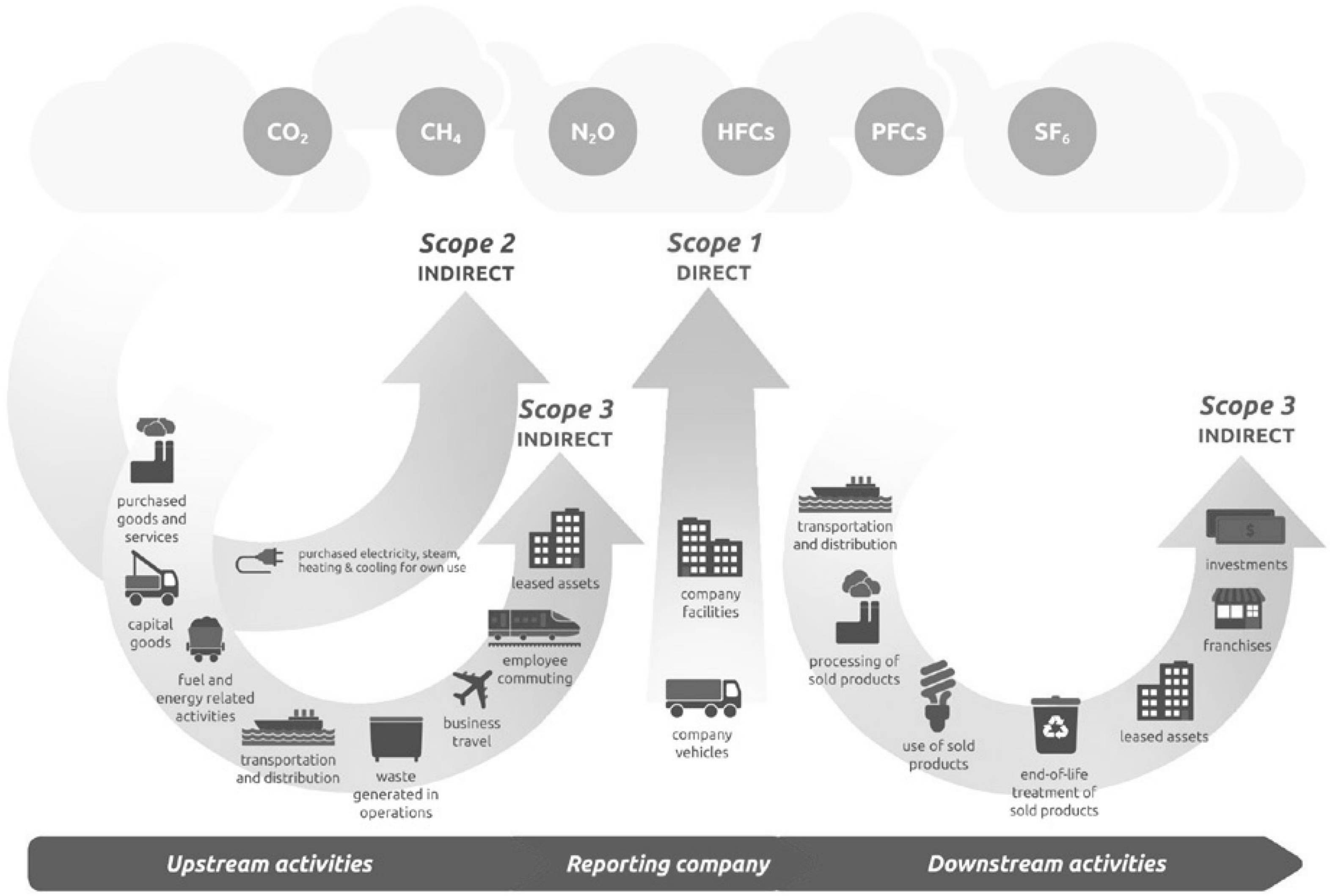

Figure 16. Scope 1, 2 and 3 emissions. Source: GHG Protocol [67]

In order to estimate accurate scope 3 emissions with high confidence in the industry, rail operators and managers will need to complete scope 3 assessment, determine the relevancy of upstream or downstream emissions categories, partners identification and quantification of scope 3 missions. GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard and Technical Guidance for Calculating Scope 3 Emissions provides a supplementary accounting and reporting standard and guidance for scope 3 estimations.

Potential emissions sources for the rail industry based on initial analysis could be mainly associated with the upstream value chain, however scope 3 scoping exercise and screening aligned with the GHG Protocol is recommended to define the emissions boundary.

Emissions sources analysed per components and subcomponents of the rail network elements are as follows.

Component	Subcomponent	Emission source
Traction energy	Fuel	Passenger rolling stock diesel consumption.
		Freight rolling stock diesel consumption.
	Electricity	Freight rolling stock diesel consumption.
		Freight rolling stock electricity consumption.
Staffing and services	Staff and offices	Materials and waste, electricity, gas, water and non-rail business travel (road, sea and air).
	Services	Data centres and other services
Subsystems	Track	Maintenance, renewal and disposal of rail track, concrete, timber and steel sleepers, ballast, S&Cs – signalling and control, plant and utilities and road transport of purchased materials.
	Rolling stock	Passenger and freight rolling stock maintenance, expansion and disposal.
	Stations	Electricity use, gas and other fuel use and maintenance.
	Depots	Electricity use, gas and other fuel use and maintenance.
	Structures	Renewal and maintenance of bridges, earthworks, tunnels, culverts, retaining walls, sea Defences and other structures.
	Electrification	Renewal and maintenance of electrification (e.g., booster transformer, AC Protection Relay, Conductor Rail, cables, switchgear, Overhead Line Equipment (OLE) structures, re-wire and campaign changes), Transformer Rectifier, Plant and utilities, Road transport, Electricity and gas use in operations, Wager for operations and SF6 losses.
	Train control systems	Signalling and telecoms electricity, gas, water, renewals and maintenance and transport.

Table 5. Potential emission sources per rail elements

9.3 Decarbonisation strategies

Carbon decarbonisation in the rail industry would need a collaborative approach to halve emissions by 2030 and achieve net zero by 2050, drive attraction of investment, government support and policy settings to spur rapid action, develop and deploy low and/or zero emissions technologies[68] and to adapt to a changing climate.

Transport decarbonisation could follow emissions decarbonisation strategies aligned with Avoid-Shift-Improve. Avoid reducing total transport needed through smart urban planning and development, urban forms, policy settings and behavioural change. Smart urban design, planning and development that considers denser cities with mixed land use patterns could reduce the transport demand for daily activities and therefore emissions. Rail freight produces 16 times less carbon emissions per tonne kilometre in comparison to road freight[69]. Rail passenger travel generates 30 per cent less carbon pollution than road travel for each kilometre travelled[70] .

Shifting transport modes requires many enablers, such as government support, transport infrastructure investments away from road and towards active and public transport expansion, optimal transfer plans, shorter travel time and improved travel efficiency and service. Rail offers energy efficiency, diversification and environmental gains, e.g., positive impacts on congestion and reduced emissions over road transport. Decarbonising the rail industry will ensure it remains an important part of the Australian transport sector into the future. Rail decarbonisation strategies include energy efficiency, uptake of low and/or zero emissions technologies and increase the use of electricity from renewable sources[71].

Rail faces various challenges to decarbonise related to its large infrastructure and long-life assets. While studies continue demonstrating the benefits or rail over road, there are policy disadvantages for freight operations such as inequity infrastructure costs, infrastructure provision, regulation and inconsistent improvements and investment in rail freight performance and competitiveness.

Collaboration among the rail industry and advocacy to governments to level the benefits of freight and passenger rail over road is key to enable increased improvements and innovation within the rail industry decarbonisation. Promotion of the rail industry could be supported by maximum rail network usage and intermodal integration, removal of technical barriers,

adoption of digital technologies, maximizing revenues and ensuring that all forms of transport pay not only for the use of the infrastructure they need, but also for the adverse impacts they generate[72]. To achieve high uptake levels of decarbonisation for the rail industry, ambitious national policy packages and strategic approaches, collaboration and harmonisation are needed. The rail industry must come together to unify efforts and keep pace as other transport sectors decarbonise. Greater advocacy for rail transport modal shift and further research and development to encourage uptake of emerging low and/or zero emissions technologies are key elements.

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[68] *KPMG, Roads Australia, Australasian Railway Association and Infrastructure Sustainability Council (2022) The journey to net zero, https://roads.org.au/wp-content/uploads/Journey-to-net-zero_Final_ForWeb.pdf*

[69] *Deloitte (2017) Value of Rail. The contribution of rail in Australia*

[70] *Australasian Railway Association (2020) Value of Rail*

[71] *Jaramillo, P., S. Kahn Ribeiro, P. Newman, S. Dhar, O.E. Diemuodeke, T. Kajino, D.S. Lee, S.B. Nugroho, X. Ou, A. Hammer Strømman, J. Whitehead (2022) Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.012*

[72] *International Energy Agency (2019) The Future of Rail, https://iea.blob.core.windows.net/assets/fb7dc9e4-d5ff-4a22-ac07-ef3ca73ac680/The_Future_of_Rail.pdf*

The rail industry must continue focusing on energy efficiency initiatives that could significantly further reduce GHG emissions, particularly for traction energy. Improvements in data collection, modelling and analysis to better understand energy use, cost and performance will support the ongoing identification of energy efficiency measures and initiatives for the rail industry. Multiple energy efficiency measures exist, including[73]:

- Improving driving behaviour and remote monitoring,
- Improved designs, aerodynamics and general operating conditions,
- Maximising the length of trains, even power distribution and double stacking for freight transport,
- Optimising loading of freight transport,
- Route and locomotive optimisation analysis,
- Smart cruise control, speed and throttle management,
- Driver assistance software and system,
- Wheel/rail lubrication,
- Enabling excess regenerative energy capture,e.g., reuse and regenerative braking,
- Auxiliary power reductions and reducing transmission losses, and
- Routine maintenance and efficientmaintenance planning.

A recent study to drive action on transport's journey to net-zero was completed in partnership between the Australasian Railway Association (ARA), Infrastructure Sustainability Council (ISC) and Roads Australia (RA). The study includes 46 recommendations to accelerate decarbonisation in the sector, including the adoption of fuel efficiency standards to assist in the transition to low emission vehicle uptake. The main five recommendations offered for decarbonisation of the transport sector include a national strategic approach, introduction of policy, investment and incentives, exemplar governance structures processes and approaches, collaboration, capacity building and education and adoption and promotion of technologies[74].

Promising low and/or zero emission technologies for the rail industry include biofuels, battery-electric trains and hydrogen. Research, development and infrastructure are key for technology innovation and will enable the prioritisation of short-term emission reduction strategies as well as medium to long-term future emissions reductions and benefits within the rail sector. Substituting diesel with biodiesel blends yields reductions in both net GHG emissions and petroleum consumption[75].

Biofuels can be directly substituted for and blended with conventional fuel. The most common are B5 (up to 5% biodiesel) and B20 (up to 20% biodiesel). B100 is pure biodiesel is rarely used as a transport fuel due to lack of regulatory incentives, pricing and may require equipment modifications. According to U.S. Department of Energy, B100 Biodiesel (not widely used in Australia) reduces emissions by about 74% and B20 reduces carbon dioxide emissions by about 15% (20% of the emissions reduction benefit of B100).[76] Biofuels trials in trains are happening worldwide. B100 biofuel is currently being tested in Transport Express Régional (TER) trains in France (Régiolis B100 biofuel experiment). The B100 biofuel is made from 100% French rapeseed and will allow for a 60% reduction in the GHG emissions without the need to chain the power system. B100 use in trains was authorised under French law in 2018.[77] Europorte is a rail freight operator in France, partnering with Avril Group to test Oleo100, a B100 type fuel made of French rapeseed in commercial service. The objective of this experiment is to replace part of the Non-Road Diesel (GNR) of the thermal Euro4000 diesel locomotives with a renewable fuel, guaranteeing the co-production of local plant proteins for livestock feed and reduce greenhouse gas emissions by 60% over the entire life cycle of the fuel, from the field to the rail.[78]

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[73] *Australian Government, Department of Industry, Science, Energy and Resources Pacific National (2021) ESG Report One Rail Australia (2019) Sustainability Report*

[74] *KPMG, Roads Australia, Australian Railway Association and Infrastructure Sustainability Council (2022) The journey to net zero.*

[75] *Whitaker, M. and Heath, G., 2010. Life cycle assessment comparing the use of jatropha biodiesel in the Indian road and rail sectors (No. NREL/TP-6A2-47462). National Renewable Energy Lab.(NREL), Golden, CO (United States).*

[76] *U.S. Department of Energy (N.D.) Biodiesel Blends, https://afdc.energy.gov/fuels/biodiesel_blends.html Argonne National Laboratory (2008) Life-Cycle Assessment of Energy and Greenhouse Gas Effects of Soybean-Derived Biodiesel and Renewable Fuels, https://greet.es.anl.gov/files/e5b5zeb7*

[77] *SNCF (2021) Rapeseed- powered TERS could leave diesel behind, https://www.sncf.com/en/innovation-development/innovation-research/ter-trains-replace-diesel-with-rapeseed*

[78] *Saipol (2021) Europorte and Saipol united to decarbonize railways with Oleo100, https://www.saipol.com/en/news/europorte-and-saipol-united-for-decarbonizing-rail-with-oleo100/*

For example, rail managers and operators such as Rio Tinto, BHP, Fortescue and Roy Hill in the Pilbara region are implementing initiatives to develop low-carbon solutions that will reduce and displace the use of diesel in rail and mobile fleets, expected to be material emission reductions beyond 2030. RTOs in the region have purchased battery-electric locomotives to initiate trials before 2025, capable of regenerative braking that will reduce about 30% of diesel-related carbon emissions per locomotive[79]. Investment in new fuel-efficient locomotives has been a focus for other RTOs such as Pacific National to reduce emissions and operating costs, whilst also improving productivity, reliability and availability[80].

Hydrogen is expected to support rail decarbonisation and research, pilots, trials and demonstrations along the supply chain are happening and will need to continue to provide clear direction and scale-up requirements for long-term development. Australia's National Hydrogen Strategy sets a vision for a clean, innovative, safe and competitive hydrogen industry that benefits all Australians and aims to position it as a major global player by 2030. The Government states that over the next five years, with international markets still emerging and domestic demand uncertain, investing in hydrogen production and use will be quite high-risk, but not investing is even riskier.[81]

Coradia iLint is the world's first passenger train powered by a hydrogen fuel cell, which produces electrical power for traction. This zero-emission train entered into commercial service in Germany in 2018 on a 65km route and emits low levels of noise, with exhaust being only steam and condensed water. Its energy storage is in lithium-ion batteries with up to 1000 m autonomy and refuelling in 15 minutes[82]. Germany began permanent operations for 14 hydrogen powered trains called "Coradia iLints" in March 2022. Success in Germany resulted in orders for Alstom to build several trains for use in France, Italy, Austria, the UK, and Hungary and other manufacturers also began working on hydrogen powered rail worldwide.[83] Aurizon has partnered with Anglo American to undertake a Hydrogen Powered Trains Feasibility Study to assess the introduction of hydrogen-powered trains and battery hybrid power units for bulk freight, with mining industry applications in Queensland corridors which use diesel fuelled locomotives under study[84]. Fortescue Metals Group is developing and trialling hybrid locomotives that run on green ammonia and battery storage to replace diesel fuels[85].

[79] *Rio Tinto (2021) Our Approach to Climate Change 2021*

BHP (2022) BHP orders four battery-electric locomotives for WAIO rail network, https://www.bhp.com/news/media-centre/releases/2022/01/bhp-orders-four-battery-electric-locomotives-for-waio-rail-network

Fortescue (2022) New milestone for Fortescue's decarbonisation strategy with purchase of two new Battery Electric Locomotives, https://www.fmgl.com.au/in-the-news/media-releases/2022/01/05/new-milestone-for-fortescue's-decarbonisation-strategy-with-purchase-of-two-new-battery-electric-locomotives

[80] *Pacific National (2021) ESG Report FY2021*

[81] *Australian Government (2019) Australia's National Hydrogen Strategy*

[82] *Alstom (n.d.) Coradia iLint™ – the world's 1st hydrogen powered train*

[83] *Palmer, C (2022) Hydrogen-Powered Trains Start to Roll, Engineering, vol 11, pp. 9-11, https://doi.org/10.1016/j.eng.2022.02.003*

[84] *CSIRO (2022) Hydrogen Powered Trains Feasibility Study, https://research.csiro.au/hyresource/hydrogen-powered-trains-feasibility-study/*

[85] *Fortescue Metals Group (2021) Climate Change Report FY21*

Challenges to uptake renewable fuel and zero emissions technologies include:

- Capital costs and affordability of retrofitting existing locomotives and/or new locomotives,
- Fuel delivery, logistics and storage infrastructure,
- Ensuring access of renewable fuel supply and supporting infrastructure,
- Changes in operational performance and technologies,
- Industry skills for operation, maintenance and supporting infrastructure,
- Synergies with other sectors and complex coordination challenges,
- Rail and own safety standards compliance,
- Ensuring consistent quality standards and
- Potential damage to locomotive engines and impact on equipment warranties.

Electrification of passenger rail network in metropolitan areas has been largely implemented in Australia. Electrified rail trains can take advantage of the rise of renewable sources in the electricity mix and ensure initiatives to maximise the use of electricity from renewable sources. The rail industry could assess the opportunity to generate electricity from renewable sources and the procurement of certified renewable energy. According to the Department of Industry, Science, Energy and Resources, 24% of Australia's total electricity generation was from renewable energy resources in 2020, the highest since levels recorded in the mid-1960s. Solar and wind have been the primary drivers of the renewable generation expansion over the last decade. State governments are making commitments to provide greener electricity. Queensland, Northern Territory is committed to generating 50% of its electricity needs from renewable resources by 2030, New South Wales target to 50% of state emissions by 2030 and Victoria government targeting 100% renewable electricity by 2025 for Victorian Government operations. South Australia aspiration is to achieve 100% net renewables by 2030. Tasmania and ACT have already achieved 100% renewable electricity generation.

Sydney Trains and NSW TrainLink have transitioned its network to net zero emissions. NSW government has committed to a four-year agreement with Snowy Hydro-owned Red Energy for the electricity used by the network[86]. NSW's new Regional Rail Fleet will build an Australian first new fleet with diesel-electric bi-mode technology. Trains will be able to connect to overhead power when running in electrified networks and reduce diesel consumption and emissions[87].

Trams in Melbourne are linked to renewable energy thanks to two Victorian solar farms, part of the State Government's Solar Trams Initiative[88]. Canberra light rail runs on 100% renewable energy[89] and Sydney Metro Northwest offsets 100% of its emissions associated with operational electricity via the procurement of electricity from a new renewable energy project in NSW[90].

While the rail industry should focus on identifying and assessing the best ways to decarbonise by 2050, carbon offsets might play a significant role in the medium-term. After emissions reduction, any remaining emissions may be 'cancelled out' by purchasing carbon credits. Carbon credits are awarded to projects that store, avoid, or reduce emission from the atmosphere, and may include reforestation or renewable energy projects. There are accreditation standards that ensure that carbon offset projects are implemented, run and managed properly and that the credits represent real and actual emissions sequestered or avoided.

The table below summarises some decarbonisation opportunities, benefits and barriers to overcome by the industry.

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[86] *Sydney Morning Herald (2021) Sydney rail network goes green with renewable energy deal, https://www.smh.com.au/national/nsw/sydney-rail-network-goes-green-with-renewable-energy-deal-20211020-p591n1.html*

[87] *Transport for NSW (2022) Regional Rail, https://www.transport.nsw.gov.au/projects/current-projects/regional-rail*

[88] *Yarra Trams (n.d.) Our focus on sustainability, https://yarratrams.com.au/our-focus-on-sustainability*

[89] *Australian Capital Territory (2019) ACT Climate Change Strategy 2019-25*

[90] *Sydney Metro City & Southwest (2019) Sustainability Strategy 2017-2024 https://www.sydneymetro.info/sites/default/files/2021-09/CSW-Sustainability-Strategy-June-2019_0.pdf*

The table below summarises some decarbonisation opportunities, benefits and barriers to overcome by the industry.

Decarbonisation opportunity	Description	Benefits	Barriers
Regulatory change and modal shift	Regulatory changes may include policy settings and Government incentives to facilitate the low and/or zero emissions technologies uptake, heightened investment in rail projects and infrastructure, programmes that encourage customer behaviour change and modal shift and land planning and changes in urban form.	• Acceleration of decarbonisation through a modal shift to rail. • Cost reductions of low-carbon transport modes. • Decrease in road traffic congestion due to increased public transport usage.	• Rail limited capability to absorb modal shift without increased Government support and policy settings • National prioritisation of other transport sectors for decarbonisation, such as road.
Energy efficiency	Strategies such as improved design, double stacking of freight and wheel/rail lubrication, operational efficiencies and regenerative energy capture and reuse	• Reductions in GHG emissions and operational costs. • Reductions in fuel and electricity consumption • Reductions in need of renewable sources	• Increasing energy efficiency alone will not result in the required long-term emissions reductions. • Insufficient retirement of inefficient internal combustion engine vehicles
Sustainable biofuels	Sustainable biofuels are a low-carbon alternative to diesel. The most promising biofuel in rail transportation is biodiesel. Biodiesel can be used in current diesel engines and is produced from high oil content crops, waste vegetable oils and animal fats.	• Biofuels are potentially compatible with existing infrastructure. • Blends up to 20% are currently available. • B100 can yield emissions reductions of 75%. • Improved air quality.	• Only three biodiesel plants of scale in Australia. • Limited supply. • Biofuels will likely be prioritised for aviation and shipping. • Blends higher than 80% biodiesel may damage engines.
Battery - electric and regenerative braking	Advances in battery technologies could facilitate the electrification and decarbonisation of locomotives. Locomotives could be capable of generating additional energy through regenerative braking which allows kinetic energy to be recovered during braking.	• Battery-electric locomotives reduce emissions by 30% compared to diesel locomotives. • Reduced reliance on diesel fuel. • Regenerative braking generates additional energy during transit. • Battery technology is advancing quickly, signalling the potential for higher energy density and lower cost in the future.	• Battery technology requires approximately 20 times the space of diesel fuel and is many times heavier. • Resource availability, circular materials and cost of critical minerals required to manufacture batteries. • Uncertainty surrounding the evolution of different battery technologies.

Table 6. Decarbonisation strategies benefits and barriers

The table below summarises some decarbonisation opportunities, benefits and barriers to overcome by the industry.

Decarbonisation opportunity	Description	Benefits	Barriers
Electrification	The overhead catenary supplies the train with the energy required to power them. Rail is currently the most electrified mode of transport in the world and can take advantage of the rise of renewables in the electricity mix	• Electric locomotives are quieter than diesel locomotives. • As the proportion of renewable energy in the grid increases, emissions from electrified rail will continue to decrease.	• Purchase or generative renewable energy is required to be sustainable unless grid is 100% from renewable resources. • Infrastructure is resource and investment intensive, and vulnerable to weather events.
Green hydrogen	Produced through a process of electrolysis powered by renewable sources. Green hydrogen is distinct from brown hydrogen which is created through burning coal or lignite.	• Near-zero carbon production. • Currently deployed in Germany on passenger routes. • Able to be released without contributing to atmospheric or water pollution. • Hydrogen can be stored in large quantities for long periods of time.	• Low density and high energy intensity during production and transportation phases. • Not yet introduced in freight rail. • Hydrogen supply chains are yet to be established at scale. • Currently more expensive than diesel. • Policy framework and market development is required for development.
Green Ammonia	Green ammonia is produced synthetically by reacting nitrogen with hydrogen using renewable energy sources such as wind or solar.	• Ammonia has the potential for long distance routes. • Ammonia carries up to 70% more energy than liquid hydrogen. • Requirements for the safe production, storage and use are well established	• Ammonia has a relatively low burning velocity and high ignition temperature, and thus remains challenging for conventional internal combustion engines. • Ammonia could involve health and safety concerns.
Bi-mode/ tri-mode/ hybrid	Trains can connect to overhead power when on electrified lines and return to diesel use when on non-electrified lines. Bi-mode uses diesel and electric technology and tri-mode have three different power sources, diesel, electric and battery.	• Trains can reduce diesel consumption and emissions when using electrified lines. • Tri-mode could also operate with on-board traction battery power supply in non-electrified lines.	• Limited electrified lines in regional and remote areas to maximise carbon reduction • Diesel is still consumed, and biodiesel needs further development to yield 100% emissions reductions.

Table 6. Decarbonisation strategies benefits and barriers (continued)

The table below summarises some decarbonisation opportunities, benefits and barriers to overcome by the industry.

Decarbonisation opportunity	Description	Benefits	Barriers
Electricity from renewable resources	Electricity generation from renewable resources on site or on the ground to offset electricity consumption and conserving energy usage. It includes Power Purchase Agreements and Australian state efforts to decarbonise the grid.	• Renewable electricity generates no emissions and reduces air pollution. • Solar photovoltaics (PV) and wind continue to be the cheapest source of new electricity generation capacity in Australia • Avoid electricity cost increase or fluctuations. • Reduce the load the industry places on the electricity grid with power generation.	• Capital cost of infrastructure to generate renewable electricity. • Space and land availability. • Large quantities of purchased renewable electricity could affect market price.
Carbon offsetting	After all avoidable emissions have been minimised, remaining emission may be 'cancelled out' by purchasing carbon credits.	• Will assist in achieving net-zero after all other strategies have been exhausted. • Opportunities to build a carbon offset portfolio	• Carbon credits are in high demand and experience price fluctuations.

Table 6. Decarbonisation strategies benefits and barriers (continued)

9.3.1 Decarbonisation in other transport sectors

Demand-side options and the uptake of low emissions technologies can reduce demand for all transport services and support the shift to more energy efficient modes, that will reduce emissions. Road transport is focused on vehicle electrification as the primary driver of emissions reduction; however, studies demonstrated this strategy alone to be insufficient to decarbonise by 2050 and there is a need to reduce, shift and improve[91]. Sustainable biofuels, low emissions hydrogen, and derivatives are some of the decarbonisation strategies for shipping, and aviation, but require production process improvements and cost reductions.

The table below shows the main decarbonisation initiatives in other transport sectors and challenges that could support the understanding of decarbonisation for the rail industry.

[91] AustRoads (2020) Decarbonisation of Road Transport Network Operations in Australia and New Zealand, https://austroads.com.au/publications/network/ap-c110-20

The table below shows the main decarbonisation initiatives in other transport sectors and challenges that could support the understanding of decarbonisation for the rail industry.

Transport mode	Carbon reduction opportunities and initiatives	Challenges
Road	• Reduce vehicle kilometres travelled when delivering the transport task. • Improve the emissions efficiency of road vehicles. • Reallocate the transport task to a different transport mode with a lower emissions footprint. • Multimodal planning, High Occupant Vehicle (HOV), Mobility as a Service (MaaS), multimodal navigation and payment apps. • Improvement in the business functions of the road network transport operations. For example, integrated transport planning and traffic management. • Incorporate more vehicles powered with low carbon electricity. • Utilise alternative technologies to diesel such as diesel hybrid-electric, battery electric, and hydrogen fuel cells.	• Electric vehicles transition will not be sufficient to achieve net zero for road. • Incentives to accelerate retirement of inefficient internal combustion engine vehicles is necessary. • Accessibility of low-carbon technologies remains low due to uncompetitive costs compared to conventional diesel and gasoline vehicles. • Hydrogen-based fuel cells require further development to overcome the lower durability, higher energy consumptions and higher costs. • For short- to medium-distance travel, private cars are likely to continue to displace public transit.
Aviation	• Operational efficiency, fleet modernisation and innovation investment. • Optimise air traffic management and operational procedures while maintaining safety.[91] • Increase investment in and use of sustainable aviation fuel (SAF).[92] Seven different SAFs have been approved by ASTM International. SAFs can be blended at up to 50% with traditional jet fuel without the need for aircraft or fuel infrastructure changes. • Utilise lower carbon aviation fuels (LCAF). • Continue research into hydrogen as a possible future aviation fuel. [90] • Development of electrification of aircraft systems, and electric or hybrid aircraft designs.	• Improved airplane technology and operations for decarbonisation will likely be unable to keep up with projected growth of the aviation industry. • Despite changes in engine technology over time, the basic configuration of an aircraft is likely to remain the same until at least 2037.[93] • Alternative fuels are not yet economically competitive. For example, bio-SAF costs approximately three times the price of kerosene.[91] • Government subsidisation of alternative fuels will be crucial to the transition away from kerosine.
Shipping	• Reduce demand for shipping by improving logistics and packaging processes. • Optimise operations and ship design. For example, improve hull design, vessel shape and power and propulsion systems.[94] • Transition to renewable fuels such as biofuels and green ammonia for long distance routes. • Utilise synthetic fuels such as e-Methanol, which can reduce emissions by 80%.[91] • Increase uptake of battery- or hybrid-electric ships for short-sea shipping such as ferries and inland waterways.[91]	• R&D is needed to help reduce costs of alternative energy carriers. If the cost barrier is not overcome, shipping may experience reduced demand as a consequence, and hence emissions reductions. • Limited availability of biofuels due to inter-sectoral competition, particularly with aviation. • Further development of safe storage and handling of Hydrogen and Ammonia is necessary.

Table 7. Decarbonisation initiatives and challenges in other transport sectors

[92] ICAO (2019) 2019 Environmental Report Aviation and Environment, https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20(1).pdf

[93] Jaramillo, P., S. Kahn Ribeiro, P. Newman, S. Dhar, O.E. Diemuodeke, T. Kajino, D.S. Lee, S.B. Nugroho, X. Ou, A. Hammer Strømman, J. Whitehead (2022) Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.012

[94] IRENA, 2021. A pathway to decarbonise the shipping sector by 2050. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

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