Rail Decarbonization: Global Outlook

What are the next steps to achieve net zero by 2050 for rail stakeholders in various parts of the world?

June 5, 2024

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This third article in our rail decarbonization series looks at the current state of railway systems around the world and presents actions to accelerate progress toward net zero. The recommendations we provide for rail stakeholders build upon the ecosystem perspective (Figure 1 below) explored in the first article, which discusses how rail decarbonization is inextricably linked to the wider transport sector, energy sector and built environment. The major steps the rail sector needs to take to decarbonize are outlined in the second article. In addition, the first two articles address how to achieve a shift from road and aviation to rail, a short-term means to reduce the substantial emissions from the transportation sector.

This is the third article in a series. Click below to read the first two articles.

Article 1 – Rail Decarbonization: An Ecosystem Perspective

Article 2 – Rail Decarbonization: Strategic Pivot

Our rail decarbonization series recognizes that decarbonization is a change process on a global level and across all sectors and industries. However, complacency within the rail industry—resulting from the perception that rail is sufficiently green—impedes the bold, immediate action needed to reduce embodied carbon in rail infrastructure and, at the same time, avoid falling behind increasingly decarbonizing road-based travel. An awakening among stakeholders is needed, and ownership, rather than delegation, emerges as the catalyst for real change.

Here we take a look at the state of rail decarbonization around the world, presenting a broad perspective from various countries and regions. We then apply the ecosystem and ownership principles to provide specific recommendations for how rail stakeholders can own their part of the rail decarbonization journey.

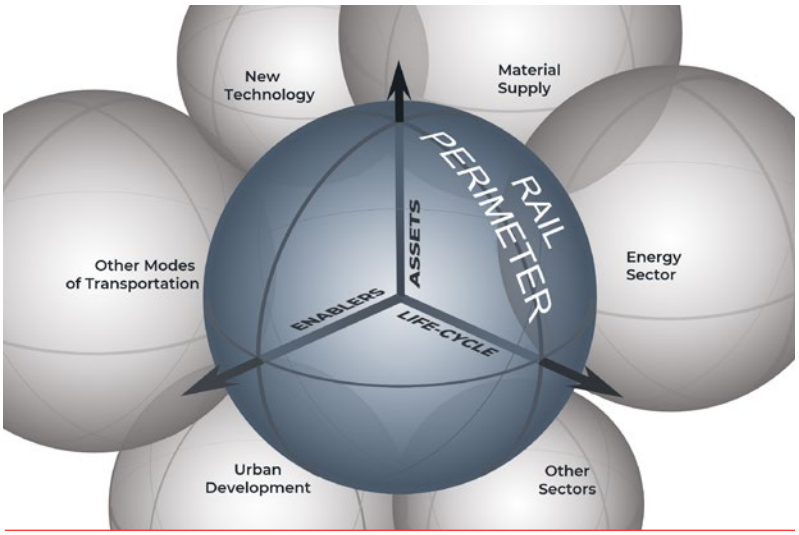
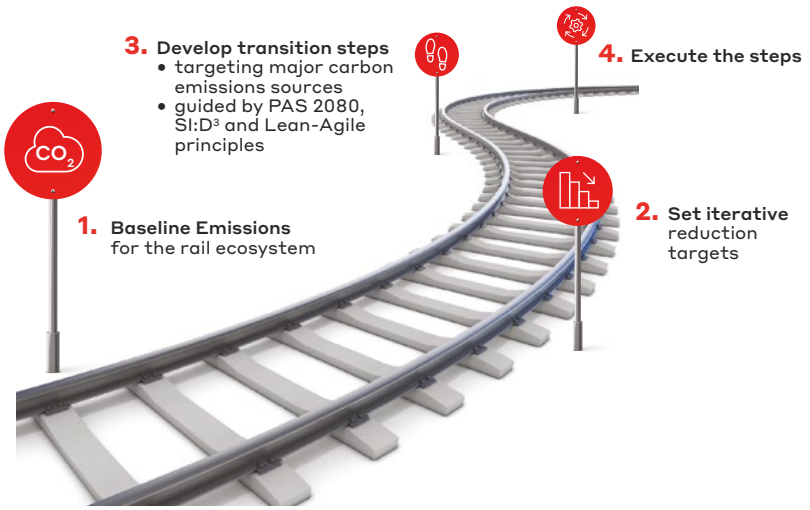


Figure 1 – The Rail Ecosystem – Adopting the ecosystem perspective requires consideration of sectors that intersect with rail—in particular, the energy sector, other modes of transport and the material supply sector—as this wider view is necessary on the journey to decarbonize rail. The ecosystem perspective takes into account the whole lifecycle of an asset, identifying trigger points—where decisions can be made by rail stakeholders (enablers) along the decarbonization journey.



1. Develop greenhouse gas (GHG) baseline – Keeping the ecosystem perspective in mind, include construction, operations and asset renewal in the baseline for a given year.
2. Commit to ambitious emissions-reduction targets.
3. Develop a transition plan guided by the ecosystem perspective and the PAS 2080 framework. Focus on the big emissions culprits.
4. Execute the plan.

Figure 2 – General Decarbonization Strategy
Developing tangible roadmaps with clear interim transition steps fosters focus on shorter-term goals and generates the sense of urgency lacking in milestones set far into the future.

TERMS USED IN THIS ARTICLE

Embodied carbon refers to the greenhouse gas emissions released during the lifecycle stages of an infrastructure asset: raw material extraction, transportation, manufacturing, construction, maintenance, renovation, and end-of life (in contrast with operational carbon, which is released from the ongoing operation of the railway asset). In addition, in this article, the word *carbon* is used to refer to carbon dioxide (CO_2) and all other greenhouse gases.

Scope 1 emissions covers direct GHG emissions from owned or controlled sources; **scope 2** covers indirect emissions from the purchase and use of electricity, steam, heating and cooling; **scope 3** includes all other indirect emissions that occur in the upstream and downstream activities of an organization.

PAS 2080 is a global standard for reducing whole-life carbon in infrastructure. The framework provides a breakdown of responsibilities and activities for all members of the value chain so that they can jointly deliver the decarbonization of assets.

The **circular economy** is a model of production and consumption where materials never become waste and nature is regenerated; the circular economy involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible.

SI:D³, WSP's systems integration approach, creates a migration plan to convert stated goals into benefits for rail stakeholders.

Lean-Agile methodology seeks to improve efficiency by eliminating waste.

Generic steps for main rail stakeholders to support decarbonization ownership

To support the rail industry in developing the transition plan to net zero (step 3 in Figure 2), we have set out a summary of typical roles and key actions in Figure 3 below—elaborating on the generic steps with an indicative timeline that can form stakeholder-focused roadmaps. The following sections offer recommendations for stakeholder-specific roadmaps in various countries/regions. Each section provides an analysis of the current state of the rail system, actions needed in the urgent, near-future phase and how to take ownership in the long-term phase—toward meeting the 2050 target established in the Paris Agreement from 2015 and to sustain momentum beyond 2050. In order to develop a regional roadmap, it is useful to first understand the characteristics of the region. For this purpose, the regional sections include a table providing some of the general parameters of the railway. In addition, for some countries/regions we present examples of the rail industry's structure to indicate the main stakeholders and how decarbonization can be achieved.

PAST	PERIOD OF URGENCY		EXTENDING OWNERSHIP			SUSTAIN
2015 PARIS BASELINE	2024	2027	2030 50% LESS	2035	2040	2050 NET ZERO	2124
Operators & Maintainers	Commit to industry roadmaps. Require supply chain data.	Enhance operational efficiency. Only use zero-carbon energy.	Reduce operational carbon (e.g. alternative fuel, carbon capture).		Decarbonize Asset Base (depots, etc.) and maintenance activities.	Zero-carbon fleets.	
Asset Owners	Commit to industry roadmaps. Require supply chain data.	Set whole-life carbon targets. Plan for asset replacement and renewal considering whole-life carbon.	Construction sites are resource and energy efficient, powered by zero-carbon sources.		Decarbonize Asset Base and activities.	Only build net-zero emissions projects.	
Investors	Commit to industry roadmaps. Require supply chain data.	Only finance new infrastructure and plant, and renovations with net-zero targets.			Only finance renovations and new infrastructure if net-zero emissions.		
Suppliers	Commit to industry roadmaps and set embodied carbon targets.	Declare embodied carbon of 50% of standard products. Retrofit solutions with lower operational emissions.	Declare embodied carbon of standard products.		Use energy only from net-zero sources	No scope 3 emissions.	
Designers	Commit to industry roadmaps and early design for low whole-life carbon.	Propose embodied targets best practice. Use circular principles. Share lifecycle assessment data.			Propose in requirements all projects are 100% zero emissions.		
Policymakers							
Transport Authorities	Develop net-zero strategy.	Set system-wide net-zero targets through policy and contractors.	Implemented policies with progressive targets for embodied carbon, mandatory.				
Governments	Develop net-zero strategy.	Implement targets for new infrastructure and renewals. All certification include embodied carbon requirements.	Implemented policies with progressive targets for embodied carbon, mandatory–with national roadmaps.				
NGO, Networks and Researchers	Convene sectors to co-create national net-zero roadmaps.	Develop calculation methods, design tools & guidance.	Contribute to establish database & benchmarks.				

LEGEND

- Roadmaps
- Data
- Tools
- Finance
- Target setting/ benchmarks
- Disclosure
- Policy
- Design
- Zero-carbon energy
- Leadership action
- Technology/ operation

Figure 3 – Generic steps for each of the main rail decarbonization enablers globally

For rail operators and owners, the approach may include fleet electrification, clean energy adoption and operational efficiency enhancements—e.g. moving from diesel-locomotives to electric alternatives and optimizing scheduling and route planning to minimize energy consumption. Infrastructure managers (those who own and maintain rail infrastructure assets) can play a pivotal role by modernizing rail infrastructure and implementing sustainable construction practices. Roadmaps for infrastructure managers may include electrifying tracks or providing battery charging facilities, integrating energy-efficient signalling systems and utilizing low-emissions/recycled materials for construction and renewals. Rail suppliers and manufacturers should also develop specific roadmaps to align with decarbonization goals—e.g. research and development of low-carbon technologies, transitioning production processes to clean energy sources and optimizing supply chains to minimize emissions. Policymakers and government agencies not only shape the regulatory landscape but also should provide financial incentives to encourage decarbonization efforts. Their roadmaps may involve implementing carbon-pricing mechanisms, establishing regulatory frameworks to promote clean energy adoption in rail transport and allocating funding for research and development of clean energy technologies.

Guided by global experience, regional understanding and interactions with stakeholders in decarbonization, we present recommendations to shape regional strategies that will accelerate the transition toward a carbon-neutral future in rail transportation. The starting point for accelerated change varies between countries and regions. Therefore, the specific steps are also different. However, there are key actions that can be taken across regions, which we share in the conclusion.

Africa

Current State of the Railway System

Africa's railway infrastructure is a study in contrasts, reflecting the continent's diverse economic and geographic landscapes. The state of rail transport in Africa is characterized by diversity in development levels, with significant variations across regions and countries. The continent has been witnessing efforts to revitalize and expand its rail infrastructure as part of broader economic and social development goals.

Rail infrastructure and services in Africa range from modern, urban metro systems in Cairo and Addis Ababa, among other cities, to long-distance passenger and freight services that cross national borders.

For the rail sector, climate change threatens infrastructure integrity through increased flooding, landslides and heatwaves, potentially disrupting services and increasing maintenance costs. Moreover, changes in rainfall patterns could impact hydroelectric power supply, crucial for electrified rail systems, underscoring the need for resilient and adaptive infrastructure planning.

In response to the dual challenges of climate change and sustainable development, African nations are increasingly prioritizing decarbonization across sectors, including rail transport. Electrification of rail lines, adoption of renewable energy and modernization of rolling stock represent key actions to reduce the carbon footprint of rail services.

These efforts are part of a broader ambition to shift toward low-carbon, sustainable economies. However, achieving these goals requires overcoming significant challenges, including financial constraints, technological barriers and the need for regional cooperation and policy harmonization.

The outlook for rail transport in Africa is cautiously optimistic, with ongoing projects and planned investments signalling a commitment to improving rail services.[1] However, the success of these endeavours will depend on continued political will, sustainable financing models and addressing technical and logistical challenges. This regional analysis will focus on rail decarbonization efforts in South Africa and how the country's rail sector is approaching this new frontier.

Rail transport is seen as a key component of sustainable transport strategies, with the potential to reduce road congestion, lower carbon emissions and improve urban air quality.

1 Call for balance in investments for road and rail infrastructure, South African Government News Agency, January 25, 2024.

Parameter	Information	Per capita	Data year	Reference
MARKET SIZE AND OWNERSHIP				
Population	60.6 million	–	2022	Dept: Statistics South Africa
Area (sqm)	1.22 million sqkm	20,000 sqm	2022	South African Government
Annual passenger km	3.5 billion	58	2020	The World Bank
Urban Mass transit (metro, LRT, city commuter)	Prasa – Passenger Rail Agency of South Africa (MetroRail Service)		2024	Passenger Rail Agency of South Africa
Regional, interregional, national, High-speed	Gautrain – High Speed Prasa – Shosholoza interregional & national		2024	gma.gautrain.co.za www.prasa.com
Annual freight tonnes km	149 million			Transnet
Rail Network total length (km)	22,000			Transnet
Privately owned share	No private railway operators			
Electrification share	27%			Transnet
RAIL SHARE OF TRANSPORT & EMISSIONS				
Rail share of passenger transport	9%	–	2022	Dept: Statistics South Africa
Rail share of freight transport	14%	–	2022	Dept: Statistics South Africa

Table 1 – Data on the South African rail market

Challenges and Commitments

Many African countries face challenges in maintaining and upgrading rail infrastructure due to financial constraints, technical challenges, and sometimes political instability. However, international funding and partnerships are increasingly available for rail projects, with China and multilateral development banks being notable partners in financing and constructing new rail infrastructure in various parts of Africa.[2] Interoperability is a technical challenge as different track gauges and standards across countries and even within countries hinder the interoperability of rail services, affecting regional connectivity.

South Africa's railway system is vital for transporting minerals and commodities for the mining sector, which is a backbone of the national economy. The network, one of the most developed in Sub-Saharan Africa, has a significant portion of its routes electrified; therefore, Transnet is leading the way in rail decarbonization on the continent. Electrification not only enhances the efficiency of rail operations but also reduces the reliance on diesel-powered locomotives, contributing to lower emissions. The electrification of rail lines serves as a foundation for further decarbonization initiatives, enabling the integration of renewable energy sources into the rail system. This electrification primarily benefits the major corridors used for both freight and passenger services, including the suburban networks around major cities such as Johannesburg and Cape Town, as well as key freight routes.

Within the rail sector, Transnet, the transport and logistics company owned by the South African government, has made a commitment to achieve net-zero emissions by 2040. This commitment highlights the company's leadership in environmental sustainability within the African rail sector. This ambitious target aligns with global climate change mitigation efforts and sets a precedent for other African rail operators.

Transnet's decarbonization strategy focuses on leveraging biofuels, green hydrogen and renewable energy to transition away from fossil fuels. These energy sources are pivotal in reducing scope 1 and scope 2 emissions aligning with the broader South African Just Transition Framework[3] and the global goal of net-zero emissions by 2050.

Optimizing train operations, upgrading infrastructure and adopting smart technologies can deliver immediate environmental benefits while paving the way for more comprehensive decarbonization efforts.

The journey toward decarbonizing Africa's railways, with South Africa at the forefront, embodies the continent's broader aspirations for sustainable development and climate resilience. By embracing electrification, renewable energy and innovative technologies, Africa can transform its rail sector into a model of environmental stewardship. The path is complex and fraught with challenges, but with continued investment, collaboration and strategic vision, the vision of a green and resilient rail network in Africa is within reach.

2 Ben Payton, Parallel Lines – US and China vie for African rail dominance, African Business, September 8, 2023.

3 Just Transition Framework, Presidential Climate Commission.

Recommended Actions Toward 2050 and Beyond

While the initiatives explored in this section relate to South Africa, they can also be implemented throughout the African continent.

Transnet's commitment to achieving net-zero emissions by 2040 and its strategic focus on mitigating scope 1 and scope 2 emissions through biofuels, green hydrogen and scaling up of renewable energy form a solid foundation for decarbonizing its rail infrastructure.

Beyond these primary measures, there are several additional initiatives that rail operators could consider in further advancing their decarbonization efforts. These include accelerating the electrification of rail lines, which not only reduces reliance on diesel powered locomotives but also allows for the integration of renewable energy sources directly into rail operations; improving energy efficiency by implementing advanced energy management systems; upgrading to more energy-efficient locomotives; and retrofitting existing rolling stock with regenerative braking systems and other energy saving technologies.

Developing on-site renewable energy generation—such as solar panels at stations, on rooftops and on land owned by rail operators—could offset a significant portion of the rail system's energy needs. Wind energy could further diversify the renewable energy portfolio. Beyond using green hydrogen as a primary mitigation measure, investing in fuel-cell technology for locomotives could revolutionize rail transport by providing a powerful and clean alternative to diesel engines.

In parallel, there are other important contributory measures to consider—investing in reforestation and ecosystem restoration and developing carbon capture and storage (CCS) technologies for stationary sources within railway operations. Leveraging digital technologies to optimize routes, reduce idling and enhance overall operational efficiency can lead to significant emissions reductions. Implementing smart-grid technologies such as smart meters will enable more efficient use and distribution of renewable energy within its network.

Collaboration is essential to support scope 3 emissions reductions. Actions to support accelerated progress include working closely with the freight and logistics sectors to streamline operations and reduce overall transport emissions through modal shifts and efficiency gains; partnering with academic and research institutions to pilot new technologies and best practices in rail transport sustainability; and engaging actively in policy development processes to support the creation of favourable regulatory frameworks for clean energy and transport innovations.

Enhancing awareness and participation in decarbonization efforts from stakeholders—including customers, suppliers and the broader community—will support scope 3 emissions efforts; scope 3 emissions efforts can also be strengthened through the implementation of stringent sustainability criteria for suppliers and partners, which will encourage broader adoption of low-carbon solutions across the value chain.

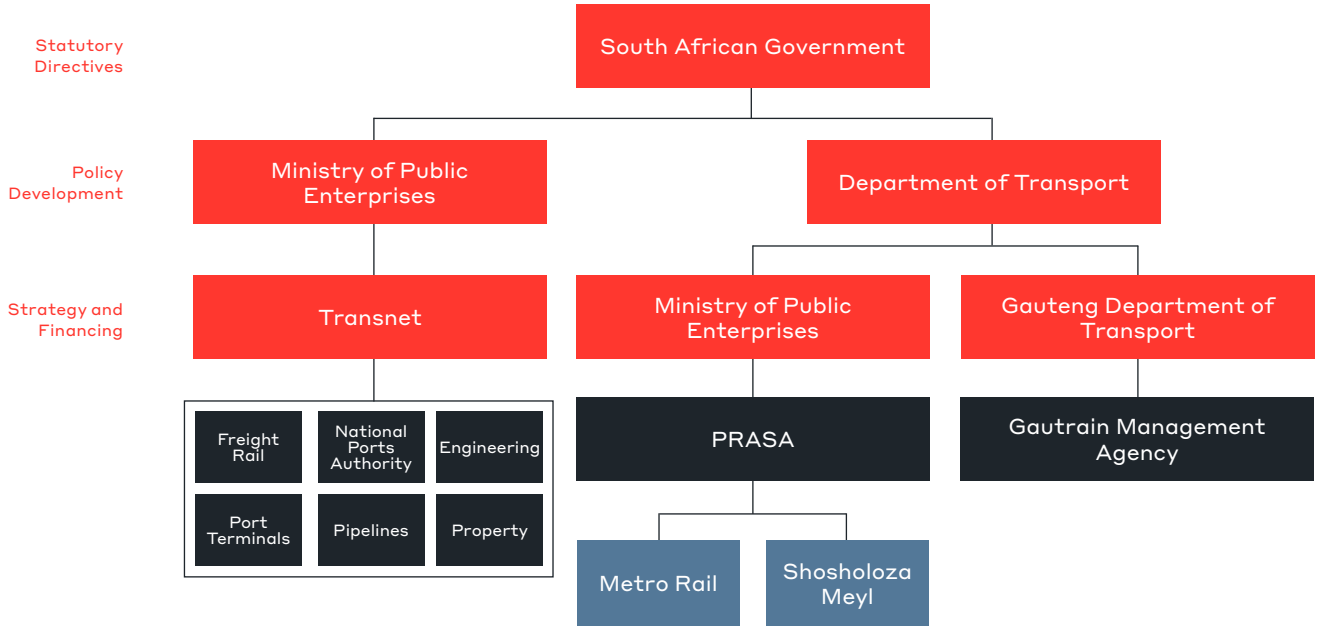


Figure 4 – Rail sector structure and organization in South Africa

Asia

Current State of the Railway System

Across Asia—which is the largest continent geographically with 60% of the world's population—many countries are experiencing rapid industrialization and urbanization, leading to increased carbon emissions throughout the lifecycle of products, from production to consumption and disposal. Asia accounts for 49% of global CO_2 emissions of which 11.5% is due to the transportation industry.[4]

The current broad action to decarbonize across Asian countries is switching from internal combustion engine vehicles and diesel locomotives to electrified railways, thereby eliminating direct CO_2 emissions. Most Asian cities, however, already have modern electrified urban railway systems.

Table 2 – Data on the Asian rail market

Parameter	Data	Per capita	Data year	Reference
MARKET SIZE AND OWNERSHIP				
Population	4.9 billion		2024	World Population Review
Area (sqkm)	17.2 million	3,500 sqm	2024	Britannica
Annual passenger km	1,580 billion	320	2021	UIC
Urban Mass transit *Main operators: Shanghai Metro, Beijing Subway, Guangzhou Metro, Tokyo Metro, Seoul Metropolitan Subway, Delhi Metro, Toei Subway, Osaka Metro, BTS Skytrain, Rapid KL, etc*	37.1 billion	8		Based on public information from government and industry sources.
Regional, interregional, national, High-speed *Main operators: China state Railway Group Compan, Japan Railways Group, South Korea*	661 billion	134	2023	UIC
Annual freight tonnes km *Main countries: China, India*	7,000 billion		2019	SLOCAT
Rail Network total length (km) *Mostly owned by government*	452,000			Based on public information from government and industry sources.
Privately owned share *Main Owner: Japan Railways group*	5%			Based on public information from government and industry sources.
Electrification share	64.6%			Based on public information from government and industry sources.

4 Asia is the largest continent geographically and the most populous continent. Source for the numbers: Historical GH Emissions, ClimateWatch, accessed May 20, 2024.

Parameter	Data	Per capita	Data year	Reference
RAIL SHARE OF TRANSPORT & EMISSIONS				
Rail share of passenger transport	18.9%			Based on public information from government and industry sources.
Rail share of freight transport	18%			Based on public information from government and industry sources.
Transport sector share of total emissions	11.5%		2020	Climate Watch
Rail share of transport emissions	44%		2020	Asian Development Bank
Freight share of rail emissions	56%		2020	Asian Development Bank

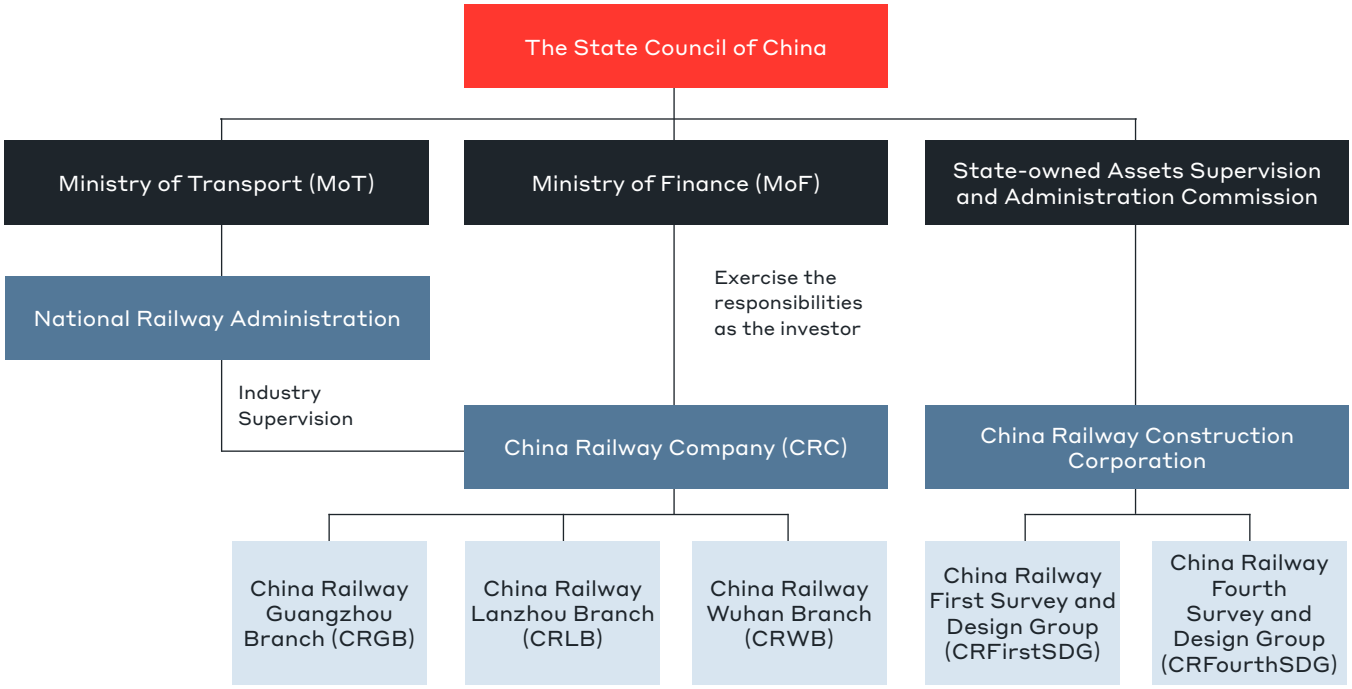


Figure 5 – Rail sector structure and organization in China

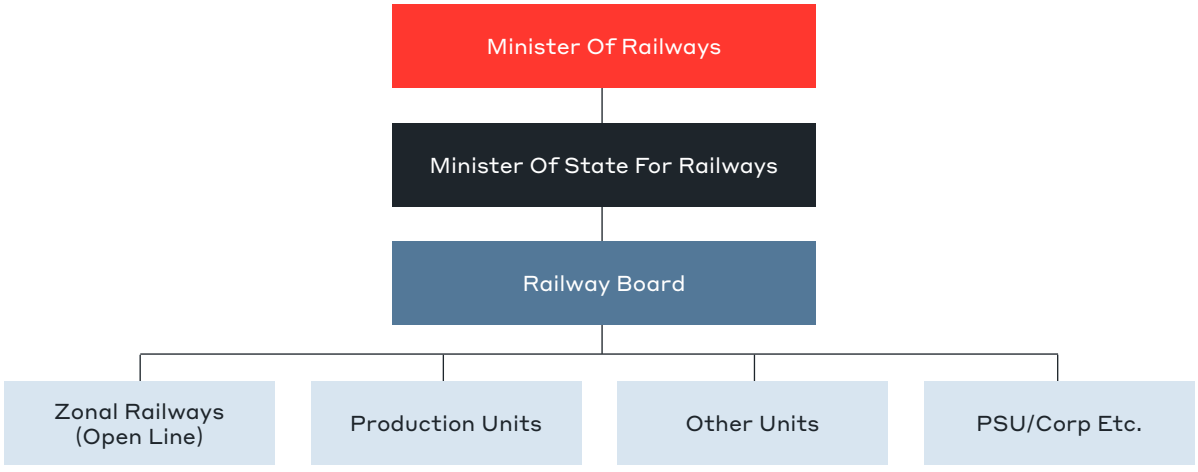


Figure 6 – Rail sector structure and organization in India

Current Actions

Hong Kong, India, and Singapore have achieved more than 90% electrified railway. In the other big Asian railway markets, China and Japan, three quarters of the network is electrified. Malaysia, Indonesia, Vietnam and the Philippines have set aside up to 7% of their GDP to electrify and expand their mass rapid transit (MRT), light rail transit (LRT) and high-speed rails.[5] According to the Association of Southeast Asian Nations, an estimated investment of USD 270 billion has been committed toward this initiative. China has also been pivotal in pushing the electric railway development across other Asian countries and wider through initiatives such as the Belt and Road Initiative.[6]

Although electrified railways serve as a solution for many Asian countries, Hong Kong and Singapore, for example, have taken further steps toward decarbonizing their rail systems. The major stakeholders—Hong Kong's Mass Transit Railway (MTR) and Singapore's Land Transport Authority (LTA)—per their latest sustainability reports, have implemented different policies and initiatives, categorized into construction and operation phases, to further decarbonize their rail operation.

Apart from railway setting the benchmark toward decarbonization, both MTR and LTA have shown support toward the decarbonization of other modes of transportation, each by installing at least 40 electric vehicle (EV) charging stations across their office buildings and mall car parks.

Hong Kong MTR

Construction: Achieved BREEAM certification for stations and attained Final Gold and Final Platinum BEAM Plus Standard awards for properties contributing to railway operations.

Operation: Installed over 2,100 solar panels generating 160,000kWh of electricity at depots. Implemented supercapacitor energy storage and regenerative braking technology across AC and DC rail lines, capturing 1,700KWh of regenerative energy daily to power station facilities.

Singapore LTA

Construction: LTA mandates rolling stocks designed for minimum 92% recyclability.

Operation: LTA employs regenerative braking, recovers approximately 30% of consumed energy, and issued tenders in 2023 for solar deployment generating 7.9MWp in MRT stations and rail depots. Additionally, LTA utilizes platform screen doors, LED lighting and Dual Speed Escalators to reduce energy consumption within rail premises.

5 Rail Development in ASEAN: Role of national and state governments, Southeast Asian Infrastructure, August 1, 2023.

6 Ibid.

Recommended Actions Toward 2050 and Beyond

Toward the 2050 goal, Asian countries could actively support railway decarbonization by taking action in several areas: electrification and renewable energy; ESG strategy and expansion; energy efficiency and circular economy; and policy integration. Many Asian countries, such as India, are actively electrifying their railway networks and integrating renewable energy sources.

Setting specific targets on energy intensity and consumption, improving water and waste management and adopting a circular-economy model can help railways achieve their ESG targets and reduce their carbon footprint.

Translating national climate strategies into sector-specific strategies and making sectors accountable by setting GHG targets can drive progress. This ensures that climate goals are integrated with development goals and involve all stakeholders in strategy development and implementation.

While many Asian countries are driving toward decarbonization by electrifying their railway, a lot of work must be done for most countries to catch up with their more developed peers. As Asia continues to grow, the strategic development of its rail infrastructure will be crucial in meeting the dual challenges of economic development and environmental sustainability.

Rail needs to be prioritized over other modes of less carbon-efficient public transport. The continuous development of a sustainable transport industry in Asia requires comprehensive development strategies encompassing both immediate and future objectives with thoughtful implementation. Actions should include electrification of existing lines coupled with network expansion—necessitating significant investment from governments and private entities.

Research and development initiatives are key to pioneering transportation solutions that are low-cost, carbon-efficient and longer lasting. Research and development from other sectors and markets has to be continuously adapted and improved upon for long-lasting battery-powered trains or zero-emissions hydrogen trains to be implemented.

Regional collaboration is essential in cultivating the market dynamics and expertise necessary to address the challenges of climate change. The rail sector's decarbonization journey is no exception; leveraging the technological prowess and cooperative spirit of the region's developed nations is vital. This can enable the developing countries of the region to rapidly advance and align with the sustainability efforts of their regional peers.

Australia and New Zealand

Current State of the Railway System

Australia and New Zealand cover a vast area. Populations are concentrated in cities, which are separated by long distances of unpopulated areas. This unique geography contributes to a unique system of railway infrastructure.

Railways in Australia and New Zealand can be broadly categorized: urban commuter; freight and regional passenger; and heavy haul transport. These three rail categories exhibit their own characteristics and face their own particular challenges to decarbonization.

Table 3 – Characteristics of Australian rail market

	Urban Commuter	Freight and regional passenger	Heavy Haul (especially Iron Ore & Coal)
Average trip Distances	<100km	100s of km	Approx 400-500km mine to port
Train Weight	Circa max 400 tonnes for double-decker trains	Circa max 10,000 tonnes	Circa 30,000 tonnes
Electrified	Typically, Electrified	Typically, Unelectrified	Typically, Unelectrified[7]
Service Frequency	High frequency	Lower frequency	Moderate frequency
Asset ownership	Typically state owned (infrastructure and rolling stock)	Private RS operators Mixed infrastructure ownership	Mostly private ownership (infrastructure and rolling stock)

7 The coal rail network of Aurizon in Queensland is mostly electrified.

Table 4 – Data on the Australian rail market

Parameter	Data	Per capita	Data year	Reference
MARKET SIZE AND OWNERSHIP				
Population	26 million	—	2023	Australian Bureau of Statistics
Area (sqkm)	7.7 million	0.29	2004	Australian Government
Annual passenger km	13 billion	500 km	2023	Australian Infrastructure and Transport Statistics – Yearbook 2023 (bitre.gov.au)
Annual freight tonne-km	460 billion		2023	Australian Government Publication Trainline 10
Rail Network total length (km)	32,700		2023	Australian Government Publication Trainline 10
Electrification share	10.6%		2023	Australian Government Publication Trainline 10
RAIL SHARE OF TRANSPORT & EMISSIONS				
Rail share of passenger transport	3%	—	2023	Australian Government Publication Trainline 10
Rail share of freight transport tonne-km *Dominated by Iron ore*	58%	—	2023	Australian Government Publication Trainline 10
Transport sector share of total emissions	21%	—	2023	Australian Government Towards net zero for transport
Rail share of transport emissions *Scope 1, 2 and 3*	5.%	—	2023	Australian Infrastructurre and Transport Statistics – Yearbook 2023 (bitre.gov.au)
Freight share of rail emissions	71.7%	—	2023	Australian Infrastructurre and Transport Statistics – Yearbook 2023 (bitre.gov.au)

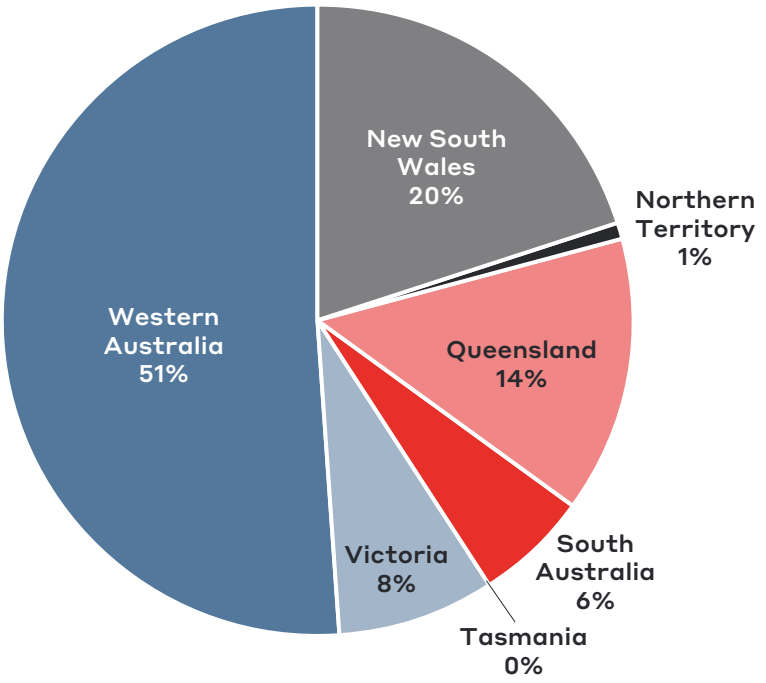


Figure 7 – Rail emissions by Australian states (2021)

Despite significant attention and investment from the country's rail industry, current net-zero solutions for Australia's heaviest emitting railways (heavy haul iron ore and regional freight and passenger) are widely regarded as being too immature or uneconomical for immediate implementation. To compound the challenge, Australia is typically seen as a "fast follower," quick to adopt a technology that has recently been proven in another jurisdiction, as most suppliers of railway technology sit outside of Australia.

Four large mining companies in the Pilbara region of Western Australia transport iron ore from mine to port via private rail networks. Iron ore exports from Western Australia are so significant that they account for most of the nation's rail freight task. These rail networks are unelectrified and rely on diesel-electric locomotives for traction.

Current Actions + Actions Toward 2050 and Beyond

Heavy Haul

As the use of diesel contributes the bulk of the rail carbon footprint on these networks, miners have looked to alternative energy sources as a driver of decarbonization in their operations.

All four major iron ore miners are in the process of procuring and trialling battery locomotives from Progress Rail and Wabtec. Despite favourable geography, with loaded trains travelling downhill to port and empty trains travelling uphill to mine, the power output and energy storage required from these locomotives is immense, and all will likely require some level of electrification to be feasible (when utilizing current battery chemistries). When compared to other decarbonization investment opportunities within the iron ore businesses, the high cost of rail electrification is likely to be difficult to justify in the short term. With this in mind, it is not surprising that use of renewable diesel to supplement existing fossil fuel use is increasingly being seen as a potential interim solution. One particularly attractive quality of renewable diesel is that it does not require major changes to operations or equipment. However, there is no current supply of renewable diesel within Australia, and the future supply profile and costs are difficult to forecast. In addition, there are environmental and social challenges associated with biofuel production (particularly first-generation biofuels), including deforestation and impacts on the supply of food crops. For this reason, KiwiRail in New Zealand will try to move away from biodiesel.

The Pilbara region of Western Australia has been identified as a future hydrogen export hub, so it follows that different hydrogen propulsion technologies—ammonia, hydrogen combustion and hydrogen fuel cell—are being trialled. (The results of these trials have not been made public.) However, hydrogen technologies will face a challenge to overcome the power and energy storage requirements of these heavy haul trains. Similar to electrification, switching to a hydrogen fuel supply would require the adoption of distribution and storage infrastructure, and represent changes to operations. To become viable, this switch would require a national strategy, with all levels of government and various ministries coming together.

It is likely that emissions reductions in the short term will be incremental and driven by similar technologies pursued by the freight sector (such as hybridization, more efficient engines, automatic start-stop features and improved driver strategies).

Given the long timeframes likely required to deliver infrastructure changes and introduce new fuel supplies, it is critical that asset owners have established actionable roadmaps that align to their emissions reduction targets. To accelerate meaningful change, governments can introduce certainty to the industry by promoting clean energy supplies.

Freight and long-distance passenger

The purchase and operation of new, more efficient diesel rolling stock is driving CO_2 reduction in Australian and New Zealand freight locomotive fleets. The procurement of more efficient rolling stock designs is in response to industry demands to decrease fuel consumption and emissions.

All of the major freight operators in Australia have purchased new locomotives within the last three years. There have been contracts signed for in-excess of 100 locomotives since 2021 that are already or will be in service within the next few years. The majority of these locomotives will support either existing contracts or new operations. Meanwhile very few of the existing national Australian fleet of approximately 2,000 locomotives have been earmarked for decommissioning.

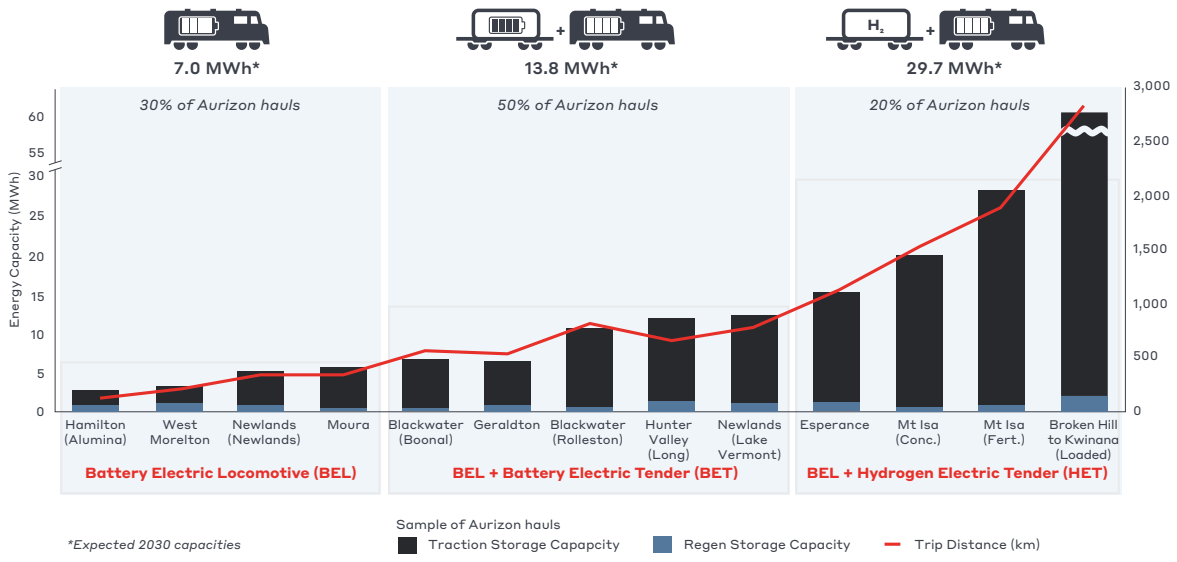


Figure 8 – Aurizon's expected traction technologies to service their haul routes post 2030

In recent years the freight sector has shown an interest in the use of alternative energy sources. Aurizon appears to be leading the industry with projects encompassing battery-electric locomotives, battery-electric tenders and a feasibility study to assess the introduction of hydrogen-powered trains for bulk freight. The company recently signed a deal to retrofit one of their existing 4000-class diesel locomotives with battery power and has noted this will be the first freight unit to be constructed in Australia powered by batteries.[8]

Similarly, Downer, a designer and manufacturer of locomotives within Australia, has developed a hybrid battery-electric-diesel locomotive design that "can seamlessly switch between using onboard energy storage to overhead catenary line energy (25kVa or 1500 VDC) or to a small diesel backup generator (or a combination of all three sources), which provides significant cost savings and carbon reduction across the rail network."[9]

Urban commuter

The majority of urban commuter transport within Australia is electrified. Therefore, the biggest opportunity to reduce operational carbon in the short- to medium-term relates to the decarbonization of the energy grid. The driving force behind the carbon-intensity reductions are the state and federal emissions-reduction targets in conjunction with the advent of economical renewable energy sources.

The use of diesel rolling stock on urban commuter networks is limited to selected lines in the Melbourne and Adelaide Metro. However, several initiatives have been undertaken to reduce the reliance on diesel. Notable examples in the Adelaide rail network are the electrification of the Seaford, Flinders and Gawler lines and hybridization of diesel rolling stock to improve fuel efficiency. Meanwhile, Canberra has continued the trend of electrified urban passenger rail through the procurement of 5x light rail vehicles (LRVs) that are fitted with batteries to work under a catenary-free extension to the existing network.

Asset owners of electrified networks are increasingly targeting efficiency improvements as a means of reduced energy consumption (and reduced cost operation). Efficiency improvement initiatives often focus on the storage of energy from regenerative braking through wayside and onboard systems. However, there is also the opportunity to improve the efficiency of rolling stock traction systems through mid-life upgrades and broader opportunities when procuring new rolling stock.

While operational emissions associated with urban commuter rail across Australia and New Zealand will decline with limited action on behalf of rail operators, reducing the embodied carbon associated with large infrastructure projects proves far more difficult. These projects consume immense volumes of steel and concrete, materials which in the short- to medium-term are likely to continue to be highly carbon intensive. Despite the challenges, efforts are being made to reduce the embodied carbon associated with infrastructure projects. Asset owners are increasingly incorporating the cost of carbon into project business cases. Meanwhile, engineering consultancies are developing their capability to deliver projects in line with the PAS 2080 standard. New technologies are also being used to influence the emissions associated with new infrastructure. One example of this is WSP's Track Alignment Optimiser tool. The tool compares millions of potential rail alignments, identifying the most cost-effective routes (often influenced by infrastructure requirements such as bridges, tunnels, earthworks, track length, etc.). This tool enables concept designs to be developed extremely quickly while reducing cost of infrastructure and, consequently, significantly reducing embodied carbon. When combined with an analysis of operation energy consumption, it is now possible to trend toward lowest lifecycle carbon designs.

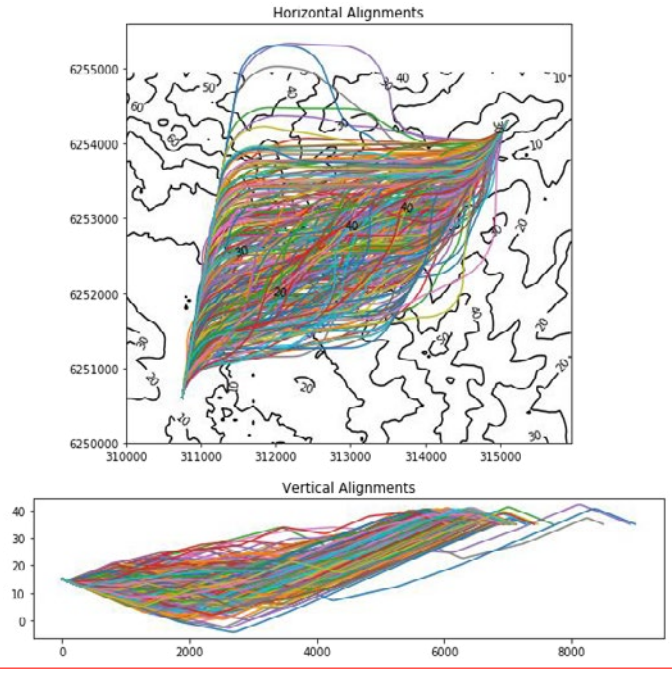


Figure 9 – Visualization produced by WSP's Track Alignment Optimiser tool

8 Work starts on first zero-emissions capable freight locomotive built in Australia," May 30, 2023.

9 Freight & Motive Systems, Solutions to drive a sustainable future, Downer.

Canada

Current State of the Railway System

Being the second largest country in the world by land mass, Canada's distinctive features—such as its varied physical attributes and terrain, its exposure to extreme fluctuations of temperature and humidity, and the distances between populated city centres—set its rail sector apart on a global scale. Across the country, electrified light rail networks are expanding or are being built new in Montreal, Ottawa, Toronto, Calgary and Vancouver. These urban mass-transit-system projects play a vital role in helping decarbonization initiatives by promoting public transit options and reducing the volume of car emissions in our city centres. Such projects can also capture opportunities to bring greater progress in decarbonization by including detailed environmental assessments that quantify the greenfield and brownfield short- and long-term carbon impacts resulting from construction and chosen materials.

In the meantime, there are various steps that demonstrate progress in key areas of decarbonization.

Table 5 – Data on the Canadian rail market

Parameter	Data	Per capita	Data year	Reference
MARKET SIZE AND OWNERSHIP				
Population	41 million		2024	Statistics Canada
Area (sqkm)	9.98 million	244,000 sqm	2021	Britannica
Annual billion passenger km	1.73 billion	42	2019	World Bank
Annual freight tonnes km	446 billion		2019	World Bank
Class 1 Rail Network total length (km)	43,500		2022	Transport Canada
Privately owned share	98%		2021	Transport Canada
Electrification share	0.30%		2021	Railways – The World Factbook, Central Intelligence Agency, accessed March 25, 2024.
RAIL SHARE OF TRANSPORT & EMISSIONS				
Rail share of freight transport	70%		2023	Railway Association of Canada, Rail Trends 2023, 2023.
Transportation sector share of total emissions	23%		2017	The Standing Senate Committee on Energy, the Environment and Natural Resources
Rail share of transport emissions	4.20%		2020	Transport Canada
Freight share of rail emissions	95%		2022	Delphi Group & Pollution Probe, Towards Net Zero: Developing a Rail Decarbonization Roadmap for Canada, December 2022.

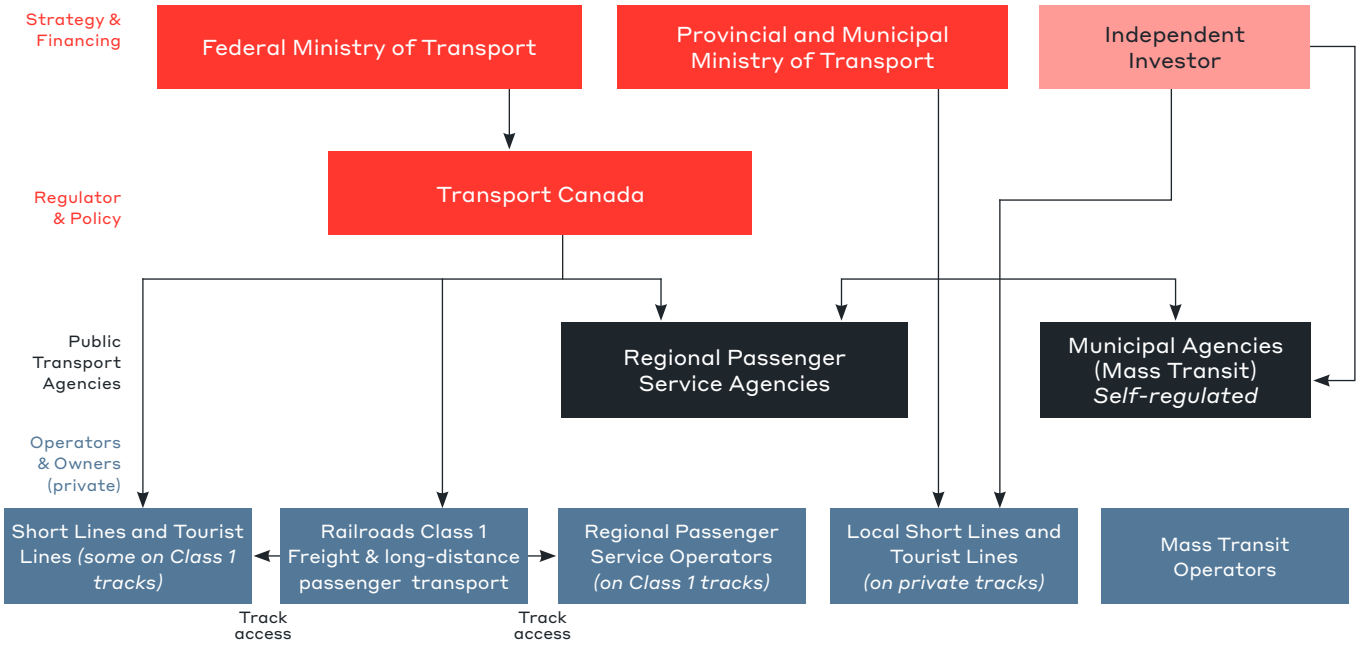


Figure 10 – Rail sector structure and organization in Canada

Current Actions

Asset Owners

Mass Transit Systems

Initiatives have been undertaken by Class 1 and mass transit stakeholders to reduce their carbon footprint, increase ridership capacity and improve operational efficiency. Most of the initiatives focus on fleet renewals and network electrification.

City	Programs
Montreal	EXO: 25% of the older diesel locomotive fleet replaced with Tier IV compliant new diesel locomotives. REM: Phase 1 of the 64 km electrified light rail is in passenger service. Phases 2, 3 and 4 are currently undergoing final testing and commissioning.
Ottawa	O-Train: Line 1 Confederation Line: 12.5 km electrified light rail in passenger service since 2019 with 12 km east and 15 km west network extension under construction. Line 2 and Line 4 Trillium Line: Network extension and introduction of new Tier IV compliant Diesel Multiple Units (DMU) currently undergoing final testing and commissioning with planned service commencement 2024/ 2025.
Toronto	Toronto Transit Commission (TTC): The electrified tram network is being extended. Alongside the addition of multiple lines, the existing fleets are being upgraded to double passenger capacity. GO Transit: Extension of the network and electrification of four major commuter lines in the Greater Toronto area.
Calgary	C-Train: The electrified light rail service is being extended with the addition of the Green Line.
Vancouver	Sky Train: The electrified light rail service is currently upgrading its fleet to respond to and plan for increasing passenger capacity.

Freight and long-distance passenger transportation

Two private freight railways, Canadian National (CN) and Canadian Pacific Kansas City (CPKC) own approximately 80% of the 43,461 km of Class 1 track in Canada.[10]

VIA Rail Canada Inc. (VIA Rail), the largest Class 1 public transportation agency in Canada, operates on behalf of the Government of Canada as a Crown corporation to provide intercity rail services connecting regional and remote communities across the country. VIA Rail operates over 12,500 km of track, of which 97% is owned by freight railways.

Freight and passenger transportation services continue to purchase fuel-efficient locomotives as part of their multiyear fleet renewal programs.

Progress during the 2021–2024 timeframe includes a number of implementations. CN and CPKC have retired and/or modernized their older fleets by procuring new locomotives and overhauling existing locomotives with EPA[11]-certified diesel engines and/or equipped them with improved traction systems, energy management systems and data telemetry systems.

VIA Rail procured and is in the process of cascading new Tier 4-compliant trainsets onto the Quebec City-Windsor corridor.[12]

Even with these initiatives focused on fuel-efficient locomotives, only 8.5% of all Canadian Class 1 locomotive fleets are Tier 4-compliant (highest EPA standard for reduction of emissions), while 17% remains below Tier 0 (base level of EPA emissions standards).[13]

In terms of fuel-savings technologies and operational efficiencies, freight and passenger transportation services continue researching and implementing fuel-saving and operational-efficiency initiatives. CN and CPKC have equipped their fleets with horsepower tonnage analyzers, energy management systems (to regulate speed and compute optimal fuel-efficient routes) and telemetry systems (to collect data to improve performance and conserve fuel).

VIA Rail initiated a pilot project to test an artificial-intelligence-enabled train simulator, which can provide VIA Rail locomotive drivers with operational recommendations to potentially reduce fuel consumption and GHG emissions en route up to 15%.[14]

Of the 3,606 locomotives that constitute the total Class 1 locomotive fleets in Canada, 84% (i.e. 3,034 locos) of the Canadian fleets have been equipped with anti-idling devices, such as automatic engine stop-start systems (AESS) or auxiliary power units, to minimize emissions from unnecessary idling.[15]

Freight transportation services continue to research and implement renewable fuels such as biodiesel blends; CN is actively working with its biodiesel fuel suppliers and locomotive manufacturers.

Alternative propulsion systems are also front and centre as freight transportation services and rolling stock manufacturers continue to drive new research and testing. CN has purchased and is testing a Wabtec FLXdrive battery-electric freight locomotive, a 100% battery-driven heavy-haul locomotive. CPKC

Figure 11 – VIA Rail passenger train

received Canadian government funding to expand research and testing of its hydrogen-driven heavy-haul locomotive program. Supported by the Quebec Government, Alstom launched a pilot project to introduce its Alstom Hydrogen iLINT (multiple unit) train in commercial service as a tourist train in the Charlevoix region for several months.

Privately and Publicly Funded Research

Partnerships between public, private and academic entities are developing, and these partnerships will continue to play a critical role in the continued decarbonization of the rail network in Canada.

From 2021 through 2024, research has been driven by various actions:

- Transport Canada and other government agencies are exploring the use of low-carbon diesel and renewable fuel sources; investigating viability of hydrogen propulsion fuel cell; and investigating risks and hazards pertaining to the implementation of hydrogen- and battery-powered locomotives.

10 *Transportation in Canada, Overview Report*, Transport Canada, 2022, p. 21.

11 EPA refers to the Environmental Protection Agency in the United States.

12 New Fleet Fact Sheet, VIA Rail Canada, accessed June 5, 2024.

13 *Locomotive Emissions Monitoring Report 2021*, Railway Association of Canada.

14 Contributing to a more sustainable future with artificial intelligence: VIA Rail extends pilot project to reduce fuel consumption, VIA Rail Canada, November 24, 2022.

15 *Locomotive Emissions Monitoring Report 2020*, Railway Association of Canada.

- There are a few notable efforts from CN, the first being a collaboration with the University of Montreal to develop mathematical models to improve operational and fuel efficiency; in addition, a partnership has been established with Progress Rail and Chevron REG to test renewable fuel blends; the company is also investigating the reduction of transportation costs and end-to-end emissions across their entire supply chain.
- CPKC is in partnership with Ballard Power Systems to develop and test new hydrogen fuel-cell modules.

Policymakers

The Government of Canada has stated its commitment to reduce and eliminate GHG emissions and have the transportation sector work toward becoming net zero by 2050. To this end, the following are the more notable regulations that have been put in force to promote compliance and adoption by the rail industry during 2021-2024: The Greenhouse Gas Pollution Pricing Act; Canada Net Zero Emissions Accountability Act; and the Enhanced Railway Safety Act (implementing stricter regulations to control criteria air contaminants emissions).[16]

In addition, Transport Canada has mandated the CSA Group to identify codes and standards from international sources that could be used to inform safe design and operation of alternative propulsion sources, such as hydrogen fuel cell and battery-powered locomotives. It is the aim of this initiative to produce a roadmap for developing a more robust set of codes and standards within North America.

Recommended Actions Toward 2050 and Beyond

Supplemental steps are required by all stakeholders to accelerate decarbonization efforts to achieve Canada's committed targets:

Asset Owners

Prior to expanding and/or building new mass transit systems, provincial municipal bodies should require transit agencies to engage an environmental feasibility study phase to identify and propose design resolutions to short- and long-term carbon impacts arising during project construction, system operation, and asset maintenance and renewal lifecycles.

Freight and passenger transportation services asset owners should actively pursue the decarbonization of their networks by electrifying their busiest corridors; coupling electrification initiatives of the railway network with the implementation of secondary modes of traction power, such as hydrogen and battery propulsion, to provide complete end-to-end net-zero last-mile options; and pivoting toward the implementation of renewable low-carbon biodiesel blends for their locomotive fleets where alternative modes of traction power are not commercially viable.

Entities seeking government-funded transportation budgets should commit to providing a comprehensive environmental assessment report during the feasibility phase, addressing carbon footprint concerns.

Privately and Publicly Funded Research

Stakeholders should commit to researching and developing emissions-free technologies, with a particular focus on improving alternative propulsion systems and implementing sustainable and responsible recycling and disposal protocols of fuel cells, both hydrogen and battery.

Policymakers

Policymakers, such as the Government of Canada and Transport Canada, can facilitate long-term commitment to sustainable transport in several ways: by reviewing and revising existing regulatory frameworks to identify and eliminate any inherent biases that can hinder the adoption of net-zero modern technologies and the approval of certified international suppliers with a proven track record of service; developing a unified set of decarbonization regulations governing both freight and passenger operations in North America; promoting the adoption of only sustainable energy sources—green, not grey—to power the Canadian transportation network; and mandating the evaluation and mitigation of carbon costs throughout the construction lifecycle as part of future project financing.

In addition, government policymakers and transit regulators, such as Transport Canada, should establish regulatory policies outlining set timelines and roadmaps for Class 1 asset owners and operating agencies to achieve a net-zero-carbon footprint. Policymakers can encourage:

- Operating agencies to provide comprehensive training to railway crews, emphasizing the impact of driving behaviours on fuel usage and efficiency.
- Asset owners to conduct emissions audits of their railway fleets, prioritizing emissions-reduction efforts based on audit results. Existing diesel fleets should be modernized and converted in advance of major overhauls or end of life.
- Government policy to enforce mandated fleet retrofit or renewal timelines to achieve Tier 4 or net-zero compliance.

16 Criteria Air Contaminants (CACs): Emissions of criteria air contaminants contribute to smog, poor air quality and acid rain. CACs include Total Particulate Matter (TPM), Particulate Matter less than or equal to 10 Microns (PM10), Particulate Matter less than or equal to 2.5 Microns (PM2.5), Sulphur Oxides (SOx), Nitrogen Oxides (NOx), Volatile Organic Compounds (VOCs), Carbon Monoxide (CO) and Ammonia (NH3).

Continental Europe and the Nordics

Current Regional Status

The Nordics and mainland Europe as a region has its own diverse characteristics and multifaceted development when it comes to rail decarbonization. The European green deal on rail decarbonization intends to make rail the backbone of the sustainable and smart mobility strategy by significantly increasing and better managing the capacity of railways, which can be seen as ambitious and challenging. To reduce the barriers in the European rail area, the European Commission has been guiding each member state to complete the single market for rail services by releasing up-to-date legislative railway packages since 2001.[17]

The latest 4th Railway Package of 2016 has reinforced regulations from a technical perspective and a governance and market-opening perspective—to build a higher level of safety, interoperability and reliability in the European rail network. With this call, Europe's Rail Joint Undertaking (EU-Rail) is established by the European Union (EU) to implement a series of programs representing the new European partnership on rail research and innovation.

Figure 12 (p. 21) presents the major rail governance organization in the EU with a focus on the innovation pillar and the system pillar.[18] The system pillar is key to establish a strategic European standardization of the future EU's railway system in accordance with different levels of various rail systems. The system pillar is also aimed at developing the means for implementation by coordinating a Technical Specifications for Interoperability (TSI) input plan and standardization, which could benefit not only the EU but also the global rail system. Furthermore, rail-promoted policies from the EU align with these packages to synergize the impact on the implementation level. This article section focuses on several European countries with examples based on information from WSP's previous project experience.

17 Rail transport, Fact Sheets on the European Union, European Parliament.

18 System Pillar: TSI and Standards, Europe's Rail.

Table 6 – Data on the European market (EU and EFTA mainly); figures will vary for the different countries

Parameter	Data	Per capita	Data year	Reference
MARKET SIZE AND OWNERSHIP				
Population	435 million	—	2023	World Bank
Area (sqkm)	4.67 million	10,700 sqm	2023	World Bank
Annual passenger km	400 billion	545	2022	Eurostat
Annual freight tonnes km	400 billion		2021	Eurostat
Rail Network total length (km)	237,000		2021	Statista
Privately owned share	Mostly publicly owned	—	—	
Electrification share	57%	—	2024	Eurostat
RAIL SHARE OF TRANSPORT & EMISSIONS				
Rail share of passenger transport	5.4%	—	2021	Statista
Rail share of freight transport	17%	—	2021	Eurostat
Transportation sector share of total emissions	25%	—	2024	European Environment Agency
Rail share of transport emissions	0.4%	—	2019	UIC

Governance

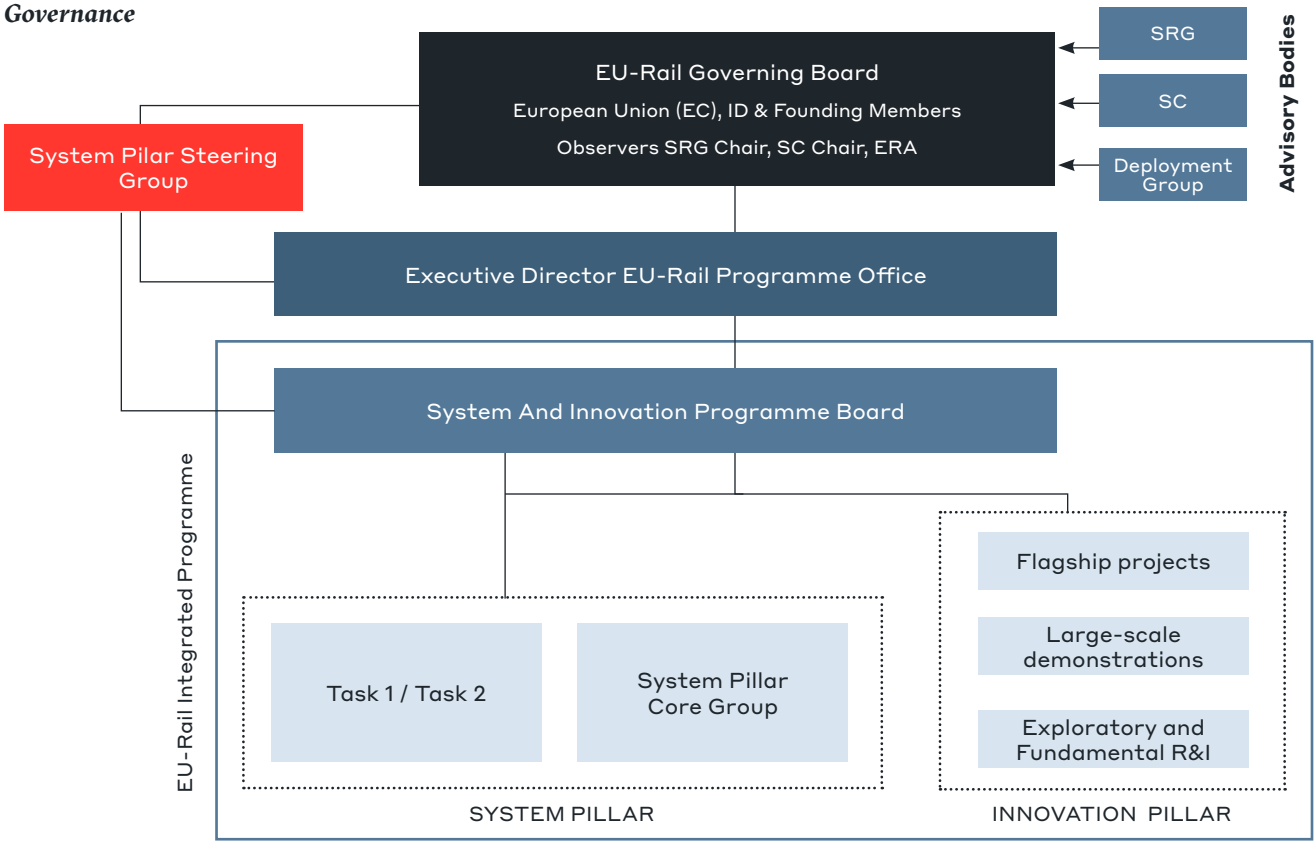


Figure 12 – Rail sector governance chart for Europe

Current Actions

The EU has set a goal for climate neutrality (net-zero GHG emissions) by 2050. To further pave the way toward this target, a reduction of at least 55% in net GHG emissions by 2030 should be achieved, followed by a 90% reduction by 2040. Most of member states determine the milestones of climate targets (2030, 2040, 2050) based on their national decarbonization strategy, which provides a holistic view of GHG emissions reduction in a timely manner for each country; this strategy is used as a baseline for the other important stakeholders within the member states.

Under the EU's standard, these goals vary among countries based on their status and ambitions. Finland has set this goal for 2035, and Sweden aims to achieve it by 2045. The Swedish traffic administration, Trafikverket, has closely designed its decarbonization strategy to contribute to the goal from the Swedish Government.[19] The German national rail operator Deutsche Bahn has set an even more progressive goal than the German Government.[20] However, identifying the specific causes of falling behind the emission targets is always challenging due to the multitude of contributing factors.

Rail Electrification in European Countries, 2021

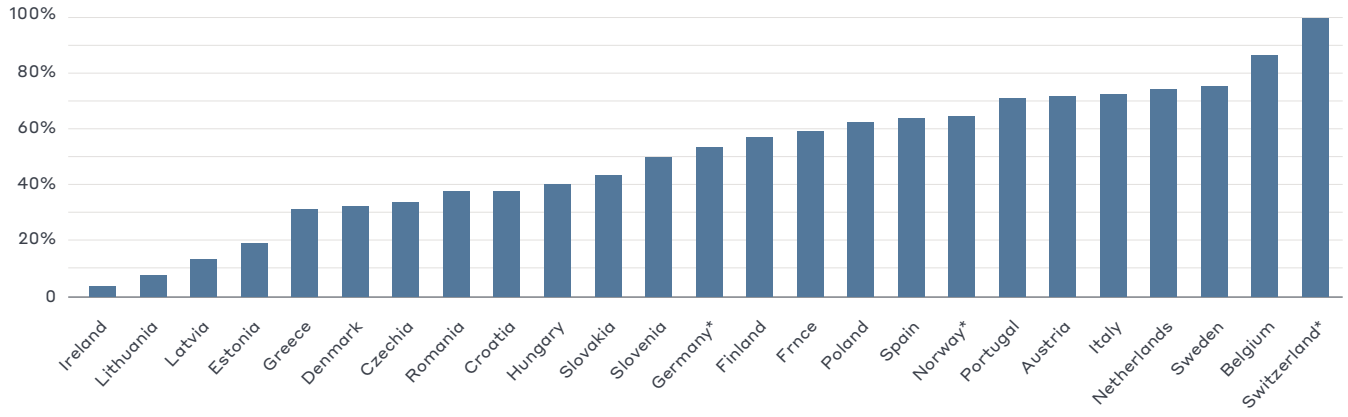


Figure 13 – Rail Electrification in European Countries, 2021 – Countries with asterisk have data available from different years than 2021.

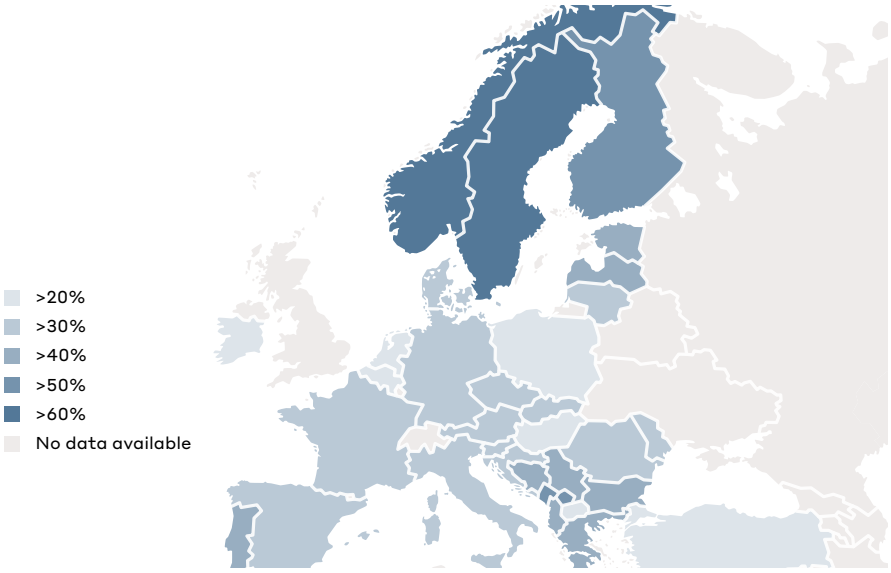


Figure 14 – Renewable energy, electricity use in European countries, 2021 – based on information from Eurostat.

The rail systems of the Nordics and mainland Europe were formed as part of the industrial revolution. There is a relatively high electrification percentage (Figure 13) on the European continent but with drastic variations among countries, due to their historical backgrounds; this variation points to missing electrification coverage in crucial transport network corridors. The Trans-European Transport Network (TEN-T) policy launched in 2014 aimed to fulfil the European network gap in rail infrastructure in support of the 4th railway package. Further electrification needs to consider the current and planned share of energy from clean sources (Figure 14).

19 Trafikverkets, Miljörapport 2022.

20 Deutsche Bahn, Integrated Interim Report, January–June 2023.

Rail ownership in the Nordics and mainland Europe spans a wide spectrum due to the different status of the member states. The call for a governance and market opening from the EU is appealing to a deregulated railway market in order to create a competitive rail sector for both passenger and freight. The rail ownership (Figure 15) model was rolled out for the member states based on the deregulated Swedish rail market.

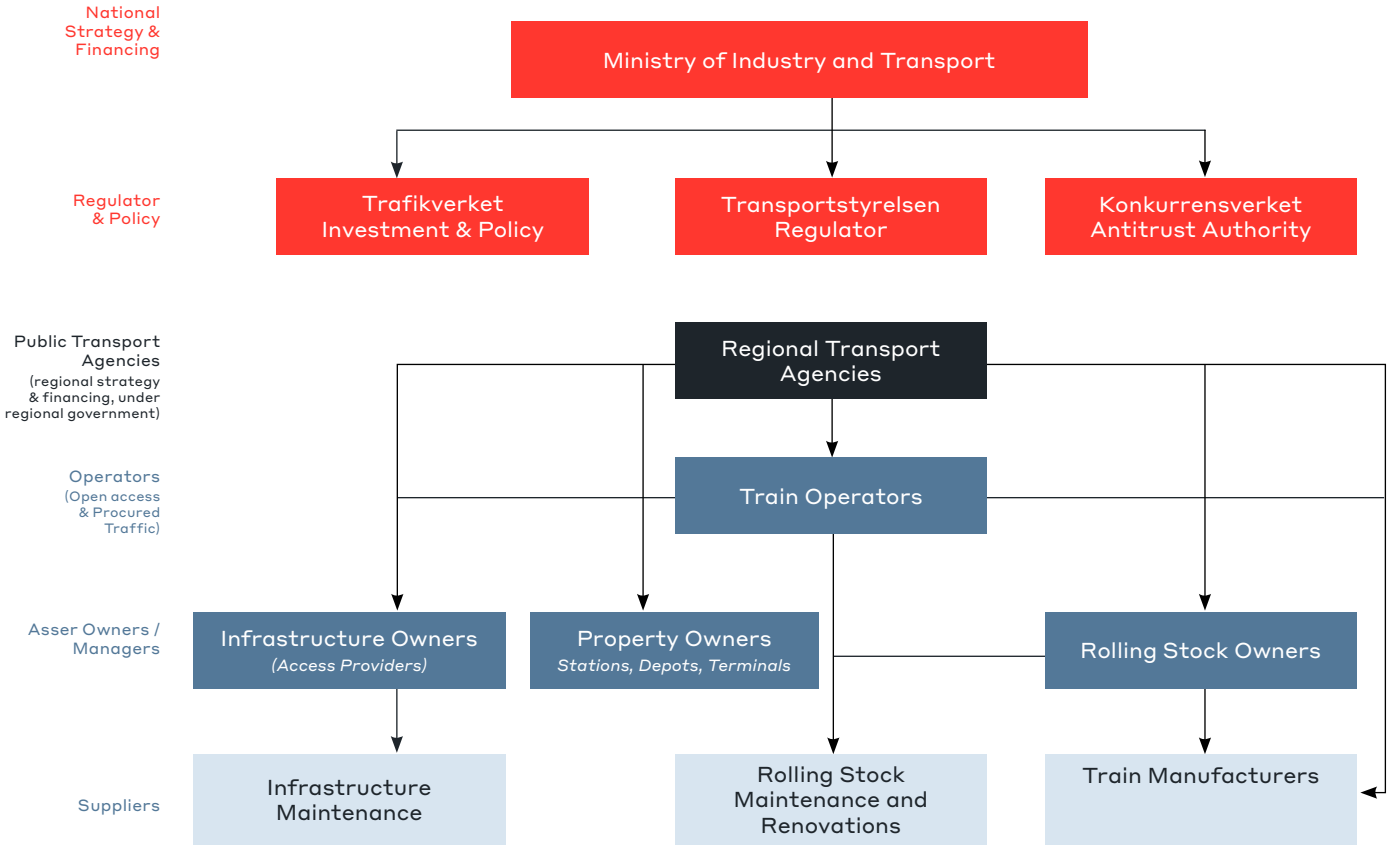


Figure 15 – Swedish Rail Sector Structure: some organisations have multiple functions and belong to more than one 'box' in the structure

The 4th Railway Package addresses these measures to enable the EU's rail decarbonization goal:

- Regulation on European Rail Agency (ERA)
- Directive on the interoperability of the rail system
- Directive on railway safety
- Regulations on opening the market for domestic passenger rail transport services
- Directive establishing a Single European Rail Area (SERA)
- Rules for the standardization of railway undertakings accounts

Toward the 2050 goal and Beyond:

To achieve the net-zero goal, the EU has emphasized the importance of creating sustainable, smart and resilient mobility, with the rail sector playing a crucial role in each aspect.

A sustainable railway involves the use of fossil-free alternatives, offering alternative transport choices and implementing pricing that reflects the environmental impact. Clean energy alternatives have been extensively promoted to reduce dependences on fossil fuels. By 2022, the share of renewable energy reached 9.6% in the EU with the Nordic countries pioneering the use of renewables in the transport sector.[21] The demonstration of this progress is mainly the renewable electricity consumption from road and rail transport. The awareness of a sustainable rail system should expand to the entire lifecycle, where applying circular-economy principles facilitates consideration of the lifecycle of rail infrastructure. This approach goes hand-in-hand with using resources efficiently. Incorporating more recycled materials and renewable raw materials into rail infrastructure plays a significant role in reducing GHG emissions. Deutsche Bahn plans to at least double its recycled content in rail steel, ballast and concrete sleepers by 2030 as a result of emissions reduction of around 300,000 metric tons of CO_2.[22]

Resilient railway systems demand affordable, accessible transport, improved staff conditions and minimized incidents. Policymakers and stakeholders stress the urgency of enhancing rail efficiency, with the TEN-T policy critical for EU transport development.

Efficiency and integration are crucial for enhancing the attractiveness of rail passenger transportation. This involves measures such as reducing travel time, offering passenger-centric night train schedules and expanding denser high-speed networks. Minimizing the complexity of transfers, both physically (through appropriate transfer times and reduced waiting times and barriers for passengers with luggage) and systemically (by simplifying ticketing processes) is essential. Initiatives such as refining EU freight corridors aim to improve rail efficiency by removing bottlenecks and enhancing modal integration. Additionally, making rail transport more affordable and accessible requires sustainable funding mechanisms to balance promotion and sustainability efforts.

To achieve decarbonization in the rail sector, a holistic approach should encompass the following:

- Establishment of a robust policy and regulatory framework to support actions and collaborations.
- Involvement of stakeholders from governmental, operational and industrial sectors to maximize potential.
- Using more low-carbon alternatives, such as recycled materials and renewable raw materials, in rail infrastructure.
- Expansion of rail electrification and utilization of clean energy sources.
- Reduction of energy consumption through efficient options and consideration of lifecycle cost.
- Investment in technologies and innovations to optimize rail operations.
- Improvement of cross-border travel integration and efficiency to encourage modal shift to rail for both passenger and freight.

21 "Share of renewables in transport increased slightly in 2022," Eurostat, February 5, 2024.

22 Deutsche Bahn, Resource protection, accessed March 22, 2024.

Latin America

Current State of the Railway System

Currently, Latin America has very few examples of active railway lines, most of them state-owned and located in countries such as Mexico and Argentina, where this type of rolling stock predominates; their infrastructure, in most cases, is more than 30 years old. Most other countries have plans for urban and suburban mass transportation systems. However, mixed-use interregional passenger and cargo rail systems are still at the very beginning of the planning and design stages throughout the region.

In this context, and given the nature of existing railway systems, the greatest opportunity associated with decarbonization in the rail sector is to promote this means of transport and the associated infrastructure. This is conceived as complement to and a gradual replacement for the existing systems in place, which is predominantly road-based.

Due to the nascent rail industry, there is opportunity to build in low-carbon design solutions, including materials, from the start.

Landmark projects in the region include the Tren Maya, Mexico (USD 28.5 billion), Bogotá Metro Line 2, Colombia (USD 8.4 billion) and the Santiago-Valparaíso train, Chile (USD 3.8 billion), which are in various stages of development. In Chile, the Santiago Metro network expects to grow by 57% in the next 10 years and become net zero by the year 2025, while the state-owned railway company EFE aims to triple its passengers in the same period.

Table 7 – Data on the Latin America markets

Parameter	Data	Per capita					
Market size and Ownership	Latin America		Chile	Argentina	Peru	Colombia	Brazil
Population (million)	500		18.5	46.6	32.4	49.3	219
Area (million sqkm)	16.5	33,000 sqm	756	2,780	1,300	1,140	8,510
Annual passenger (million km)	5,340	10.7	700	426	132	319	2,300
Urban Mass transit (million km)	5,190	10.3	600	423	130	318	2,300
Regional, interregional, national, High-speed	150	0.294	100	3.05	2.24	0.666	
Annual billion freight tonne km	Varies		3,550				
Rail Network total length (thousand km)	101		6.63	37.0	2.02	1.66	29.8
Privately owned share	Varies, freight mostly private, passenger mostly public						
Electrification share	From 0 to 30%						

Current Actions, Challenges + Recommended Actions Toward 2050 and Beyond

Promotion and planning of efficient new railway systems as a means of transport, focusing on electric and hybrid lines, is the most essential step on the decarbonization journey.. Additionally, capabilities and data infrastructure must be built, as there is a need for standards and a solid research base for the development of lower-carbon materials.

In terms of the promotion and planning of new railway systems, governments of the region need to promote more efficient logistics systems that promote an increase in cargo capacity. As such, they are currently pushing for additional rolling stock, which is being strongly supported by multilateral banks and international investment funds from developed countries (e.g. Japan, South Korea and France).

There are a few private actors in the region that own and operate railways, such as FCAB in Chile and Boliva or FDP in Colombia, mostly linked to the mining and port industries. However, they are not considered key players due to their size and/or highly specific purpose of their networks.

In this emerging railway context, lack of experience, governance and regulations often lead to poorly planned projects that delay the processes and/or cause entities to give up on continuing with them. A shift in the ownership and operation paradigm of linear infrastructure could create opportunities for private-sector involvement, mirroring practices observed in Europe.

Given this state of affairs, suppliers, designers and asset owners should push for sustainable construction methods and materials, not only for linear infrastructure, but also for other buildings, such as yards and depots. These efforts should be carried out using a lifecycle approach, accounting not only for the direct emissions but also for those throughout the entire value chain.

For countries with existing and functional railway networks, such as Argentina, Mexico and Chile, governments should increase overall ridership and railway-based services, including the expansion of networks for transport and cargo. The region faces worsening vehicular congestion due to increased vehicle numbers and insufficient transportation infrastructure investment. Passenger and cargo rail offer reliable travel options, although subsidized intercity fares are often not feasible. Urban congestion charging is a potential solution for heavily congested cities such as Bogota or Santiago and Lima, where rail transit is expanding.

Policymakers should promote 100% clean energy-supply contracts for the railway systems through tax incentives and similar measures.

From a supplier and designer perspective, the use of sustainable materials and construction methods will likely be mandatory as asset owners, which are mainly state-owned companies and agencies, such as EFE in Chile and OMM in Mexico, will be obliged to comply with stricter climate regulation. For this reason, early adoption could enable a higher-maturity level sooner and, as such, a competitive advantage.

Additionally, early adoption will allow for the reduction of asset-owner emissions, in line with potential net-zero commitments. Finally, new building and material technologies that offer not only lower emissions but also better reliability and durability represent a better economic choice in the long run.

Summary of recommended actions for stakeholders

Railway systems in the region are either non-existent or just starting to develop, responding to needs for connectivity, efficiency and sustainability in both cargo and passenger transportation. This status gives the region a unique opportunity to implement low-carbon solutions from the very beginning.

The period of urgency to 2030

- Suppliers – Carry out carbon inventories to include as part of Environmental Product Declarations, which communicate the environmental impact of materials over their lifetime.
- Designers – Invest and build capabilities relating to net-zero designs and advisory.
- Asset Owners – Commit to industry net-zero targets; require supply-chain data; develop standards for contractors to acquire lower-carbon materials for depot and train yards, stations, and tunnels and bridges.
- Investors – Account for financial risks related to the transition to a low-carbon economy; and develop net-zero standards for selecting transport and freight investment.
- Policymakers – Prioritize railway-based transportation and cargo in public spending and reduce barriers to entry of new sustainable materials manufacturers and vendors (e.g. incentives, lower taxes, research funding, etc.)
- NGOs, networks and researchers – Develop materials, techniques and strategies to lower the carbon footprint of the construction phase.

Between 2030 and 2050

- Suppliers – Implement strategies to lower the embodied carbon footprint of construction materials, such as 100% clean-energy-supply contracts and the use of composite materials to lower the percentage of clinker in cement.
- Designers – Carry out designs that consider lower-carbon materials throughout the value chain; incorporate a lifecycle approach into design efforts and apply circular economy pillars; optimize infrastructure design to minimize use of resources and introduce nature-based solutions to offset embodied and operational carbon footprint; and establish flexibility in future use, and design accordingly.
- Asset Owners – Require compliance with contractor standards and 100% clean energy-supply contracts. Prefer local suppliers to lower the transport-related carbon footprint and boost the local economy. Include carbon footprint as a metric in the procurement evaluation of rolling stocks. Require compliance with contractor standards.
- Investors – Require compliance with net-zero standards.
- Policymakers – Review progress of projects and stakeholders on net zero commitments, and re-assess measures needed to reach net-zero targets. Rethink concessions systems to allow for better and higher use of railways by many different operators.
- NGOs, networks and researchers – Continue research in lower carbon footprint, and check the compliance of stakeholders regarding net-zero commitments.

Middle East

Current State of the Railway System

The Middle East faces climate-change-related risks including, high temperatures, water scarcity, disease risks, erratic rainfall, land degradation, rising sea levels and food security. Six Gulf Cooperation Council (GCC) countries—the United Arab Emirates (UAE), Saudi Arabia, Qatar, Bahrain, Kuwait, and Oman—have ambitious emissions targets under the Paris Agreement, which is aiming for 43% emissions reduction by 2030 from 2019 levels. This region urgently needs swift decarbonization efforts. Urban mobility in the Middle East is rapidly changing with new travel modes in discussion, such as hyperloop and suspended sky pods.

Governments are prioritizing sustainable urban mobility with railways reshaping the region's transport landscape. Rail decarbonization emerges as a vital move, especially as the Middle East's rail networks are still nascent. This presents an opportunity to leapfrog older, carbon-intensive infrastructure—integrating electrification, renewable energy and efficient technologies from the outset.

Currently, 14 notable railway projects[23] are underway or planned in the region. These projects imply a significant commitment to enhancing rail infrastructure across the Middle East.

Rapid economic growth and urban development have been necessitating the development of modern transport infrastructure—from 2000 to 2013, Saudi Arabia had the highest CO2 emissions from transport and Qatar's emissions grew at the fastest rate in the region with a 285% increase.[24]

The Middle East's opportunity to reinvent rail networks can impact economies positively. Governments recognize public transport's broader benefits—to address pollution, congestion and safety and advance positive business cases to support future strategies.

23 Mahnoor Bahri, "Upcoming Rail Projects in the Middle East," Construction Week, December 6, 2023.

24 Overview of CO_2 emissions in the Arab Region: National versus Sectoral Emissions, United Nations Economic and Social Commission for Western Asia, December 2013.

Table 8 – Data on the Middle East market

Parameter	Data	Comment	Data year	Reference
MARKET SIZE AND OWNERSHIP				
Population of the Region/Country (million)	57.3	Across 6 GCC states: Saudi Arabia, UAE, Oman, Bahrain, Qatar, Kuwait	2021	GCC-Stat.org
Area (sqkm) of the Region/Country	2.56 million	Sum of 6 component states	2021	The World Bank
Number of total annual passenger km	>1 million	For Dubai, UAE Metro Only Insufficient Evidence for Qatar and Saudi Arabia	2023	Khaleej Times
Urban Mass transit (metro, LRT, city commuter)	Same as above			
Regional, interregional, national, High-speed	N/A			
Number of total annual freight tonnes km				
Rail Network total length (km)	7,400	Dubai Metro (Active), Dubai Tram (Active), Saudi North (Not fully operational), Saudi East, Haramain High-Speed. Etihad Rail (Not fully operational), Doha Metro, Lusail Tram		Saudi Arabia Railways Etihad Rail Based on public information from government and industry sources
Privately owned share		All projects are nationalized		
Electrification share	639	km electrified (Dubai Metro and Tram, Doha Metro and Lusail Tram, Haramain Railway, Saudi)		Saudi Arabia Railways link required
RAIL SHARE OF TRANSPORT & EMISSIONS				
Transportation sector share of total emissions	42MTCO$_{2e}$	This is only for United Arab Emirates Freight Transport: 12 MTCO$_{2e}$		The United Arab Emirates' First Long-Term Strategy

Current Actions

A look at the UAE

The United Arab Emirates (UAE) leads the Gulf Cooperation Council (GCC) in sustainability—the first GCC country to ratify the Paris Agreement, hosting COP28 and pioneering the Net Zero by 2050 Strategic Initiative, setting a precedent for others. This strategic vision aligns with the nation's recognition for urgent climate action, given future escalating climate impact projections on the Arabian Peninsula by 2040. Over 85% of the UAE's population and 90% of its infrastructure are in coastal areas, highlighting the need for climate risk mitigation.

The UAE government, a key enabler, drives decarbonization efforts in its nationwide strategies, including the UAE Long-Term 2050 Strategy among 16 other initiatives, specifically focusing on transportation and railway development. One such example is the Dubai Demand Side Management (DSM) program, aiming to reduce transport sector energy demand by 60% and emissions by 56% by 2050.[25]

The Dubai Metro has transformed urban transport since 2009, saving over 1 billion private car trips, reducing congestion, cutting 2.6 million tons of CO2 and yielding Dh115B in cumulative financial benefits.[26] As of 2019, the metro facilitated around 202,978,067 trips annually. Additionally, the metro's initiative of installing 19,968 energy-saving LED bulbs in stations and facilities saved 16.7 million kilowatts of energy within two years, reducing the carbon footprint by 7,283 tons CO2.[27]

Furthermore, the Dubai Metro incorporates advanced technologies such as the regenerative braking system, which minimizes power consumption by generating power during braking. It operates on 750-volt direct current (DC) third rail technology, supported by a 33KV network featuring a ring feeder system that feeds traction and low voltage power substations along the metro route. The Roads and Transport Authority (RTA) has also undertaken a significant project by installing solar energy panels at the metro and tram depots, contributing to the Dubai

25 The United Arab Emirates' First Long-Term Strategy (LTS), Demonstrating commitment to Net Zero by 2050, Ministry of Climate Change and the Environment, UAE, 2023, p. 32.

26 Ibid., p. 72.

27 "Dubai Metro eliminated one billion vehicle trips over 11 years," ARN News Centre, Dubai International Project Management Forum (DIPMF), January 27, 2022.

Clean Energy Strategy. This initiative is set to add a total of 9.959 megawatts of solar power to the grid, also aligning with the RTA's own plan for net-zero emissions public transport by 2050.

Etihad Rail, another major rail project in the UAE, with a planned network over 1,200 kilometres, connects major centers in the UAE. It targets a 21% annual reduction in carbon emissions by 2050, removing 8.2 million tonnes of CO2, the equivalent to taking 300 trucks off the roads per train journey. This will result in reduced congestion and maintenance costs, and align with the UAE's sustainability goals.

UAE's Modal Shift Strategy aims for a transformative shift to net-zero-carbon public transport use led by expanding metro, tram and rail services, following the avoid-shift-improve methodology.[28] Strategies include minimizing the need for travel, promoting rail transport for passengers and freight, decarbonizing existing vehicles through electrification and alternative fuels and prioritizing rail electrification.

Actions Toward 2050 and Beyond

Passenger Rail Initiatives

Shifting to rail is helping UAE tackle 21 MtCO2e GHG emissions[29] from private travel, accounting for 50% of total transport emissions and 10% of nationwide emissions in 2019. Plans include investing in 1000 km of rail infrastructure between 2025 and 2030 due to a 20% population growth by 2050; decarbonization across passenger rail, cars, taxis, buses and motorcycles, aiming for a 22% reduction in GHG emissions by 2050; and electrified cross-country passenger deployment starting in 2025, aligning with high-speed rail route activation.

Freight Rail Initiatives

Decarbonizing freight transport in the UAE involves shifting to rail and decarbonizing heavy-duty trucks and rail infrastructure to reduce significant GHG emissions from long-haul freight, amounting to 12 MtCO2e in 2019), requiring targeted actions for carbon footprint reduction. Decarbonizing freight transport aims to reduce GHG emissions in the transport sector by 27% by 2050, with expected substantial cost savings from less reliance on heavy-duty trucks, improved operational efficiency and implemented decarbonization measures.

Diesel trains will be progressively substituted by hydrogen-powered trains starting in 2025; while the electrification of freight trains is not currently being considered due to low trip frequency and long distances, this may be a possibility in the future.

Stakeholder Initiatives

The UAE recognizes the importance of engaging a diverse group of stakeholders—including government bodies and private sector organizations, NGOs, corporations, academia, civil society and the international community—to mobilize collective action toward net-zero targets.

Educational campaigns are needed to promote the advantages of passenger rail projects, particularly toward changing attitudes as many people still prefer private vehicles over public transport due to perceived convenience.

Continuing initiatives include government investment for metro, tram and rail with a program to expand public transport infrastructure, shifting transport from roads to rail, supporting sector decarbonization and easing congestion. Passenger rail planning, financing and construction has been scheduled for 2023 to early 2030s.

Efforts are underway to further support an interconnected, unified and sustainable mobility system. These include introducing last-mile options, such as autonomous EV buses, trackless trams and scooters, which aim to bridge the gap between transit hubs and final destinations, encouraging modal shifts toward sustainable travel.

Strategic partnerships with key public transport players such as municipal Metro authorities and Etihad Rail are part of the comprehensive approach under the UAE Net Zero by 2050 Strategic Initiative. Going forward, railway decarbonization and broader net-zero initiatives also align with the UAE's Centennial 2071 Strategy's four pillars—future-focused government, diversified knowledge-based economy, excellent education, and a happy and cohesive society.

In addition to understanding the urgency of rail decarbonization, rail decarbonization is also seen a strategic move to support broader sustainability goals. Unlike many developed countries with outdated rail infrastructure, the Middle East has an opportunity to develop new railway systems that embrace decarbonization from the start.

28 Mohamed Hegazy, Domenik Kohl, "Driving change: How "Avoid & Shift" targets can transform land transport, Race to Resilience, Race to Zero, December 1, 2023.

29 $MtCO_{2e}$ = metric tons of carbon dioxide-equivalent. CO_{2e} is used to measure and compare emissions from greenhouse gases based on how severely they contribute to global warming. Metrics for CO_{2e} would show how much a particular gas would contribute to global warming if it were carbon dioxide. Refer to Inspire Clean Energy.

Decarbonization Drivers

Although Middle Eastern economies have a dependence on oil and gas, there are several drivers that have been encouraging the shift toward a cleaner future.

Economic Drivers:

- Middle eastern economies are actively seeking to diversify their economies. Investing in clean energy technologies can create new industries, jobs and export opportunities.
- Many have embedded decarbonization into their long-term vision, not only to comply with global agreements, but also due to the benefits of a green economy. For example, The UAE aims to grow the economy 7% annually, doubling GDP to AED 3 trillion in line with the We the UAE 2031 vision, seeing climate action as necessary to achieve this.[30]
- This is mainly due to renewable energy sources, such as solar and wind, which have drastically reduced costs over recent years. While upfront investment does exist for electrified railway systems, operational costs can be lower than fossil fuels especially with fluctuating oil prices.

Social Drivers:

- Air quality is a major health concern in Middle Eastern cities. Transitioning to electrified rail significantly reduces air pollution and congestion in densely populated areas. This leads to improved public health and quality of life for residents.

Technological Advancements:

- While still in its early stages for trains, the Middle East is considering hydrogen fuel cell technology, which offers a promising long-term solution for long-distance routes especially for freight transport.
- Trains powered by hydrogen fuel cells can achieve ranges comparable to diesel locomotives with zero emissions.[31]
- Currently, diesel trains are expected to be progressively substituted for freight transport in the UAE, starting 2025.

30 The United Arab Emirates' First Long-Term Strategy (LTS), Demonstrating commitment to Net Zero by 2050, Ministry of Climate Change and the Environment, UAE, 2023, p. 33.

31 Luxfer Gas cylinders, Hydrogen Trains.

United Kingdom

Current State of the Railway System

Increased usage of the railway, by transferring people and goods away from road, is an urgent priority in driving down overall transport emissions in the short-term. This shift will be achieved through incentivizing the use of rail and making it an attractive transport mode for people's needs. Three areas of focus are required: an attractive price point; available capacity; and delivery of a reliable railway. Only through focus in these areas will rail become sufficiently attractive to users as a viable alternative to road.

As part of rail reform within the rail sector in the United Kingdom (UK), fares and fare structure are being reviewed and simplified. It is hoped that the simplification and standardization of fare structures will begin to attract more passengers to rail. The establishment of a growth target of a 75% increase in rail freight moved by 2050 is a key enabler to encourage modal shift of goods to rail.[32] Achieving this target has been backed by financial commitments from Government including a £90m fund to support projects to enhance freight operations and make safety improvements alongside continued provision of the Modal Shift Revenue Support (MSRS) Grant, which provides grant funding to operators when switching from road to rail. The MSRS in 2022-2023 helped remove 900,000 lorry journeys from Britain's roads, saving around 40,000 tonnes of CO2e.[33]

Network reliability needs to be improved through continued and strengthened collaborative working and direct-action planning; a culmination of incidents on routes radiating from London to the South-West, North-West and Midlands has seen Network Rail (the infrastructure manager) and train operators introduce joint performance improvement plans to provide greater confidence in reliable operations and address key areas of asset deficiency.

The way the railway in the UK is being used is changing, with a greater focus on ensuring capacity allocation is optimized based on the requirements of users.

These focus areas are enabling the railway to become an increasingly more attractive offer for passengers and freight users and receive continued financial support from the UK Government. Together they will be critical in achieving the shift to rail needed to reduce overall transport emissions.

While the overall direct emissions from rail are relatively low in the UK, attention is still required on reducing these as far as possible. With over a third of the rail network electrified and accounting for over 70% of total passenger journeys,[34] the use of electricity in rail operations is already significant. With the UK national grid progressively decarbonizing through the abolition of coal-fired power stations and the increases in renewable energy through the delivery of new solar and wind with a target to have a net-zero energy grid by 2035, rail emissions will continue to decarbonize naturally.

32 Rail Freight Growth Target, December 2023, Department of Transport, GOV.UK.

33 Carbon dioxide equivalents (CO_{2e}) are a measure of the effect of different greenhouse gases (GHGs) on the climate. By converting different emissions to the equivalent amount of carbon dioxide (CO_2), their impacts can be compared. Refer to Climate Partner.

34 Office of Rail and Road, Rail Infrastructure and Assets, GOV.UK.

There are over 300 diesel trains in operation approaching the end of their operational lives, having been introduced into service in the late 1980s and early 1990s. Decisions on the type of replacement trains will be critical to further decreasing direct rail emissions. Urgency is needed around establishing clear and credible plans for additional electrification and deployment of battery trains, with specific consideration given to battery train operations and how this technology will require a changed operational approach.

Given operational cost cutting in public-sector operators and the need for rail freight to be a commercially viable proposition for end-users, the inflated price that biofuel carries often cannot be justified; as such, its widespread deployment is likely to remain limited. Long-term government strategy calls for biofuel to be prioritized for use in sectors that are perceived to be more difficult to decarbonize such as aviation.

Hydrogen for rail operations in the UK is not likely to be play a significant role. The relatively poor energy density of hydrogen coupled with the constrained gauge envelope of the network means the ability to fit the required train-bourn equipment within the constraints is challenging without some compromise. For freight, hydrogen poses a particular problem as "fee-earning" wagons in a consist would require removal to provide "fuel-wagons" for hydrogen. This causes an unacceptable impact to the economic and commercial viability of rail freight, meaning it is unlikely to be a suitable solution. Some hydrogen rail applications could be seen on the network over the longer term, but this would require the wider hydrogen economy to grow with rail acting as a secondary or tertiary customer as part of a wider hydrogen supply chain.

It is key that the UK Government provides a clear vision for the hydrogen economy and how hydrogen will be used to support decarbonization of all sectors.

Table 9 – Data on the UK Rail market

Parameter	Data	Per capita	Data year	Reference
MARKET SIZE AND OWNERSHIP				
Population (million)	67			
Area (sqkm)	243,000	3,600 sqm		
Annual passenger km	58.6 billion	857 km	2023	Passenger rail usage | ORR Data Portal
Annual freight tonnes km	16 billion		2023	
Rail Network total length (km)	15,800		2023	
Privately owned share	minimal		2023	
Electrification share	~40%		2023	
RAIL SHARE OF TRANSPORT & EMISSIONS				
Rail share of passenger transport	2% of trips, 8% by distance, 6% by time		2023	Government Rail Statistics
Rail share of freight transport	216bn tonne-kms (total) – 175bn by road, 25bn by water, 16bn by rail (7.5%) For rail main commodities approx 1/3 intermodal, 1/3 construction, rest all others.		2022	Government Rail Statistics Government Freight Statistics
Transportation sector share of total emissions	26%		2023	Government Transport Statistics
Rail share of transport emissions	1.50%		2023	Government Transport Statistics

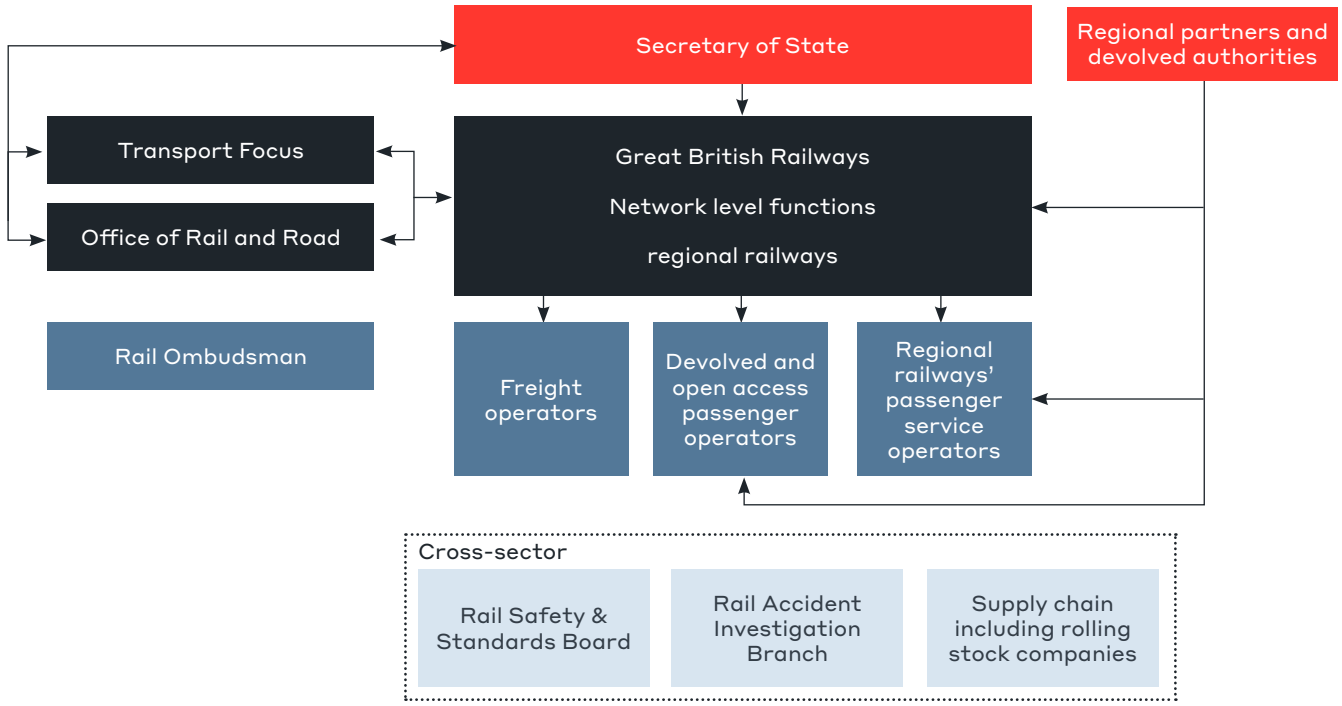


Figure 16 – Rail Sector Structure in the UK

Current Actions

Megaprojects, such as High Speed Rail 2 (HS2), are driving innovation in this area and achieving high levels of embodied carbon savings through alternative materials, design practices and construction techniques. Rail is playing an active part in initiatives such as the Industrial Deep Decarbonisation Initiative (IDDI)[35] a great example of embodied-carbon savings in action—cross-economic groups are coming together to understand how decarbonization of major materials such as steel, concrete and asphalt can be sourced in a more environmentally friendly way. Rail should continue to play a part in such initiatives and adopt principles such as low-carbon procurement as seen by Network Rail, which will begin to embed this at a point-of-use level.[36]

Network Rail's Environmental and Sustainability Strategy[37] presents a significant opportunity to change the way rail enhancements and renewals are considered. Embedding principles around climate-resilient assets, zero waste, circular economy and biodiversity enhancements is ensuring that a holistic approach to climate change and decarbonization is being considered. Tying this strategy to business planning, infrastructure renewals and future procurement of all types of work and services is beginning to bear fruit; driving and embedding these principles over the coming years will be essential to delivering challenging emissions reductions targets for both direct and indirect emissions.

Recommended Actions Toward 2050 and Beyond

The rail network needs to be continually optimized and capacity increased to allow ongoing modal shift of people and goods. To drive optimized transport-emissions efficiency, it is important that the right modes of transport are used for the right movements with focus provided on the relevant modes, playing to their strengths. Only by adopting this approach can emissions from the transport system as a whole be optimized. Achieving such a modal balance will require a cultural shift as well as definition and planning of the transport and logistics system in a coordinated manner across all modes.

Planning multiple modes of transport to coincide and integrate with each other enables end-to-end journeys to be optimized from both a time and emissions perspective. Whole transport system planning is a major stumbling block in allowing this to be achieved, with both governmental department structures and individual transport modes being siloed in their approach. Considering the benefits of cross-modal planning—and making this a reality—can drive significant benefits for both transport users and overall system costs and emissions in the long-term.

35 Industrial Deep Decarbonisation, United Nations Development Organization.

36 Our ambition for a low-emission railway, Network Rail.

37 Environmental Sustainability Strategy, Network Rail.

Achieving long-term direct emissions reduction and the legislative target of net-zero emissions by 2050 will require expansion of the electrified rail network and more extensive deployment of battery trains. Delivering the large volume of electrification required to support the decarbonization of rail freight and intensively used areas of the passenger network will require significant capital investment. The Traction Decarbonisation Network Strategy[38] suggested that up to £50bn (2020 prices) could be required to support almost total removal of direct rail traction emissions. This is clearly an exceptionally large capital commitment even when spread over a 25-year period and as a result is unlikely to be either affordable or viable for the UK Government to provide. Despite this, there is a clear need for the UK Government to provide funding to continue to develop and deliver some electrification schemes across the rail network. With commitments made as part of the Integrated Rail Plan for the North and Midlands (IRPMN) and Network North (NN), several potential future electrification schemes are beginning to emerge and be developed. Clarity and confirmation of funding for these schemes are needed, and the industry should work collaboratively to drive down unit rates for electrification delivery as far as possible.

It is imperative that rail continues to retain close working relationships with other economic sectors through initiatives, such as the Faraday Institution,[39] to ensure that learning and advancements can be directly transferred into rail to support enhanced operations.

It will be critical to optimize carbon planning to include considerations around ongoing maintenance and ultimately decommissioning. Work undertaken on Birmingham Curzon Street station, being developed as part of HS2, is ensuring that station operations are net zero from day one. Furthermore, the station is being designed for future flexibility such as alternative uses and ultimately being designed to minimize carbon emissions during deconstruction in the long-term future. These efforts have shown how low-carbon approaches could reduce total emissions by over 50% compared with conventional design approaches. The application of key initiatives such as the PAS 2080 accreditation, which demonstrates competency in managing whole-life carbon, will become increasingly critical to future infrastructure projects and will continue to drive emissions-reduction-focused design.

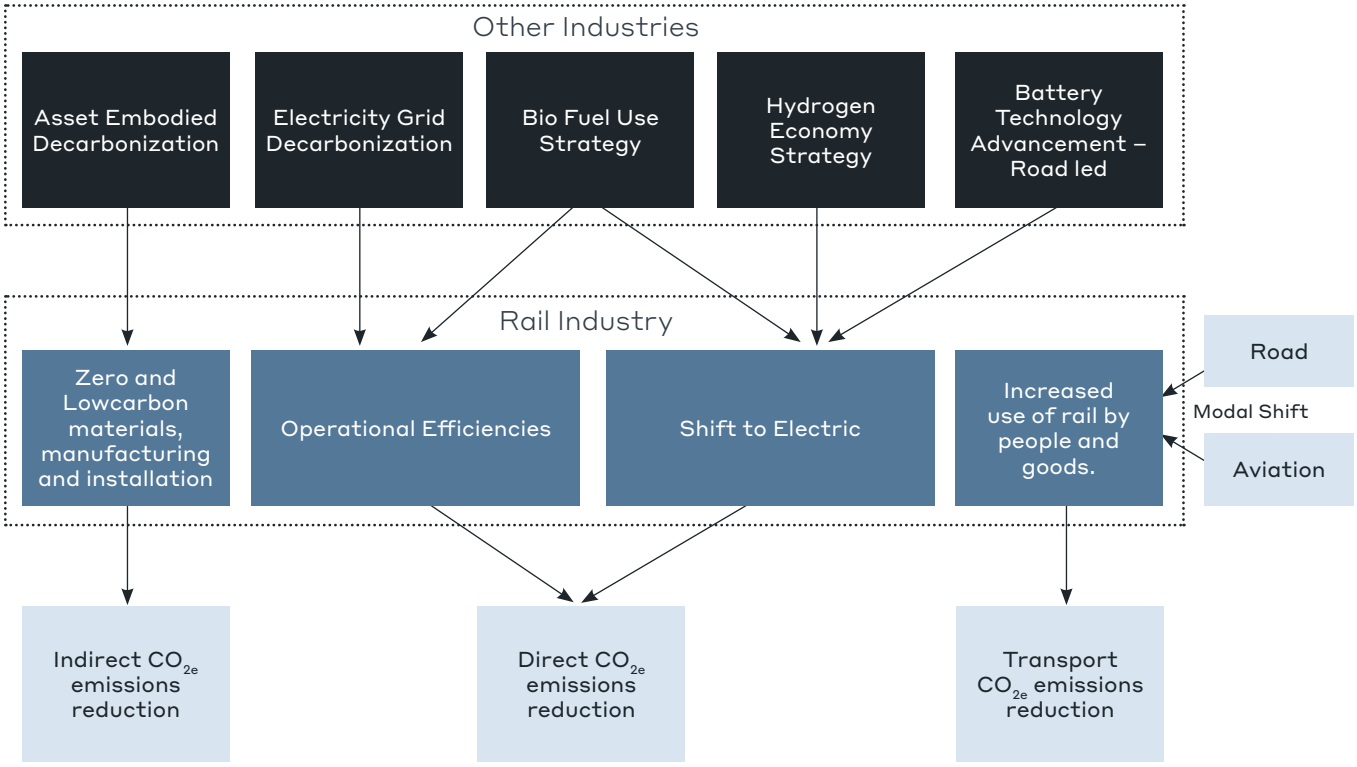


Figure 17 – Illustration of principal emissions-reduction measures for the rail industry and how rail can contribute to reducing emissions from the transport sector as a whole.

38 Traction Decarbonisation Network Strategy, July 31, 2020.

39 The Faraday Institution – Powering Britain's Battery Revolution.

United States

Current State of the Railway System

Rail is one element of the large transportation system in the United States (US). Rail carries a small percentage of intercity passenger trips but is more dominant for local travel in larger cities. Rail has a much higher mode share of US freight, carrying 29% of all ton-miles moved in 2022; rail's share of freight volume has been relatively constant for 40 years but has declined slightly from its recent peak in the early 2000s.

Private freight operators own the vast majority of rail infrastructure in the US—over 158,000 miles of track, 23,500 locomotives and almost 276,000 freight cars. There are over 600 private rail companies in the US that own right-of-way and locomotives, but the industry is dominated by the seven largest companies which account for two thirds of freight mileage. As in Canada, diesel traction is by far the most predominant power mode for freight rail.

There is only one major intercity rail passenger company, Amtrak, which operates almost 400 locomotives and over 1,300 passenger cars along 21,000 system route miles that span the country. Most Amtrak routes operate on right-of-way that is owned and operated by private freight rail companies. Amtrak's busy Northeast Corridor route from Boston to Washington DC uses electric locomotives powered by catenary; all other operations use diesel locomotives.

Within the largest metropolitan areas, there are 15 heavy-rail systems (at grade and subway) and 23 light-rail systems (at grade), all of which are electrified. Together these systems operate almost 800 million car miles and over 11 billion passenger miles annually. There are also 30 commuter rail systems in the US, which typically operate between major cities and their suburbs, either on dedicated tracks or tracks owned by freight operators. All of these systems use diesel locomotives to operate almost 350 million car miles and 9.8 billion passenger miles annually.

While they only represent a small percentage of the whole transportation solution, public passenger rail agencies are leading the efforts to decarbonize and reduce the carbon footprint of the transportation system as a whole.

Table 10 – Data on the US Rail market

Parameter	Data	Comment	Per capita		Reference
MARKET SIZE AND OWNERSHIP					
Population (million)	331			2020	US Census Bureau
Area (sqkm)	10 million	3.8 million square miles	30,000 sqm	N/A	US Census Bureau
Annual passenger km	9,500 million	5,930 billion passenger miles approximately 8% below pre-pandemic levels	28.6	2021	US Bureau of Labor and Statistics
Urban Mass transit	28 billion	Main operators: Metro – NYC Transit, Washington WMATA, Chicago CTA, Boston MBTA. Light Rail – San Diego MTS, Los Angeles MTA. Commuter Rail – NY MTA LIRR, MY MTA MNR, New Jersey NJT, Chicago Metro		2022	US Bureau of Labor and Statistics APTA2023 Q4 Ridership Report
Regional, interregional, national, High-speed	8 billion	Main operator Amtrak		2022	US Bureau of Labor and Statistics
Annual billion freight tonnes km	2,500	Class 1 Freight Operators: BNSF Railway, Canadian National Railway, Canadian Pacific Kansas City, CSX Transportation, Norfolk Southern Railway, Union Pacific Railroad		2022	Bureau of Transportation Statistics
Rail Network total length (km)	294,000	Majority owned and operated by private freight companies		2014	CIA.gov
Privately owned share	96%	Class 1 Freight Operators: BNSF Railway. Canadian National Railway, Canadian Pacific Kansas City, CSX Transportation, Norfolk Southern Railway, Union Pacific Railroad		2024	AAR.org
Electrification share	0.44%	82km of electrified rail just completed by Caltrain in California.			
RAIL SHARE OF TRANSPORT & EMISSIONS					
Rail share of passenger transport	0.25%	2021 is latest data. Prior to pandemic, levels were around 0.61%		2021	US Bureau of Labor and Statistics
	N/A				
Rail share of freight transport	29%			2021	Bureau of Transportation Statistics
Transportation sector share of total GHG emissions	29%			2022	US Environmental Protection Agency
Rail share of transport GHG emissions	2%			2024	US DOT Federal Railroad Administration
Freight share of rail GHG emissions	86%			2024	AAR.org

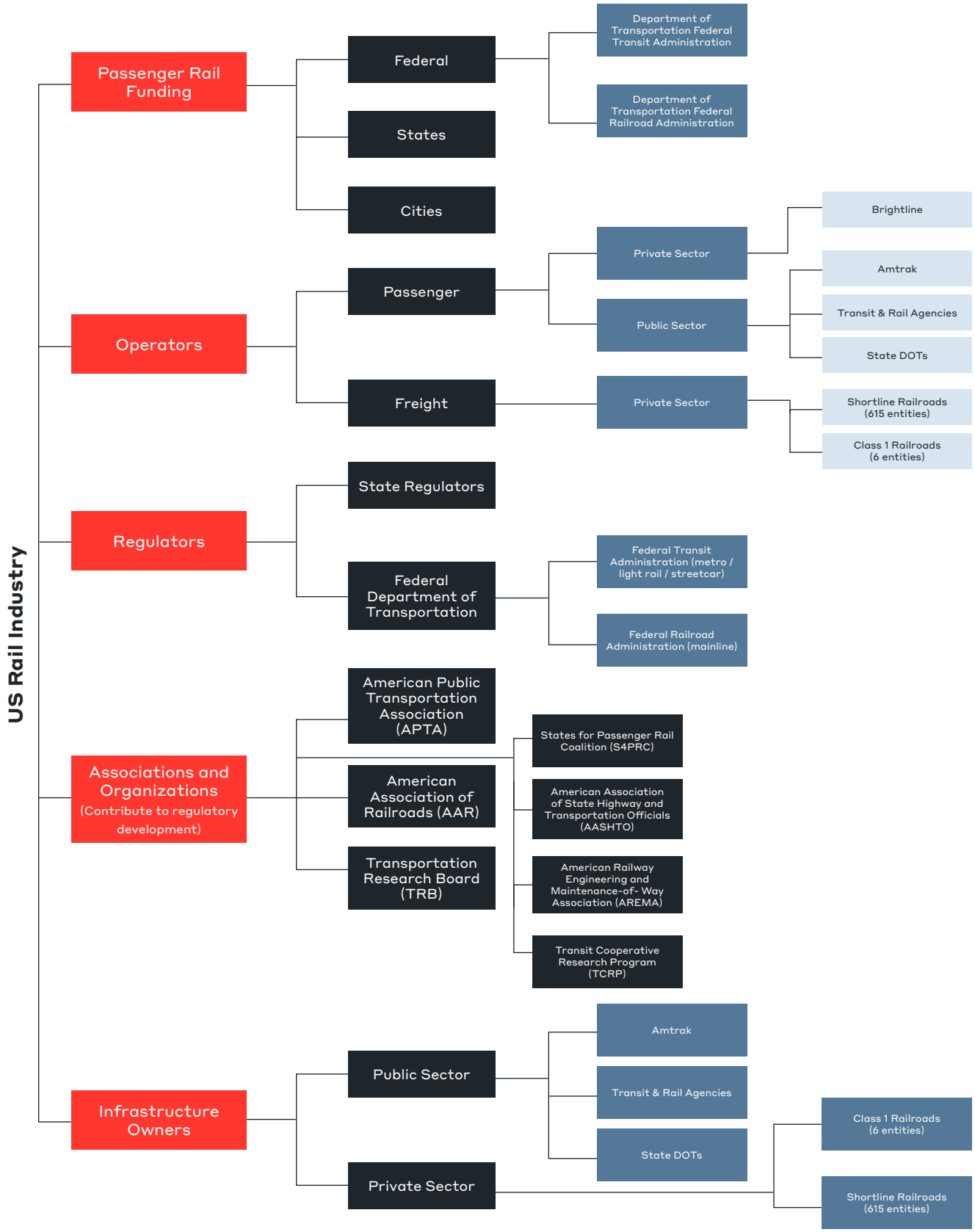


Figure 18 – Rail Sector Structure in the US

Current Actions

Regulation and Policy

Zero-emissions propulsion technology associated with battery-electric or hydrogen-electric solutions are still considered emerging technologies at the power and range levels needed for much of passenger and freight rail in the US; therefore, economic business cases remain challenging to demonstrate viability. Technology advancements and increased access to hydrogen through national strategic hydrogen hubs are expected to improve business cases in the coming decade.

Regulatory change is therefore currently the primary driver of improvement across the United States. These are already driving improvements in the environmental performance of rail. Significant improvements have been achieved in the past two decades. In 2004, the Federal Environmental Protection Agency issued the requirement that by 2015 Tier 4 diesel engines were to be mandated for new and rebuilt engines. These engines are designed to reduce particulate and NOX emissions.

At state and agency levels, regulatory and policy changes are also driving reduction in carbon emissions. California, for example, through the California Air Resources Board, has prescribed increasing use of Tier 4 diesel engines.

State policy in California has also focused on economic levers. Carbon credits tied to renewable diesel usage as well as increased fossil fuel tariffs have led to the following result: over 20% of the diesel fuels used are reduced-carbon-footprint fuels such as HRD (Hydro-renewable diesel).

Agency-level policy shift is also driving decarbonization. Agencies such as Massachusetts Bay Area Transportation Authority (MBTA) have stated at board level that they will no longer purchase diesel traction power; MBTA's Rail Vision Plan outlines an electrified future augmented with battery-electric vehicle solutions.

Investment

The Bipartisan Infrastructure Law (BIL), signed into law in 2021, provides significant levels of federal investment in all areas of national infrastructure—including unprecedented levels for rail and transit.[40]

The main areas of focus for BIL are expansion of conventional and high-speed rail and state-of-good-repair investments for passenger rail to improve the viability of rail and transit solutions in comparison to other modes.

Higher frequency, all-day solutions for local mainline passenger rail are progressing in states such as Massachusetts and Utah. In Utah, the state Department of Transportation is advancing double tracking of the Frontrunner rail alignment to allow higher frequency service.

High speed rail programs in California, Nevada, Texas and the Pacific Northwest are also securing significant funding to develop complementary transportation solutions to current highway and air-based options. For California High Speed Rail, the electrical power is planned to be fully derived from renewable sources.

Perhaps the biggest rail recipient of funding under BIL is the Northeast Corridor with multiple megaprojects designed to improve the resilience and performance of the busiest passenger rail corridor in the Unites States. Investments are delivering new tunnels and bridges along the route, including some new alignment, to help increase capacity and reduce journey times.

Pilot Programs

With respect to battery-electric and hydrogen rail vehicles, a small number of orders are starting to be placed in the United States. San Bernardino County Transportation Authority in California is procuring a FLIRT-H2 Hydrogen Multiple Unit from Stadler US; the same technology is currently undergoing testing in Colorado. In March 2024, this train set a new world record for range for a hydrogen-powered rail vehicle at over 1,700 miles. Such demonstration pilot programs will help establish operating and maintenance practices and parameters and advance the technology to allow other agencies to adopt similar solutions with a better understanding of system requirements, needs and risks.

Toward 2050 and Beyond

Federal, state and local government policy is expected to remain the driving force for decarbonization of rail until technology advances shift the business case balance toward zero- and low-carbon solutions.

Through increased adoption of decarbonization technology, it is expected that both supply and demand will exponentially increase over the coming decade, accelerating the achievement of the business case balance point.

Increasingly agencies and authorities are understanding the value of their linear assets to the transportation system. This is leading to more plans for higher asset utilization, with increased traffic density providing passengers with higher-frequency options, enhancing rail as a more viable alternative.

40 Federal Road Administration, U.S. Department of Transportation.

Conclusion

The generic steps summarized earlier in this article (Figure 3) are globally applicable, though priorities and sequences may vary based on regional starting points and on specific stakeholder needs.

The detailed analysis of the rail decarbonization trends for each country/region shows some similarities for jurisdictions with comparable geographical size, structure of the rail freight market, legal background and financial situation.

After close examination of the state of rail decarbonization in areas around the world, some key actions emerge from a geographical tapestry of opportunities and challenges. The conclusions below are aggregated in geographical groups where common decarbonization strategies could be implemented.

Regional Insights

- **Africa, Latin America and the Middle East:** We see opportunity to develop low-carbon rail from the start of emerging rail systems, with financial constraints and political challenges impeding progress in the former two regions. Investment in electrified mass transit and new onboard propulsion technologies offer substantial economic and decarbonization benefits.
- **Asia:** Many Asian countries already have high percentages of electrified railways, presenting opportunities for further electrification in smaller nations. There is a strong potential for economic and decarbonization gains through prioritizing investment in electrified mass transit rail and long-distance networks using new onboard propulsion technologies.
- **Europe:** The rail system, with varying levels of low-carbon energy usage, reflects its position as the cradle for the global rail industry, playing a crucial role in (decarbonization) technology development. However, low rail modal share combined with interoperability issues across borders, due to differing technical standards and political commitment, pose challenges for rail to take a lead in transport emission reductions. European emphasis is placed on shifting transportation to rail, and in some countries, transitioning to low-carbon electricity. New low-carbon onboard technologies are already playing a role in furthering operational decarbonization of the sector, leading the way for decarbonization of lines where electrification is not a viable option.
- **Australia and Canada:** Both countries face challenges with vast, sparsely populated areas where diesel rail freight dominates and carries massive volumes on privately owned non-electrified networks. Existing net-zero solutions for the countries' heaviest emitting freight railways are widely regarded as being too immature or uneconomical for immediate implementation. In these regions (as is the case in the US and New Zealand), the purchase and operation of new, more efficient diesel rolling stock is driving CO_2 reduction for freight. Passenger rail is focused on partly electrified, publicly owned mass transit in major cities. In Australia and Canada, urban transport is mostly electrified, and in Australia the focus is on grid decarbonization for both state and small-scale private initiatives. In Canada, continued expansion of electrified light rail networks depends on partnerships between public, private and academic entities for further decarbonization of the rail network.
- **The United States and the United Kingdom:** In the US, the Bipartisan Infrastructure Law (passed in 2021) fosters significant investment in rail and transit, including high-speed passenger rail. The US is also promoting public-private partnerships to develop green hydrogen production, distribution, storage and usage, which will also improve public and private business cases. The US and the UK landscapes demonstrate the value of policy- and regulatory-driven change implemented jointly with the rail industry. Megaprojects in the United Kingdom show that it is possible to achieve high levels of embodied carbon savings through alternative materials, design practices and construction techniques that have been developed in cross-sector collaboration. The co-led (United Kingdom and India) Industrial Deep Decarbonization Initiative demonstrates the power of a global coalition of public and private entities to stimulate demand for low-carbon industrial materials.

Common Strategies

Formal partnerships and informal collaborations are key to accelerating collective support from rail stakeholders to bring the benefits of new technologies to emerging and expanding rail systems. Formal partnerships, working alongside and with governments, can accelerate change through material use, technology adoption, innovative funding and expansion of electrified rail networks. Informal collaborations facilitate knowledge sharing to reduce scope 1-3 emissions. Building a powerful coalition through such efforts is a key element of our envisioned change model for expediting transport decarbonization.

Applying and integrating the PAS 2080 framework will enable rail stakeholders to fully understand the responsibilities of all members of the value chain through a whole-life approach to carbon reduction, using the ecosystem perspective.

Clear and bold government policy must continue to drive decarbonization until technology advancements shift the business case toward low-carbon solutions. With a cost placed on carbon emissions, many alternatives become viable for reducing *embodied carbon*—which dominates rail emissions—in major materials, such as concrete and steel; in addition, using recycled materials rather than manufacturing anew becomes an attractive option.

Artificial intelligence can come into play for optimizing routes to minimize carbon and for improving new construction techniques. Reductions in *operational emissions* can similarly be brought about through policy and incentivized through carbon pricing—e.g. new low-carbon onboard energy systems, energy management systems and operational efficiency. Finally, network optimization, capacity increase and improving multimodal transport through whole transport system planning can lead to higher utilization of already built assets.

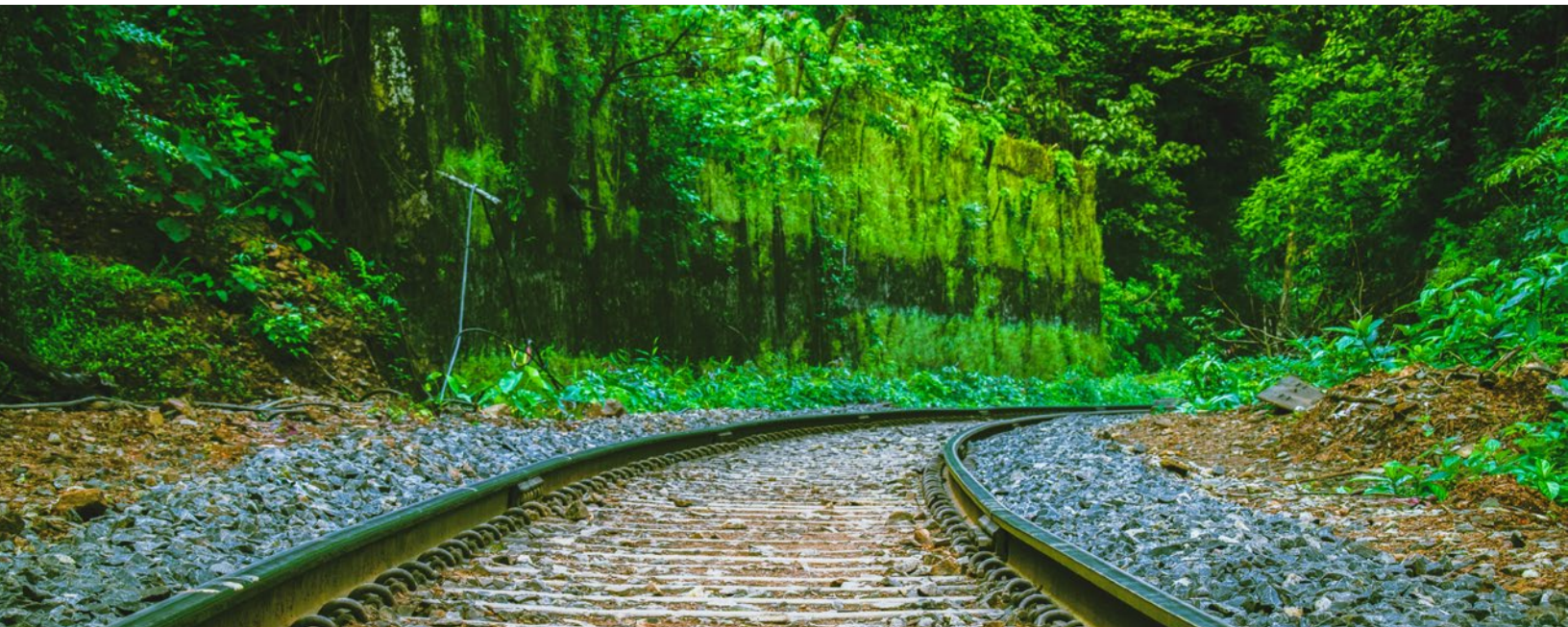
An ecosystem perspective, explored in the first article in the decarbonization series, opens up rail decarbonization opportunities—making the best impact depends on collaboration with other sectors and business areas, such as urban planning, new materials and low-carbon electricity production; collaboration is also essential to foster a multimodal transport system with sustainable last-mile options, such as EV buses and trucks, trackless trams and scooters.

Even with other modes of transportation decarbonizing, rail is inherently energy efficient, space efficient and can carry large loads over great distances at high speed. That is why rail can play a significant role in decarbonizing the transportation sector as a whole, short term and over the long term, and why a higher rail share of transportation should be prioritized. The latter can be achieved through incentive pricing and fare structures as well as increased capacity and by providing reliable railway services that are accessible to all people who want to use them.

Climate-resilient railways will be imperative going forward, as even with the best efforts, current global warming trajectories indicate that the world will fail to meet the targets that are necessary to avoid further floods, droughts and wildfires.

Coming Focus

Upcoming pieces will explore strategies for ensuring climate-resilient railways and share best practices, methods and tools developed through our rail decarbonization efforts.



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