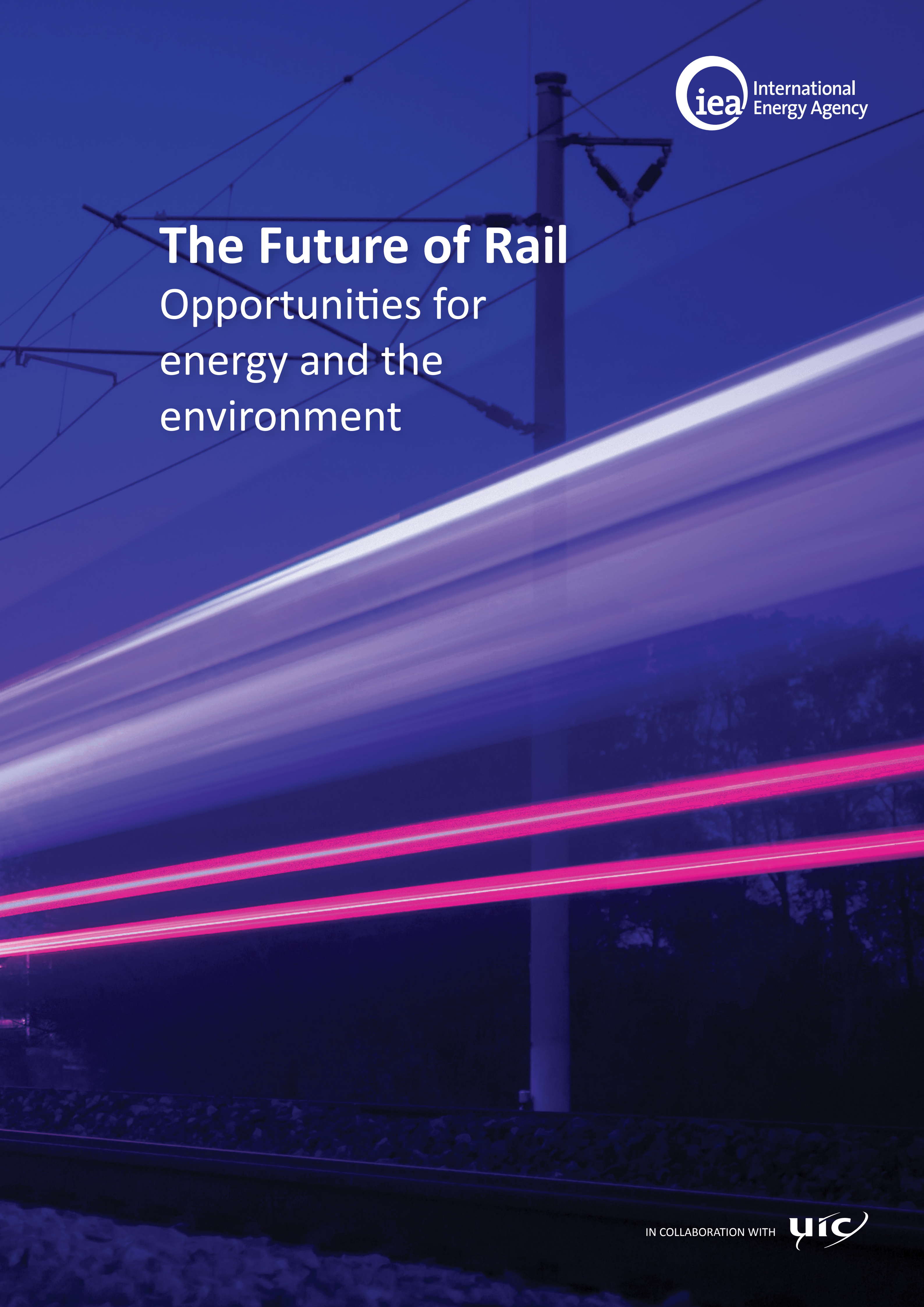

International Energy Agency

# The Future of Rail

## Opportunities for energy and the environment

IN COLLABORATION WITH UIC

# The Future of Rail

Opportunities for energy and the environment

# INTERNATIONAL ENERGY AGENCY

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# Foreword

Rail transport is often neglected in public debates about future transport systems. Maybe this is because rail transport dates back centuries and helped fuel the industrial revolution. And yet, despite the advent of cars and airplanes, rail of all types has continued to evolve and thrive.



In cities, metros and light rail offer reliable, affordable and fast alternatives to road transport, reducing congestion as well as local pollutant and greenhouse gas emissions. High-speed rail provides a high-quality substitute for short-distance flights between major urban centres. Freight rail offers a low-emissions and low-cost linkage in freight supply chains.

From an energy and emissions perspective, rail is also among the most energy-efficient and lowest-emitting transport modes. Despite the traffic it carries, rail consumes only 2% of total transport energy demand. Rail is also the transport sector that is most electrified: three-quarters of passenger movements and half of freight rely on electricity.

Urbanisation and digitalisation, among other megatrends, may redefine how energy is used in transport in the future. Rail has the opportunity to play an important role if it can leverage its unmatched advantages in moving people and goods along heavily utilised, high-demand routes. In doing so, it can provide substantial benefits for energy and the environment – by diversifying energy sources and providing more efficient mobility, rail can lower transport energy use and reduce carbon dioxide and local pollutant emissions. Rail's benefits extend to economic and social realms: if well designed and operated, in the right contexts rail systems can be very competitive on the most important mobility service metrics: speed, convenience, reliability and price.

The report puts a particular focus on India, a country that joined the IEA family in 2017. India's achievements in the energy sector in recent years have been remarkable, including successfully bringing electricity to all the country's villages and ramping up renewables deployment, demonstrating India's commitment to advancing the critical role of energy for society and development.

I would like to extend my gratitude to India's Minister of Railways, Piyush Goyal, and other partners in India for their contributions to ensuring that this report contributes relevant, concrete and actionable analysis on India's ambitious railway plans. This report elaborates on the unique social and economic role of rail in India, where rail is sometimes referred to as the "lifeline of the nation".

This report was prepared by the IEA in collaboration with many partners and experts, in particular the International Union of Railways. Importantly, it is the fourth in our series looking at what we see as the "blind spots" in global energy: segments of energy demand that deserve greater attention from policy makers. Previous studies in the series have focused on energy use in petrochemicals, air-conditioning and trucks. Given the scale of the environmental challenge and opportunities for social development of the global transport sector, and its important role for energy use, I sincerely hope that this report will provide meaningful input to the global debate.

**Dr. Fatih Birol**

**Executive Director**

**International Energy Agency**

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The agenda, presentations and the summary of the workshop are available at: www.iea.org/workshops/global-rail-and-energy-workshop.html.

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# Executive summary

**Rail has a long-standing position as one of the pillars of passenger mobility and freight transport.** Today, conventional rail provides nearly one-sixth of the world's long-distance passenger travel around and between cities. High-speed rail provides a high quality substitute to short-distance intracontinental flights. In cities, metros and light rail offer reliable, affordable and fast alternatives to road travel, reducing congestion and carbon dioxide ($CO_2$) emissions and local pollution. Freight rail enables high capacity goods movements over very long distances, allowing access to trade for resources that otherwise would likely be stranded and facilitating operation of major industrial clusters.

**Rail is among the most efficient and lowest emitting modes of transport**. **With a strong reliance on electricity, it is also the most energy diverse.** Rail networks carry 8% of the world's motorised passenger movements and 7% of freight transport, but account for only 2% of energy use in the transport sector. Rail services consume less than 0.6 million barrels per day (mb/d) of oil (about 0.6% of global oil use) and around 290 terawatt-hours (TWh) of electricity (more than 1% of global electricity use). They are responsible for about 0.3% of direct $CO_2$ emissions from fossil fuel combustion and the same share (0.3%) of energy-related emissions of fine particulate matter ($PM_{2.5}$). The high efficiency of train operations means that rail saves more oil than it consumes and more emissions than it generates. If all services currently performed by railways were carried by road vehicles, such as cars and trucks, then the world's transport-related oil consumption would be 8 mb/d (15%) higher and transport-related greenhouse gas (GHG) emissions would increase by 1.2 gigatonnes (Gt) $CO_2$-equivalent ($CO_2$-eq) on a well-to-wheel basis.

**Most rail networks today are located in India, the People's Republic of China, Japan, Europe, North America and the Russian Federation, while metro and light rail networks operate in most of the world's major cities.** About 90% of global passenger movements on conventional rail take place in these countries and regions, with India leading at 39%, followed by the People's Republic of China ("China") (27%), Japan (11%) and the European Union (9%). Globally, about three-quarters of conventional passenger rail activity use electricity, and the remaining quarter relies on diesel. Significant investments have been made in high-speed rail and metros, most notably in China, which has overtaken all other countries in terms of network length of both types within a single decade. Today China accounts for about two-thirds of high-speed rail activity, having overtaken both Japan (17%) and the European Union (12%). The regional distribution of urban rail activity is more even; China, European Union and Japan each have around one-fifth of urban passenger rail activity. Both high-speed and urban rail are entirely powered by electricity. Freight movements are concentrated in China and the United States, each of which accounts for about one-quarter of global rail freight activity, and the Russian Federation ("Russia"), which accounts for one-fifth. Despite the fact that electrification of freight rail faces greater challenges than other rail types, half of global freight movements rely on electricity.

**The future of rail will be determined by how it responds to both rising transport demand and rising pressure from competing transport modes.** Rising incomes and populations in developing and emerging economies lead to strong demand for mobility, but social considerations and the need for speed and flexibility tend to favour car ownership and air travel. Rising incomes also drive demand growth in freight, where higher incomes, together with digital technologies, have sharply increased demand for rapid delivery of higher value and lighter goods. The rail sector has important advantages to exploit in competing for business, but this will require additional strategic investments in rail infrastructure, further efforts to improve its commercial competitiveness and technological innovation.

**In the Base Scenario, annual investment in rail infrastructure increases to USD 315 billion (United States dollars) in 2050, on the basis of projects currently in various stages of construction and planning.** In this scenario, which assumes no significant new emphasis on rail in policy making, the pace of infrastructure build is fastest in urban rail. The length of metro lines under construction or slated for construction over the coming five years is twice the length of those built over any five-year period between 1970 and 2015. The result is unprecedented growth in passenger movements on urban rail; global activity in 2050 is 2.7 times higher than current levels. Growth is strongest in India and Southeast Asia, which see more than a sevenfold growth in passenger movements on urban rail, albeit from a low baseline. In the three countries with the highest urban rail activity today, activity increases by more than threefold in China, 25% in Japan and 45% in the European Union.

**The Base Scenario also sees strong growth in high-speed rail networks, particularly over the coming decade.** As has been the case over the past decade, China accounts for a large share of high-speed rail developments; nearly half of those projects undertaken between now and 2050 are in China. The result is strong activity growth on high-speed rail: passenger movements in China increase more than threefold, while those in Japan increase by 85% and by 66% in the European Union. Construction of non-urban rail infrastructure in India is particularly notable, supporting volumes of passenger activity that, by 2050, are unparalleled anywhere in the world. However, despite impressive global growth, rail does no more worldwide than maintain its current share in activity relative to personal cars and passenger air travel by 2050. Global freight activity across all categories nearly triples in 2050 from 2017 levels.

**Strong growth of rail activity in the Base Scenario brings up rail energy demand: by 2050 rail electricity use reaches nearly 700 TWh**. By 2050, 97% of passenger rail movements and two-thirds of freight take place on electrified rail, meaning that rail remains far and away the most electrified of all transport modes. Rail's energy use, however, pales in comparison with the energy it saves by diverting traffic from other modes. In 2050, if all rail services were performed by cars and trucks, oil demand would be 9.5 mb/d higher (or 16%) higher than in the Base Scenario. GHG emissions from transport would increase by 1.8 Gt $CO_2$-eq (or 13%) above the Base Scenario in 2050. Fine particulate matter ($PM_{2.5}$) emissions would rise by 340 kilotonnes (kt).

**The High Rail Scenario explores how these benefits might be further capitalised.** The scenario rests on three pillars: *Minimising costs per passenger-kilometre or tonne-kilometre moved* by ensuring maximum rail network usage, removing technical barriers and integrating rail services seamlessly into the portfolio of available mobility options. *Maximising revenues from rail systems*, such as through "land value capture", i.e. capitalising on the "aggregation" capacity of railway stations whereby commercial and residential properties in their proximity increase in value due to improved mobility options and greater activity, and using this value to finance rail systems. And *implementing policies that ensure that all forms of transport pay adequately for the impacts they generate.* Traditionally this has been accomplished through fuel taxes, but road pricing, and especially congestion charging, may be effective going forward.

**In the High Rail Scenario, global passenger activity on rail grows to a level that is 60% higher than in the Base Scenario in 2050, and freight activity is 14% higher.** Urban rail has the greatest potential for additional growth: activity on metros and light rail in 2050 is 2.6 times higher than in the Base Scenario, concentrated in densely populated cities in China, India and Southeast Asia. The High Rail Scenario also captures the potential for high-speed rail to provide a reliable, convenient and price competitive alternative to short-distance intracontinental passenger air services. Activity on high-speed rail in the High Rail Scenario is 85% higher than in the Base Scenario, reflecting strategic investments in this mode.

**Aggressive, strategic deployment of rail can lead $CO_2$ emissions in global transport to peak in the late 2030s.** By 2050, oil use in the High Rail Scenario is more than 10 mb/d lower than in the Base Scenario. GHG emissions are 0.6 Gt $CO_2$-eq lower and $PM_{2.5}$ emissions are reduced by about 220 kt, the latter primarily as a result of diminished aggregate vehicle kilometres by cars and trucks. Primarily as a result of increased urban and high-speed rail operations, electricity use by rail in 2050 is 360 TWh higher than in the Base Scenario, 50% more than in the Base Scenario, an increase that is roughly equal to the current total electricity consumption of Thailand and Viet Nam combined.

**Annual average investment in the High Rail Scenario in trains and rail infrastructure combined is USD 770 billion, a 60% increase over investment in the Base Scenario.** The biggest part of the increased investment goes to infrastructure for urban rail (nearly USD 190 billion) and high-speed rail (USD 70 billion); the additional costs of the trains are small in comparison. As a result of these investments, in 2050 fuel expenditures are reduced by around USD 450 billion, relative to the Base Scenario. India could save as much as USD 64 billion on fuel expenditures by mid-century.

**Rail activity in India – a special focus in this report – is set to grow more than any other country, with passenger movements in India reaching 40% of global activity.** Activity in India is already among the highest in the world, being second only to China for passenger movements and fourth for freight movements. Rail remains the primary transport mode in India connecting numerous cities and regions. Indian Railways is also the country's largest employer. As a result, the railway network in India is sometimes referred to as the lifeline of the nation. Guaranteeing affordable passenger mobility by rail to the entire population has always been a priority in India. Today rail passengers in India travel 1.2 trillion kilometres, more than the distance travelled by cars; and about one-third of total surface freight volumes are transported by rail, a very high share by global standards. By far, coal is the predominant commodity carried on freight trains today in India.

**Indian Railways is spearheading a wide range of ambitious undertakings.** Construction has started on the first high-speed rail line. The total length of metro lines is planned to more than triple in the next few years. Two dedicated freight corridors are planned to enter operation in 2020. The country is set to double, or possibly even triple, existing capacity on the most utilised rail routes, and it aims to electrify the entire broad gauge network by 2022. With these and other measures realised in the Base Scenario, rail passenger movements almost triple and freight movements more than double over current levels by 2050. Electricity consumption from rail operations increases by nearly a factor of six, reaching almost 100 TWh. Electrification of highly utilised corridors leads to reductions in oil use by rail to less than 10% of current levels, reaching 3 000 barrels per day in 2050. As in other countries, rail in India saves more energy and emissions than it consumes: in the Base Scenario, rail activity in 2050 reduces oil demand by 1.6 mb/d, GHG emissions by 270 Mt $CO_2$-eq and $PM_{2.5}$ emissions by 8 kt.

**Going beyond the targets captured in the Base Scenario, India has the potential to serve as an example to other emerging economies.** In the High Rail Scenario, India further increases investment in railways, commissioning high-speed rail lines to connect every major city along the "Golden Quadrilateral", achieves the target of doubling the share of rail in urban areas by 2050 and constructs dedicated freight corridors to connect all the largest freight hubs. Shifts in transport activity from road modes and aviation lead to additional savings in oil consumption of 1.5 mb/d, compared to the Base Scenario, and to an additional reduction in GHG emissions of 315 Mt $CO_2$-eq and 6 kt of $PM_{2.5}$.

**Two categories – urban and high-speed rail – hold major promise to unlock substantial benefits both in India and throughout the world.** In an era of rapid urbanisation, urban rail systems can provide a reliable, affordable, attractive and fast alternative to travel by road: metro and light rail can reduce congestion, increase throughput on the most heavily trafficked corridors and reduce local pollutant and GHG emissions. With co-ordinated planning, urban rail systems increase the attractiveness of high-density districts and boost their overall economic output, equality, safety, resilience and vitality of metropolises. High-speed rail can provide a high quality substitute for short-distance intracontinental flights. As incomes rise, demand for passenger aviation, a mode of transport that is extremely difficult and expensive to decarbonise, will continue to grow rapidly. If designed with comfort and reliability as key performance criteria, high-speed rail can provide an attractive, low-emissions substitute to flying.

# Introduction

## Purpose and scope



On a worldwide basis, the transport sector today is responsible for almost one-third of final energy demand and nearly two-thirds oil demand. It is also responsible for nearly one-quarter of global carbon dioxide ($CO_2$) emissions from fuel combustion and is a major contributor to air pollution, particularly in urban areas. Changes in transportation fuel use are, therefore, fundamental to achieving a global energy transition, which will guarantee energy security, alleviate air pollution and mitigate climate change. The challenge is heightened by the rapid pace of rising demand for mobility, especially in developing economies, where cities are growing exponentially, creating a need for more efficient, faster and cleaner transportation. Rail has characteristics that enable it to reduce energy demand in transport and draw on diverse energy sources. It can mitigate $CO_2$ emissions from transport and contribute to a broader transition towards sustainability. Its particular strengths are: energy efficiency (on average, trains are close to 12-times more energy efficient than road and air travel in terms of final energy per passenger transported and 8-times more efficient than trucks per tonne of freight carried); its reliance on very diverse energy sources; and its contribution to reducing congestion on road networks. Rail provides mobility with minimal emissions of harmful air pollutants and, thanks to agglomeration effects, facilitates economic growth.

Rail today serves passenger and freight mobility needs in countries across the globe. In 2016, rail services were an important component of passenger mobility in People's Republic of China ("China"), India, Japan, European Union and Russian Federation ("Russia"), and provided a significant fraction of all goods movements in North America, China, Russia and India. Globally, rail constituted 8% of passenger transport and 7% of freight movements in 2016. Rail accounted for less than 2% of transport energy, far less than the sector's share of transport activity. The reasons are multiple: the large carrying capacity of trains, compared to other modes; the high efficiency of electric motors; and the efficiency of fuel use resulting from the very low resistance offered by the steel-to-steel interface between wheels and tracks. With roughly one-third of its global energy consumed in the form of electricity, rail is also currently the only transport mode that does not rely almost exclusively on oil. The share of electricity in rail energy use exceeds 70% in major economies, such as China and the European Union. In Japan, this share is more than 90%.

In highly populated "megacities", many of which are in Asia (with more yet to be built), urban rail (metro and light rail) plays a critical role in large-scale passenger movements. This form of rail travel diversifies the transport energy mix, reduces local air pollution, alleviates congestion and improves overall productivity. But there are also limiting factors. Because of its capital-intensive nature, urban rail requires very high throughput in order to achieve its environmental and economic goals.

This report examines how the role of rail in global transport might be elevated as a means to reduce the energy use and environmental impacts of transport services. It explores plausible scenarios to 2050 in which such an enhanced role is achieved, assessing the environmental, societal and energy security implications.

This analysis is guided by the essential need to respect the economic viability of rail undertakings and sheds light on the key instruments that can turn potential benefits into actual achievements. Crucial components of the solutions identified are:

- Minimising costs per passenger-kilometre or tonne-kilometre moved, ensuring that the preconditions for maximum rail network use are in place (e.g. through urban planning measures that provide integration of different modes of transport with rail networks), taking steps to remove technical barriers (e.g. through the adoption of international standards which facilitate inter-operability) and fully exploiting digital technologies to ensure that rail services are well integrated into the range of mobility options available to passengers and freight users.
- Maximising revenues from rail systems, capitalising on the "aggregation" capacity of railway stations (land value capture), a model which has already made several rail systems profitable. In this model, the increase in value of commercial and residential properties in the proximity of stations that arises as a result of improved mobility options and greater activity is "captured" to finance rail systems.
- Ensuring that all forms of transport pay not only for the use of the infrastructure they need, but also for the impacts they generate (e.g. through road pricing and congestion charges). The opportunity for effective action on this front will be enhanced by increased transport electrification and the transition towards road vehicle automation, both of which are likely to require price signals to modulate demand.

This report highlights the capacity of rail transport to deliver economic and environmental benefits, even in the face of widespread adoption of efficient road vehicles and low-carbon energy (regardless of the pace at which these other important developments occur). The opportunities offered by rail transport to meet energy and environmental goals cannot be the sole determinant of transport policies, but these objectives can be successfully integrated into the development of those policies.

## Structure of the report

The first chapter describes the current status of the world's railways. It examines the main elements that have shaped the systems and their significance in terms of both the energy sector and environmental concerns.

Chapter 2 outlines how the railway system and its energy needs are likely to evolve to 2050 on the basis of the policies, regulations and projects so far announced. These projections constitute the Base Scenario.

Chapter 3 examines the implications of capitalising the capacity of rail to meet multiple policy goals. The High Rail Scenario shows the extent to which a significant shift of passengers and goods to rail transport, compared with the Base Scenario, could be achieved, the policy instruments which might be deployed to that end and the environmental and financial implications of such a scenario. Chapter 4 takes a deep dive into railway systems in India, a country which currently stands out globally for the proportion of passenger movements that takes place by rail and the significant share of goods transported by rail. Both the challenges and opportunities are immense.

### *Definitions*

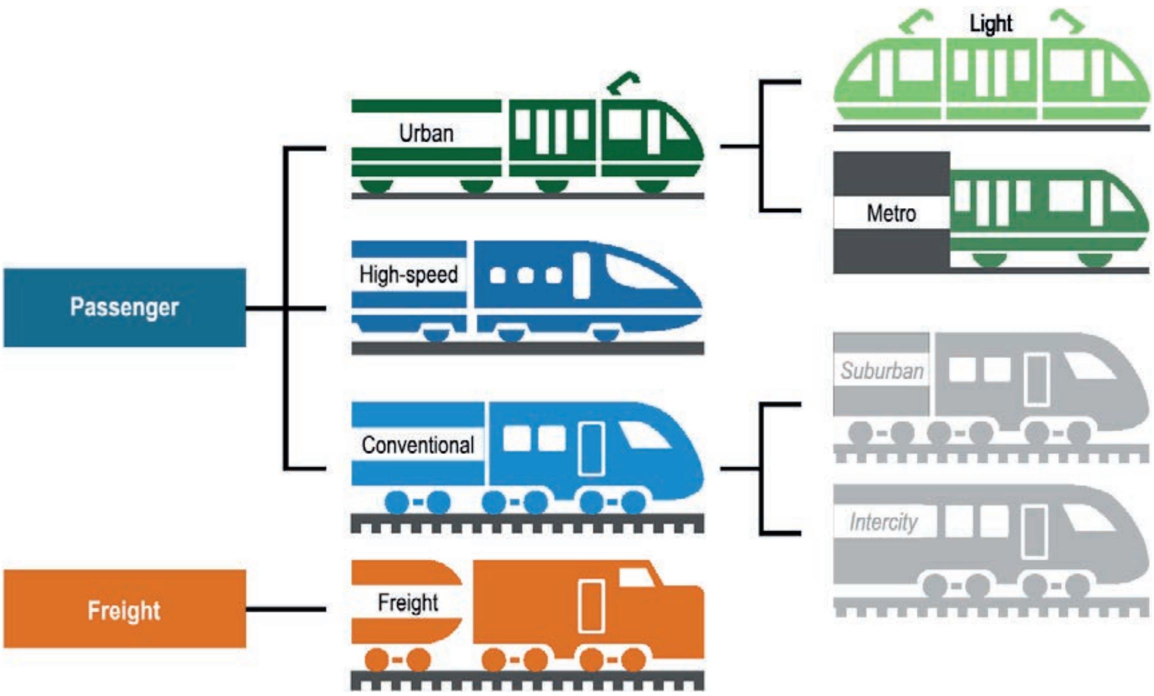
#### *Classification of rail transport services*

This report assesses the contribution railways can make to providing various types of services, referred to as passenger or freight rail. Categorising sub-sets of passenger and freight rail is a challenging undertaking. For passenger rail, this has been addressed by considering key characteristics, such as speed and location, but always within the limitations of the data available. The categories and terminology employed are:

- **Conventional rail**, covering medium- to long-distance train journeys with a maximum speed under 250 kilometres per hour and suburban train journeys connecting urban centres with surrounding areas.
- **High-speed rail**, defined as rail services over long distances between stations, operating at a maximum speed above 250 kilometres per hour.
- **Metro rail**, refers to high-frequency services within cities, designed for high capacity transport (standing passengers and many wide doors for rapid boarding and exit), which are fully separated from other traffic and are often developed as an underground and/or elevated network.
- **Light rail**, refers to tramways and other urban transport systems, most often at street level and offering lower capacity and speed compared with metro rail.

For the purpose of this analysis, metro rail and light rail are often aggregated as **urban rail** (that is rail within cities and the immediately surrounding area), while conventional and high-speed railway systems are together referred to as **non-urban rail**. In the discussion of rail infrastructure, the term **conventional rail lines** (or tracks) designates the infrastructure used by both passenger conventional rail and freight rail.

**Figure In-1 Classification of various railway services and infrastructure**




In addition to metro systems and light rail, urban areas are also serviced by commuter, or suburban, rail systems, connecting the city centres with suburban areas. While commuter rail services constitute a significant proportion of passenger transport activity, they are not separately identified here because of data unavailability or unreliability.[1] In this analysis, commuter rail is included in the figures for conventional rail services. This is a significant limitation for some aspects of the analysis, since commuter rail is an important part of urban mobility, but unfortunately it cannot be fully isolated.



Classification issues are simpler for freight rail, which is defined here as the transport of goods on dedicated freight trains.

### *Key parameters*

The extent to which rail services are used is defined here as **rail activity**. It is expressed by measuring the number of passengers or tonnes carried across a given distance, in passenger-kilometres or tonne-kilometres (ten individuals riding a train for ten kilometres equates to 100 passenger-kilometres, and likewise for tonnes of goods). These passengers or goods are transported on trains driven on rail networks across a given distance. **Train activity**, measured here in train-kilometres, is defined as the sum of all kilometres driven by all trains in a given year.

The extent of the networks catering for these movements is expressed in terms of **track-kilometres**, which may be aggregated into a lower number of **line-kilometres**, reflecting the fact that lines can be composed of one or more tracks.

Trains are assessed in terms of their energy consumption (typically expressed in units of energy per train-kilometre) and their greenhouse gas (GHG) emissions. The latter are measured here either as **well-to-wheel** $CO_2$ emissions (i.e. emissions imputable to both the production of the fuel and its use) or as **life-cycle** $CO_2$ emissions, also accounting for the $CO_2$ emissions resulting from the construction of trains and rail networks.

## Data sources

Historical data for conventional and high-speed rail transport data come from the International Union of Railways (UIC, 2018), up to 2016. To supplement these data, the figures are processed by the International Energy Agency (IEA) and combined with statistics from national sources[2] and the IEA energy balances. For urban rail, historical data are derived from the International Association of Public Transport (UITP) global databases for metro and light rail statistics, the Millennium Cities Databases (UITP, 2015; UITP, 2017; UITP, 2018b), and the Institute of Transportation and Development Policy's rapid transit database (ITDP, 2018).

Historical data for all modes other than rail are collected by the IEA as part of the activities related to the development of the IEA Mobility Model (IEA, 2018), which is a techno-economic database and simulation model that enables detailed analysis and projections of transport activity, vehicle activity, energy demand and well-to-wheel greenhouse has gas and pollutant emissions. Historical data are available to 2016. The IEA Mobility Model was used to develop estimations for 2017. The same model is also the main tool used for the development of the quantitative projections analysed in this report (IEA, 2018).

[1] Isolating commuter rail data is not an easy task. Even when the category is explicitly differentiated, organisations use various definitions for commuter rail. For example, the International Association of Public Transport defines regional and suburban commuter rail using indicators that include the distance between stations (between 1 and 25 kilometres), the speed of the trains (40-60 kilometres per hour) and the maximum duration of a single journey (one hour) (UITP, 2018a). This definition can easily overlap with intercity rail, especially in densely populated countries. The Institute of Transportation and Development Policy defines commuter rail according to whether the use of the service is specifically designed for rapid boarding operations on networks that are not shared with other rail transport services (ITDP, 2018).

[2] National and regional data sources include: National Bureau of Statistics of China, 2018; Eurostat, 2018; Indian Railways, 2018; Japan Ministry of Land, Infrastructure and Tourism, 2018; AAR, 2017; and Russian Federation State Statistics Service, 2018.

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# 1. Status of rail transport

## Highlights

- In 2016, passengers travelled over 4 trillion kilometres by rail, around 8% of total transport passenger-kilometres. Rail travel is concentrated in a few regions: People's Republic of China ("China"), the European Union, India, Japan and the Russian Federation ("Russia"), which together make up about 90% of global passenger rail activity. Despite rapid expansion of metro and high-speed rail systems over the past decade, the share of rail in global motorised passenger transport has remained roughly constant.
- Today, around 600 billion passenger-kilometres are travelled by high-speed rail every year compared with 3 100 billion by conventional rail. Two-out-of-three high-speed rail tracks are in China, which starting from virtually zero only a decade ago has built over 41 000 kilometres of high-speed rail tracks. The speed and size of this achievement place it among the largest infrastructure projects of recent years.
- Nearly 200 cities worldwide have metro systems. The combined length of the metro tracks exceeds 32 000 kilometres. Light rail systems add 21 000 kilometres of track length, across more than 220 cities. The pace of extension of China's metro network since 1990 has outstripped the global average, pushing the country's share of global metro networks from less than 10% in 1990 to more than 28% in 2017. Since urban rail is typically electric, travel by metro and light rail systems gives rise to none of the tailpipe emissions associated with road transport and can achieve zero-emissions mobility overall.
- About 7% of global freight transport activity, as measured in tonne-kilometres, goes by rail. Growth was very rapid at the turn of the century, but slackened and levelled off thereafter. In contrast to Europe, Japan and Korea, where rail networks mostly serve passengers, rail networks in North America overwhelmingly cater to freight transport. In Russia, more than half of freight activity takes place on rail. Australia, Brazil, Canada, India and South Africa also carry substantial volumes of goods by rail.
- Rail transport today accounts for close to 2% of final transport energy use, a modest share compared with rail's share of transport activity. Three-quarters of passenger rail transport and almost half of all freight rail are electric, using around 290 TWh of electricity every year (25 Mtoe). Diesel-powered trains account for the remainder of final energy use (0.6 mb/d, or 28 Mtoe a year). Electric and diesel trains together give rise to around 3% of all well-to-wheel greenhouse gas emissions from the transport sector.
- Although rail is an energy consumer, it also makes an important contribution to containing energy demand. If all passenger and freight services currently carried by rail switched to road vehicles, such as cars and trucks, global oil demand from transport today would be 16% higher (8 mb/d). The contribution rail makes to containing GHG emissions is as significant as its energy savings. If all current passenger and freight traffic by rail shifted to road vehicles, global GHG emissions would increase by 1.2 Gt of $CO_2$-eq, or 12% more than total emissions from transport today.
- Investment in rail infrastructure is expensive. In order for a rail construction project to pay off, high passenger or freight throughput is necessary. If this condition is met, shifting large quantities of transport away from cars, trucks and planes delivers very important societal and environmental benefits, which may not be fully captured in conventional commercial pricing.

## Introduction

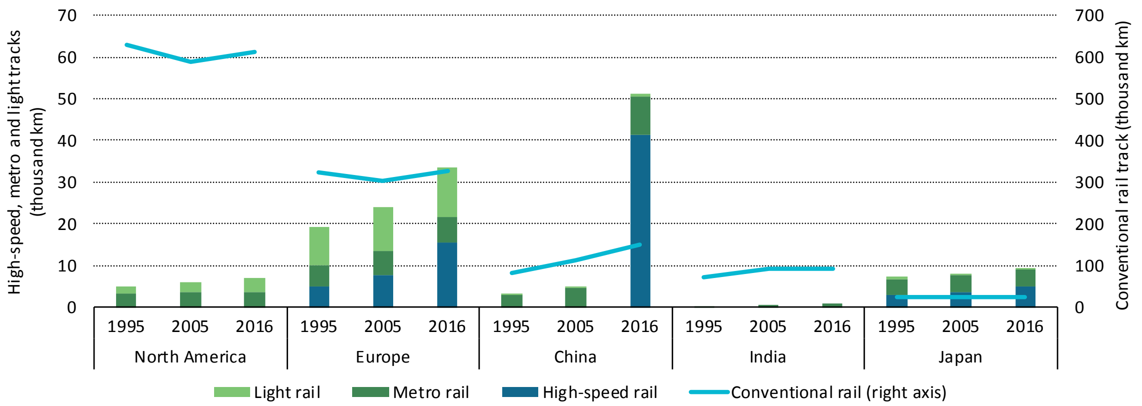
This chapter provides an overview of the world's rail transport services, looking at transport networks, activity, energy demand and greenhouse gas (GHG) emissions. It also explores how rail transport systems have developed, offering insights into the main differences across regions and attempting to identify the key socio-economic forces behind rail development. As well, the chapter provides details of the determinants of the global energy and carbon intensity of passenger and rail transport services.

## Rail transport networks

This section considers the evolution of rail networks and the state of past and present infrastructure. Rail infrastructure refers, in particular, to rail tracks and lines (with any one rail line consisting of one or more tracks); the importance of electrical equipment and signalling systems is highlighted in later sections. The overall length of a country's railway tracks gives some indication of the priority given to investment in rail transportation and the capacity of the network. Three main types of rail infrastructure are discussed: conventional (shared by passenger and freight trains), high-speed and urban (consisting of metro and light rail systems).

Conventional rail tracks make up 94% of all rail track-kilometres, but their length has grown very little in recent years (Figure 1.1). Urban and high-speed rail networks, on the other hand, have grown significantly, their length having doubled and tripled in several countries in recent years.

**Figure 1.1 Track length by region and network type, 1995-2016**




Note: Conventional rail includes infrastructure used both by conventional passenger and freight rail.

Sources: IEA assessments based on UIC (2018a); UITP (2018a); UITP (2017); ITDP (2018); AAR (2017); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); National Bureau of Statistics of China (2018) and Russian Federation State Statistics Service (2018).

**Key message • Conventional rail networks have changed little over the past two decades, while metro and high-speed rail have grown strongly.**

Even though new metro lines are regularly being opened in the European Union and North America, along with high-speed rail lines in the European Union, Asia is the epicentre of most recent and ongoing developments. The most impressive rail infrastructure expansion in recent years is China's rapid development of high-speed rail corridors. Non-existent before 2008, the length of China's high-speed rail network has overtaken that of all other countries in the world combined. Today, nearly two-thirds of the world's high-speed rail lines are in China.

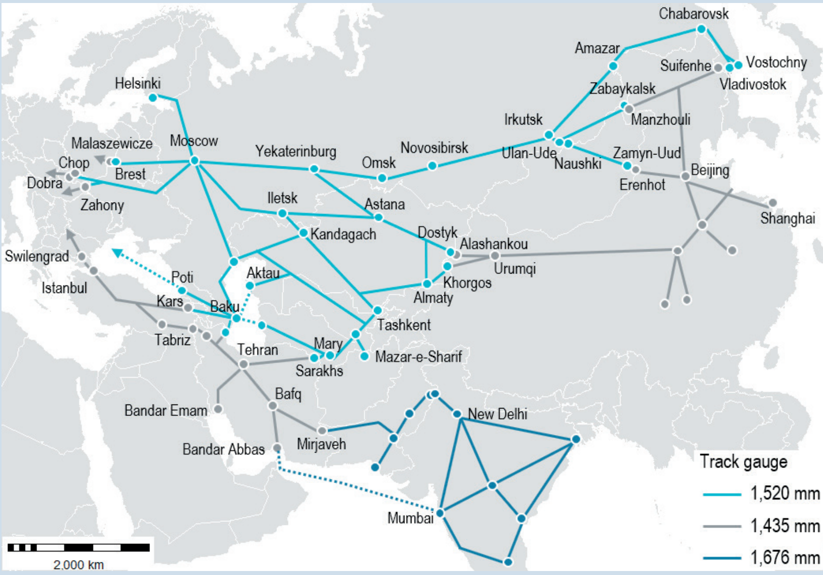
**Box 1.1 Technical characteristics of the network and inter-operability of rail services**

The independent development of railway systems in different countries led to the adoption of a variety of track gauges (i.e. the spacing between rails), power systems (using alternative or direct current and voltage) and signalling conventions. These choices have constrained the integration of railway systems.

For passenger rail, network integration barriers have been limited. In the case of urban passenger rail services, this is because breaks occur in most cases at railway stations, where passengers would be likely to transfer in any case. In the case of long-distance rail transport, the constraints have been fewer because of the timing of high-speed rail development, which occurred once the importance of network integration and inter-operability had been widely accepted.[1] Allowing the rolling stock to be powered via various electrical systems, new technology permits differences in drive systems to be overcome. Although there will always be additional administrative cost for trains operating across borders, if the tracks have the same gauge, the trains can be adapted to different overhead line characteristics.

Freight rail typically travels long distances and therefore is subject to more significant network integration barriers than passenger rail. This is especially relevant in Europe and the Eurasian corridors, where, at switch of gauge locations, cars must exchange their bogies[2] for the different sized tracks (Figure 1.2). If this is not possible, goods are transferred from one train to another. The use of freight containers facilitates this, but transfers still increase time and cost.

**Figure 1.2 Eurasian freight rail corridors**




Note: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Source: Eurasian Rail Corridors (UIC, 2017a).

**European Union**

In 2010, European Regulation EU913/2010 created 11 freight rail corridors open to different rail operators (European Union, 2010). The goals of the corridors include the standardisation of operational practices, signalling systems, electrification, increases in the maximum possible length of a train to 740 metres, 100 kilometres per hour operating speed, 22.5 tonnes axle load, loading gauges (allowed height and width of the train) and track gauges by 2030 for the core network and by

[1] All major high-speed services outside Russia operate on standard gauge, regardless of the gauge used in the conventional network. For future high-speed connections between Russia and China, the railway operator China Rail, is developing an adjustable gauge high-speed train (RT, 2016).

[2] A bogie is the underframe, or chassis, of a rail vehicle; the axles and attached wheels are contained within the bogie.

2050 for the overall network. However, improvements on this scale are typically slow and require the co-operation of national governments, which is not always a given (European Court of Auditors, 2016).

**Central and Eastern Asia**

Freight rail traffic between Europe and Asia is growing rapidly, but its modal share remains limited compared with shipping, mostly hampered by issues related to border crossings and inter-operability. Breaks of gauge occur between China, former Soviet Union countries and Europe, as well as between Pakistan and Islamic Republic of Iran ("Iran") on the southern route (Figure 1.2). Other inter-operability issues also exist due to the separate development of the rail networks in each country (UIC, 2017a).

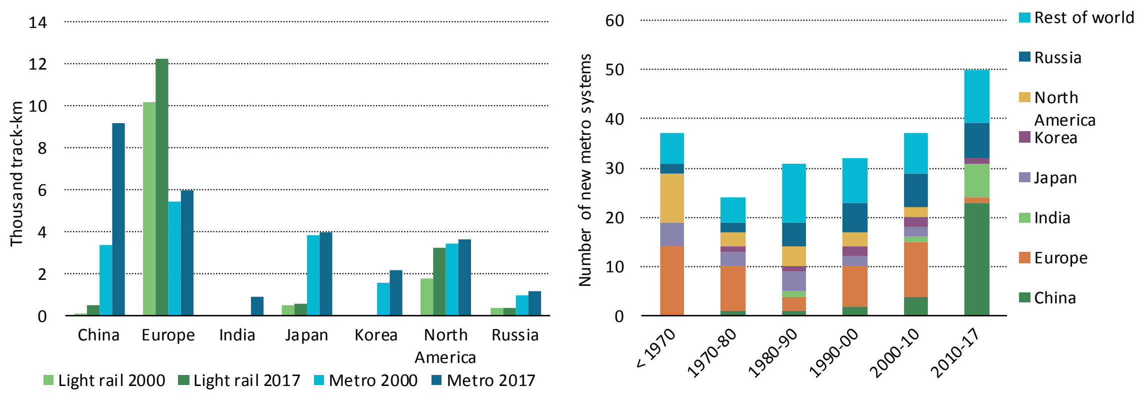
**North America**

Inter-operability in North America was achieved rapidly due to the relative simplicity of the rail market. Freight operators own their networks and operate in only three national contexts (Canada, Mexico and United States), facilitating more co-ordination. This is in stark contrast with Europe and Eurasia, where there are many different countries, operators and infrastructure managers to co-ordinate in one corridor. Larger diversity in the services, such as established domestic passenger and freight services for which international standardisation is an additional cost with no direct benefit, is also a hindrance. To increase inter-operability, co-operation and organisation is required between all relevant parties in a network.

## *Urban rail network*

Worldwide in 2017, 194 cities had metro systems and operated over 32 000 kilometres of track (UITP, 2018c; ITDP, 2018). Plus, 221 cities had light rail systems, with 21 000 kilometres of track. Since 2010, new metro systems have opened in 43 cities, 32 of which are in Asia (Figure 1.3). Length of the overall network of metros has increased by 4 800 kilometres since 2000, when the total length was 11 300 kilometres. In the next five years, new lines and extensions are expected to open in many countries, including the first lines to be built in sub-Saharan Africa (in Abidjan, Abuja and Lagos) (UITP, 2018a).

**Figure 1.3 Extension of urban rail networks (metro and light rail), 2000-2017 (left) and opening of new metro systems, 1970-2017 (right)**




Note: The light rail line figures for 2017 are estimates based on UITP (2018d) and ITDP (2018).

Sources: IEA analysis based on UITP (2015a), UITP (2018d) and ITDP (2018).

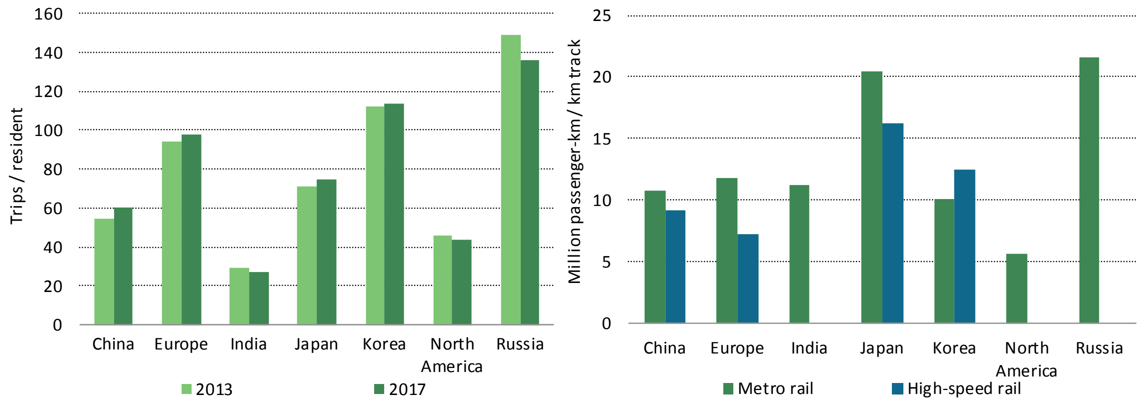
**Key message • China's metro network became the largest metro network in the world in just one decade, overtaking that of the European Union in 2015.**

The intensity of the use of metro systems is an important indicator of their current relevance and potential for further growth. A first metric for comparison is the average number of metro trips per urban resident in a year. Figure 1.4 (left) shows how this indicator has evolved over the past five years in selected regions. There are clear regional differences, reflecting several factors such as the proportion of the city area that is served by a metro system and accessibility to the stations. India and North America have the lowest number of trips per urban resident, indicating that a smaller portion of the urban population uses the metro system compared with countries and regions with more developed urban rail networks, such as Russia, Korea, European Union and Japan.



A second indicator for the intensity of metro use is the number of passenger-kilometres per kilometre of network length (Figure 1.4, right), which illustrates how busy the existing network lines are. Metro systems have by far the highest utilisation rate of all rail systems (whether measured in train-kilometre or passenger-kilometre) per kilometre of track length. The figure shows that metro systems are much more intensively used in Russia and Japan, where metro occupancy and frequency are extremely high, whereas intensity is lower in the rest of the world, in particular in North America. Figure 1.4 also compares metro with high-speed rail utilisation. On average, a metro system sees 13 million passenger-kilometres per year per kilometre track, compared to 9 million per high-speed rail track. Conventional rail tracks carry much less, though they also transport goods. Advancing traffic management systems may extend the potential utilisation rate of urban rail networks (see Box 1.4).

**Figure 1.4** **Average annual metro trips per urban resident, 2013-2017 (left); and metro network utilisation versus high-speed rail, 2017 (right)**




Notes: For the figure on the left, results are based on a weighted average of the number of annual trips per city resident (weighted relative to the number of residents per city) taking into account only cities that have a metro system.

Sources: For the figure on the left, data are from the UITP (2018d). The figure on the right represents IEA estimates based on UIC (2018a); UITP (2018a); National Bureau of Statistics of China) (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017); and Russian Federation State Statistics Service (2018).

**Key message • Russia, Korea and the European Union have the highest levels of metro ridership. Metro network utilisation per kilometre of track is higher in Russia and Asian countries than in Europe and North America. Metro utilisation of rail networks is much higher than high-speed rail.**

## *Conventional rail network for passenger and freight services*

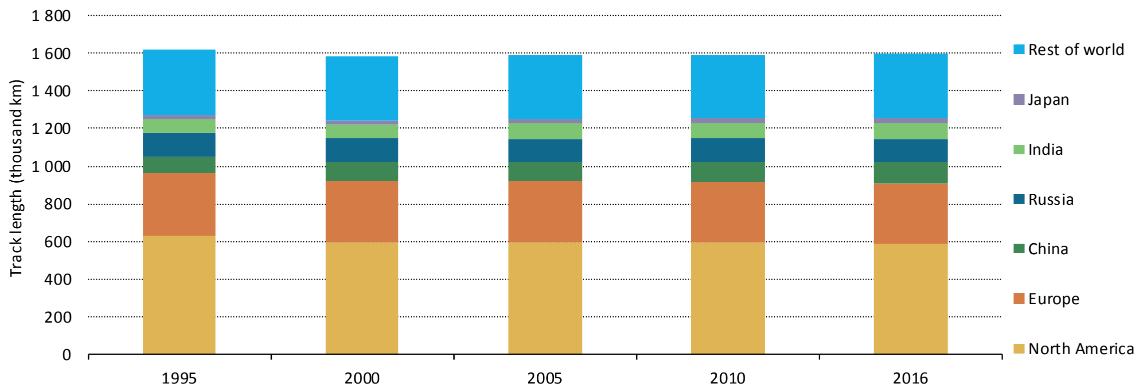
The length of tracks used for conventional passenger and freight rail services has hardly grown over the past twenty years, i.e. very little new conventional rail infrastructure was built (Figure 1.5). The longest conventional rail network today is in North America, followed by the European Union, Russia, India and China.

Passenger utilisation of the conventional rail network is more intensive in Japan than in any other country. This is due to the fact that a large number of networks in Japan are suburban, or commuter, rail systems, which have activity patterns closer to those of metros than of intercity trains.[3]



**Figure 1.5 Conventional rail infrastructure track development, 1995-2016**

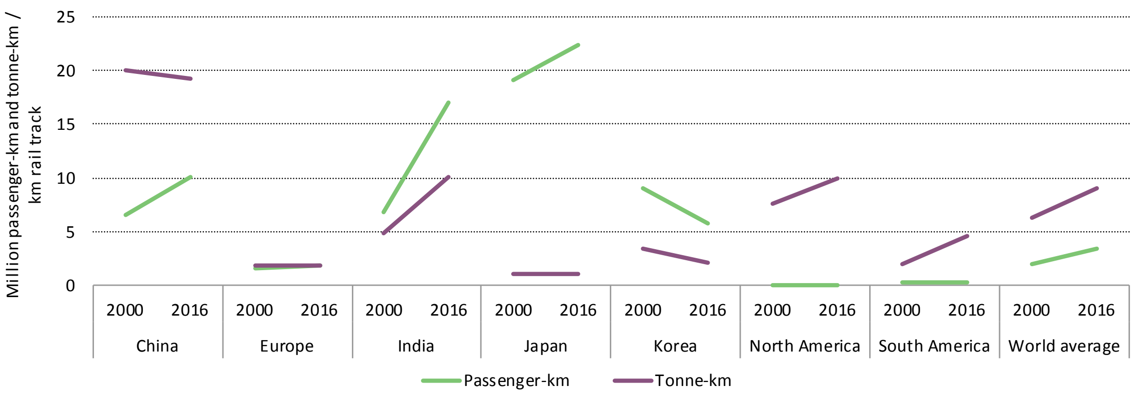



Note: The figure includes all conventional rail tracks, used both for passenger and freight transport.

Sources: IEA assessments based on UIC (2018a); National Bureau of Statistics of China) (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017); and Russian Federation State Statistics Service (2018).

**Key message • Global conventional rail tracks did not expand significantly over the past twenty years.**

**Figure 1.6 Non-urban rail activity per kilometre of track, passenger and freight, 2000 and 2016**




Sources: IEA assessments based on UIC (2018a); National Bureau of Statistics of China) (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017); and Russian Federation State Statistics Service (2018).

**Key message • Almost all regions have experienced more intensive rail transport activity per track kilometre, except the European Union and Korea.**

Since 2000, almost all countries and regions have experienced intensified use of rail networks as activity levels increased while the networks remained relatively constant in length (Figure 1.6). At the global level, passenger track utilisation (passenger-kilometres per track kilometre) increased by 75% between 2000 and 2016, and freight track utilisation (tonne-kilometres per kilometre track) by 45%. This intensification was strongest in India, with increases of 150% for

[3] The UITP estimates that the network length of commuter rail services at 150 000 kilometres (UITP, 2018a).

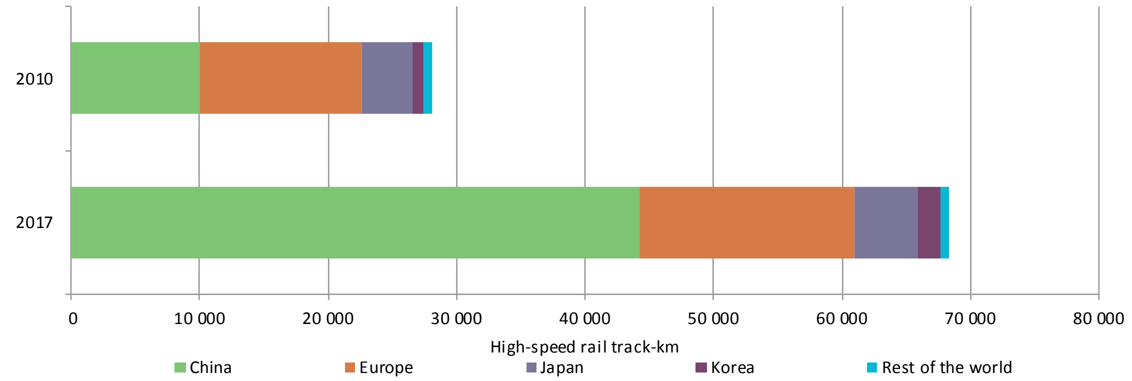
passenger transport and 110% for freight. In China, passenger activity per track-kilometre has risen by 54% since 2000, and Association of Southeast Asian Nations (ASEAN) countries by 33%. Freight rail activity per track-kilometre increased most in South America, rising by 127% between 2000 and 2016. Korea is the only country that has increased its network capacity faster than demand growth: both freight and passenger rail activity increased, but the rate of growth was faster.



## *High-speed rail network*

With more than sevenfold growth since 2000, high-speed rail has been the main area of infrastructure growth in the global rail network, reaching close to 68 000 track-kilometres in 2017. The main reason is the addition of many new lines in China (Figure 1.7).[4] High-speed rail accounts for 4% of all rail tracks in the world today, yet high-speed rail infrastructure exists in only 14 countries.[5]

**Figure 1.7 High-speed rail track length by key region, 2010 and 2017**




Note: High-speed rail lines are assumed to be bi-directional, i.e. consist of two tracks per line.

Source: IEA analysis based on (UIC, 2018b). (This source also includes tracks with maximum speeds under 250 kilometres per hour, though those are not included in this analysis.)

Key message • **China is the clear leader in global high-speed rail network expansion in recent years while networks in Europe and Japan expanded at a slower pace.**

High-speed rail tracks are used much more intensively than conventional rail tracks, which share a large part of their network activity with freight rail. Figure 1.8 shows that, on average, high-speed rail tracks are used by almost three-times as many trains as conventional tracks.

Utilisation of the high-speed rail network also differs strongly between lines. For example, the Tokaido line of the high-speed rail connection between Tokyo and Nagoya – one of the most intensively used high-speed rail lines in the world – has a frequency of more than 15 trains per hour at peak times, whereas the number of trains per hour using the *Train à Grande Vitesse* (TGV) corridor between Paris and Lyon during the morning and evening peaks (also with high

[4] In the past five years, China added on average more than 6 000 kilometres of high-speed rail track per year, roughly the same length as the total high-speed rail network length of Japan and Korea combined. Today China accounts for 65% of the world's high-speed tracks, followed by the European Union with 24%.

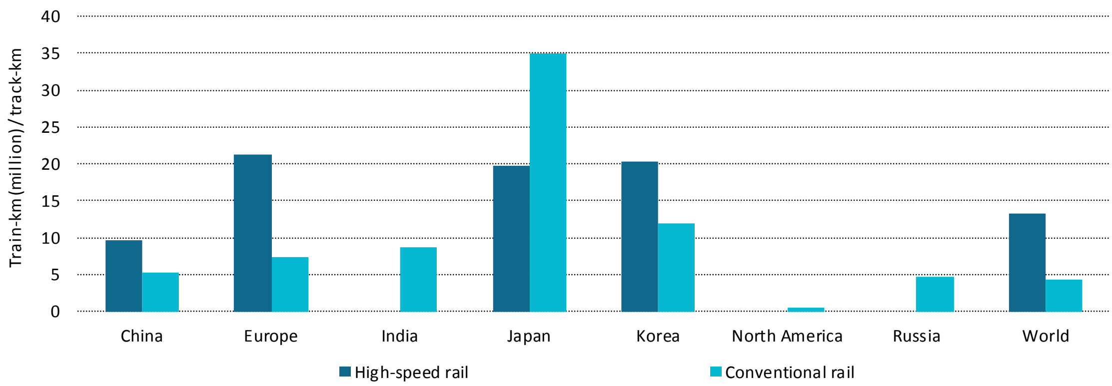
[5] Austria, Belgium, China, Chinese Taipei, France, Germany, Italy, Japan, Korea, the Netherlands, Spain, Switzerland, Turkey and United Kingdom.



utilisation) is 8 or 9 trains per hour (IHRA, 2017). This indicates potential for more intensive use of high-speed rail lines.

**Figure 1.8 Passenger train activity for high-speed rail and conventional rail per track-kilometre, 2016**




Note: Train-kilometres on conventional tracks include both passenger and freight trains. High-speed rail tracks are assumed to be used only by high-speed passenger trains.

Sources: Train-kilometre and conventional track length are derived from UIC (2018a). High-speed rail track length source is UIC (2018b) with the assumption that high-speed rail infrastructure has two tracks per line.

Key message • **High-speed rail lines are more intensively used than conventional rail. Japan is an exception due to its very high share of commuter rail, which is included as conventional activity.**

**Box 1.2 Maglev and the Hyperloop**

A proposed alternative to high-speed rail is *maglev* (derived from magnetic levitation). Maglev technology relies on a system of coils and magnetic fields that move the train along the track and allows very high speeds. Unlike traditional rail systems, the train carriage does not come into contact with the track.

As of early 2018, there were six maglev systems in operation (Maglev.net, 2018). The best known is the Shanghai maglev, operating between the city's Pudong International Airport and Longyang Road Station, close to the city centre. Capable of a top speed of 430 kilometres per hour, the 30 kilometres trip takes eight minutes. Other maglev systems, operating at much lower speeds, are being developed for use in high capacity urban areas (e.g. in Beijing) or dedicated connections (e.g. at Seoul's Incheon airport). Japan aims to use maglev technology to achieve speeds of 500 kilometres per hour on a high-speed line that is under construction between Tokyo and Nagoya, which is designed to reduce the travel time between these two cities – at a distance of 286 kilometres – to a mere 40 minutes (Japan Rail Pass, 2018). There are plans for an eventual extension to Osaka.

High-speed maglev technologies have high energy requirements (Crozet, 2016). For example, the maglev connection being built between Tokyo and Nagoya is expected to consume between four- and five-times as much power as the Tokaido Shinkansen (Kingsland, 2018).

High-speed maglev technology shares the high throughput characteristic of rail infrastructure, but it faces even higher infrastructure construction costs. In Korea, Incheon Airport's maglev project is estimated to have cost roughly USD 32 million per kilometre (Hall, 2018). In Shanghai, the cost exceeded USD 35 million per kilometre (Hall, 2018). The system under construction in Japan is estimated to cost USD 260 million per kilometre, partly due to the fact that 86% of the Tokyo-Nagoya route will run through underground tunnels (Smith, 2017). The cost of low speed maglev systems, which are becoming popular in China, is more encouraging (Tabeta, 2017). Such systems bring the benefits of low noise and low vibrations to urban environments. Even so, because of the high investment cost, maglev is likely to be confined to routes that can guarantee high intensity use, e.g. running between megacities, at a reasonable distance, or connecting important transport hubs, such as airports and city/business centres.

Another alternative technology, the *Hyperloop*, is based on a passenger or cargo pod that uses an electromagnetic propulsion system[6] operating through a low-pressure tube (SpaceX, 2013).

Proponents of the hyperloop claim that the technology is more efficient than other land transport modes, due to the low-pressure environment in the tubes through which the vehicle travels. Feasibility studies have been carried out which indicate that hyperloop technology could be two- to three-times more energy efficient per passenger transported than high-speed rail (Taylor, Hyde and Barr, 2016). Hyperloop proponents also claim that the investment and operational costs would be one- to two-thirds lower than those of high-speed rail, while travel time could be several times faster than high-speed rail, with speeds exceeding 1 000 kilometres per hour (SpaceX, 2013; Hyperloop One, 2018). Cost estimates for a Los Angeles and San Francisco connection are close to USD 6 billion (less than 10% of the projected costs the high-speed rail line currently under construction between the two cities) (CNBC, 2018).

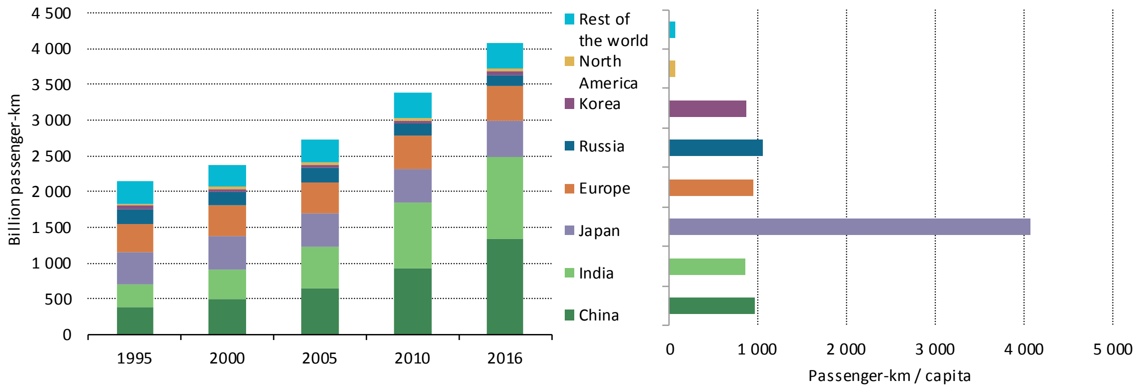
These claims have come under serious scrutiny, however, because of the high energy requirements of hyperloop technologies and perceived under-estimation of land acquisition, which suggests that full functionality of the technology would result in costs comparable with those of high-speed rail links. For the Los Angeles to San Francisco hyperloop connection cited, cost estimates attempting to account for these impacts could be as high as USD 40 million per kilometre, which is similar to the Los Angeles - San Francisco high-speed rail line currently under construction (Taylor, Hyde and Barr, 2016; New York Times, 2013; CNBC, 2018). More importantly, the number of people that can be hosted in the pod is economically less than fifty. This appears to limit the possibility of safely attaining the frequency of service necessary to move large numbers of people (Crozet, 2016).



# Rail transport activity

## *Passenger rail*

**Figure 1.9 Passenger rail activity, 1995-2016 (left) and passenger-kilometres per capita, 2016 (right)**




Sources: IEA assessment based on UIC (2018a); UITP (2018a); ITDP (2018), National Bureau of Statistics of China (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

**Key message • Rail passenger activity has risen by 91% in the past two decades, mostly in China and India. Japan, by far, has the highest rail activity per capita.**

Passenger rail transport activity comprises urban and non-urban passenger movements and is typically measured in passenger-kilometres per year. Such activity has increased significantly over the past twenty years, but is concentrated in a few regions (Figure 1.9): China, India, Japan, European Union and Russia together account for more than 90% of passenger rail activity

[6] The drivetrain includes an electric motor, inverter and battery system (Decker et al., 2017).

worldwide and have much higher rates of passenger activity per capita than other regions. In 2016, more than 4.1 trillion passenger-kilometres were served by rail transport. The usage patterns of passenger rail vary across countries and depend on patterns of population density and income, as illustrated in Box 1.3.



Passenger rail activity trends are not uniform across countries.

- In *China*, rail transport activity more than doubled between 2005 and 2016, largely reflecting major investment in high-speed rail lines and urban rail networks. Having instituted its first high-speed rail line in 2008, today high-speed rail passenger activity in China represents roughly one-third of all national non-urban rail activity. China has surpassed the combined global volume of high-speed rail passenger-kilometres. Metro activity also strongly increased in the last ten years, going from 43 billion passenger-kilometres in 2005 to about 72 billion today.
- *India* has the second-highest absolute level of passenger rail activity today, close behind China, accounting for nearly 30% of global rail passenger activity, carried on a vast network of railway lines. Activity measured in per capita passenger-kilometres has increased steadily every year since 1995. Most of the activity is on conventional suburban and intercity trains, though a number of metro lines are in operation and others are under construction, along with one high-speed rail line.
- *Japan*, by far, is the global leader in terms of passenger train activity per capita and rail transport activity continued to increase in the past decades, though slowly (Figure 1.9). Almost half of non-urban rail trips are made on Japan's famous high-speed trains and urban rail plays a very significant role in urban passenger transport, accounting for 18% of rail passenger-kilometres nationwide.
- In the *European Union*, historically the first region to build an international rail network, rail activity has risen slowly but steadily in recent decades, both in the case of urban and non-urban transport. Part of its passenger activity has shifted from conventional to high-speed rail. By 2016, high-speed rail accounted for roughly one-quarter of non-urban passenger-kilometres.
- In *Russia*, despite a vast rail infrastructure endowment and high per capita rail use, the level of total rail activity has dropped since 2000, although urban rail activity has remained largely constant.
- *Korea* has witnessed the most rapid shift from conventional rail to high-speed rail: in 2016, high-speed rail accounted for more than two-thirds of passenger rail activity. Urban rail activity also accelerated rapidly, increasing by two-thirds since 1995.

Globally, rail transport activity has nearly kept pace with the overall increase in demand for mobility. The share of rail in total motorised passenger transport activity (i.e. all except walking and cycling) has declined only slightly, from 9% in 2000 to 8% in 2016 (IEA, 2018a). But the rate of growth of rail transport activity compared to growth in other transport modes was not uniform across all regions.

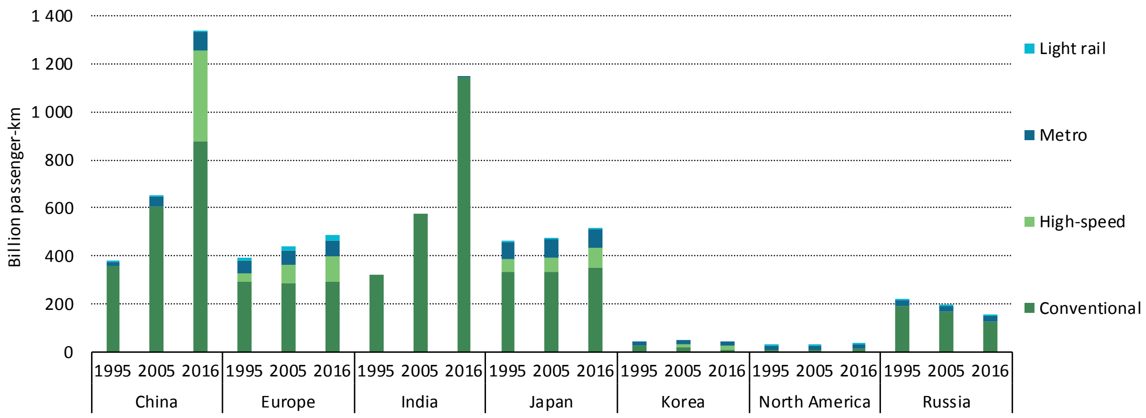
- In *India*, for example, rail passenger activity grew by a factor of 2.6 between 1995 and 2016, but other modes of transport grew more rapidly, resulting in a reduction in the share of passenger rail activity.
- In *China*, though rail activity doubled in the past decade, the modal share of rail in passenger activity has reduced by 70% since 2000, indicating much more rapid activity growth in other modes, most notably in air and passenger car transport.
- *Japan* is one of the very few advanced global economies that have witnessed both a strong increase in rail passenger activity and a continued increase in the share of rail in overall

transport passenger activity. In 2016, rail accounted for 34% of all motorised passenger activity in Japan, up from 31% in 2000.

- In *the European Union*, the modal share of passenger rail has remained constant, around 8%, over the last twenty years.[7]
- In *Russia,* the drop in passenger rail activity has been accompanied by a decline in the share of rail in total passenger mobility: the share of rail in total passenger transport activity fell from 18% in 2000 to 7% in 2016.
- *Korea,* on the other hand, has seen both a significant increase in absolute rail passenger activity and a constant rail modal share. Between 2000 and 2016, rail activity grew by 8% and the modal share held at 6%.



**Figure 1.10 Passenger activity by rail type**




Sources: IEA assessment based on UIC (2018a); UITP (2018a); ITDP (2018), National Bureau of Statistics of China (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

**Key message • Most passenger rail activity takes place on conventional trains, though growth in activity is most significant in metro and high-speed rail.**

## *Urban rail*

Urban rail, including metro and light rail services, satisfied demand for roughly 500 million passenger-kilometres in 2017, accounting for 2% of global urban passenger transport activity and 9% of total rail passenger activity. Activity on urban rail networks has increased continuously over the past century (dating back to the first metro system opening in 1863 in London). It has accelerated rapidly in recent years, mostly due to significant development of new metro systems in Asia.

Urban rail accounts for around 5% of total passenger rail demand in China and around 15% in the European Union, Japan and Russia (Figure 1.11, right). In Korea almost half and in North America over 60% of total passenger rail demand is served by urban rail. The high proportion in North America is attributed to the small volume of non-urban passenger rail. In Korea, it reflects the relatively small size of the country and the significant extension of metro networks in major urban areas. In India, conventional rail is more dominant, with urban rail accounting for only 1% of passenger rail.

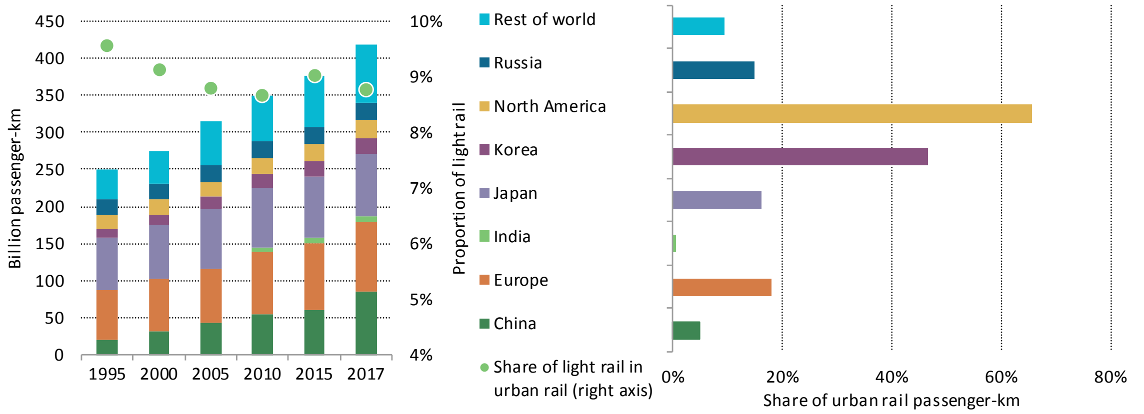
[7] Also noteworthy is the fact that Europe is the region where air travel has seen the fastest growth in recent years, going from 15% of passenger transport activity in the year 2000 to 24% in 2015.

China is home to several of the world's busiest metro systems (Table 1.1) and accounts for more than a quarter of global urban rail activity (Figure 1.11, left). With 6% average annual growth between 2005 and 2017, metros in Chinese cities have been the largest contributor to growth in urban rail activity in the recent years. Despite challenges in terms of economic viability, the rise of urban rail systems in China is expected to continue in the next decade, where many new rail lines are under construction (see section on rail transport networks).



**Figure 1.11 Urban rail activity, 1995-2017 (left) and shares of urban rail in total passenger rail, 2017 (right)**




Notes: Urban rail consists of metro rail and light rail in the classification used in this report. The urban rail activity for 2017 is based on reported data in the case of metros and an estimate in the case of light rail, based on UTIP (2018d) and ITDP (2018).

Sources: IEA assessment based on UTIP (2015a), UTIP (2018d) and ITDP (2018).

**Key message • The largest portion of urban rail activity over the last decade is in Asia with rapid growth as many new metro systems were built in China.**

**Table 1.1 Most used metro and light rail systems**

| Metro (2017) | | Light rail (2014) | |
|---|---|---|---|
| City | Number of trips per year (millions) | City | Number of trips per year (millions) |
| Tokyo | 3 420 | Budapest | 396 |
| Moscow | 2 369 | Vienna | 363 |
| Shanghai | 2 045 | Bucharest | 322 |
| Beijing | 1 988 | Prague | 317 |
| Seoul | 1 878 | St. Petersburg | 312 |
| Guangzhou | 1 821 | Warsaw | 264 |
| New York City | 1 806 | Moscow | 252 |
| New Delhi | 1 789 | Cologne | 210 |
| Mexico City | 1 679 | Zürich | 205 |
| Hong Kong, China | 1 600 | Zagreb | 204 |

Sources: UITP (2018d) for metro and UITP (2015b) for light rail.

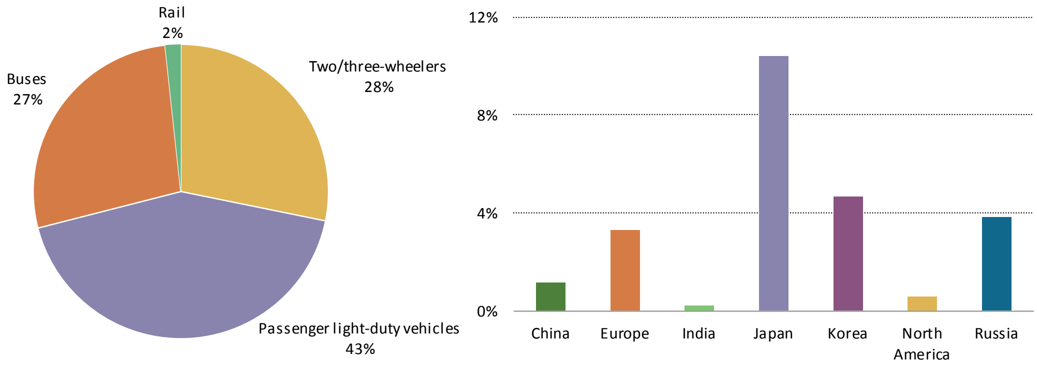
**Key message • The busiest metro systems are located in very large cities, while light rail is more important in European cities.**

In 2017, light rail systems accounted for an estimated 34 billion passenger-kilometres, providing a significantly smaller proportion of global urban rail activity than metro rail, which accounted for almost 500 billion passenger-kilometres. This is partly explained by the much lower vehicle capacity and operational speed of light rail services compared with metro rail, and partly by the concentration of the light rail network in a relatively small number of countries. While metro rail is more heavily represented in Asia (where the world's megacities are concentrated), light rail is most abundant in the European Union, which is home to the world's ten largest light rail systems operating over half of the total 12 000 kilometres of light rail tracks (Table 1.1).



Globally, urban rail accounts for a relatively small share of urban passenger transport activity (Figure 1.12). Japan, Korea and Russia, which host several of the busiest metro systems in the world, have a share of urban rail that is higher than the world average. The share of light rail activity in urban rail activity is 23% in the European Union compared with 9% globally.

**Figure 1.12 Modal shares of urban transport activity in passenger-kilometres (left) and as a share of urban rail in total urban passenger activity by country (right), 2017**




Note: The figures include metro and light rail systems within city limits and do not include suburban and commuter rail networks.
Source: IEA (2018a).

**Key message • On a global scale, rail accounts for a minor share of urban passenger transport. On a country basis, Japan and Korea have the highest shares of rail in urban transport.**

## *Conventional and high-speed rail*

On a global basis, conventional and high-speed rail have consistently accounted for around 15% of the passenger-kilometres travelled by all transport modes outside of city limits since 2000 and around 90% of all travel by rail (even with extensive metro construction in many countries). There has been a net increase of conventional rail and high-speed rail activity from 2.1 trillion passenger-kilometres in 2000 to 3.9 trillion passenger-kilometres in 2016, an average annual growth rate of 4% (Figure 1.13, left).

This pace for overall conventional and high-speed rail expansion, in part, is driven by the increase of conventional rail in India, where activity nearly tripled between 2000 and 2016. This has been a principal influence to sustain the global average annual growth rate of conventional rail at 3.3%. By 2016, India represented 37% of conventional passenger rail activity worldwide, ahead of China, with 29%, and Japan, with 11%.[8]

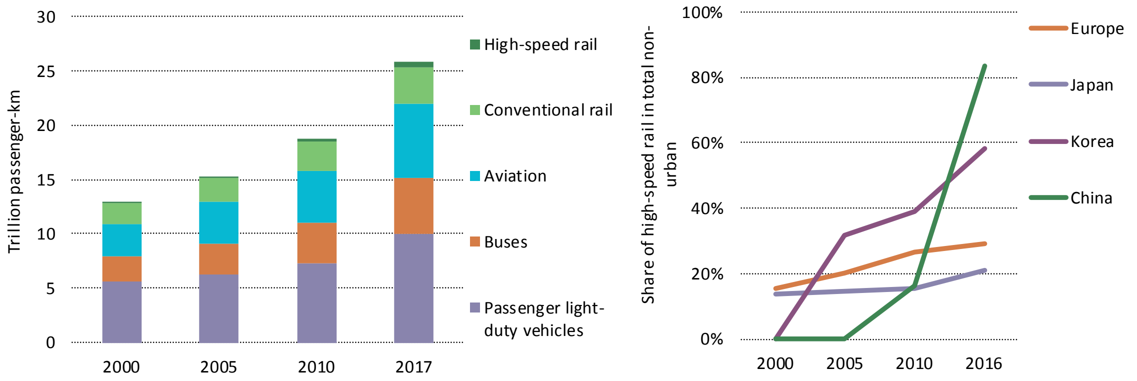


[8] The UITP estimates that 90% of rail passengers in the European Union use regional or suburban commuter rail (likely to be reported under conventional rail services) (UITP, 2016). According to the UITP, the countries that transport the most



**Figure 1.13 Non-urban transport activity by mode, 2000-2017 (left) and the share of high-speed rail in non-urban rail, 2000-2016 (right)**



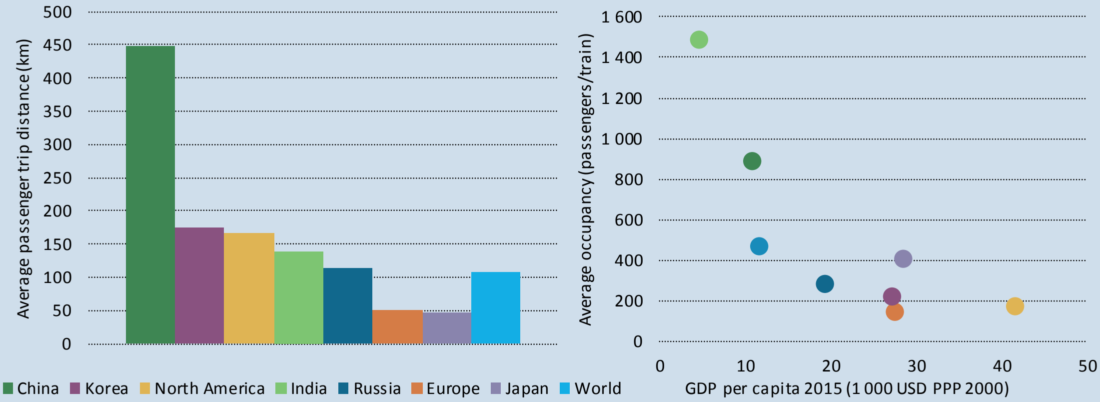

Sources: IEA (2018a); UIC (2018b).

**Key message • Non-urban road passenger transport and aviation have grown at the same rate as non-urban rail since 2000.**

**Box 1.3 Usage patterns of conventional passenger rail services**

There are key differences between countries and regions which rely on high shares of conventional rail for passenger transport. Two parameters are especially interesting: the average distance covered in a single trip (Figure 1.14, left) and the passenger train occupancy factor (Figure 1.14, right).

**Figure 1.14 Conventional rail average passenger trip distance and train occupancy, 2016**




Note: GDP = gross domestic product; PPP = purchasing power parity.

Sources: IEA assessment, based on UIC (2018a); National Bureau of Statistics of China (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

**Key message • Unsurprisingly, average trip distances are longest in the biggest countries. Train occupancy rates are positively correlated with relatively low per-capita income.**

The average distance covered in a single trip varies across countries: in China it is almost 450 kilometres, while in Korea, North America, India and the Russia the average is 100 - 200 kilometres. Average trip distances in more densely populated or smaller countries or

passengers by commuter rail are Japan (about 16 billion trips per year), India (4.5 billion trips per year) and Brazil (1 billion trips per year) (UITP, 2018e).

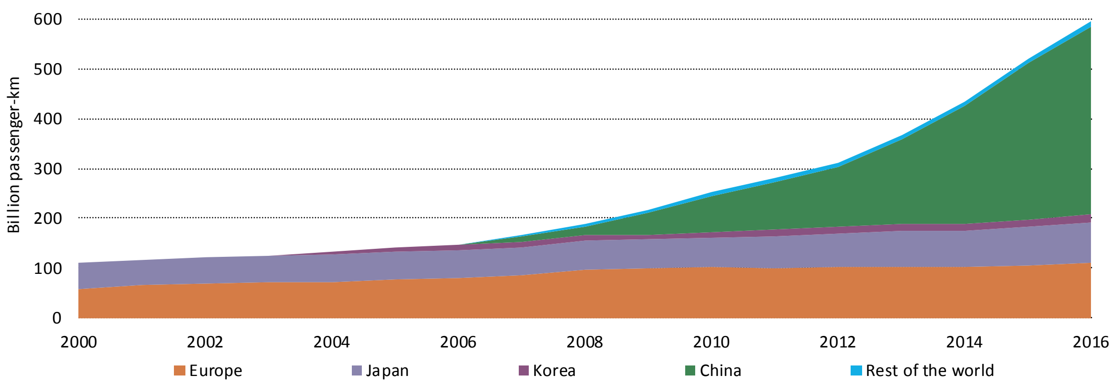
regions, such as Japan and the European Union, are close to 50 kilometres. This reflects the importance of suburban/commuter rail (typically characterised by high passenger throughput and relatively short trip distances) in the total of conventional rail travel in countries with higher densities.

Passenger train occupancy rates also vary notably, with high-income countries at the low-end of the spectrum and emerging economies at the high-end. India has the highest average occupancy rate, followed by China and Japan. A conventional train in India typically transports almost ten-times more passengers than the average conventional train in the European Union.



High-speed rail developments in the European Union and several Asian countries (mostly China) have shifted some demand away from conventional rail and also generated new travel demand. Despite its limited geographical spread, high-speed rail activity grew by more than 11% per year between 2000 and 2016, nearly three-times faster than growth in any other non-urban transport mode, attaining nearly 600 billion passenger-kilometres in 2016. Most growth occurred after 2007, mainly driven by the surge in China (Figure 1.15) (UIC, 2018b). By 2016, high-speed rail activity represented 16% of overall activity on conventional and high-speed networks, up from 6% in 2000.

**Figure 1.15 High-speed rail activity for key regions, 2000-2016**




Sources: IEA assessment based on UIC (2018a).

**Key message • High-speed rail activity worldwide expanded fivefold in less than ten years, predominantly in China.**

**Box 1.4 Digital technologies: autonomous trains and advanced rail traffic management and control systems**

Rapid advances in data, analytics and connectivity are driving a wave of digitalisation including in the transport sector (IEA, 2017). As demand for rail mobility increases faster than new infrastructure construction, digital technologies can facilitate more intensive use of tracks by reducing the time and distance between trains, to increase capacity and boost returns on investment while improving user convenience and maintaining high safety standards.[9]

*Advanced traffic management and control systems* help ensure the safe and efficient operation of rail transport. These systems include Communication-Based Train Controls (CBTC),[10] extensively used for urban rail, where they are combined with Driver Assistance Systems (DAS) to maximise the use of the network. They also include the European Railway

[9] High utilisation rates can make rail projects more economically viable and decrease the time necessary to offset life-cycle emissions from infrastructure construction (particularly underground or elevated segments), as discussed in the "additional emissions: looking at rail from a life-cycle perspective" section.

[10] CBTC include Automatic Train Operation (ATO), Protection (ATP) and Stop (ATS) technologies.

Traffic Management System (ERTMS), which uses control, command, signalling and communication systems to ensure the inter-operability of trains across the region, primarily on conventional and high-speed rail networks.[11] All these technologies have the capacity to maximise network utilisation by reducing the headway between trains,[12] and they have also demonstrated effectiveness in reducing energy consumption by up to 15% (Dunbar, Roberts and Zhao, 2017).[13]

*Automated trains* offer the promise of improved safety, lower costs and improved energy efficiency,[14] beyond the level achieved by advanced traffic management and control systems. The rail sector defines “Grades of Automation” (GoA) under the International Electrotechnical Commission (IEC) 62267 standard, which range from fully manual operations, such as a tram operating in street traffic (GoA-0), to unattended, fully automated operations (GoA-4). The first fully automated metro (GoA-4) opened in 1981 in Kobe, Japan and there are now over 1 000 kilometres of GoA-4 lines in 42 cities worldwide, or around 7% of the total installed metro networks (UITP, 2018a; UITP, 2018f).

While the number of driverless metros is expanding rapidly on closed and secured lines, there are significant challenges in deploying fully autonomous trains on open, uncontrolled or unsecured lines (such as trams, intercity and freight lines). On this front, two examples of recent progress are the operation of a driverless freight train on a 280 kilometre heavy-haul line in Western Australia and the testing of the world’s first autonomous tram in Potsdam, Germany (Burroughs, 2018; Connolly, 2018). Efforts are underway to deploy autonomous driving technology in conventional rail services as well: to ensure compatibility between ERTMS and developments in automation. The European Union initiative “Shift2Rail” is working on potential standardisation and inter-operability of automated train operations with ERTMS (Siemens, 2016). In addition, the French rail operator, SNCF, has announced plans to deploy “semi-autonomous” trains by 2020 and fully automated trains by 2023 (Railway Gazette, 2018).

The use of other digital technologies such as big data analytics and artificial intelligence, also offer opportunities to significantly improve services for end-users through seamless integration across different modes and other measures.[15] They can also contribute to improving energy efficiency[16] and reducing costs for operators.[17] Digitalisation is also

[11] The ERTMS has two primary components: GSM-R (Global System for Mobile Communications - Railways) and ETCS (European Train Control System), (European Commission, 2018). GSM-R is a dedicated radio communication system for voice and data services. ETCS is a signalling and train protection system used to monitor train speed and movements.

[12] The ERTMS can enable capacity on existing tracks to be increased by 40%. Simulations of higher levels of ERMTS signalling (Level 2 and 3) demonstrate that utilisation could be more than doubled (ERTMS, 2018).

[13] The combined use of CBTC systems and DAS can result in additional energy savings. CBTC, coupled with more reliance on coasting, has demonstrated average energy savings of 16% in the Paris metro system (Urien, 2013).

[14] For example, fully automated train operations have the potential to reduce energy consumption by up to 20% by optimising driving patterns while taking into account other variables such as real-time weight and timetables (Trentesaux et al., 2018; Siemens, 2016; González-Gil et al., 2014; Douglas et al., 2015).

[15] In the Netherlands for example, Nederlandse Spoorwegen (NS) is testing its Zitplaatszoeker app, which uses colour-coded occupancy visualisation (using weight sensors on tracks) to help customers to find a seat and ensure a more even distribution of passengers and weight (Vosman, 2018).

[16] Massive volumes of data collected by sensors on trains and tracks can be analysed to optimise operations at the train and system level in real-time. Such data can be used to educate drivers on the practices best designed to reduce energy consumption, including through DAS. The potential energy saving of DAS range from 5-20%, depending on connectivity to traffic management systems, use of system-level optimisation and type of route (González-Gil et al., 2014; Institute for Futures Studies and Technology Assessment - UIC, n.a.; Douglas et al., 2015). Digital technologies can also enable optimised timetabling and planning of rail operations, favouring energy savings. For example, energy-efficient train timetabling (EETT) – i.e. developing an optimised timetable across a network to maximise energy-efficient driving – can lead to energy savings of up to 35% (Scheepmaker, Goverde and Kroon, 2017)

[17] The use of big data analytics and artificial intelligence can inform and improve maintenance regimes, helping to reduce costly repairs and downtime, improving safety outcomes and extending asset lifetimes. With the help of digitalized assets and data, condition-based and predictive maintenance reduce maintenance costs by up to 25%, or nearly EUR 17 billion globally per year (McKinsey and Company, 2017). Big data analytics on smarter components, like wheel bearings, can also provide insights to improve the design of future components, improving performance, extending lifetimes and reducing waste.

facilitating better integration of mobility services,[18] in both passenger and freight, in which there is strong potential for rail to play a central role.

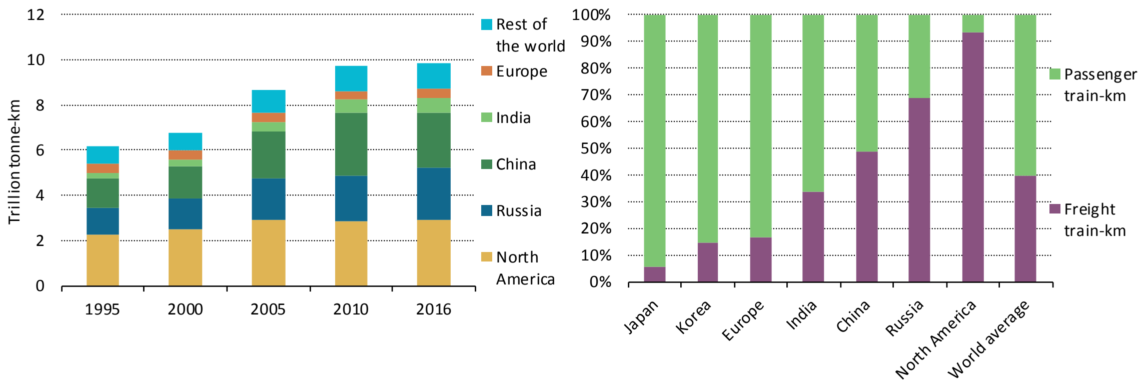
## *Freight rail*



Freight transport activity by rail, measured in tonne-kilometres per year, increased overall at an average pace similar to that of passenger rail over the past two decades. Activity growth from 1995-2005 was very rapid, but slowed between 2005 and 2010, and remained almost constant between 2010 and 2015 (Figure 1.16, left). Similar to passenger rail services, most rail freight activity is concentrated in a few regions, though not necessarily overlapping. North America, China, Russia and India have the highest levels of freight rail activity.

Comparing freight and passenger train-kilometres, Canada, Mexico and the United States (where rail infrastructure is primarily used for freight) freight train activity outweighed passenger train activity by 14 to 1 in 2016, (Figure 1.16, right). The primacy of freight rail is also discernible in Russia (2.2 freight train-kilometres for every passenger train-kilometre), in Brazil (1.9) and Australia (1.9).[19] By contrast, the European Union, Japan and Korea employ the rail networks primarily for passenger transport. These differences are reflected both in prioritisation policies and infrastructure ownership; for example freight trains get network priority in North America and South Africa, while passenger services are prioritised in the European Union, India and Japan.

**Figure 1.16 Freight rail activity in selected countries, 1995-2016 (left) and share of passenger and freight trains in total train-kilometres, 2016 (right)**




Note: In the figure on the left, freight volumes in Japan and Korea are too small to be visible so their freight activity is included in the rest of the world category. The most significant countries in the rest of the world are Australia, Brazil and South Africa.

Sources: IEA assessment, based on UIC (2018a); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); (Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

**Key message • Freight rail activity has risen steadily over the last twenty years. The ratio of freight rail activity relative to passenger rail activity varies significantly from country to country.**



[18] Often referred to as "Mobility as a Service" (MaaS).

[19] The context situation in Europe and the United States has been explored in the literature, including in the work of (Vassallo and Fagan, 2007).

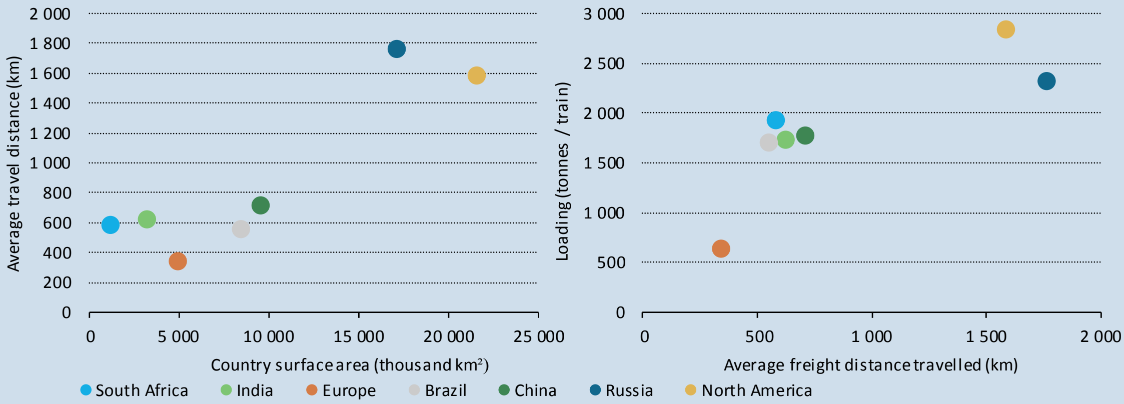
**Box 1.5 Usage patterns of freight rail services**



Countries characterised by strong reliance on freight rail for the movement of goods tend to be those having both high train loading and long distances to cover (Figure 1.17). Countries with such large surface areas and abundant raw material resources include Russia and the United States, where freight rail journeys are characterised by the longest average distance worldwide (more than 1 600 kilometres, twice the world average) carried on freight trains which are among the largest in the world, with average loads ranging between 2 200 and 2 900 tonnes per train.

Average distances are less in China and India (between 600 and 900 kilometres) and so are loads (1 500 to 2 000 tonnes per train, the same range as the world average). Europe and Japan have the lowest average distances (less than 400 kilometres in the European Union) and loads (less than a third of the values of Russia and North America and less than half of the global average).

**Figure 1.17 Average freight transport distance versus country surface area (left) and train loading versus average transport distance (right), 2016**



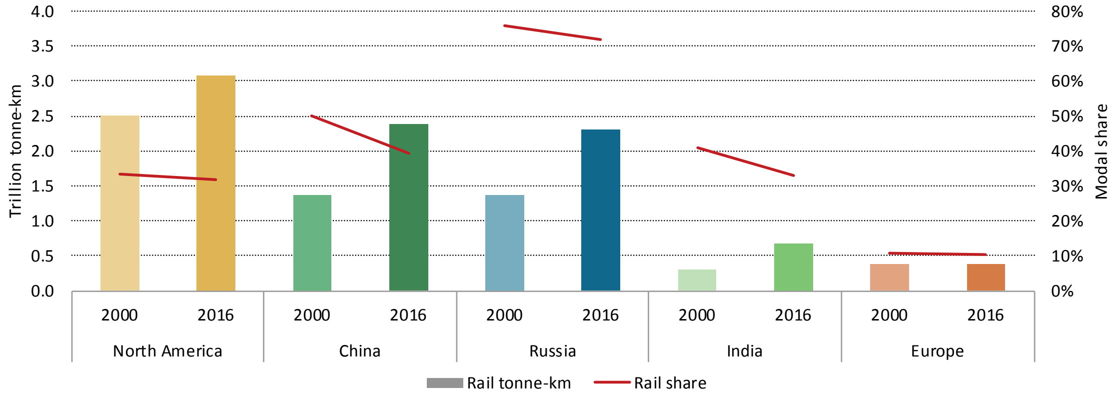

Sources: IEA assessment, based on UIC (2018a); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); AAR (2017) and Russian Federation State Statistics Service (2018).

Key message • **Average freight rail distances are typically higher in large countries and long-distance trains generally carry high freight loads.**

The share of total goods moved by rail varies widely across countries (Figure 1.18). By far, Russia has the highest share with over 75% of all surface goods transport being moved by freight trains. In China the share is 39%. In the North America and India, rail makes up over 30% of surface freight transport, close to the world average (28%). The share is significantly lower in the European Union, 10% in 2016, while in Japan and Korea it is less than 5%.

Most surface freight is otherwise transported by heavy trucks (above 16 tonnes), 45% of surface goods transport on average in 2016. With rail accounting for 28%, medium trucks, light commercial vehicles and three-wheelers make up the remaining 27%. Even though rail has limited opportunity to replace intercontinental shipping, this freight category should certainly not be neglected as a potential market, which accounted for 73% of all freight tonne-kilometres in 2016.

**Figure 1.18 Freight rail activity and share in total surface goods transport**




Note: The percentages give the share of rail among all surface freight modes. Intercontinental shipping and air freight are excluded, with shipping being several orders of magnitude larger than air freight.

Sources: IEA Mobility Model (IEA, 2018a) using assessments based on UIC (2018a); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); (Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

Key message • **Since 2000, freight rail activity has increased significantly in absolute terms in most countries while the rail modal share has decreased.**

# What shapes rail transport?

Most large passenger rail networks were built with the assistance, at least to some extent, of a central authority, typically public, that assumed part of the risks. As a capital-intensive business, rail requires clarity of political intention and a solid business case for commitments to be made.[20] A solid business case depends upon the adequate demand as in large population centres or freight hubs that generate high demand for transportation volumes sufficient to pay back the significant investments.

Maximising the use of railway capacity is critical for economic viability, as it reduces unit cost and maximises revenues. Once the most important demand centres are connected, rail networks develop further, as opportunities arise for higher capacity utilisation derived from interconnected lines.[21] Operators may decide to prioritise passenger or freight rail, depending on country-specific circumstances. In their best configuration, rail networks become part of a seamless framework of mobility services, playing a core role in passenger and freight mobility overall.

## *Passenger rail*

Key examples of major investments in the initial development of passenger rail lines include:

- Development of urban rail networks, first in Europe and Japan, over the course of the 20th century and, more recently, in China and other emerging economies in Asia.

[20] As in the case of any major investment in large transportation infrastructure (i.e. oil or gas pipelines), a guarantee of long-term and sizeable use is required.

[21] Interconnections are important to strengthen capacity utilisation, as demonstrated by the benefits derived from the development of multiple metro lines in a given urban area.

- Development of high-speed rail lines, first in Japan, with the Shinkansen network development that started in the 1960s, then in Europe, spearheaded by the French TGV and most recently in China.
- Development of long-distance conventional rail networks in Europe, Japan and India over the course of the 20th century, before competition from aviation became a serious threat.



The best opportunities for urban rail networks arise in very big cities with large and concentrated populations, since they are the areas most likely to experience congestion and negative impacts of poor air quality. Large, dense cities can guarantee high levels of demand for passenger rail services from people living within the catchment of each station.[22]

In the case of conventional and high-speed services, the strongest opportunities for rail arise in cases where the centres of transport demand are:

- Within distances that enable rail to compete effectively, in terms of the overall journey time, against the most relevant alternative (road transport for conventional rail, both road and air transport for high-speed rail).
- Large enough to justify a high frequency of service along the lines.

These situations typically arise in cities with a large population, which are located roughly 300 to 1 000 kilometres apart, and where the average level of income creates sufficient demand for long-distance travel.

The most commercially successful rail networks are those which are effective in maximising capacity utilisation, in cutting costs and in supplementing revenue from ticket sales by generating revenue from related activities (particularly land value capture, i.e. the increase in land values arising from capitalising on high levels of activity around railway stations).[23] Metros and high-speed rail lines lead the way in terms of high capacity utilisation (see Figures 1.4, 1.14 and 1.27). Land value capture has been most successfully exploited in Japan and Hong Kong, China,[24] and automation and the reorganisation of services placing stronger focus on lines having the highest frequentation proved its crucial role in cutting costs (Siemens, 2016; Mazzola, 2018).

High capacity public transport is a crucial element in facilitating mobility in large metropolitan areas, where rail services effectively reduce reliance on road networks, thereby reducing congestion, as well as local pollution and GHG emissions. High-speed rail also provides links between satellite cities and metropolitan areas, enhancing so called agglomeration economies (Fang, 2013). For these reasons, passenger rail has often been supported by public policies. The most notable example in this respect is the imposition of public service obligations in the European Union.[25]

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[22] People can generally be expected to walk to a station that is within a range of 500 metres (Louf, Roth and Marc, 2014), or they may access it through other means of local transport.

[23] Land value capture has been a significant method of funding for various (typically urban) projects. The opportunity arises where the rail transport network developers purchase land at pre-railway prices and develop residential, commercial and tertiary facilities, enabling them to capture the increase in property value induced by the railway operations. Governments may share in the risks and rewards by direct investment or through the taxation of higher value properties. The anticipated change in property value can mobilise debt financing.

[24] In Japan, over 30% of the revenue of JR-East (a regional railway operator) comes from non-transport sources, e.g. leasing office buildings, shopping centres (JR-East, 2017). In Hong Kong, China, non-transport sources produce over 60% of the revenue of the Mass Transit Railway, the city's public transport operator, (MTR - Mass Transit Railway Hong Kong, 2016).

[25] Public service obligations can be imposed on operating companies by legislation or by means of a remunerated contract to reward public services not fully compensated by a commercial market. In the case of passenger transport, the case for

## Freight rail

High freight rail transport activity is normally related to the existence of large landlocked resources that can be effectively exploited if traded widely and often over long distances both on a domestic basis and as export-oriented industrial clusters that require the transport of significant quantities of goods or large volumes of commodities.

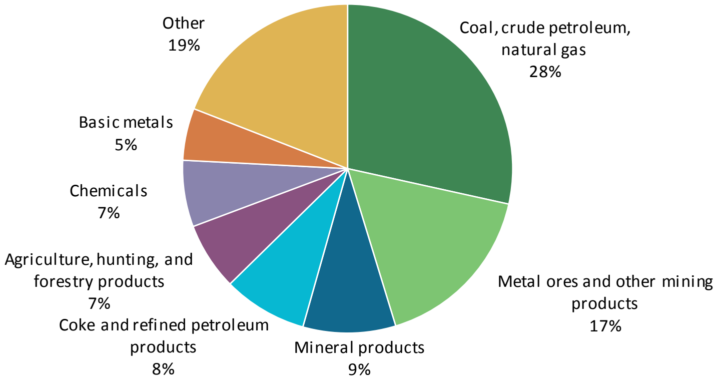
- *Russia* is a clear example. It has abundant supplies of coal, timber and minerals, most of which are located in Siberia and the eastern part of the country, while the main centres of economic activity are primarily in the west. To facilitate and expand international trade of such resources requires the movement of goods to the country's ports, along its eastern and western coastlines. In consequence, Russia has built an extensive rail network (primarily used for freight) to serve the coastal ports, as a contribution to the development of its economy. This is reflected in the very high share of rail freight in transport activity (over 50% of the total tonne-kilometres of the country, including maritime shipping) (IEA, 2018a).
- In the *United States*, 32% of the total mass transported by freight train was coal, followed by grain and grain mill products with 13% and chemicals at 11% (AAR, 2017). Another 11% of the activity is attributed to intermodal transport, largely shipping containers, which contribute 20% of gross rail freight revenue.
- Freight rail in *China* moves inland resources over long distances to the coastal parts of the country, demonstrating the relevance of rail for export-oriented industrial clusters.
- In *India*, freight rail is currently dominated by the movement of bulk materials, especially coal, and the carriage of large quantities of bulk goods to large demand hubs.
- In *Australia* and *South Africa*, freight rail benefits from the availability of large quantities of primary materials (in particular, coal and other mining products) and their export.[26]

Coal and mineral products have been, to date, the most common type of freight transported by rail around the world (Figure 1.19). The lower reliance on freight rail in Europe, Japan and Korea reflects industrial structures which rely to a lesser extent on the primary sector and the shorter distances between the main industrial clusters and major ports.

intervention in the public interest may rest on issues of social pricing, accessibility and environmental benefits. In the case of major European rail operators like the *Société Nationale des Chemins de fer Français* (SNCF) (France), *Deutsche Bahn* (DB) (Germany) and *Ferrovie dello Stato* (FS) (Italy), subsidies for public services accounted for, respectively, 28%, 30%, and 26% of the revenue of passenger businesses, while non-subsidised passenger revenue covered 91%, 81%, and 61% of the costs associated with operating the related passenger services (SNCF Mobilités, 2016; Deutsche Bahn, 2016;FS, 2016).

[26] The narrow gauge heavy-haul coal and iron ore export railways in South Africa are notable examples of the successful exploitation of rail's economic fundamentals. Train weights of 35 000 tonnes are achieved (ten-times more than the average North American train weight); and, as an example, on the iron ore line, the tariff is less than USD 0.01 per tonne-kilometre, while remaining a profitable business for the freight railway.

**Figure 1.19 Shares of materials transported by freight railways worldwide, 2016**




Note: Materials measured in tonnes.

Sources: (AAR, 2017), National Bureau of Statistics China (2017); Indian Railways (2018a); Statistics Canada (2016); Globaltrans (2017); UIC (2018); SAFF/SIADE (2017); Ukrstat (2018); Transnet (2016); Agencia Reguladora del Transporte Ferroviario (2016).

Key message • **Minerals, coal and agricultural products account for the bulk of total freight rail activity.**

Three categories of rail activity catering for freight may usefully be distinguished: mature and market-driven railways prioritising freight movements; mature railways which prioritise passenger movements, but also provide freight services; and developmental railways.

Mature and market-driven railways prioritising freight movements are characteristic of the United States and Canada. Freight rail started there with an initial period of route and infrastructure growth, which was followed by a rationalisation phase. This phase was driven by free market principles – represented, for the United States, by the 1980 Staggers Rail Act (United States Public Law 96-448, 1980), providing for the deregulation of rail transport in order to achieve higher network density, the lowest possible operating costs and high levels of customer satisfaction. These are railways where freight trains are prioritised, enabling operators to optimise their schedules to meet the needs of their freight customers.[27]

Mature railways prioritising passenger movements are usually also open to freight services. This is the case with respect to the large European railways (such as those in France, Germany and Italy). These are systems that were based, originally, on uncoordinated route and infrastructure growth, but industrial maturity has resulted in interlinked economic centres, freight corridors and ports exhibiting benchmark efficiencies. However, inter-operability barriers persist and the prioritisation given to passenger rail limits the optimisation of freight transport.[28]

Developmental railways are those where expansion of the network is deliberately fostered as a contribution to social and economic development through the provision, *inter alia*, of improved access and high employment. The best examples are to be found in China, India and Russia.

[27] If freight is prioritised, infrastructure investments are directed towards increasing the freight capacity of the system (increasing train lengths, load carrying capacity of tracks, changes in terminals and sidings, or increasing clearance for double stacking containers), meaning that one train can carry more cargo. As an example, moving the same amount of freight in Europe, compared to the United States, requires more than four-times the number of trains (UIC, 2018). A negative of prioritising freight rail is that passenger rail services become less reliable and struggle to compete with alternative transport.

[28] The prioritisation of passenger transport typically involves a requirement for reliable, on-time services through structured, planned and scheduled operations, with timetables often being developed months in advance. This generates constraints for freight operators, both on access to the network and dispatching trains. These constraints reduce both the competitiveness of freight rail over competing modes and opportunities for growing market shares.

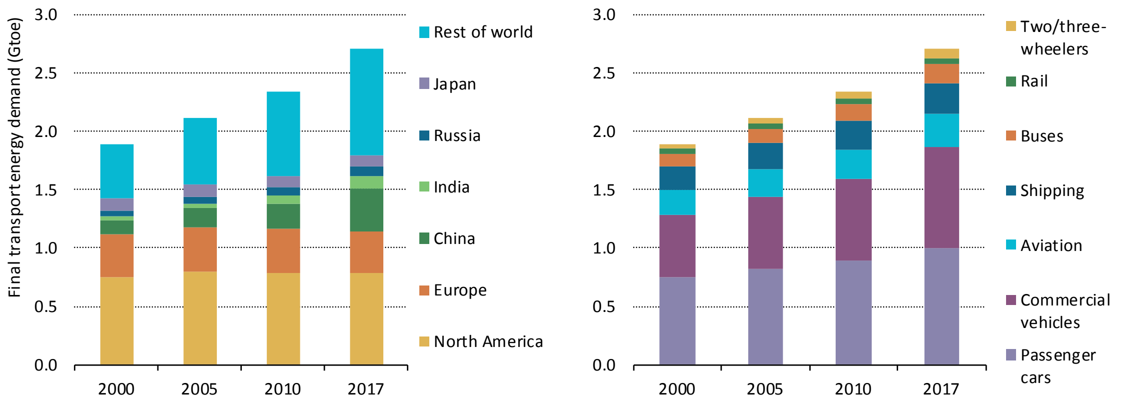
# Rail transport and the energy sector

## *Energy demand from rail transport*

On a global basis, the transport and industry sector each account for 29% of final energy use, the residential sector for 22% with the remainder used in commercial and public services, agriculture and others (IEA, 2018b). Within transport demand, the European Union and North America are the source of the world's highest energy requirements, but emerging economies, such as China, India, South Africa and Brazil are catching up quickly (Figure 1.20). Railways today consume close to 2% of transport final energy use, a modest share relative to road, maritime and air transport, especially since rail constitutes a much higher share of transport activity (8% of total passenger-kilometres and 7% of total tonne-kilometres).



**Figure 1.20 Final energy use in transport by region and mode, 2000-17**




Note: Gtoe = gigatonnes of oil equivalent.

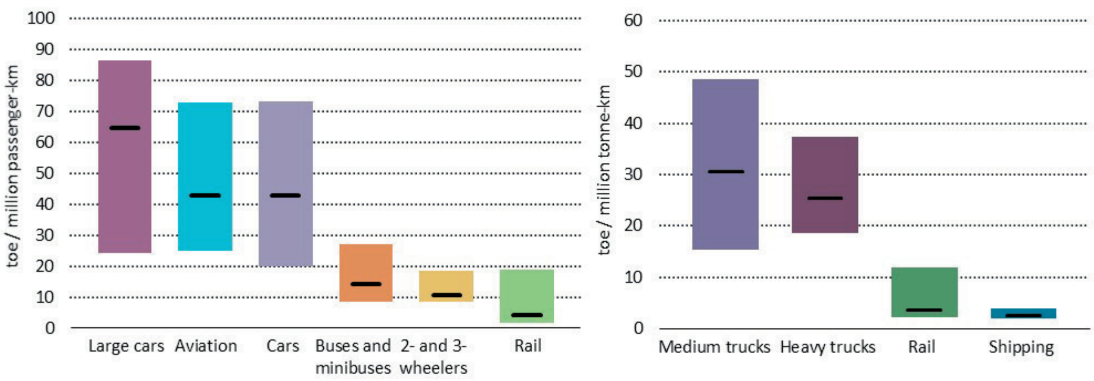
Sources: IEA Mobility Model (IEA, 2018a), using assessments based on UIC (2018a); UITP (2018d); ITDP (2018); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

Key message • **Energy demand from the transport sector has risen significantly in the past decade, driven mostly by growth in Asia and by demand in road transport.**

The key reason for the gap between its share of activity and its energy use is rail's much better energy efficiency, compared with road transport and aviation (Figure 1.21). When expressed as final energy use per passenger-kilometre or tonne-kilometre, the energy intensity of rail generally significantly outperforms other transport modes given its unique characteristics.[29]

[29] Moving passengers and goods by rail is more energy efficient than by road by a wide margin. Rolling friction losses of steel-to-steel contacts are far lower than those of rubber tyres (on the order of 85-95% lower than those of truck tyres, for instance). Trains also benefit from the higher performance of electric motors versus internal combustion engines as well as high capacities, capable of transporting very large passenger and goods volumes per vehicle. In addition, rail has the advantage of infrequent stopping, with traffic segregation and right-of-way.

**Figure 1.21 Energy intensity of different transport modes, 2017**

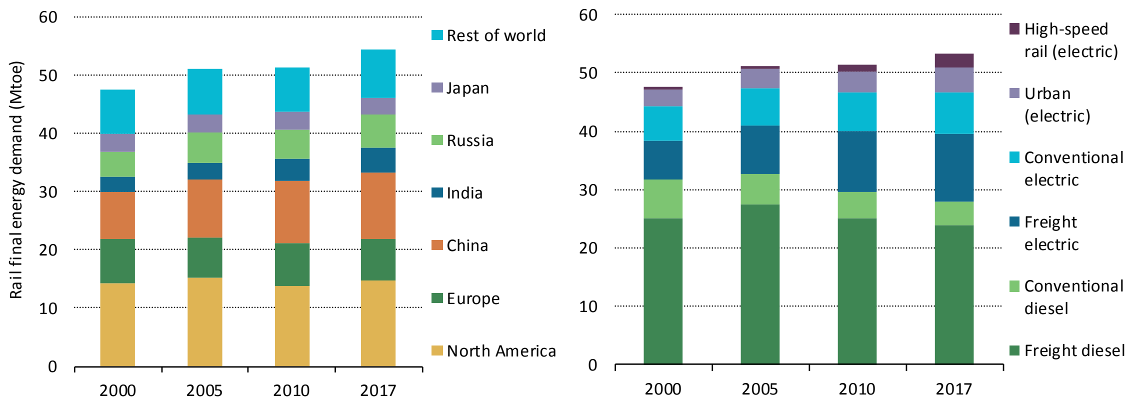



Notes: toe = tonne oil equivalent. The boxes in this figure indicate the range of average energy intensity in various countries, while the horizontal lines represent the world averages.

Sources: IEA Mobility Model (IEA, 2018a), using assessments based on UIC (2018a); UITP (2018d); ITDP (2018a); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

Key message • **Rail is the most energy-efficient means of motorised passenger transport, much more energy efficient than road freight.**

**Figure 1.22 Final energy demand in rail transport by region and type, 2000-17**




Note: Mtoe = million tonnes of oil equivalent.

Sources: IEA assessment based on UIC (2018a); UITP (2018d); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

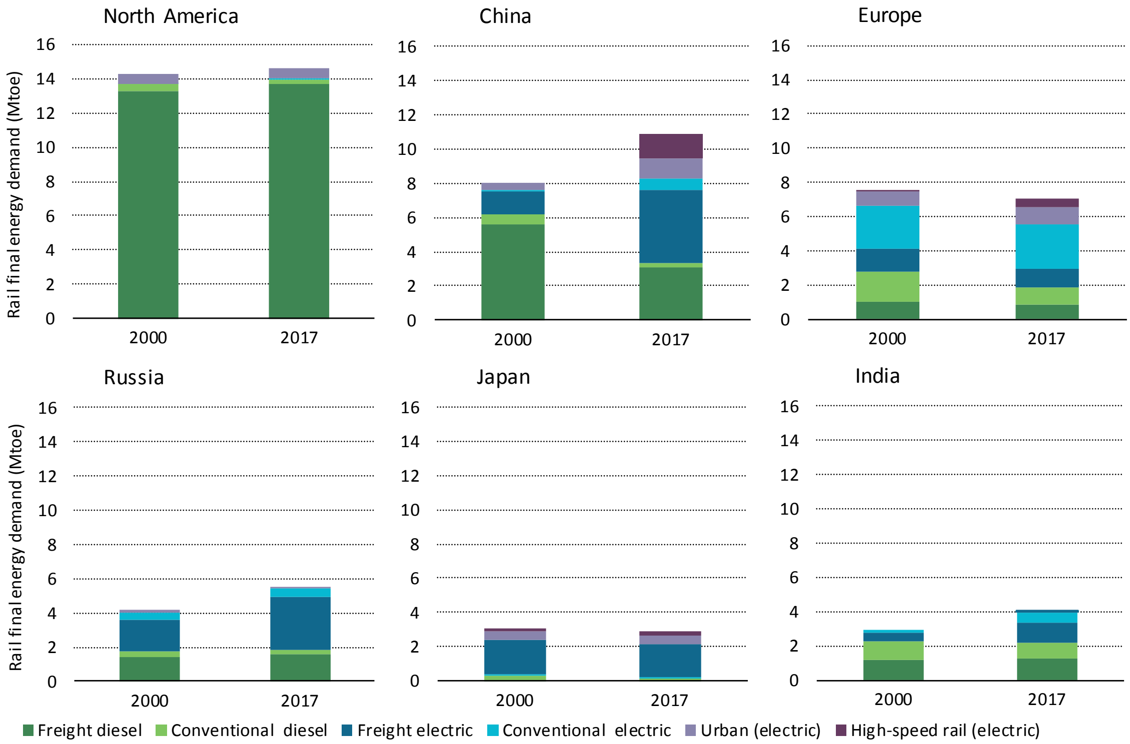
Key message • **Overall, rail energy demand has remained relatively constant in recent years. Today, diesel freight trains account for roughly half of rail energy use.**

The trend of energy use in rail has varied considerably across countries (Figure 1.22). Since 2000, energy use for passenger transport has grown significantly in China and India. Energy use in rail also has increased in Japan, albeit more slowly, while it has slightly declined in the European Union, Russia and the United States, broadly mirroring trends in overall activity.

Rail is a significant energy consumer, but it is also a significant contributor to reducing energy demand. If all passenger and freight traffic currently served by rail transport were carried by alternative transport modes, global oil demand from transport today would be 16% higher (by 8 million barrels per day [mb/d]).[30]

**Figure 1.23 Final energy demand in rail transport by region and type, 2000 and 2017**






Notes: Mtoe = million tonnes of oil equivalent. The data shown are the result of a bottom-up analysis of data provided by the cited sources, calibrated using data from the top-down analysis of the IEA World Energy Balances database (IEA, 2018b). Small divergences may arise between the latter and the data used for the figure due to different modelling methodologies.

Sources: IEA Mobility Model (IEA, 2018a) using assessments based on UIC (2018a); UITP (2018b); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

Key message • **Energy demand for rail has declined in the European Union and Japan, remained constant in North America and increased in Russia, China and India in the period since 2000.**

Electricity constitutes 47% of rail energy use, amounting to 290 terawatt-hours (TWh) (or 25 million tonnes of oil equivalent [Mtoe]) today, while diesel accounts for 53%, roughly equivalent to 29 Mtoe, or 0.6 mb/d (Figure 1.22, right). About 55% of electricity use in rail transport is for passenger services, and most of the diesel (85%) is for freight services. Countries with the highest shares of electricity use for rail transport tend to be those with the most passenger rail activity. For example, in the European Union, Japan and Korea, passenger trains account for well over 80% of train-kilometres and use electricity, whereas in the United States, passenger trains account for only 7% of train-kilometres and of which only 1% are fuelled by electricity. China, India and Russia fall somewhat in between, with 45% to 65% of all rail energy use in the form of electricity and 30% to 65% of all train-kilometres travelled by passenger



[30] This assessment accounts for total product demand and the refining losses associated with it. However, it considers primary energy only, and not the conversion and transmission of electric power. For passenger transport, average energy intensity for road transport and aviation is taken into account to assess avoided energy demand. Energy intensity of heavy freight trucks is considered to asses avoided energy demand from freight transport.

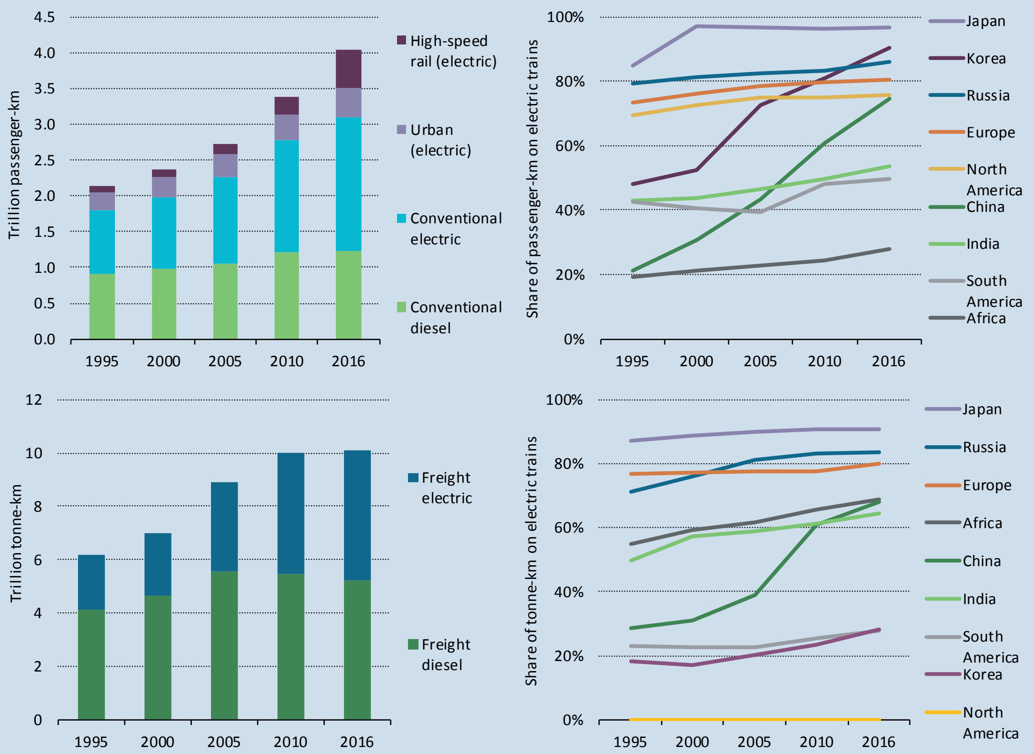
trains. Further details on the forces behind rail transport electrification and, in particular, on the key determinants of these energy demand figures are presented in Box 1.6.

### Box 1.6 Electrification of rail transport



Today, three-quarters of passenger rail transport activity takes place on electric trains, which is an increase from 60% in 2000, with the rest served by trains using diesel fuel (Figure 1.24).[31] These figures take into account virtually all urban rail activity, all high-speed rail activity and most conventional rail activity. For freight rail, electric trains accounted for 48% of the total tonne-kilometres in 2016 (one-third in 2000). The regions with the highest share of electric train activity are Europe, Japan and Russia, while North and South America still rely heavily on diesel.

**Figure 1.24 Passenger and freight rail transport activity by fuel type (left) and share of activity on electric trains (right), 1995-2016**



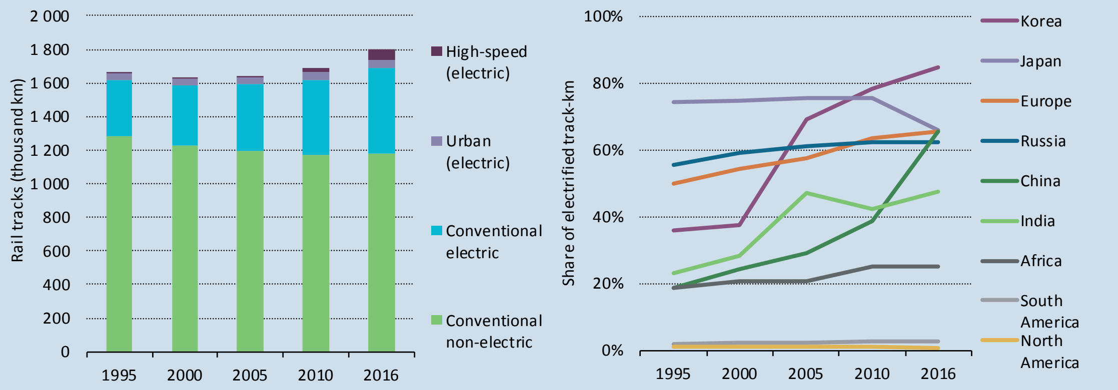

Sources: IEA Mobility Model (IEA, 2018a) using assessments based on UIC (2018a); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

Key message • **Global rail activity is slowly shifting towards electricity for both passenger and freight transport.**

The importance of electric rail activity for passenger services contrasts with the dominance of non-electrified lines in rail networks (Figure 1.25). While three-quarters of passenger-kilometres and around half of tonne-kilometres worldwide are carried by electric trains, only one-third of rail tracks are equipped with electrical infrastructure.

[31] Historically, the first trains used coal and a boiler to fuel steam engines. Such technology was still marginally used in China (National Bureau of Statistics of China, 2018) and India (Indian Railways, 2018b) until the early 2000s, when it was fully discarded. Few trains use natural gas as a fuel. Very recently, pilot projects for hydrogen-powered trains have been undertaken in Germany (see Chapter 2, Box 2.1). These are not included in this discussion.

**Figure 1.25 Share of electrified rail tracks, 1995-2015**




Sources: IEA Mobility Model (IEA, 2018a) using assessments based on UIC (2018a); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

**Key message • Rail tracks have been progressively electrified, with the strongest efforts made in China, India and Korea.**

The differences in electrification between passenger-kilometres, tonne-kilometres and track-kilometres reflect the following dynamics:

- The United States relies completely on diesel for freight rail transport, while other countries (including Russia and South Africa) rely predominantly on electricity for freight rail transport.[32]
- Passenger rail is significantly more electrified than freight in almost all regions: on average 74% of all passenger-kilometres are on electric trains and 48% of freight tonne-kilometres are carried by electric trains.
- Electrified rail routes have higher utilisation rates than non-electric ones. On average, electrified lines carry five-times more passenger-kilometres per kilometre track than non-electrified lines, and twice as many tonne-kilometres. This reflects the priority given to electrification of rail network segments with high activity, where payback periods for the investment costs are shorter.
- Regions with higher reliance on urban rail and high-speed rail are those with the largest share of passenger-kilometres served by electricity, while other regions rely more on diesel. This is because urban rail and high-speed rail are fully electrified, due to technical requirements, and enjoy high network utilisation rates, justifying higher investment costs.[33]

## *Energy intensity of rail transport services*

Major factors influencing the energy intensity of rail transport (expressed in terms of energy per passenger-kilometre or per tonne-kilometre) include:

- Changes in the specific energy consumption of trains (energy/train-kilometre).

[32] For freight rail, the practice of stacking containers to maximise train loads may sometimes be a limiting factor for freight rail electrification. This is because maintaining the height limitation imposed by the presence of overhead line electrification (OLE) infrastructure means that maintaining the overall load while electrifying the tracks would require the use of much longer trains or the use of the "third rail" approach (rather than OLE). Both longer trains and third rail electrification would add costs. The solution of longer freight trains, combined with OLE, has been adopted in Russia, where electric freight trains are fully capable of transporting massive volumes of goods over very long distances.

[33] Note also that electric trains are significantly more efficient than diesel-electric, especially in situations where rapid acceleration and frequent starting and stopping are necessary, a pattern that is characteristic of urban rail. The rapid acceleration of high-speed trains can only be achieved with electric trains.

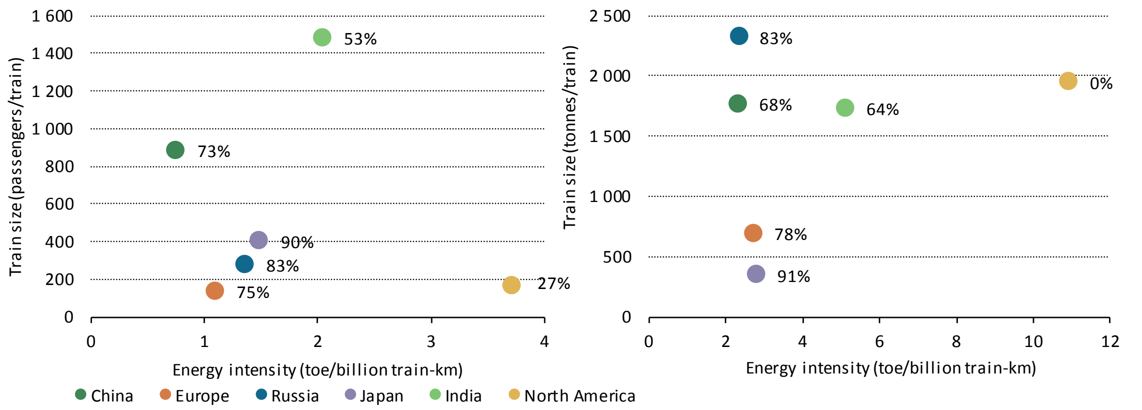
 

- Variations in train capacities and their utilisation rates (leading to different rates of passenger-kilometre per train-kilometre, or tonne-kilometre per train-kilometre).[34]



As discussed, the specific energy consumption of trains depends largely on powertrain types and train size. The positive relationship between energy intensity and train size is explained by the simple fact that more energy is needed to move larger volumes of people and goods, especially at low speed and in the absence of regenerative braking. All else being equal, electric trains are less energy intensive than diesel trains because electric motors have much higher thermodynamic efficiencies than internal combustion engines. Electric motors are also much better placed to enable regenerative braking, minimising inertial losses (especially relevant in the case of frequent stops). As a result, countries with large shares of trains running on electricity tend to have lower energy demand per train-kilometre for similar sized trains (Figure 1.26).

**Figure 1.26 Specific energy consumption of passenger (left) and freight (right) trains as a function of train size and the share of electric activity, 2016**




Notes: toe = tonne oil equivalent; MJ = megajoule. Percentages represent the share of train-kilometres using electricity. Train sizes are represented by the ratio of passenger-kilometres (or tonne-kilometres) to train-kilometres. This would be a good indicator of size if all trains had the same capacity and capacity utilisation rate. In reality, this is not the case. Urban rail services, for example, are designed to provide greater capacity per wagon than other types of passenger rail services. The choice of ratio of passenger-kilometres (or tonne-kilometres) and train-kilometres as an indicator of train size is dictated here by limited data availability.

Sources: IEA Mobility Model (IEA, 2018a) using assessments based on UIC (2018a); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

**Key message • Rail systems that use small trains and have a high share of electric traction have lower energy consumption per train-kilometre.**

Variations in train capacities and their utilisation rates depend on the specific circumstances of each region. Such conditions include the state of economic development, nature of the transport demand (passenger or freight) and the geographic and structural characteristics of the region.

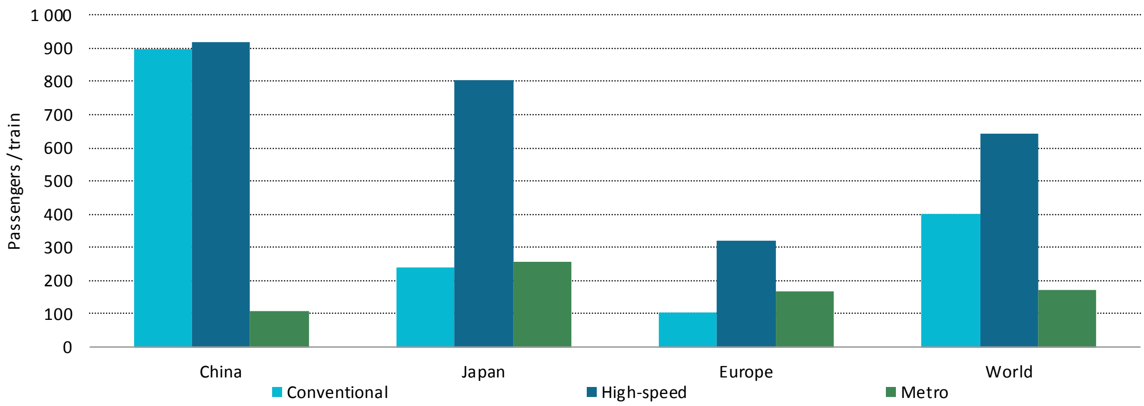
As discussed in Box 1.3, income level has a strong correlation with occupancy rates for all passenger rail services (Figure 1.14). In addition, long freight distances usually imply high freight train capacities and loads (Figure 1.17). These are important factors affecting the energy intensity of rail transport. Figure 1.27 shows the variation of train occupancy across different

[34] The trends shown in Figure 1.26 are determined by the combined effect of activity developments and the evolution of energy intensities (energy/passenger-kilometres and energy/tonne-kilometre).

passenger rail service types (urban, conventional and high-speed), looking specifically at China, the European Union and Japan, the regions with the largest volumes of passenger traffic for conventional, high-speed and metro rail. The comparison shows that high-speed rail occupancy (and consequently energy efficiency) is significantly higher than for other rail modes, even though higher speeds require more energy. Average train occupancies are two- to three-times higher in China and Japan than in the European Union.



**Figure 1.27 Average train occupancy across different passenger rail service types in key regions, 2016**



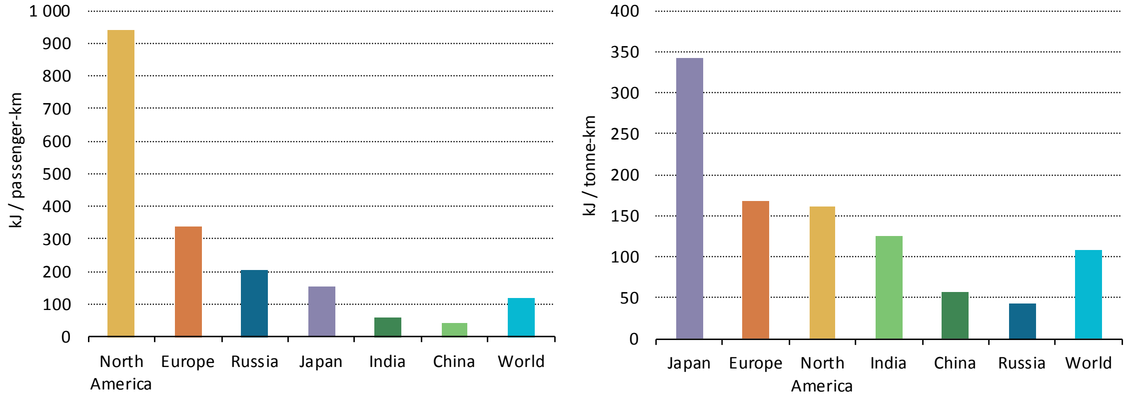

Sources: IEA Mobility Model (IEA, 2018a) using assessments based on UIC (2018a); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

**Key message • High-speed rail typically transports between one-third and three-times more passengers per train than conventional rail.**

The combined effect on the energy intensity of rail services of changes in specific energy consumption, capacities and utilisation rates on the energy intensity of rail services is summarised in Figure 1.28. For passenger rail, the countries with the lowest energy use per passenger-kilometre are China and India, largely because of high train occupancy and loads. Japan is third with the highest share of electric passenger transport and high passenger load factors (see Box 1.3). Even though European trains are highly electrified, they are more energy intensive per passenger-kilometre than the world average, due to lower occupancy rates than in Asia. Trains in the United States consume three-times more energy per passenger-kilometre than those in Europe because of their low occupancy and the low rate of electrification.

Energy use for rail freight also shows a strong dependency on train loading. Russia stands out as the most energy-efficient freight rail system, thanks to a high share of electric traction and high loads. The United States has the highest freight loading, giving it the best energy efficiency per tonne-kilometres of trains using diesel (essentially the only fuel used for freight rail in the United States). China, Brazil, India and South Africa have comparable characteristics of specific energy use and train loads. The European Union and Japan are less energy efficient per tonne-kilometre, due to significantly smaller loads.

**Figure 1.28 Energy intensities of passenger (left) and freight (right) rail, 2016**




Sources: IEA Mobility Model (IEA, 2018a) using assessments based on UIC (2018a); National Bureau of Statistics of China (2018); Eurostat (2018); Indian Railways (2018a); Japan Ministry of Land, Infrastructure and Tourism (2018); AAR (2017) and Russian Federation State Statistics Service (2018).

**Key message • Trains in the United States and the European Union are less energy efficient per passenger-kilometre than trains in Asia, primarily due to lower occupancy. Freight trains in Russia and China are the most energy efficient due to high loading and electrification.**

## GHG emissions and local pollutants

In this report, the environmental factors related to rail transport focus primarily on GHG and local pollutant emissions. Local pollutants have the greatest impact on human health in densely populated urban areas (see Box 1.8). Other environmental impacts (e.g. those related with land-use change, habitat disruption, effects of noise and visual disruption, impacts of mineral extraction related to the high steel and concrete demand, as well as consequences of the use of pesticides on rail tracks) are not assessed here.

### *Well-to-wheel GHG emissions in rail transport*

In 2016, the transport sector as a whole accounted for 24% of direct $CO_2$ emissions from fuel combustion, or 7.9 gigatonnes (Gt) (IEA, 2018b).[35] Rail transport accounted for 89 million tonnes (Mt) of these $CO_2$ emissions, or 0.3% of total energy-related emissions. Measured on the more comprehensive well-to-wheel (WTW)[36] basis and including all GHG emissions, 230 Mt carbon-dioxide equivalent ($CO_2$-eq) were emitted. Compared with other modes, passenger rail accounted for less than 2% of all WTW GHG emissions from passenger transport, a figure comparable with rail's share (1.1%) of final energy use by all forms of passenger transport, and well below the 8% share of passenger rail in total passenger-kilometres travelled in all forms of transport. In transporting freight, trains released around 4% of all the WTW GHG emissions of the freight transport sector as a whole, a similar figure to the 3% share of freight rail in total final energy use and lower than rail's share (7%) of all freight transport activity.

[35] Direct emissions from other sectors include electricity and heat production with 41%, manufacturing industries and construction with 19%, residential sector with 6% and others 10%. Direct emissions, in contrast to well-to-wheel emissions, only account for emissions from direct fuel combustion, neglecting the impacts of extraction, transport and refining.

[36] Well-to-wheel emissions include the sum of emissions due to the conversion of fuel to kinetic energy for vehicle propulsion during combustion or use in the vehicle (tank-to-wheel) plus those occurring to produce, store and transport the fuel (or energy carrier) to the vehicle (well-to-tank).

**Box 1.7 Sector coupling: linking renewables-based power generation with rail power demand**

As rail is the only mode of transport that is widely electrified today, it is uniquely positioned to take advantage of the growing role that renewable forms of energy are playing in electricity mixes. Many railway operators take this further, ensuring that they source their energy from renewables, thus reducing the overall carbon intensity of the transport services they offer.



In Europe, rail companies purchase renewable energy certificates and guarantees of origin which, in 2017, on average, contributed to reducing specific passenger $CO_2$ emissions by over 15%, compared to electricity sourced directly from the national grids. Freight specific $CO_2$ emissions were reduced by only 6%, suggesting that sector coupling measures were more frequently adopted in the presence of a direct relationship with consumers than in case of business-to-business relationships (UIC, 2017b). Since 2017, NS, the railway company in the Netherlands, has sourced all of its tractive energy from domestic wind installations and others in Belgium and Scandinavia, resulting in no net $CO_2$ emissions (NS, 2017). Also in 2017, renewable energy sources accounted for 42% of Deutsche Bahn's traction energy mix, on the way to its goal of achieving $CO_2$ free rail transportation by 2050 (DB, 2018).

Worldwide, rail operators and infrastructure managers are increasingly taking advantage of the land they own to reduce dependence on the grid by operating their own renewable energy production means. For example, as of 2018, Japan Rail-East operates wind turbines, solar panels and a 12.4 megawatt (MW) biomass power plant (JR-East, 2017). The railway operator in Switzerland (SBB CFF FFS) owns and operates six hydroelectric plants, which provide around 75% the company's traction power needs, while Austrian Railways (ÖBB) have installed hydropower capacity of 279 MW (UIC, 2017b). In Santiago, Chile, the city metro operator built two solar photovoltaic power plants in 2017, which supply 60% of the metro's energy use, bringing the share of energy sourced from renewables to 76% (Metro de Santiago, 2017).

**Box 1.8 Opportunities for rail to reduce air pollution**

Air pollution is a major externality of the transport sector and poses health risks especially to urban populations. In 2015, transport accounted for 53% of global nitrogen oxides ($NO_X$) emissions and for 11% of total particulate matter (PM) emissions (IEA, 2018c). Rail transport accounted for 4% and 5% of total transport-related $NO_X$ and PM emissions.

Almost all cities (98%) with more than 100 000 inhabitants in low- and middle-income countries are exposed to air quality levels which exceed World Health Organization (WHO) limits.[37] This percentage is 56% in developed economies (WHO, 2018). Urban air pollution from transport originates from fuel combustion in the internal combustion engines of two/three-wheelers, passenger cars, buses and commercial vehicles, as well as from non-tailpipe pollutant emissions, including the wear and tear of brakes and tyres. Many countries have imposed tailpipe pollutant emission standards for passenger cars, such as the Euro standards, which set permissible emissions per vehicle-kilometre for pollutants such as carbon monoxide (CO), $NO_X$ and PM. Global best practice on emission standards (e.g. Euro VI for trucks and Euro 6d for cars, or Tier 3 standards in the United States) do effectively reduce pollution from road traffic. But many low- and middle-income counties have yet to adopt best practice. Moreover, actual driving emissions have been widely found to significantly exceed regulated limits (Bernard et al., 2018).

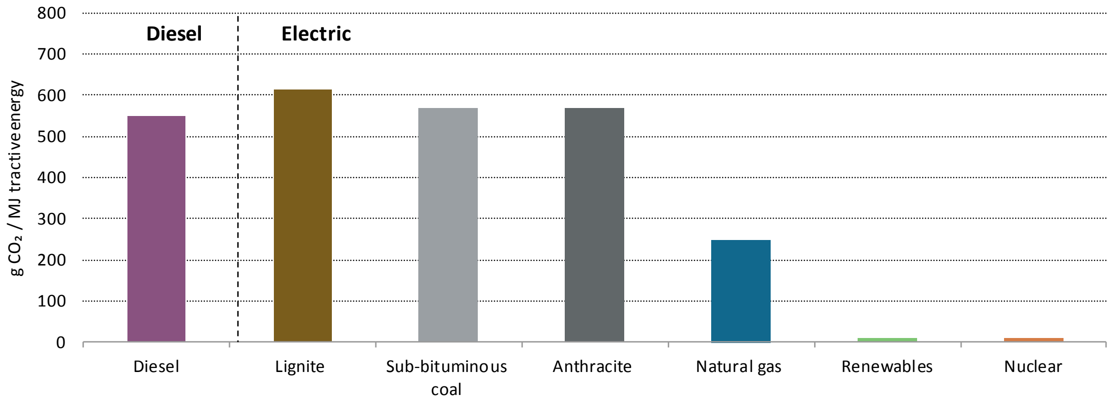
[37] Lower income populations also are more affected by key negative externalities from transport, such as air pollution and road accidents (Rode et al. 2014; Drabo, 2013).

In cities with good scope to limit personal vehicle ownership by offering all-electric transport options, rail is well placed to contribute significantly to reducing air pollution, particularly in developing countries.[38]



The carbon intensity of WTW GHG emission is the crucial factor explaining the differences between energy and GHG emission shares. Carbon intensity depends on the type of traction used by the trains (primarily diesel or electric), on the energy intensity of the rail service considered and on the WTW carbon intensity of the energy used. The carbon intensity of diesel traction does not vary significantly across regions. On the other hand, the carbon intensity of electricity depends on the fuel used to generate power. Figure 1.29 compares the WTW carbon intensities of diesel fuel and electricity produced from various primary sources. It shows that electric trains can effectively reduce emissions, compared with diesel-powered trains, but only if the power generation mix is not largely dependent on primary fuels with high carbon content, such as coal. Box 1.7 explores how the benefit of rail in terms of GHG emission reductions, compared with other forms of transport, can be enhanced further by voluntary actions within the rail transport sector.

**Figure 1.29 Average WTW carbon intensities for diesel powertrains, compared with electric powertrains using various primary sources**




Notes: g $CO_2$/MJ = grammes of carbon-dioxide equivalent per megajoule. Tractive energy is the final energy necessary to move the vehicle forward. These results are obtained assuming a diesel train efficiency of 35%, an electric powertrain efficiency of 90% and a power plant efficiency of 50%.

Source: Emissions factors per unit energy of fuel used from IEA (2012).

**Key message • Electric trains are significantly less carbon intensive than diesel trains if they draw power from primary energy sources with low-carbon content.**

The much lower carbon intensity of rail (per passenger- or tonne-kilometre) compared with most other modes of transport, means the rail sector already plays a key role in containing

[38] A wealth of evidence has been collected showing a link between the opening of urban rail systems and cuts in ambient concentrations and intake of the harmful pollutants emitted by internal combustion engines (primarily PM, NOx, CO and a range of hydrocarbons). Gendron-Carrier et al. (2018) show that the construction of metro networks in cities results in a significant impact on air quality, reducing particulate concentration by 4% on average in a ten kilometre radius around the city centre. The effect is larger near the city centre; more highly polluted cities, especially in Asia, experienced larger pollution reductions after opening a metro network. Concentrations of CO, NOx, $PM_{10}$ and sulphur dioxide along corridors have been shown to fall by around 5-10%. Specific case studies have shown that opening new urban rail lines can reduce local concentrations of selected pollutants or limit their increase with reductions of up to 23% observed in CO concentrations (Park and Nese Sener, 2019; Chen and Whalley, 2012). Case studies in Beijing, Guangzhou and Mexico City also observed significant air pollution reductions after opening metro systems (Yang, Zhang and Ni, 2014; Shang and Zhang, 2013; Bel and Holst, 2018).

global GHG emissions. If all passenger and freight transport demand currently satisfied by rail were served by planes and road vehicles (cars and trucks) then global GHG emissions would increase by 1.2 Gt $CO_2$-eq (13% higher than total transport emissions) (IEA, 2018a). Looking forward, efficient electric motors and increasingly low-carbon power mixes could enable rail to contribute substantially to achieving zero-emission mobility from a WTW perspective.

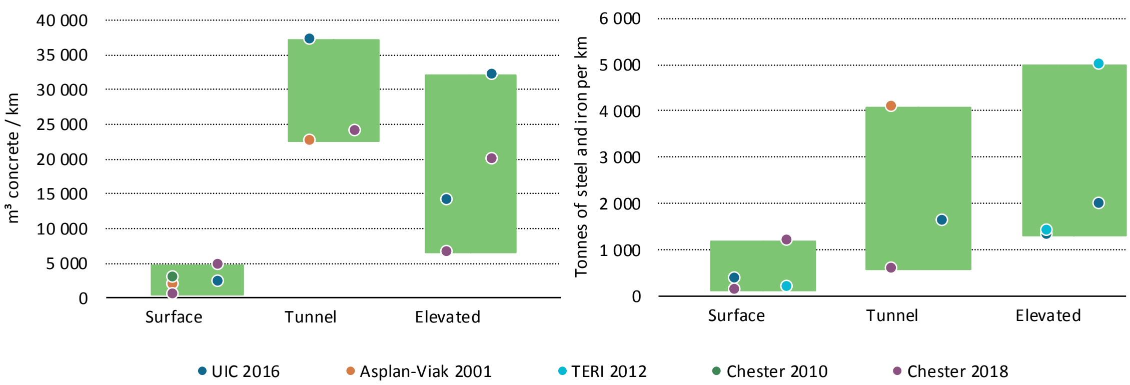


## Additional emissions: Looking at rail from a life-cycle perspective

The operation of trains is not the only source of emissions from rail transport. Emissions also arise from the construction of the railway network, the manufacture of the rolling stock, its maintenance and ultimate disposal. These emissions must also be taken into account when assessing the capacity of rail projects to reduce GHG emissions. Environmental life-cycle assessments for rail projects show that the projects best able to deliver net benefits are those having the following characteristics:

- Infrastructure characteristics that minimise the need for large amounts of steel, iron and concrete per kilometre (required for bridges, viaducts and tunnels) (Figure 1.30). The production of steel and concrete is responsible for a large fraction of embodied emissions.[39]
- Trains operating high loads that minimise emissions per train-kilometre, thanks to efficient electric motors and a low-carbon power mix.
- High potential for a shift away from those transport modes with high carbon intensities in the use phase: aviation and cars for passenger rail, and trucks for freight rail.
- High passenger or freight throughput to facilitate maximising the emission savings for every passenger/tonne-kilometre switched from road and aviation to rail, so diminishing the relative importance of emissions due to the manufacture and maintenance of transport vehicles and networks.

**Figure 1.30 Concrete, steel and iron use for one kilometre of conventional rail line (double track)**




Note: Boxes represent the range of material use in various projects and points represent values in the academic research mentioned in the cited sources. Elevated structures include bridges and viaducts. It should be noted that the use of tunnels and viaducts may have other important benefits, for example increased safety and less land use, and necessity for additional infrastructure for line crossings.

Sources: Chester and Horvath (2010); UIC (2016) and TERI (2012).

**Key message • Railway lines, in particular those with numerous tunnels, viaducts and bridges are concrete and steel intensive.**

[39] This is true for studies in various regions, for example (Chester and Horvath, 2010). According to TERI (2012), concrete and steel production and their transport account for 70% of $CO_2$ emissions during the railway construction phase, and steel production alone accounts for over 50% of infrastructure GHG emissions (UIC, 2016).

## *High-speed rail*

A case of two large cities considering a high-speed rail connection in order to mitigate GHG emissions from passenger cars, buses and planes is portrayed in Table 1.2 and Figure 1.31. They assume a 500 kilometre distance between the two cities and 20 million single trips made annually by all means of transport (comparable to the passenger activity between Paris and London [Behrens and Pels, 2012]).

In order illustrate the impact of different system characteristics on GHG emissions, three cases are considered. The first case, "high potential" for rail to reduce emissions, considers a high-speed rail line with few tunnels and bridges, using efficient electric trains powered by a low-carbon electric system and with high occupancy rates, which is able to effect sizeable modal shifts to rail while leading to only moderate incremental demand. The second case, "medium potential", assumes characteristics that fall between the high and low cases. The "low potential" case assumes more pessimistic conditions for GHG emission reductions: numerous tunnels and bridges, a carbon-intensive power grid, limited shifts from road and aviation, significant induced demand and low train occupancy.

**Table 1.2 Transport emissions mitigation with high-speed rail: selected variables in three cases**

| Category | Variable | Unit | High potential | Medium potential | Low potential |
|---|---|---|---|---|---|
| Rail infrastructure construction | Share of tunnels | Proportion of total track length | 2% | 5% | 10% |
| | Share of elevated | Proportion of total track length | 5% | 10% | 40% |
| Train efficiency and power mix | Well-to-wheel emission intensity | g $CO_2$-eq/passenger-kilometre | 3.2 | 13.5 | 23.5 |
| Source of demand | Formerly in aviation | Share of all trips | 20% | 10% | 5% |
| | Formerly in cars | Share of all trips | 20% | 10% | 5% |
| | Formerly on buses | Share of all trips | 5% | 2% | 1% |
| | Newly generated | Share of all trips | 10% | 15% | 20% |
| Train occupancy | Occupancy factor | Passengers/train | 850 | 750 | 650 |

Note: g $CO_2$-eq = grammes of carbon-dioxide equivalent.

Sources: The choice of the share of tunnels and bridges on the rail line are based on various case studies examined in Akerman (2011); Bueno, Hoyos and Capellan-Perez (2017); Chen and Whalley (2012); Chester and Horvath (2010); TERI (2012) and UIC (2016). The values given here range between 1.6 and 4.4 thousand tonnes of $CO_2$-eq per track-kilometre for high-speed lines at ground level, 9.3 and 17.3 for high-speed lines in tunnels, and 6.2 and 18.4 for lines on bridges or viaducts. The intensity of vehicle emissions is from IEA, 2018a. Assumptions as to the extent of modal shifts and train occupancy are made as a result of a comparison of the methodologies of Westin and Kageson, 2012; Dalkic et al., 2017; Behrens and Pels, 2012; Chester and Horvath, 2010.

**Key message • The impact on $CO_2$-eq emissions of a new high-speed rail line is dependent on numerous parameters related to topography, passenger behaviour and operational practices.**

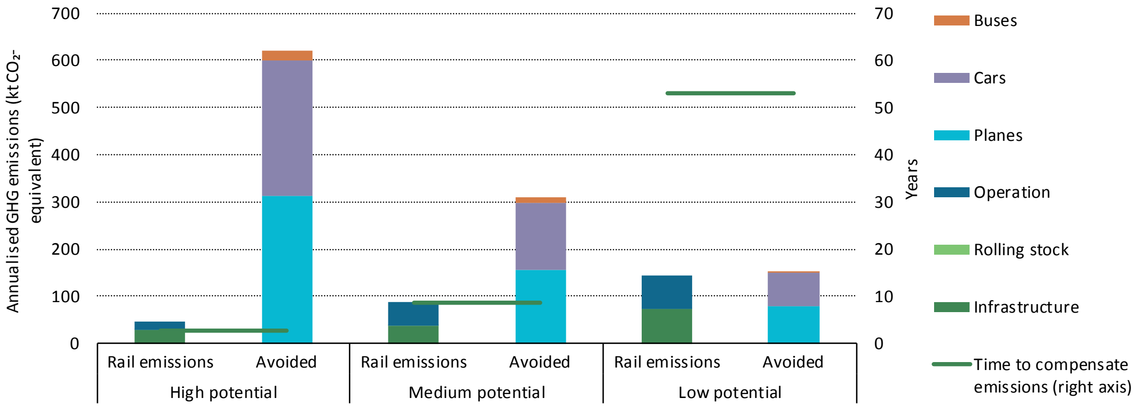
Figure 1.31 compares emissions that occur over 60 years of use of the rail infrastructure against the operational emissions from buses, cars and planes that would have occurred in the absence of a high-speed rail line between the cities. It also shows the time needed for the rail connection to offset the carbon footprint of the construction of the rail infrastructure and vehicles. The results indicate that the payback time is as low as three years in the high potential case and nine years in the medium potential case. In this analysis, a high-speed rail project with the pessimistic assumptions of the low potential case lead to only very small net reductions in emissions over a 50-year timeframe.

The GHG payback time for a high-speed rail line is higher where frequencies of use are low. In the example, if the total yearly transport demand between both cities were to be changed from

20 million to 10 million, the avoided emissions imputable to the saving of fuel use by other transport modes shrinks by half, raising the comparative impact of the emissions from infrastructure construction and increasing payback times significantly.



**Figure 1.31 Annualised life-cycle GHG emissions, GHG savings and time needed to compensate upfront emissions for a new high-speed rail line**




Sources: IEA analysis based on sources and assumptions noted in Table 1.2.

**Key message • If optimal conditions are met, a new high-speed rail line can produce almost immediate net $CO_2$ benefits by reducing air and car journeys.**

## *Urban rail*

The GHG emissions reduction potential of metro systems can be illustrated by an example similar to that shown for high-speed rail. Table 1.3 shows the assumptions made for high, medium and low potential cases for a new metro line competing with buses and cars in a large city. The assumptions are a metro line of 20 kilometres, an 8 kilometre average trip length and a 60-year project lifetime. Passenger activity along the 8 kilometre route is assumed to be 1 million passenger trips per day, by all modes of transport. If the share of the trips made by car prior to the construction of the new metro infrastructure is 70% of all motorised trips (the rest being on buses), the three cases detailed in Table 1.3 reflect situations in which the metro manages to attract 300 000 to 600 000 of these trips. This is consistent with the proportion of passengers transported in existing metro systems (RATP, 2018; UITP, 2018b). Other key differences between the three cases include progressively more pessimistic assumptions about emissions due to the type of infrastructure, WTW fuel efficiency, shift potential from other modes and load factors.

Figure 1.32 shows that a metro line can effectively reduce GHG emissions only if it can meet certain requirements, notably in terms of the extent of GHG emissions from train operations and the capacity to shift passengers from more energy and carbon-intensive modes. The primary influence is the carbon emissions per passenger-kilometre stemming from the electricity used by metros and also on the level of emissions associated with the construction of metro (the higher material requirements needed for the construction of elevated and underground rail networks). Load factors also show a significant impact.

An important caveat is that this exercise does not account for emission savings from the avoidance of bus and car manufacturing and recycling, or the emissions stemming from the construction of infrastructure to accommodate passenger cars, such as parking spaces. The GHG emission savings from a new metro line would be larger if the potential reduction in car ownership were fully factored into the calculations.



A second caveat is that no account is taken of the environmental and health benefits derived from improved urban air quality, given that electrified rail networks reduce the concentration of particulates and other polluting substances in high exposure areas such as urban roads. Similarly, no value is placed on the potential of metro systems to alleviate road congestion, allowing more rapid transportation and thereby delivering valuable time savings. Additional benefits include reduced noise, lower accident rates and increased opportunities to reorganise the urban environment in favour of pedestrians and cyclists.

**Table 1.3 Transport emissions mitigation with a new metro line: selected variables in three cases**

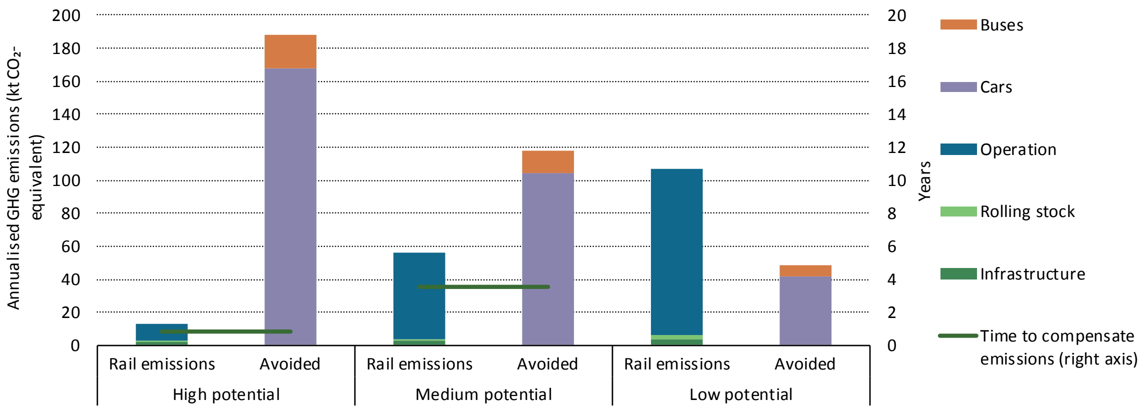
| Category | Variable | Unit | High potential | Medium potential | Low potential |
|---|---|---|---|---|---|
| **Rail infrastructure construction** | Total embedded emissions | kt $CO_2$-eq | 89 | 162 | 231 |
| **Train efficiency and power mix** | Well-to-wheel emission intensity | g $CO_2$-eq/passenger-kilometres | 6 | 45 | 110 |
| **Source of demand** | Formerly in cars | Share of all trips | 40% | 25% | 10% |
| | Formerly on buses | Share of all trips | 15% | 10% | 5% |
| | Newly generated | Share of all trips | 5% | 10% | 15% |
| **Train occupancy** | Occupancy factor | Passengers/train | 250 | 170 | 45 |

Note: kt = thousand tonnes; g $CO_2$-eq = grammes of carbon-dioxide equivalent.

Sources: Values for embedded emissions from metro infrastructure construction and maintenance are based on ranges provided in Chester and Cano (2016); Li et al., (2018) and TERI (2012). The range indicated by these sources is roughly from 5 to 11 tonnes $CO_2$-eq per kilometres of metro line, with the lower value for metro lines at surface level, and higher values for underground or elevated lines. Emissions intensity is estimated based on historical values from France (low intensity), Germany (medium) and China (high), and for occupancy rates in Japan (high occupancy), Germany (medium) and China (low).

**Key message • The $CO_2$-eq implications of metro construction and use vary significantly from region to region, in particular emissions intensity per passenger-kilometre can vary by an order of magnitude.**

**Figure 1.32 Annualised life-cycle GHG emissions, GHG savings and time needed to compensate upfront emissions for a new metro line**




Note: In the low potential case, the investment in $CO_2$-eq mitigation never reaches breakeven, so no emissions compensation period is shown.

Sources: IEA analysis based on sources and assumptions noted in Table 1.2.

**Key message • Metros achieve higher GHG emissions savings if they can attract commuters who would otherwise use a car. The emissions intensity of the metro operation also plays a decisive role.**

## *Freight rail*

An example used to assess the capacity of freight rail transport to deliver GHG emission reductions on a life-cycle basis involves the construction of a new double-track freight corridor with an (arbitrary) length of 500 kilometres connecting two important freight nodes with an annual freight demand of 50 million tonnes.[40] Road transport is the only alternative mode considered, since air shipping is appropriate only for very different types of goods, and maritime transport does not compete directly with surface transport (except in coastal areas). The key parameters considered in the three cases are given in Table 1.4. The GHG emissions savings are assumed to come not only from truck operation, but also from the avoidance of the emissions otherwise embedded in the vehicle itself, since a company replacing truck haulage by freight rail will require a smaller trucking fleet.

**Table 1.4 Transport emissions mitigation with a new 500 kilometre freight rail corridor: selected variables in three cases**

| Category | Variable | Unit | High potential | Medium potential | Low potential |
|---|---|---|---|---|---|
| **Rail infrastructure construction** | Total embedded emissions | kt $CO_2$-eq | 1 700 | 2 200 | 4 300 |
| **Train efficiency and power mix** | Well-to-wheel emission intensity | g $CO_2$-eq/tonne-kilometre | 9.5 | 14.0 | 23.2 |
| **Modal share** | Train / truck shares | % | 50/50 | 30/70 | 10/90 |
| **Train occupancy** | Load carried | tonnes/train | 2 900 | 1 900 | 800 |

Note: kt = thousand tonnes; g $CO_2$-eq = grammes of carbon-dioxide equivalent.

Sources: Embedded emissions for rail construction assume the same values as calculated for high-speed rail (see Table 1.2). Train emissions intensity and loadings are based on country benchmarks, with high potential based on Russia, medium potential by the weighted world average and low potential by emission factors in China and train loading in the European Union.

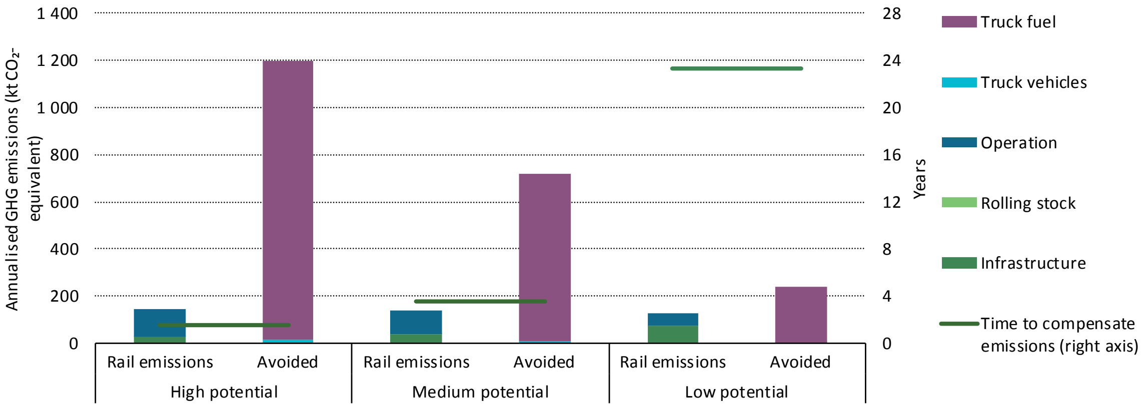
Key message • **A new freight rail corridor is estimated to have the capacity to replace 10-50% of road freight. The intensity of train emissions varies proportionally to train size.**

The analysis suggests that, in the best case, net emission benefits are achieved after slightly more than one year after infrastructure construction (Figure 1.33). This is largely due to the fact that the emissions intensity of freight rail is nearly ten-times lower than that of trucks. The medium case offers net benefits in less than four years, while the most pessimistic scenario achieves emissions neutrality after 24 years.

To summarise, the extent of the GHG value of building a new rail line depends on a combination of topological considerations and infrastructural decisions, the level of operational efficiency of the train, load factors and electricity mixes and, most of all, the total volume of passengers or freight shifted to rail. Under favourable conditions, rail can deliver important GHG emission savings by shifting traffic away from passenger cars, trucks and planes. Many other considerations need to be taken into account, such as the impact on air quality (especially in urban areas), the value of reduced road congestion, savings in travel time and noise. Another caveat is that this analysis does not attempt to evaluate the potential for and value of efficiency increases in electric vehicles in other transport modes or the impact of vehicle sharing.

[40] Estimation based on average national freight volumes by mode in (IEA, 2018a). This 50 million tonnes is about equivalent to 5% of the total annual freight transported by rail in a large country such as India or Russia.

**Figure 1.33** **Annualised life-cycle GHG emissions, GHG savings and time needed to compensate upfront emissions for a new freight rail line**




Sources: IEA analysis based on sources and assumptions noted Table 1.4 The emissions intensity and load factor for trucks is the world average value for heavy trucks in 2015 (IEA, 2018a). Emissions associated with the manufacture, maintenance and recycling of train and truck rolling stock is based on TERI (2012).

**Key message • The improved energy efficiency of freight rail over transport by road leads to rapid net benefits; even the low potential case achieves significant $CO_2$-eq reductions after 24 years.**

## Conclusions

The information presented in this chapter underlines the importance of high passenger and/or freight throughput to the success of rail operations. High throughput enables the high capital cost of rail networks to be spread across many users thereby minimising unit costs, and generates robust revenue streams from fares.

High throughput is also key to rail's lower energy intensity per passenger- and tonne-kilometre than other transport modes. It also favours electrification and, thus, energy diversification. The life-cycle analysis shows that high throughput delivers significant environmental benefits (relative to mobility via other modes), minimising the time required to offset the emissions incurred in building new rail infrastructure (after which rail has a continuing advantage in this respect, relative to other motorised modes of transport).

Conditions that can enable high throughput include:

- A favourable physical context for the rail links, such as high population density and constraints on other forms of transport.
- Meticulous planning of rail network development, for example thorough analysis of the character of freight consignments, their origins and destinations.
- High rates of utilisation of the rail networks, thanks to advanced signalling and communication technologies.

Polices and technologies that support rail development include:

- Urban densification and integrated transport and urban planning. For example, changing zoning laws to promote transit-oriented development.
- Regulations and corporate initiatives to standardise freight parcels.
- Use of information technologies to facilitate the integration of different transport modes.
- Fiscal instruments designed to ensure that the costs of all modes of transport reflect infrastructure needs and externalities including societal and environmental impacts.

How rail markets should be organised to deliver these benefits is a question to which there is no single or simple answer. Liberalised markets have been shown to improve the competitiveness and efficiency of rail in some circumstances (e.g. in North America), although the presence of a dominant operator may be desirable in the early stages of rail development to avoid costly duplication of infrastructure.

Building on this background, Chapters 2 and 3 explore the implications of two scenarios depicting how rail travel may develop in the period to 2050.



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# 2. Outlook for Rail in the Base Scenario

## Highlights



- Rail is an important pillar of passenger and freight transport today, though it faces increasing competition from other modes. Historical trends show that as incomes rise so does demand for individual mobility in cars and travel by planes; public transport tends to lose market share in overall travel activity as a result. Presented here, our Base Scenario demonstrates how these factors play out in the period to 2050. It assumes the transport and relevant policies that are in place today and those that have been announced including national and regional targets for expanding rail infrastructure.
- Demand for passenger mobility rises rapidly across all transport modes, including rail, in the outlook to 2050. Global passenger rail activity more than doubles (+116%) from present levels, reaching almost 9.4 trillion passenger-kilometres, yet retaining its share of rail in total passenger activity at around 10%. People's Republic of China ("China") and India continue to account for the largest part of passenger rail activity, owing to the vast size of their rail networks, high occupancy levels and plans for infrastructure extension. The combined share of global rail activity in China and India increases from about 60% today to 70% by 2050.
- Global freight activity in 2050 across all modes triples relative to 2017 levels, driven by economic growth. Freight activity on rail grows, but the pace lags behind robust increases in maritime and heavy truck freight activity. As a result, the share of rail in overall freight activity declines from 7% in 2017 to 5% in 2050. Rail's share in surface freight transport (i.e. excluding shipping) declines from 28% in 2017 to 23% in 2050, as rising demand for rapid delivery of high value and lighter goods favours a continuing shift from rail to road in most regions. China, Russian Federation ("Russia") and the United States account for about 70% of the projected increase of freight rail activity. In China, economic growth drives rapid freight rail growth, even though the share of rail in surface freight transport as a whole falls substantially, from around a third in 2017 to about a quarter in 2050.
- Increasing transport demand and current capacity bottlenecks require rail networks to be extended by more than 430 000 track-kilometres through to 2050, a 27% increase from 2016. The length of metro track extends by nearly 45 000 kilometres (137% from 2017) and high-speed rail tracks by 46 000 kilometres (65% more). As a result, combined metro and high-speed rail activity almost triples. Global average annual investment needs in rail infrastructure are USD 315 billion (United States dollars), about 50% higher than they were over the past decade.
- Energy demand for transport grows by over 40% by 2050 in the Base Scenario, led by road and air travel. Rail energy use increases by 75% to 90 Mtoe, maintaining its current level of around 2% of total transport energy use. Electricity satisfies much of rail energy demand growth, up 140% to around 700 TWh in 2050. Diesel use for rail rises slightly to 0.58 mb/d. Increased reliance on electricity is particularly strong in passenger rail transport because both urban and high-speed rail expand and are entirely electric. Absent passenger and freight activity by rail, oil demand in 2050 would be 9.5 mb/d higher, 16% higher than the total projected demand from transport in that year.
- Closely mirroring energy trends, global well-to-wheel GHG emissions from the entire transport sector in the Base Scenario reach 14 Gt $CO_2$-eq in 2050. The share of rail in total transport emissions remains below 3%. Rail transport keeps emissions lower than they would be otherwise: without rail, global transport-related well-to-wheel GHG emissions in the Base Scenario would be higher by 1.8 Gt $CO_2$-eq, 13% higher in 2050. In addition, urban rail avoids the emissions of 340 kt of $PM_{2.5}$.

# Introduction

Rail transport is an important part of passenger and freight activity today but, as competing pressures arise from other major motorised modes of transport, there is no guarantee that it will maintain its position in the future. In relation to passenger transport, rail is confronted by increasing demand for individual, flexible and seamless mobility, readily available at any time of day and for any possible destination. Personal cars offer such service and, with the advent of electric cars, some of the main environmental shortcomings of individual motorisation, most prominently local pollution and greenhouse gas (GHG) emissions, might be substantially reduced in the future. Air travel is another significant competitor, often connecting people faster and with more flexibility to their destination, generally with less reliance on the construction of complex network infrastructure.

The challenges to freight rail are also formidable. The main competitors are road freight trucks, which generally offer a more flexible option than freight rail: freight trucks rely less on dedicated infrastructure and are much more modular in the scope of activity, meaning they require lower delivery volumes than rail to make a business case. Yet, trucks are more energy and emissions intensive per tonne-kilometre than rail, and cause considerable damage to the road infrastructure (forces on roads reflect the cube of axle weight). Currently, they are rarely charged for either their emissions or infrastructure damage.

This is the context for discussion of the Base Scenario in this chapter. The Base Scenario models how rail transport might handle competitive pressures on the basis of existing policies and those that have been announced as of December 2018. It considers rail transport in the context of overall energy and transport trends, taking account of all policies that have been adopted in other energy sectors, including power, industry and buildings.[1] This includes the commitments made in the Nationally Determined Contributions (NDCs) under the Paris Agreement. Significantly, while these actions require substantial changes in investment and use patterns in energy and elsewhere, they prove, in the analysis, to be insufficient to limit expected warming to 2 degrees Celsius by the end of the century.

For transport, the policies taken into account include rising road vehicle fuel-economy standards, as well as the International Civil Aviation Organization (ICAO) targets to improve the energy efficiency of airlines by 2% annually and the International Maritime Organization's (IMO) Energy Efficiency Design Index, which mandates an annual average energy efficiency improvement of the shipping fleet of 1% between 2015 and 2025. For rail, the scenario takes account of all recent trends and, as stated, all declared policy intentions that could shape the future development of rail transport.[2]

The future of rail relies in many ways on the roll-out of new infrastructure, the pace of which is a key constraint on growth. The Base Scenario reflects declared intentions including: the pace of

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[1] All non-transport projections in this scenario are drawn from the New Policies Scenario of the *World Energy Outlook-2018* (IEA, 2018a).

[2] The development of passenger activity in the Base Scenario is projected from 2018 to 2050 on the basis of a few key assumptions. The key drivers of activity growth are developments in national gross domestic product (GDP) (World Bank, 2018), and urban and non-urban population developments (UN DESA, 2017). The projections account for structural differences across countries, taking into account the influences of long-term levels of fuel taxation and geography on population density, vehicle ownership and usage patterns, as well as modal shares. Developments in GDP per capita, together with changes in the size and share of populations living in cities of various sizes, drive projections of passenger activity. The projected modal split of passenger activity across two/three-wheelers, passenger cars, buses, rail and air travel is based on literature informed estimates of the effects of policies, including pricing measures (e.g. on vehicle purchase and fuel taxation) and urban "travel demand management" policies, such as congestion charging, low-emissions zones and internal combustion engine and diesel circulation restrictions.

development of rail transport infrastructure (including projects to develop new high-speed rail lines or expand existing ones), targets for capacity utilisation, plans to electrify railway lines and targets of modal shares for rail in transport activity. In addition to the specific targets (Table 2.1), urban rail activity projections to 2025 are informed by planned “greenfield” metro and light rail projects to 2023; beyond that the expansion of urban rail infrastructure is projected on the basis of the perceived potential role for urban rail, in line with the known investment criteria and broad assumptions about the opportunities open to rail in an era of urbanisation. High-speed rail activity projections to 2050 are based on approved or planned construction of high-speed rail lines.[3]



**Table 2.1** **Selected targets and rail development policies by region in the Base Scenario**

| Region | Description | Source |
|---|---|---|
| **Europe** | Investments to complete the core of the Trans-European Transport Network and implementation of the European Rail Traffic Management System by 2030, supporting activity growth of 1.4% per year for non-urban passenger rail, 2.5% per year for high-speed rail and 1.2% per year for freight rail from 2010 to 2050. | European Commission (2016); European Commission (2017) |
| **People’s Republic of China** | The 13th Five-Year Plan provides for the extension of high-speed rail lines by 30 000 kilometres by 2020, connecting more than 80% of all large cities. | NDRC (2016) |
| **Russian Federation** | Russian Railways: achieve activity growth of 3.0% per year for passenger rail and 4.5% per year for freight rail from 2017 to 2025. | Ivanov (2018) |
| **India** | Low Carbon Strategies for Inclusive Growth of the Indian Government’s Planning Commission provide for activity growth of 7.0% per year for both passenger and freight rail from 2017 to 2025. | Planning Commission, (2014); National Institution for Transforming India, (2018) |

The pace of adoption of new technologies in the Base Scenario similarly reflects declared intentions, and, where policy intentions are unclear, the pace of change that would be needed in the transport sector to achieve the NDC pledges. In rail, this includes more electrification, starting with the most used routes; increased adoption of automated train driving (which is already in place in urban rail in some cities)[4] and increasing use of communication-based train controls. The Base Scenario does project radical technological change, beyond current expectations, in any transport mode.

The projections in the Base Scenario signal to policy makers and other stakeholders the direction which today’s ambitions are likely to take the rail sector. This does not make this scenario a forecast. Alongside other uncertainties, like the pace of economic growth and technology change within the rail sector as well as beyond, adjustments will be made to policies affecting the rail sector in the future, beyond those already announced, responding to new circumstances or priorities. The Base Scenario is not a normative scenario: it does not depict a

[3] Key sources for this assessment include the European Commission (2016). Data on the growth of network extension and activity (in passenger-kilometres) on high capacity urban rail developments come from the International Association of Public Transport (UITP) (Union Internationale des Transports Publics) (UITP, 2018a; UITP, 2018b). Data on new metro and light rail projects to be opened in the coming years are from the Institute for Transportation and Development Policy (ITDP, 2018). Information on prospects for new urban rail developments in China are from the Office of the State Council (2018a, 2018b) Announcements on high-speed rail lines planned are from the International Union of Railways (UIC) (Union Internationale des Chemins de Fer) (UIC, 2018). The Base Scenario takes into account projects under construction or already approved, as well as information shared with the IEA and the UIC in a joint workshop on rail and energy, and in particular, indications from Ivanov (2018); Strohschneider (2018); Lee (2018); and in the case of India from Pillai (2018); Sinha (2018) and Mishra (2018).

[4] Over the next five years, an additional 2 200 kilometres of fully automated metro lines are expected to be in operation (representing over 40% of new length), led by growth in Asia-Pacific, Europe and the Middle East (UITP, 2016; UITP, 2018).

future for rail that could be deemed desirable or one that policy makers or other stakeholders should try to bring into being. It provides an analytical basis for expectations about the future and thereby also serves as an invitation for policy improvement if the outcomes described are sub-optimal.

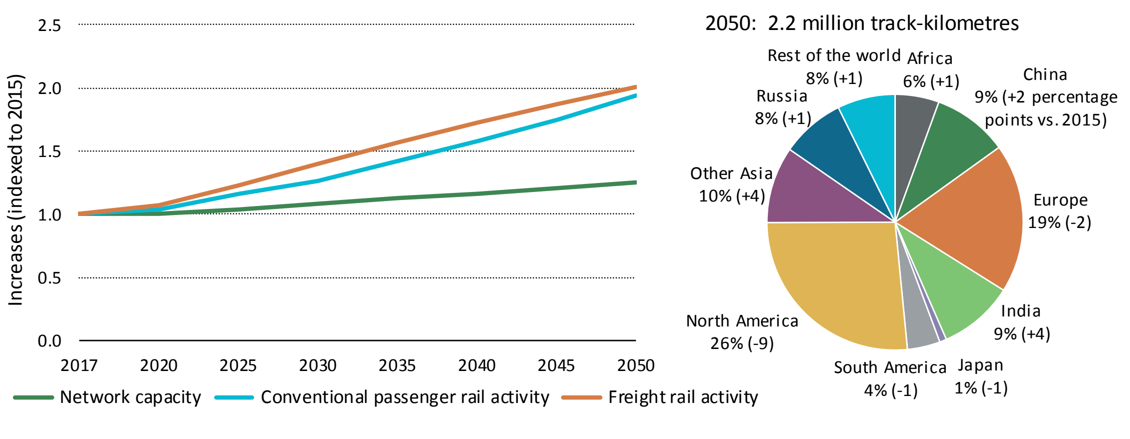


## Rail network developments

In the Base Scenario, between 2016 and 2050, the global rail network (urban, conventional and high-speed rail) expands from 1.6 to 2.1 million track-kilometres, a 26% increase in 34 years. By 2050, metros account for 3% of the total of all rail track-kilometres and high-speed rail for 5% (up from 2% and 3%, respectively, in 2016).

In line with recent progress in the utilisation of network capacity (as measured by the ratio of train-kilometres per year to track-kilometres), activity grows at a faster rate than the construction of new tracks. From 2016 to 2050, more than 430 000 track-kilometres for conventional and freight rail are built (an increase of more than a quarter from 2016). In the same period, due to higher track utilisation and increased occupancy on conventional rail, the number of passenger-kilometres and tonne-kilometres on the global rail network both more than double (Figure 2.1, left). By 2050, the global capacity utilisation rate of the conventional rail network improves by about 60%, conventional and freight annual train-kilometres reach 12 400 per track-kilometre (up from 7 700 per track-kilometre in 2016). In 2050, North America remains the region with the most extensive conventional rail network (over one-quarter of global track-kilometres), mostly used for freight, followed by Europe, India, China and Russia. India and Russia are the two countries that extend their conventional rail networks most substantially in the period to 2050 (Figure 2.1, right).

**Figure 2.1 Global conventional rail network extension and activity in the Base Scenario. Activity (left), 2017-50 and regional distribution of conventional rail extension (right), 2050**




Source: IEA (2018b).

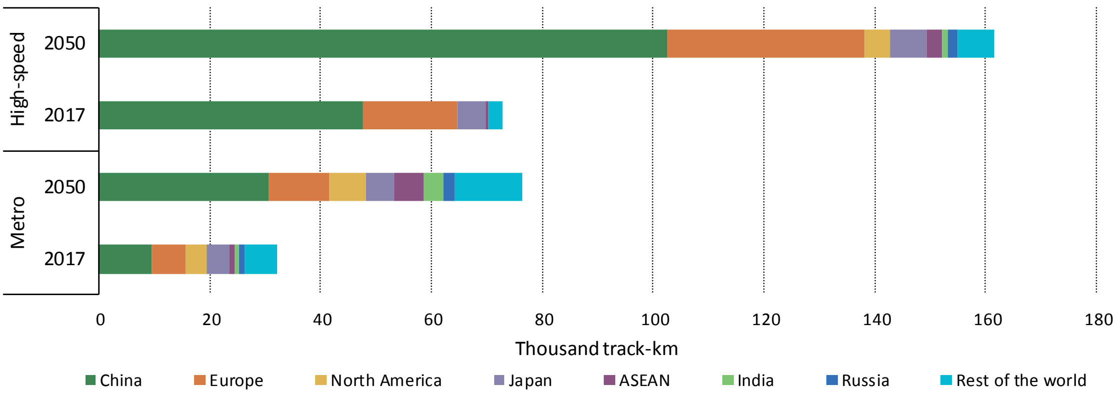
**Key message • Higher capacity utilisation means that activity increases faster than network construction. By 2050, North America (prioritising freight) and Europe (prioritising passenger) have extended their rail networks the most.**

Metro and high-speed rail networks grow the fastest, their track-kilometres increasing by about 140% for metro and 65% for high-speed rail from 2016. The lengths achieved in 2050 are about 76 000 track-kilometres for metro and 113 000 track-kilometres for high-speed rail (Figure 2.2). Metro and high-speed rail networks can achieve far higher rates of utilisation than conventional rail as the intervals between trains are shorter; the average utilisation rate worldwide for metro is 85 000 annual train-kilometres per track-kilometre and 29 000 for high-speed rail. As a result, the continued rapid expansion of metro and high-speed rail networks accommodates large increases in passenger activity. The volume of passenger-kilometres on metros increases by about 150% and on high-speed rail by 200% by 2050.

China maintains its recently attained standing as the country with the world's largest metro network: by 2050, the length of its metro network tracks increases more than threefold to over 30 000 kilometres, making up 40% of the world's metro track length. Europe, North America, India and other Asian countries also expand their metro and light rail systems.



**Figure 2.2 Global metro and high-speed rail by track-kilometres and region in the Base Scenario, 2017 and 2050**




Notes: ASEAN = Association of Southeast Asian Nations. It includes Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam.

Source: IEA (2018b).

**Key message • China continues to maintain its place as the country with the most extensive metro and high-speed rail networks globally in 2050. Europe maintains its status as the second-largest region in high-speed rail, while metro rail networks expand rapidly in emerging economies.**

**Figure 2.3 Existing and planned high-speed rail track developments in the Base Scenario**


Note: Under the conventions of this scenario, the category *planned* applies only to projects that have been officially approved.

Source: IEA analysis based on UIC (2018).

**Key message • Most of the high-speed rail network length in the Base Scenario in 2050 has already been built or is under construction. By 2050, the number of countries with high-speed rail tracks doubles.**



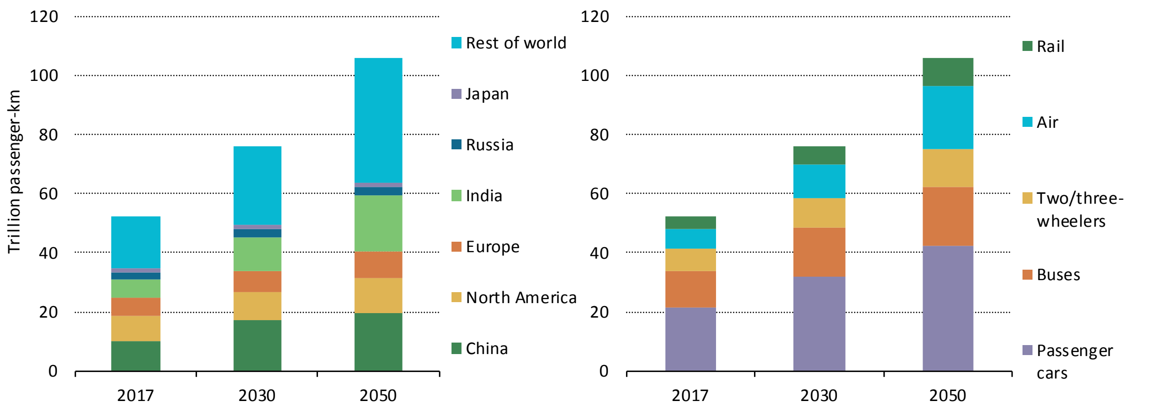
High investment costs mean that the expansion of high-speed rail networks is viable only where a combination is found of relatively high activity and densely populated urban areas to ensure adequate funding and high passenger utilisation rates (Nash, 2015). Despite these strict prerequisites, the number of countries with at least one high-speed rail line more than doubles in the Base Scenario, from 14 today to 29 by 2050.[5] Most of this network expansion takes place in Asia, although China's share of high-speed rail track length is expected to decrease from 70% in 2017 to 57% in 2050. Europe, North America, India and other Asian countries also expand high-speed rail networks in the Base Scenario (Figure 2.3).

# Rail transport activity

## *Passenger rail*

Demand for passenger mobility by all means of transport continues to rise in the Base Scenario. As the global economy nearly triples in size by 2050 and the world population grows by around 30%, passenger transport activity increases to over 100 trillion passenger-kilometres, more than twice as high as in 2017. Increasing demand for mobility in emerging economies is the main factor, arising as a consequence of rising incomes and a growing middle class (Figure 2.4). Non-rail modes of passenger transport experience significant growth alongside rail: world passenger car ownership reaches 240 per 1 000 people by 2050, roughly twice as high as today; the number of two/three-wheelers on the world's roads increases to 1.4 billion in 2050, up from less than 1 billion today; and air travel grows strongly bringing revenue passenger-kilometres (a measure of air travel activity) up to 21 trillion in 2050 (from 6 trillion today).

**Figure 2.4** **Passenger transport activity by all motorised means by region (left) and mode (right) in the Base Scenario, 2017, 2030 and 2050**




Source: IEA (2018b).

**Key message • Emerging economies significantly increase their share of total passenger travel in 2050. Rail accounts consistently for roughly one-tenth of all passenger activity through 2050.**

Rail transport is no exception. In the Base Scenario, global passenger rail activity more than doubles (+116%) from present levels, reaching 9.4 trillion passenger-kilometres in 2050. The result is that rail broadly maintains its present modal share of global passenger activity throughout the projection period, at close to one-tenth of all activity. In the Base Scenario,

[5] Denmark, Morocco, Saudi Arabia and the United States have high-speed rail lines under construction. Canada, India, Indonesia, Islamic Republic of Iran ("Iran"), Israel, Malaysia, Singapore, Thailand, Poland and Russia plan to build their first high-speed rail lines in the period to 2050.

urban rail in 2050 covers 2% of activity in cities, its share ranging from less than 1% in North America and India to 15% in Japan.[6] Outside cities, rail accounts for a share of total motorised passenger-kilometres ranging between less than 1% in North America to half in Japan. The global average is 14% (IEA, 2018b).[7]



Within rail, non-urban rail dominates, simply because shorter travel distances on urban rail result in lower volumes of aggregate activity (passenger-kilometres) when compared with non-urban rail.

The rate of growth in passenger rail activity is by no means uniform across the world in the Base Scenario; it depends on the rate of growth in demand and the emphasis put on achieving further extension of rail use. In Europe and Japan, per capita demand for passenger mobility is already largely stable (apart from demand for aviation, which continues to grow). Even so, in Europe, passenger rail activity increases to 840 billion passenger-kilometres by 2050, 60% above current levels, supported in the European Union by the plans of various member states to increase the network length of high-speed rail by 80% by mid-century, and by the European Commission's promotion and co-funding of high-speed rail projects (see Table 2.1).[8] Rail growth in Europe is further evidenced by near-term plans in cities to extend metro and light rail networks by more than 10% over current levels in the coming five years. In Japan, passenger rail activity decreases by 14% by 2050, in the context of overall decreases in all passenger transport activity (of more than 5%), due to declining population. Rail activity in Korea is set to increase by approximately 70%, driven by high-speed rail. Passenger rail activity in North America continues to play a minor role, mostly in cities.

Most of the growth of passenger rail activity in the Base Scenario is attributable to expanding rail use in emerging economies, most notably in India (where passenger rail activity triples between 2017 and 2050, mostly on the conventional rail network) and China (where passenger rail doubles, mostly on its extensive high-speed rail network). The situation in India, (discussed in detail in Chapter 4) is that, despite the marked increase in the provision of urban rail (plans over the coming decade are to more than double the current metro system length) and in urban rail activity, rail does no more than maintain its relative importance (in terms of modal share), as road transport and aviation similarly experience strong growth. In China, the share of passenger rail in overall transport activity increases as a result of the construction of urban and high-speed rail networks that is already underway. The growth slows after 2030 though, pending confirmation of further infrastructure projects (Figure 2.5).

China and India remain the countries with far and away the highest levels of passenger rail activity over the outlook period. With their vast size and generally high train occupancy, China and India increase their combined share of global passenger rail activity (in passenger-kilometres) to over 70% by 2050 (from slightly more than 60% today). However, train activity (measured in train-kilometres) remains higher in Europe, and by 2050 the European Union accounts for one-quarter of all train-kilometres globally, closely followed by China (23%) and India (16%). The discrepancy between passenger rail activity and train activity is explained by the fact that that train occupancy in the European Union is far lower than in China and India.

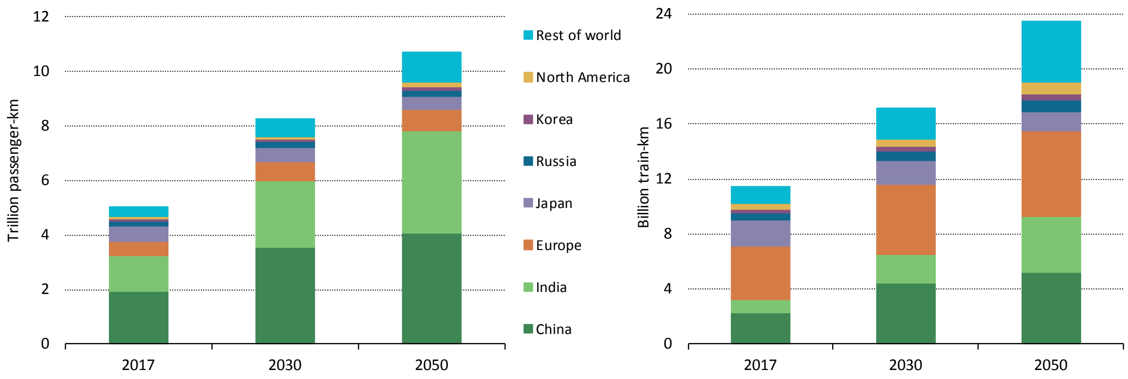


[6] Other modes taken into account include two/three-wheelers, cars and buses.

[7] In the case of non-urban transport, rail shares are assessed accounting for aviation, and intercity trips by car and buses.

[8] The activity projections in the Base Scenario are in line with the projections for non-urban rail of the European Commission (2016).

**Figure 2.5** **Passenger rail activity by region in passenger-kilometres (left) and train-kilometres (right) in the Base Scenario, 2017, 2030 and 2050**




Source: IEA (2018b).

**Key message • India and China dominate world rail passenger activity and expand their share to 70% by 2050. Train-kilometres travelled remain highest in Europe, where occupancy is lower.**

## *Urban rail*

Today, 54% of the world's population lives in urban areas, but only one-tenth of that population lives in large cities with access to urban rail systems, most of which are in Europe and Asia.[9] Partly as a consequence of this fact, metro and urban light rail account for less than 1% of motorised passenger-kilometres travelled worldwide. Additionally, the metric of passenger-kilometres alone does not convey the value of high throughput, space efficient, affordable mobility that metro and light rail systems provide to billions of residents in the world's largest cities.

By 2050, the number of people living in cities is expected to grow by 2.5 billion people, reaching two-thirds of the global population. Total urban transport demand is projected to rise, in consequence, by 1.7% per year on average through 2050. Most of the urbanisation occurs in developing and emerging countries: between 2017 and 2050, urban transport activity across all modes grows by a factor of 1.7 in China, 2.2 in India and 3.7 in Africa.

Urban rail systems can be expected to be developed in those regions where the number and size of densely populated megacities increases. In the Base Scenario, global urban rail activity is projected to grow from 420 billion passenger-kilometres in 2017 (1% of all urban transport activity), to one trillion in 2050 (2% of urban transport activity), a rise of more than 2% per year on average (Figure 2.6). In the Base Scenario, 200 new metro lines are opened in the next five years, including the first in sub-Saharan Africa. These will add nearly 7 000 kilometres of new metro lines to the global network (UITP, 2018a). Around 900 kilometres of new light rail lines are also planned in the next four years, mostly in Europe, but also in Asia and the Americas (UITP, 2018b).

China is projected to achieve the biggest increase in urban rail activity through 2050, despite a slowdown after 2030 to reflect recent announcements of the government.[10] India experiences a

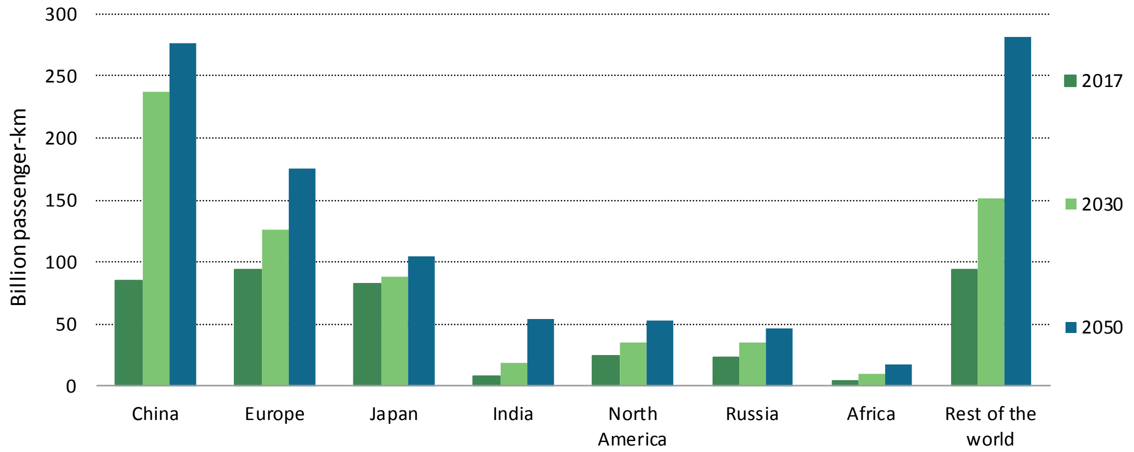
[9] However, about 30% of the global population lives in cities with sufficient density and size to justify infrastructure investment in metro and light rail networks (IEA analysis based on CIESIN, 2005).

[10] Between 2018 and 2022, 4 800 kilometres of new metro lines are expected to be opened in China, more than doubling the length of its system in 2017 (UITP, 2018a; UITP, 2018d). In the Base Scenario, the increase slows from 2030 to 2050, following the recent decision by the government to reduce the pace of construction of urban rail in light of the need to

higher rate of growth than China, at 6% per year, partly achieved because of starting at a lower baseline.[11] The Base Scenario also projects several new urban rail networks in Africa. Starting from a low activity level in 2017 of 4.5 billion passenger-kilometres, the total volume of urban rail activity in Africa reaches 17 billion passenger-kilometres in 2050. This matches the level of urban rail activity of the United States and is one-third that of India.



**Figure 2.6 Urban rail activity by region in the Base Scenario, 2017, 2030 and 2050**




Source: IEA (2018b).

**Key message • Urban transport activity growth is highest in China and mainly takes place before 2030. In the next five years, China is expected to double its current metro network length.**

## *Conventional and high-speed rail*

In the Base Scenario, activity on conventional and high-speed rail lines, taken together, increases by 45% over today's level in 2030, and by almost 120% by 2050 (Figure 2.7) (IEA, 2018b). About 80% of this growth occurs in China and India, although Africa is expected to increase the fastest (albeit from a low starting point).

Conventional rail activity in the Base Scenario almost doubles between 2017 and 2050, to 6.2 trillion passenger-kilometres. As other transport modes outside of cities experience significant activity growth, rail continues to represent around 15% of total non-urban activity (although large regional differences exist). Rail passenger activity over India's conventional rail network is expected to almost triple by 2050, accounting for more than 80% of global growth in conventional rail's passenger traffic.[12]

Japan and North America experience a decline in the number of passenger-kilometres travelled by conventional rail, as a result of the gradual shift towards high-speed rail, lower travel

ensure financial sustainability for metro projects (Poon, 2018; Office of the State Council, 2018a; Office of the State Council, 2018b).

[11] The government of India has announced that it intends to mitigate the negative impacts of rapid urbanisation (particularly air pollution and congestion) by building mass transit systems. The Metro Rail Policy 2017 states that cities with a population of at least two million may start planning mass transit systems, including urban rail and bus rapid transit systems (MoHUA, 2017).

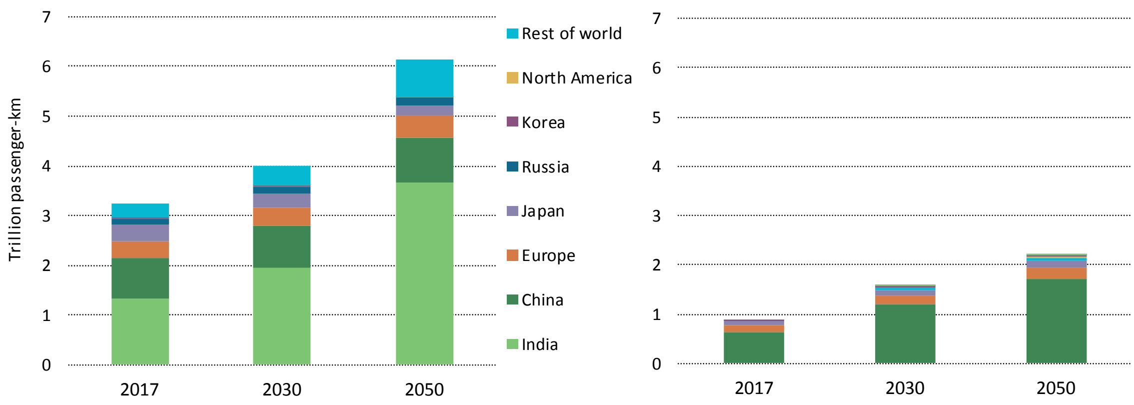
[12] India's expansion is based on plans to invest in upgrades to the conventional rail network. These mostly involve doubling tracks on over-utilised existing routes and creating dedicated freight corridors to accommodate more activity and improve service quality. This could increase track length by 30-35% (Indian Railways, 2018).

demand per capita and competition from other transport modes. In Europe, activity on conventional railways increases by more than 40%, while it stagnates in China (even as activity on high-speed rail grows more than fourfold).



High-speed rail projects that are already under construction or approved lead to a threefold rise in high-speed rail passenger activity in 2050 relative to 2017. High-speed rail activity is then equivalent to more than 60% of all conventional and high-speed rail activity, taken together, in 2017 (but it is still less than 30% of all non-urban rail activity in 2050) (Figure 2.7). Nonetheless, the share of high-speed rail within these two categories grows by nearly 50% over today's level (19%) by 2030 to 28%. Given the absence of certainty on continuing investments in future high-speed rail projects, within the constraints of the assumptions of this scenario, growth in this category slows and its share remains constant from 2030 to 2050. Despite the ambition of the existing plans for expansion of the high-speed rail network (see Figure 2.2), the global share of high-speed rail tracks within the total length of the non-urban rail network grows only from 4% to 5% between 2017 and 2050.[13]

**Figure 2.7 Conventional (left) and high-speed rail (right) activity in the Base Scenario, 2017, 2030 and 2050**




Source: (IEA, 2018b).

**Key message • Conventional rail activity grows in emerging economies, led by India; it declines in developed economies, as it is replaced by high-speed rail. High-speed rail grows threefold, mostly driven by China.**

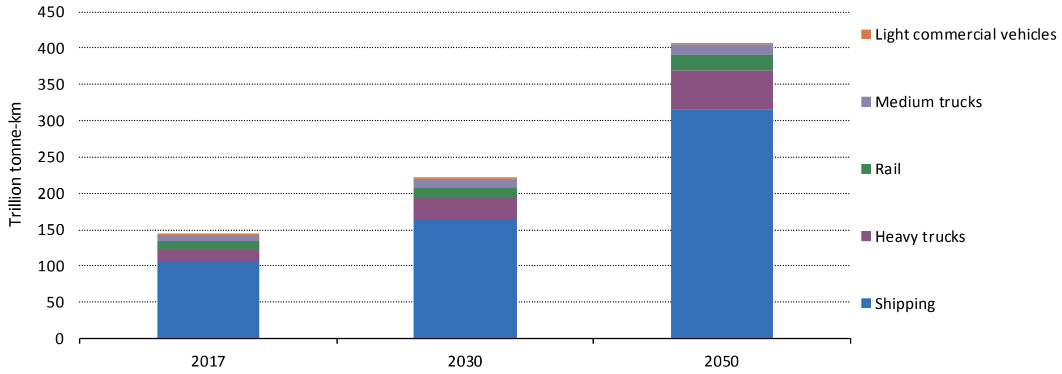
## *Freight rail*

Freight transport activity by all modes is projected to triple in the Base Scenario, reaching more than 400 trillion tonne-kilometres in 2050, closely tracking the growth of global GDP. Freight activity growth is primarily on ships and heavy-duty road vehicles (primarily maritime) and on heavy-duty road vehicles (Figure 2.8). These two modes combined covered 81% of all freight transport activity in 2017 and are projected to cover 83% in 2050 (IEA, 2018b).[14] The prominence of road freight in the projections of freight activity growth reflects the diversity of the road transport service needs of very diverse economic actors and the flexibility of road transport.

[13] High-speed rail achieves higher network utilisation rates (in both passenger-kilometres and in train-kilometres per track-kilometre) compared with conventional rail, and hence contributes to higher activity growth per additional kilometre of track than conventional rail.

[14] With almost 100 trillion tonne-kilometres, shipping accounted for more than 73% of the total freight activity (in tonne-kilometres) worldwide in 2015, while heavy freight trucks accounted for 12% (IEA, 2018b).

**Figure 2.8** **Global freight activity by transport mode in the Base Scenario, 2017, 2030 and 2050**




Source: IEA (2018b).

**Key message • Rail accounted for 7% of global freight activity in 2017 and 5% is projected in 2050 (rail growing less than shipping and road freight transport). The modal share of rail in surface freight (i.e. excluding shipping) falls even more notably, from 28% 2017 to 23% in 2050.**

Despite the fact that freight rail transport (like all other freight movements) has in the past been positively coupled with economic growth, the degree of correlation varies widely and it will not necessarily continue in the future. The various influences at work include geography, policies and investment climate (as well as the relative priority given to freight movements by rail to passengers). Increasing demand for flexibility means that successfully integrating freight rail services into the overall freight transport system will be a criterion for success of freight rail in the future. In the Base Scenario, freight rail is assumed to expand at rates closely coupled with economic growth in those countries in which it already has a large share of freight movements, such as Russia, China, United States and India.[15] Overall, despite the fact that freight rail activity doubles to more than 20 trillion tonne-kilometres by 2050, activity growth in other modes (road and shipping) outpaces rail, so that rail's share in overall freight activity falls from 7% of all tonne-kilometres in 2017 to 5% in 2050.

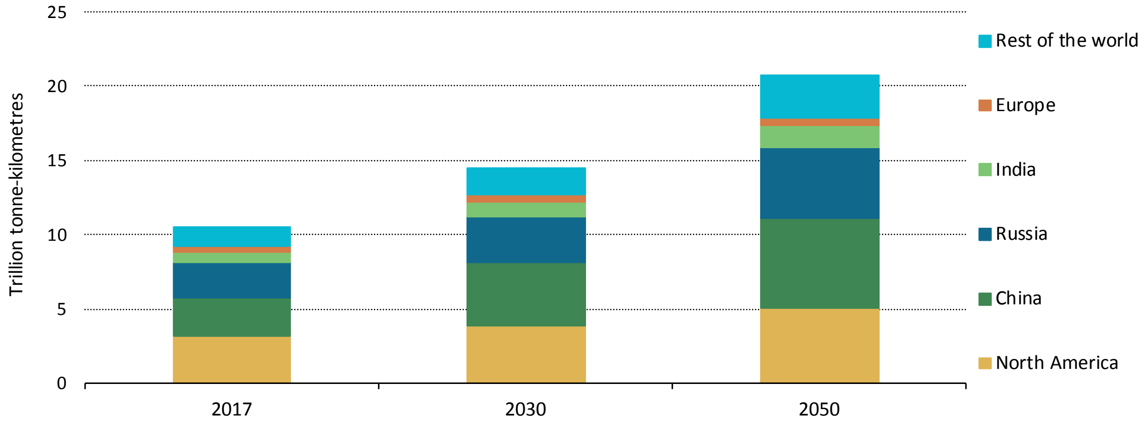
China, Russia and the United States account for most of the absolute growth of freight rail activity in the Base Scenario, contributing 33%, 23% and 14% of the projected increase, respectively (Figure 2.9). India's freight rail activity, though smaller in magnitude, more than doubles by 2050, with India experiencing the highest growth rate of all major freight rail regions. In China, economic growth drives up freight rail activity, although the share of rail in all surface freight transport[16] falls from about 40% in 2017 to one-third in 2050, losing ground to road. In Russia, freight rail correlates closest with economic growth in the Base Scenario, meaning that activity doubles by 2050, compared to today's level. The United States also sees a significant expansion of freight rail, the level rising by about 60% over today's figure. In India, road freight transport activity gains strongly, compared with freight rail, meaning that, despite expansion of rail freight, the share of rail falls to 15% of all surface freight transport (from one-third in 2017).[17] European rail freight activity reaches more than 550 billion tonne-kilometres in 2050 (43% up from 2017), but the rate of growth is lower than in all other main freight regions. By 2050, China, India, Russia and the United States continue to account for about 80% of global freight rail activity.

[15] In Russia, rail carried more than 70% of all surface transport tonne-kilometres in 2015. This share was 40% in China, 33% in the United States and 32% in India (IEA, 2018b).

[16] In this paragraph, shares of surface transport take into account only road and rail modes, and exclude inland waterways.

[17] The competition from road is strongest for goods where rail is already sharing the market with road transport, and it takes place despite opportunities for increased container traffic.

**Figure 2.9 Global freight rail activity by region in the Base Scenario, 2017, 2030 and 2050**



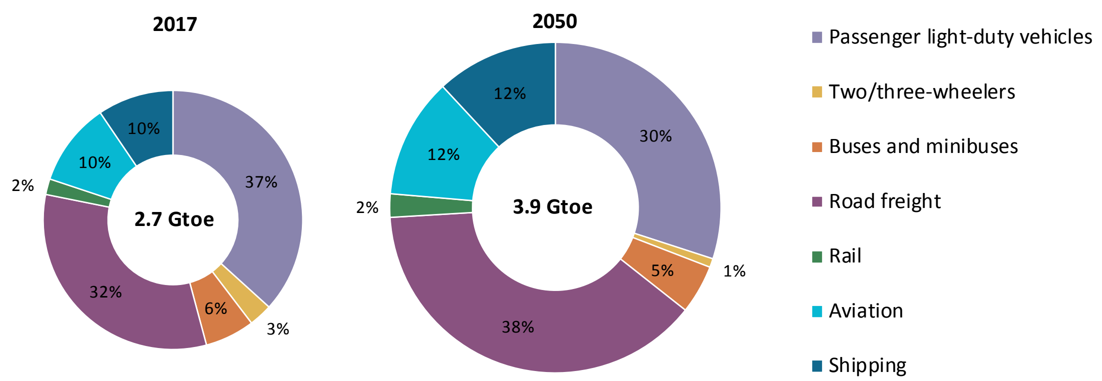

Source: IEA (2018b).

**Key message • Freight rail activity doubles to 21 trillion tonne-kilometres in 2050, with China, Russia and the United States accounting for most of the growth.**

## Implications for energy demand

In the Base Scenario, global energy demand from transport steadily rises from around 2.7 gigatonnes of oil equivalent (Gtoe) in 2017 to 3.9 Gtoe in 2050, an overall increase of more than 40% (Figure 2.10). The largest share of the growth in transport energy demand (both in absolute and relative terms) is in road freight vehicles (including light commercial vehicles and trucks) which, in 2050, consume 600 million tonnes of oil equivalent (Mtoe) more than today. The next fastest growing transport modes, in terms of energy demand, are shipping and aviation, which in 2050 consume 200 Mtoe and 170 Mtoe more than in 2017, respectively (Figure 2.10). Rail transport energy use (both passenger and freight) increases from around 53 Mtoe in 2017 to almost 90 Mtoe in 2050, an increase of 72%. Rail continues to account for some 2% of energy demand in the transport sector.

**Figure 2.10 Global energy demand from transport by mode in the Base Scenario, 2017 and 2050**




Note: Gtoe = gigatonnes of oil equivalent. Source: IEA (2018b).

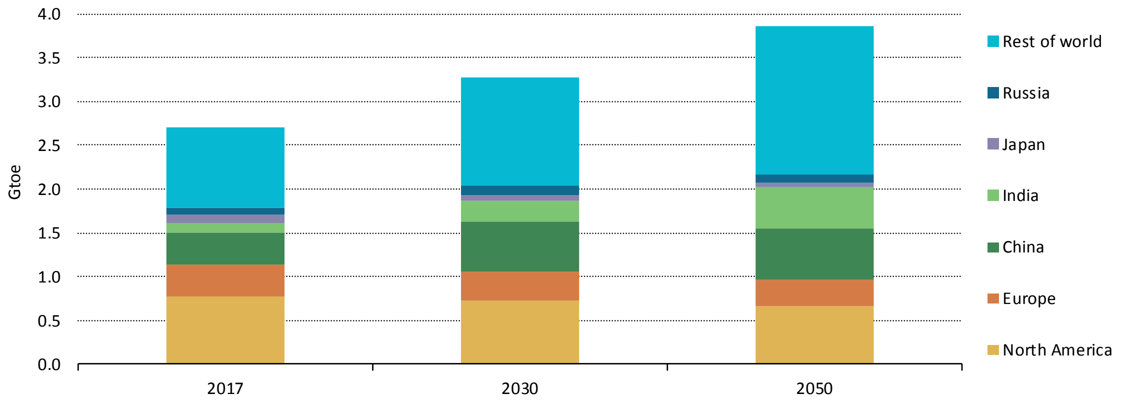
**Key message • Transport energy demand increases by 43% through 2050, driven, in particular, by road freight transport, shipping and aviation.**

Relative to today, energy demand from all forms of transport combined is lower in 2050 in the Base Scenario in many industrialised countries, such as North America, Europe and Japan

(Figure 2.11). Besides the slow growth (and, in certain countries, decline) in transport activity that is projected in these regions, declining energy demand is achieved primarily through progress in energy efficiency due to the adoption of fuel-economy standards for passenger cars and trucks. In emerging economies, transport energy use increases strongly, reflecting significant growth in transport activity, particularly in road use and aviation, only partially offset by energy efficiency improvements in each transport mode. India is an important contributor to growth, with its transport energy demand almost quadrupling between 2017 and 2050.



**Figure 2.11 Global energy demand from transport by region and mode in the Base Scenario, 2017, 2030 and 2050**

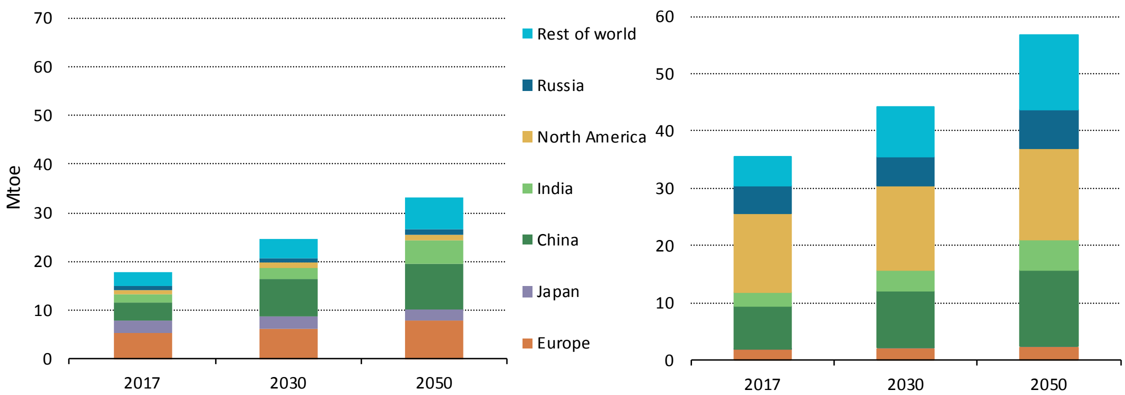



Note: Gtoe = gigatonnes of oil equivalent. Source: IEA (2018b).

**Key message • Energy demand for transport strongly increases to 2030 in China, while it remains stable in Europe and North America. The strongest growth to 2050 occurs in India and other developing economies.**

Measured per unit of transport activity, rail remains the least energy-intensive mode in passenger transport and the second-least energy-intensive mode in freight (after waterborne transport). The share of rail energy absorbed by passenger transport, as a proportion of total rail energy demand, rises from 33% in 2017 to 37% in 2050. Consistent with growth in passenger and freight rail activity in both China and India, these countries account for most of the increase in energy use in both categories of rail service (Figure 2.12).

**Figure 2.12 Global energy demand for passenger (left) and freight (right) rail in the Base Scenario, 2017, 2030 and 2050**




Note: Mtoe = million tonnes of oil equivalent. Source: IEA (2018b).

**Key message • Energy demand from rail grows in both the passenger and freight sectors (with passenger rail at a faster pace), totalling 90 Mtoe in 2050.**

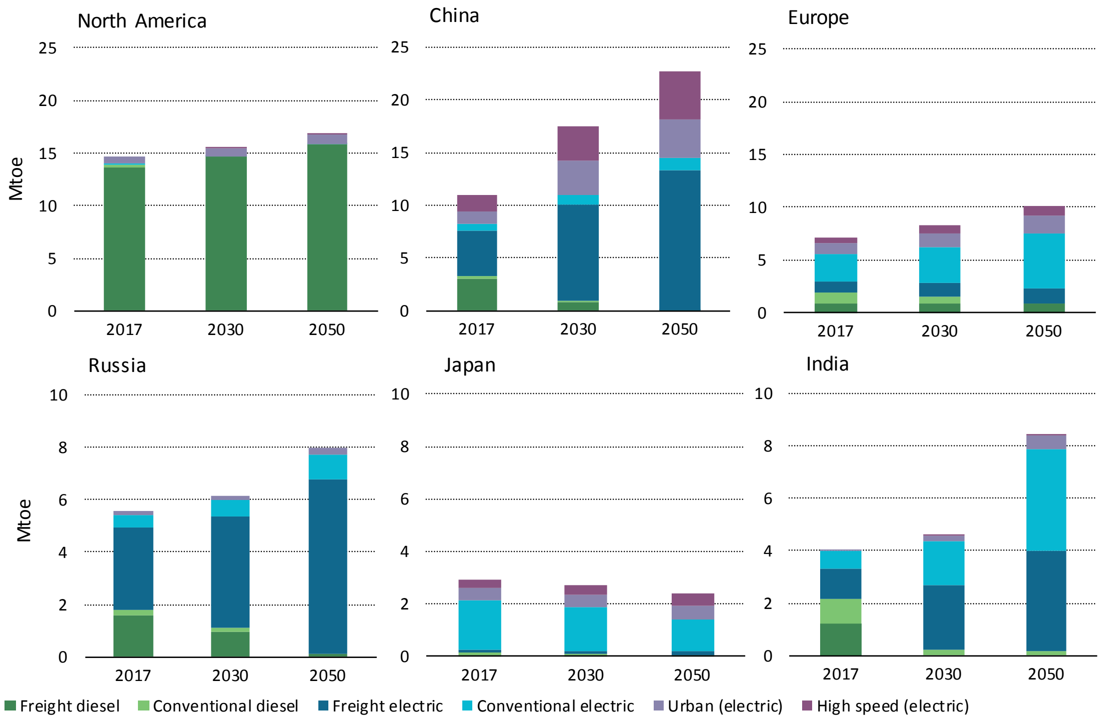
 



The majority of rail energy demand growth is met in the form of electricity in the Base Scenario, consumption increasing from close to 300 terawatt-hours (TWh) in 2017 to nearly 700 TWh in 2050. Diesel use in rail increases only slightly, from 0.56 million barrels of oil per day (mb/d) in 2017 to 0.58 mb/d in 2050. Passenger rail transport experiences the strongest degree of electrification, influenced by the deployment of urban rail and high-speed rail, both of which are entirely electric (Figure 2.13). North America is the only region that does not experience significant electrification, since most rail transport in North America is for freight purposes and uses diesel. By 2050, more than half of the global rail diesel demand is consumed by freight trains in North America.

As a much more energy-efficient transport mode than road and air, rail delivers important energy savings, in particular by reducing oil demand. If the projected activity served by passenger and freight rail in the Base Scenario were shifted entirely to road transport and aviation, oil product demand in 2050 would be higher by 9.5 mb/d.[18] By 2050, despite maintaining a roughly constant share (2%) of final energy consumption in transport, rail makes up 9% (up one percentage point) of motorised passenger activity and a significant (if lower) share of freight (5% of all freight movements and 23% of surface freight).

**Figure 2.13 Energy demand from rail by region and technology in the Base Scenario, 2017, 2030 and 2050**




Note: The scale in the top three figures (North America, China, Europe) differs from that in the bottom three (Russia, Japan, India).
Source: IEA (2018b).

**Key message • Rail transport becomes almost completely electrified in all major rail countries and regions, except North America.**

[18] This result is obtained on the assumptions that non-urban rail would be replaced by aviation, passenger light-duty vehicles (PLDVs) and buses, while urban rail would be replaced by two/three-wheelers, PLDVs and buses. In 2050, the world average fuel economy of aviation is 21.2 tonnes of oil equivalent (toe)/passenger-kilometre, road passenger transport is 18.4 toe/passenger-kilometre and road freight transport is 21.1 toe/tonne-kilometre (IEA, 2018b).

**Box 2.1 Technologies to enable further electrification and zero-emissions rail services**

Rail is already the most electrified mode of transport (IEA, 2018b). Although the share of electrified tracks is still expanding in most countries, further electrification of rail networks will give rise to diminishing returns on investment, given that highly utilised lines are the first to be electrified. Rising electricity use by rail in most regions, except North America, can be met by various technologies including, but not limited to overhead line electrification (OLE), and can offer cost-effective means for reducing GHG and local pollutant emissions.



As an intermediate step towards electrification, train manufacturers in recent decades have started producing bi-modal diesel-electric and electric locomotives (OLE). This helps to improve regional conventional passenger rail coverage in areas without electrified tracks (New Jersey Real-Time News, 2011; Bombardier, 2018; Railway Technology, 2018).

Beyond bi-modal diesel-electric options, several technologies offer zero tailpipe emissions on non-electrified tracks and will move towards zero well-to-wheel (WTW) emissions in the coming decades, as electricity supply continues to be decarbonised in most regions (IEA, 2018a). The most innovative zero WTW emission technologies are battery-electric trains and hydrogen fuel cell trains.

Battery-electric trains have been designed to enable switching between OLE electric and all-battery[19] phases of operation. Bombardier's Talent 3 and Siemen's Cityjet eco battery-electric hybrids[20] are pre-commercial prototypes suitable for passenger rail transport (Frintert, 2018; International Railway Journal, 2018). The Talent 3 currently has an all-battery range of 40 kilometres and the manufacturer's target distance is 100 kilometres. Several manufacturers have also introduced hybrid diesel-electric battery technologies for freight rail.[21]

Hydrogen trains have been deployed experimentally and are under further development. In 2015, French train manufacturer, Alstom, and the Canadian producer of hydrogen generation, fuel cells and other similar technologies, Hydrogenics, established a partnership to develop a hydrogen train (Hydrogenics, 2015). In 2018, successful testing of the hydrogen fuel cell concept concluded and two hydrogen trains entered operation along an approximately 100 kilometre regional conventional passenger train track in Lower Saxony, Germany (Alstom, 2018). The plan is to expand to 14 trains by 2021 (Alstom, 2018). Independently, Toyota recently announced a partnership with the Japan Rail-East to develop a hydrogen train in Japan (Kyodo, 2018).

In order to evaluate their economic viability, these innovative technologies have been assessed against diesel-electric, diesel-electric hybrid and OLE trains (Figure 2.14 andFigure 2.15), using a range of options to reflect differences between passenger and freight rail operations, typical train sizes, and uncertainties with respect to system costs. The cost estimates cover:

- Two train configurations: a regional conventional passenger train for a typical European case and a heavy-duty freight train for movements in North America, each coupled with a representative frequency of network utilisation (a key determinant of unit costs of OLE infrastructure).
- Two sets of cost assumptions for batteries, fuel cell systems and hydrogen production, representing a conservative case and a more optimistic case.

[19] The battery would be charged by OLE power when the train is running or, if OLE is not deployed, at the end of the line or in a depot.

[20] Deutsche Bahn has partnered with CRRC Corporation Limited (CRRC) on an electric-battery hybrid switcher locomotive pilot (Barrow, 2018). Vossloh, a global manufacturer of rail technologies, including locomotives, aims to adapt its DE-18 locomotive design in order to create a battery-electric hybrid locomotive (Vossloh, 2018). Aselsan, a Turkey-based company, has recently released an electric-battery hybrid switch locomotive (Railway Gazette, 2018).

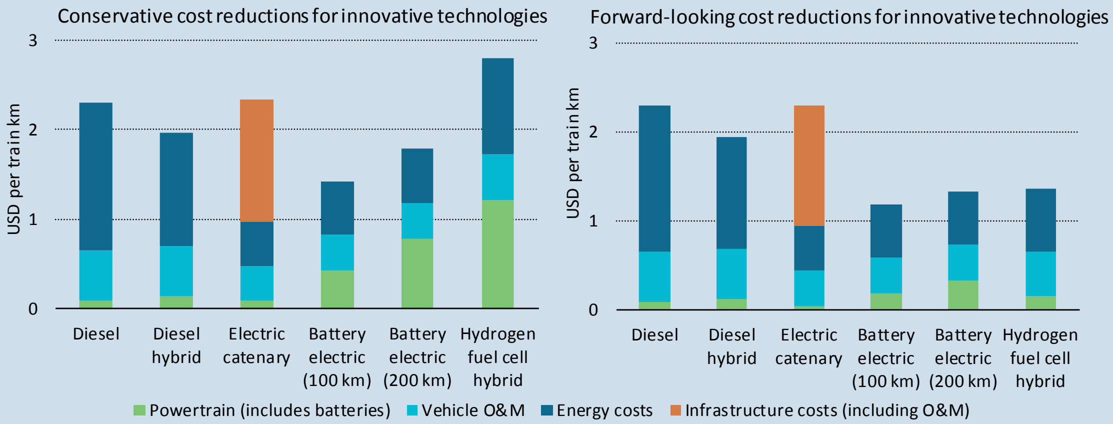
[21] Hybridisation can be an enabler of regenerative braking. With the necessary battery improvements, hybridisation can recover energy that would otherwise be released through transistors. The energy saving potential of train hybridisation has been estimated to range from 17% to 32% (Evans, 2010; Hoffrichter, Hillmansen and Roberts,2015), depending on route characteristics, including frequency of acceleration, deceleration and other factors. Relying more on stored regenerative braking energy, a vehicle's prime propulsion system could be reduced in size, which would save money or, at least, offset some of the higher cost of battery storage technologies.



The results for the regional passenger train configuration using fuel prices that are representative of a European case (i.e. accounting for significant taxation on diesel fuel) show that network electrification is viable in competition with diesel and diesel hybrid trains if the average frequency of use is six or more trains per hour, while battery-electric trains (which are capable of running in battery-powered mode for up to 200 kilometres) are cost competitive with diesel-fuelled options or OLE electricity, even with battery costs of USD 600 per kilowatt-hour (kWh) (Figure 2.14). Hydrogen trains can compete with battery-electric options, given an optimistic outlook on cost reductions.

**Figure 2.14 Comparative cost analysis of regional passenger train technologies with zero-tailpipe emissions**




Notes: O&M = operation and maintenance. The energy consumption used for this train configuration is 19 kWh/train-kilometre for diesel, 15 kWh/train-kilometre for diesel hybrid, 5.8 kWh/train-kilometre for all-electric train, 5.9-6 kWh/train-kilometre for battery-electric train and 9.1 kWh/ train-kilometre for fuel cell hybrid train. The power rating of the trains is 1 200 kilowatts (kW) (four railcars of 300 kW each). Battery-electric trains are run for 100 or 200 kilometres solely on battery, and are assumed to use OLE (also to recharge batteries) for the rest of their travel. This leads to battery requirements of 700 kWh for the 100 kilometres train and 1.5 megawatt-hours (MWh) for the 200 kilometre train versions. Depreciation of all equipment is assumed at a rate of 10% per year, and costs are evaluated over a ten-year lifetime, using a 10% discount rate to account for future costs. The diesel fuel price is USD 1.4 per litre (L). The electricity price is USD 0.17/kWh. The hydrogen fuel cost is USD 56 per gigajoule (GJ) in the conservative case and USD 33/GJ in the more optimistic one (costs reflect hydrogen production via onsite electrolysis). O&M costs are equal to USD 0.92/train-kilometre for the diesel and diesel hybrid, USD 0.65/train-kilometre for all-electric trains and USD 0.83/train-kilometre for the fuel cell hybrid. The OLE cost is USD 1.1 million per track-kilometre and is assumed to have a lifetime of 35 years with a discount rate of 10%. The frequency of use of the service is six trains per hour on each track-kilometre. Battery costs are USD 600/kWh for the conservative case and USD 250/kWh for the optimistic one. Fuel cell stack costs range from USD 1 000/kW in the conservative case to USD 50/kW in the optimistic one. The average annual mileage of all trains is 115 000 kilometres/year. Base vehicle costs are assumed to be the same for all trains and are therefore excluded.

Sources: Hoffrichter, Hillmansen and Roberts (2015); Argonne National Laboratory (2018); Evans (2010); ÖBB (2003); ÖBB (2004); IEA (2018c); IEA (2015); IEA (2017); Downer-Electro Motive (2012); Ernst and Young, GmbH (2016); Barrow (2018); International Railway Journal (2018); Brady (2017); Aquino et al. (2017); Fuel Cell Technologies Office (2018); Boer (2013).

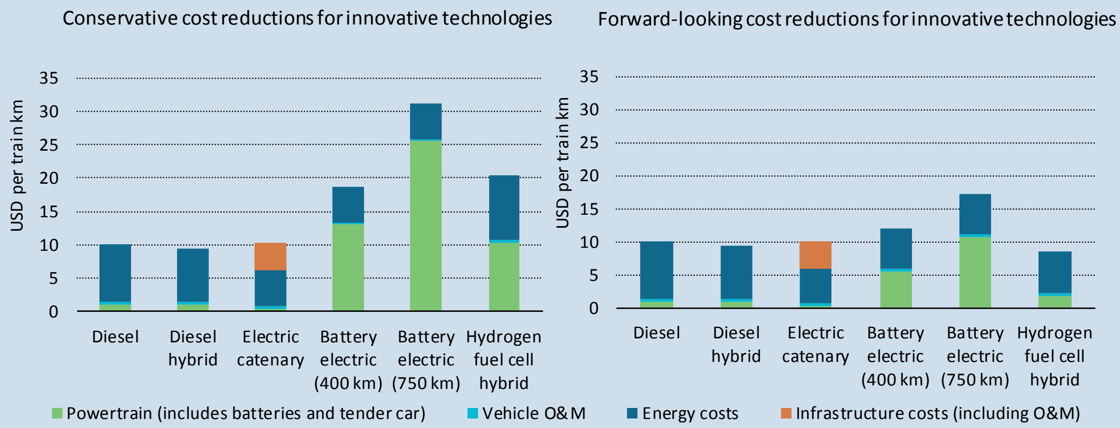
**Key message • Electric (OLE) regional trains are cost competitive with diesel-electric trains with frequencies of use above six trains per hour per track-kilometre. Battery-electric trains are already cost competitive with conservative battery costs. Hydrogen trains can also compete given an optimistic outlook on cost reductions.**

In the case of heavy freight train configuration, applying OLE electricity to freight rail networks could be cost competitive, despite low diesel fuel costs, where the level of traffic rises above two trains per hour (Figure 2.15).[22] Should costs come down significantly for the newer technologies, hydrogen

[22] The frequency of operations of freight trains along a given stretch of track varies substantially on different routes. Within the United States, these variations are both regional, and between rural and urbanised areas. Since the freight industry operates mostly over long distances, the decision to electrify would consider this constraint, so an average of two trains per hour for a broad portion of the network would be a minimum prerequisite. The level of rail traffic needed to make electrification cost-effective also depends on passenger rail activity along a given freight route. In fact, on routes with low frequency freight rail, an increase in passenger traffic could facilitate the cost effectiveness of installing OLE along the

fuel cell locomotives could also become competitive. Battery-electric only demonstrates competitiveness on the basis of optimistic battery price improvements for distances of less than 400 kilometres.

**Figure 2.15 Variable costs of ownership for zero tailpipe emissions freight rail over ten years**




Notes: O&M = operation and maintenance. The energy consumption used for this train configuration is 174 kWh/train-kilometre for diesel, 162 kWh/train-kilometre for diesel hybrid, 52 kWh/train-kilometre for all-electric train, 56-60 kWh/train-kilometre for battery-electric trains and 79 kWh/ train-kilometre for fuel cell hybrid train. The power rating of the trains is 9.9 MW (three locomotives). Battery-electric trains are run for 400 or 750 kilometres solely on batteries and are assumed to use OLE (also to recharge batteries) for the rest of the travel. Corresponding battery requirements are 27 MWh for the 400 kilometres and 54 MWh for the 750 kilometres versions. The hydrogen train and the battery train require an extra tender car[23] to transport the required fuel costing USD 135 000. Depreciation of all equipment is assumed to be 10% per year; costs are evaluated over a ten-year lifetime, using a 10% discount rate to account for future costs. The diesel fuel price is USD 0.9/L. The electricity price is USD 0.17/kWh. The hydrogen fuel cost is USD 56/GJ in the conservative case and USD 33/GJ in the optimistic one (costs reflect hydrogen production via onsite electrolysis). O&M costs are equal to USD 0.71/train-kilometre for the diesel and diesel hybrid, USD 0.50/train-kilometre for all-electric train and USD 0.64/train-kilometre for fuel cell hybrid. The OLE cost is USD 1.1 million per track-kilometre and is assumed to have a lifetime of 35 years with a discount rate of 10%. The frequency of use of the service is two trains per hour on each track-kilometre. Battery costs are USD 600/kWh for the conservative case and USD 250/kWh for the forward-looking one. Fuel cell stack costs range from USD 1 000/kW in the conservative case and USD 50/kW in the forward-looking one. The average mileage of all trains is 120 000 kilometres/year. Base vehicle costs are assumed to be the same for all trains and therefore are excluded.

Sources: AAR (2018); Argonne National Laboratory (2018); Evans (2010); Hoffrichter (2015); Tita (2015), IEA (2018c); (Surface Transportation Board (2018); Ernst & Young (2016); IEA (2015); IEA (2017); Barrow (2018); International Railway Journal (2018); Brady (2017); Aquino et al (2017); Fuel Cell Technologies Office (2018); Boer (2013).

**Key message • Rail network electrification is viable with traffic levels above two trains per hour per track-kilometre. Hydrogen fuel cell and battery-electric locomotives become competitive with lower technology costs.**



corridor, despite trade-offs due to the quality of passenger services on networks prioritising freight transport (see Drivers of rail transport section).

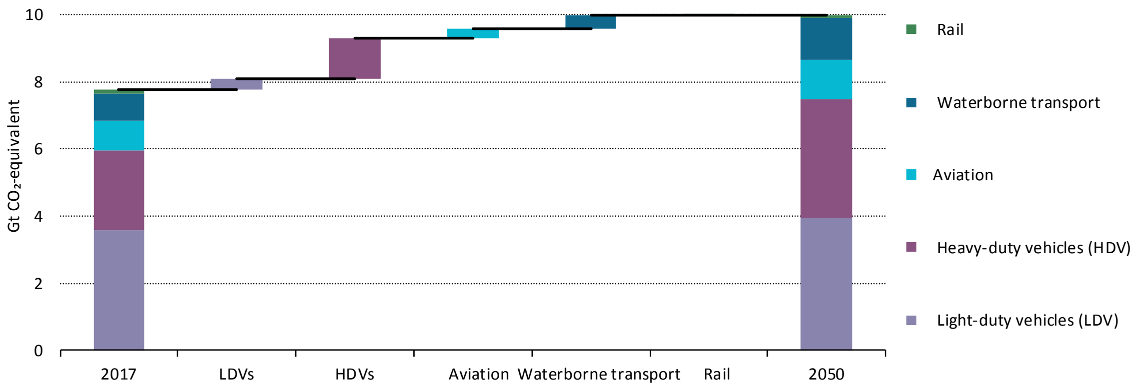
[23] The hydrogen train that recently began operation in Germany uses compressed hydrogen, as do several bus systems in the United States that use fuel cells. Where very large amounts of fuel are required to move the train, liquid hydrogen on-board storage may be required, as it has a higher volumetric energy density than its gaseous counterpart. Based on typical volumetric battery densities, the volume needed for a 400-750 kilometre battery would occupy 25-50% of a locomotive, excluding cooling. This means that an additional tender train would be needed to store the battery (Johnson Matthey, 2015).

# Implications for GHG emissions and local pollutants

## *Direct $CO_2$ emissions*

In the Base Scenario, looking at all forms of transport, direct carbon dioxide ($CO_2$) emissions at the tailpipe resulting from the combustion of fossil fuels increase by 32% in 2050 relative to 2015 (Figure 2.16). The majority of this increase in emissions, about 1.2 gigatonnes (Gt) of $CO_2$, comes from heavy-duty vehicles (buses and trucks). Tailpipe emissions from fossil fuel combustion by light-duty road vehicles increase in absolute terms by less than half as much (0.5 Gt $CO_2$), followed by increases in shipping (0.43 Gt $CO_2$) and aviation (0.32 Gt $CO_2$). Direct combustion emissions from rail are roughly constant between 2015 and 2050, even with increased rail activity, as the sector continues to electrify.

**Figure 2.16 Direct $CO_2$ emissions from fuel combustion in the Base Scenario, 2017-50**




Source: IEA (2018b).

Key message • **The majority of the increase in direct $CO_2$ emissions is attributable to growing activity by heavy-duty vehicles, road freight in particular. Increasing emissions from heavy-duty vehicles are nearly as large in magnitude as those from light-duty vehicles, aviation and waterborne transport combined.**

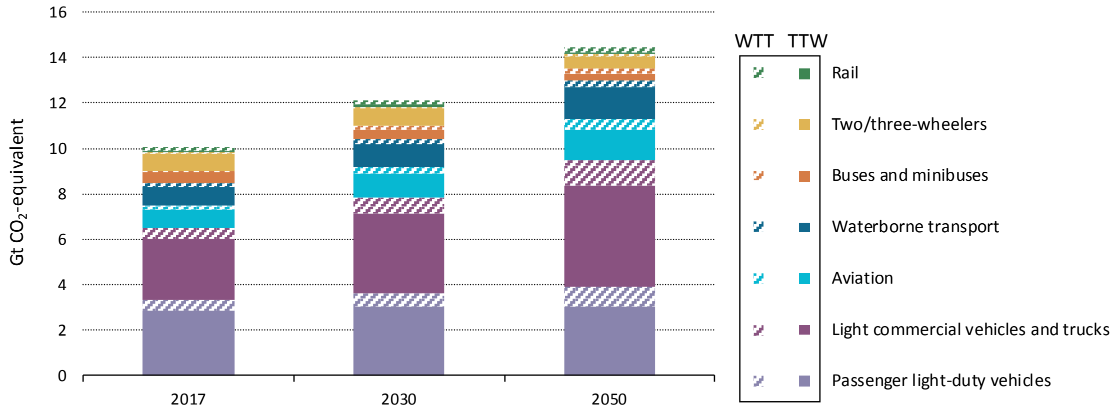
## *Well-to-wheel GHG emissions*

Well-to-wheel (WTW) GHG emissions[24] from transport increase about 50% between 2017 and 2050 in the Base Scenario, from 9.6 to 14 Gt carbon-dioxide equivalent ($CO_2$-eq), closely tracking energy demand trends (Figure 2.17). The share of tank-to-wheel (TTW) emissions in total WTW GHG emissions decreases from 83% in 2017 to 76% in 2050, primarily as a consequence of increased electrification of the transport sector.

Within the rail sector, global WTW GHG emissions grow by 24% from 0.25 Gt $CO_2$-eq in 2017 to 0.32 Gt $CO_2$-eq in 2050. The combined result of electrification and the gradual reduction in the carbon intensity of power generation leads to lower growth of rail sector GHG emissions (24%) relative to increases in energy demand (66%).

[24] See the glossary for definitions of well-to-wheel (WTW) GHG emissions, which are the sum of well-to-tank (WTT) and tank-to-wheel (TTW) emissions.

**Figure 2.17 Well-to-wheel GHG emissions in the Base Scenario, 2017, 2030 and 2050**



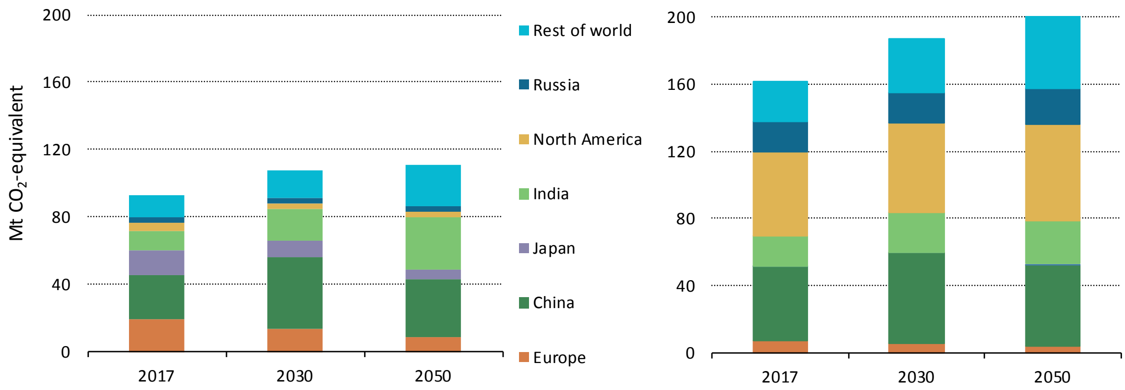

Note: WTT = well-to-tank (dashed background); TTW = tank-to-wheel (solid background).

Source: IEA (2018b).

**Key message • Emissions growth closely tracks energy demand, even though electrification, in both road and rail modes, contributes to a reduction in well-to-wheel GHG emissions, as well as to a growing share of wheel-to-tank emissions in the total.**

WTW GHG emissions from passenger rail reach around 0.1 Gt $CO_2$-equivalent by 2050 in the Base Scenario (Figure 2.18). This is a 20% increase with respect to 2017, but is much lower than the doubling of passenger rail energy demand, reflecting the benefits of electrification of passenger railways. The same decoupling occurs, though to a lesser extent, in freight rail. As a result, GHG emissions growth is contained. In the Base Scenario, transport-related well-to-wheel GHG emissions would be 13% higher by 2050 if the passenger and freight activity of rail were covered by other transport modes.[25]

**Figure 2.18 Well-to-wheel GHG emissions from passenger (left) and freight (right) rail in the Base Scenario, 2017, 2030 and 2050**




Source: IEA (2018b).

**Key message • Well-to-wheel GHG emissions from passenger rail stabilise at around 110 Mt $CO_2$-eq; emissions from freight rail steadily increase and remain about twice as high as emissions from passenger rail.**

[25] This result is obtained assuming that high-speed rail would be replaced by aviation, and that conventional and urban rail would be replaced by passenger cars. The world average WTW GHG emission factor in 2050 for aviation is 0.08 Mt $CO_2$-eq per billion passenger-kilometres. For road passenger transport the number is 0.09 Mt $CO_2$-eq per billion passenger-kilometres and for road freight transport 0.08 Mt $CO_2$-eq per billion tonne-kilometres (IEA, 2018b).

Levels of GHG emissions from freight rail remain nearly twice as high as those from passenger rail throughout the outlook period, rising by 27% by 2050 to reach 0.2 Gt $CO_2$-eq. Again, this compares favourably with the almost 60% growth of freight rail energy demand.



As in the case of energy demand, GHG emissions from passenger rail decline in Japan (down about two-thirds between 2017 and 2050), Europe (-54%) and North America (about -30%). The trend is reversed in emerging economies, because of their much stronger growth in rail activity. In China*,* GHG emissions from passenger rail peak in 2030 and then decouple from increasing energy demand as a result of electrification and decreasing carbon intensity of electricity production.

Annual freight rail emissions fall in Japan (-66%) and Europe (about -50%) by 2050. In all remaining regions, emissions increase, although at slower rates than the growth in energy consumption, due to growing share of electric traction and decarbonising of power generation. In North America, freight rail remains reliant on diesel traction, as long distances with low utilisation do not support installation of OLE given the costs and logistical challenges.

## *Emissions of local pollutants*

As discussed, growing demand for personal travel will lead to more activity in cars and trucks in the Base Scenario. Across all modes, passenger transport activity in 2050 more than doubles from 2017 levels and freight activity triples. At the same time, the adoption of emission control technologies in cars and trucks and broad application of emissions standards, reduces specific (per kilometre) fine particulate ($PM_{2.5}$) emissions from cars and trucks. However, non-combustion $PM_{2.5}$ emissions, which come from the abrasion and corrosion of vehicle parts (e.g. tyres, brakes) and road surfaces, are still relevant. By 2050, the average $PM_{2.5}$ combustion emissions per vehicle-kilometre of a passenger car are one-third the current level, and those of the average heavy freight truck are 40% the current level (IEA, 2016). By 2050, declining combustion emissions intensity more than offsets growing activity and the net effect is 10% decrease in $PM_{2.5}$ emissions from road transport modes.

Despite these improvements, air quality continues to be a pressing challenge, particularly in cities, affecting the health and life expectancy of billions of urban inhabitants. Rail makes a positive contribution to the reduction of atmospheric pollutant emissions, with a resulting positive impact on air quality in urban areas. In the Base Scenario, urban rail activity is expected to increase in all regions, though with a limited increase in developed economies and Russia, and a strong increase in emerging economies. Air quality is an issue in all countries, but the cities with the heaviest pollution problems are in Asia. The growth in urban rail transport in the Base Scenario alleviates some of the problem: China has the strongest growth in urban transport activity in absolute volumes, and India experiences the fastest growth in urban rail infrastructure deployment. In the Base Scenario, by 2050, urban rail avoids 0.7 million tonnes of $PM_{2.5}$ emissions in urban environments compared with a situation in which rail activity was covered by road vehicles.[26]

[26] This result is obtained considering that the activity of urban rail in 2050 is replaced by passenger light-duty vehicles, two/three-wheelers and buses maintaining their relative modal shares and considering pollutant emission factors for the different modes (IEA, 2018a).

## Investment requirements

Transport infrastructure in general, and rail infrastructure in particular, is extremely capital intensive to build. Over the period 2010-15, average annual investment in road infrastructure in the group of major countries listed below[27] totalled USD 540 billion (2015 USD on purchasing power parity [PPP] basis), 2.7-times higher than the USD 200 billion investment in the same group of countries in rail infrastructure (OECD, 2017). Combined investments in airports and seaports over the same period and in the same countries were USD 43 billion, about one-fifth of those in rail (OECD, 2017).[28]

In total, average annual investment in road and rail infrastructure worldwide in the Base Scenario amounts to about USD 1.9 trillion. At USD 315 billion, annual investment in rail infrastructure to mid-century is estimated at around one-fifth of investment in road infrastructure. Moreover, where rail is able to provide competitive mobility services, (particularly in high throughput corridors), investment in rail can offset investment in other transport modes, such as airports, roads and parking spaces for cars, and, importantly, consumer expenditures on personal vehicles and fuel. Other benefits include reduced air pollution in urban areas and lower GHG emissions, though these are difficult to monetise.

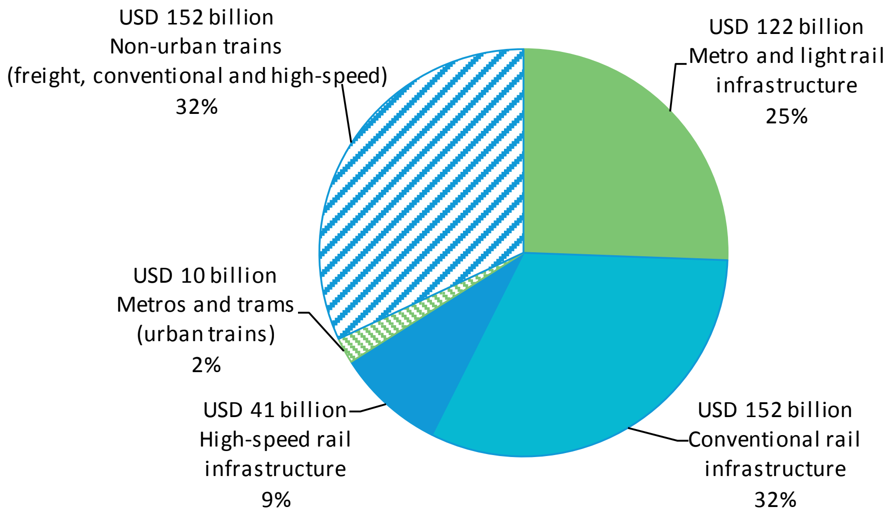
Rail construction costs depend on a number of factors, including the costs of land acquisition, labour and materials, the number of tracks per line, track electrification, the need for tunnels or bridges and the intended operating speed. These and other factors give rise to large differences in costs which, per line-kilometre for conventional rail, can range from USD 0.5 to 20 million (Gattuso and Restuccia, 2014; Von Brown, 2011). For urban light rail the costs range from USD 10 to 25 million (Rode et al., 2014). High-speed rail lines are even more expensive, with costs of USD 20 - 80 million per line-kilometre, with elevated or tunnelled track raising costs further (Campos and de Rus, 2009; Wu, Nash and Wang, 2014; ETSAP, 2011; UIC, 2018). Metro is more expensive still: costs typically range USD 50 - 350 million per line-kilometre (Lepeska, 2011; Pedestrian Observations, 2013; Davies, 2012) and tend to be higher for underground metro construction in densely populated urban centres.

Besides investment in rail infrastructure, there are numerous other investment requirements in the rail sector, first and foremost for the rolling stock. Comprehensive global annualised average investment needs in the Base Scenario amount to around USD 475 billion (2015 USD PPP), of which expenditure on infrastructure – building the networks, including electrifying new and existing conventional rail networks – amounts to USD 315 billion. This figure is no surprise, given the high capital costs of rail infrastructure (Figure 3.23). The remaining third of the investment in rail goes to renewing and expanding train fleets. Most investment in trains over the coming decades involves renewing and updating the fleet of conventional, freight and high-speed trains, and a very small share goes to the metro and light rail train stock.

[27] These include Australia, Canada, China, most European Union member states, India, Japan, Korea, Mexico, Russia, Turkey and United States.

[28] Global rail investments over the 2010-15 period as estimated in the IEA Mobility Model are slightly higher than those reported for the 42 major countries by the OECD and total around 230 billion (IEA, 2018b). Country estimates are similar to those reported in the OECD database and the higher estimate is consistent with the global scope of the IEA modelling.

**Figure 2.19** **Annual average investment costs in the Base Scenario, 2018 to 2050**




Source: IEA (2018b).

**Key message • Roughly USD 475 billion needs to be spent annually on building, operating and maintaining rail. Nearly two-thirds of this is required to build and maintain rail lines, and the remainder to renewing and expanding the rolling stock.**

Average annual investment of USD 315 billion in rail infrastructure means that future infrastructure investments will run at roughly 50% above recent levels to meet the rail deployment policy targets in the Base Scenario. This underscores the extent of the commitment necessary to realise the ambitious passenger and freight movement targets in certain regions.

## Conclusions

On the basis of declared intentions on the pace of development of rail transport infrastructure, plans to electrify railway lines and targets for modal shares of rail in overall transport activity, rail activity is set to grow strongly in the Base Scenario. And yet, despite the emergence of urban and high-speed rail systems in regions of the world where these systems do not currently exist, the modal shares of passenger rail in overall transport activity stay roughly constant in the period to 2050. The share of freight activity on rail in surface freight transport falls, from 28% today to 23% in 2050.

For rail to maintain current shares of passenger transport and to continue to play a role in freight supply chains will require substantial investment. Annualised average investment in rail infrastructure worldwide would need to increase by about 50% more than levels in recent years. This will require financing at a level that will necessitate the ingenuity of many of the countries where rail can provide the most benefits.

Beyond the developments of the Base Scenario, there remains considerable additional potential for rail to reduce the dependence of transport on oil and to contain the rise in $CO_2$ and local pollutant emissions. This is true above all in cities, where urban rail systems can contribute more to the vitality of growing metropolises by reducing road congestion and making trips faster, more reliable and more convenient. It is also the case among cities, where demand for alternatives to short- to medium-distance flights could provide a niche for high-speed rail to diversify transport energy sources and reduce emissions.

Chapter 3 explores the implications for transport energy use and emissions of investment and policies that promote greater reliance on rail in the period to 2050. It summarises the key policies that might help to achieve a High Rail Scenario, and discusses other benefits that could be realised by taking advantage of the full potential of rail.



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# 3. High Rail Scenario: Unlocking the Benefits of Rail

## Highlights



- Increasing the rail sector's share in global transport offers major benefits. Rail is much more energy efficient than any other mode of transport and it relies to a significant extent on electricity, offering a distinct opportunity to reduce energy use, $CO_2$ emissions and air pollution. In an urban environment, rail has significant advantages as it moves large flows of passengers, can mitigate congestion and realise economic benefits through agglomeration effects. High-speed rail is the only established alternative to aviation on short-distance flights and freight rail the only alternative to long-distance inland road freight transport, two sectors that account for large and rapidly growing shares of transport-related energy demand and emissions and, so far, where alternative technology options are limited.
- The High Rail Scenario explores the extent to which rail can replace less efficient transport modes including cars, two/three-wheelers, aviation and trucks. Compared with the Base Scenario, policies to promote rail and encourage operational efficiency across all modes in the High Rail Scenario reduce and shift 11.5 trillion passenger-kilometres from airplanes, cars and two/three-wheelers, and 7.4 trillion tonne-kilometres from trucks in 2050. Despite a limited increase in electricity demand (620 TWh higher than in the Base Scenario in 2050), transport energy demand overall is much reduced (by 15%) in 2050. Some 90% of this net reduction is in oil use, which is 10 mb/d lower than in the Base Scenario in 2050.
- The High Rail Scenario delivers significant environmental benefits: by 2050, transport-related well-to-wheel GHG emissions are 2.1 Gt $CO_2$-eq (or 16%) lower than in the Base Scenario, and rail makes it possible to avoid an additional 220 kt (35%) of $PM_{2.5}$ emissions. Direct energy-related $CO_2$ emissions from transport peak before 2040 in this outlook and then decline to 2015 levels by 2050. The High Rail Scenario alone does not achieve the targets of the Paris Agreement, but the substantial emissions reduction achieved make rail an essential component of a more comprehensive energy and transport strategy.
- Minimising costs, maximising potential revenues and ensuring that all transport modes pay not only for the use of the infrastructure but also for the adverse impacts they generate (e.g. through road pricing and congestion charges) are crucial strategies to unlock the significant benefits to sustainable transport that rail can offer. Achieving the modal shifts outlined in this scenario requires both increased policy effort and substantial investment. Average annual investment in rail infrastructure is USD 640 billion between 2018 and 2050, 90% higher than in the Base Scenario. Capture of the added land value attributable to rail investment is central to the economic viability of rail infrastructure projects. To improve the competitiveness of rail with other modes, transport pricing policies that embody the principles of "user pays" and "polluter pays", together with digital technologies to optimise rail operations and improve the integration of rail in overall mobility services, are required.
- Additional investment would be required in rail infrastructure, but expenditure on vehicles in the High Rail Scenario is reduced compared with the Base Scenario, and so are investments in road and parking infrastructure, and expenditure on transport fuels (15% lower than in the Base Scenario in 2050). The savings are achieved through increased reliance on more efficient transport modes and reduced use of private passenger and road freight transport, reducing the need for expenditure on roads, the number of vehicles to be acquired and overall fuel demand.

# Introduction

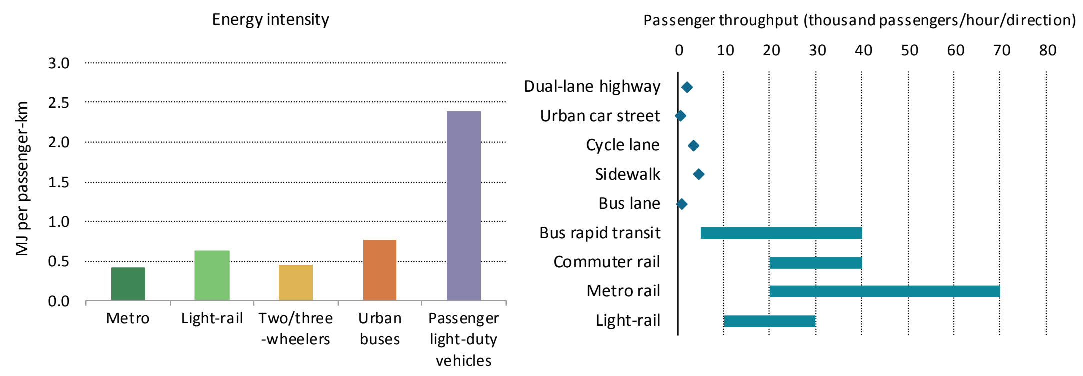
This chapter explores the extent road transport demand can be fully satisfied with lower reliance on cars, two/three-wheelers, planes and trucks through increased reliance on rail. It briefly illustrates potential motivations for shifting transport activity to rail modes, building on observed examples and elaborating on the often unparalleled benefits that rail offers compared with other modes from an energy and transport perspective. This chapter focuses on the High Rail Scenario – a plausible future in which rail plays an enhanced role in the transport sector through modal shifts. As in the previous chapters, it illustrates key parameters characterising network extension, passenger and freight activity, energy demand and environmental implications, as well as investment needs. The concluding section highlights the policy actions required to enable a transition from the Base Scenario to the High Rail Scenario.

## *Motivations for increasing the role of rail transport*

### *Urban rail*

In the urban context, rail transport systems outperform road-based transport in all respects: efficiency of transport, lower energy requirements and fewer toxic emissions. Urban rail has unmatched capacity to transport large volumes of passengers (passenger throughput), and generally a relatively low energy use per passenger-kilometre travelled (Figure 3.1). Where reliant on electricity as a fuel, urban rail does not give rise to tailpipe emissions of greenhouse gas (GHG) or local pollutants, avoiding the associated environmental and health issues. Urban rail can also contribute to enhanced road safety and lower accident mortality.

**Figure 3.1 Energy intensity and passenger throughput of different urban transport systems**




Note: MJ = megajoule; km = kilometre.

Sources : IEA (2018) and Rode et al. (2014).

Key message • **Metros, commuter rail and light rail all have high throughput capacity, higher than most alternative urban transport options and are important where traffic volumes are high.**

In terms of transport policy, the high passenger throughput capacity of urban rail creates opportunities to mitigate congestion while providing access to and travel within cities.[1] There are associated indirect economic benefits: reduced time-loss in traffic and cost savings arising

[1] Congestion reduction is achieved by successfully drawing activity to high throughput and generally more space-efficient modes, which reduces overall (lower-throughput) private car and taxi shares. Shifting people that were using personal vehicles onto metro lines both reduces the number of personal vehicles on the road and enables the reallocation of road space for other uses.

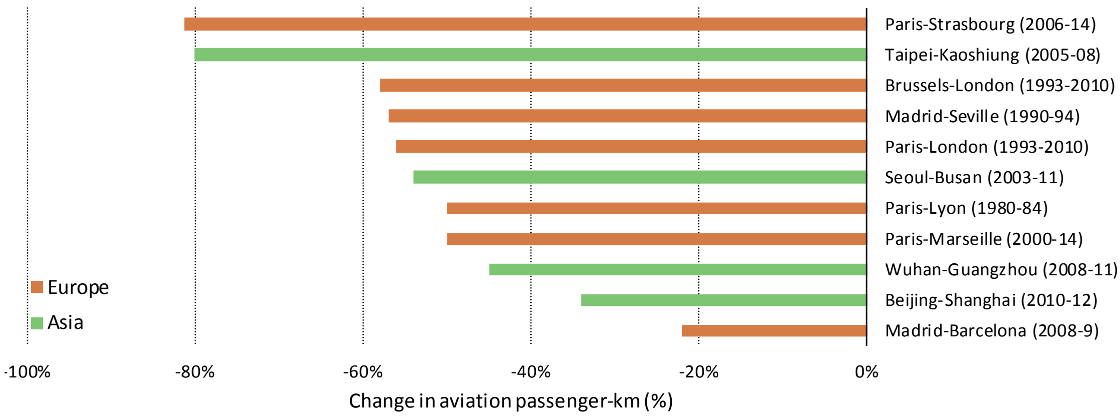
from the easy proximity of economic actors. There are concrete examples of congestion improvements. For example, in Beijing, where car registrations far surpass designed road capacity, each new metro opening has significantly decreased congestion, reducing delay times by an average of 15% (Yang et al., 2018). Similar congestion reduction was observed in the city of Guangzhou with the opening of its metro system and the trend accelerated when the metro system was expanded (Yang, Zhang and Ni, 2014). It is possible to evaluate time lost in traffic. For example, in the case of New York City, it is estimated that USD 13 billion per year is lost as a direct result of traffic congestion (PFNYC, 2006).



## *Conventional and high-speed rail*

Shifting long-distance trips from aviation (primarily short-distance flights) and cars to conventional and high-speed rail is generally energy efficient and can deliver significant environmental gains. High-speed rail offers the only established low-carbon alternative to aviation, a sector that is one of the most challenging to decarbonise, for the transport of large volumes of passengers over distances of up to about 1 000 kilometres. About 60-80% of present high-speed rail activity can be shown to derive from shifts away from conventional rail and planes, with the remainder from avoided road traffic (10-20%) and induced demand (10-20%) (Givoni, 2013). There is some evidence of substantial (even nearly total) high-speed rail substitution for air traffic (Figure 3.2). More broadly, Figure 3.3 shows that countries with existing high-speed rail lines tend to have proportionately fewer short-haul flights than countries without high-speed rail. This is consistent with the observation that high-speed rail is most competitive with competing modes for trips with travel times ranging from 1 hour up to 3.5 hours (Givoni, 2013; UIC, 2018).

**Figure 3.2** **Average change in passenger activity on selected air routes after high-speed rail implementation**

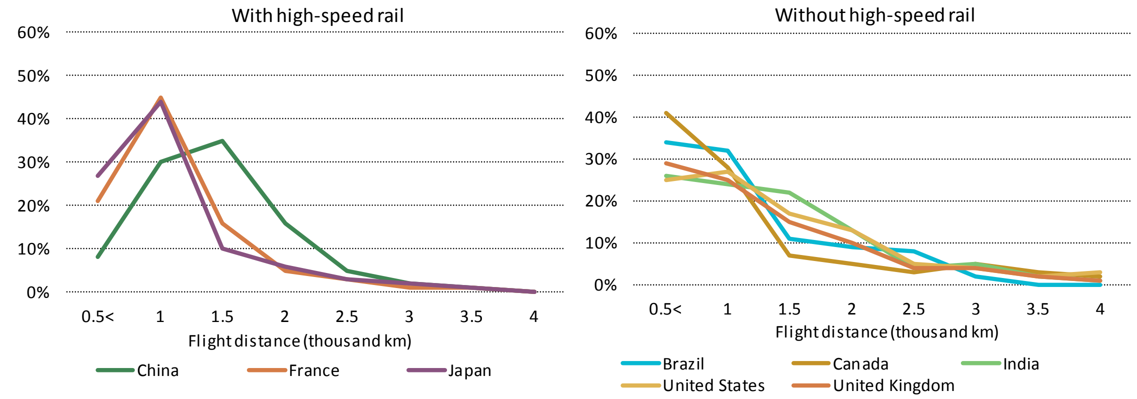



Sources: Xia (2016); Börjesson (2014); Givoni (2013); Chen (2017); Commissariat Général au Développement Durable (2016).

Note: The periods of time vary from line to line in this figure, which needs to be taken into account when comparing these elements.

**Key message • High-speed rail lines can reduce aviation activity on the same corridors by as much as 80% within a short timeframe of becoming operational.**

**Figure 3.3 Percentage of flights for various route distances for selected countries of departure with and without significant high-speed rail networks, 2017**



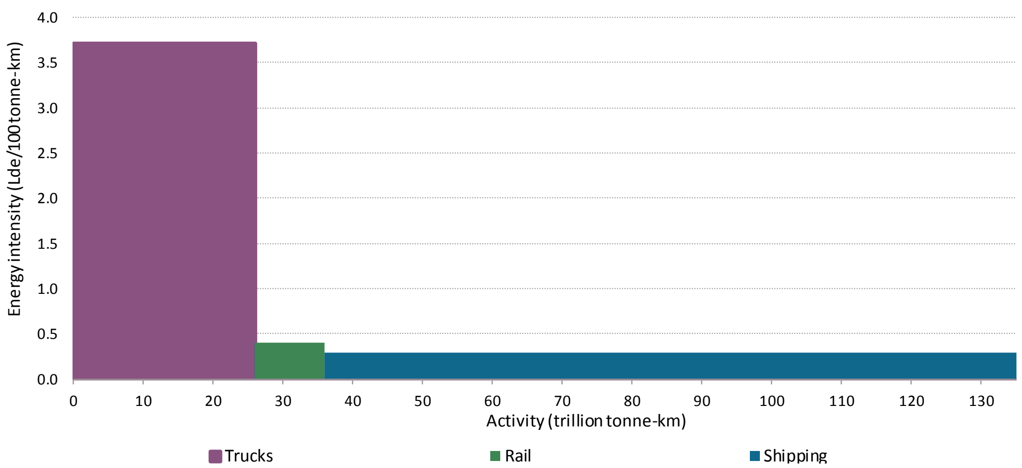

Source: IEA analysis based on OAG (2018).

**Key message** • **Flights of less than 500 kilometres are fewer relative to those of 1 000 to 1 500 kilometres in countries with established high-speed rail.**

## *Freight rail*

Increased efficiency and fewer emissions are also the main benefits from a shift of freight transport activity from road to rail. This stems from the lower amount of energy per tonne-kilometre needed to move goods on rail (Figure 3.4). Rail is the most established sustainable alternative to trucks, also one of the sectors that is more challenging to decarbonise for the transport of large volumes of freight over long distances. The energy and environmental case is not as compelling as in the case of a shift from maritime transport to rail, since the two modes have similar energy intensity per tonne-kilometre; but rail can rely more readily than shipping on a diverse mix of fuels and energy carriers. In addition to energy efficiency, diversification and environmental gains, shifting road transport to rail can deliver positive impacts on congestion, particularly that arising from long-distance truck movements.

**Figure 3.4 Global fleet average freight energy intensity and relative size of transport activity, 2015**




Notes: Lde = litres of diesel equivalent. In this figure, total transport activity in 2015 by billion tonne-kilometres is 26 for trucks, 10 for rail and 99 for shipping.

Source: Analysis based on IEA (2018).

**Key message** • **Rail uses around 10% of the energy required to transport a unit of freight by trucks, and is the only transport mode offering serious competition with trucks for land-based freight.**

# Trends in the High Rail Scenario

## *Main assumptions*

As illustrated in Chapter 2, transport energy demand and associated environmental impacts in the Base Scenario are set to grow significantly to 2050 on the basis of existing and planned policies, despite an impressive growth of rail transport. Further enhancing the role of rail can be a possible means to contain the projected rise transport energy demand as well as carbon dioxide ($CO_2$) and local air pollutant emissions. That is why this chapter develops an alternative scenario – the High Rail Scenario – which shows the energy and environmental benefits that could be achieved through stronger action to enhance the role of rail. Reinforcing the role of rail does not entirely eliminate the environmental impact of transport. But it does offer a pragmatic agenda for change, all the more so since enhancing the role of rail does not depend on any technological breakthroughs or radical innovations on the policy side.

The High Rail Scenario presents a plausible future in which rail plays an enhanced role in the transport sector by replacing much transport demand from cars, two/three-wheelers and road freight transport, relative to the Base Scenario. Given that rail transport is very capital intensive, unlocking an enhanced role for rail requires action to increase its economic attractiveness. For this reason, the High Rail Scenario rests on three main pillars:

- **Minimising costs per passenger-kilometre or tonne-kilometre moved**, in order to ensure that the preconditions for maximum rail network usage are in place (e.g. through urban planning measures that provide integration of other modes of transport with the rail transport network); that technical barriers are removed (e.g. through the adoption of international standards that facilitate inter-operability); and adoption of digital technologies to facilitate the integration of rail services into the range of mobility options available for passengers and goods (to facilitate higher throughput).
- **Maximising revenues from rail systems**, capitalising on the "aggregation" capacity of railway stations (land value capture), a model which has already made several rail systems profitable.
- **Ensuring that all forms of transport pay not only for the use of the infrastructure they need, but also for the adverse impacts they generate.** Traditionally, this has been done through fuel taxation, but road pricing and especially congestion charging are likely to be more effective means for regulating the infrastructure and congestion impacts of road vehicles. The case can be strengthened by increased transport electrification and a transition towards road vehicle automation, both of which are likely to require price signals to modulate demand.[2]

A broader range of policy tools includes measures influencing urban structures, forms and densities, and instruments that increase the implicit cost (time and money) of driving personal vehicles. They are elaborated in the policy section at the end of the chapter.

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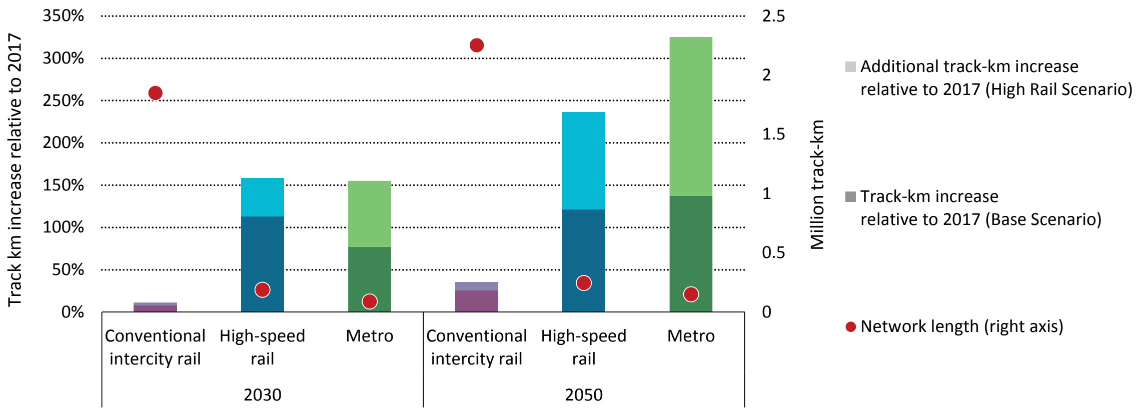
[2] In the case of electrification, negative external impacts of cars and trucks would be limited to impacts on road infrastructure and congestion, and so taxation schemes would need to be designed to address these impacts, as opposed to those (like local pollution and GHG emissions) associated with vehicles running on internal combustion engines. In the case of self-driving cars, congestion pricing or similar schemes would be needed to prevent likely increases in congestion coming from the lower costs and higher convenience of vehicle travel.

## Rail network developments in the High Rail Scenario

In the High Rail Scenario, the total (including conventional, high-speed and urban) rail network length reaches 2.65 million track-kilometres by 2050, which is 0.4 million more than in the Base Scenario. This difference is largely due to the significant additional investment assumed to take place in metro and high-speed rail networks in the High Rail Scenario and a sizeable increase in the conventional rail network (Figure 3.5). Metro and high-speed rail networks expand faster than conventional rail; relative to 2017, the global high-speed rail network length more than triples by 2050 in the High Rail Scenario, while the metro network length increases more than fourfold. Passenger-kilometres increase fivefold on metros and more than fourfold on high-speed rail over the period. The concentration in Asia of the extra investment in metro and high-speed rail transport (where train capacities are larger) contributes to an overall increase in the capacity utilisation rates of metro and high-speed rail at the global level.

**Figure 3.5 Rail network additions in the High Rail and the Base Scenario relative to 2017**




Source: IEA (2018).

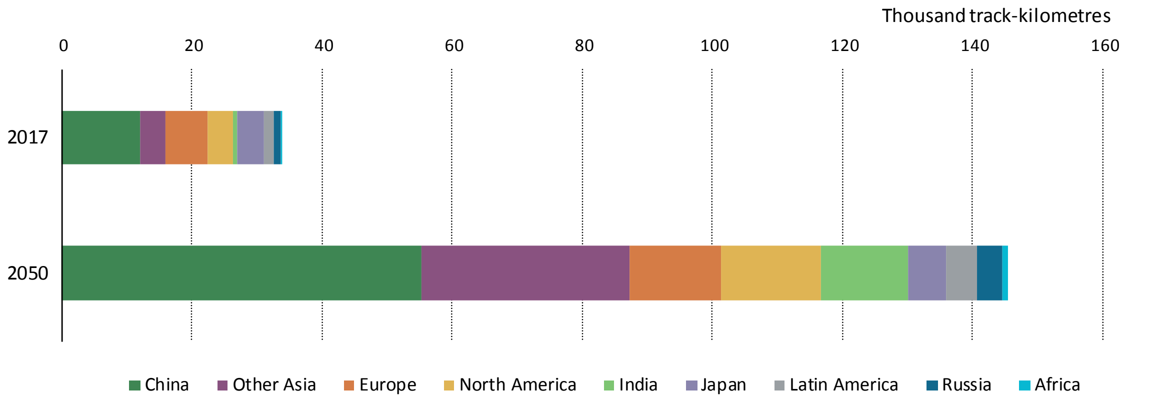
**Key message • Expansion of the metro and high-speed rail networks in the High Rail Scenario significantly exceeds that in the Base Scenario. The rate of growth of these parts of the rail network exceeds that of conventional rail.**

While the conventional rail network grows relatively slowly (36% between 2017 and 2050), the sheer size of the existing network means that it is the dominant growth area in absolute terms (close to 600 000 kilometres by 2050). By comparison, metro and high-speed rail additions reach almost 300 000 kilometres by the same year.

The metro rail network increases its length by 325% between 2017 and 2050, to reach over 150 000 kilometres (Figure 3.6). People's Republic of China ("China") adds the most track length in absolute terms between 2017 and 2050 (about 43 000 kilometres), although the growth rate is higher in India (reaching close to 13 000 kilometres by 2050, up from roughly 1 000 kilometres in 2017). The balance of the global metro rail network shifts strongly towards Asia, where over two-thirds of all metro track-kilometres are to be found by 2050. Other regions where the length of metro systems is relatively low, including Africa, South America, North America and Russian Federation ("Russia"), more than triple or quadruple their metro network in the same timeframe. Europe and Japan, which already have large metro network coverage in their main cities, add almost 8 000 kilometres and 1 700 kilometres of tracks, respectively, providing almost 240 billion additional passenger-kilometres of transport per year, compared to 2017. In all world regions, the rate of train activity growth is faster than the track build-out: in the High

Rail Scenario, the capacity utilisation rate of the metro network is improved by 40% (in terms of train-kilometre/track-kilometre) by 2050, with shorter intervals between trains enabled by digitalisation.[3]

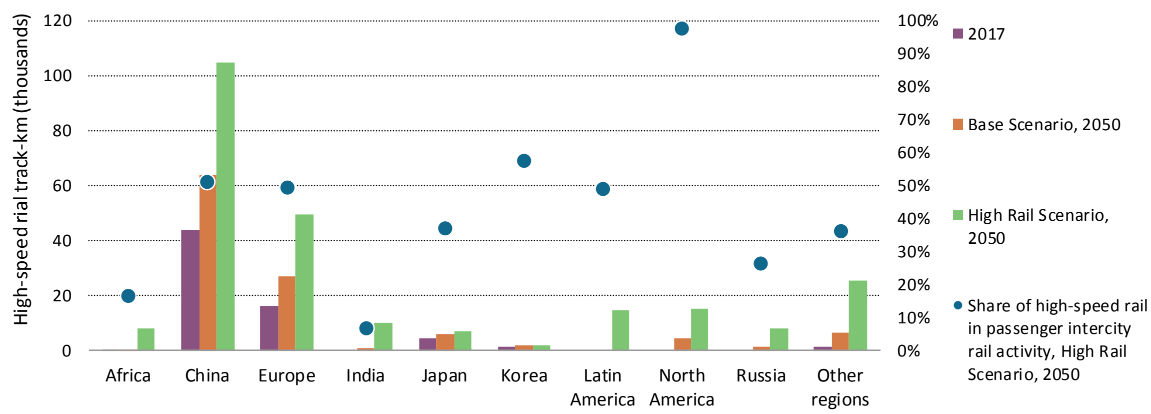
**Figure 3.6 Metro rail network build-out by region in the High Rail Scenario, 2017 and 2050**




Source: IEA (2018).

**Key message • The length of the metro rail network increases by 325% between 2017 and 2050, at which point over two-thirds of metro rail tracks are located in Asia.**

**Figure 3.7 Network build of high-speed rail by country in the Base Scenario and High Rail Scenario, 2017 and 2050**




Source: IEA (2018).

**Key message • High-speed rail construction in the High Rail Scenario goes well beyond that of the Base Scenario and includes development of high-speed rail in regions where it is not yet planned.**

Asian countries (above all China) and Europe remain the dominant high-speed rail regions in 2050, together accounting for almost 60% of global high-speed track-kilometre growth in the High Rail Scenario (Figure 3.7). The additional high-speed rail construction goes well beyond

[3] Given the high occupancy and network utilisation rates, metro and light rail services are not significantly subject to changes in track-kilometre per passenger-kilometre. The key determinants of the ratio between metro and light rail passenger activity and networks extension are structural effects associated with the adaptation of metro capacities to passenger flows (metros in densely populated megacities of emerging economies that need to guarantee higher throughput per track-kilometre compared with Europe) and network utilisation levels that are 7% higher in the High Rail Scenario than in the Base Scenario by 2050 due to a higher reliance on digital technologies. Improvements in track utilisation (vehicle activity per track-kilometre) alleviate the upward pressure on track growth.

that in the Base Scenario, which takes into account only projects under construction and planned. In the High Rail Scenario, the network will also be used more intensively, the growth rate of high-speed rail activity exceeding the rate of network growth, enabled by digital technologies.[4]

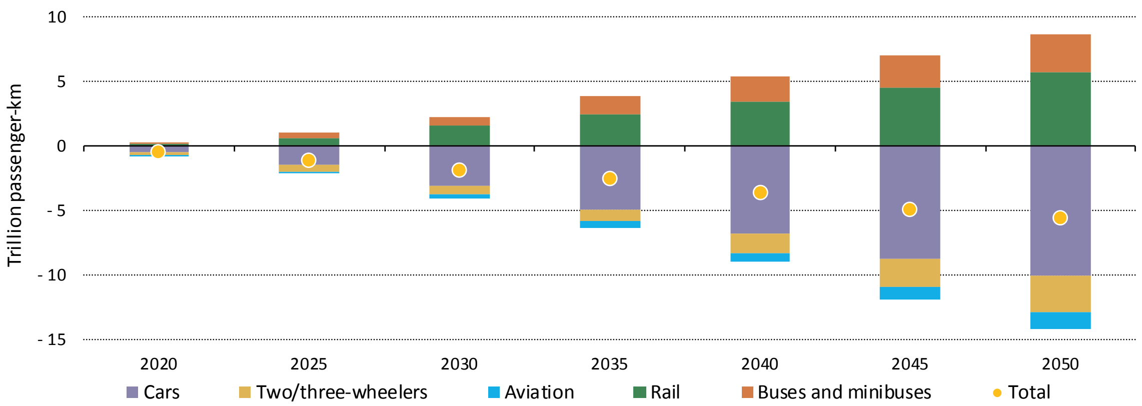


# Rail transport activity

## *Passenger rail in the High Rail Scenario*

Passenger rail activity increases in the High Rail Scenario to 15 trillion passenger-kilometres in 2050, exceeding by about 6 trillion passenger-kilometres the level of the Base Scenario (Figure 3.8). Other public transport activities (namely travel by bus) also increase, induced, in particular, by the adoption of integrated urban transport concepts that allow for better integration of rail services with other public transport options. Overall passenger activity in the High Rail Scenario *declines* relative to the Base Scenario, as routes are optimised and some travel is avoided by measures influencing urban design and density and pricing and travel demand management policies which have an impact on the frequency and length of trips.

**Figure 3.8 Change in passenger activity in the High Rail Scenario relative to the Base Scenario, 2020-50**




Source: IEA (2018).

Key message • **The High Rail Scenario results in a shift from transport in cars, two/three-wheelers and planes to public transport relative to the Base Scenario.**

The shift of activity to rail is greatest in urban transport, where a growing proportion of short trips improve the viability of shared mobility solutions and non-motorised modes of transport that feed rail needs. Most of the reduction in passenger activity in the High Rail Scenario occurs in passenger cars, because of the relatively high use of personal vehicles in urban mobility in the Base Scenario and the opportunities available in cities to reduce trip distances and drive modal shifts with urban densification and improved design. Another area in which rail activity rises significantly is high-speed rail, which out competes short-haul flights in the High Rail Scenario.

[4] In the High Rail Scenario, the increase in capacity utilisation of high-speed rail is maximised thanks to better schedule planning and digital solutions, which allow for shorter intervals between trains. Capacity utilisation in the High Rail Scenario is 10% higher than in the Base Scenario. The same 10% improvement in capacity utilisation has been assumed for conventional rail in the High Rail Scenario.

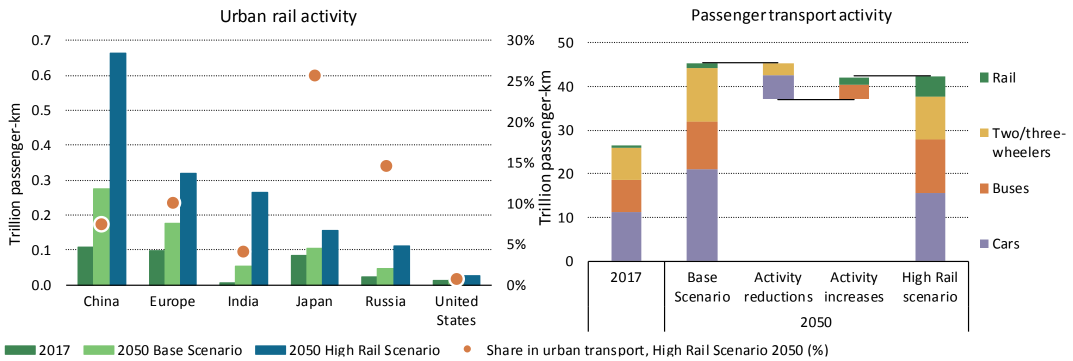
## *Urban rail*

The share of rail in urban passenger transport activity increases from almost 2% in 2017 to 3% in 2025 in the High Rail Scenario, compatible with the UITP target of doubling the market share of public transport between 2005 and 2025 (UITP, 2014), if the share of travel is calculated by reference to large and densely populated cities and by reference to rail in isolation.[5] By 2050, the share of rail in total urban passenger-kilometres exceeds 6%, three-times the share in the Base Scenario. Meanwhile, total urban transport activity grows from 26 trillion passenger-kilometres in 2017 to 42 trillion passenger-kilometres in 2050. These shifts are largely driven by strong urbanisation in the emerging economies.



As urban rail activity increases in the High Rail Scenario, by 2050 cars account for 37% of the total urban passenger-kilometres compared to 47% in the Base Scenario (Figure 3.9). China experiences the strongest absolute increase in urban rail activity in the High Rail Scenario, followed by India where passenger activity on metros is growing fastest. However, China and India's share of rail in all urban passenger-kilometres (7% and 4% respectively) remains below the level of Japan (26%) and Europe (10%). The urban rail market share in the North America remains lower than elsewhere (1%). Increased reliance on rail for urban passenger movements is stronger in cities characterised with highly concentrated urban structures, thanks to the higher likelihood in those circumstances of sufficient throughput to make an economic and environmentally sound case for rail investments.[6]

**Figure 3.9 Urban motorised transport activity shifts in the High Rail Scenario relative to the Base Scenario, 2050**




Note: Urban rail includes both metro and light rail.

Source: IEA (2018).

**Key message • In the High Rail Scenario, the share of rail in urban passenger activity exceeds 6% by 2050, almost three-times its share in the Base Scenario.**

[5] It is assumed that the UITP targets are for ridership across all modes of urban transport. According to these criteria, in cities with high densities (of at least 750 people per square kilometres) and with populations of more than 600 000 residents, and assuming that trip lengths in 2005 and 2025 for urban driving (on cars and buses) and for other modes (e.g. two-wheelers, minibuses, and buses) vary according to the relative speeds of these modes in such cities, the ridership on rail doubles from around 2% in 2005 to 4% in 2025, hence meeting the UITP target. Note further that the market share of overall urban public transit (including both buses and rail) does not meet the UITP goals.

[6] In the Base Scenario, the urban rail projections are based on the extension to metro and light rail planned for the coming five years (UITP, 2018a; UITP, 2018b). The share of rail in urban activity thereafter is determined by the share of populations living in cities of sufficient size and density to metro travel, and by modal shares commensurate with these constraints. In the High Rail Scenario, these constraints and considerations still apply, but the share of urban travel allocated to rail grows at a faster pace, driven by policy initiatives and investment.

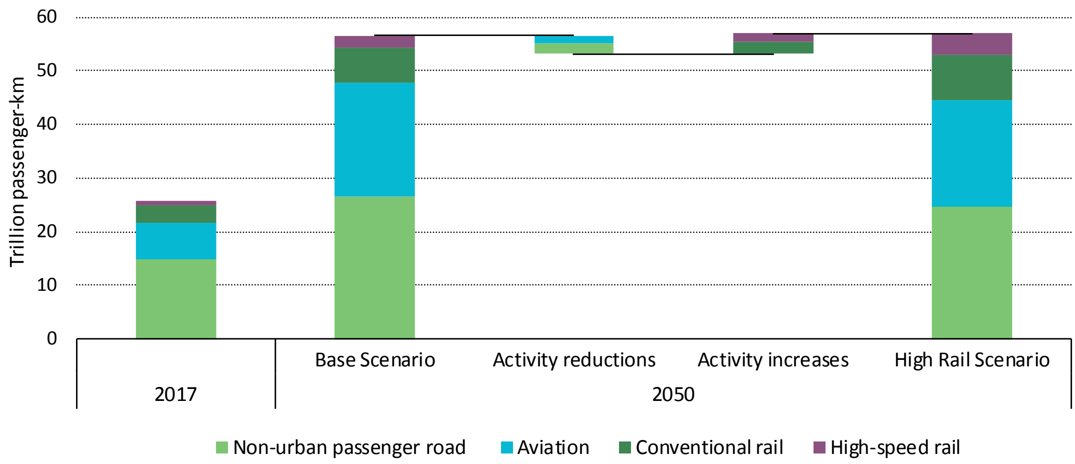
 



## *Conventional and high-speed rail*

In the High Rail Scenario, conventional and high-speed rail activity more than triples, from almost 4 trillion passenger-kilometres in 2017 to 12.4 trillion passenger-kilometres in 2050 (nearly 50% more than in the Base Scenario). This higher non-urban rail activity results from a shift from other more energy-intensive non-urban modes, i.e. cars, buses and planes, to conventional and high-speed rail (Figure 3.10).

**Figure 3.10 Global non-urban passenger transport activity by mode in the High Rail Scenario relative to the Base Scenario, 2050**




Source: IEA (2018).

**Key message • In the High Rail Scenario, shifts from aviation and road transport feed increases in activity on conventional and high-speed rail services, without significant change in the overall level of non-urban passenger movements.**

In the High Rail Scenario, conventional rail accounts in 2050 for two-thirds of all non-urban rail, down from about 80% today. High-speed rail exploits its full potential for competitive high-speed transit by rail to divert passengers away from airports with more than 1 million passengers per year (see Box 3.1 for more details on the methodology employed). By 2050, this means that 6% of all aviation passenger-kilometres in the Base Scenario are shifted to high-speed rail. By 2050, 4.1 trillion passenger-kilometres are carried on high-speed rail, representing one-third of all non-urban rail travel. This market share is higher than in the Base Scenario (where it is roughly a quarter). China accounts for half of global high-speed rail activity by 2050, followed by Europe (12%), India (8%), the Association of Southeast Asian Nations (ASEAN) region (5%) and Japan (4%).

**Box 3.1 Assessment of global modal shift potential between air and high-speed rail travel**

For this report, we have analysed the potential for a shift from short-haul air travel to high-speed rail. The analysis builds on the empirical observation that high-speed rail systems can induce modal shifts from air travel, using information on aviation demand patterns.

Here the potential for flights to be competitively shifted to high-speed rail is determined taking into account three main factors:

- High-speed rail routes avoid water bodies and tunnelling through elevated terrain, so prioritising railway links that entail lower construction costs.

- The journey duration between pairs of cities by rail must offer time savings compared to aviation.[7]
- The centres of demand are sufficiently large, to ensure the economic viability of the investments required for high-speed rail connection.[8]

In 2015, with an average high-speed rail speed of 215 kilometres per hour, 14% of flights could be displaced by high-speed rail. Close to 95% of displaceable flights are over distances of less than 800 kilometres, and close to 40% of displaceable seat-kilometres on flights of less than 600 kilometres could be competitively shifted to rail under the factors considered.



**Table 3.1 Number of flights and seat-kilometres displaceable by high-speed rail in various cases**

| Displacement potential of global total | Central case (rail speed 215 km/hr, no tunnels) | With tunnels (relative to central case) | 250 km/hr (relative to central case) |
|---|---|---|---|
| Flights | 14% | +1 percentage point | +4 percentage points |
| Aviation seat-kilometres | 3%[9] | +1 percentage point | +2 percentage points |

Source: IEA analysis based on OAG (2018).

Key message • **14% of global flights could be competitively shifted to high-speed rail under current typical flight and high-speed rail conditions, without the need for costly bridge or tunnelling infrastructure.**

The sensitivity cases in Table 3.1 show that as the average speed of high-speed rail increases with technological progress, more shift potential can be reaped. On the other hand, engaging in costly tunnelling in challenging terrain does not significantly enhance aviation to rail shift potential. The potential for high-speed rail to be time-competitive with existing flight routes varies according to various geographical features such as distance between large cities and topography (Figure 3.11). Additionally, in countries where high-speed rail is already established, short-distance flights have already partly been displaced, creating a lower potential for additional shifting. The case of Japan, a country with challenging terrain, illustrates that other elements, such as high passenger throughput and high network utilisation, can explain successful deployment of high-speed rail, despite the significantly higher costs of many tunnels.

By 2050, the potential for time-competitive shifts between aviation and rail, in terms of the percentage of seat-kilometres captured, is estimated to be 0.5% greater than in 2017, as the number of eligible airports grows[10] and the average speed of high-speed rail lines increases to 250 kilometres per hour.

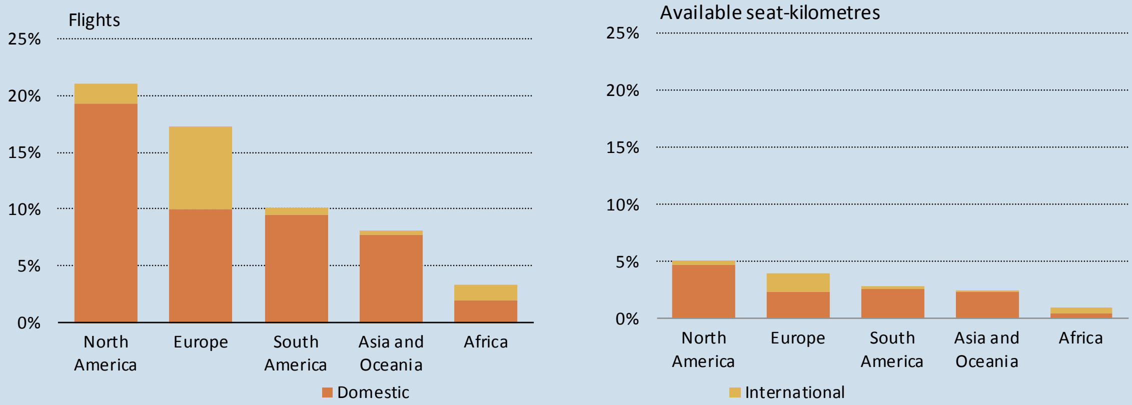
[7] The time competitiveness assessed here accounts for flight travel time from OAG (2018), and high-speed train travel time (assumed at 250 kilometres per hour in 2050), plus "penalty" time, defined as: the air route penalty time accounts for 1 hour travel between original departure point and airport, 1.5 hours for airport check-in, controls, boarding and luggage pick-up, and 1 hour from the airport to the final destination. The rail route penalty time accounts for 30 minutes travel between original departure point and train station, 20 minutes waiting time at train station and 30 minutes from the train station to the final destination.

[8] Routes are screened based on a minimum airport passenger throughput of 1 million passengers annually (both for origin and destination airports) in order to exclude low volume routes, where the commercial case for high-speed rail would be too limited. Their identification is based on passenger activity in 2017 from OAG (2018).

[9] The share of seat-kilometres that could potentially be shifted (3%) is significantly lower than the share of flights that could be shifted (14%), as high-speed rail and aviation compete over relatively short distances, operated by relatively small airplanes.

[10] The number of eligible airports in 2050 is assessed adjusting the 2017 throughput figures to accord with the growth in passenger-kilometres projected for aviation in the Base Scenario for each region. The increase in passenger throughput is assumed equal for all airports in a given region.

**Figure 3.11 Share of flights and available seat-kilometres that high-speed rail could displace based on competitive travel times by departure country**




Note: Assumptions shown in Table 2.2.

Source: IEA analysis based on OAG (2018).

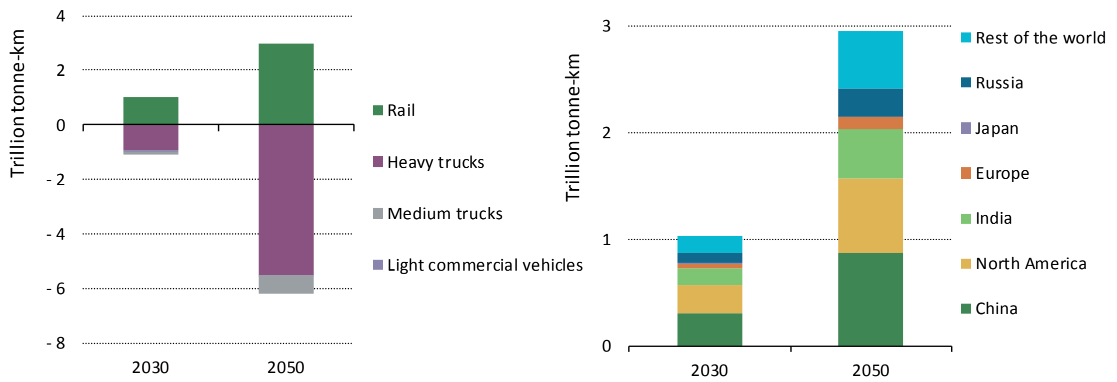
**Key message • The potential for high-speed rail to be time-competitive with flights depends mainly on geographical considerations, e.g. distance between large cities, and topography.**

## *Freight rail in the High Rail Scenario*

Freight rail in the High Rail Scenario increases by 3 trillion tonne-kilometres in 2050, relative to the Base Scenario, despite a 5% decline in freight activity overall, due to structural changes in the supply chain and overall improvements in logistics (Figure 3.12). This change, effected by pricing policies, investments in intermodal terminals and better integration of rail into supply chains, occurs primarily through shifts from heavy-duty road freight to rail. Increased rail capacity allows rail to retain its market share of bulk commodity transport, enlarge the range of commodities carried (e.g. by larger shares of fertilisers, agricultural products and intermediate manufactured commodities) and intercept part of the surface transport of containers. China, North America, Russia and India account for most of the net increase – regions that have significant inland freight transport movements, major shares of freight rail transport, and in which road freight movements on heavy-duty vehicles are large enough to justify modal shifts.

In the High Rail Scenario, the contribution of rail freight transport to overall freight transport (excluding shipping) remains stable at around 27% in 2050, while in the Base Scenario this share decreases from 28% in 2017 to 23% in 2050. In principle, freight rail could gain additional market share against long-distance maritime transport, but such a development is not considered in the High Rail Scenario.

**Figure 3.12** **Change in surface freight transport activity (left) and freight rail activity (right) in the High Rail and Base scenarios, 2030 and 2050**




Source: IEA (2018).

**Key message • In the High Rail Scenario, rail increases its market share of freight transport mainly at the expense of heavy trucks. The largest freight activity gains are in China, North America, Russia and India.**

**Box 3.2** **Relationship between the High Rail Scenario and the UIC activity targets**

In 2014, the International Union of Railways (UIC) set two aspirational targets for increased rail activity: passenger transport to increase market share by 50% in 2030 and 100% in 2050, compared to 2010 levels; and freight transport to match the activity level of road transport by 2030 and to exceed road freight volumes by 2050 (UIC, 2014). With a 75% increase in market share compared to 2010, the High Rail Scenario approaches the UIC's activity target in the passenger sector by 2050, though it does not meet it; nor does it meet the lower target in 2030. Fully meeting the UIC target for 2050, as well as the 2030 goal would probably require incremental shifts, and in particular a higher reliance on high-speed rail, in comparison with the results projected in the High Rail Scenario.

Freight achieves a surface modal share slightly below one-third both in 2030 and 2050. Achieving the UIC's activity targets for the freight sector is unlikely to be feasible without shifting part of long-distance maritime freight transport to rail. If the UIC freight target were to be met by shifting activity from ships to rail, the required shift would amount to 37 and 90 trillion tonne-kilometres in 2030 and 2050, respectively, which corresponds to 23% and 30% of the total shipping activity projected for those years.

## Implications for energy demand

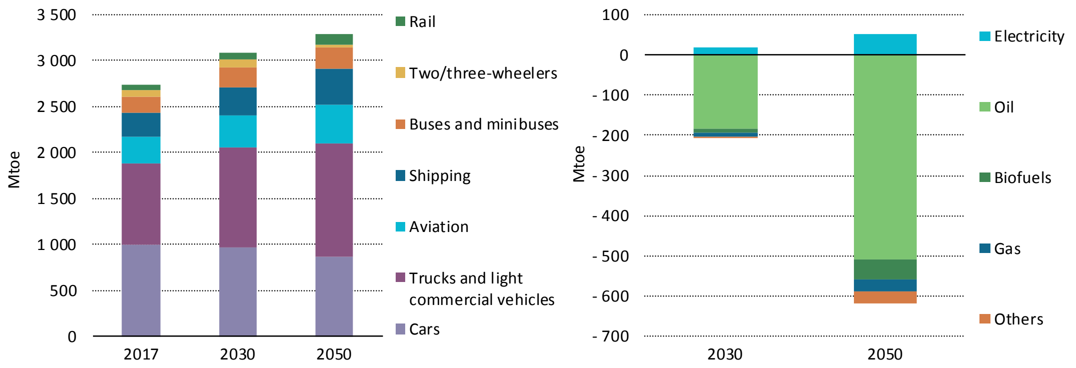
Total transport energy demand in the High Rail Scenario reaches 3 100 million tonnes of oil equivalent (Mtoe) in 2030 and 3 300 Mtoe in 2050 (Figure 3.13). Compared to the Base Scenario, this is a reduction of 565 Mtoe in energy demand by 2050, of which 510 Mtoe (approximately 10 million barrels per day [mb/d]) is oil. The High Rail Scenario does not take into account changes in market shares of different powertrain technologies, compared with the Base Scenario, assuming the same energy intensity for each technology option. Therefore, the differences in energy demand are imputable only to structural shifts across modes, differences in the modal energy mixes and net reductions in travel activity due to reduced trip distances. Shifts from cars, two/three-wheelers, trucks and planes are responsible for most of the energy demand reductions, although these are mitigated somewhat by an increase in electricity demand from rail by almost 320 terawatt-hours (TWh) (27 Mtoe) by 2050, relative to the Base Scenario.

Total energy demand for the rail sector in 2050 is around 125 Mtoe in the High Rail Scenario, 42% more than in the Base Scenario. Despite increases in activity, rail transport accounts for only 4% of total transport energy demand in 2050. In both of the scenarios the rail sector experiences strong electrification (Figure 3.14). The share of electricity in fuel demand in the rail sector rises from 47% in 2017 to 73% in 2050 in the High Rail Scenario. Overall, annual electricity consumption by rail in the High Rail Scenario increases almost fourfold, to about 1 060 TWh per year (91 Mtoe) by 2050, while diesel consumption increases by 19% to 0.7 mb/d (34 Mtoe per year).



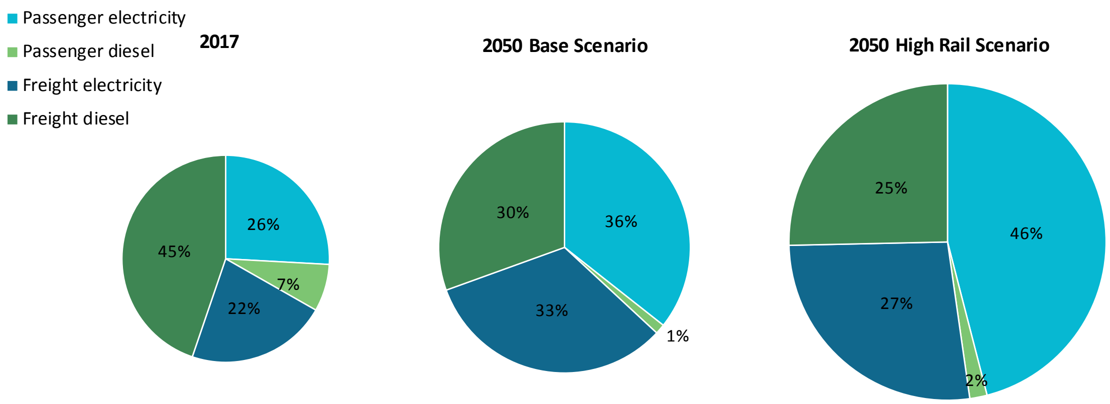
**Figure 3.13 Transport energy demand in the High Rail Scenario by mode (left) and change in energy demand relative to the Base Scenario (right), in 2017, 2030 and 2050**




Source: IEA (2018).

**Key message • Compared with the Base Scenario, the High Rail Scenario sees a reduction in oil demand for transport of 10 mb/d in 2050.**

**Figure 3.14 Energy demand in rail by activity and fuel type in the Base and High Rail scenarios, 2017 and 2050**




Note: The chart area is proportional to total rail energy use: 53 Mtoe in 2017, 88 Mtoe in 2050 in the Base Scenario and 125 Mtoe in 2050 in the High Rail Scenario.

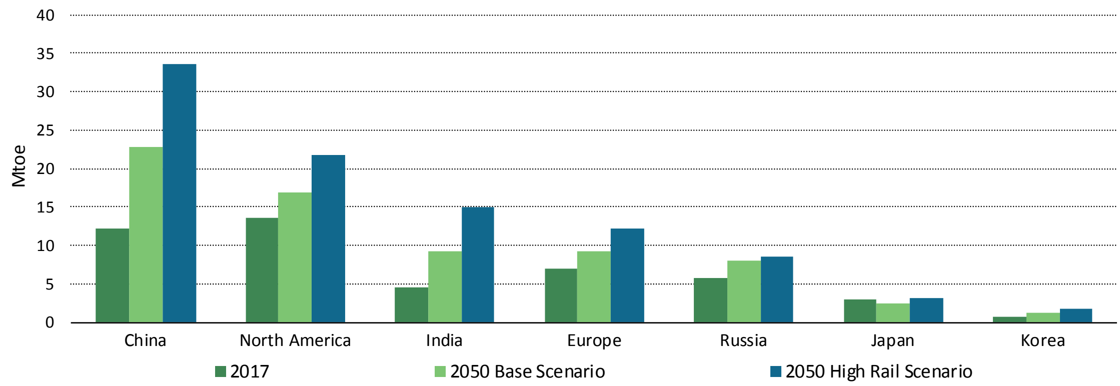
Source: IEA (2018).

**Key message • Both scenarios project increased rail electrification, converting almost half of freight energy use from diesel to electricity.**

By 2050, China and India are projected to have the highest increase in rail energy use in the High Rail Scenario, relative to the Base Scenario (Figure 3.15). Rail energy demand remains highest in volumetric terms in China, where rail by 2050 accounts for 6% of total transport energy use, up from 4% in the Base Scenario. Rail energy demand in North America also grows strongly, predominantly in freight.



**Figure 3.15 Projected rail energy demand growth by region**



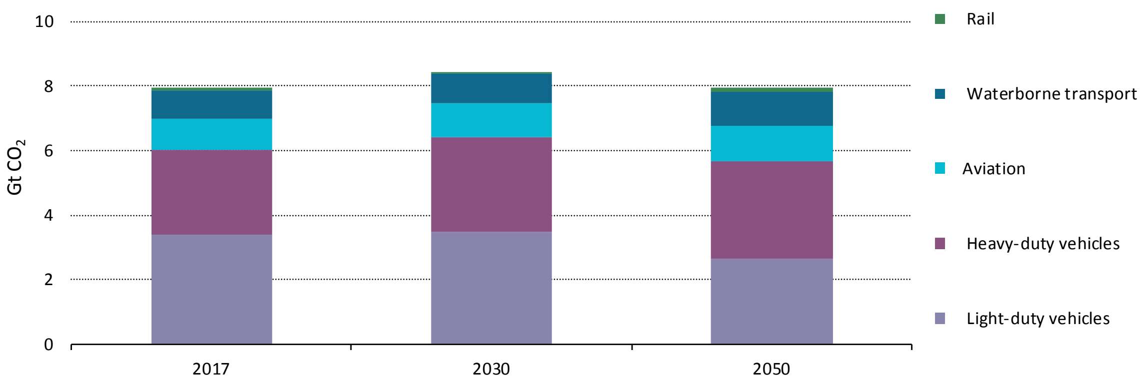

Source: IEA (2018).

**Key message • The High Rail Scenario would entail on average one-third higher energy consumption for rail relative to the Base Scenario.**

# Implications for GHG emissions and local pollutants

## *Direct $CO_2$ emissions in the High Rail Scenario*

**Figure 3.16 Direct $CO_2$ emissions from fuel combustion in the High Rail Scenario, 2017-50**




Source: IEA (2018).

**Key message • Due to the effects of modal shift, direct energy-related $CO_2$ emissions from transport in the High Rail Scenario peak between 2030 and 2050, after which they start to decline; by 2050, $CO_2$ emissions drop to the level of 2017.**

In the High Rail Scenario, direct $CO_2$ emissions at the tailpipe resulting from the combustion of fossil fuels are higher in 2050 than in 2017 (Figure 3.16). However, while $CO_2$ emissions in the Base Scenario grow continuously through 2050, in the High Rail Scenario $CO_2$ emissions peak between 2035 and 2040, after which they start to decline. Most of the savings in direct $CO_2$ emissions observed in the High Rail Scenario, compared with the Base Scenario, results from lower emissions from light-duty road vehicles (1.3 gigatonnes of carbon dioxide [Gt $CO_2$] less in 2050) and heavy-duty vehicles (0.5 Gt $CO_2$ in 2050) as a result of lower levels of activity in these modes. Direct combustion emissions from rail are roughly constant between 2017 and 2050, despite greater activity on rail, as the sector continues to electrify.

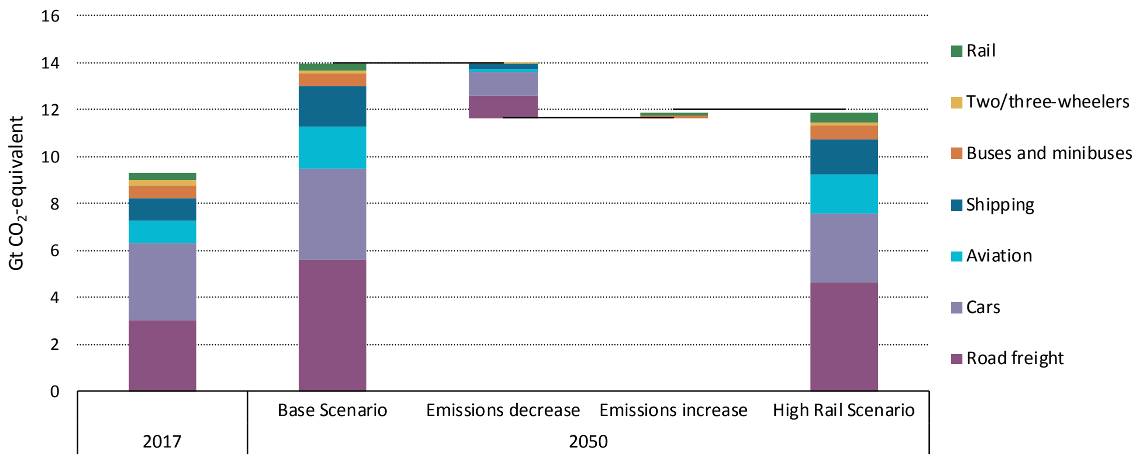


## *Well-to-wheel GHG emissions*

The activity shifts between passenger and freight modes lead to a reduction in annual transport-related well-to-wheel (WTW) GHG emissions of 2.1 Gt $CO_2$ equivalent ($CO_2$-eq) emissions per year, a 17% reduction from the Base Scenario (Figure 3.17). This is achieved as a result of the much lower energy intensity of rail modes, compared with road-based modes or aviation.[11]

In passenger transport, GHG emission reductions are achieved by reducing and shifting activity from cars, two/three-wheelers and from aviation to urban, conventional and high-speed rail. Shifting 11.2 trillion passenger-kilometres from road transport[12] and aviation results in a reduction of roughly 1 Gt $CO_2$-eq WTW GHG emissions, while the additional volume of passenger-kilometres on rail accounts for only 110 million tonnes (Mt) $CO_2$-eq. Shifting and reducing freight activity reduces road freight emissions by nearly 1 Gt $CO_2$-eq, offset from increased freight rail by 33 Mt $CO_2$-eq emissions from increased activity.

**Figure 3.17 Well-to-wheel GHG emissions from transport in the Base and High Rail scenarios**




Source: IEA (2018).

**Key message • In the High Rail Scenario, shifting transport modes cuts by half the increase in emissions (2015-50) projected in the Base Scenario. Emissions increases due to shifting passenger and freight activity to rail are more than an order of magnitude lower than those displaced from other modes.**

[11] The High Rail Scenario maintains the same assumptions regarding vehicle technology improvement and fuel technology mix as the Base Scenario. Estimated future energy use per passenger-kilometre of high-speed rail activity remains around 90% lower than in aviation throughout the projection period. This is achieved despite improvements in aviation that enable the sector to meet the International Civil Aviation Organization (ICAO) goal of reducing the energy intensity of aviation by 2% per year (ICAO, 2013).

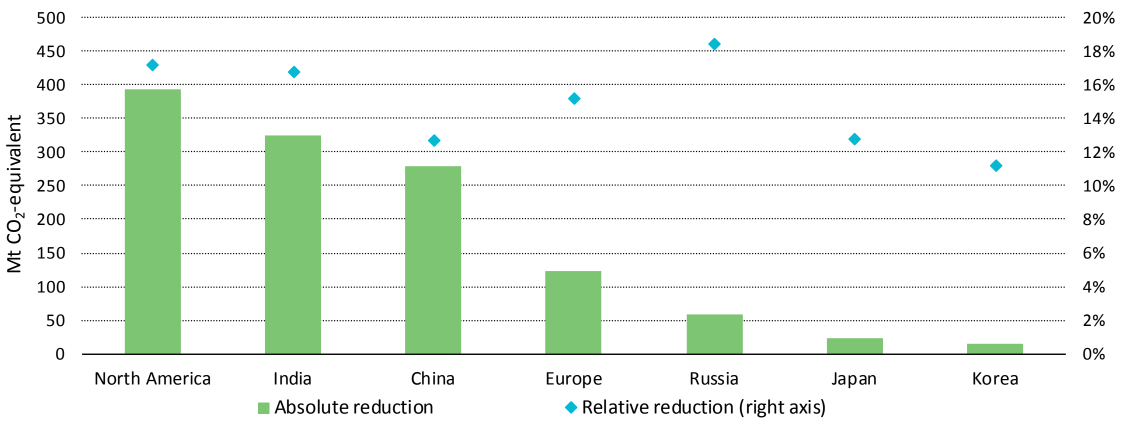
[12] Note that this includes GHG emission reductions occurring due to lower activity in cars, two/three-wheelers (1 Gt $CO_2$-eq), as well as aircraft (0.1 Gt $CO_2$-eq), partly offset by GHG emission increases for buses (0.1 Gt $CO_2$-eq).

The GHG emission reductions achieved in the High Rail Scenario, relative to the Base Scenario, are fairly evenly distributed across countries (Figure 3.18). By 2050, shifts to rail and other public transport enable most countries to reduce GHG emissions from transport by 13-18%, compared to the Base Scenario.

In addition to reducing overall transport sector GHG emissions, the High Rail Scenario also delivers air quality benefits, particularly in urban areas. By 2050, the shift to rail in the High Rail Scenario makes it possible to avoid an additional 220 thousand tonnes (kt) of fine particulate ($PM_{2.5}$) emissions from transport (nearly 35% higher savings) compared with the Base Scenario.



**Figure 3.18** **WTW GHG emissions savings from transport by region in the High Rail Scenario relative to the Base Scenario, 2050**




Source: IEA (2018).

**Key message • Transport-related GHG emissions reductions in the High Rail Scenario, relative to the Base Scenario, are between 11% and 16% in 2050, depending on the country. In North America, China and India savings are greater than 300 Mt of $CO_2$-eq per year.**

While the environmental benefits of the High Rail Scenario are substantial, far greater sustainability gains can be realised by coupling increased activity on rail with other changes in the broad energy system (including more rapid deployment of low-carbon electricity generation) and by accelerating the adoption of more efficient vehicles across all modes of transport, i.e. in light- and heavy-duty road vehicles, shipping, and aviation (Box 3.3).

**Box 3.3** **Contribution of the High Rail Scenario to achieving the Paris Agreement targets**

Taken in isolation, the High Rail Scenario does not meet the Paris Agreement targets. In order to reduce GHG emissions in line with those targets, shifting road-based transport modes and aviation to rail (as illustrated in the High Rail Scenario) needs to be complemented by energy efficiency and fuel switching measures to reduce the carbon intensity of the service provided. The effects of this full suite of measures are presented in Figure 3.19: they reduce transport energy use by 39% and cut well-to-wheel GHG emissions by 67% by 2050, compared with the Base Scenario.

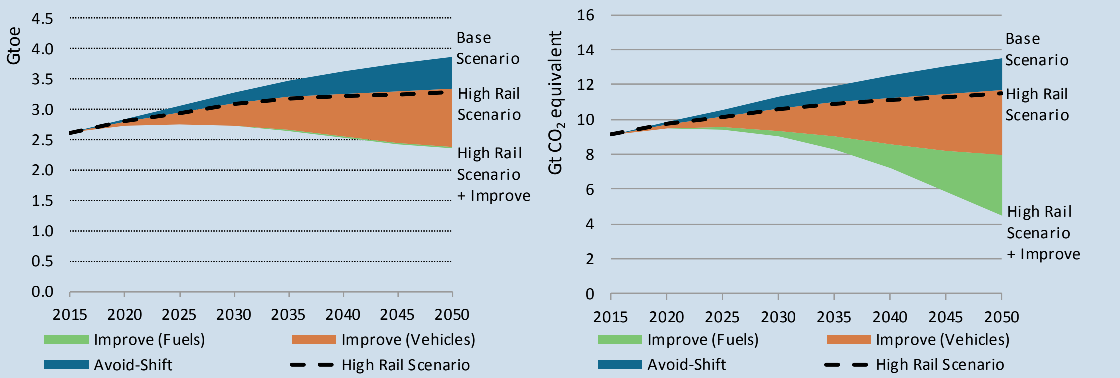
The key technological solutions assumed in the High Rail Scenario include:

- Strong improvements in the energy efficiency of combustion engines in all transport modes.
- Enhanced electrification of the transport sector, mainly in short- and- medium-distance road modes and rail.
- Decarbonisation of electricity generation.
- Increased adoption of other low-carbon fuels, such as advanced biofuels, electro-fuels and hydrogen, mainly for long-distance road-based modes, aviation and shipping.

Figure 3.19 illustrates that the relative contribution to reducing oil demand and GHG emissions of vehicle efficiency technologies ("+ improve vehicles wedge") and the transition to alternative fuels and decarbonisation of the power supply ("+ improve fuels wedge") is substantial. Yet, the contribution of modal shift in transport is crucial to meeting the Paris Agreement targets.

The small difference between the blue wedge in the figure (showing the contribution of modal shifts of the High Rail Scenario, once it becomes part of a broader strategy) and the dashed line (which shows energy and GHG emission levels achieved in the High Rail Scenario) indicates that the GHG emission reductions obtained from modal shifts to rail are robust to changes in the technology and fuel mix.[13]

**Figure 3.19 Transport energy demand (left) and WTW GHG emissions (right) by scenario**




Source: IEA (2018).

Key message • **Reducing oil demand and GHG emissions from the transport sector in line with the Paris Agreement targets requires a combination of measures including modal shifts, improved vehicle efficiency, low-carbon fuels and power sector decarbonisation.**

Figure 3.19 also sheds light on what is required to meet the specific energy and $CO_2$ emission targets for the rail sector set out by the International Union of Railways (UIC). The UIC aim is for the rail sector to achieve a 50% reduction in specific final energy consumption from train operations by 2030 and a 60% reduction by 2050, relative to a 1990 baseline (UIC, 2014). In addition, the sector is to reduce specific $CO_2$ emissions from train operations by 50% by 2030 and 75% by 2050, relative to a 1990 baseline (UIC, 2014). Achieving these targets requires the rail sector to adopt aggressive strategies to improve energy efficiency, to make a transition to low-carbon fuels and to reduce the carbon intensity of electricity supply. The rail sector would need to draw upon the unique potentials it has to adopt zero-emissions train technologies and to optimise utilisation of its assets and infrastructure.

## Investment requirements in the High Rail Scenario

In the High Rail Scenario, travel demand management and measures to promote modal shifts result in changes in both investment and consumer expenditure. With declining passenger vehicle activity and increasing mobility by rail (and bus), public and private investments are shifted from road to rail infrastructure (for a summary of the range of costs for different types

[13] There is a small gap observable between the blue wedge and the dotted line in Figure 3.19. This is attributable to the effect where combining mode-shifting with "improve" measures diminishes somewhat the energy and GHG reduction effect from mode-shifting. This is because improvements in the "inefficient" modes to be replaced by rail are stronger with improve measures, reducing the gap between the average energy- and carbon intensity of services on rail versus the inefficient modes it displaces by mode-shifting.

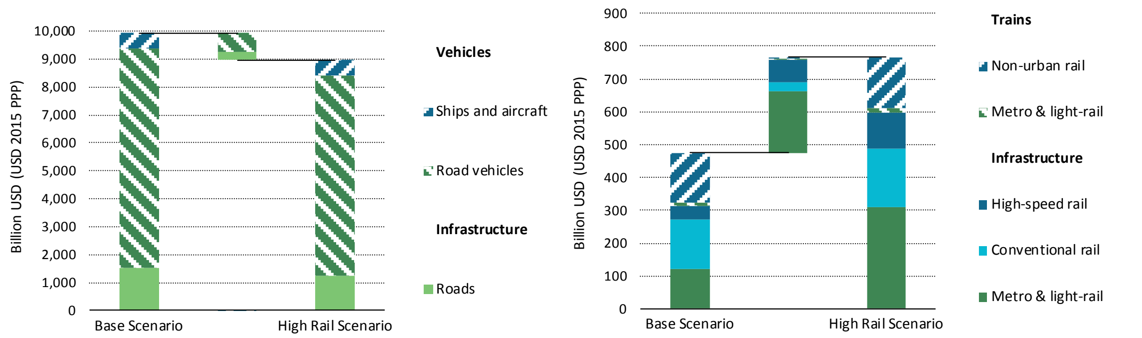
of rail infrastructures, see the Investment section in Chapter 2).[14] The two scenarios also imply different outlays for vehicles. In the High Rail Scenario, greater use of public transit and cycling and walking allows people to reduce reliance on personal vehicles and the associated spending on vehicles and fuel. These savings are partially offset by increased expenditure on buses and trains.



Global average annualised outlays for road transport infrastructure are lower in the High Rail Scenario than the Base Scenario by around USD 300 billion (United States dollars) (USD year-2015 purchasing power parity [PPP] basis), a reduction of about 20% (Figure 3.20). Annual savings from reduced expenditures on vehicles (primarily road vehicles, though trains, planes and ships are also included) are even larger in absolute terms (about USD 670 billion, compared with the Base Scenario), though the decline is smaller in percentage terms (8%).

Global average annualised outlays on trains and rail infrastructure are higher in the High Rail Scenario than in the Base Scenario by USD 290 billion (USD year-2015 PPP), or 60% more (Figure 3.20). Nearly all of the additional investment is directed to urban rail infrastructure (nearly USD 190 billion) and high-speed rail infrastructure (USD 70 billion). The additional cost of the trains themselves is small in comparison, due to the improved operations and efficiency realised in the High Rail Scenario.

**Figure 3.20 Average annualised outlays on transport vehicles and infrastructure across all modes (left) and on trains (right) in the Base and High Rail scenarios, 2018-50**




Notes: PPP = purchasing power parity. Estimates of the costs of road and rail infrastructure construction, reconstruction and operation and maintenance are based on literature estimates per lane-kilometre and per track-kilometre from various sources, and are validated against investment data from the OECD (2017). Paved lane-kilometres are estimated based on data from the International Road Federation (2012). Infrastructure costs are estimated, based on the projected extensions of road and rail infrastructure, which, in turn, are based on utilisation rates (in vehicle-kilometres per lane-kilometre or track-kilometre) of these elements. Vehicle costs are benchmarked to evaluations of the current cost, and their development is estimated based on energy efficiency component cost curves and total production volumes.

Source: IEA (2018).

**Key message • Annual average savings on road infrastructure total USD 270 billion and savings on vehicles (including cars, trucks, and aircraft) are around USD 670 billion. To achieve these savings, the High Rail Scenario requires additional annual average investments on the order of USD 290 billion, most of which are for urban and high-speed rail infrastructure.**



[14] Changes in energy consumption patterns and urban form, of course, would also result in more widespread, second-order changes. Examples include shifting investments in energy supply (e.g. from oil production and refining to electricity generation), and city infrastructure (e.g. from single family households to apartment complexes and mixed-use developments). No attempt has been made to capture these implications of the High Rail Scenario.

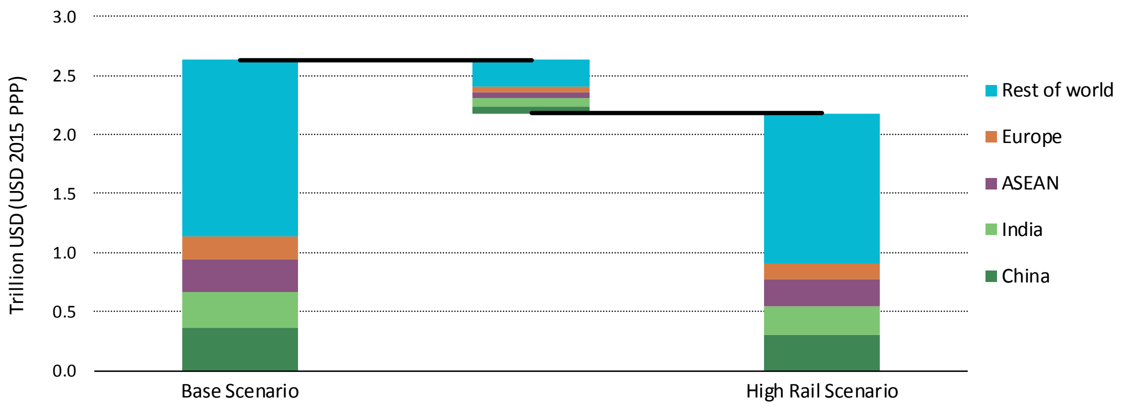
 



### *Fuel expenditure*

Increased reliance on rail can bring about a reduction in expenditure on road transport fuels, mostly oil. By 2050, worldwide expenditure on fuel is around USD 450 billion lower in the High Rail Scenario than in the Base Scenario. India stands to save USD 65 billion (22% of fuel expenditure). The global average reduction of fuel expenditure is 15% (Figure 3.21).

**Figure 3.21 Fuel expenditure savings in the High Rail Scenario, 2050**




Source: IEA (2018).

**Key message • Global fuel expenditure is reduced by 17% in 2050, with disproportionately large savings for India.**

## Policy opportunities to promote rail

The three pillars that underpin the High Rail Scenario – minimising service costs, maximising revenues and ensuring that the costs of all modes of transport reflect infrastructure needs and societal and environmental impacts – all improve the economic competitiveness of rail. Ensuring high passenger and freight throughput is also instrumental to achieve this condition. As outlined in Chapter 1, high throughput is also key to ensure that rail transport comes with lower energy and carbon intensity per passenger- and tonne-kilometre than other transport modes.

Green bonds are a financial instrument that can facilitate the availability of funding and reduce the cost of financing capital-intensive rail projects by lowering interest rates (Box 3.4). Market liberalisation, can improve rail's economic competitiveness by increasing network utilisation.[15] Railways have been liberalised in some advanced economies with developed railway networks, with varying degrees of success in terms of improving railway utilisation. In early stages of planning and constructing a rail network though, development under a dominant operator can avoid costly duplication of infrastructure.

Policy opportunities to promote rail and make it more competitive with other transport modes are highlighted in the next sections. They focus on specific opportunities in rail services in passenger (urban, conventional and high-speed) and freight transport.

[15] Market liberalisation gives new market entrants access to networks that in many cases have been previously controlled and operated by a single operator. It can promote vertical separation: the separation of the network manager from its users. In the railway sector, market liberalisation can split the ownership and/or operation of infrastructure functions (network managers) and train operators (network users).

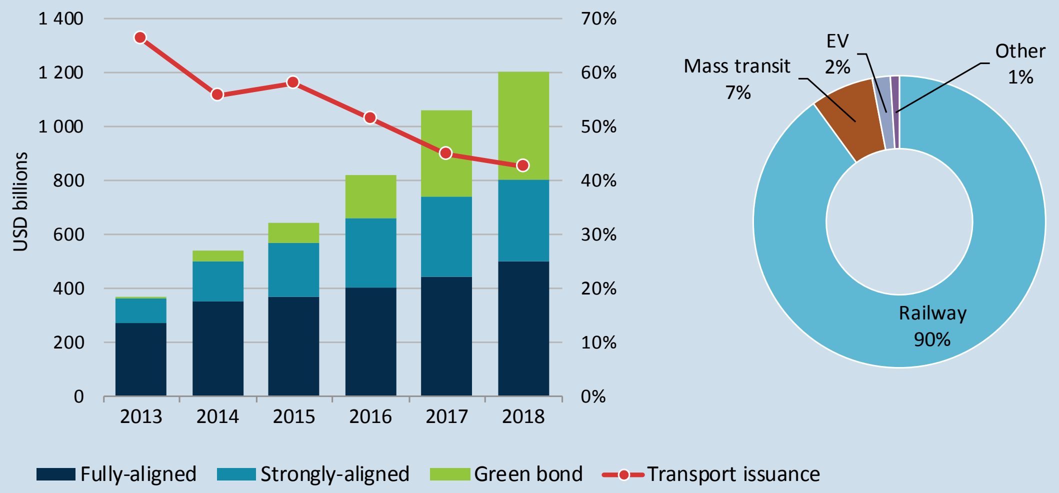
**Box 3.4 The use of environmentally friendly bonds to finance rail infrastructure**

The bond market is increasingly being used by policy makers and financiers as a source of low cost financing or refinancing for "green" projects.[16] Such financing instruments earmark proceeds to finance projects and activities related to renewable energy, energy efficiency, sustainable waste management, sustainable land use (forestry and agriculture), biodiversity, clean transportation and clean water.

The Climate Bonds Initiative tracks environmentally friendly bonds in three categories: (1) "fully-aligned" issuers that derive 95% or more of revenues from green business lines; (2) bonds from "strongly-aligned" issuers that derive 75-95% of revenue from green business lines; (3) labelled and certified green bonds, for which certification generally follows the guidelines outlined in the Green Bond Principles (GBP) developed by the International Capital Market Association [17]

The market of fully- and strongly-aligned issuers points to significant potential for the green bond market to scale up. Labelling a bond as green provides benefits to issuers: it allows them to reach a wider investor basis and to fund environmentally beneficial projects, while signalling the company's sustainability credentials. For investors, the green bond label facilitates the identification of green debt products and ensures a higher degree of project transparency.[18]

**Figure 3.22 Breakdown of environmentally friendly bonds by year and type**




Note: EV = electric vehicle.

Source: IEA analysis based on Climate Bonds Initiative (2018).

**Key message • Environmentally friendly bond issuance has grown substantially in recent years and the value of green bonds issued has grown particularly rapidly.**

Since the first green bond was issued in 2007, the market has grown rapidly. Overall, environmentally friendly bond issuance has more than doubled within the past decade, from USD 600 million in 2007 to USD 1.4 trillion in 2018 (Figure 3.22, left). By 2018, green bonds accounted for roughly one-third of all environmentally friendly bond issuances.

[16] The main benefits are lower interest rates than those that could typically be obtained from a bank, the potential to raise more capital (e.g. through co-financing) and increased flexibility in the use of capital. In addition, while returns from environmentally friendly bonds have so far proven similar to standard bonds, changes in policy due to climate concerns may influence investor portfolio decisions may be adding to the attractiveness of green bonds.

[17] The GBP are voluntary process guidelines that recommend transparency and disclosure, and promote integrity in the development of the green bond market by clarifying the approach for issuance of a green bond (International Capital Market Association, 2018).

[18] Issuers of green bonds can also go a step further and seek to certify their bonds or loans under the Climate Bonds Standard to demonstrate that the financed assets are aligned with Paris Agreement targets (Climate Bonds Initiative, 2017).

Of the environmentally friendly bonds issued to date worldwide, 44% are for projects in the transport sector accounting for USD 532 billion of outstanding bonds. The share of transport-related bond issuances in the overall amount of environmentally friendly bonds has declined in recent years, due to overall market diversification leading to more low-carbon projects in other sectors (in particular in the buildings sector). Nevertheless, transport-related bonds represent the largest single sectoral market share. Asia-Pacific countries (led by China) are the leaders in transport issuance, accounting for 45% of the market, followed by Europe (39%) and North America (16%).



Qualifying bonds in transport are issued by companies whose activities relate to vehicle technologies, transport infrastructure or transport system improvements. Railway companies make up 90% of the sector's outstanding climate-aligned issuance volume (Figure 3.22, right).

## Passenger rail

### Urban rail

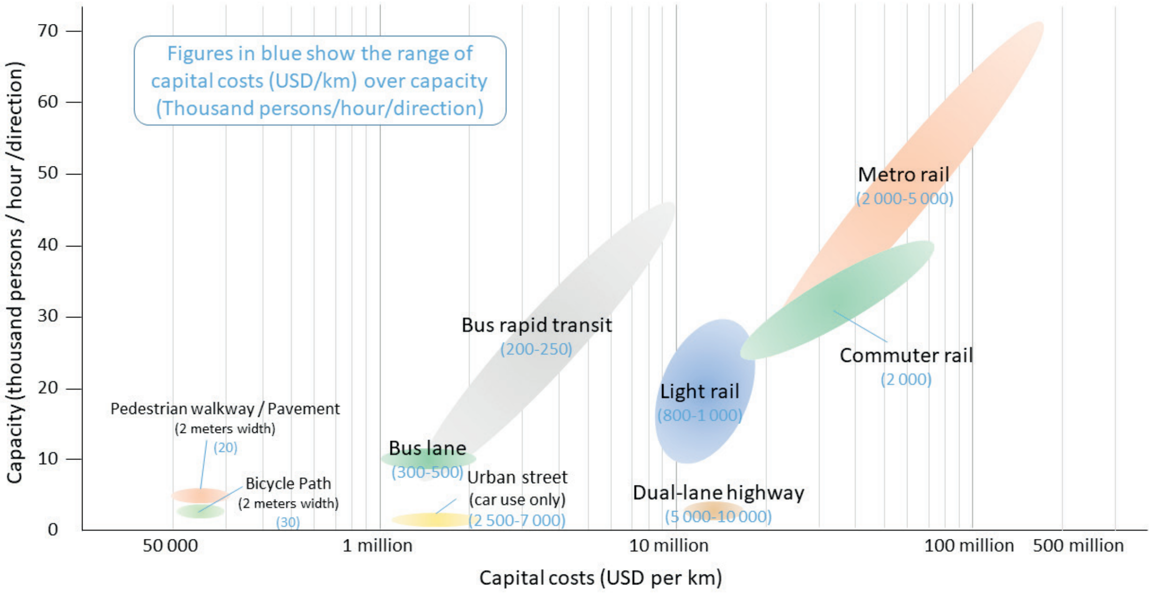
Increasing the share of urban rail in transport to unlock the associated social, environmental and energy security benefits requires dedicated policy action. Without such action, it will be difficult to realise the vast increase of urban rail activity illustrated in the High Rail Scenario, because of the significant investment and long-lead times (often around ten years per project) associated with new urban rail infrastructure. Measures are available to encourage higher use of urban rail systems, innovative financing mechanisms are available to help lower obstacles to the expansion of urban rail, and project cost efficiency can lower fares and thereby increase the appeal of urban rail to passengers.

The capital costs of various forms of urban transport infrastructure and measures to increase passenger throughput capacity can differ by orders of magnitude (Figure 3.23). Urban rail systems, especially metro and commuter rail systems are expensive, but their throughput capacity is unparalleled, and can result in a competitive cost per unit of transport capacity compared with cars. High passenger throughput is crucial not only to ensure the economic viability of the construction and operation of urban rail services but also to realise fully their potential advantages.[19]

Metro, light rail and commuter rail therefore are generally best suited to cities that need to handle large volumes of passenger traffic within a dense urban area: cities with large populations and high urban densities have the best opportunity to ensure that high shares of trips take place on well-developed, high capacity public transport networks. Examples of successful developments of this kind are in Hong Kong (China), Shanghai, Singapore, Taipei and Tokyo (LTA, 2011; TLS, 2015). With high capacity and utilisation, these cities generate revenue from fares that cover costs and no operational subsidies are needed (Figure 3.24).

[19] The analysis of the life-cycle performance of rail services presented at the end of Chapter 1, for example, indicates that urban rail projects require high capacity and high frequency of utilisation in order to offset the emissions produced in the construction phase.

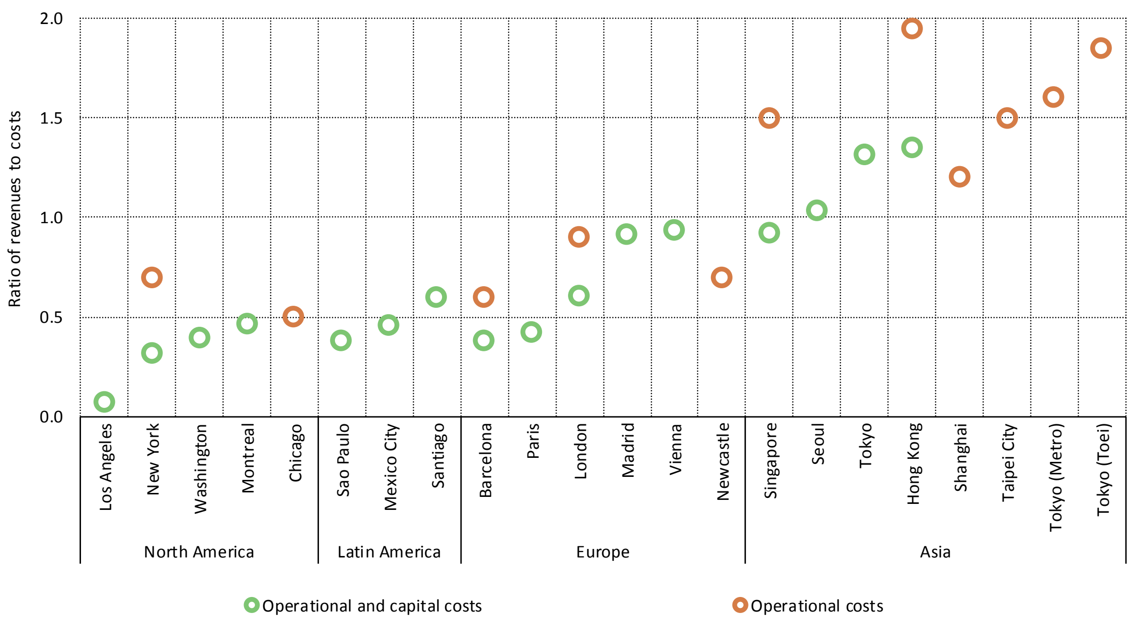
**Figure 3.23 Costs and throughput capacities of urban transport infrastructure**




Source: IEA analysis based on Rode et al. (2014).

**Key message • Urban rail is uniquely positioned to provide high passenger throughput and while its capital costs per kilometre are high, capital costs per throughput capacity are lower than for urban road infrastructure.**

**Figure 3.24 Contribution of fares to cover costs in public transport systems in various cities**




Note: The recovery ratio indicated here is the ratio of revenues generated by public transport systems, including rail and bus systems, relative to costs. If the ratio is less than 1 the system operates at a loss; if it is above 1, the system is profitable. The reference to Tokyo refers to the entire metropolitan region, while Tokyo metro and Tokyo Toei refer to the two rapid transit systems serving the Tokyo metropolitan region.

Sources: LTA (2011) and (2015).

**Key message • The ratio of public transit fare revenues to costs tends to be high in densely populated Asian cities and lowest in low-density cities in North America. Density is a significant determinant of the financial viability of public transport.**



Financing the development of an urban rail network does not need to rely on taxation and subsidies alone: there are additional potential sources of revenue. In particular in the case of rail, capturing land value benefits in financing plans can offset the high cost of capital investment. "Land value capture" describes action to benefit from the increase in residential and commercial property value that occurs in proximity to nodes and stations. This value can be captured in several ways (OECD, 2000): for example, network developers can be allowed to undertake high-profit commercial projects (such as building retail space, restaurants and hotels inside or annexed to stations), providing an opportunity for the developer to share in the increase in land value to help finance the high capacity transport network. Tax increment financing is another approach, which involves the use of property taxes to draw on the increased land value in the proximity of high capacity transport nodes in order to finance the public transport development.

The Mass Transit Railway (MTR) Corporation in Hong Kong, China offers a concrete example of successful public transport financing through land value capture (Sharma and Newman, 2017; Padukone, 2013). The MTR signs contracts with businesses operating along transport corridors that compensate the MTR through partial ownership, a portion of property development fees and/or a fraction of the profits generated by those businesses. This approach, in the circumstances of the constrained geography of Hong Kong, China (i.e. high population density) has helped the MTR to achieve the world's highest recovery cost ratio (Figure 3.24), with 60% of total revenues coming from non-transport sources. Japan Rail-East also has taken a similar approach and around 30% of its revenues come from non-transport sources.

Transport taxation offers another option for financing urban rail systems: vehicle purchase or registration taxes can be allocated to metro or light rail network extensions and improvements. Taxes on motor fuels can also fund urban rail; in the United States, around one-quarter of gasoline tax revenues are allocated to funding public transport (Agarwal, 2018). Pricing policies, such as road pricing, congestion charging, tolls on specific sections of the road network and parking fees can also be earmarked for investment in high capacity public transport infrastructure.[20] Pricing measures can also be coupled with access restrictions for personal vehicles in urban areas (i.e. during rush hour) to encourage high public transport throughput. Such cross-modal subsidisation models also make public transport more attractive by increasing the operational costs of private modes, so reducing its appeal. Subsidies for operations can be economically justified, provided that they do not exceed the direct and indirect economic, social and environmental benefits not captured in commercial pricing. In several European cities, subsidies meet around half the operational expenses of public transport operators (Durkan, Durkan and Reynolds, 2000; EMTA, 2010).

High passenger throughput is more readily achieved in large, dense urban areas, which means that urban rail infrastructure is most effectively developed in conjunction with policies that promote high-density living and integrate transport and urban development planning. Commuting times can be minimised when cities adopt an integrated approach that incorporates mass transit with walking, cycling and other last-mile solutions.[21] Large and rapidly developing

[20] Only a handful of cities apply congestion charging and cordon pricing to manage transport demand, primarily in Europe (London, Milan, Stockholm and several cities in Norway) and Asia (Singapore). San Francisco's dynamic parking pricing programme, SFpark, acts as a sort of congestion pricing, extracting public revenue from parking rather than moving cars, adjusting parking prices at different times of the day and in different urban areas (Verhoef, Nijkamp and Rietveld, 1995).

[21] In Guangzhou, China, for example, the integration of bus rapid transit with the metro system and cycling infrastructure has resulted in reduced vehicle congestion and an estimated reduction of 86 000 tonnes of $CO_2$ emissions (Yang, Zhang and Ni, 2014). The success of this system is attributed to the holistic and forward-thinking planning that characterised its conception and implementation.

cities in emerging economies are well positioned in this respect, but they are also those which often face considerable difficulty in mobilising the required investment from public finance. [22,23]

## *Conventional and high-speed rail*



As with urban rail, developing conventional and high-speed rail projects involves high investment costs and long-lead times, therefore requiring high throughput prospects. Another challenge, especially in the case of high-speed rail, is the need to compete with aviation. Some of the financing solutions identified for urban rail can be applied to conventional rail (commuter trips) and high-speed rail services. For instance, instruments related to land value capture similarly apply, given the attractiveness of rail stations for commercial development. Similarly, there is an economic case for the use of fiscal instruments reflecting the environmental and social benefits of the project.

Conventional rail projects generally bear a high risk of relatively low rates of network utilisation. This important limiting factor requires acute business attention to the minimisation of losses and maximisation of revenues and may justify policy intervention to ensure the benefits of the network are fully realised. Promoting the adoption of digital technologies can help. Data, analytics and connectivity can improve understanding of consumer needs and preferences, providing insights into potential demand which can be used to improve the service quality and competitiveness of conventional rail services. Examples include responding to anticipated changes in demand by altering the frequency and/or the volume of operations, segmenting user groups to provide differentiated services and pricing, and providing real-time updates to travellers, for example on connections.

Adequate investment in physical assets is another requirement for successful conventional commuter and intercity rail. Fleet renewal improves both the efficiency of an operator's stock, and the customer experience. Using digital technologies to optimise asset utilisation, adopting modular units that are appropriately sized to demand increases cost efficiency. Voluntary agreements, incentives and even regulatory requirements may be justified to foster the adoption of other digital technologies, such as communication-based train controls. System extensions, upgrades and even retirements can serve to concentrate operations in crucial corridors. This is not to say that conventional rail operations should be restricted to operations in profitable corridors, but rather that clarity about the advantages of conventional rail and its role within total passenger movements should inform investment decisions.

Like conventional rail projects, high-speed rail projects require close analysis of passenger flows to inform planning. The analysis begins from study of the demand for high-speed travel evident in existing aviation and personal vehicle activity, then taking into account the additional demand that may be generated by agglomeration effects. There may be a case for government targets to generate interest in high-speed rail investment. Such targets are contained in the European Union's white paper advocating the transfer of medium-distance air traffic to rail (European Commission, 2011). Improving the integration of high-speed rail with airports can strengthen the shift in demand towards rail for high-speed domestic/short distance

[22] The long-lead and construction times needed to realise urban rail projects, which contrast with the short incumbency of elected officials in many countries, are a further barrier to city governments considering new urban rail projects.

[23] Cities facing tight budgetary constraints may find that the lower costs and shorter timelines from project conception to realisation make bus rapid transit (BRT) an attractive alternative to urban rail (IEA, 2002). However, BRT risks becoming a victim of its own success; if the capacity of BRT corridors and networks is insufficient to meet demand (as can happen in a rapidly growing city), the quality of service may decline (e.g. slower operational speeds, crowded buses), making it difficult to retain or recover dissatisfied customers. In cases where very high throughput is envisaged, there is a need to find viable mechanisms for financing urban rail.

movements. Examples of high-speed rail and airport integration already exist in Europe, in the form of co-operative agreements between airlines and rail transport operators.[24]

## *Freight rail*



As in the case of passenger transport, using rail to transport freight can usually be justified in economic terms only in areas and directions where freight volumes are high. A prerequisite for freight rail infrastructure investment is, therefore, an understanding of existing freight flows, and the specific characteristics and customer needs of various market segments (Box 3.5).

For freight rail, a key opportunity is to closely connect with other transport modes and to well integrate within the logistics supply chain (i.e. intermodal integration). Containerisation, or the standardisation of the size of freight transport units, is essential to facilitate door-to-door (intermodal) solutions in conjunction with road. Rail can also benefit significantly from the presence of third-partly logistic operators which offer integrated and seamless solutions for goods transport.[25]

In North America, large intermodal companies, logistics service providers and railways have created large freight terminals (super-hubs). From 2000 to 2017, the number of domestic containers transported in the United States tripled, while international container traffic grew 60% (a 50% faster growth than the US economy). Domestic container transport even continued growing even during the recession of 2008-09 (Figure 3.26).

In Europe many rail freight terminals were developed by local municipalities (or were supported by them) acting together with intermodal companies, and often driven by sustainability concerns. In emerging economies, this market is completely underdeveloped, as neither the private sector nor regional governments have had much success with central planning for railways. The reason is that the economies of scale of freight rail usually favour long distances that cross municipal, district and provincial boundaries. Overcoming the resulting barriers requires planning driven by regional entities and national governments (and involving inter-ministerial collaboration).[26] One obstacle in emerging economies is that the type of intervention required (such as logistics hubs) usually depends upon private sector inputs, but many countries are not well-disposed or geared towards public-private partnerships. Pro-active policy development in finance ministries on how to structure public-private partnerships is recommended.

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[24] For example, the AIRail Service provided by Lufthansa and Deutsche Bahn has connected Frankfurt airport with Stuttgart since 2001, and with Cologne since 2003. In France, Air France and SNCF launched TGV AIR in 1994, under which the intermodal passenger transportation between Paris' Charles de Gaulle airport (CDG) and Lille is exclusively operated by TGV. Similarly, Thalys International has co-operated with several airlines (Air France, KLM, American Airlines, Lufthansa and SN Brussels) to provide intermodal services to passengers on three Thalys links, namely, Brussels-CDG, Anvers-Schiphol, and Paris (Nord)-Brussels National Airport (Jiang and Zhang, 2014).

[25] Relevant businesses are classified as first- and second-party logistics service providers, providing basic transport and warehousing services, typically including railway companies and third party logistics contractors, who integrate services to provide a seamless solution, acting as intermediaries between clients and first and second class service providers. The presence of these intermediaries can lead to effective exploitation of the advantages of railways over other modes of transport. To seize these opportunities, freight rail needs to be an integrated component of freight logistics solutions. This is likely to be facilitated by progressive evolution towards an open, shared and modular system wherein physical goods are moved on multiple transport modes using standardised containers, a common protocol and tools, and shared transport and technological assets (IEA, 2017).

[26] Joint planning between rail and road interests, based on total freight-flow analysis (Table 3.2), can strengthen the utilisation of freight rail infrastructure by fostering intermodality, and favouring investment in intermodal facilities, terminals and logistics. This can improve rail's position in the supply chain by stimulating infrastructure development close to supply and demand, and decreasing last-mile distances. These actions can also deliver improvements in road freight logistics, shortening distances, improving the chance that road vehicles will keep appointments and eliminating road freight waste.

**Box 3.5 Better understanding of freight flows and market segmentation for freight rail transport**

Knowledge of freight routes and volumes can typically be gained through commodity flow surveys, freight movement analysis, gravity models and econometric estimation methods. The objective should always be complete knowledge of all freight flows per commodity between all regions on all modes within a country, an understanding of the relative cost involved for each flow, and a long-term forecast of shifts in freight flows. The regions and commodities should be disaggregated to the finest possible level to allow the accurate identification and sizing of freight market segments, so as to identify rail friendly freight. Such detailed analysis in major emerging economies has enabled the identification of five main freight-flow segments. These five segments are shown in Table 3.2, as well as the identification of their corresponding infrastructure characteristics, economic potential and status of rail availability in emerging regions.



**Table 3.2 Freight-flow segments and corresponding rail requirements, potential and development status**

| Market segment | Bulk mineral exports or imports | Mineral distribution industries | Movement of intermediate manufactured commodities | Movement of manufactured and fast-moving consumer goods between distribution centres | Rural freight |
|---|---|---|---|---|---|
| Typical commodities | Coal, iron ore, manganese | Coal, iron ore, manganese | Steel coils, bulk cement | Palletised commodities that can easily be containerised | Mixed |
| Network | Dense purpose-built lines | Purpose-built lines (often through rural areas) | Connecting industries through sidings | Dense corridors | Low-density flows |
| Terminals | A few densified and purpose-built loading points | Connection between purpose-built loading points and sidings | Siding-to-siding traffic | Intermodal facilities linked with sidings | Rural distribution and collection centres |
| Rail solution | Heavy-haul or unit trains between industries and ports | Unit trains between mines and industries | Groups of coupled wagons between sidings | Heavy intermodal unit trains between logistics hubs | Wagon loads with facilities for connecting and disconnecting wagons |
| Road interface | No road redistribution | Limited road redistribution | Some road redistribution | Seamless interface between road and rail, will always require last-mile distribution | Typically more road-friendly |
| Modal shift potential to rail | High - often 100% | High - 60-80% of all freight | Medium – often 40-60% of all freight | Medium - often 40-60% of all long-distance unitised fast-moving consumer goods movements close to densified corridors | Low potential |
| Status of rail offering in emerging economies | Medium: heavy-haul is often not installed | High | Medium: service levels, often heavily contested | Low: service, no designed rail/road interface or managed supply chain | Medium |

Notes: Sidings are a side-track that is distinct from the running track. Sidings are constructed to be able to connect a manufacturing site to the running track, or to let a faster train pass a slower one on a given track.

Source: Based on Havenga (2012).

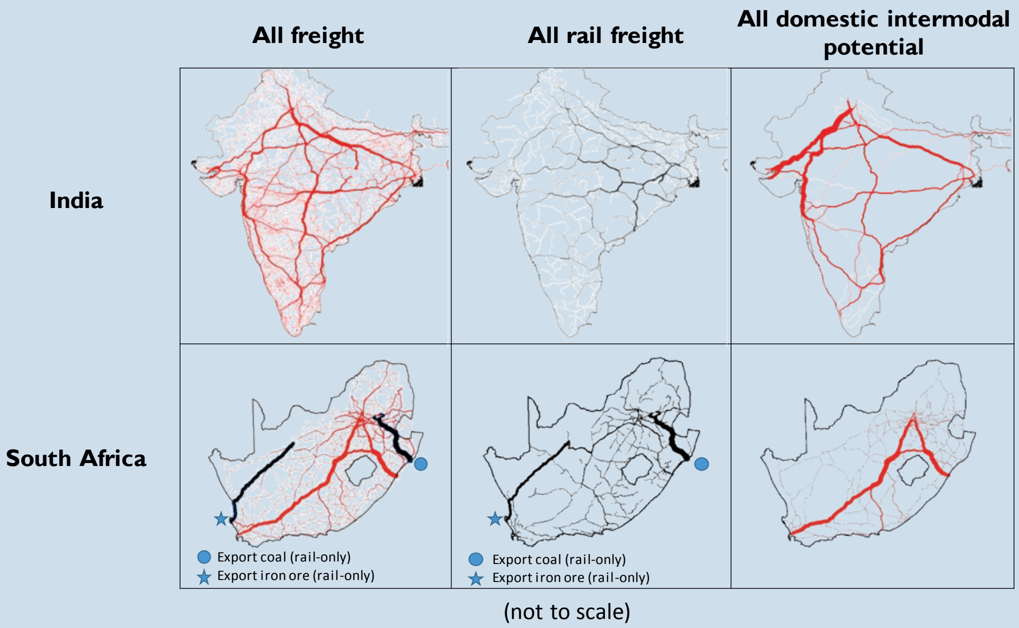
**Key message • The potential to shift freight transport activity to rail is highest for bulk minerals for export. For intermediate manufactured commodities, intermodal developments are crucial.**

Better understanding freight flows at the national level and understanding spatial and sectoral quantification of market segments is important. With an accurate model, the ideal rail markets can be accurately identified and rail infrastructure investments and delivery services appropriately targeted. An example of such quantified freight flows in two emerging market economies (India and South Africa) is provided in Figure 3.25. For both countries, domestic intermodal flows of manufactured and fast-moving consumer goods (column 4 in Table 3.2) are highlighted to showcase rail potential.



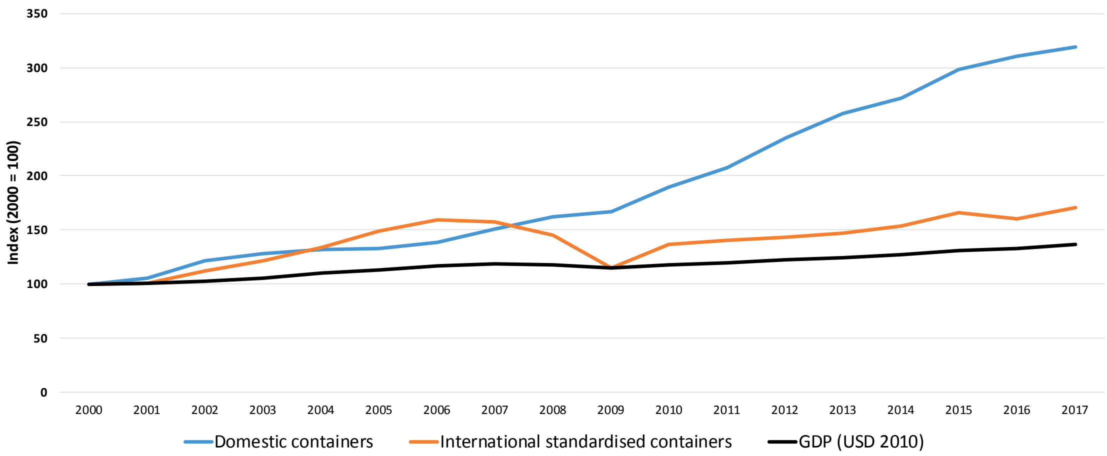
**Figure 3.25 Examples of freight-flow modelling to inform rail potential and infrastructure investments**




Source: Simpson, Havenga and Aritua (2016).

**Key message • Corridors with high density of goods movements and relevant market segmentation have the greatest relevance for investments in freight rail infrastructure.**

**Figure 3.26** **Number of containers used in intermodal transport relative to GDP in the United States, 2000-17**




Note: GDP= gross domestic product.

Source: Intermodal Association of North America (2018).

**Key message • The number of domestic containers and international containers has grown faster than GDP since 2000; domestic intermodal movement increased much faster than international traffic.**

Fiscal measures, in particular congestion charges and emission taxes based on use of the transport network and externalities, are the most direct policies to increase the competitiveness of freight rail. They make freight rail more cost competitive against road freight, especially over longer distances, and may support the development of concentrated freight corridors. Fiscal measures can also alter the trade-off between long transport requirements and local production (some emerging economies enjoy low production costs and economies of scale), and may favour domestic and regional freight over maritime freight movements, supporting production closer to the centre of demand, and ultimately reduce total freight activity demand.

**Box 3.6** **Case of the Alpine initiative in Switzerland**

In 1994, comprehensive action to support a shift to rail in freight transport was approved by voters in Switzerland, the Swiss Alpine initiative (Federal Office of Transport, 2016a). The principle adopted was that the capacity of transalpine roads should not be increased, and that additional transalpine freight traffic was to be carried by rail.[27] The goal was to limit the number of trucks crossing the Alps on an annual basis.

The measures adopted included road charges on freight vehicles, introduced in 2001, investments in new rail infrastructure and rail reform. The road charges apply to all road freight vehicles over 3.5 tonnes, which pay between USD 0.023 and USD 0.031 per tonne-kilometre (depending on the pollutant emissions performance) (Federal Customs Administration, 2018). The result has been a doubling of the tonnage transported per truck (i.e. higher utilisation), compared to 1999, faster fleet renewal and a significant decline in the number of transalpine heavy-duty truck crossings (Figure 3.27) (Sperlich, 2018).

Two-thirds of the revenues from the road charges are used to finance improvements in the rail infrastructure, including network expansion, higher efficiency and lower travel times. The Gotthard Base tunnel will be the longest railway tunnel in the world at 57 kilometres when completed in 2020.

[27] Transalpine traffic refers to international freight moving from Switzerland, France and Austria to Italy, and vice-versa.

Combined with the Ceneri Base tunnel (15 kilometres), which will also be completed in 2020, time savings of 45 minutes per crossing will be achieved, while the consumed energy will decline (Federal Office of Transport, 2016b).

Figure 3.27 **Number of transalpine crossings by heavy-duty road vehicles in Switzerland, 1994-2016**


Source: Federal Department of the Environment, Transport, Energy and Communications (2017).

Key message • **The Swiss Alpine Initiative has succeeded in significantly reducing the number of heavy-duty truck transalpine crossings since 2001.**

## Conclusions

The High Rail Scenario shows how relying on three pillars – minimising cost, maximising revenues and ensuring that all transport modes pay the full costs of the infrastructure they use and their societal and environmental impacts – can help to diversify transport energy sources, reduce oil dependence and curb rising emissions.

The benefits of the increased investments needed to realise the full potential of rail in urban and non-urban rail extend beyond the immediate energy and emissions savings. By mid-century, two-thirds of the global population will live in cities, many of which have yet to be built and will be conurbations with high population density. In these circumstances, metro and light rail are uniquely able to offer reliable networks with high passenger throughput. Using urban rail along the most highly congested corridors can reduce congestion as well as air and noise pollution. It can also augment economic activity and property values. Commuter and high-speed rail networks can bring similar benefits over longer distances, connecting major population centres to one another.

However, in addition to benefits that extend beyond energy and the environment, there are other considerations that must be weighed carefully in crafting and implementing transport policies. In cases where essential prerequisites that give advantages to rail are fulfilled, an increased reliance on rail can promote broader accessibility, improved safety and lower costs. But in other cases, such as for suburban or rural residents, rail investments must be weighed against more flexible and less frequent forms of motorised transport. One key to exploiting the advantages of rail will therefore be to recognise its limitations and the trade-offs between investments in rail versus other alternative forms of mobility.

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# 4. Focus on India

## Highlights



- India's railway system is the fourth-largest in the world in terms of rail track length and carries the world's second-highest volume of passenger traffic (in terms of passenger-kilometres). Rail activity is growing, although at a slower pace than activity on other transport modes; since 2000, rail passenger traffic in India has increased by almost 200% and freight traffic by 150%, but the share of rail in overall transport activity has fallen. Latent demand for mobility in India is huge. For example, on average, each Indian travels about 3 kilometres per day by privately owned road vehicle, compared to 17.5 kilometres in Europe.
- In the Base Scenario, India's rail transport activity grows strongly by 2050; passenger rail by 200%, to 3.7 trillion passenger-kilometres and freight rail by 160%, to 1.9 trillion tonne-kilometres. These increases stem primarily from efforts to increase the attractiveness of passenger rail services, investment to address infrastructure bottlenecks for conventional rail, as well as for urban and intercity high-speed rail, e.g. the completion of the Ahmedabad-Mumbai corridor. The share of rail in overall passenger transport activity stays broadly at today's levels through 2050, but that of freight falls.
- The energy and emissions intensity of rail in India is low, meaning that rail services always save energy and emissions, compared with other transport modes. Today, rail in India uses 0.04 mb/d of oil and 22 TWh of electricity, but it simultaneously avoids 0.6 mb/d of oil use. It emits 29 Mt $CO_2$-eq, while avoiding 98 Mt $CO_2$-eq and 60 kt of $PM_{2.5}$ emissions. In the Base Scenario, these benefits compound as rail-related electricity use climbs to almost 100 TWh and oil use falls to 0.003 mb/d in 2050, rail avoids 1.6 mb/d of oil use, 270 Mt $CO_2$-eq and 8 kt of $PM_{2.5}$ emissions.
- The High Rail Scenario reflects the results of strategic commitment to further enhance the role of rail in India. In this scenario, the competitiveness of rail services is improved by containing operational costs, increasing non-tariff revenues from rail stations and neighbouring areas, and offering additional and improved passenger services. Investment in urban and intercity rail infrastructure helps to overcome infrastructure bottlenecks and staged completion of additional high-speed rail projects helps high-speed rail compete with aviation along the "Golden Quadrilateral" and its two diagonals. The result is a significant rise in rail activity: by 2050, passenger rail activity and freight rail activity are respectively about 40% and 25% higher than in the Base Scenario, saving an additional 1.5 mb/d of oil, 315 Mt $CO_2$-eq and 6 kt of $PM_{2.5}$ emissions.
- Rail, the lifeline of the nation, is facing competitive pressures from both road transport and aviation, which will increase further as road and aviation infrastructure expand and improve. Tapping into opportunities to generate additional revenue will strengthen the competitive edge of rail and reduce the reliance of passenger fares on cross-subsidies from bulk commodity transport by freight rail.

## Introduction

Following India's independence in 1947, 42 different railway systems were merged, forming a national railway network of 55 000 kilometres (Indian Railways, 2018a). Initial government efforts focused on extending and re-routing to improve connectivity among large cities, as well as electrification. By the 1950s, when travel demand started increasingly to be satisfied by road transport in many parts of the world, roads carried only 26% of India's passenger movements and 14% of freight (MoRTH, 2009).



**Map 4.1 Railway network map of India, 2017**


This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Source: IEA elaboration based on Department of Science and Technology of Government of India (2018).

**Key message • The railway network in India is widespread and connects the entire country.**

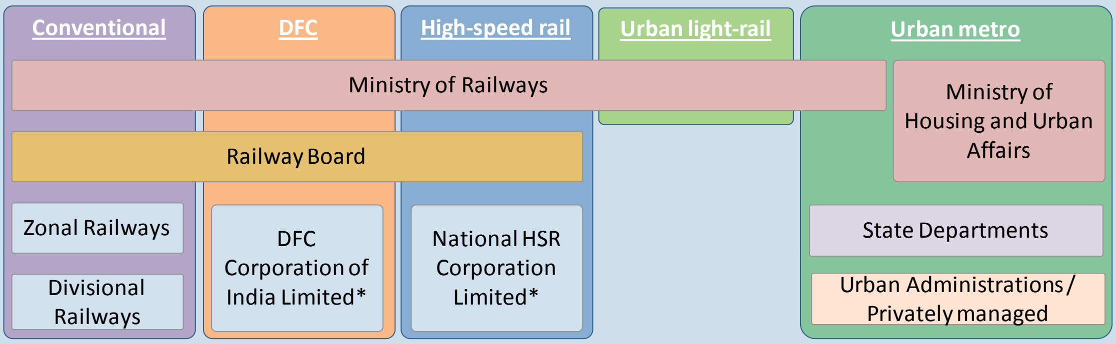
India's railway system has played a fundamental role in the country's development, transporting people and goods throughout its vast territory, integrating markets and connecting communities (NTDPC, 2014). Railway infrastructure serves to bind the country together (Harrington, 2007). Today, the conventional rail system in India comprises a total route length of 67 368 kilometres (Map 4.1), shared between passenger and freight transport (Indian Railways, 2018b). This makes India's railway system the fourth-largest in the world in terms of track length, after the United States, People's Republic of China ("China") and Russian Federation ("Russia"), though the Indian system also carries the second-highest volume of passenger traffic (as measured by passenger-kilometres), in the world (UIC, 2017). About half of India's conventional rail tracks are electrified, making it the third-largest electrified railway system in the world, after Russia and China. There are also metro railway systems in ten large cities (Sinha, 2018a). Two dedicated freight corridors (DFCs) and one high-speed rail line are under construction. Moreover, several additional metro railways systems are planned and additional high-speed rail projects are under evaluation.



**Box 4.1 Governance and organisation of rail transport in India**

Most conventional rail transport in India is administrated by Indian Railways (IR), a mostly publicly owned entity, dating back 165 years, which operates under the aegis of the Indian Ministry of Railways (MoR) (Indian Railways, 2018b). Indian Railways is managed by the Railway Board, which is headed by a chairman and includes six functional members (responsible in in the areas of traffic, staff, engineering, traction, rolling stock and finance) and four director generals (Figure 4.1). For administrative purposes, IR is split into 17 zones responsible for railway operation, each one managed by a general manager (Indian Railways, 2018c). The Railway Board co-ordinates the Zonal Railways. The zonal railway systems are quasi-independent business entities, which are further divided into 68 smaller operating units, called divisions, which are the lowest co-ordinating and managing units of the conventional railways in India. In addition, there are production units, training establishments and other subordinate entities under the control of the Railway Board.

**Figure 4.1 Structure of governance of rail transport in India**




*Special purpose vehicle (SPV) under the administrative control of the Ministry of Railways

Notes: DFC = dedicated freight corridor; HSR = high-speed rail.

Source: IEA elaboration based on Indian Railways (2018c).

**Key message • MoR directly controls conventional rail and it administers DFCs and high-speed rail projects through special purpose vehicles. MoHUA controls metro systems.**

DFCs in India are managed by the Dedicated Freight Corridor Corporation of India (DFCCIL), a "special purpose vehicle" (SPV) formed in 2006 under the administrative control of the MoR. DFCCIL is responsible for the planning, development, construction and operation of DFCs in India. It answers to the Railways Board and, through the Board, to the MoR.

High-speed rail is managed by the National High Speed Rail Corporation Limited (NHSRCL), jointly owned and administrated by the MoR and the state governments currently involved in the creation of the high-speed rail corridor, namely Maharashtra and Gujarat.

In India, urban transport is regulated at the state level, with states and union territories in charge of planning and developing urban transport systems. For urban metro systems, the Ministry of Housing and Urban Affairs (MoHUA) is in charge of central regulation and planning, while states, cities or private entities (in some cases jointly) are in charge of operations and business development. MoR is in charge of safety and standards issues.

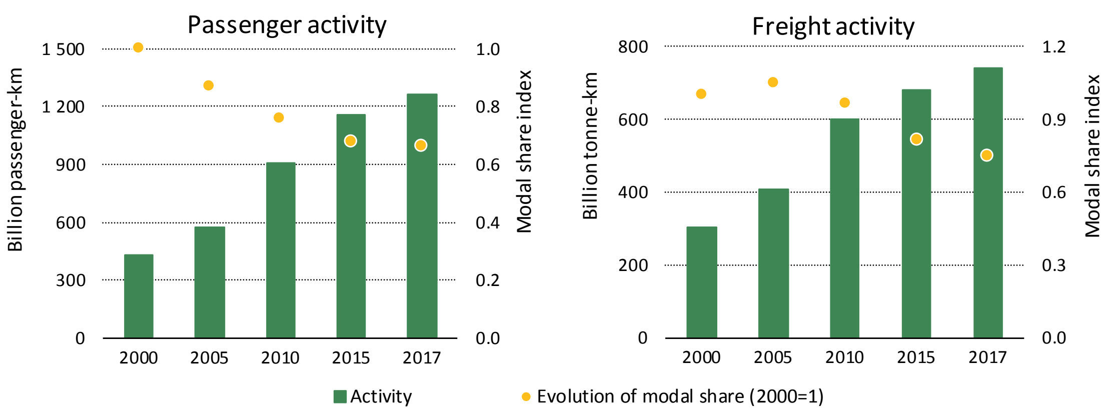
The National Transport Development Policy Committee (NTDPC) of India has suggested organisational reforms in IR in the interest of sustaining economic growth in India (NTDPC, 2014). It has recommended an institutional separation of the policy, regulatory and management roles that are currently performed by the Railway Board. The recommended structure would give competence on policy development to the MoR, while a new authority would be responsible for technical regulations and a corporation would be in charge of operation and management (MoR, 2015).

## Status of rail transport

Between 2000 and 2016, passenger activity (measured in passenger-kilometres) on India's railways increased by 200% and freight activity (in tonne-kilometres) by 150% (Figure 4.2). Despite growing more slowly than rail activity growth, track length has increased and tracks have been upgraded to permit higher speeds and heavier axle load operation. As of 2017, approximately 22 million passengers and 3 million tonnes (Mt) of goods were moved by conventional rail every day (Indian Railways, 2018b), using a fleet of nearly 11 500 locomotives (over 6 000 diesel and nearly 5 400 electric locomotives, the remainder being steam-powered), nearly 55 500 conventional passenger coaches and 278 000 freight wagons.

Although growth in recent years has been impressive, road passenger and freight activity has increased at a faster pace and, as is occurring in many other countries, competition from aviation has been intensifying (NTDPC, 2014). The result has been a gradual decrease in the share of rail in passenger and freight activity (Figure 4.2).

**Figure 4.2 Evolution of passenger and freight rail transport activity and share in transport sector in India, 2000-17**




Source: IEA based on Indian Railways (2018b) and MoRTH (2017).

**Key message • Passenger and freight railway activity in India has steadily increased over time, but at a slower rate than transport by other modes, decreasing the rail modal share.**

One reason for the decline in modal share is that the rail network in India has undergone limited expansion over the last 60 years (Planning Commission, 2013). Whereas the total length of national road highways increased by 75% between 2000 and 2015 (MoRTH, 2017), while rail track length extended by just above 5% (Indian Railways, 2018b). The share of rail in total transport infrastructure investment has been declining, while that of road has increased (NTDPC, 2014). As a result, there are infrastructure capacity constraints on Indian Railways, with many high-density routes saturated (Indian Railways, 2015). The government is taking measures to modernise the railway sector and augment capacity, such as establishing the DFCCIL to accelerate the deployment of DFCs, constructing several metro systems in large cities and building the nation's first high-speed rail line.



## Passenger rail

### Urban rail

The construction of metro systems in India started late in comparison to many other countries, but, in recent years, development across the country has been rapid. Kolkata was the first city in India to build a metro rail system, in 1984, followed by New Delhi, in 2002. The success of the New Delhi metro in terms of offering a high quality service throughout the National Capital Region has inspired other Indian cities to develop their own metro systems (UITP, 2018a). Currently, ten Indian cities have an operating metro system (Kolkata, Delhi, Bengaluru, Gurgaon, Mumbai, Jaipur, Chennai, Kochi, Lucknow and Hyderabad) and two more cities (Pune and Nagpur) are constructing systems (Sinha, 2018a) (Map 4.2). [1]

Overall in India, about 500 kilometres of metro lines are operational, 620 kilometres are under construction (both to expand existing systems and to create new ones), and 600 kilometres are being planned (Sinha, 2018a). As is common practice in building metro systems, construction in India tends to take place in phases, the network being progressively expanded to cover a larger area of the city. In the early stages of metro development, a relatively small proportion of the urban population has access, especially in larger cities.[2]

In 2015, the national government approved a proposal to build metro systems in 50 cities. These new systems would be realised through SPVs, with state and central government jointly financing the projects (most are being planned as 50:50 joint ventures between the two levels of government) (Railway Pro, 2018) and, in 2016, the government earmarked USD 1.5 billion (United States dollars) (Indian Rupee [INR] 100 billion) for metro projects (UITP, 2018a). In 2017, the government published a Metro Rail Policy, which encourages cities with more than two million inhabitants to plan mass transit systems, including metro railways (MoHUA, 2017). Significantly, it was stated that private sector participation will form an essential requirement for all metro rail project proposals seeking central government financial assistance.[3]

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[1] Besides metro, more than 200 kilometres of bus rapid transit (BRT) systems are operational and an additional 282 kilometres are under construction, nationwide (UITP, 2018a). The Ministry of Urban Development has provided financial assistance to 11 cities for the construction of 504 kilometres of additional BRT lanes (UITP, 2018a).

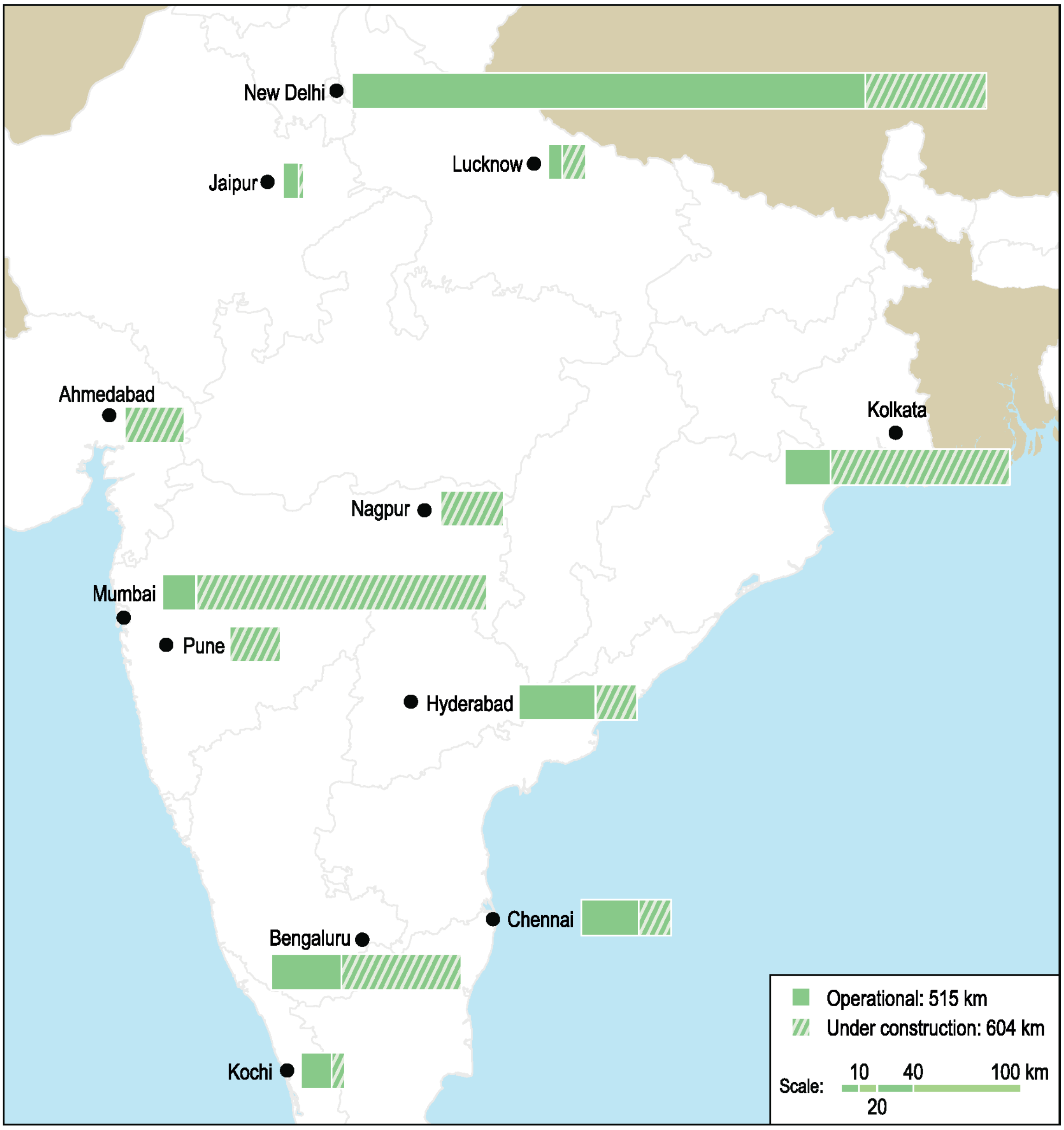
[2] For instance, in New Delhi the number of annual metro trips grew from 703 million in 2013 to 1.8 billion in 2017, while population size remained stable (UITP, 2018b). Ridership grew in tandem with system expansion over these five years (ITDP, 2018).

[3] The ownership and operation of urban rail and metro systems in India is characterised by a mix of public and private models (Sinha, 2018a).



**Map 4.2** **Existing and under construction metro systems in India**




This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Sources: IEA based on Sinha (2018a).

**Key message • Metro systems are expanding rapidly; operating in ten urban areas and under construction in six cities.**

## *Conventional passenger rail*

Conventional railways in India have higher passenger traffic activity than any other rail system in the world, measured in passenger-kilometres, and the second-largest number of passenger trips after Japan (UIC, 2017). In 2016-17, more than eight billion passenger journeys were made on Indian railways, achieving a total passenger transport activity of more than 1 100 billion passenger-kilometres (Indian Railways, 2018b). Train speeds are modest, however. In 2017, the average speed of ordinary passenger trains was 33.9 kilometres per hour and 50.9 kilometres per hour for express trains (Indian Railways, 2018b).

Conventional passenger rail services help to meet both suburban commuter and intercity passenger mobility needs. Suburban services account for just over half the total passengers carried by conventional passenger rail services, but for less than one-eighth of total activity as measured by passenger-kilometres. The remaining passenger traffic is intercity and long distance (Table 4.1) (Indian Railways, 2018b).



**Table 4.1 Proportion of suburban and intercity service in total passenger rail activity, 2017**

| Type of service | Number of passengers | Traffic in passenger-kilometres |
|---|---|---|
| Suburban/commuter | 56.3% | 12.6% |
| Intercity | 43.7% | 87.4% |

Source: IEA based on Indian Railways (2018b).

Key message • **Despite serving more than half of total passengers, suburban/commuter rail transport accounts for only about one-eighth, in terms of passenger-kilometres.**

In 2017, Indian Railways revenues from passenger traffic were USD 5.79 billion (INR 46 280 crore), 4.5% higher than the previous year (Indian Railways, 2018b). Suburban/commuter traffic contributed 5.8% of passenger earnings and intercity contributed 94.2%. Overall, the passenger railway sector in India has been losing money for several years (Indian Railways, 2018b). The losses generated by the passenger sector have grown from approximately USD 2.7 billion (INR 200 billion) in 2010 to USD 5.5 billion (INR 400 billion) in 2017.

To fulfil the vision of railways connecting the country, revenues from the freight sector are currently used to cross-subsidise loss-making passenger transport (Indian Railways, 2015). This has resulted in charges for freight rail transport that are significantly higher than in other countries,[4] especially over the past five years.[5]

## *High-speed rail*

At present, India does not have high-speed rail.[6] In 2015, India and Japan signed an agreement to develop a high-speed rail line, called MAHSR, to connect the cities of Ahmedabad and Mumbai.[7] This high-speed rail line, which is expected to become operational in 2023, will have a total length of 508 kilometres and ten intermediate stops. It will be served by Shinkansen type trains of Japanese design, which can achieve maximum operating speed of 320 kilometres per hour (NHSRCL, 2017). The MAHSR will reduce travel time between the terminal stations from approximately nine hours (by bus) or six hours (by conventional rail) to two hours. MAHSR is expected to have a competitive advantage over air travel for three reasons: considering door-to-door travel time, high-speed rail is faster; it provides a fast connection between multiple city pairs not currently served by air; and it can operate more reliably in all weather conditions (Mishra, 2018). The commercial competitiveness of MAHSR with aircraft operating on the same route will depend on whether MAHSR successfully contains costs so as to offer fares in the same range as air travel (USD 18 to 65).

[4] The fare-to-freight ratio (defined as the ratio between revenue per passenger-kilometres and revenue per tonne-kilometres) in India is about 0.24, well below the 0.7 to 1.9 range observed elsewhere (Kamboj and Tongia, 2018).

[5] To maintain total revenues as coal shipments declined, between 2012 and 2017, IR increased coal freight charges at a rate four-times higher than inflation (Kamboj and Tongia, 2018).

[6] Despite not having a high-speed corridor, in 2016 the semi-high speed Gatimaan Express came into operation between Delhi and Jahansi (NDTV, 2016), with a maximum speed of 160 kilometres per hour.

[7] Approximately 80% of the funding for the project is provided by Japan's International Cooperation Agency (JICA), which will provide a low interest loan repayable over 50 years, with an initial 15 year moratorium (Mishra, 2018).

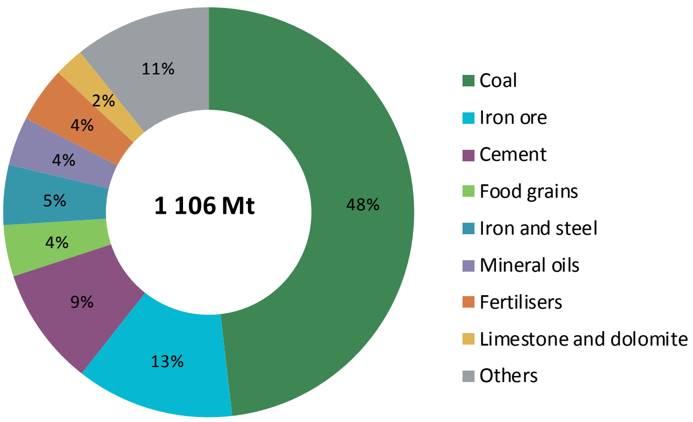
High-speed rail can play an important role in India. As salaries rise, the value of time spent in transit is set to increase, making it important to provide fast options on medium and long-distance trips. Due to the lack of high-speed rail and the availability of low cost airlines, the number of passengers travelling by air in India, in recent years, has increased at one of the highest rates in the world (Business today, 2018; ICAO, 2018). The realisation of MAHSR will support a limited shift of journey from aviation to high-speed rail and there is the potential for more.



## *Freight rail*

In 2017, Indian Railways carried approximately 1.1 billion tonnes of goods and realised an overall level of freight activity of 620 billion tonne-kilometres (Indian Railways, 2018b). Coal haulage accounts for about 40% of the freight transported today, on a tonne-kilometre basis (Indian Railways, 2018b). In addition to coal, iron ore and cement are key commodities carried by the railways. These three commodities combined account for about 70% of total freight carried (Figure 4.3).

**Figure 4.3** **Transport of bulk commodities by Indian Railways, 2017**




Source: IEA based on Indian Railways (2018b).

**Key message • Coal is the dominant good transported by the freight rail system.**

Most coal carried by railways in India is to supply power plants: 340 Mt of the total 574 Mt of coal transported by rail in 2016 (Kamboj and Tongia, 2018). In recent years, while the total volume of coal moved by rail has continued to grow (albeit at a slower rate than in the past), the average distances that this coal is moved have declined.[8] Given the important role of coal in the commodity basket carried by Indian Railways, this has led to a decline in total rail freight activity (in terms of tonne-kilometres). While there are a large number of reasons for this reduction in rail freight traffic, two stand out:

- The coal linkage rationalisation realised by the Ministry of Coal, Ministry of Power and the Ministry of Railways to make the coal supply chain more efficient and to cut costs (Ministry of Coal, 2017).
- The construction of new coal-fired power plants close to the eastern region (where coal is produced) and near coastal areas (where import centres are located). In the past, coal was

[8] The slower rate of growth of coal is due to the overcapacity of coal power plants and an increasing penetration of renewables for power generation.

transported long distances, mostly from the east to the north of the country, where the majority of coal-fired power plants are located. However, as renewable power capacity has expanded and the price of coal increased (partially due to increasing tariffs of freight rail transport), the coal power plants located far from coal mines have been dispatched less often. They are not likely to be retrofitted (Kamboj and Tongia, 2018).



In India, in contrast to most other countries (other than the United States), rail remains a significant mode of freight transport, accounting for approximately 30% of total surface freight movements in 2017 (i.e. excluding maritime transport) (IEA, 2018a). Though this share has decreased from about 41% in 2000, as road-based transport has captured a larger share of growth in the freight market. Indian Railways has become largely a bulk commodity carrier, although even this traffic has increasingly shifted to road in recent years (Planning Commission, 2014; Indian Railways, 2018b).

Several concurrent factors have contributed to the reduction of rail's share in freight transport:

- Capacity constraints in the railway network (NTDPC, 2014).
- Insufficient integration of other services into the rail supply chains: namely, first-mile and last-mile linkages. This highlights the need for logistical hubs and intermodal service providers (NTDPC, 2014).
- Expansion of the road infrastructure and adoption of multi-axle trucks (which carry higher loads and thus achieve lower costs per weight unit and offer more flexibility and convenience) (Planning Commission, 2014).
- Increasing freight rail tariffs (Kamboj and Tongia, 2018).

Indian Railways attempted to offset the reduction of revenues from decreasing freight traffic by increasing freight tariffs, especially those for moving coal.

### *Dedicated freight corridors*

To increase the competitiveness and improve the prospects for increasing the modal share of rail in freight transport, Indian Railways is building two DFCs: one (the Eastern Corridor) connects Dankuni (in West Bengal) and Ludhiana (in Punjab), and the other (the Western Corridor) links JNPT (the port near Mumbai) with Delhi. Such DFCs are particularly important considering the high level of congestion on these routes (DFCCIL, 2018). Moreover, given that the highways along these corridors carry 40% of total national road freight movements (Planning Commission, 2014), the potential for shifting traffic from road to rail is significant. The mean traffic through the Eastern DFC is expected to be coal going to the coal-fired power plants located in the north of the country from coal fields located in the east.[9] The Western DFC is mainly intended to carry containers from the ports on the west coast to the north and to carry coal, cement and iron and steel in the other direction. Both DFC projects are expected to be completed by the end of 2020 (DFCCIL, 2018). Once completed, the DFCs will provide two main benefits to the Indian Railways network:

- They will be able to carry longer freight trains, with higher loads and higher speeds (Pillai, 2018).[10]

[9] The Easter DFC ends at Dankuni, which is far from Kolkata port and from the city centre where most freight originates or is off-loaded. The authorities concerned are well aware of the need to pay attention to the integration of the Eastern DFC into the logistics of West Bengal and Kolkata.

[10] In 2016, the average speed of diesel and electric broad gauge freight trains was approximately 23 kilometres per hour (Indian Railways, 2018b). The Planning Commission estimates that on DFCs, freight trains could reduce transit times and achieve maximum speeds of 100 kilometres per hour (Planning Commission, 2014).

- They will reduce freight traffic on existing lines, making way for more passenger train traffic, improving passenger train reliability and allowing passenger trains to attain higher speeds.

The government has a longer term vision to build DFCs along the quadrilateral linking the four cities of Delhi, Mumbai, Chennai and Kolkata (the so called "Golden Quadrilateral") and its two diagonals (Planning Commission, 2014). Improving freight transport on these lines is a strategic priority, given that 58% of Indian Railways freight traffic occurs on these routes, which, in recent years, have become heavily congested (DFCCIL, 2018).

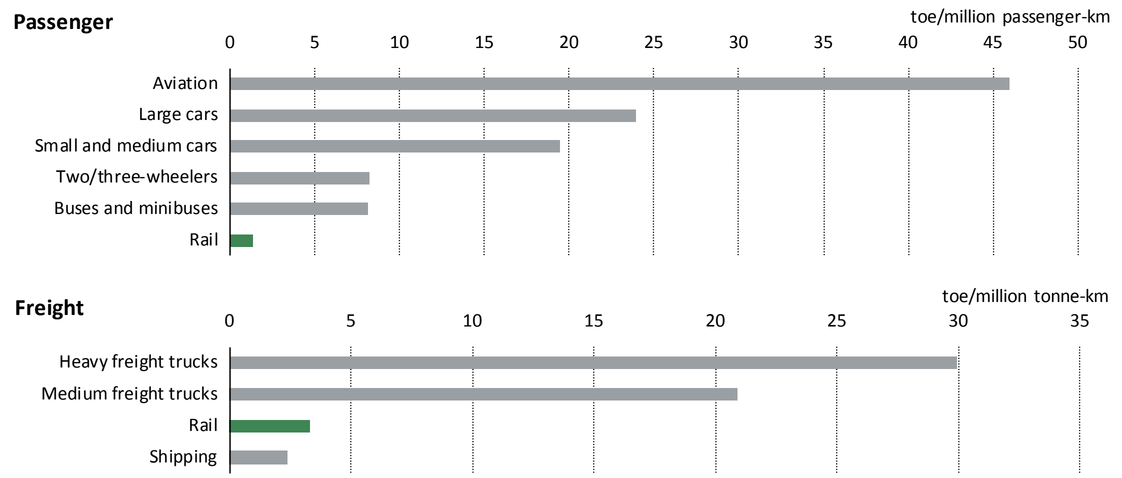


# Rail transport energy demand and emissions

## *Energy demand from rail transport*

As in other countries, rail transport in India is characterised by lower energy intensity than other modes of transport (Figure 4.4). Although passenger light-duty vehicles in India are normally much smaller than in other countries and hence use less fuel, on average, per kilometre driven, the energy intensity of passenger rail transport is still 93% lower than that of passenger light-duty vehicles (IEA, 2018a). In the freight sector, for each tonne-kilometre, railways consume about 84% less energy than a medium-sized freight truck.

**Figure 4.4 Energy intensity by transportation mode in India, 2017**




Notes: toe = tonnes of oil equivalent. Energy intensity of rail is calculated as the weighted average of all rail technologies.
Source: IEA (2018a).

**Key message • In 2017, rail transport in India consumed 18 toe less per million passenger-kilometre than small and medium cars, and 17 toe less per million tonne-kilometre than medium freight trucks.**

In 2017, rail's share of total transport energy use was 4%, significantly lower than rail's share in passenger and freight transport activity (IEA, 2018a).[11] India's rail sector in 2017 consumed approximately 4.1 million tonnes of oil equivalent (Mtoe) of energy to meet its traction requirements. At 0.04 million barrels of oil equivalent per day (mb/d), diesel was the primary

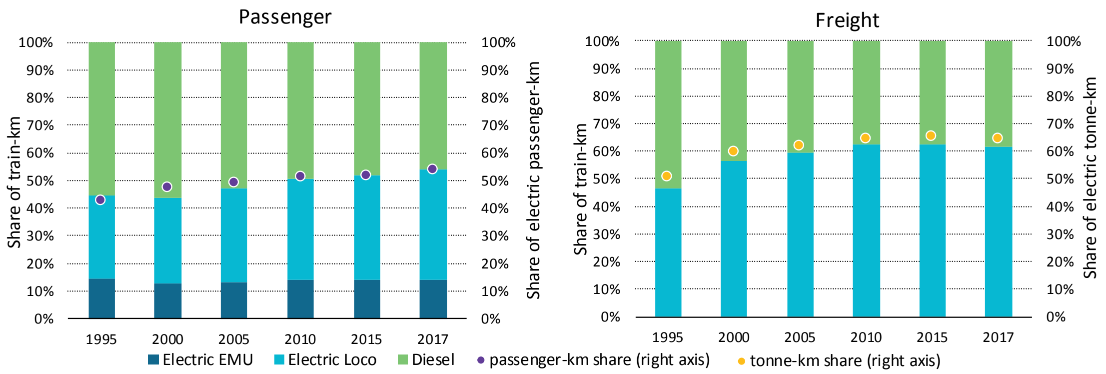
[11] The share of rail is calculated accounting for all passenger and freight transport modes, except for waterborne transport (due to data availability limitations).

fuel, accounting for more than half of the total. While this level of consumption is significant, account also needs to be taken of the oil savings attributable to rail travel: if all the passenger and freight traffic that is currently on rail instead was carried by road, oil product demand would be 0.6 mb/d.[12]



At around 22 terawatt-hours (TWh), the electricity used by Indian trains accounted for less than 2% of total Indian electricity demand in 2017 (IEA, 2018b). Electricity is used both for passenger and freight services. Within the category of passenger services, all metros are electrified, while 54% of conventional rail activity (in passenger-kilometres) uses electricity. A higher percentage of freight traffic is hauled by electric traction. In 2017, electricity provided about 65% of total freight energy use, in terms of tonne-kilometres (Indian Railways, 2018b) (Figure 4.5).

**Figure 4.5 Conventional train traffic by type of traction in India, 1995-2017**




Notes: EMU = electric multiple unit); Loco = locomotive.

Source: IEA based on Indian Railways (2018b).

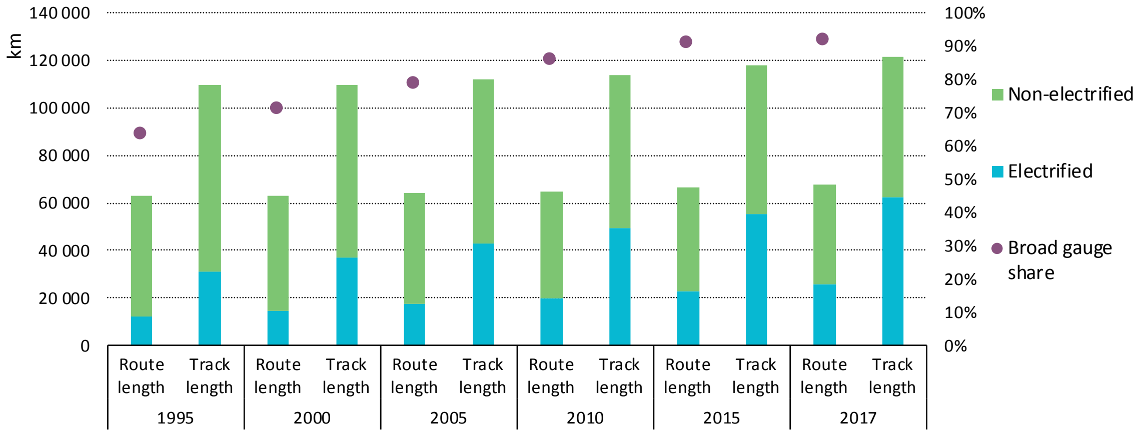
**Key message • Freight rail traffic is dominated by electric trains.**

Rail electrification has been an important objective of Indian policy since 1960. The electrified share of the rail network (in terms of route length, including conventional rail and metros) has increased from 24% in 2000 to 38% in 2017 (Figure 4.6). In parallel, a doubling and tripling of the capacity of the most utilised lines have been achieved and much accomplished in terms of conversion from narrow gauge and metre gauge to broad gauge (Indian Railways, 2018b). By 2017, the share of broad gauge reached 92%.[13] For conventional rail, almost all double and multiple track sections and electrified routes are broad gauge, while narrow and metre gauge routes are largely single track, non-electrified routes.

[12] This result is obtained on the assumption that passenger rail would be replaced by aviation, cars, buses and two/three-wheelers, that freight rail would be replaced by heavy freight trucks and that all the energy demand is oil. The weighted average fuel economy of passenger transport in India in 2017 is 10 toe/million passenger-kilometre and that for freight trucks is 30 toe/million tonne-kilometre (IEA, 2018a).

[13] The share of traffic on narrow and medium gauge tracks is very low compared to the share on broad gauge tracks (Indian Railways, 2018b). The size of broad gauge tracks in India is 1.676 metres.

**Figure 4.6 Electrification of the Indian railway network and the share of broad gauge, 1995-2017**




Notes: Route length includes both conventional rail and metro rail; track length includes only conventional rail.

Sources: IEA based on Indian Railways (2018b) and Sinha (2018a).

Key message • **The overall extension of route length in India has been limited. Projects have mainly involved doubling or tripling the capacity of selected lines, gauge conversion and electrification.**

Electric locomotives and electric multiple units (EMUs) are normally equipped with regenerative braking, a technology that converts the kinetic energy of the train (during braking) into power that is injected back into the overhead lines and can be used by other trains circulating on the same route, thus reducing overall electricity demand.

Indian Railways is making serious efforts to electrify the railway system and improve the efficiency of electric traction, but it is also making operational and technological improvements to its diesel train fleet (Financial Express, 2018). For passenger trains on short routes, the first set of measures includes replacing diesel locomotives by diesel-electric multiple units (DEMU), providing fuel savings of approximately 10%. Future plans include installing auxiliary power units on all new diesel locomotives, introducing Common Rail Electronic Direct Injection on the fleet of diesel locomotives, and applying other fuel efficiency measures (Indian Railways, 2018a). Moreover, in 2015, Indian Railways started blending bio-diesel at a 5% share and, since then, such blending has been progressively introduced across a number of locations (Indian Railways, 2018b). Indian Railways also has plans to change the system used to provide power to coaches from the End-on-Generation to the Head-on-Generation scheme, which allows power for air conditioning and lighting in the coaches to be drawn from the locomotive, instead of from diesel generators installed at both ends of the train. This is a means of reducing diesel consumption (Indian Railways, 2018a).

## *GHG emissions and local pollutants*

As elsewhere, the performance of rail with respect to road transport in terms of well-to-wheel (WTW) greenhouse gas (GHG) emissions largely depends on the carbon intensity of the power grid, particularly because electricity already accounts for a large share of energy use in rail in India. Despite the generally high carbon intensity of the power mix, rail in India currently avoids, on average, emissions of nearly 60 grammes of carbon-dioxide equivalent (g $CO_2$-eq) per passenger-kilometre, compared with a small and medium-size car, and around 50 g $CO_2$-eq per tonne-kilometre compared with a medium freight truck (IEA, 2018a).[14] In 2017, the tank-to-wheel $CO_2$ emissions (i.e. those associated with diesel combustion) from rail in India accounted for approximately 7 Mt $CO_2$-eq. Additional well-to-tank $CO_2$ emissions (i.e. those associated with upstream power generation and oil recovery) accounted for about 22 Mt $CO_2$-eq, a total of about 29 Mt $CO_2$-eq.[15]



In India, local air pollution is a major issue. According to the World Health Organization, in 2016 ten Indian cities were among the twenty most polluted cities in the world (WHO, 2018). Sources of air pollutant emissions in India are varied and transport is not always the major contributor. Indeed, at the national level, the contribution of transport to the total emissions of fine particulate matter ($PM_{2.5}$) is limited to 4% (IEA, 2018c), though in Delhi the share is closer to about 9% (IIASA, 2018). With increasing levels of motorisation, road transport's contribution to air pollution is expected to increase. The progressive tightening of vehicle emission standards in India is an important means of tracking the increasingly life-threatening levels of local air pollution, as are the Environmental Protection Amendment Rules for the power sector.[16] Thanks to the lower emissions intensity of rail, relative to road, and its high rate of rail electrification, rail-based transport in India offers an important way to mitigate local air pollution. In 2015, rail in India avoided the emission of 60 kilotonnes (kt) of fine particulate matter ($PM_{2.5}$).[17]

## Outlook for rail to 2050

As in other countries, there is no certainty as to the long-term outlook for rail in India. Given the large investment required, an increased role for rail will depend on government resolution and intervention. As outlined, rail infrastructure development has not kept pace with the demand for passenger travel and freight activity, leading to infrastructure bottlenecks. Safety is a vital and pressing consideration (Box 4.2). And the competitive pressures from other modes of transport means that rail will need to continue to invest and innovate to maintain and enhance its role as the lifeline of the nation.

In the following sections, we explore the future of rail in India in two scenarios. The Base Scenario projects developments solely on the basis of existing policy announcements and the announced targets of the Indian government, analysing their implications for rail. In the High Rail Scenario, opportunities are seized to boost the role of rail in India. The challenges and potential benefits are examined. Both scenarios are positioned in the context of wider transport, economic and social policies in India.[18]

[14] These results are obtained by comparing the WTW GHG intensity of rail (averaging across metro and conventional rail) with that of small and medium-size cars in India in 2017. The carbon intensity of rail in India (considering the Indian-specific load factor of 1 511 passenger-kilometres per train-kilometre for intercity rail and of 262 passenger-kilometres per train-kilometre for metro rail) was estimated at 9 g $CO_2$-eq per passenger-kilometre in 2017 (IEA, 2018a).

[15] Indian Railways also plans to reduce the carbon intensity of the power it consumes. It has already installed 36.5 megawatts (MW) of wind generation capacity and 14 MW of solar photovoltaic (PV) capacity and plans to install 1 gigawatt of solar PV and 500 MW of wind power (Indian Railways, 2016).

[16] Bharat Standard (BS) IV, based on EURO 4, has been enforced for all new vehicles since April 2017. BS VI, based on EURO 6, will apply to all new vehicles registered from April 2020. With such tightening of the emissions standard regulations, the Ministry of Road Transport and Highways (MoRTH) is leapfrogging directly from EUR 4 equivalent to EUR 6 equivalent (Transportpolicy.net, 2018).

[17] This result is obtained by assessing the implication if rail passenger activity in India in 2015 had been replaced by passenger light-duty vehicles, two/three-wheelers and buses maintaining the relative modal shares, and freight rail activity replaced by heavy freight trucks, using appropriate pollutant emission factors for the different modes (IEA, 2016).

[18] For more detailed discussions of the other energy sector trends in India in the Base Scenario, which set the context for the railway projections, see *World Energy Outlook-2018* (IEA, 2018c).

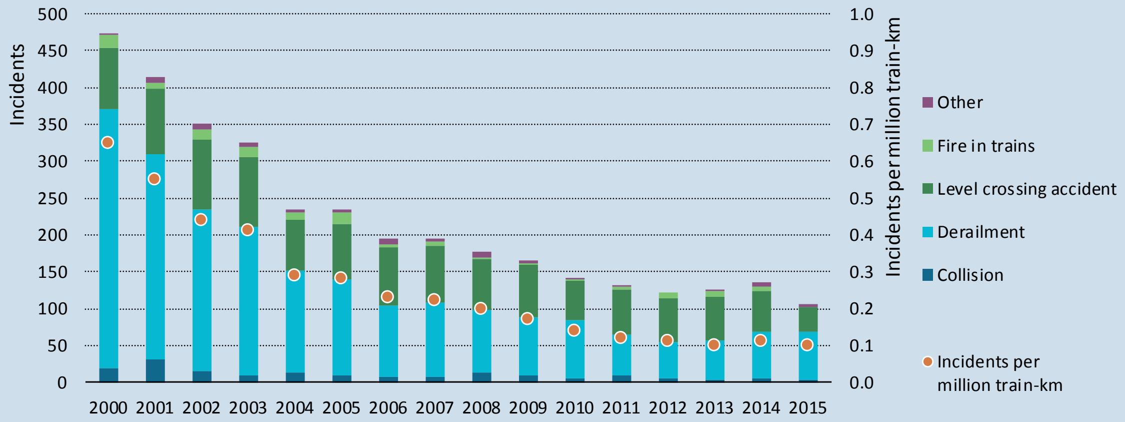
**Box 4.2 Safety on Indian Railways**

Safety is a vital concern for Indian Railways, which operates a system that is both in need of modernisation and heavily congested, with 40% of rail sections carrying more than 100% of design capacity (MoR, 2016).

Derailments, accidents at level crossings and collisions have been the principal type of accident. Inadequate funding for expansion and modernisation of assets, coupled with the difficulty of providing for maintenance on a saturated network has made safety a particular challenge. As shown in Figure 4.7, significant progress has been made in reducing the number of such (and other) accidents. From nearly 500 accidents in 2000, the number of rail accidents has steadily decreased and was 73 in 2017. This improved railway safety was achieved during a period of significant traffic growth, meaning that accidents per million train-kilometres have fallen sharply and are now less than 0.10 (Indian Railways, 2017). The direction of the trend is similar for rail passenger casualty statistics, from a high of 315 in 2005-06 to 40 in 2015-16.[19]

About 60% of the accidents in India involve a derailment, so a thorough examination of track and coach conditions is required if such accidents are to be further reduced. A review suggested that about 5 000 kilometres of track required repairs and upgrading (MoR, 2016), of which less than half was being undertaken annually. There is a need to adopt more efficient technologies for track maintenance and to upgrade the rolling stock that carries passengers. Where possible, Indian Railways is addressing such needs, for example by switching to Linke Hofmann Busch (LHB) coaches from 2018-19, renewing tracks and adopting completely mechanised track maintenance.

**Figure 4.7 Trend of train incidents on Indian Railways, 2000-2015**




Source: IEA based on Indian Railways (2017).

**Key message • Significant progress has been made in reducing the number of accidents.**

Level crossings are also a needed area for attention regarding safety. Trains have the right-of-way at level crossings, but they have been the site of a large number of accidents. Accidents at level crossings, including unmanned crossings (crossings without barriers or signalling) were reduced from 30 350 in 2014 to 28 600 in 2016 by creating bridges and developing manned crossings (Indian Railways, 2017). But clearly more needs to be done.[20]

Collisions remain the most serious form of rail accidents and have been given close attention. The situation should improve as the transition to advanced signalling and collision avoidance systems progresses. Given that a large percentage of accidents are due to human error (or misjudgement), a

[19] The total number of deaths on railway tracks, however, is significantly higher with 49 790 deaths reported in the two years between 2015-17 (Indian Express, 2018). These figures include trespassing incidents.

[20] During 2018, unmanned level crossings have been completely removed on broad gauge networks.

complete move to multi-aspect signalling systems, coupled with Train Protection Warning Systems (TPWS) and Train Collision Avoidance Systems (TCAS) would significantly reduce accidents resulting from human error or speeding.

Almost all studies and reviews undertaken in the last couple of decades have highlighted under-investment as one of the prime reasons for accidents. Indian Railways has increased the safety component in its budget (USD 1 billion in its 2017 budget, up from USD 27 million in 2016). This prioritisation needs to be sustained to make the system more reliable and safer.



## Outlook for rail in the Base Scenario

### Context

Passenger and freight mobility needs are on the rise in India, and the latent demand for both is immense. For example, passenger car ownership in 2017 was 26 vehicles per 1 000 inhabitants in India, compared with about 130 in China, 360 in Europe and 660 in the United States (IEA, 2018a). Much individual travel demand is currently satisfied by two/three-wheelers, where ownership levels are well above the world average. The room for further growth in demand is huge: the average per capita distance travelled by privately owned cars or two/three-wheelers in India is about 3 kilometres per day, compared to 17.5 kilometres per day in Europe.

The government of India has launched a number of initiatives in recent years to foster the development of rail (Table 4.2). These target the expansion of railway infrastructure and the rationalisation of existing routes, with a particular focus on coal haulage. The overall context is a strong focus on enhancing overall mobility across all modes of transport, through improved infrastructure. For example, the Ministry of Road Transport and Highways (MoRTH) recently announced an initiative to address the bottlenecks within road transport in order to facilitate growth, fostering enhanced regional and intermodal connectivity, entailing projects that will create an additional 8 300 kilometres of highways, making the process for land acquisition and compensation easier and introducing electronic toll collection (MoRTH, 2018). For aviation, the UDAN Regional Connectivity Scheme, released in 2016, was designed to promote affordable flying by regulating maximum fares (per hour of travel and per distance) and by simplifying the regulations for companies that wish to operate international routes (Ministry of Civil Aviation, 2018; The TIMES of India, 2018).

**Table 4.2 Key targets and announced rail development policies in India**

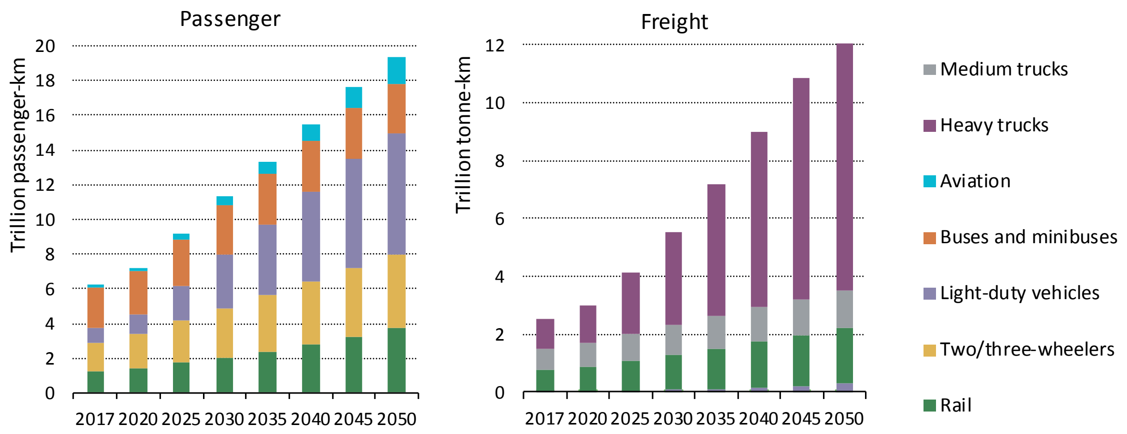
| Policy/target name | Description | Source |
|---|---|---|
| **Network expansion** | Doubling or tripling of existing over-utilised lines. | NTDPC, (2014) |
| **Advanced rail signalling system** | Progressive adoption of advanced signalling to increase efficiency and enhance safety. | Indian Railways (2018b) |
| **Rail share in freight** | Goal set: 45% rail share in inter-regional freight transport by 2032. | NTDPC (2014) |
| **Coal linkage rationalisation** | One-time effort promoted by the Ministry of Coal and Ministry of Power, together with the Ministry of Railways, to rationalise existing coal linkages. | Ministry of Coal (2014 and 2018), (Ministry of Coal, 2018) |
| **Scheme for harnessing and allocating koyala (coal) transparently in India (SHAKTI)** | Optimise utilisation of railway lines for coal linkages to the power sector. | Ministry of Coal (2017) |
| **Liberalised rail haulage of containers** | The market for containers shipped by rail is open to the private sector, in order to foster competition and increase container traffic by rail. | Planning Commission (2013) |
| **DFC completion** | Eastern and Western DFCs operative in 2020. | DFCCIL (2018) |

| Policy/target name | Description | Source |
|---|---|---|
| **Mission Raftaar** | Announced in 2017, this policy aims to double the average speed of freight trains and to increase the speed of intercity trains by 25 kilometres per hour in the next five years. | MoR (2018) |
| **Schemes to improve the financing of rail freight** | Examples are the Automobile Freight Train Operator Scheme, Special Freight Train Operator Scheme, Smart Freight Operation Optimisation & Real Time Information. | Indian Railways (2018b) |
| **Metro Rail Policy 2017** | Cities with a population larger than two million are encouraged to plan mass transit systems. | MoHUA (2017) |
| **Metro systems development** | In addition to the existing 515 kilometres of metro lines, complete the construction of an additional 620 kilometres of lines. Progress the planning of a further 600 kilometres. | Sinha (2018a) |
| **MAHSR completion** | The high-speed rail corridor between Mumbai and Ahmedabad is under construction, with a target date for first operation in 2023. | NHSRCL (2017) |
| **Electrification** | IR's electrification target is to have 90% of broad gauge rail electrified by 2021 and a proposal to electrify 100% of the broad gauge network by 2022 has been approved. | Indian Railways (2016); Singh (2018) |

## *Trends in the Base Scenario*

In the Base Scenario,[21] total passenger transport activity increases by about 210% through 2050, reaching around 19 trillion passenger-kilometres (from 6.2 trillion in 2017). This growth is mainly satisfied by cars; as in other rapidly growing countries, rising incomes and demand for individual motorisation mean that passenger car ownership grows fast in India, to just above 200 cars per 1 000 inhabitants by 2050. Rail passenger transport reaches about 3.7 trillion passenger-kilometres in 2050 (a 200% increase over 2017), broadly maintaining today's level of rail share in passenger transport (Figure 4.8).

**Figure 4.8 Passenger and freight transport activity by mode in India in the Base Scenario, 2017-50**




Note: Passenger rail activity includes conventional rail, metro and high-speed rail.
Source: IEA (2018a).

**Key message • In the Base Scenario, passenger transport activity exceeds 19 trillion passenger-kilometres and freight transport activity attains 12 trillion tonne-kilometres in 2050. Rail passenger activity increases by 200% and freight by 160% in the period to 2050.**

[21] See Chapter 2 for details of the Base Scenario.

India's freight activity across all modes expands even more than passenger transport in the Base Scenario. Between 2017 and 2050, total tonne-kilometres increase almost fourfold, reaching about 12 trillion tonne-kilometres by 2050 (excluding shipping). Freight rail activity increases by around 160%, a lower rate than other modes, such as heavy trucks, in particular. Rail retains its predominant role as a carrier of bulk materials. But strong growth of non-bulk materials, usually carried by road freight trucks, means that the overall share of rail freight in delivery of goods and materials is under pressure from other modes. Overall, both passenger and freight rail activity in India grows much more quickly than in other countries.

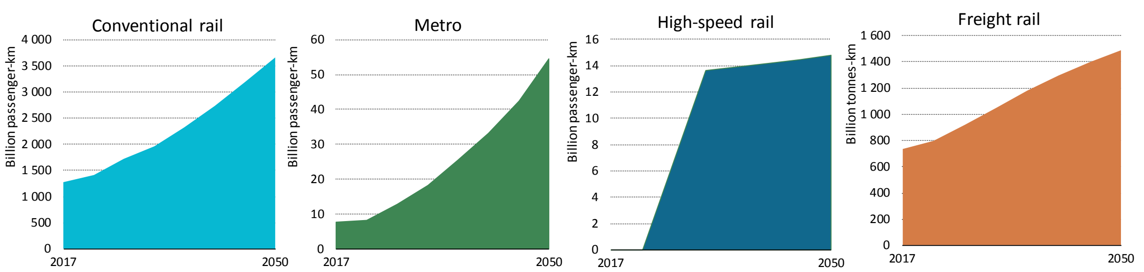


## Passenger rail

Passenger rail in India is under competitive pressure from other modes of transport, road transport in particular, but also aviation. In the Base Scenario, the existing policy emphasis on improving the road network alleviates some of the most pressing problems of quality and congestion, improving the attractiveness of road transport and rapidly pushing up car ownership. Similarly, air travel is boosted and passenger-kilometres travelled by air increase eightfold over today's level, to about 1.5 trillion passenger-kilometre by 2050. While the other transport modes grow faster than rail, the growth of passenger rail in the Base Scenario is nonetheless impressive (Figure 4.9), building on several key projects currently underway.

For *urban rail*, the completion of metro projects currently under construction adds 620 kilometres and planned projects add 600 kilometres by 2030 to the current network of about 500 kilometres of urban rail (Map 4.2). In addition, the Metro Rail Policy approved in 2017 promotes the further deployment of metro systems in other large and densely inhabited cities, achieving a total aggregated track length of 3 600 kilometres by 2050. This boosts urban rail transport and increases related passenger-kilometres by a factor of seven to 2050, from about 8 billion passenger-kilometres in 2017 to about 55 billion by 2050. Despite this dramatic increase, in 2050 urban rail in India provides only a minor share (about 1%) of total urban transport activity in the Base Scenario.

**Figure 4.9 Transport activity by railway mode in the Base Scenario, 2017-50**




Note: The high-speed rail corridor between Mumbai and Ahmedabad comes into operation in 2023 in the Base Scenario.
Source: IEA (2018a).

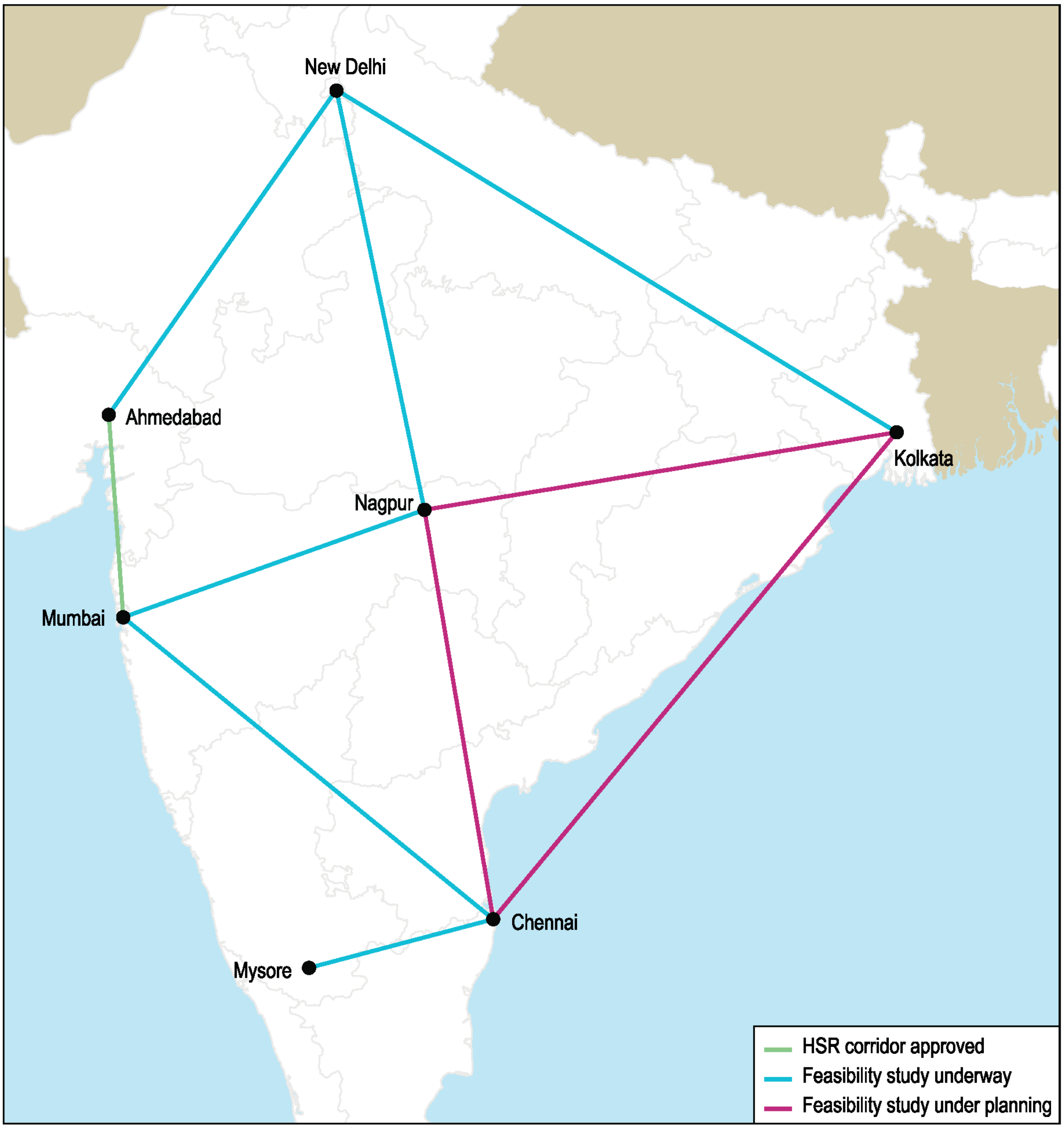
**Key message • Activity on all railway modes grows strongly.**

*Conventional rail* between cities also expands significantly, to about 3.7 trillion passenger-kilometres in 2050, an increase of about 190% over today's level. This growth is attributable to the completion of the Western and Eastern DFCs, the deployment of advanced signalling systems and incremental capacity expansion in general. Together, these measures relieve the congestion on the existing network, facilitating the increase of traffic volumes of intercity trains on the more heavily utilised routes, at higher speeds and with improved time-keeping.



**Map 4.3** **High-speed rail corridors being built and those with a feasibility study underway, and where a feasibility study is under consideration**




This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Source: IEA based on Mishra (2018).

**Key message • In the Base Scenario, only the MAHSR line is assumed to be realised.**

*High-speed rail* services are also available to passengers in India in the Base Scenario. Currently, the MAHSR (Mumbai-Ahmedabad high-speed rail) corridor is under construction and another nine high-speed rail corridors along the Golden Quadrilateral and its two diagonals are being evaluated (Map 4.3). Six high-speed rail corridors are undergoing feasibility studies and feasibility studies are planned for three additional high-speed rail corridors (Mishra, 2018).[22] In the Base Scenario, it is assumed that, alone among high-speed rail projects, the MAHSR corridor

[22] While accounting for only 16% of the network, passenger traffic along the Golden Quadrilateral and its diagonals accounts for about 50% the national total (DFCCIL, 2018).

is completed and becomes operational in 2023. On the other hand, the high-speed rail lines along the Golden Quadrilateral and its two diagonals, currently under evaluation, are not realised, against the backdrop of difficulty in acquiring land, struggle to gain public acceptance for high-speed rail projects and increasing competition from aviation.[23] In the Base Scenario, developing the MAHSR corridor alone adds 15 billion passenger-kilometres in 2050.



### Freight rail

Freight rail transport activity increases rapidly in the Base Scenario, up about 160% from today's level to about 1.9 trillion tonne-kilometres in 2050. This mainly reflects the completion of the Western and Eastern DFCs, but also the wider trends in the Base Scenario, which suggest continued growth of coal demand and container transport. The growth of coal use is particularly important, as it is the most significant commodity for freight rail transport in India. Despite a strong policy emphasis on accelerating the use of renewable energies (and solar photovoltaics in particular), rising electricity demand means that coal use for power generation grows by 115% through the end of the projection period, more than doubling overall, relative to the level today (IEA, 2018c). As a result, activity associated with the transport of coal by rail increases from 250 billion tonne-kilometres in 2015 to 580 billion tonne-kilometres in 2050. This steep increase is moderated only by the reduction in the average distance over which coal is transported (as a result of the coal linkage rationalisation and of the SHAKTI policy framework) and by changes in the siting of coal-fired power plants, which are sited closer to the extraction and import areas (Kamboj and Tongia, 2018).[24] The share of coal in overall freight rail activity slightly decreases, from around 40% in 2015 to 30% in 2050, as the need for carrying other commodities (iron and steel in particular, but also stone and mineral oil) increases at faster pace and as the development of the Western DFCs fosters the growth of container transport via rail. The share of freight rail in total freight activity varies across commodities. For commodities that currently rely heavily on rail (e.g. coal, iron and steel, iron ore, cement and stone), rail's share remains constant or even rises; on the other hand, commodities which currently have a low rail share (e.g. food grains and fertilisers) increase road share. Overall, freight rail transport grows significantly in the Base Scenario, as part of overall growth of freight transport to fuel India's rapid economic growth. Freight rail retains its share in carrying bulk materials, but struggles to enter additional markets such as those carrying non-bulk materials. The observed trends place a question mark over the feasibility of continuing the current practice of using revenues from freight rail traffic to subsidise conventional passenger rail movements. Comparing the 2017-50 increase of total freight rail activity (160%) and the rise in activity of intercity trains (200%) indicates that the existing debate about the relative level of freight and passenger fares discussed previously will intensify. Assuming that the sum of revenues from passenger and freight rail, plus the losses from passenger operations in 2015, serves as an indication of revenue needs per passenger-kilometre, the losses incurred by passenger rail operations would grow, amounting to approximately 30% of total revenues by 2050. A further increase of freight fares for coal (or other commodities) could not be counted upon to increase subsidies to passenger rail, as further rail freight tariff increases would reduce the competitiveness of freight rail transport. Moreover, further reduction of the average distance over which coal is carried to power plants (beyond the levels assumed in the Base Scenario) would further cut revenues from freight operations.

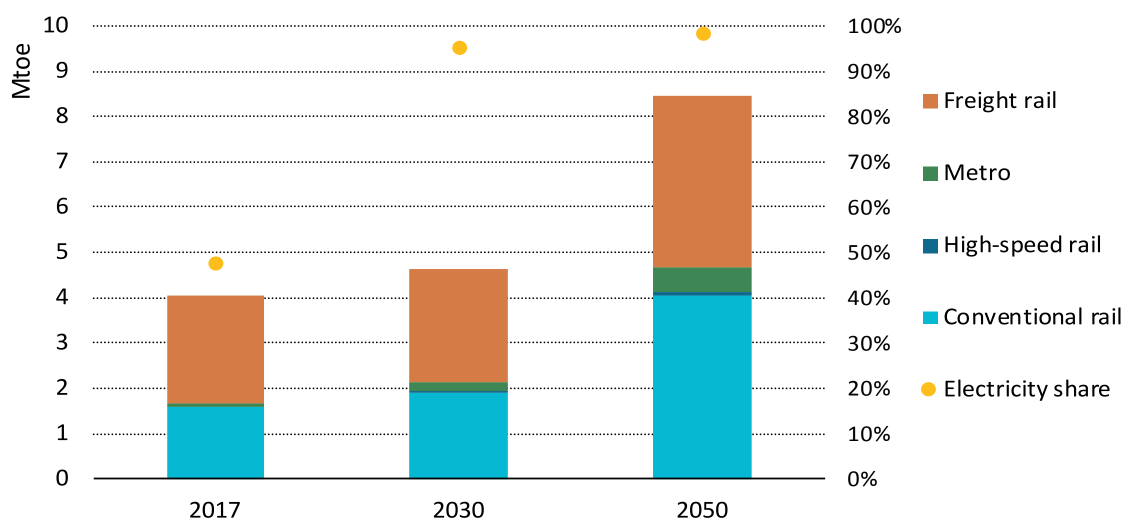
[23] The domestic aviation sector in India grew at a compound annual growth rate of 9.9% between 2007 and 2016 (ICAO, 2018).

[24] The average distance over which coal is transported in the Base Scenario is assumed to decrease by 10% in 2030 relative to the 2017 level and then to remain constant.

## Implications for energy demand

In the Base Scenario, energy demand from rail in India in 2050 is about 110% higher than in 2017. A significant increase is no surprise, given the large growth in rail activity during this period (Figure 4.9). However, the growth in energy demand from rail lags appreciably behind the rate of rail activity growth: the combination of the improved energy efficiency of the trains, network improvements and strong electrification leads to a decrease in the energy intensity of passenger rail. Efforts to increase the electrification of railway lines bear fruit in the Base Scenario, meaning that nearly all rail is electrified by 2050 (Figure 4.10). The share of electricity in the rail fuel mix rises to 95% in 2030 and 98% in 2050 (Box 4.3).[25] By 2050, the railways use almost 100 TWh of electricity, up from 22 TWh today. Oil remains part of the rail fuel mix, but consumption declines from 0.04 million barrels per day (mb/d) in 2017 to 0.003 mb/d in 2050. Actual oil use by rail pales in comparison with the oil product demand that is avoided by the omission of road transport, by 2050 rail transport avoids 1.6 mb/d of oil use, compared with a hypothetical case in which all passenger and freight activity that is transported by rail in the Base Scenario is covered by road transport.[26]

**Figure 4.10** **Energy demand from passenger and freight rail transport in India in the Base Scenario, 2017, 2030 and 2050**




Note: Mtoe = million tonnes of oil equivalent.

Sources: IEA (2018a); Indian Railways (2018b).

**Key message • Total energy demand from railways grows by 110%, and by 2050 electricity accounts for 98% of that energy demand.**

[25] This result is in line with the electrification target described in Table 4.2. The lower share of electricity in energy demand than in rail activity is explained by the higher specific energy consumption of diesel trains compared with electric trains.

[26] This result is obtained on the assumption that passenger rail would be replaced by aviation, cars, buses and two/three-wheelers, that freight rail would be replaced by heavy freight trucks and that all the energy demand is oil. The weighted average fuel economy of passenger transport in India in 2050 is about 11 tonnes of oil equivalent (toe) per million passenger-kilometres and that for freight trucks is 21 toe/million tonne-kilometre (IEA, 2018a).

**Box 4.3 Plans for the continued electrification of the conventional rail network in India**

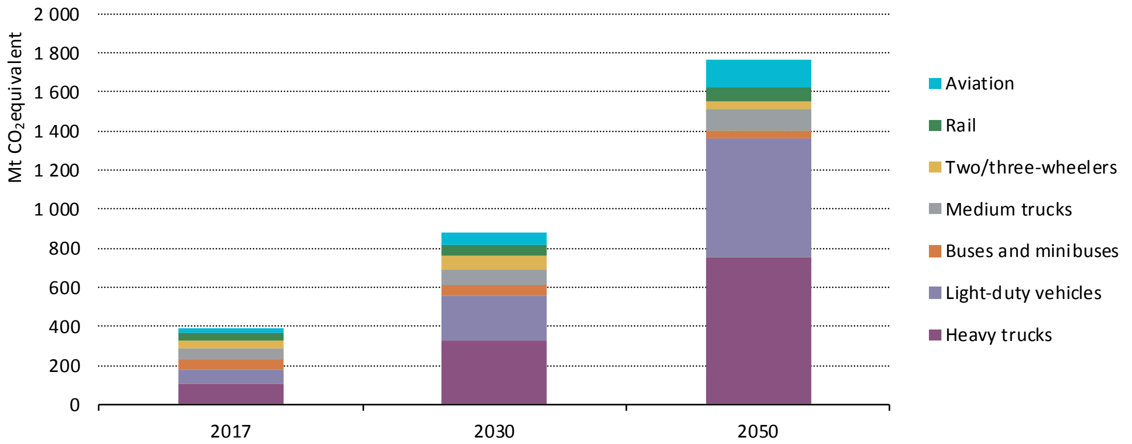
In the wake of investments in network electrification over the past decades, India is aiming at fulfilling the "Mission Electrification" programme. To meet its ambitious electrification targets, Indian Railways set a plan to accelerate the pace of electrification from 2 000 kilometres per year in 2016 to 4 000 kilometres per year in 2017 and increasing to 6 200 kilometres per year in 2019 (Indian Railways, 2016).[27] So far Indian Railways has met these targets, with a commensurate increase in the budget outlay towards traction electrification (Ramji, Nagbhushan and Bharadwaj, 2017). The goal of achieving nearly 100% electrification will require resolute budgetary support over the next decade.



## Implications for GHG and local pollutant emissions

The rapid growth in transport activity and energy use means that well-to-wheel GHG emissions attributable to the entire transport sector in India grow rapidly in the Base Scenario (Figure 4.11). Emissions increase to 1 750 Mt $CO_2$-eqby 2050, approximately a 350% increase over 2017. The largest contributions to GHG emissions growth (both in relative and absolute terms) comes from cars and aviation for passenger transport and from heavy-duty trucks for freight transport.

**Figure 4.11 Well-to-wheel GHG emissions from India's transport sector in the Base Scenario, 2017, 2030 and 2050**




Notes: Emissions related to shipping activities are not included. Emissions from rail include emissions from conventional rail (both passenger and freight), metro and high-speed rail.

Sources: IEA (2018).

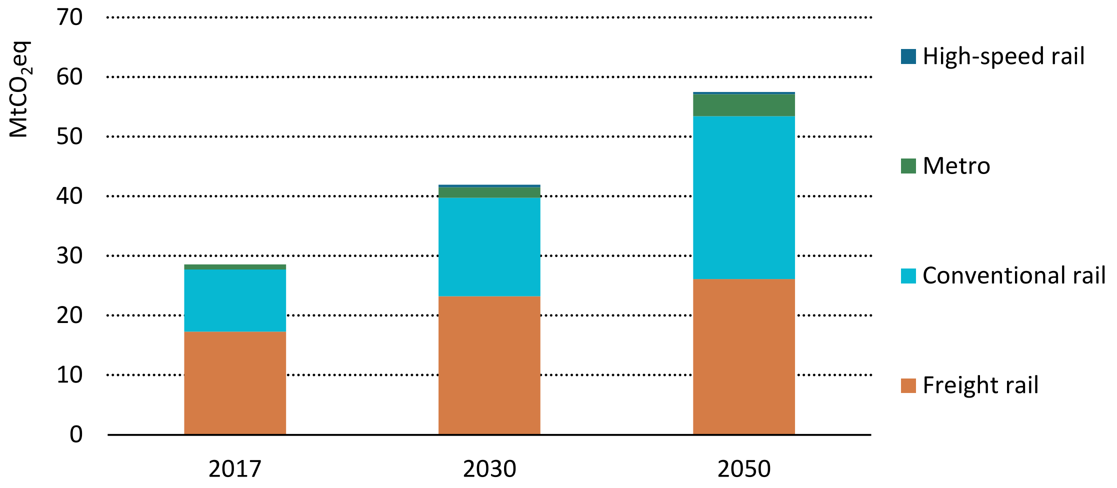
**Key message • Transport-related GHG emissions increase by 350% in period to 2050.**

Well-to-wheel GHG emissions from rail, in the Base Scenario steadily increase to reach 57 Mt $CO_2$-eq in 2050 (Figure 4.12). The well-to-wheel GHG emissions from rail are primarily indirect arising from the power sector – as electrification of the railways increases, so does the weight of power sector emissions in overall rail emissions. Nonetheless, the contribution of railways to transport-related GHG emissions remains low, even on a well-to-wheel basis; by 2050 rail transport contributes to only 2% of overall transport-related GHG emissions, a much smaller than its contribution to overall transport activity. The emissions intensity of rail transport remains lower than for all other motorised modes, saving about 270 Mt of $CO_2$-eq

[27] The 90% electrification target aims at cutting Indian Railway's fuel bill by 40%, from USD 3.6 to 2.2 billion (INR 265 billion to INR 160 billion) per year (Indian Railways, 2016).

emissions in 2050 as compared to a situation in which all rail activity was transferred to road transport.[28] In 2050, rail also avoids 8 kt of $PM_{2.5}$ emissions as compared to a situation in which all rail transport were by road transport.[29]

**Figure 4.12 Well-to-wheel GHG emissions from India's rail sector in the Base Scenario, 2017, 2030 and 2050**




Source: IEA (2018a).

**Key message • Annual well-to-wheel GHG emissions from rail are projected at more than 57 Mt $CO_2$-eq in 2050.**

## *Outlook for rail in the High Rail Scenario*

India's strong economic growth and rising energy demand in the Base Scenario present a number of wider energy challenges. Total oil demand more than doubles over the next decades as incomes grow and demand for passenger and freight activity rises; transport contributes around 60% to the overall increase in oil demand (IEA, 2018c). These figures have important energy policy implications: India's oil imports almost triple over the period, despite strong growth in the uptake of electric cars (which account for over 20% of the passenger car stock by 2050 in the Base Scenario) and regulatory efforts to reduce the average fuel consumption of cars and trucks. The environmental toll of transport activity also rises. Besides the growth in GHG emissions, transport also remains an important source of $PM_{2.5}$, nitrogen oxide ($NO_X$) and sulphur dioxide ($SO_2$) emissions through 2050, even with the successful implementation of Bharat VI standards, which alleviate much of the pollutant emissions in the Base Scenario. These challenges can be addressed by strengthening rail transport. In the following section, the High Rail Scenario (detailed in Chapter 3) is used to explore the potential benefits of such a transition to an increased reliance on rail in India. It considers what kind of changes would need to occur

[28] This result is obtained on the assumption that passenger rail would be replaced by aviation, cars, buses and two/three-wheelers, that freight rail would be replaced by heavy freight trucks. The weighted average WTW GHG emission factor of road transport in India in 2050 is 0.05 Mt $CO_2$-equivalent/billion passenger-kilometre. The WTW GHG emission factor of heavy freight trucks in India in 2050 is 0.09 Mt $CO_2$-equivalent/billion tonne-kilometre (IEA, 2018a).

[29] This result is obtained on the hypothesis that the activity of passenger rail in 2050 is replaced by passenger light-duty vehicles, two/three-wheelers and buses, each maintaining its modal share, that the activity of freight rail is replaced by heavy freight trucks and using calculated pollutant emission factors for the different modes (IEA, 2016).

in each rail sector and illustrates what impact these could have on key indicators. In addition, it discusses the kinds of policy measures that would be necessary to take the country along this path.

### *Key assumptions*



For India, the High Rail Scenario involves a significant shift of passenger and freight transport from road and aviation to rail. This shift is facilitated by action conducive to rail infrastructure investment across all types of rail, improvements in the attractiveness of passenger rail services, in particular, and action to increase the competitiveness of rail passenger and freight transport.

For *urban rail*, the High Rail Scenario assumes that India completes all the metro projects currently under construction and being planned (as in the Base Scenario), and it also fulfils the Union Internationale de Transports Publics (UITP) target of doubling the modal share of urban rail at the expense of private modes of transport (UITP, 2014). The attractiveness of metro travel and, hence, utilisation is increased by generating additional non-tariff revenues in order to keep travel fares low. Capturing land value around the metro stations and developing and taxing commercial activities in the stations are key features (Sharma and Newman, 2017). Beyond the realm of the railway authorities (but of the utmost importance), road vehicle charges and taxes on private vehicles levied based on their environmental performance strengthen the economic competitiveness of rail services.

For *conventional rail*, limited network capacity is a significant limiting factor on the expansion of the rail business in the Base Scenario (Planning Commission, 2014), so facilitating further network extension is a key assumption in the High Rail Scenario. Action to generate additional sources of revenues, while increasing the attractiveness of passenger services, is another key assumption, making it possible to reduce the dependency of passenger rail services on cross-subsidisation from freight rail. The main pillars of action in the High Rail Scenario are:

- Improving the balance of operational costs and revenues by diversifying the offer of intercity rail services (such as offering overnight connections), through increased utilisation and thereby increasing the competitiveness of rail against car travel and aviation for long-distance trips as a result of achieving higher utilisation rates.
- Differentiated tariffs and services, accounting for the prices of competing modes at different times of the day and for the origin and the destination of trips.
- The increase of non-tariff revenue from rail stations and neighbouring areas through real estate development and land value capture, both for new stations (which should be large enough to be able to host commercial activities) and existing stations (through refurbishment/ renovation).[30]

As in the case of metros, road vehicle charges and taxes levied on private vehicles, based on their environmental performance, also strengthen the economic viability of rail investments.

For *high-speed rail*, this scenario assumes that the success of the MAHSR project (which is also assumed in the Base Scenario) is followed by development of the other high-speed rail lines currently under evaluation, which are the linkages along the Golden Quadrilateral and its two diagonals (Map 4.3). In the High Rail Scenario, policy measures, such as integrating planning of

[30] Capturing non-tariff revenue from rail stations is a well-established practice in Japan and other countries. It requires developing commercial and tertiary real estate, taking advantages of the high volumes of people traffic around train stations that raise land value. Although a Rail Land Development Authority in India is tasked to develop land commercially, this aspect of non-tariff revenue earning is currently largely untapped.

high-speed rail with conventional and urban rail, real estate developments and land value capture, help to facilitate the realisation of this high-speed rail infrastructure. The introduction of carbon taxes for jet fuel also support cross-modal subsidisation and improve the competitiveness of high-speed rail *vis-à-vis* aviation.

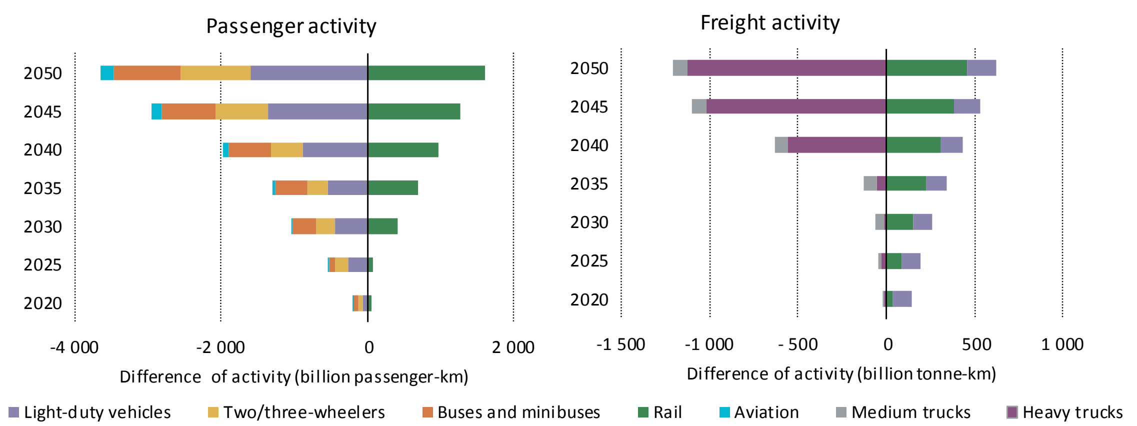


For *freight rail*, the High Rail Scenario includes three measures to support the further growth of rail-based freight transport. First, measures are taken to improve track utilisation and reduce freight fares. All the DFCs along the Golden Quadrilateral are developed to increase the share of rail transport in bulk commodity transport (e.g. iron and steel, iron ore, cement). Second, the commodity basket moved by rail is enlarged and the non-bulk commodity market is accessed (e.g. fertilisers, oil and lubricants, and agro-products), in line with the recommendation by the Planning Commission (Planning Commission, 2014). Third, rail captures a larger share of containers and other fixed, medium-sized (i.e. pallet) shipments. This is achieved by increasing the flexibility of rail through the provision of end-to-end logistics solutions to customers, facilitated by the development of logistic centres in strategic areas close to consumption centres, by digitalisation (e.g. traceability of parcels) and by treating the supply chain (and rail's part in it) holistically, exploiting co-modality opportunities.[31]

## *Trends in the High Rail Scenario*

### Passenger and freight rail activity

**Figure 4.13 Change in transport activity by mode in the High Rail Scenario relative to the Base Scenario in India, 2020-50**




Notes: A positive number indicates that the activity in the High Rail Scenario increases relative to the Base Scenario, a negative number indicates that the activity decreases. Passenger rail activity includes conventional, metro and high-speed rail.

Source: IEA (2018a).

Key message • **In the High Rail Scenario, a modal shift to rail occurs in passenger transport, mainly away from cars, and in freight transport away from heavy trucks.**

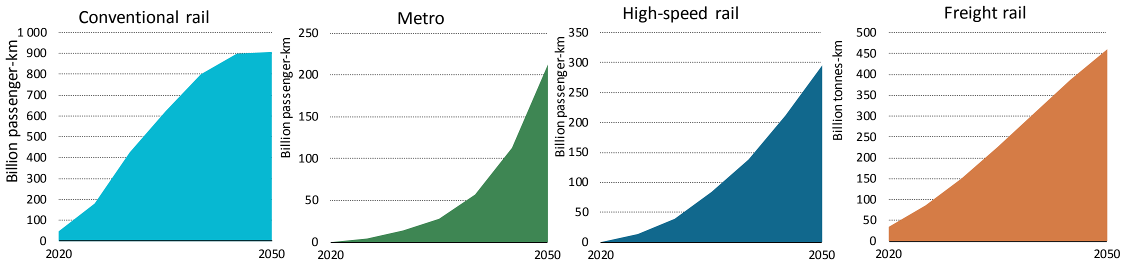
In the High Rail Scenario, rail passenger activity climbs to about 5.1 trillion passenger-kilometres in 2050, an almost 310% increase with respect to 2017 and about 40% above the level of the Base Scenario. The improved competitiveness and attractiveness of passenger rail mainly comes at the expense of passenger activity from cars, but also from aviation and two/ three-wheelers

[31] Currently, for small size shipments (even if travelling for long distances) transport by truck is often the only practicable option, due to minimum size of required wagon loads to make use of Indian Railway's freight service. This results in long waiting times to aggregate several small parcels into a minimum size load.

(Figure 4.13). In the freight sector, rail activity reaches approximately 2.4 trillion tonne-kilometres in 2050, increasing about 220% with respect to 2017 and 25% compared with the Base Scenario in 2050.

**Figure 4.14 Change in transport activity by rail sector in the High Rail Scenario relative to the Base Scenario, 2020-50**






Source: IEA (2018a).

**Key message • Transport activity in India increases in every rail sector in the High Rail Scenario.**

Rail activity in the High Rail Scenario increases for every rail sector (Figure 4.14).

*Urban rail* grows to around 270 billion passenger-kilometres in 2050, more than 33-times higher than in 2017 and almost four-times as much as in the Base Scenario. Urban rail track utilisation (in terms of vehicles per track-kilometre) increases thanks to the deployment of digital technologies that improve the management of the metro system and through improved interconnections between metro lines.

*Conventional rail* activity in the High Rail Scenario increases at a faster rate than in the Base Scenario, to reach around 4.6 trillion passenger-kilometres in 2050, approximately 265% over the level of 2017 and an increase of 25% over the level in the Base Scenario. The growth reflects Indian Railways' improved ability to respond to the expanding transport demand, offering improved service quality. Increased investment enables additional tracks to be built along high-density routes as well as the development of new lines. The realisation of the DFCs and the deployment of modern signalling systems further increase capacity, as they make possible higher frequencies and operational speeds, thereby reducing travel time. Investment in new rolling stock also expands train capacity. To accommodate the increased flow of passengers, the capacity of stations also increases in the High Rail Scenario.

Developing the corridors along the Golden Quadrilateral and its two diagonals brings *high-speed rail* activity in India in the High Rail Scenario to 310 billion passenger-kilometres in 2050, 20-times higher than in the Base Scenario.[32] Global analysis of the viability of shifts from aviation to high-speed rail (discussed in the high-speed rail section of Chapter 3) suggests that, in the High Rail Scenario, the high-speed rail corridors between the four cities of the Golden Quadrilateral will be built, even where a direct high-speed rail connection between the cities does not reduce travel time, compared to travel by airplane. This is the situation in the high-speed rail corridors between Chennai and Kolkata, Delhi and Kolkata and Chennai and Mumbai. However, the majority of high-speed rail corridors currently under assessment also benefit from deploying intermediate stations. For instance, the cumulative time savings of the high-speed rail corridor between Chennai and Mumbai are higher with the intermediate cities of

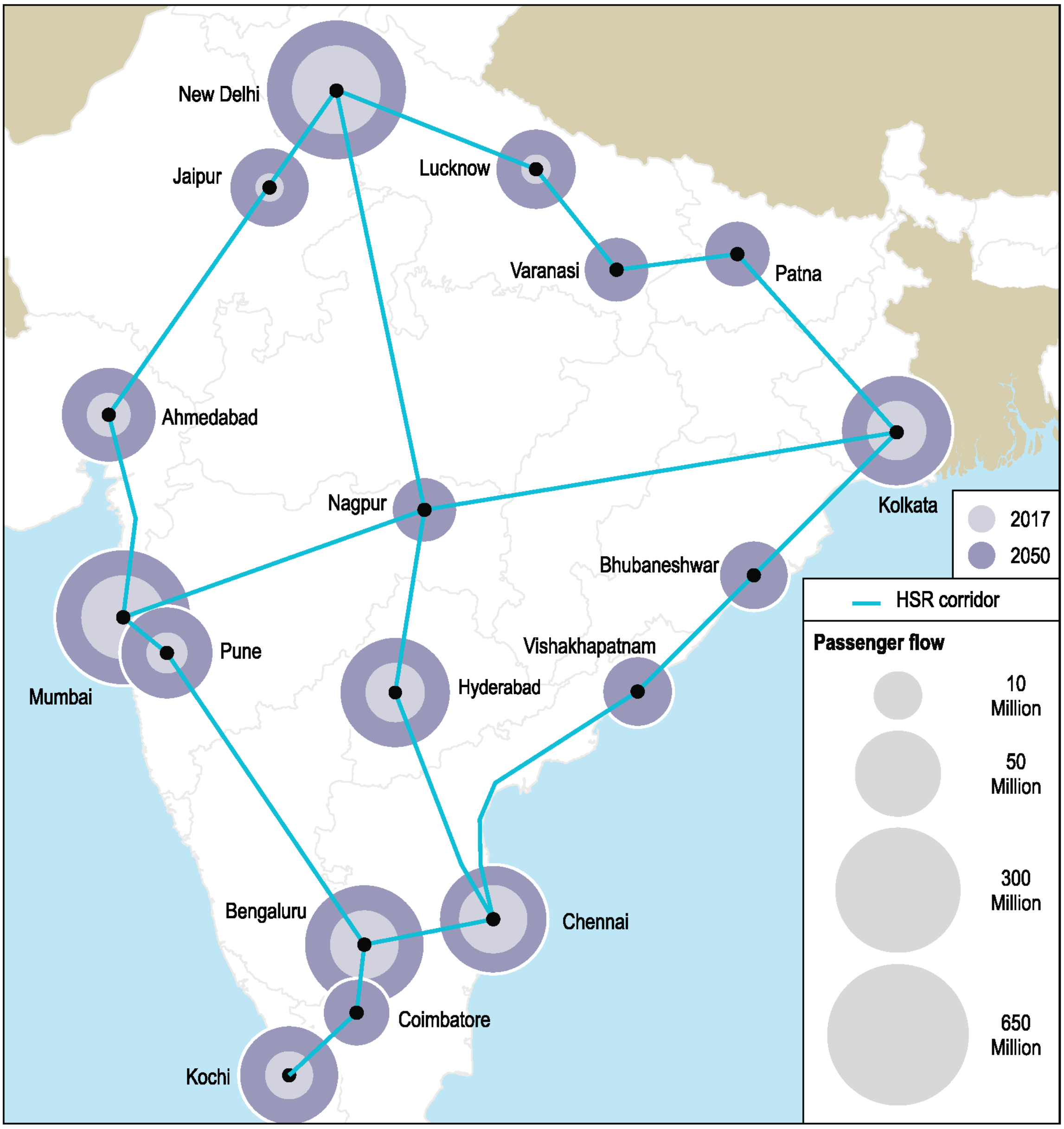
[32] The realisation of the high-speed rail corridors envisioned in the High Rail Scenario could induce additional mobility demand, possibly leading to higher growth of transport activity. However, such induced demand has not been included in the analysis.

Bengaluru and Pune also connected. Similarly, the high-speed rail corridor connecting Delhi and Kolkata benefits from a stop in Lucknow. A high-speed rail connection between these cities provides a fast alternative to air travel and generates significant passenger volumes, as the airports serving these cities currently have high passenger flows.[33]



**Map 4.4 High-speed rail network in India in the High Rail Scenario**




This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Note: HSR = high-speed rail.

Source: IEA based on OAG (2018).

**Key message • All high-speed rail corridors envisioned by the government are progressively realised in this scenario.**

[33] In 2017, the airports of Chennai, Mumbai, Delhi, Kolkata, Bengaluru and Pune each had a passenger count above 6 million per year and Lucknow above 3 million per year.

Other potential high-speed rail corridors currently have too low a passenger flow to justify a high-speed rail line, although the economic case is likely to improve as passenger flows between end and intermediate cities increase with rising incomes. The result is that the high-speed rail network in the High Rail Scenario is developed in multiple stages (Map 4.4). For example, the direct connection in the high-speed rail corridor between Chennai and Kolkata currently does not generate time savings, compared with aviation, and the possible intermediate stations, Bhubaneswar and Visakhatpnam, do not have sufficient passenger flows yet to justify the project.[34] However, thanks to population and income growth, such intermediate stations see an increase in passenger volumes by 2050 of an order of magnitude (about 25 million passengers per year), thus making the high-speed rail projects feasible. This is also the case for the high-speed rail lines along the diagonals of the Golden Quadrilateral. While in 2017 the passenger flows through Nagpur were lower than 2 million, the 20 million expected in 2050 makes all these four corridors economically feasible.

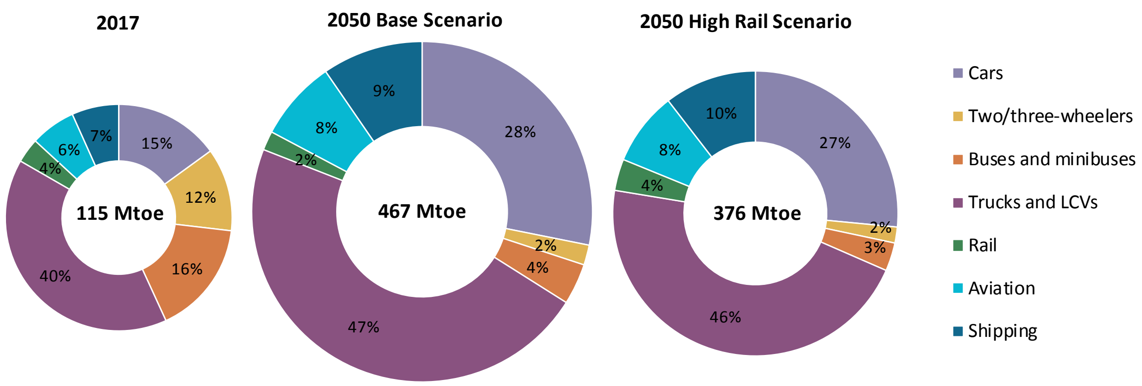


*Freight rail* activity in the High Rail Scenario increases 220% over 2017 levels, to reach approximately 2.4 trillion tonne-kilometres in 2050. This level of activity is about 25% higher than in the Base Scenario. In the High Rail Scenario, reductions in freight rail tariffs limit the income from the 220% increase in freight rail activity over 2017 levels, and so the scope to cross-subsidise intercity rail. Enhancing the role of passenger and freight rail further thereby reinforces the need, already evident in the Base Scenario, for structural solutions to raise additional revenues from passenger rail.

### Implications for energy demand

The aggregated impact of all the changes in the High Rail Scenario is that energy demand from the transport sector as a whole is reduced in 2050 by about 91 Mtoe (or 20%), relative to the Base Scenario (Figure 4.15). The reduction is mainly a result of the shift from private motorised transport and aviation to less energy-intensive railways.

**Figure 4.15 Total transport energy demand in India by mode by scenario, 2017 and 2050**



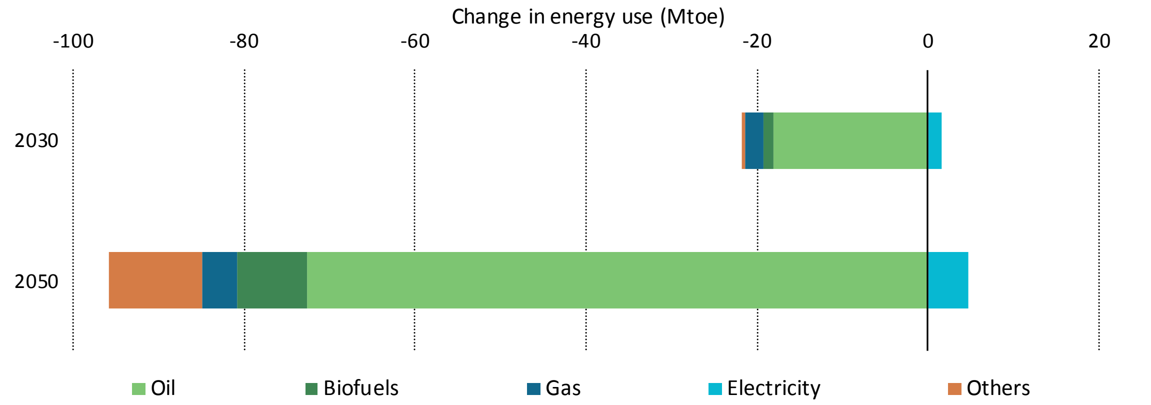

Notes: LCV = light commercial vehicle. Energy demand from rail includes conventional rail (both passenger and freight), metro and high-speed rail.

Source: IEA (2018a).

**Key message • Total energy demand from the transport sector in the High Rail Scenario grows less than in the Base Scenario; the share of energy demand from rail is higher.**

[34] The flow of passengers through the airports of Bhubaneswar and Visakhatpnam is currently below 2 million.

**Figure 4.16 Change in energy demand in transport by fuel in the High Rail Scenario relative to the Base Scenario, 2030 and 2050**




Note: A positive number indicates that energy demand in the High Rail Scenario increases relative to the Base Scenario, a negative number indicates that energy demand decreases.

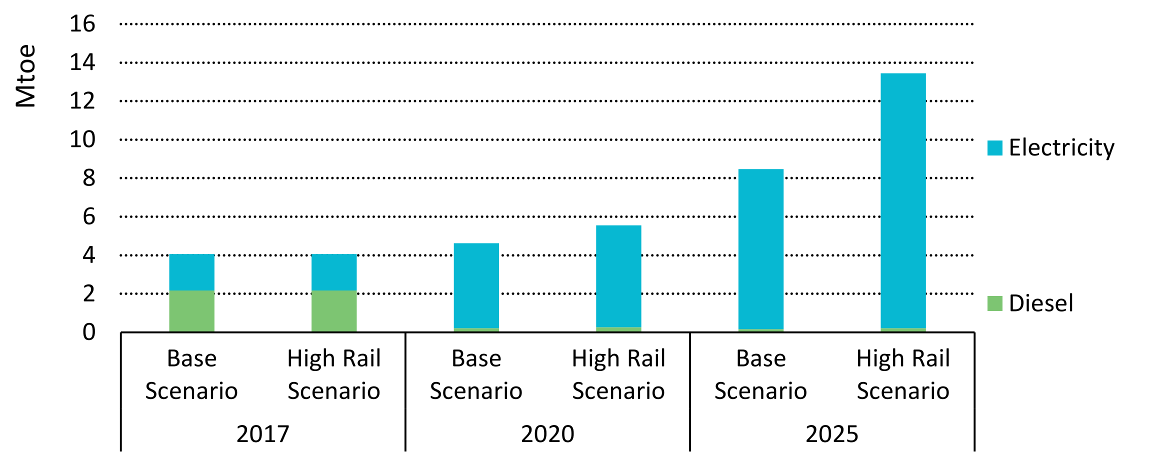
Source: IEA (2018a).

**Key message • The High Rail Scenario reduces oil demand, relative to the Base Scenario, by switching traffic to less energy intensive modes.**

The majority of the net decline in energy use in the High Rail Scenario consists of lower fossil fuel use (primarily diesel), which is only partly offset by growth in electricity use (Figure 4.16). By 2050, the total decline in the demand for oil products in India is about 1.5 mb/d, relative to the Base Scenario. The increase in electricity use is around 55 TWh.

The share of energy demand from rail in overall transport energy demand in the High Rail Scenario is higher than in the Base Scenario, reflecting the modal shift to rail. In 2050, energy demand from rail in the High Rail Scenario is about 60% higher than in the Base Scenario (Figure 4.17). This is the result of faster activity growth, but also success in efforts to electrify railways to which the traffic is directed. In the High Rail Scenario, the share of electricity in total fuel demand reaches 98% in 2050.

**Figure 4.17 Energy demand from railways in India by scenario, 2017, 2030 and 2050**




Note: The figure illustrates energy demand from conventional rail (both passenger and freight), metro and high-speed rail.

Source: IEA (2018a).

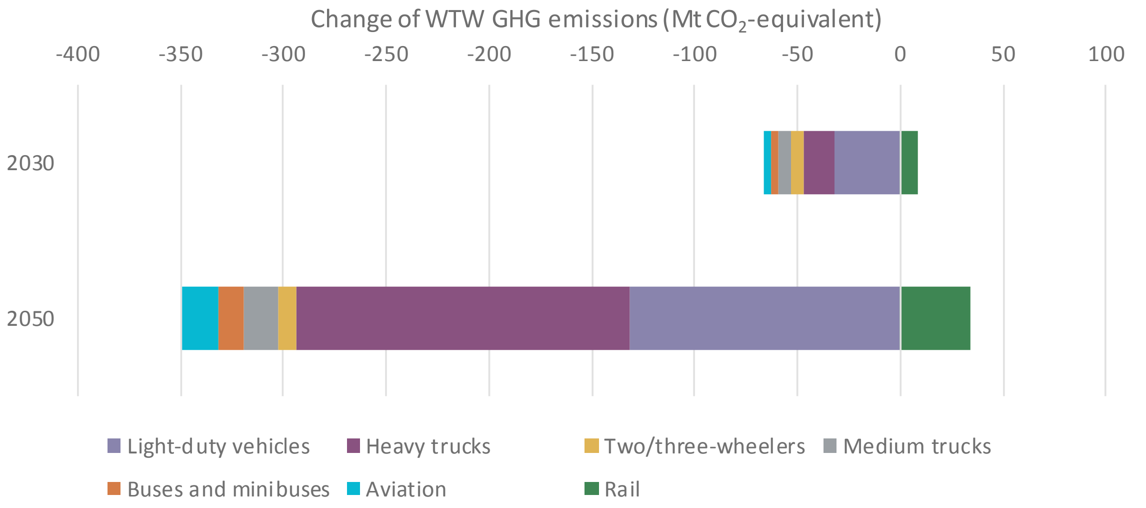
**Key message • Energy demand from rail is higher in the High Rail Scenario.**

### Implications for GHG and local pollutant emissions

Following the significant increase in transport activity, total well-to-wheel GHG emissions from India's transport sector as a whole increase steadily in the High Rail Scenario, reaching about 1.4 Gt $CO_2$-eq in 2050, which marks approximately a 270% increase over 2017. Despite this, GHG emissions are 18% lower (or 315 Mt $CO_2$-eq) in 2050 than in the Base Scenario. This takes place because the additional emissions from rail more than offset the decline in emissions from the other modes. In 2050, the increase in GHG emissions from rail is 34 Mt $CO_2$-eq. This is more than offset by reductions in light-duty vehicles (130 Mt $CO_2$-eq) and trucks (180 Mt $CO_2$-eq) (Figure 4.18). Action to cut emissions yet further is available across all transport modes, including increasing energy efficiency, scaling up low-emission technologies and measures to reduce road activity, but detailed analysis of such measure is beyond the scope of this report.

On the assumptions adopted about the pace of power sector decarbonisation, well-to-wheel GHG emissions from rail transport in the High Rail Scenario increase at a rate proportional to the increase of rail activity, from about 29 Mt $CO_2$-eq in 2017 to 91 Mt $CO_2$-eq in 2050, 34 Mt $CO_2$-eq higher than in the Base Scenario (Figure 4.19). This level could be reduced. If the power sector were fully decarbonised by 2050, then switching to rail would be a zero-carbon transport option. The High Rail Scenario also achieves a further reduction of 6 kt, in $PM_{2.5}$ emissions compared with the Base Scenario.

**Figure 4.18 Well-to-wheel GHG emissions savings in India's transport sector in the High Rail Scenario relative to the Base Scenario, 2030 and 2050**




Notes: Emissions related to shipping activities are not included. Emissions from rail include emissions from conventional rail (both passenger and freight), metro and high-speed rail. A positive number indicates that the WTW GHG emissions in the High Rail Scenario increase with respect to the Base Scenario, a negative number indicates that the emissions decrease.

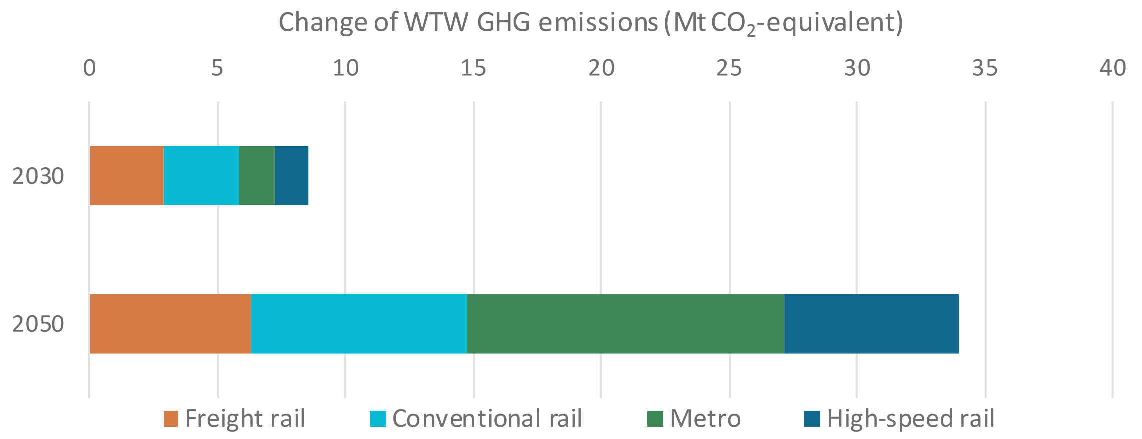
Source: IEA (2018a).

**Key message • GHG emissions from transport are 315 Mt $CO_2$-eq lower in the High Rail Scenario by 2050.**



**Figure 4.19 Increase in well-to-wheel GHG emissions from India's railways by mode in the High Rail Scenario relative to the Base Scenario, 2015-2050**




Notes: Emissions from rail include emissions from conventional rail (both passenger and freight), metro and high-speed rail. A positive number indicates that the WTW GHG emissions in the High Rail Scenario increase with respect to the Base Scenario, a negative number indicates that the emissions decrease.

Source: IEA (2018a).

**Key message • With the increase in rail activity in the High Rail Scenario, well-to-wheel GHG emissions from rail rise, particularly for metro rail.**

## Conclusions

Rail has a long history in India, and it is as important as ever as a lifeline of the nation. The latent demand for mobility in India is huge: in a country where the average per capita provision of travel by motorised modes of transport is, on average, only around one-sixth the rate in Europe, demand for mobility will boom and satisfying it in an affordable, secure and sustainable manner is essential. Similarly, strong economic growth of India will further increase freight activity, imposing similar challenges.

India's government has measures in hand to address these issues, ranging from efficiency and air pollution standards for cars and trucks to measures to promote road vehicle electrification and important infrastructure development projects. Rail has an important role to play in this effort, satisfying both transport and energy policy objectives. It is efficient and thereby enhances energy security; and it is cleaner than other transport alternatives, even in a power mix that is currently dominated by coal, so shifts in mobility lead to reductions in both local air pollutant and GHG emissions.

But there is no guarantee that rail will play the role in the long-run that our scenarios suggest. The challenges that need to be overcome are numerous and varied. They include, but are not limited to:

- Mobilising investment.
- Overcoming infrastructure bottlenecks.
- Maintaining the affordability of passenger rail while modernising and improving passenger rail services and safety.
- Enhancing the competitiveness of freight rail.
- Integrating rail into the overall transport strategy.

Generating revenue from innovative sources to improve rail services while boosting the competitiveness of freight rail and maintaining the affordability of passenger rail is a critical element for the future of rail in India. However, there are numerous opportunities that span well beyond tariff-pricing, and the more rail transport can be thought of as providing a unique service within the wider context of multi-modal passenger and freight mobility, the more opportunities there are. High-speed rail can play an important role in India; our analysis suggests many of the routes under consideration can be competitive, depending, in some cases, on the availability of intermediate stops. Realising the case for high-speed rail will, however, require careful communication with all the relevant stakeholders. Overall, the opportunity for rail to increase its role in transport in India is large. Making use of it is a long, but promising, journey.



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# Acronyms, abbreviations and units of measure

## Acronyms and abbreviations



| | |
|---|---|
| ASEAN | Association of Southeast Asian Nations |
| BRT | Bus rapid transit systems |
| DB | Deutsche Bahn |
| CO | Carbon monoxide |
| DFC | Dedicated freight corridor |
| DFCCIL | Dedicated Freight Corridor Corporation of India Limited |
| DEMU | Diesel-electric multiple unit |
| EMU | Electric multiple unit |
| ERTMS | European Railway Traffic Management System |
| ERS | High Rail Scenario |
| EU | European Union |
| FS | Ferrovie dello Stato |
| GDP | Gross domestic product |
| GHG | Greenhouse gases |
| GoA | Grades of automation |
| HS | High speed |
| HSR | High-speed rail |
| ICAO | International Civil Aviation Organization |
| ICE | Internal combustion engine |
| IEA | International Energy Agency |
| IIASA | International Institute for Applied Systems Analysis |
| IMO | International Maritime Organization |
| INR | Indian rupee |
| ITDP | Institute of Transportation and Development Policy |
| JICA | Japan International Cooperation Agency |
| LCA | Life-cycle assessment |
| MaaS | Mobility as a service |
| MAHSR | Mumbai-Ahmedabad High Speed Rail |

| | |
|---|---|
| MoHUA | Ministry of Housing and Urban Affairs (India) |
| MoRTH | Ministry of Road Transport and Highways (India) |
| MoMo | Mobility model (IEA) |
| MoR | Ministry of Railways (India) |
| NDC | Nationally Determined Contributions |
| NHSRCL | National High Speed Rail Corporation Limited (India) |
| $NO_x$ | Nitrogen oxides |
| O&M | Operation and maintenance |
| OECD | Organisation for Economic Co-operation and Development |
| PM | Particulate matter |
| PPP | Purchasing power parity |
| PV | Photovoltaic |
| REC | Renewable energy certificates |
| SHAKTI | Scheme for Harnessing and Allocating Koyala |
| SNCF | Société Nationale des Chemins de Fer Français |
| SPV | Special purpose vehicles |
| TERI | The Energy and Resource Institute |
| TTW | Tank-to-wheel |
| TPWS | Train Protection Warning Systems |
| TCAS | Train Collision Avoidance Systems |
| TGV | Train Grand Vitesse |
| UIC | International Union of Railways |
| UITP | International Union of Public Transport |
| USD | United States Dollar |
| WHO | World Health Organization |
| WTT | Well-to-tank |
| WTW | Well-to-wheel |

# Units of measure

| | |
|---|---|
| g $CO_2$ | grammes of carbon dioxide |
| g $CO_2$-equivalent | grammes of carbon-dioxide equivalent |
| g $CO_2$/km | grammes of carbon dioxide per kilometre |
| Gt | gigatonne |
| GW | gigawatt |
| GWh | gigawatt-hour |
| kt | kilotonnes |
| kW | kilowatt |
| kWh | kilowatt-hour |
| Lde | Litre diesel equivalent |
| Lge | Litre gasoline equivalent |
| mb/d | million barrels of oil per day |
| Mt | million tonnes |
| Mt $CO_2$-eq | million tonnes of $CO_2$ equivalent |
| Mtoe | million tonnes of oil equivalent |
| MW | megawatt |
| t $CO_2$-eq | tonnes of $CO_2$ equivalent |
| toe | tonne of oil equivalent |
| TWh | terawatt-hour |

# Glossary

The glossary provides definitions for terms that are used in the report. Its primary focus is on terminology that is commonly used within the rail and broader transport sectors, but which may be unfamiliar to non-specialists.



**Agglomeration effects:** Refers to the phenomenon whereby industries and people cluster around a certain area, permitting an increase in productivity across firms.

**Asset-based carrier**: Refers to a freight carrier that owns the equipment that it uses to ship freight.

**Average lead**: The average distance that either a passenger or one tonne of freight is transported. In the freight context, it is equivalent to tonne-kilometres divided by tonnes transported.

**Communications-based train control**: Train and infrastructure communication systems, such as those that exist in the European Union (ERTMS), the United States (PTC) and Japan, designed and operated to prevent train collisions from occurring and which, in the process, allow increased traffic to operate on a given railway network.

**Conventional rail:** Refers to a rail service over medium to long distance, with a maximum speed of less than 250 kilometres per hour. It includes both intercity and suburban train journeys that connect urban centres with the surrounding areas.

**Corridor:** A broad route of no predefined size that connects major sources and destinations of journeys. It is composed of a nominally linear transportation service area that may contain a number of streets, highways and/or transit route alignments. In the case of rail, it can be, but is not necessarily, synonymous with a railway line.

**Densified:** In the context of this report, it refers to measures taken to permit rail lines to be used at high intensity with high utilisation, e.g. dense freight traffic flows are high annual freight movements along a specific railway line.

**Diesel-electric:** This very common rail propulsion method relies on a diesel engine that drives an electric generator, with the electricity produced then distributed across either the locomotive or the rail car (in the case of a multiple unit vehicle) to traction motors to drive axles (and eventually the wheels). Among other advantages, this powertrain design avoids the need for a complex gearing system.

**Diesel-electric multiple unit** (DEMU)/**electric multiple unit** (EMU)**:** A multiple unit vehicle, often referred to as a DMU (diesel), DEMU (diesel-electric) or EMU (electric), which is an alternative to locomotive-hauled railcars. Frequently used for passenger services, each unit (which consists of either one or two railcars) contains its own propulsion system and space for passengers on the same vehicle(s), so a full train may consists of any number of multiple units, depending on the needs of a specific route. Thanks to its large number of powered axles and a higher power-to-weight ratio than its locomotive equivalent, a multiple unit train can usually accelerate more quickly than a diesel-electric locomotive-powered train.

**Dedicated freight corridor:** A corridor that is designed to service only freight railway traffic.

**Digitalisation:** Refers to the application of digital technologies (i.e. information and communications technology) across the economy (including in transport) to achieve desired outcomes, such as improved safety, efficiency and productivity. The “Internet of Things”, big data analytics, artificial intelligence and blockchain all rely on digitalisation.

**Freight activity:** Refers to the aggregate volume of freight movement in a given region, on a given mode, or on a specific route. It is measured in tonne-kilometres.

**Freight wagon** (wagon)**:** A railway vehicle designed and used for the transport of goods.

**Gauge** (track gauge): Width between the inner faces of the two rails of a track. This can differ across countries, according to a few common gauge specifications.



**Golden Quadrilateral:** Refers to the physical linkages, both actual and hypothetical, between the four major Indian cities of Delhi, Mumbai, Chennai and Kolkata, which form a geometric quadrilateral.

**Gravity model:** A statistical model used to estimate freight and passenger flows across an array of potential terminal location pairs.

**Headway:** The time that elapses between the arrivals at a given location of two consecutive vehicles on the same track. This term is generally used to refer to scheduled time intervals.

**High-speed rail:** Rail services that operate over long distances, operating at a maximum speed exceeding 250 kilometres per hour.

**Intermodal:** Designates the movement of goods or passengers in one journey via more than one mode of transport (e.g. a passenger taking the bus to the train station and taking the train from there, or a freight container first carried by ship then by rail and lastly by truck).

**Land value capture:** The increase in land value that arises based on greater connectivity and activity, and hence desirability, of property around railway stations.

**Linke Hofmann Busch** (LHB) **coach:** The passenger coaches of Indian Railways. They were originally developed by Linke Hofmann Busch, a German company, and in recent decades have been manufactured in India directly by Indian Railways.

**Locomotive:** A locomotive is a rail vehicle with a power of at least 110 kilowatts at the draw hook, and equipped with either a prime mover and motor or with a motor only. It is used for hauling railway vehicles.

**Light rail:** Tramways and other urban transport systems that operate usually at street level and at lower capacity and speed than metro rail.

**Metro rail:** Refers to a high-frequency rail service within cities, designed for high capacity transport (serving standing passengers and equipped with many wide doors for rapid boarding and exit). Metro rail is fully separated from other traffic and often operates on infrastructure that is primarily underground or elevated.

**Mobility as a Service** (MaaS)**:** Refers to passenger and freight transport solutions that are consumed as a service, enabled by digital platforms that integrate numerous mobility options in a unified planning and payment platform.

**Overhead line electrification** (OLE)**:** A system of support structures, wires (i.e. electric catenary wires), and other equipment (e.g. pantograph, which lies atop the roof of an electric locomotive or coach) that collectively transmit electric power from the grid to a railway vehicle in order to provide propulsion power to the vehicle and to supply other power needs.

**Passenger activity:** The aggregate volume of passenger movements in a given region, on a given mode, or on a specific route. These movements are measured in passenger-kilometres.

**Passenger-kilometre:** A unit of measurement designating the transport of one passenger over a distance of one kilometre.

**Occupancy:** The number of passengers on a train. The average occupancy is obtained by dividing the total number of passenger-kilometres by the total number of train-kilometres.

**Physical internet:** The physical internet is an open, shared and modular system wherein all physical assets used in goods delivery are moved on multiple transport modes using standardised containers, a common protocol and common tools, shared transport and technological assets. In the case of rail movements, the standardisation of the loading units, in particular, is crucial to minimising the barriers posed by goods handling for intermodal transfers.



**Railway line:** One or more adjacent tracks connecting two locations. When lines connecting different locations converge onto parallel networks (e.g. where a line from city A to B joins with a line from city C to B), the adjacent lines are not double-counted, unless both lines have their own track.

**Railway network:** All railways (of a given type, e.g. metro, light rail, conventional, high-speed rail) in a given area.

**Ridership:** The amount of people passing through a given system. In the case of rail use, this refers to the quantity of passengers being transported over a network or networks (e.g. within a given country) over a certain period of time**.**

**Special purpose vehicle** (SPV): An organisation/institution set up, often by a government, for a very specific purpose, with adequate operational independence so as to encourage private participation and ease decision making.

**Tank-to-wheel** (TTW) **greenhouse gas** (GHG) **emissions:** Emissions that are generated by a fuel while in a tank (in some cases, known as “boil-off” emissions) as well as emissions generated by fuel combustion. In the well-to-wheel framework, combustion emissions of biofuels are counted, though they may be offset or augmented by the well-to-tank emissions associated with producing and delivering the biofuel to the vehicle.

**Tonne-kilometre:** A unit of measurement in freight transport designating the transport of one tonne of goods over a distance of one kilometre.

**Throughput:** The amount of people or materials passing through a given corridor or system. In the case of rail use, this refers to the quantity of passengers or freight being transported over a specific corridor or network over a certain period of time. In the case of passenger traffic, throughput is nearly synonymous with ridership, though ridership typically refers to system or aggregate (country-level) volumes**.**

**Urban rail:** In this report, it refers to an aggregation of metro rail and light rail (i.e. rail within city limits) services. Regional and suburban trains are excluded from this category.

**Well-to-wheel** (WTW) **greenhouse gas** (GHG) **emissions:** Total emissions generated throughout the entire life cycle of a fuel, covering production, transformation, distribution and final use in a vehicle to power movement and other operations. These emissions are usually calculated as two components: well-to-tank (WTT) emissions and tank-to-wheel (TTW) emissions.

**Well-to-tank** (WTT) **greenhouse gas** (GHG) **emissions:** Refers to emissions generated during the process of resource extraction, transportation of the resource to a processing facility or power plant, fuel refinement/conversion/power generation, and delivery or transmission of the final fuel product to the point of use or vehicle tank, but excluding emissions during the conversion of the fuel to motive power.


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