

RAILWAY HANDBOOK 2017



ENERGY CONSUMPTION AND CO₂ EMISSIONS

FOCUS ON PASSENGER RAIL SERVICES

INTERNATIONAL ENERGY AGENCY

2

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
 - Improve transparency of international markets through collection and analysis of energy data.
 - Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
 - Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

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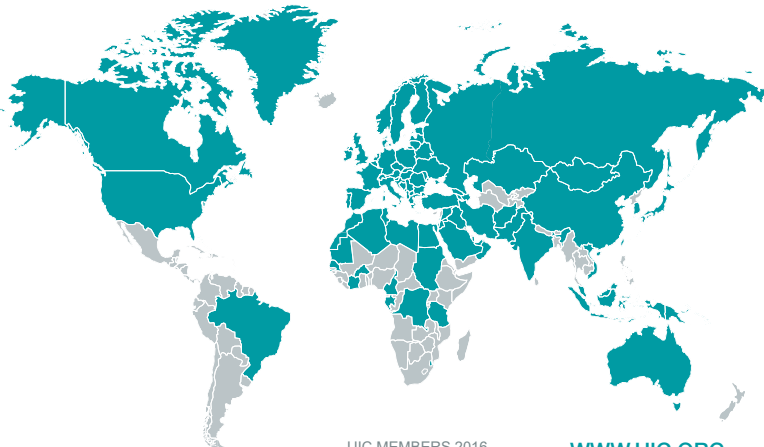
The European Commission also participates in the work of the IEA.

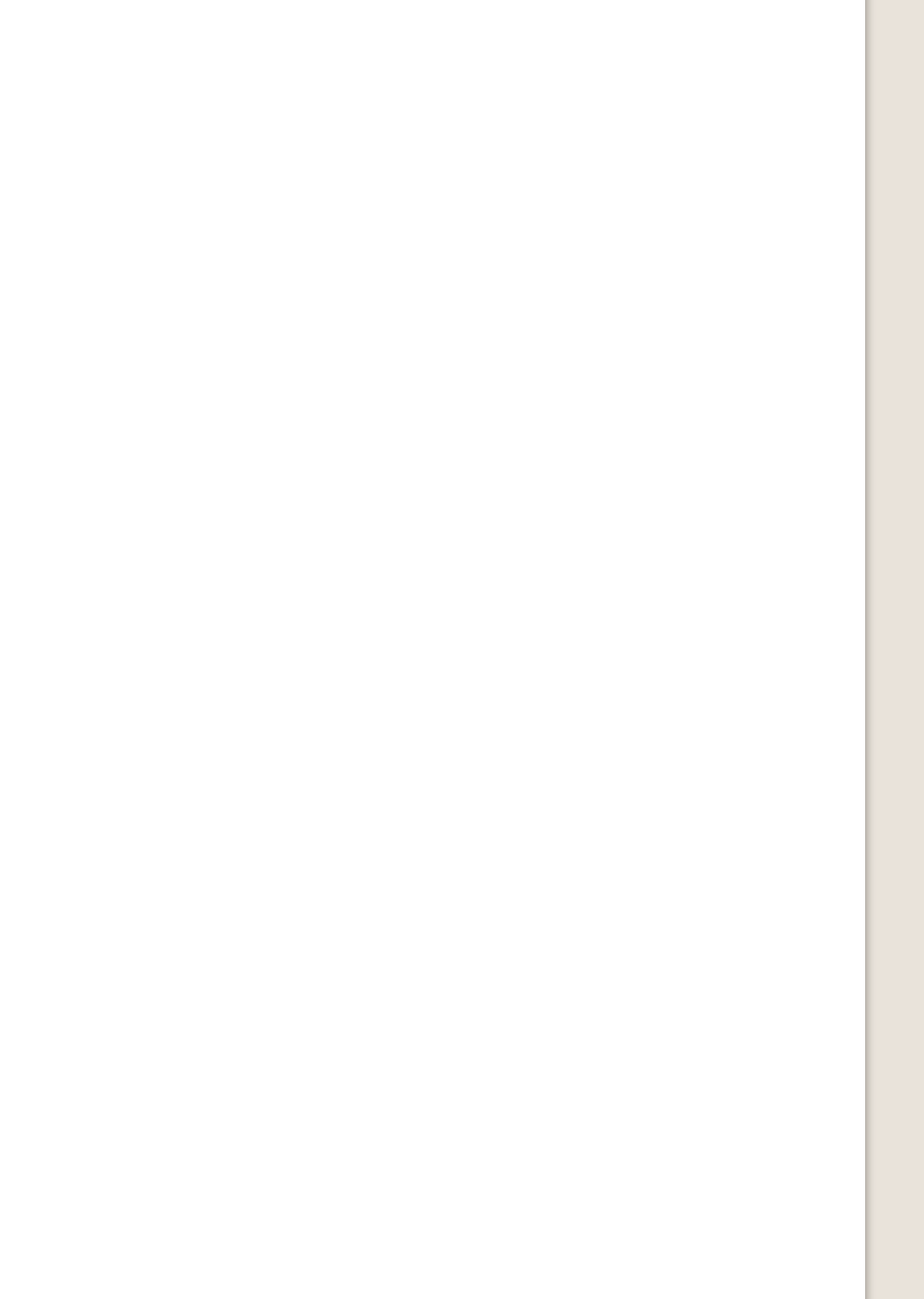
UIC: the international professional association representing the railway sector

UIC, the International Railway Association founded in 1922, counts 240 members in 95 countries across 5 continents, including railway companies, infrastructure managers & rail-related transport operators & research institutes. UIC's members represent over 1 million kilometres of tracks, 2 900 billion passenger-km, 10 000 billion tonne-km and a workforce of 7 million railway staff. The UIC mission is to promote rail transport at world level and meet the challenges of mobility and sustainable development. The UIC Energy Environment & Sustainability (EES) Platform manages 5 expert networks (Energy & CO₂ Emissions, Sustainable Mobility, Noise and Sustainable Land Use) and a portfolio of projects focusing on the development of best practice, benchmarking for environmental sustainability and reporting of corporate and social responsibility. For more information see www.uic.org.

The UIC missions:

- » Promote rail transport at world level with the objective of optimally meeting current and future challenges of mobility and sustainable development,
- » Promote interoperability, and as a Standard-Setting Organisation, create new world IRSS (International Railway Solutions) for railways (including common solutions with other transport modes),
- » Develop and facilitate all forms of international cooperation among Members, facilitate the sharing of best practices (benchmarking),
- » Support Members in their efforts to develop new business and new areas of activities,
- » Propose new ways to improve technical and environmental performance of rail transport, improve competitiveness, reduce costs.







Foreword

The International Energy Agency (IEA) and the International Union of Railways (UIC) are pleased to jointly publish the 2017 edition of the Railway Handbook on Energy Consumption and CO₂ Emissions. This publication marks the sixth consecutive year of cooperation between the two organizations and aims to provide insights on worldwide rail sector energy and CO₂ emissions performance. Positive and enthusiastic feedback received following previous publications has encouraged us to continue and reinforce this long-standing collaboration.

The data on railway energy consumption and CO₂ emissions presented in Part I of this handbook help to track progress against the targets set in the UIC Low Carbon Rail Transport Challenge, which was presented at the United Nations Climate Summit in 2014 and is currently a leading initiative in the Marrakesh Partnership. These data are also used to inform the IEA Mobility Model, an analytical tool for tracking global transport activity, energy consumption and CO₂ emissions.

Part II of this year's handbook focuses on passenger transport, and in particular on high-speed and urban rail services. Global urban and high-speed rail activity has grown rapidly in recent years, largely due to major network expansions in China. Passenger rail transport accounted for 9% of global passenger transport activity (measured in passenger-km), yet only accounted for 1% of passenger transport final energy demand in 2015. Passenger rail is the most efficient passenger transport mode, both in terms of energy use and CO₂ emissions per passenger-km, and it is increasingly relying on electricity as a fuel. This, amongst other factors explains why passenger rail services become gradually more important in low-carbon IEA scenarios to help reduce CO₂ emissions from transport.

UIC and IEA wish to thank the UIC members who have submitted data in support of this publication, and other stakeholders who have contributed. Together the IEA and UIC are committed to monitoring energy use and CO₂ emission performance from railways, providing insights on the development of the transport sector.

We hope that this work will provide policymakers and other stakeholders with useful insights on railway performance with regard to energy use and CO₂ emissions, highlighting how railways can contribute to the Paris Agreement and energy related aspects of the United Nations Sustainable Development Goals.

Fatih Birol

International Energy Agency
Executive Director

Jean-Pierre Loubinoux

International Union of Railways
Director General



Acknowledgments

This publication has been made possible thanks to UIC railway members, who have contributed to UIC statistics on railway activity, energy consumption, and CO₂ emissions, and to the IEA Energy Data Centre, which has collected and managed energy balances and CO₂ emissions data from fuel combustion.

A special mention goes to the cooperation of Ignacio Barron, Nicholas Craven, Linus Grob, Vanessa Perez, Cheul Kyu Lee and Kenzo Fujita (UIC) and Erik Maroney (IEA) for the completion of this work and to the contributions from UIC members improving the data collection.

Gratitude is also extended to Daniele Arena and to the Sustainable Development Foundation for its technical support, especially to Raimondo Orsini, Massimo Ciuffini and Luca Refrigeri.

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Layout update: Marina Grzanka, marina.grzanka@gmail.com

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Railway Handbook 2017




















Energy Consumption and CO₂ Emissions

Focus on Passenger Rail Services

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Introduction

The 2017 edition of the Railway Handbook on Energy Consumption and CO₂ emissions is the sixth publication of this series. The previous five editions are available for download at the UIC website.

As in previous editions, this handbook aims to provide the latest insights into the rail sector's developments of transport activity, energy consumption and CO₂ emissions.

For Part I, this handbook combines IEA statistics (IEA, 2017a; IEA, 2017c) and rail data estimates from the IEA Mobility Model (IEA, 2017b) together with UIC statistics (UIC, 2016a) and the UIC Environmental Performance Database (UIC, 2016b and 2017a). Further data, particularly on activity of transport modes other than railway, comes from national statistics offices and international organisations (e.g. OECD and Eurostat). These data are supplemented by sector or region-specific databases such as the High-speed Lines in the World database (UIC 2017b).

Part I of this handbook presents railway statistics related to the energy and CO₂ emission performance of the transport sector. Whereas last year's edition presented new statistics for the year 2013 only, this year's edition adds new data for two consecutive years, meaning statistics for 2014 and 2015 are included.

Globally, the railway sector was responsible for 1.9% of transport final energy demand, and for 4.2% of CO₂ emissions from the transport sector in 2015. In comparison, road transport accounts for a share of 75.3% of final energy demand, and for 72.6% of CO₂ emissions from transport. Rail accounts for a relatively larger share of transport activity demand. In 2015, rail accounted for 6.3% of global passenger transport activity (in passenger-km) and for 6.9% of global freight transport activity (in tonne-km). The difference in magnitude of the share of activity and CO₂ emissions can be largely explained by the better energy efficiency (per passenger-km and tonne-km) of the rail sector compared to the road sector. A continued increase of the share of electricity used in the rail sector was observed between 2013 and 2015, as well as an increase of the share of renewables used for electricity generation, which contributes to further improving the CO₂ intensity of rail.

Since 1975, a steady improvement of the railway energy intensity is observed. This development continued for freight rail transport between 2013 and 2015, but in the passenger rail sector a slight worsening of energy intensity was observed in the same period. This is consistent with the unprecedented shift in China from conventional rail to high-speed rail.

Part II of this handbook features an in-depth analysis of passenger rail services, with a focus on urban and high-speed rail. In 2015, passenger rail transport (including urban rail services) accounted for 9% of global passenger activity (passenger-km) (IEA 2017b). The share of Asia in total passenger rail activity grew significantly over the past decades. Asia accounted for 50% of passenger rail activity in 1985, grew to 60% by 2000, and finally reached 75% in 2015.

In 2015, the passenger rail sector consumed nearly 700 PJ of final energy, which constitutes one-third of the rail sector. Electricity accounts for almost three quarters of passenger rail final energy demand, and this share is increasing. This is consistent with the growth of urban and high-speed rail services, both characterized by a high dependence on electric traction.

High-speed rail activity has grown rapidly especially in recent years, making it the fastest growing passenger rail service. On average, global high-speed rail activity grew by 14% per year between 2005 and 2015. A strong growth is especially observed between 2013 and 2015, when activity increased by nearly 70%. This increase is largely influenced by a surge activity observed in China, where high-speed rail activity grew by 170% between 2013 and 2015.

In the IEA 2°C Scenario [2DS] and Beyond 2°C Scenario [B2DS] (having a 50% chance of limiting global warming to 2°C and 1.75°C respectively) the rail sector plays a key role in reducing CO₂ emissions from transport. High speed rail is especially relevant as large proportions of short haul aviation activity (trips up to 1000 km) are shifted to high-speed rail towards 2060.

The expansion of metro networks and high capacity/high frequency commuter rail networks has significantly increased urban rail activity in recent years. The growth of these systems can largely be attributed to growth observed in China. High-capacity/high frequency rail activity within Chinese cities has grown by 150% between 2005 and 2015.

Both metros and high capacity/high frequency commuter rail have a better specific energy consumption per passenger-kilometer compared to buses, passenger cars, and two-wheelers. High capacity urban rail requires, on average, less than a tenth of the energy needed per kilometer travelled compared with passenger cars. High capacity urban rail is also more than twice as energy-efficient per passenger-km compared with tramways and light rail systems. This is primarily due to the higher occupancy rates, or load factors, of high capacity urban rail.

To achieve CO₂ emission reductions in line with 2DS and B2DS trajectories, significant modal shift in urban transport from private vehicles (passenger cars especially) to more efficient public transport modes are also needed. Consequently, the demand for urban rail services is projected to grow by a factor 6 in the 2DS and by a factor 8 in the B2DS between 2015 and 2060.

A decorative horizontal line with a light brown background, featuring several colorful paper scraps (green, blue, yellow, orange) scattered around it.

**Part I:
The Railway Sector
Main Data**

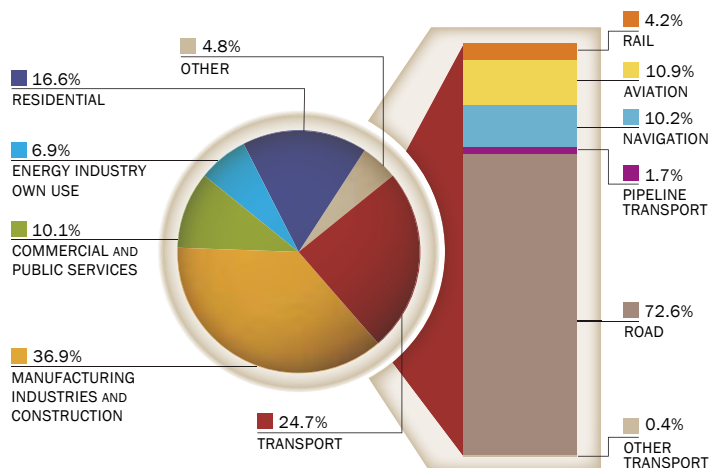
Key Facts

Energy & CO₂ emissions:

- ◆ In 2015, the transport sector was responsible for 24.7% of global energy related CO₂ emissions (8.0 billion tCO₂) and for 28.8% of global final energy consumption (113 EJ).
- ◆ The rail sector was responsible for 4.2% (336 million tCO₂) of global transport CO₂ emissions, and 1.9% (2 EJ) of transport final energy demand in the same year.
- ◆ Between 1990 and 2015, energy consumption per transport unit decreased by 35.8% and CO₂ emissions per transport unit decreased by 31.6%. In both cases, more than half of the reduction was achieved in the decade from 2005 to 2015.
- ◆ Between 2005 and 2015, rail energy consumption per passenger-km decreased by 27.8% and energy consumption per freight tonne-km decreased by 18.1%.
- ◆ Between 2005 and 2015, rail CO₂ emissions per passenger-km decreased by 21.7% and CO₂ emissions per freight tonne-km decreased by 19.0%.
- ◆ The share of oil products (diesel) in the global railway fuel mix declined from 62.2% in 2005 to 56% in 2015, and the share of electricity consequently increased. The share of electricity generated by renewables increased by 65% in the same period.

Activity:

- ◆ In 2015, rail accounted for 6.7% of global passenger transport activity (in passenger-km) and for 6.9% of global freight transport activity (in tonne-km).
- ◆ The share of high-speed rail in global intercity rail grew considerably between 2010 and 2015, doubling from 10% to 20%. This is largely driven by a surge of high-speed rail activity in China in the same period.

Fig. 1: Share of CO₂ emissions from fuel combustion by sector, 2015

Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

Source: Elaboration by Susdef based on IEA (2017a)

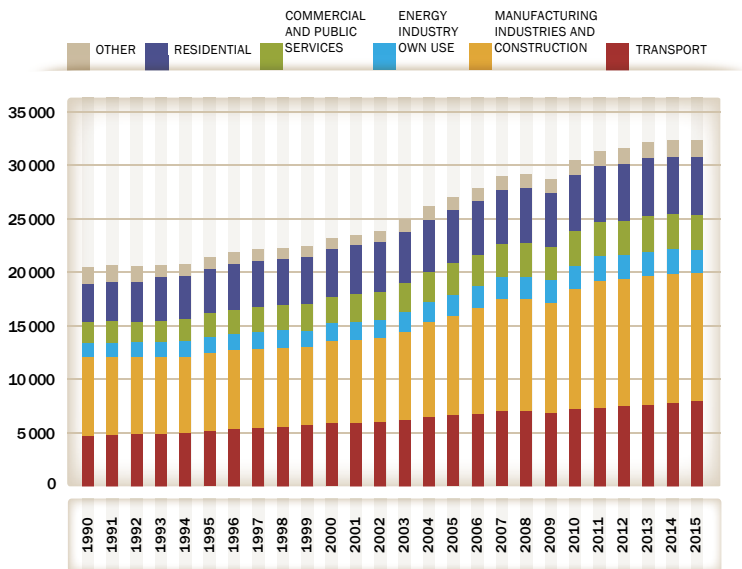
Table 1: World transport modal share, 2015

	Passenger PKM	Freight TKM	Total TU
ROAD	79.6%	20.2%	35.1%
AVIATION	13.7%	0.7%	4.0%
NAVIGATION	-	72.2%	54.0%
RAIL	6.7%	6.9%	6.9%

Note: Navigation is allocated to freight transport only.

Source: Elaboration by IEA based on IEA (2017b), UIC (2016a) and UNCTAD (2016)

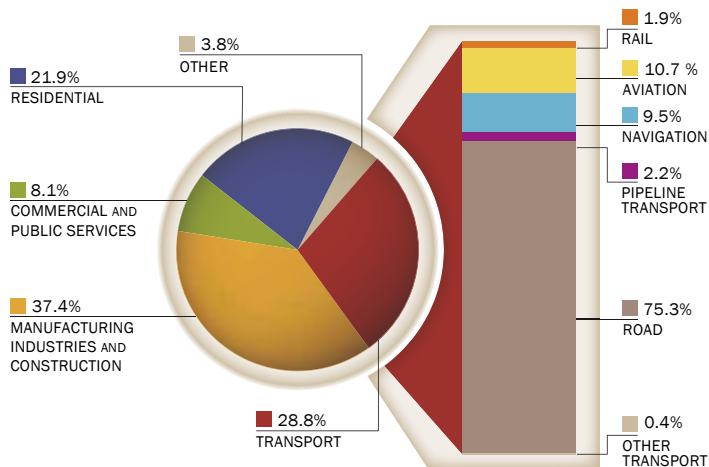
Fig. 2: Total CO₂ emissions from fuel combustion by sector, 1990-2015 (million tCO₂)



Note: Emissions related to electricity and heat production are reallocated to the end-use sectors.

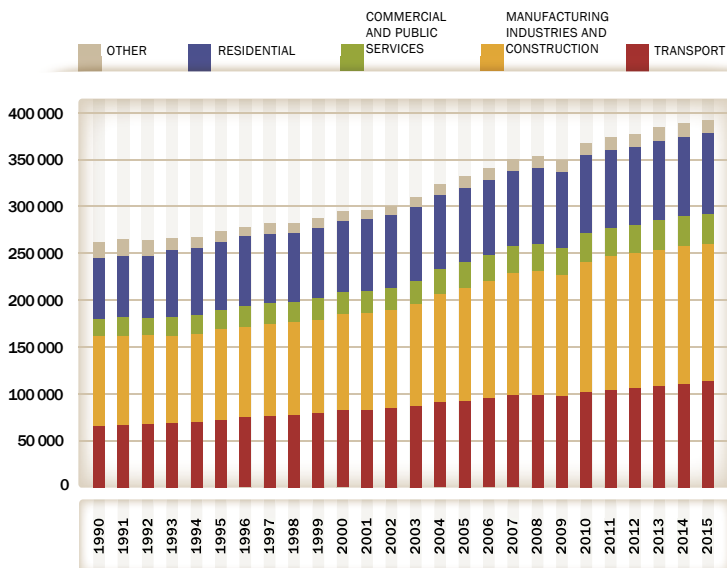
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 3: Share of final energy consumption by sector, 2015

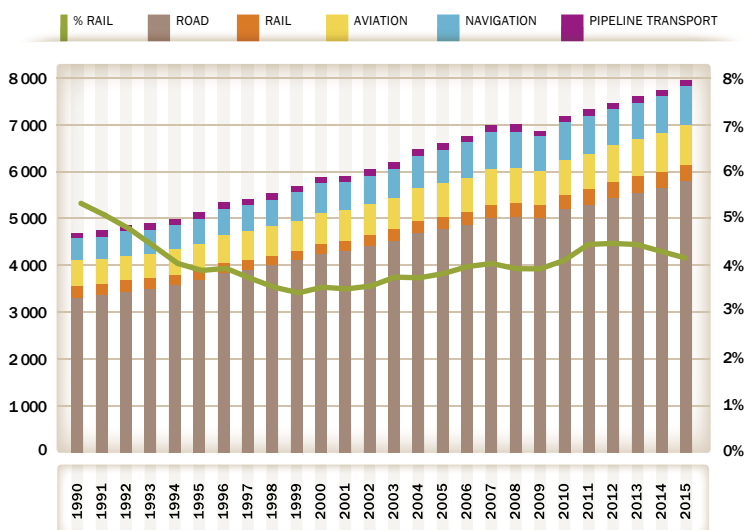


Source: Elaboration by Susdef based on IEA (2017c)

Fig. 4: Total final energy consumption by sector, 1990-2015 (PJ)



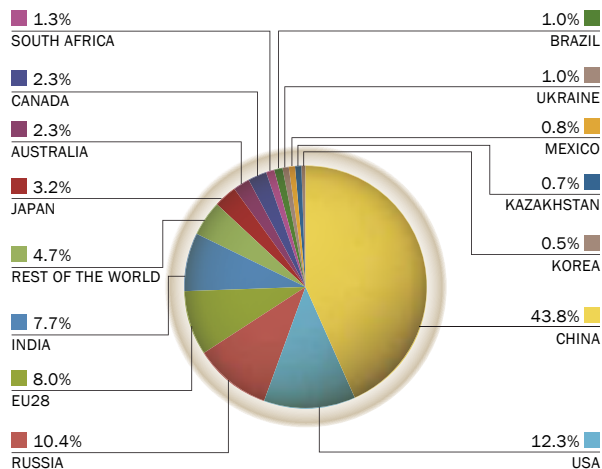
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 5: Transport sector CO₂ emissions by mode, 1990-2015
(million tCO₂ - left, share of rail in global CO₂ emissions - right)

Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

Source: Elaboration by Susdef based on IEA (2017a)

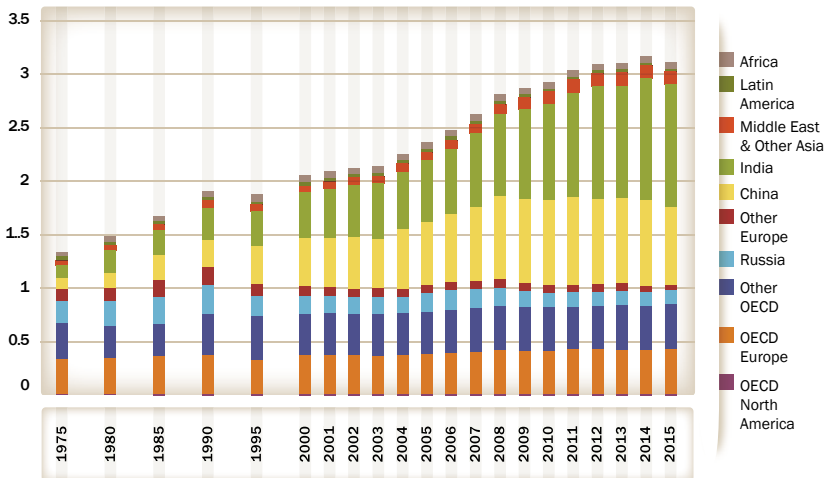
Fig. 6: Share of railway CO₂ emissions by geographic area, 2015



Note: All the emissions from electricity and heat production in transport have been reallocated to rail.

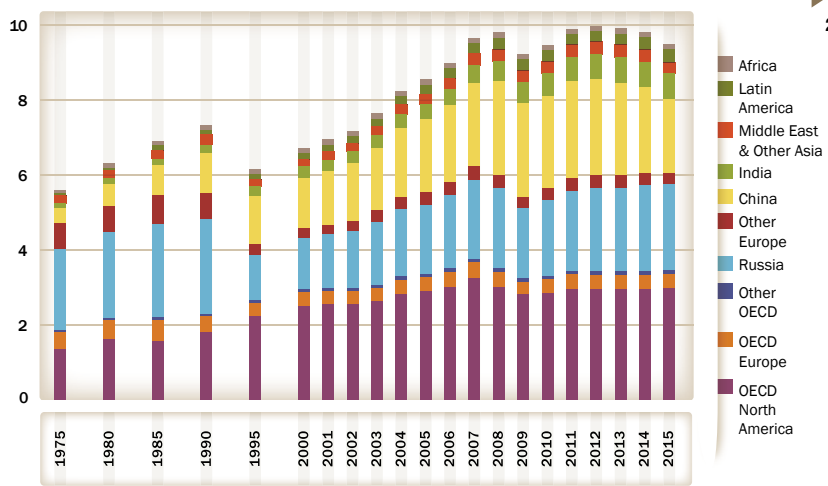
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 7: Railway passenger transport activity by geographic area, 1975-2015 (trillion pkm)



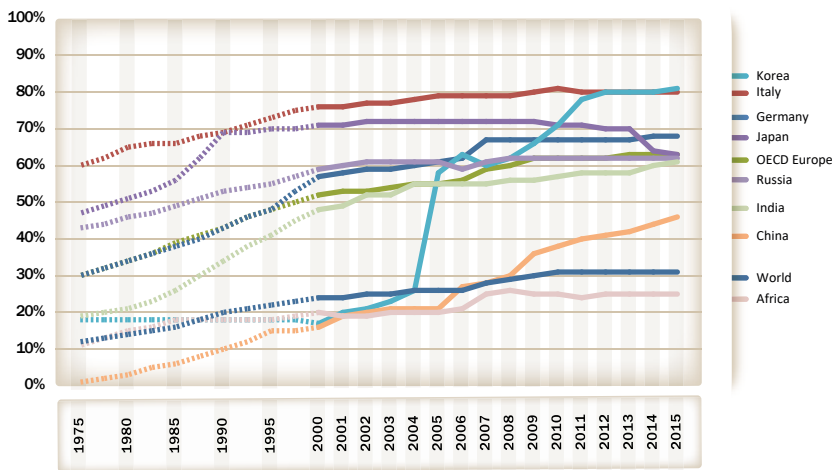
Source: Elaboration by IEA based on UIC (2016a)

Fig. 8: Railway freight transport activity by geographic area, 1975-2015 (trillion tkm)



Source: Elaboration by IEA based on UIC (2016a)

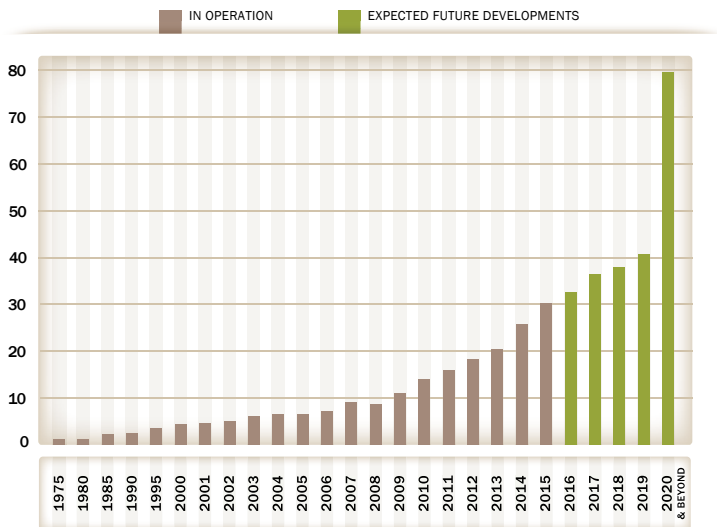
Fig. 9: Share of electrified railway tracks in selected countries and geographic areas, 1975-2015



Note: The USA are not displayed in this chart because of a lack of data.

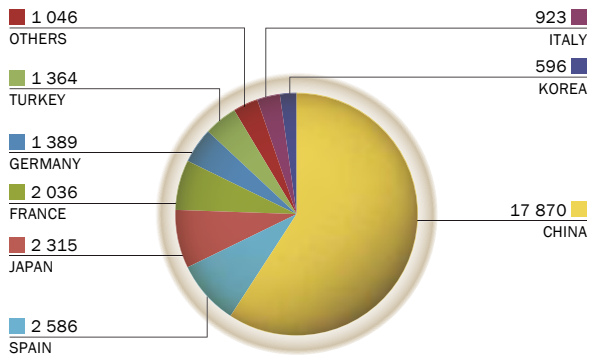
Source: Elaboration by IEA based on UIC (2016a)

Fig. 10: Global high-speed lines (>250 km/h) in operation 1975-2015 and expected future developments (thousand km)



Source: Elaboration by IEA on UIC (2016a)

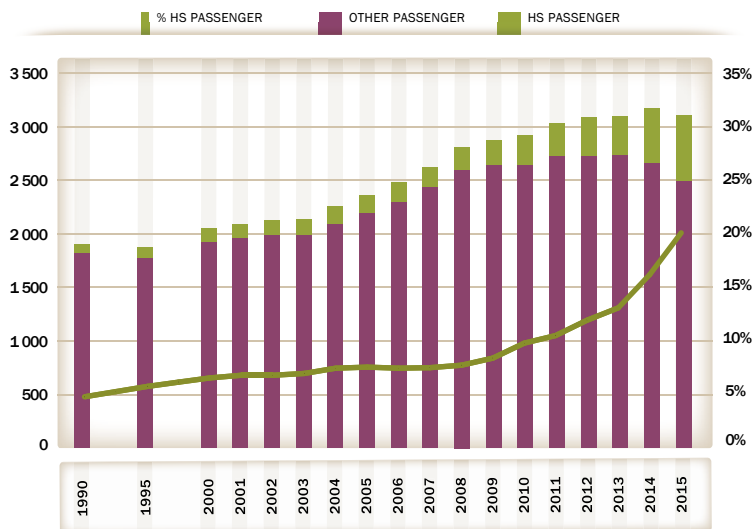
Fig. 11: High-speed lines (>250 km/h) in operation by country (km), 2015



Note: The category "Others" includes Chinese Taipei, Poland, Belgium, Netherlands, United Kingdom, Switzerland.

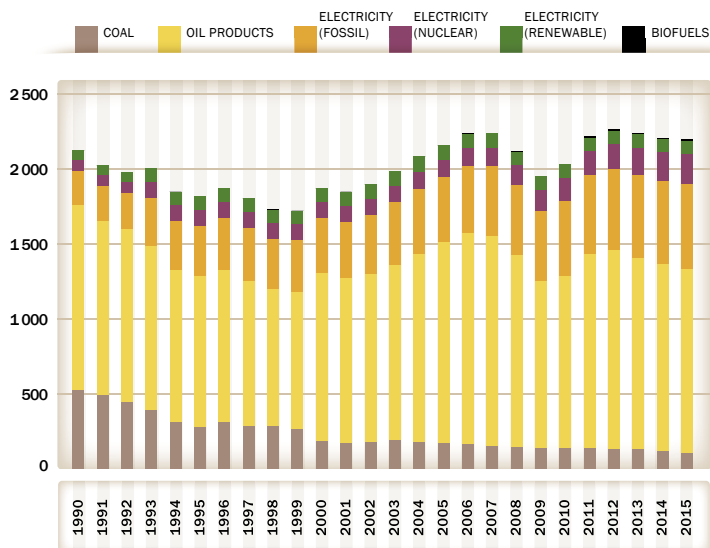
Source: Elaboration by Susdef on IEA and UIC (2016a)

Fig. 12: High-speed activity as a share of total passenger railway activity, 1990-2015 (billion pkm)



Source: Elaboration by IEA based on UIC (2016a)








Fig. 13: Railway final energy consumption by fuel, 1990-2015 (PJ)






Note: See Methodology Notes p. 109.

Source: Elaboration by Susdef based on IEA (2017c)

Table 2: World railway energy fuel mix, 1990-2015

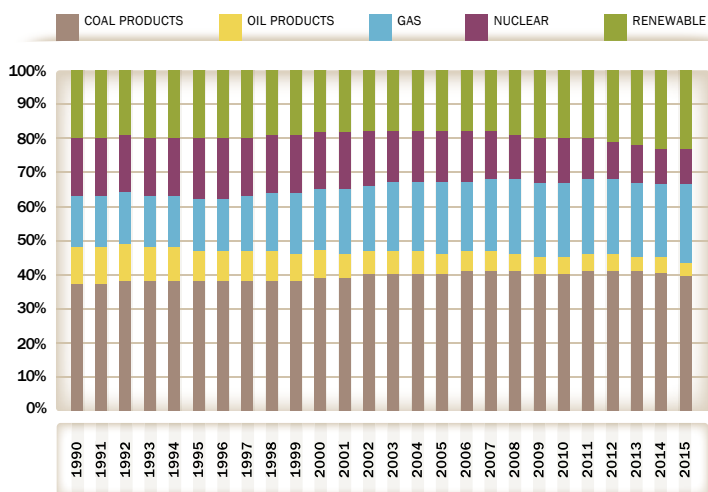
ENERGY MIX BY SOURCE		1990	2015
OIL PRODUCTS		57.9%	56.0%
COAL PRODUCTS		24.8%	4.8%
BIOFUELS		0.0%	0.4%
ELECTRICITY		17.3%	38.8%
of which Fossil		11.0%	25.7%
of which Nuclear		2.9%	4.1%
of which Renewable		3.4%	9.0%

SUMMARY BY SOURCE TYPE		1990	2015
FOSSIL SOURCE		93.7%	86.5%
NUCLEAR		2.9%	4.1%
RENEWABLE		3.4%	9.4%

Note: See Methodology Notes p. 109.

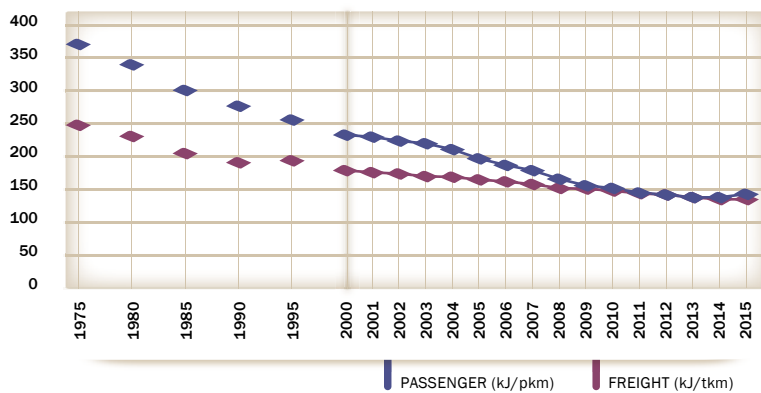
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 14: World electricity production mix evolution, 1990-2015



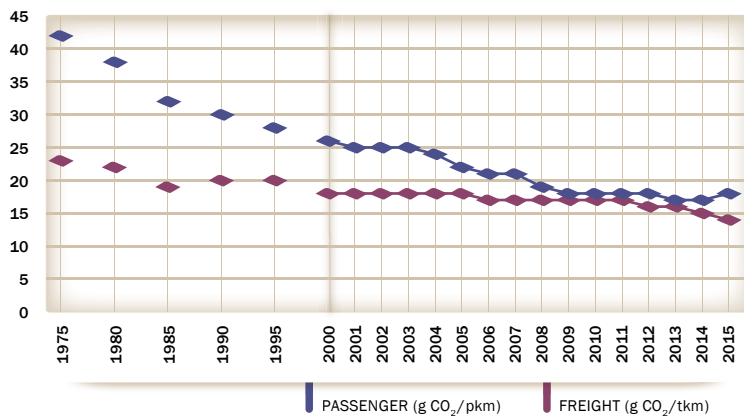
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 15: Railway specific energy consumption, 1975-2015



Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)

Fig. 16: Railway specific CO₂ emissions, 1975-2015

Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)



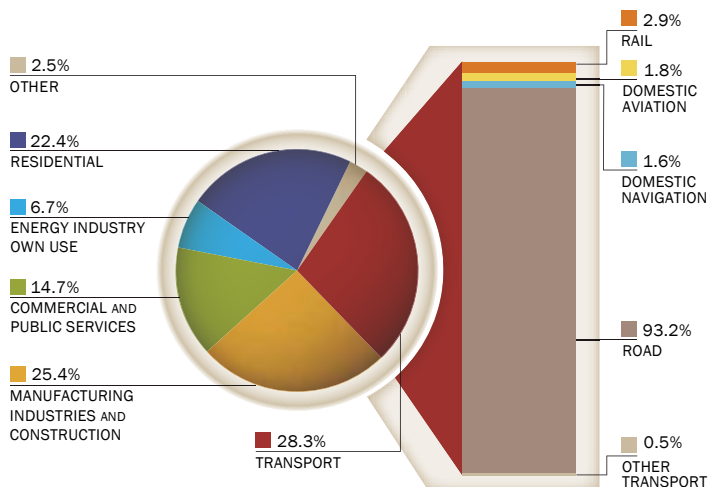
Key Facts

Energy & CO₂ emissions:

- ◆ In the European Union, the transport sector accounted for 28.3% of total energy related CO₂ emissions (907m tonnes) and 28.1% (13 EJ) of total final energy use in 2015. The transport sector is the largest contributor to energy related CO₂ emissions in the EU28.
- ◆ In 2015, the rail sector accounted for 2.9% (26.64 million tCO₂) of CO₂ emissions from transport, and for 2.1% (269 PJ) of transport final energy demand.
- ◆ Between 1990 and 2015, energy consumption per transport unit (a weighted combination between passenger-km and freight tonne-km) decreased by 22.2% and CO₂ emissions per transport unit decreased by 45.2%. About three quarters of the reduction in both cases were achieved in the decade from 2005 to 2015.
- ◆ Energy consumption per passenger-km decreased by 18.2% between 2005 and 2015, and energy consumption per freight tonne-km decreased by 19.2% in the same period.
- ◆ CO₂ emissions per passenger-km decreased by 38.1% between 2005 and 2015, and CO₂ emissions per freight tonne-km decreased by 31.2% in the same period.
- ◆ The use of oil products (diesel) in the railway fuel mix continued to decrease in recent years, dropping from 40.4% of railway final energy consumption in 2005 to 31.8% in 2015.
- ◆ The share of renewable energy in the electricity mix has more than tripled, rising from 6% to 21% between 2005 and 2015.

Activity:

- ◆ In 2015, rail accounted for 7.6% of passenger transport activity (in passenger-km), and for 15.1% of freight transport activity (in tonne-km).
- ◆ Between 2005 and 2015, passenger rail activity (in passenger-km) increased by 8.9%. Freight rail activity (in tonne-km) declined by 2.5% in the same period.
- ◆ High-speed rail accounted for 84% of the increase in passenger activity between 2005 and 2015, and for 29% of total passenger rail activity in 2015.

Fig. 17: Share of CO₂ emissions from fuel combustion by sector, 2015

Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail. “Other transport” includes emissions from Pipeline transport.

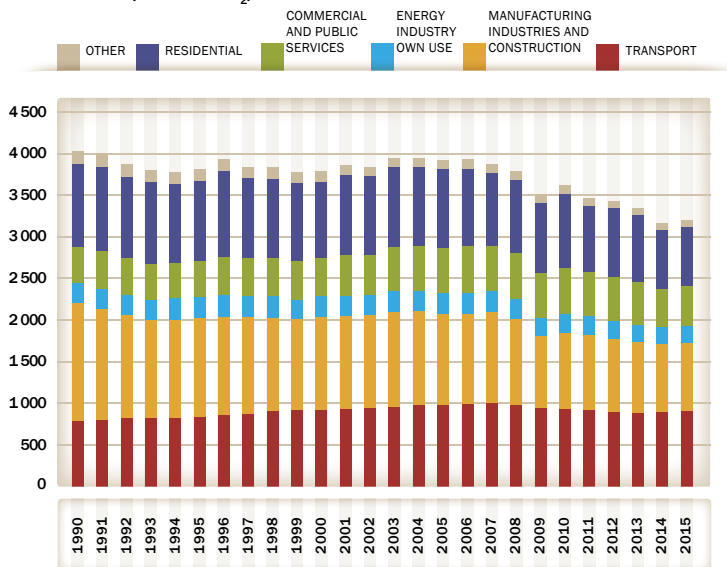
Source: Elaboration by Susdef based on IEA (2017a)

Table 3: EU28 transport modal share, 2015

	Passenger PKM	Freight TKM	Total TU
ROAD	82.2%	50.8%	71.5%
AVIATION	9.9%	0.1%	6.6%
NAVIGATION	0.3%	37.2%	12.9%
RAIL	7.6%	11.9%	9.0%

Source: Elaboration by Susdef based on EC (2017) and UIC (2016a)

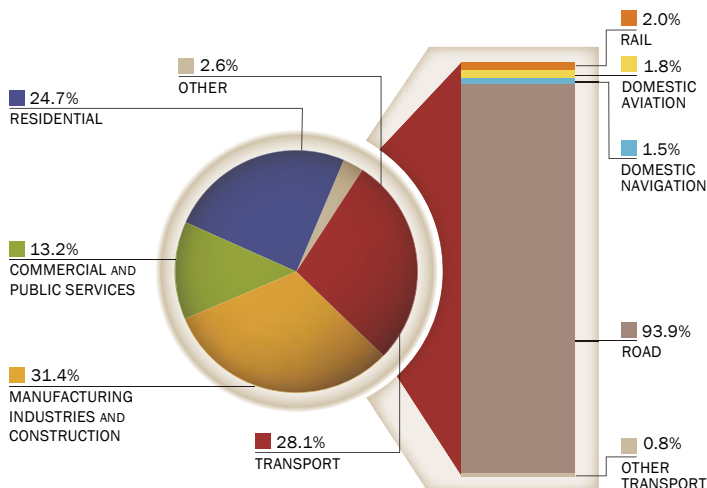
Fig. 18: Total CO₂ emissions from fuel combustion by sector, 1990-2015 (million tCO₂)



Note: Electricity and heat production related emissions are reallocated to the end-use sectors. "Other transport" includes emissions from Pipeline transport.

Source: Elaboration by Susdef based on IEA (2017a)

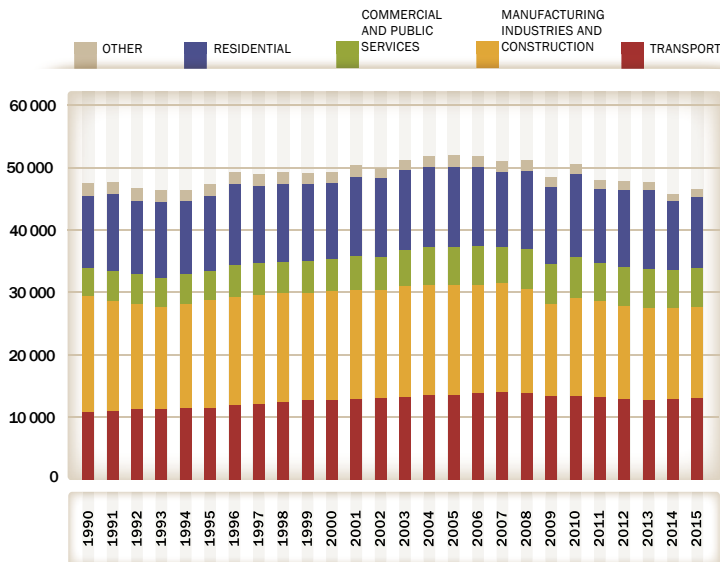
Fig. 19: Share of final energy consumption by sector, 2015



Note: "Other transport" includes emissions from Pipeline transport.

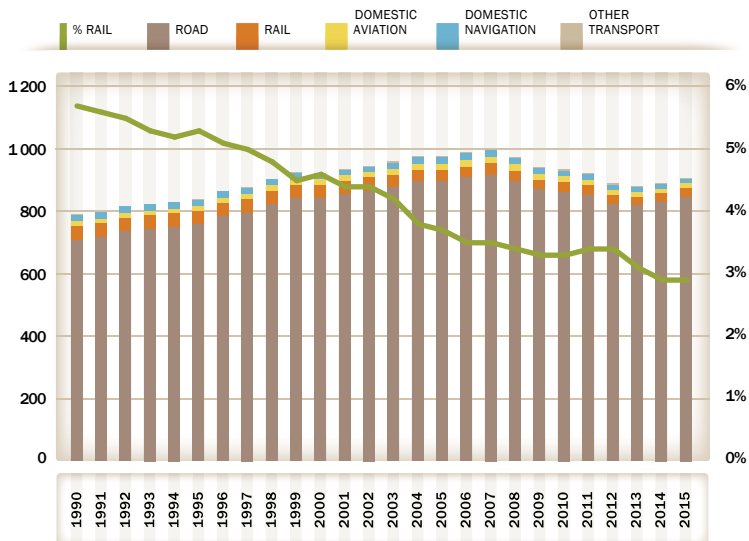
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 20: Total final energy consumption by sector, 1990-2015 (PJ)



Source: Elaboration by Susdef based on IEA (2017c)

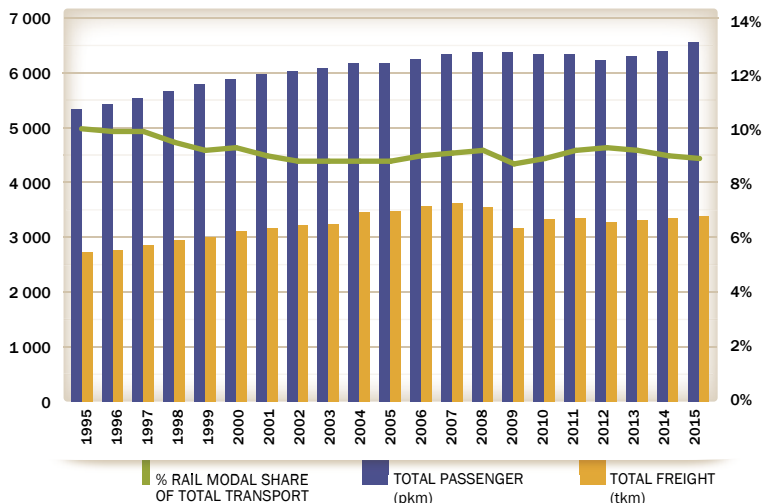
Fig. 21: Transport sector CO₂ emissions by mode, 1990-2015 (million tCO₂ - left - million tCO₂, right - rail share over total)



Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail. "Other transport" includes emissions from Pipeline transport.

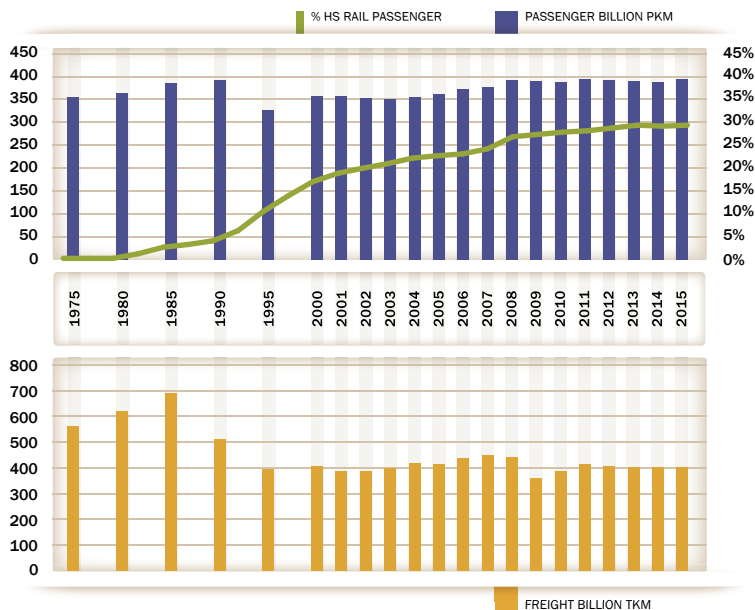
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 22: Passenger and freight transport activity - all modes, 1995-2015 (billion pkm and tkm – left, share of rail over total – right)



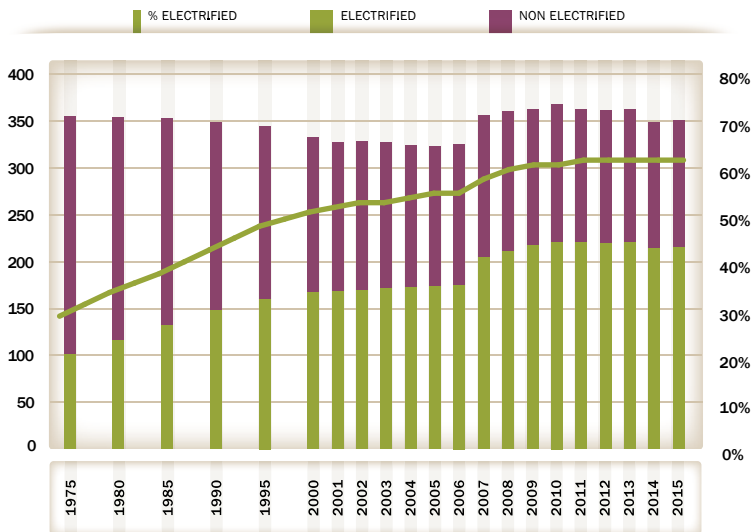
Source: Elaboration by Susdef based on EC (2017) and UIC (2016a)

Fig. 23: Passenger and freight railway activity and High-Speed activity as a share of total passenger railway activity (%), 1975-2015



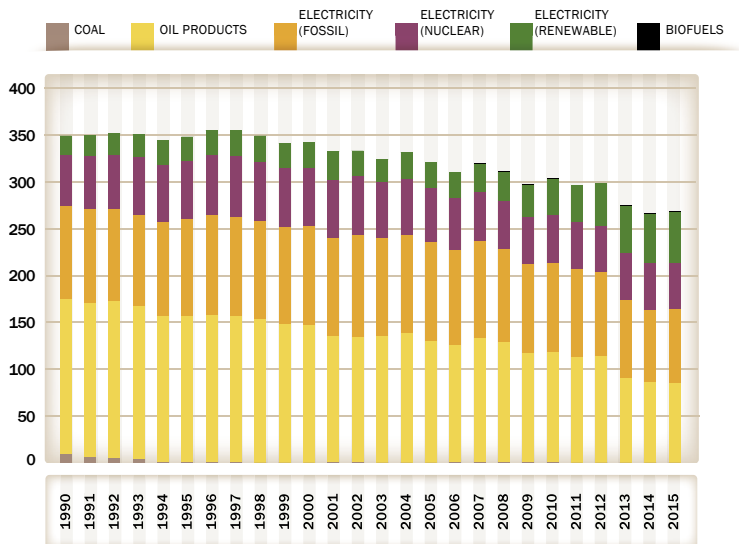
Source: Elaboration by IEA based on UIC (2016a)

Fig. 24: Length and share of electrified and non-electrified railway tracks, 1975-2015 (thousand km)



Source: Elaboration by IEA based on UIC (2016a)








Fig. 25: Railway final energy consumption by fuel, 1990-2015 (PJ)






Note: See Methodology Notes p. 109.

Source: Elaboration by Susdef based on IEA (2017c)

Table 4: EU28 railway energy fuel mix, 1990-2015

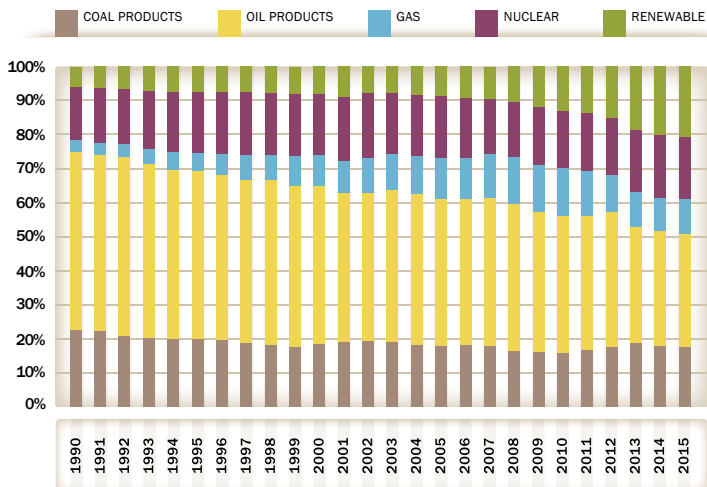
ENERGY MIX BY SOURCE		1990	2015
OIL PRODUCTS		47.6%	31.8%
COAL PRODUCTS		2.5%	0.2%
BIOFUELS		0.0%	0.4%
ELECTRICITY		49.9%	67.6%
of which Fossil		28.4%	29.2%
of which Nuclear		15.4%	18.1%
of which Renewable		6.1%	20.3%

SUMMARY BY SOURCE TYPE		1990	2015
FOSSIL SOURCE		78.5%	61.2%
NUCLEAR		15.4%	18.1%
RENEWABLE		6.1%	20.7%

Note: See Methodology Notes p. 109.

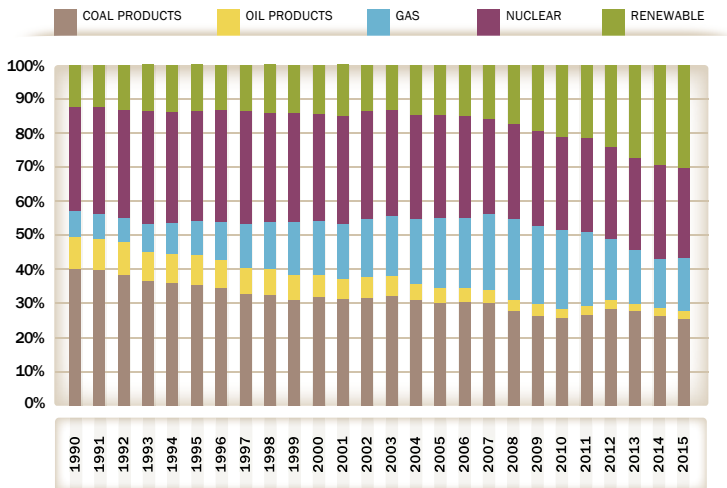
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 26: EU28 Railway energy sources mix evolution, 1990-2015



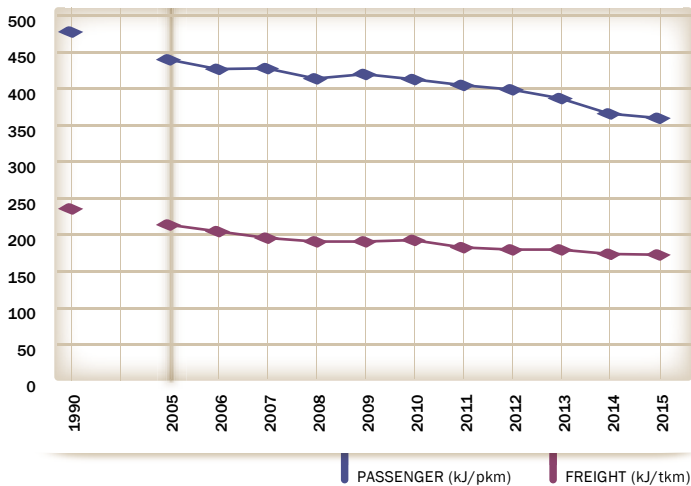
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 27: EU28 electricity production mix evolution, 1990-2015



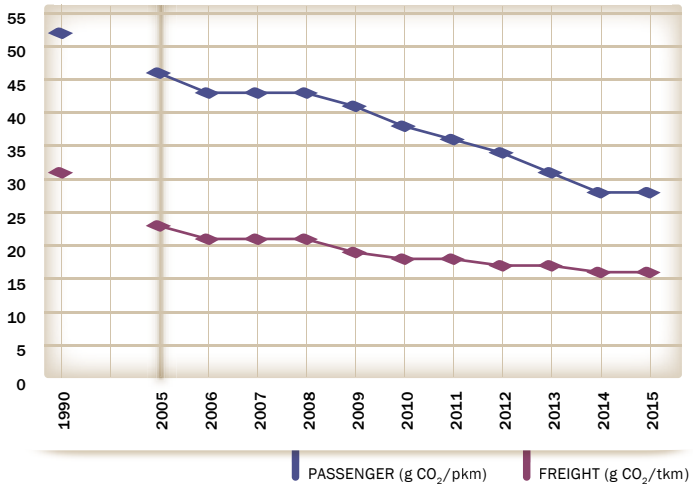
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 28: Railway specific energy consumption, 1990-2015



Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on UIC (2017a)

Fig. 29: Railway specific CO₂ emissions, 1990-2015

Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on UIC (2017a)



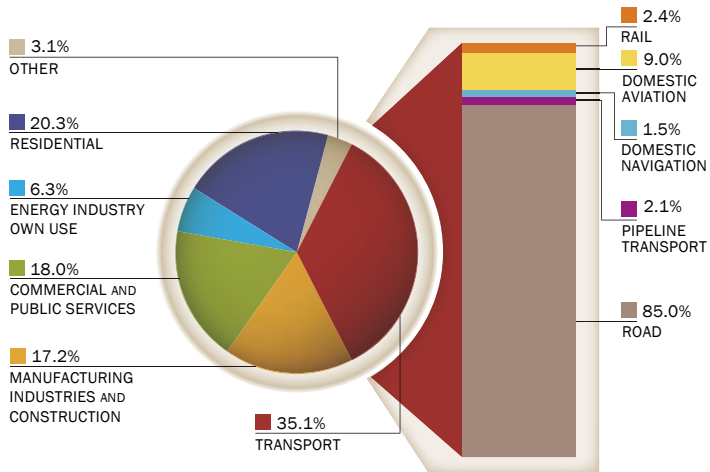
Key Facts

Energy & CO₂ emissions:

- ◆ In the USA, the transport sector accounted for 35.1% of energy related CO₂ emissions (1.8 billion tCO₂) and for 41.5% of final energy consumption (26 EJ) in 2015.
- ◆ The transport sector is the largest contributor to energy related CO₂ emissions in the USA. The USA transport sector has also the largest contribution to its national total in terms of CO₂ emissions of the countries and regions examined in Part I of this Handbook.
- ◆ The rail sector accounted for 2.4% of CO₂ emissions (41 million tCO₂) from the transport sector, and for 2.0% (530 PJ) of transport final energy demand in 2015.
- ◆ Energy consumption per passenger-km (kJ/pkm) decreased by 19.4% from 2005-2015 and energy consumption per freight tonne-km (kJ/tkm) decreased by 15.4% in the same period.
- ◆ CO₂ emissions per passenger-km decreased by 25.9% from 2005-2015 and CO₂ emissions per freight tonne-km decreased by 16.1% in the same period.
- ◆ The use of oil products (diesel) in the railway fuel mix decreased slightly from 95.8% in 2005 to 94% in 2015. Over the same period there was a slight increase in the share of electricity and biofuels.
- ◆ While electrification of US railway lines remains very low, the country has the highest share of biofuels in their energy mix of countries and regions included in this handbook.

Activity:

- ◆ While passenger rail activity in the United States has traditionally been very low by international standards (10.5 billion passenger-km in 2015), the volume of freight rail activity in the US is the highest in the world with over 2.5 trillion tonne-km in 2015.
- ◆ In 2015, rail accounted for 0.1% of passenger transport activity (in passenger-km) and for 32.8% of freight transport activity (in tonne-km).
- ◆ From 2005 to 2015, passenger rail activity (in passenger-km) increased by 21.5%, and freight rail activity (in tonne-km) increased by 2.9%.
- ◆ Although freight rail activity shows an increasing trend, it has not fully recovered from the financial crisis and its activity level was still 9.8% below its 2007 peak in 2015.

Fig. 30: Share of CO₂ emissions from fuel combustion by sector, 2015

Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

Source: Elaboration by Susdef based on IEA (2017a)

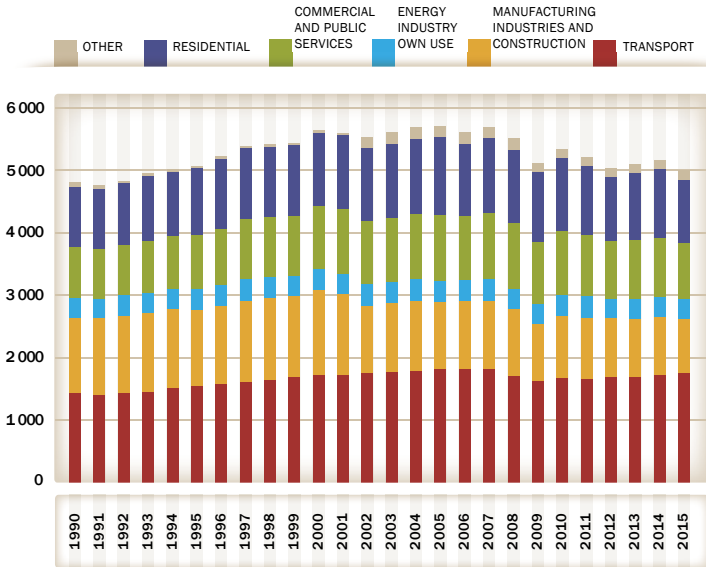
Table 5: USA transport modal share, 2015

	Passenger PKM	Freight TKM	Total TU
ROAD	87.4%	46.9%	69.9%
AVIATION	12.5%	0.3%	7.3%
NAVIGATION	0.01%	11.8%	5.1%
RAIL	0.1%	41.0%	17.7%

Note: Navigation's passenger activity has a value of 0.01%, corresponding to 667 million pkm.

Source: Elaboration by Susdef based on UIC (2016a) and NTS (2016)

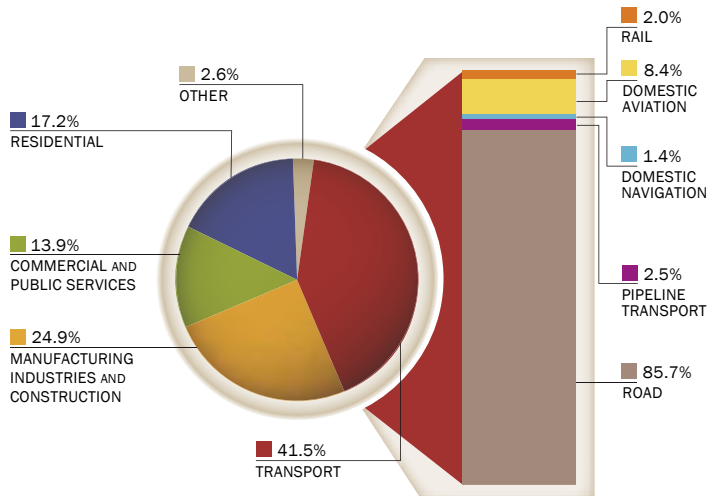
Fig. 31: Total CO₂ emissions from fuel combustion by sector, 1990-2015 (million tCO₂)



Note: Electricity and heat production related emissions are reallocated to the end-use sectors.

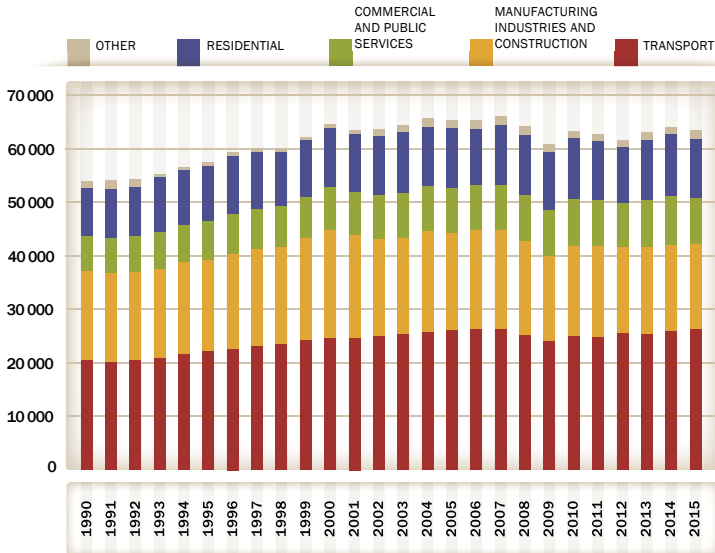
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 32: Share of final energy consumption by sector, 2015

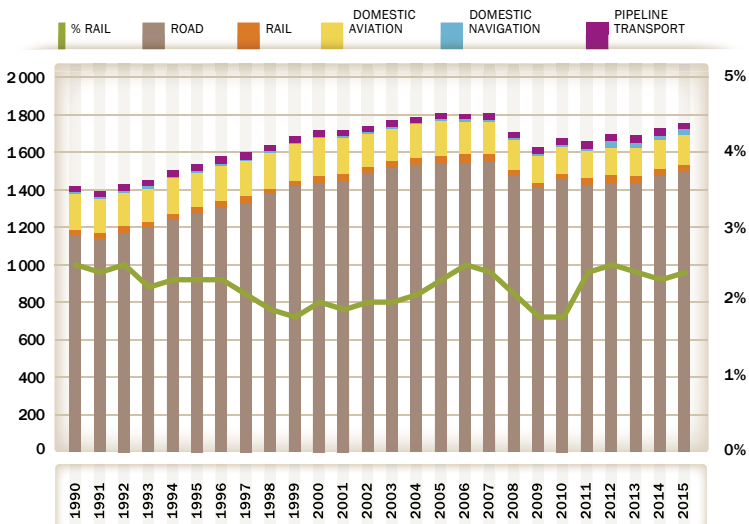


Source: Elaboration by Susdef based on IEA (2017c)

Fig. 33: Total final energy consumption by sector, 1990-2015 (PJ)



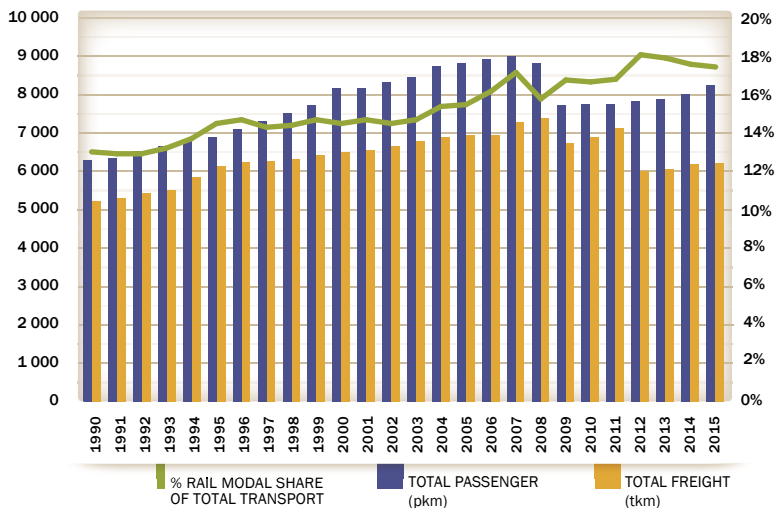
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 34: Transport sector CO₂ emissions by mode, 1990-2015
(left scale - million tCO₂, right scale - rail percentage of total)

Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

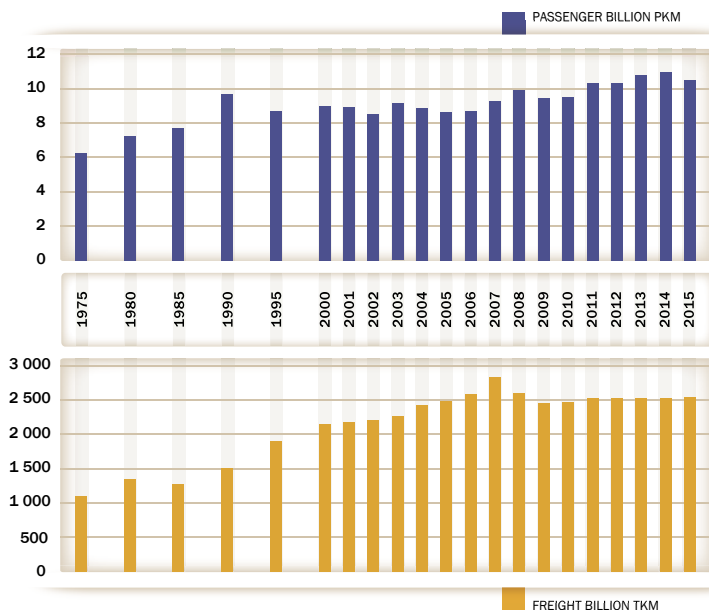
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 35: Passenger and freight transport activity - all modes, 1990-2015
(billion pkm and tkm – left, rail percentage of total – right)



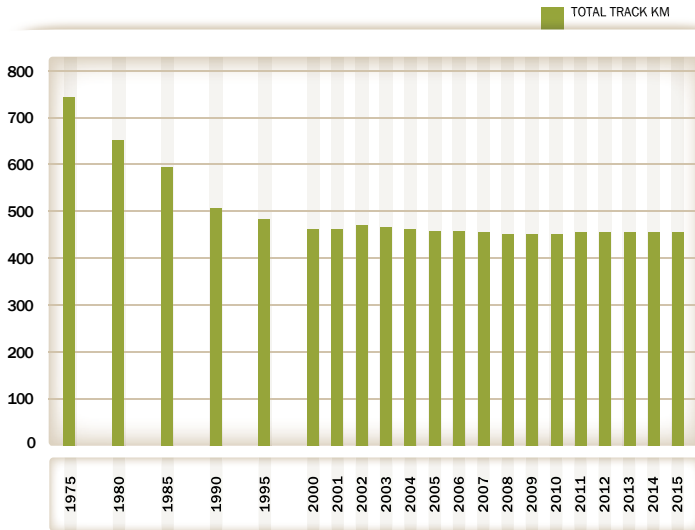
Source: Elaboration by Susdef based on IEA (2017b), UIC (2016a)

Fig. 36: Passenger and freight railway activity, 1975-2015



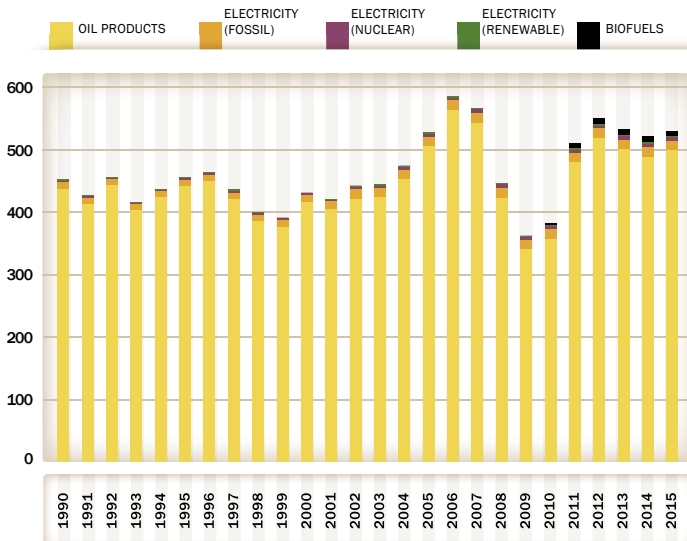
Source: Elaboration by IEA based on UIC (2016a)

Fig. 37: Length of railway tracks, 1975-2015 (thousand km)



Source: Elaboration by IEA based on UIC (2016a)







Fig. 38: Railway final energy consumption by fuel, 1990-2015 (PJ)






Note: See Methodology Notes p. 109.

Source: Elaboration by Susdef based on IEA (2017c).

Table 6: USA railway energy fuel mix, 1990-2015

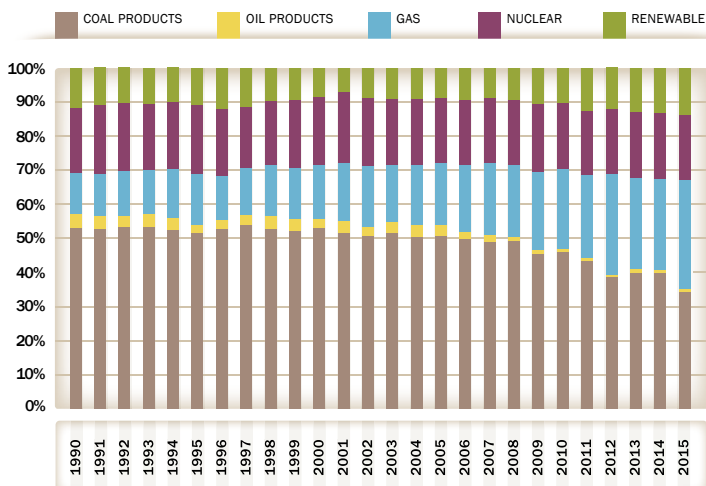
ENERGY MIX BY SOURCE		1990	2015
OIL PRODUCTS		96.7%	94.0%
BIOFUELS		0.0%	1.4%
ELECTRICITY		3.3%	4.6%
of which Fossil		2.3%	3.1%
of which Nuclear		0.6%	0.9%
of which Renewable		0.4%	0.6%

SUMMARY BY SOURCE TYPE		1990	2015
FOSSIL SOURCE		99.0%	97.1%
NUCLEAR		0.6%	0.9%
RENEWABLE		0.4%	2.0%

Note: See Methodology Notes p. 109.

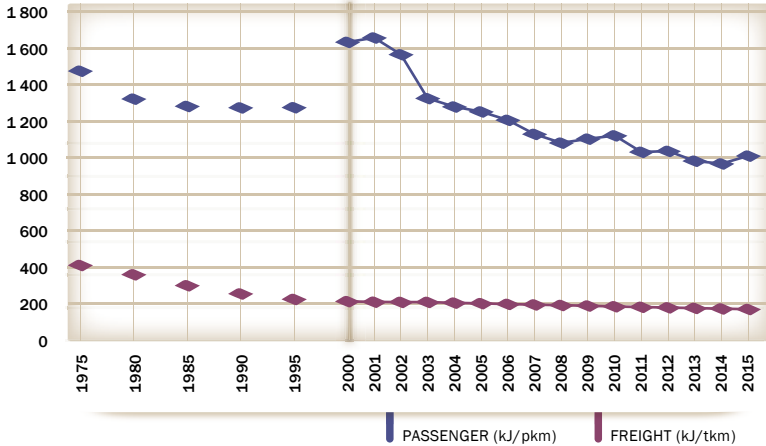
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 39: National electricity production mix evolution, 1990-2015



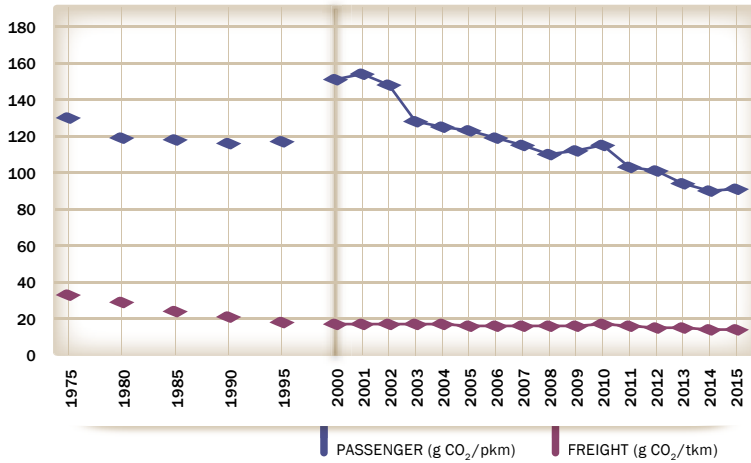
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 40: Railway specific energy consumption, 1975-2015



Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)

Fig. 41: Railway specific CO₂ emissions, 1975-2015

Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)



Japan

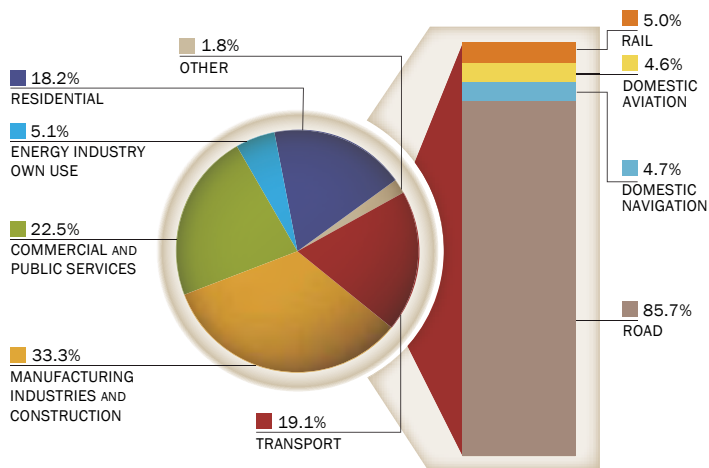
Key Facts

Energy & CO₂ emissions:

- ◆ In Japan, the transport sector accounted for 19.1% of energy related CO₂ emissions (218 million tCO₂), and for 24.5% (2.9 EJ) of final energy demand in 2015.
- ◆ Since the Fukushima accident in 2011, electricity generation from nuclear power decreased rapidly from 25% in 2010 to 1% in 2015. It has been replaced by natural gas and, to a lesser degree, by renewable energy. As a result, the rail sector accounted for 5.0% of transport CO₂ emissions (10.9 million tCO₂) in 2015, up from 4.2% in 2010. Despite this increase, railway final energy consumption decreased over the same period, accounting for 2.4% (72 PJ) of transport final energy demand in 2015.
- ◆ Energy consumption per passenger-km decreased by 15.6% between 2005 and 2015, and energy consumption per freight tonne-km decreased by 13.7% in the same period.
- ◆ CO₂ emissions per passenger-km increased by 0.9% between 2005 and 2015, and CO₂ emissions per freight tonne-km increased by 1.4% in the same period. Japan is the only region included in this handbook where CO₂ intensity of rail has increased.
- ◆ The use of oil products (diesel) in the railway fuel mix has continued to decrease from 11.5% in 2005 to 10.2% in 2015. The share of electricity increased over the same period.

Activity:

- ◆ In 2014, rail accounted for 29.8% of passenger transport activity (in passenger-km), and for 5.1% of freight transport activity (in tonne-km).
- ◆ While passenger rail transport activity increased by 8.6% between 2005 and 2015, freight rail activity declined by 6.3% over the same period. High-speed rail accounted for 44% of the increase in passenger activity and for 24% of total rail passenger-km in 2015.

Fig. 42: Share of CO₂ emissions from fuel combustion by sector, 2015

Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

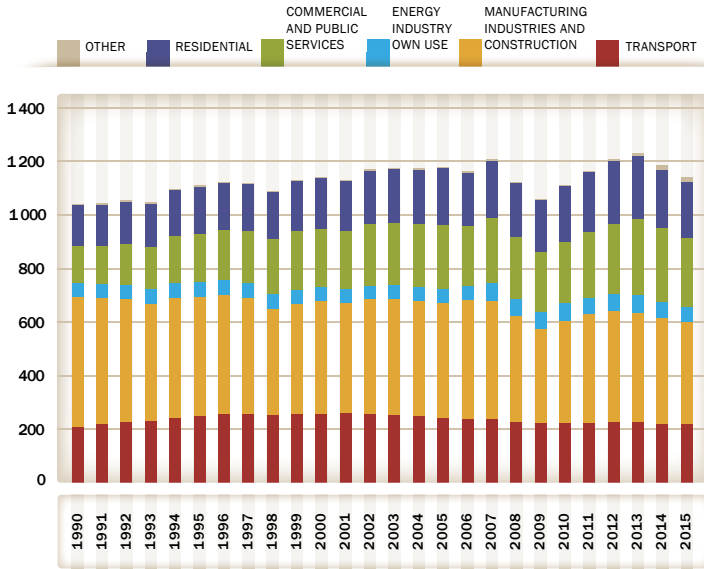
Source: Elaboration by Susdef based on IEA (2017a)

Table 7: Japan transport modal share, 2015

	Passenger PKM	Freight TKM	Total TU
ROAD	62.9%	50.9%	60.2%
AVIATION	6.7%	0.2%	5.2%
NAVIGATION	0.2%	43.7%	10.6%
RAIL	30.2%	5.2%	24.2%

Source: Elaboration by Susdef based on JSY (2017), IEA (2017b), UIC (2016a)

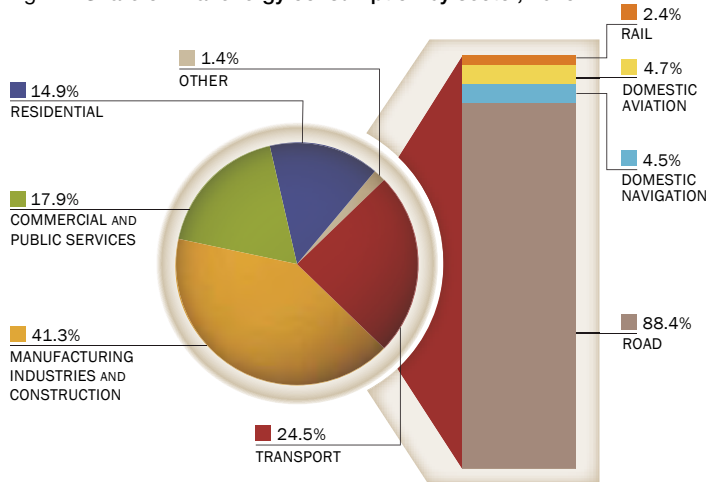
Fig. 43: Total CO₂ emissions from fuel combustion by sector, 1990-2015 (million tCO₂)



Note: Electricity and heat production related emissions are reallocated to the end-use sectors.

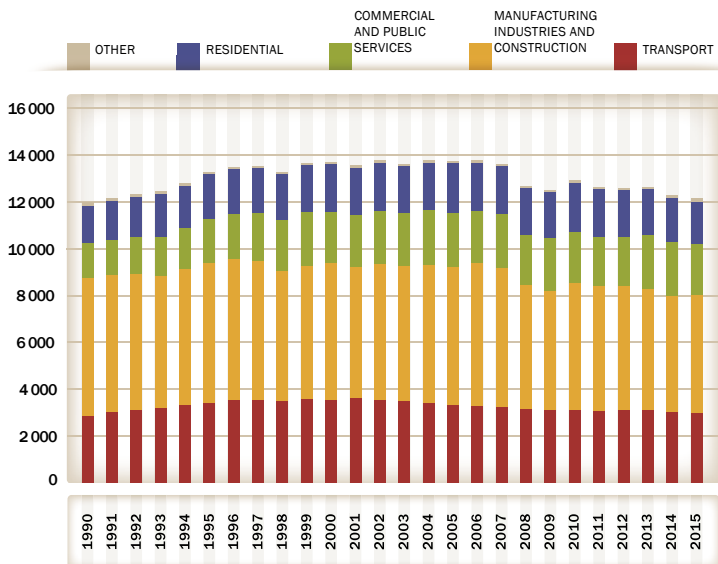
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 44: Share of final energy consumption by sector, 2015

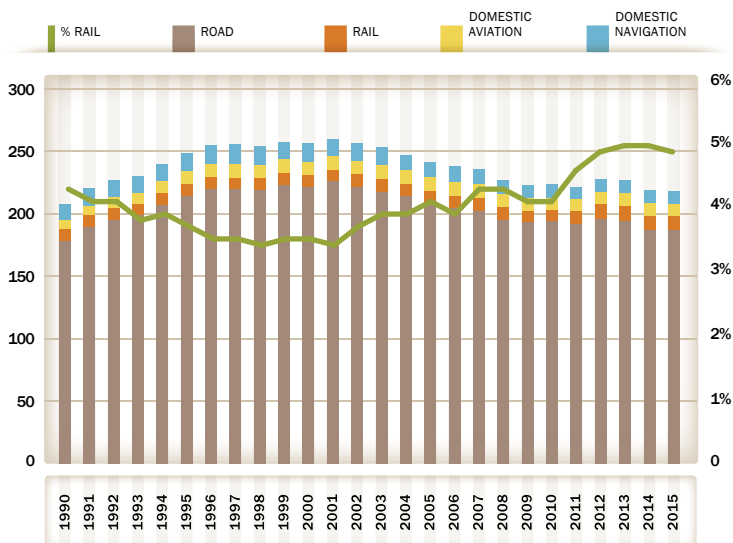


Source: Elaboration by Susdef based on IEA (2017c)

Fig. 45: Total final energy consumption by sector, 1990-2015 (PJ)



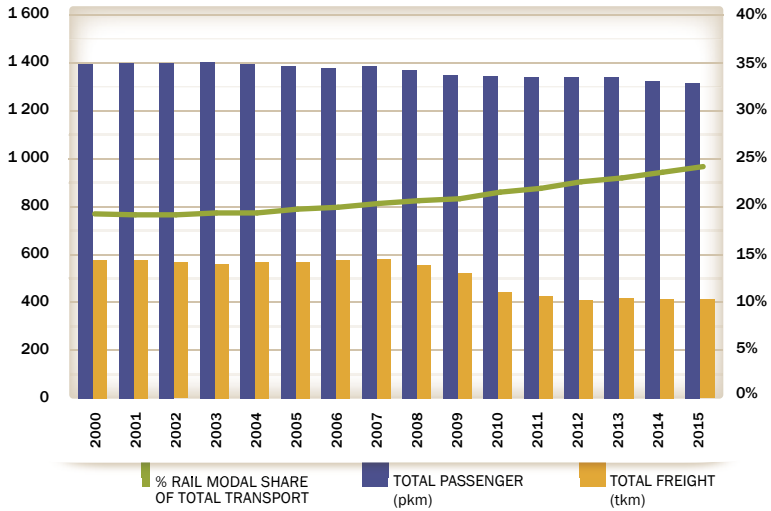
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 46: Transport sector CO₂ emissions by mode, 1990-2015 (left scale - million tCO₂, right scale - rail percentage of total)

Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

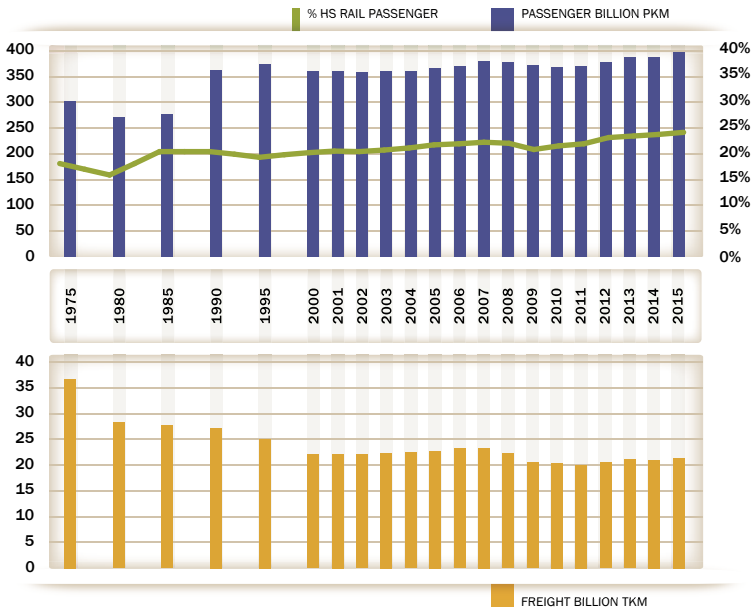
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 47: Passenger and freight transport activity – all modes, 2000-2015 (billion pkm and tkm – left, rail percentage of total – right)



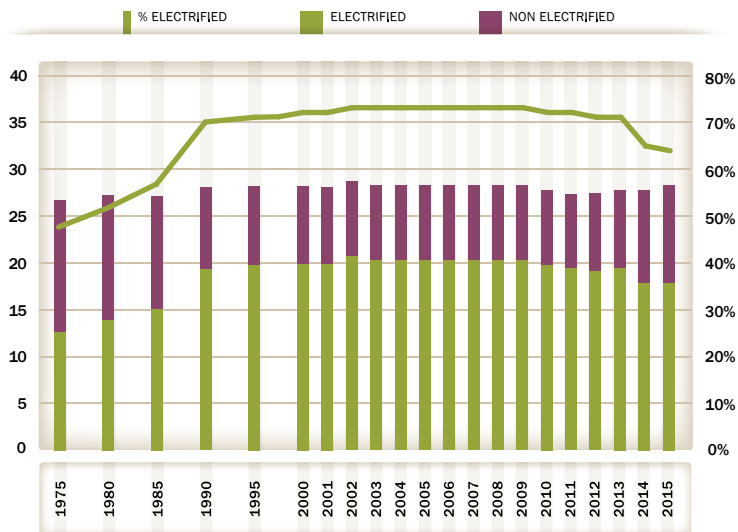
Source: Elaboration by Susdef based on JSY (2017), IEA (2017b), UIC (2016a)

Fig. 48: Passenger and freight railway activity and High-Speed activity as a share of total passenger railway activity (%), 1975-2015



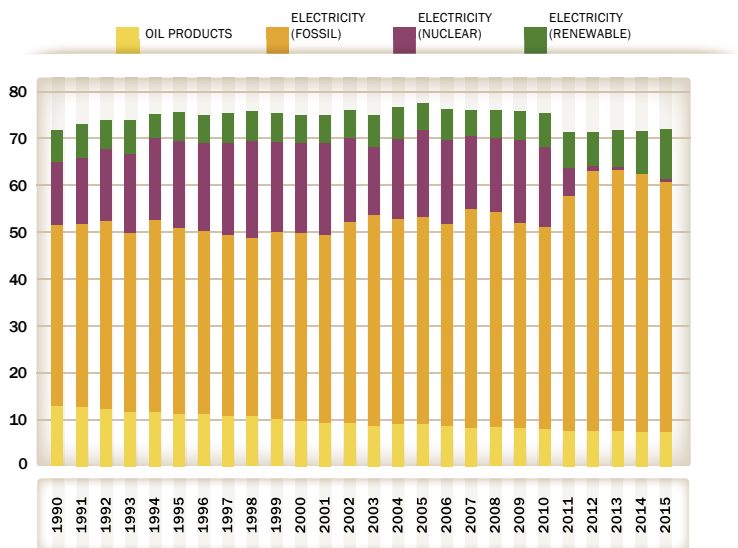
Source: Elaboration by IEA based on UIC (2016a)

Fig. 49: Length and share of electrified and non-electrified railway tracks, 1975-2015 (thousand km)



Source: Elaboration by IEA based on UIC (2016a)






Fig. 50: Railway final energy consumption by fuel, 1990-2015 (PJ)






Note: See Methodology Notes p. 109.

Source: Elaboration by Susdef based on IEA (2017c)

Table 8: Japan railway energy fuel mix, 1990-2015

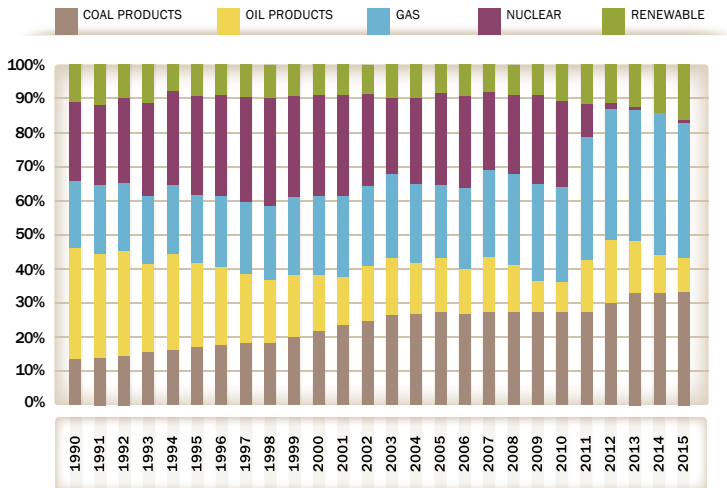
ENERGY MIX BY SOURCE		1990	2015
OIL PRODUCTS		17.8%	10.2%
ELECTRICITY		82.2%	89.8%
of which Fossil		53.9%	74.2%
of which Nuclear		19.0%	0.8%
of which Renewable		9.3%	14.8%

SUMMARY BY SOURCE TYPE		1990	2015
FOSSIL SOURCE		71.7%	84.4%
NUCLEAR		19.0%	0.8%
RENEWABLE		9.3%	14.8%

Note: See Methodology Notes p. 109.

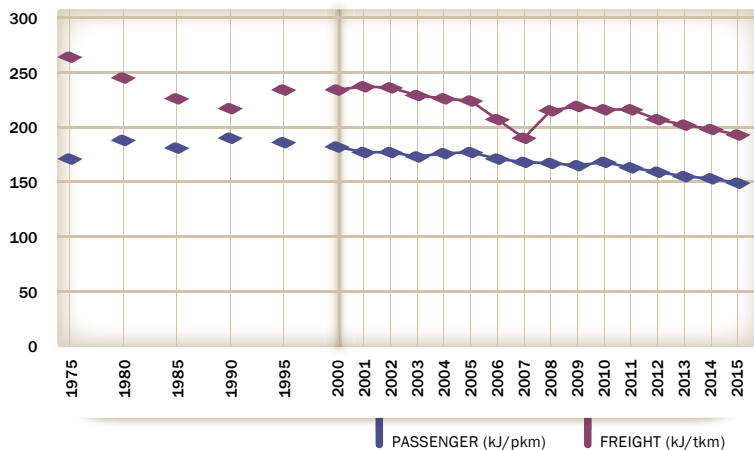
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 51: National electricity production mix evolution, 1990-2015



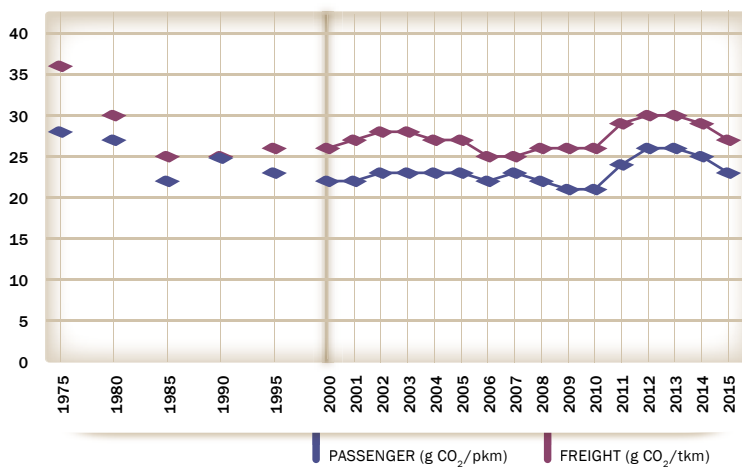
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 52: Railway specific energy consumption, 1975-2015



Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)

Fig. 53: Railway specific CO₂ emissions, 1975-2015

Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)



Russian Federation

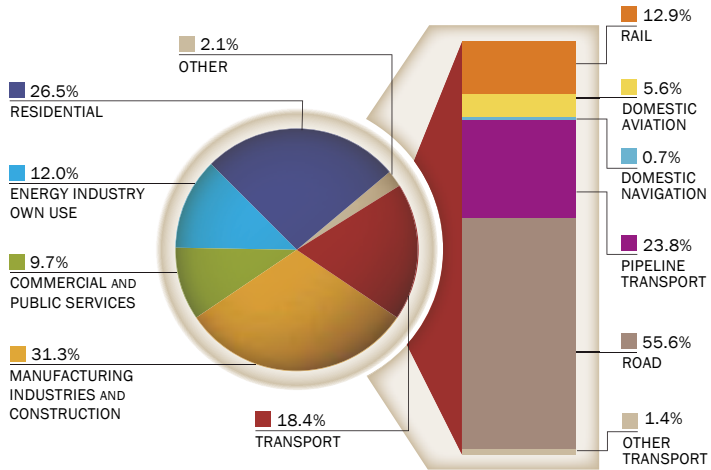
Key Facts

Energy & CO₂ emissions:

- ◆ In the Russian Federation, the transport sector accounted for 18.4% of energy related CO₂ emissions (271 million tCO₂), and for 20.5% (3.9 EJ) of final energy consumption in 2015.
- ◆ The rail sector accounted for 12.9% of CO₂ emissions from transport (35 million tCO₂), and for 6.2% (246 PJ) of the transport final energy demand in 2015.
- ◆ Energy consumption per passenger-km decreased by 0.2% between 2005 and 2015, and energy consumption per freight tonne-km decreased by 4.1% in the same period. The latter is the smallest decrease observed among the countries included in this handbook. On the other hand, the Russian freight railway system is one of the most energy efficient systems in the world.
- ◆ CO₂ emissions per passenger-km decreased by 7.6% between 2005 and 2015, and CO₂ emissions per freight tonne-km decreased by 13.3% in the same period.
- ◆ The use of oil products (diesel) in the railway fuel mix declined from 35.8% in 2005 to 27.4% in 2015. This is consistent with an increasing share of electricity in the railway fuel mix.

Activity:

- ◆ Between 2005 and 2015, passenger rail activity (passenger-km) declined by 24.6%, whereas freight rail activity (tonne-km) has increased by 24.4% in the same period.
- ◆ In 2015 rail accounted for 26.7% of total passenger activity, and for 88.4% of total freight activity.
- ◆ This is the highest share of freight activity covered by this publication.

Fig. 54: Share of CO₂ emissions from fuel combustion by sector, 2015

Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

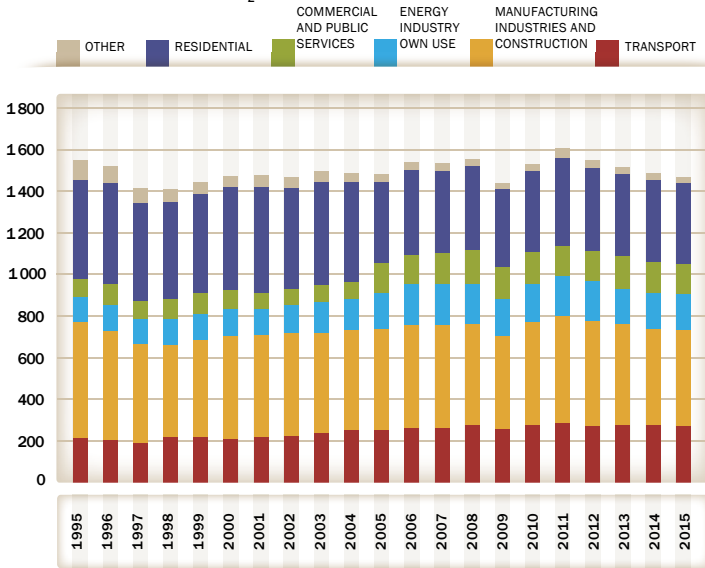
Source: Elaboration by Susdef based on IEA (2017a)

Table 9: Russia transport modal share, 2015

	Passenger PKM	Freight TKM	Total TU
ROAD	26.2%	8.9%	11.6%
AVIATION	47.0%	0.2%	7.5%
NAVIGATION	0.1%	2.5%	2.1%
RAIL	26.7%	88.4%	78.8%

Source: Elaboration by Susdef based on OECD (2017), UIC (2016a) and Rosstat (2017)

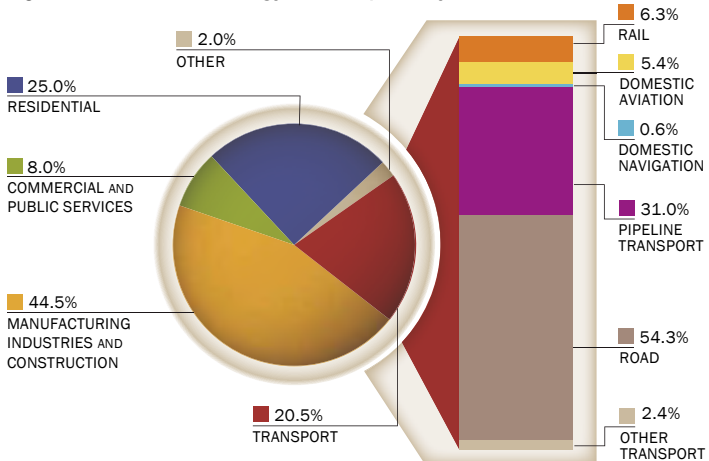
Fig. 55: Total CO₂ emissions from fuel combustion by sector, 1995-2015 (million tCO₂)



Note: Electricity and heat production related emissions are reallocated to the end-use sectors.

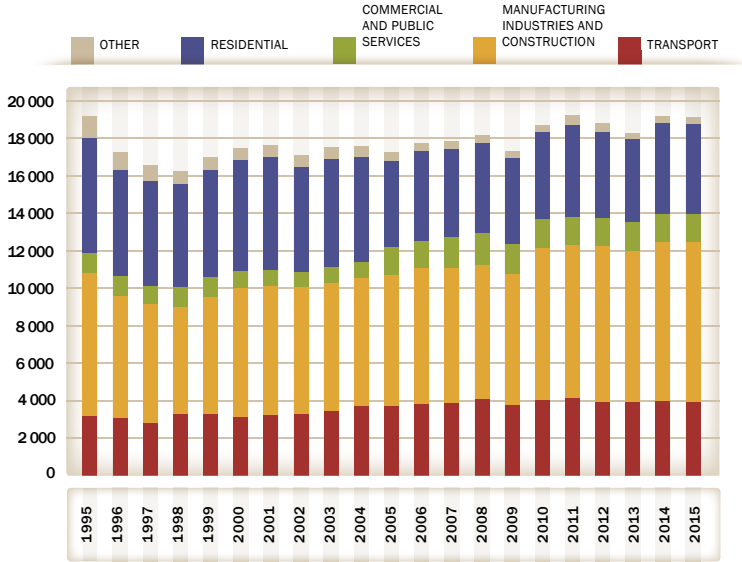
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 56: Share of final energy consumption by sector, 2015



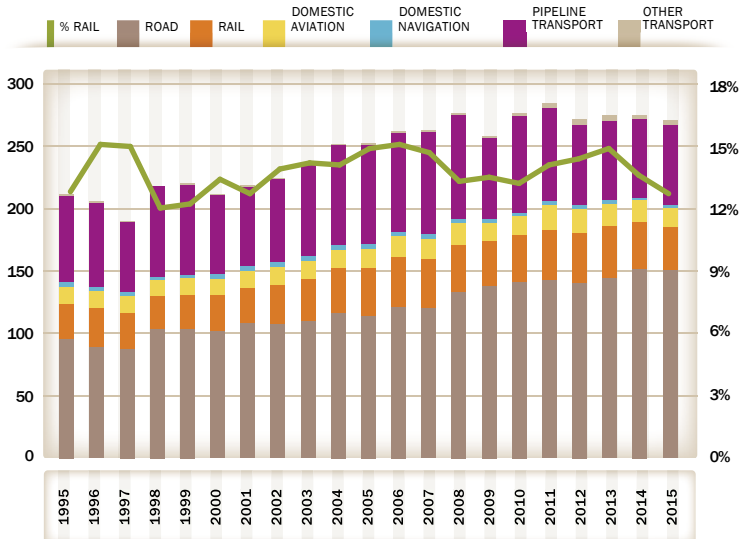
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 57: Total final energy consumption by sector, 1995-2015 (PJ)



Source: Elaboration by Susdef based on IEA (2017c)

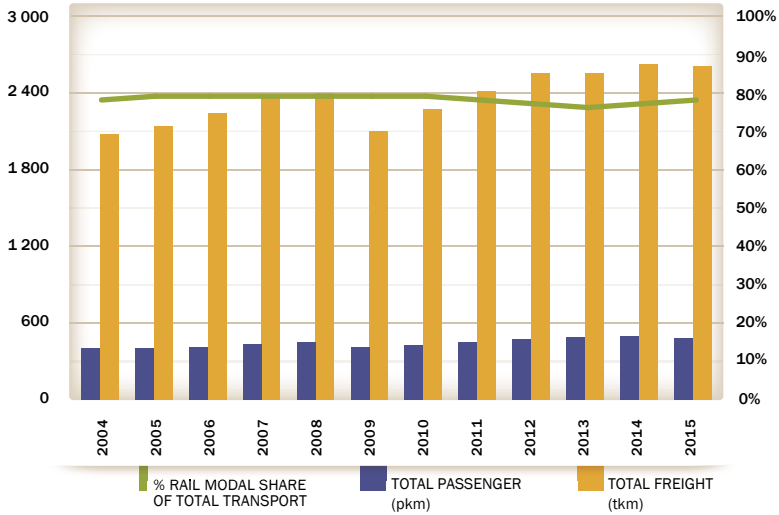
Fig. 58: Transport sector CO₂ emissions by mode, 1990-2015 (left scale - million tCO₂, right scale - rail percentage of total)



Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

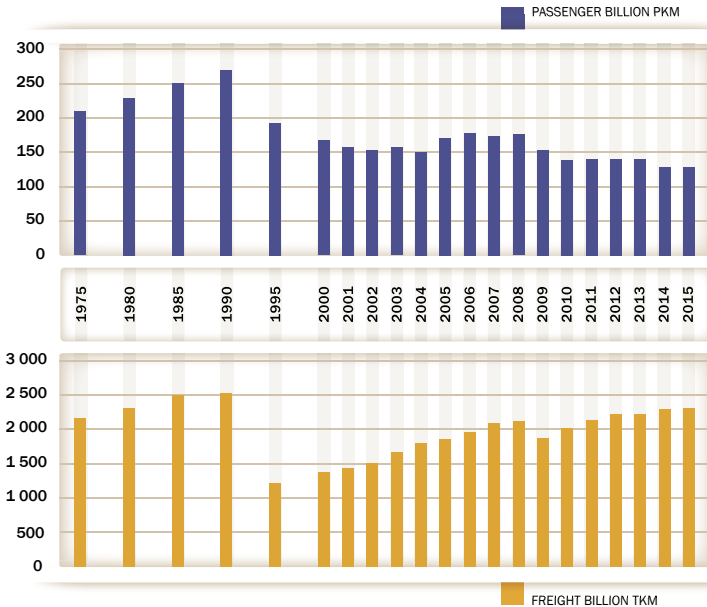
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 59: Passenger and freight transport activity – all modes, 2004-2015 (billion pkm and tkm – left, rail percentage of total – right)



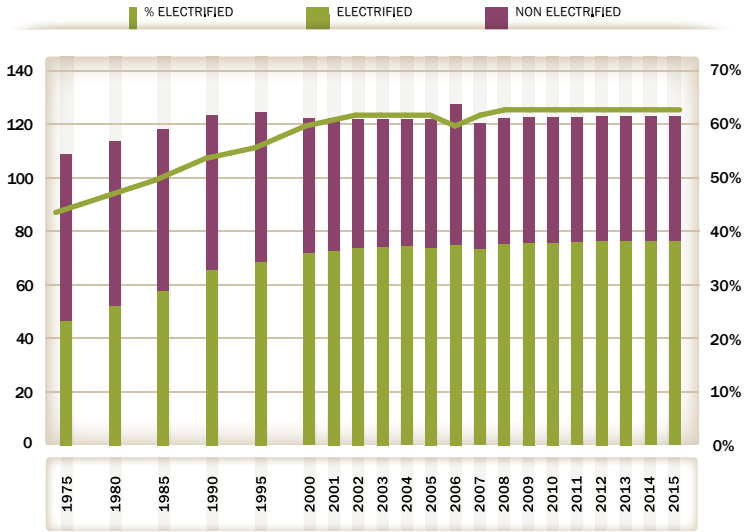
Source: Elaboration by Susdef based on OECD (2017), Rosstat (2015) and UIC (2016a)

Fig. 60: Passenger and freight railway activity, 1975-2015



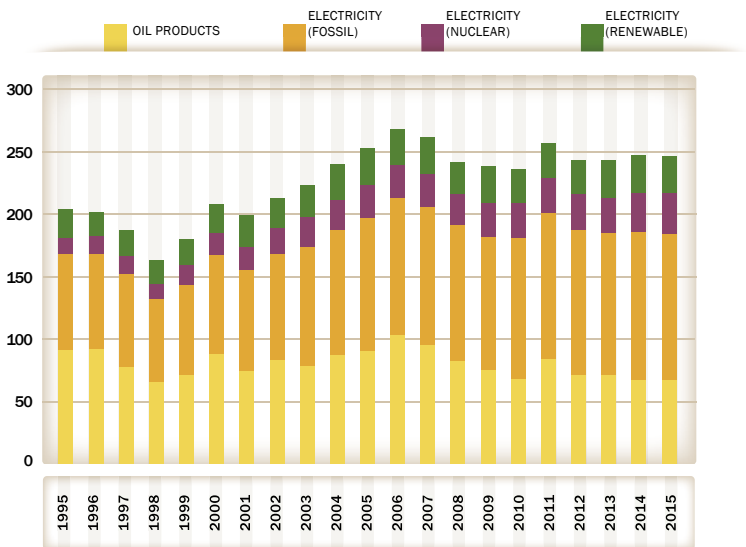
Source: Elaboration by IEA based on UIC (2016a)

Fig. 61: Length and share of electrified and non-electrified railway tracks, 1975-2015 (thousand km)



Source: Elaboration by IEA based on UIC (2016a)






Fig. 62: Railway final energy consumption by fuel, 1995-2015 (PJ)






Note: See Methodology Notes p. 109.

Source: Elaboration by Susdef based on IEA (2017c)

Table 10: Russia railway energy fuel mix, 1995-2015

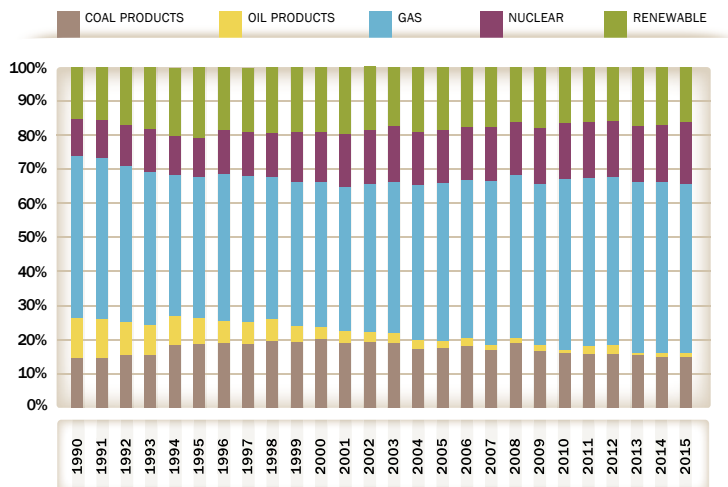
ENERGY MIX BY SOURCE		1995	2015
OIL PRODUCTS		44.6%	27.4%
ELECTRICITY		55.4%	72.6%
of which Fossil		37.6%	47.6%
of which Nuclear		6.4%	13.3%
of which Renewable		11.4%	11.7%

SUMMARY BY SOURCE TYPE		1995	2015
FOSSIL SOURCE		82.2%	75.0%
NUCLEAR		6.4%	13.3%
RENEWABLE		11.4%	11.7%

Note: See Methodology Notes p. 109.

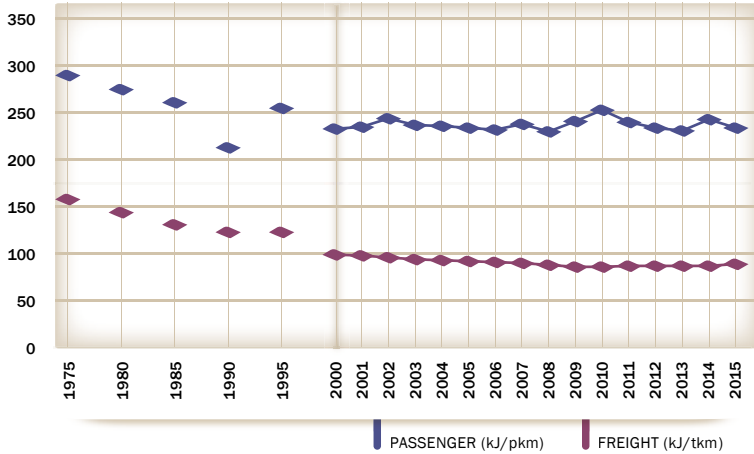
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 63: National electricity production mix evolution, 1990-2015



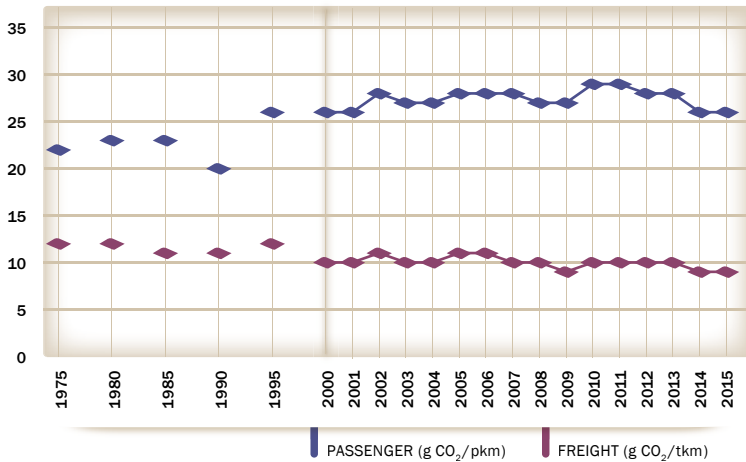
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 64: Railway specific energy consumption, 1975-2015



Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017c)

Fig. 65: Railway specific CO₂ emissions, 1975-2015

Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)



Key Facts

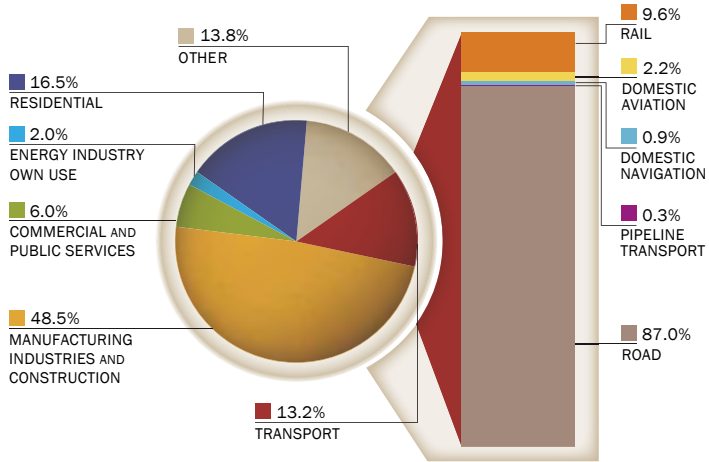
Energy & CO₂ emissions:

- ◆ In India, the transport sector accounted for 13.2% of energy related CO₂ emissions (272 million tCO₂), and for 14.9% (3.6 EJ) of final energy demand in 2015.
- ◆ The rail sector accounted for 9.6% (26 million tCO₂) of CO₂ emissions from transport, and for 5.0% (179 PJ) of transport final energy demand in 2015.
- ◆ Energy consumption per passenger-km decreased by over a third (36.2%) between 2005 and 2015, and energy consumption per freight tonne-km decreased by 17.1% in the same period.
- ◆ CO₂ emissions per passenger-km decreased by almost a third (32.8%) between 2005 and 2015, and CO₂ emissions per freight tonne-km decreased by 14.6% in the same period.
- ◆ While the amount of oil products (diesel) used to fuel trains increased due to strong activity growth between 2005 and 2015, its share in the railway fuel mix declined slightly (from 69.5% to 66.2%).

Activity:

- ◆ In 2015, rail accounted for 11.5% of passenger transport activity (in passenger-km) and for 31.2% of freight transport activity (in tonne-km).
- ◆ In 2015, India experienced the strongest increase of rail activity of all countries and regions covered in this handbook between 2005 and 2015: passenger rail activity doubled and freight rail activity grew by two-thirds.

Fig. 66: Share of CO₂ emissions from fuel combustion by sector, 2015



Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

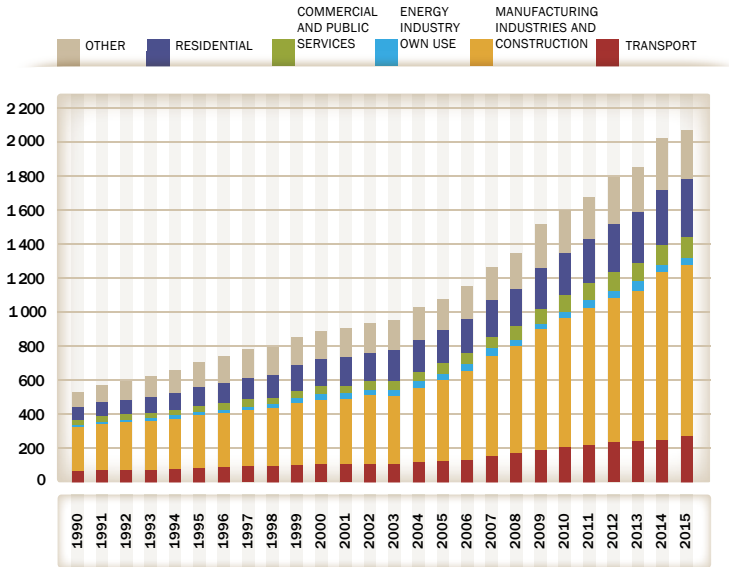
Source: Elaboration by Susdef based on IEA (2017a)

Table 11: India transport modal share, 2015

		Passenger PKM	Freight TKM	Total TU
ROAD	■	87.2%	68.6%	83.8%
AVIATION	■	1.3%	0.1%	1.1%
NAVIGATION	■	-	0.1%	N.A.
RAIL	■	11.5%	31.2%	15.1%

Source: Elaboration by Susdef based on OECD (2017), UIC (2016a) and SYB (2017)

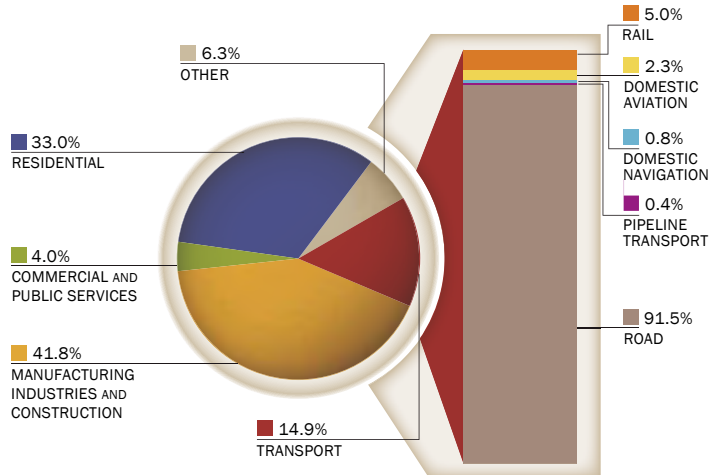
Fig. 67: Total CO₂ emissions from fuel combustion by sector, 1990-2015 (million tCO₂)



Note: Electricity and heat production related emissions are reallocated to the end-use sectors.

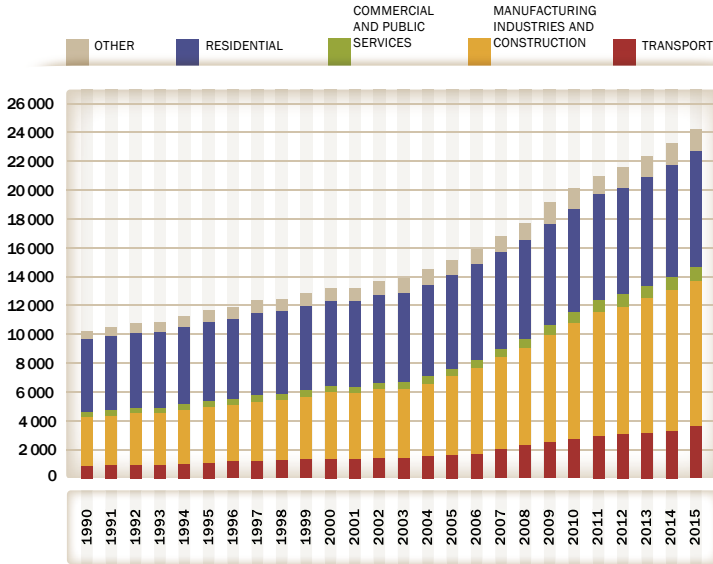
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 68: Share of final energy consumption by sector, 2015



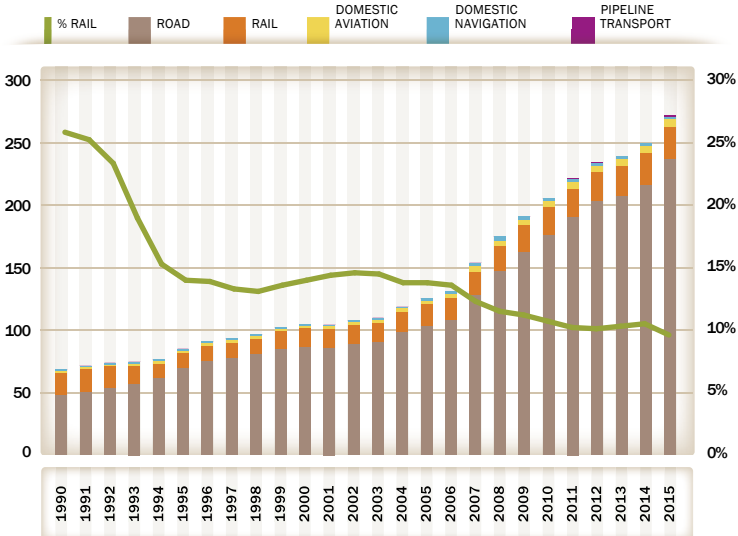
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 69: Total final energy consumption by sector, 1990-2015 (PJ)



Source: Elaboration by Susdef based on IEA (2017c)

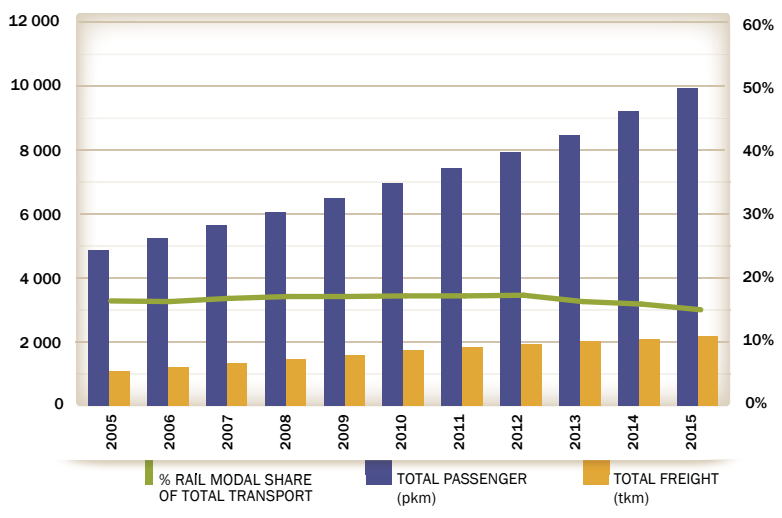
Fig. 70: Transport sector CO₂ emissions by mode, 1990-2015
(left scale - million tCO₂, right scale - rail percentage of total)



Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail.

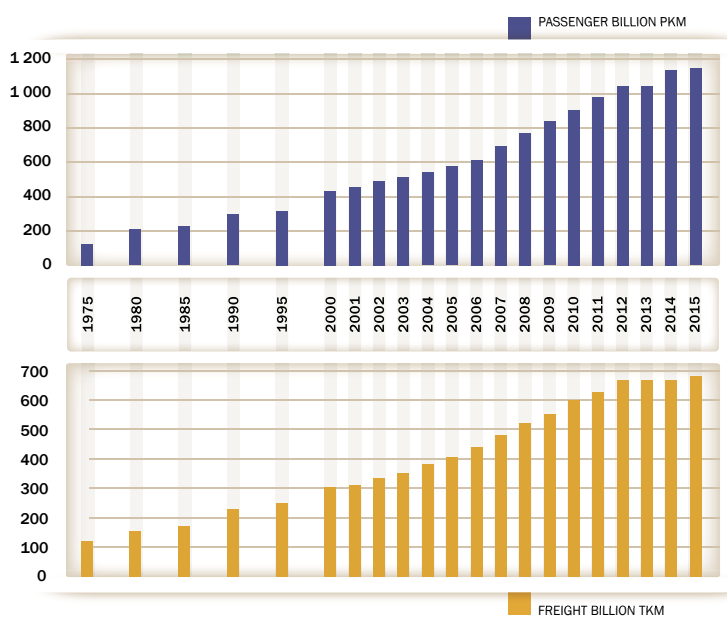
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 71: Passenger and freight transport activity - all modes, 2005-2015 (billion pkm and tkm – left, rail percentage of total – right)



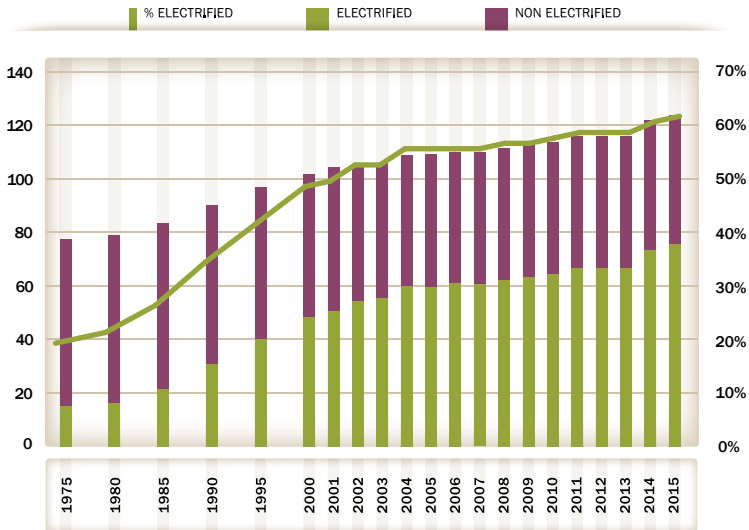
Source: Elaboration by Susdef based on OECD (2017), UIC (2016a) and SYB (2017).

Fig. 72: Passenger and freight railway activity, 1975-2015



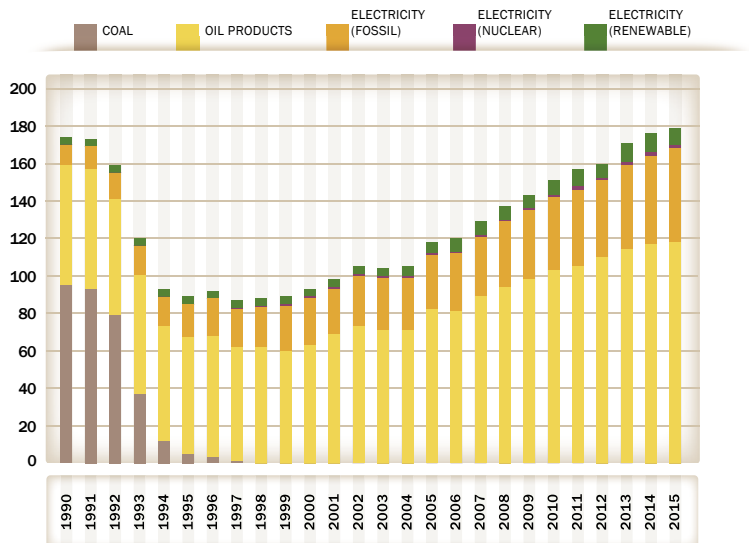
Source: Elaboration by IEA based on UIC (2016a)

Fig. 73: Length and share of electrified and non-electrified railway tracks, 1975-2015 (thousand km)



Source: Elaboration by IEA based on UIC (2016a)







Fig. 74: Railway final energy consumption by fuel, 1990-2015 (PJ)






Note: See Methodology Notes p. 109.

Source: Elaboration by Susdef based on IEA (2017c)

Table 12: India railway energy fuel mix, 1990-2015

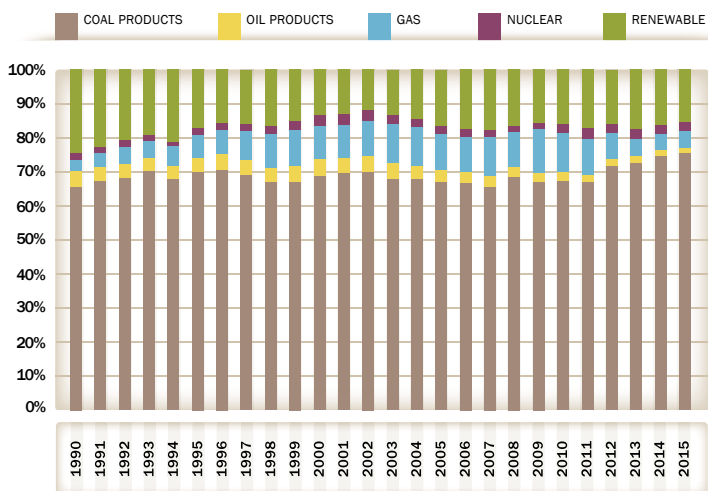
ENERGY MIX BY SOURCE		1990	2015
OIL PRODUCTS		36.9%	66.2%
COAL PRODUCTS		54.5%	0.0%
ELECTRICITY		8.6%	33.8%
of which Fossil		6.3%	27.7%
of which Nuclear		0.2%	0.9%
of which Renewable		2.1%	5.2%

SUMMARY BY SOURCE TYPE		1990	2015
FOSSIL SOURCE		97.7%	93.9%
NUCLEAR		0.2%	0.9%
RENEWABLE		2.1%	5.2%

Note: See Methodology Notes p. 109.

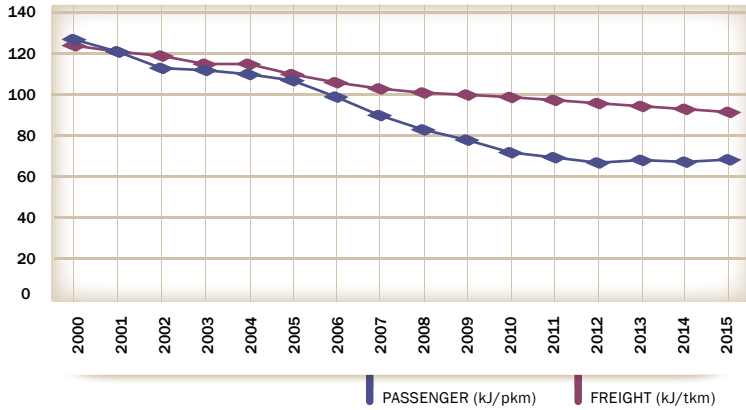
Source: Source: Elaboration by Susdef based on IEA (2017c)

Fig. 75: National electricity production mix evolution, 1990-2015



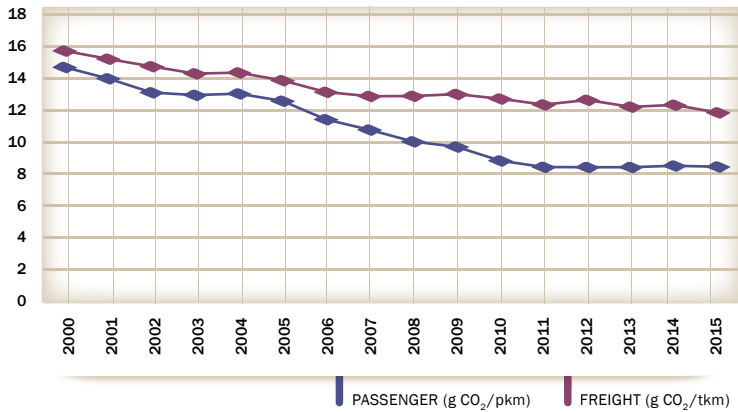
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 76: Railway specific energy consumption, 2000-2015



Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)

Fig. 77: Railway specific CO₂ emissions, 2000-2015

Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)



People's Republic of China

Key Facts

Energy & CO₂ emissions

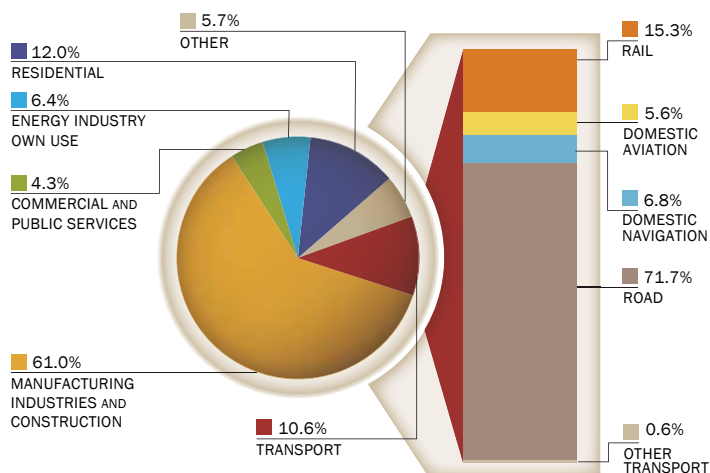
- ◆ In China, transport accounted for 10.6% of energy related CO₂ emissions (964 million tCO₂), and for 15.7% (12.5 EJ) of final energy demand in 2015. Between 2005 and 2015, CO₂ emissions from transport more than doubled, mostly due to rapid growth of road transport.
- ◆ The rail sector accounted for 15.3% (147 million tCO₂) of CO₂ emissions from transport, and for 3.7% (461 PJ) of transport final energy demand in 2015.
- ◆ Energy consumption per passenger-km increased by 44.1% between 2005 and 2015, while energy consumption per freight tonne-km decreased by 29.2% in the same period.
- ◆ The reduction of energy efficiency (per passenger-km) in passenger rail can be explained by the major growth of high-speed rail activity in recent years (see Box 2 in Part II of this Handbook). Between 2005 and 2015 the share of high-speed rail activity in passenger rail grew from 1% to more than 50%. High-speed rail has a higher specific energy consumption per passenger-km than conventional rail, explaining the increase of energy consumption per passenger-km presented in figure 88.
- ◆ This is also consistent with an increase of CO₂ emissions per passenger-km by 96.8% between 2005 and 2015. CO₂ emissions per freight tonne-km decreased by 21.5% in the same period.
- ◆ The use of oil products (diesel) in the railway fuel mix nearly halved between 2005 and 2010, and diesel accounts for 29.3% of the fuel mix today. The share of electricity use in the railway fuel mix more than tripled between 2005 and 2010.

Activity

- ◆ In 2015, rail accounted for 28.5% of passenger transport activity (in passenger-km) and for 11.7% of freight transport activity (in tonne-km).
- ◆ Between 2005 and 2015, both passenger and freight rail activity increased (by 23.9% and 1.4% respectively). High-speed rail activity increased vastly, from 7 billion passenger-km in 2005 to 386 billion passenger-km in 2015. In the process, High-speed rail replaced part of the conventional rail activity, which decreased by 41.6% between 2005 and 2010.

Infrastructure

- ◆ The share of electrified track in China has more than doubled over the ten years between 2005 and 2015, from 21% to 46%.
- ◆ China's 17 870 km of high-speed rail tracks make up almost 60% of the global high-speed rail network.

Fig. 78: Share of CO₂ emissions from fuel combustion by sector, 2015

Note: Electricity and heat production related emissions are reallocated to the end-use sectors. In transport, all the emissions from electricity and heat production are reallocated to rail. "Other transport" includes emissions from pipeline transport.

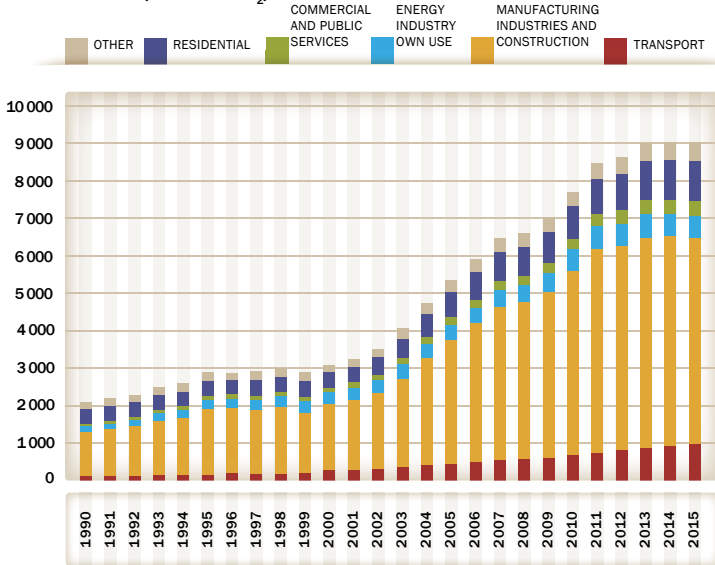
Source: Elaboration by Susdef based on IEA (2017a)

Table 13: China transport modal share, 2015

	Passenger PKM	Freight TKM	Total TU
ROAD	42.4%	34.1%	35.2%
AVIATION	28.8%	0.1%	3.8%
NAVIGATION	0.3%	54.1%	47.1%
RAIL	28.5%	11.7%	13.9%

Source: Elaboration by Susdef based on UIC (2016a) and CNBS (2017)

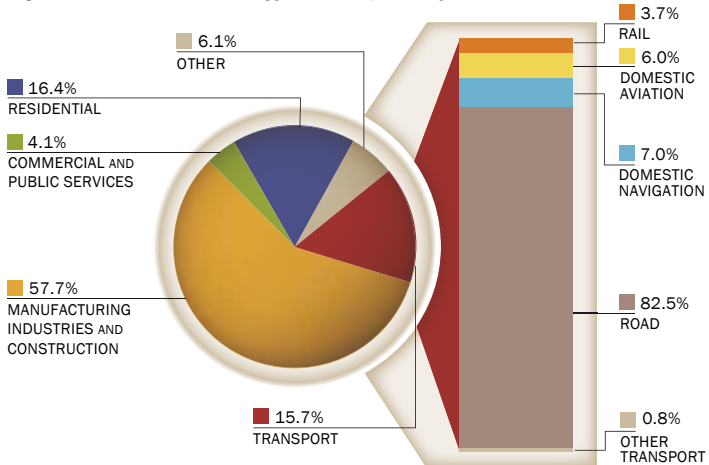
Fig. 79: Total CO₂ emissions from fuel combustion by sector, 1995-2015 (million tCO₂)



Note: Electricity and heat production related emissions are reallocated to the end-use sectors.

Source: Elaboration by Susdef based on IEA (2017a)

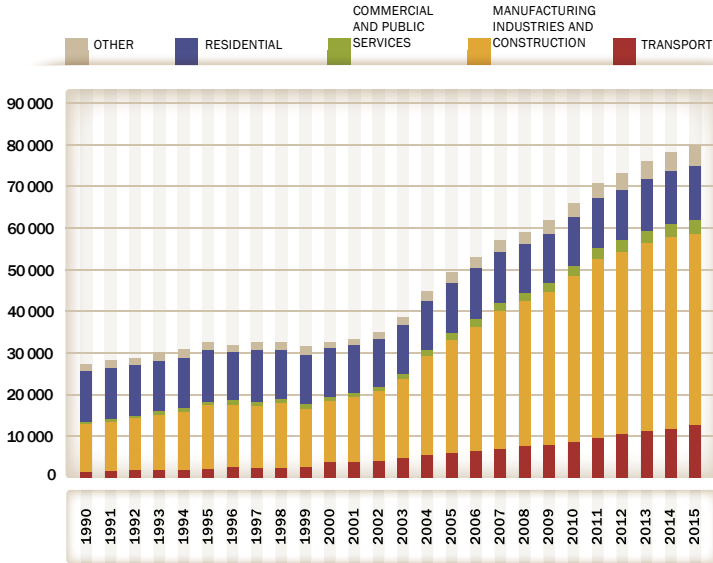
Fig. 80: Share of final energy consumption by sector, 2015



Note: "Other transport" includes emissions from Pipeline transport.

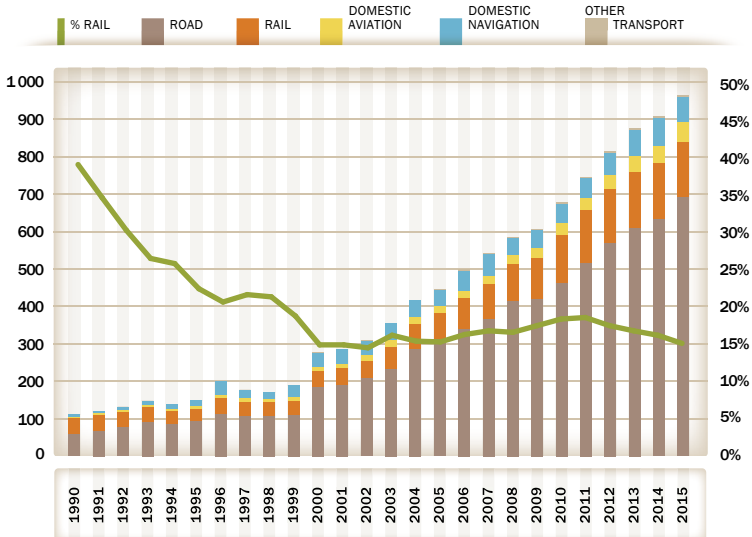
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 81: Total final energy consumption by sector, 1990-2015 (PJ)



Source: Elaboration by Susdef based on IEA (2017c)

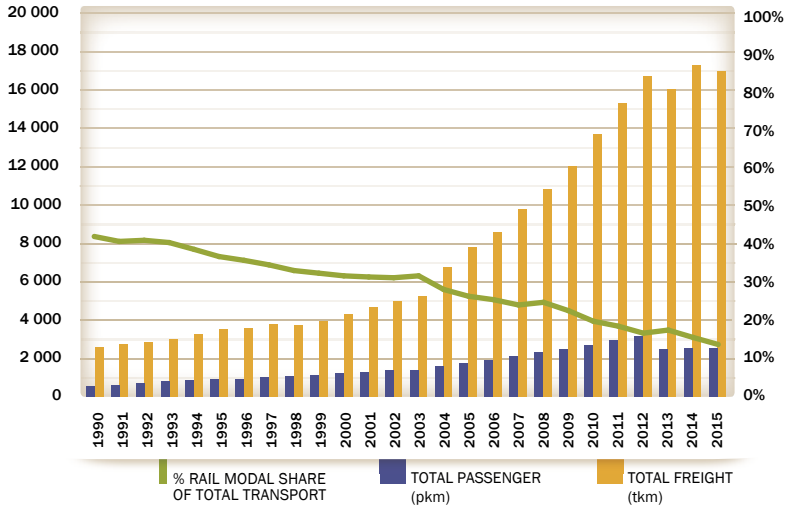
Fig. 82: Transport sector CO₂ emissions by mode, 1990-2015 (left scale - million tCO₂, right scale - rail share over total)



Note: "Other transport" includes emissions from Pipeline transport.

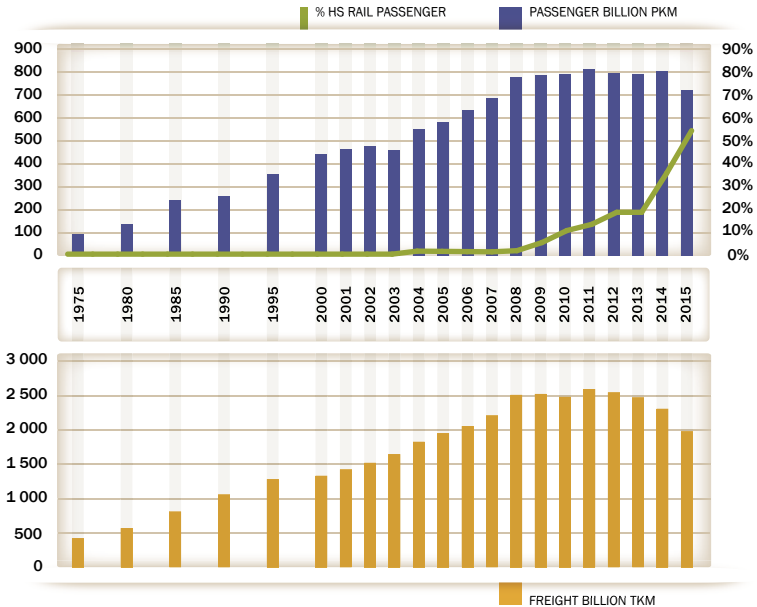
Source: Elaboration by Susdef based on IEA (2017a)

Fig. 83: Passenger and freight transport activity – all modes, 1990-2015 (billion pkm and tkm – left, rail percentage of total – right)



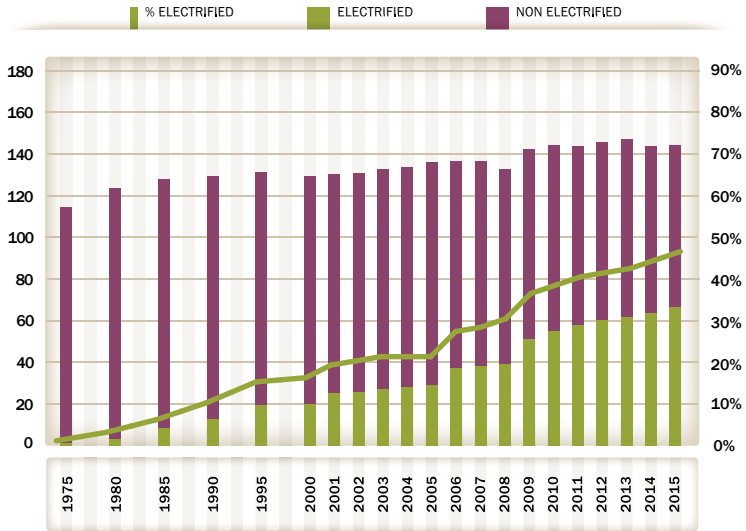
Source: Elaboration by Susdef based on UIC (2016a) and CNBS (2017)

Fig. 84: Passenger and freight railway activity and High-Speed activity as a share of total passenger railway activity, 1975-2015



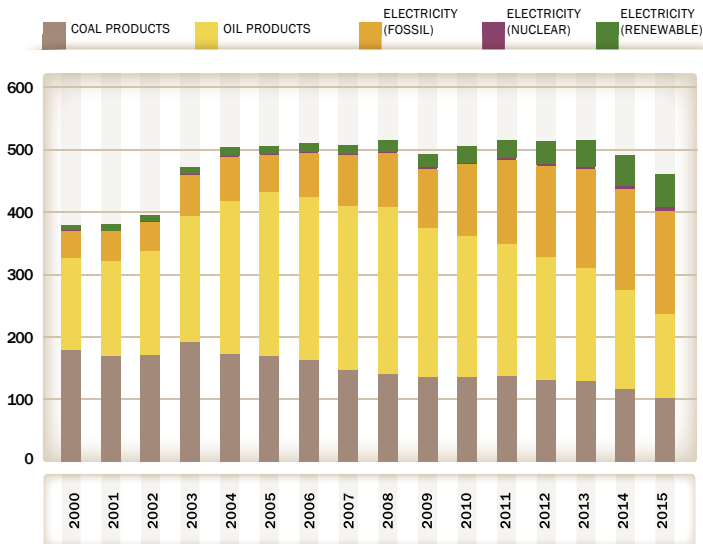
Source: Elaboration by IEA based on UIC (2016a)

Fig. 85: Length and share of electrified and non-electrified railway tracks, 1975-2015 (thousand km)



Source: Elaboration by IEA based on UIC (2016a)







Fig. 86: Railway final energy consumption by fuel, 2000-2015 (PJ)






Note: See Methodology Notes p. 109.

Source: Elaboration by Susdef based on IEA (2017c)

Table 14: China railway energy fuel mix, 2000-2015

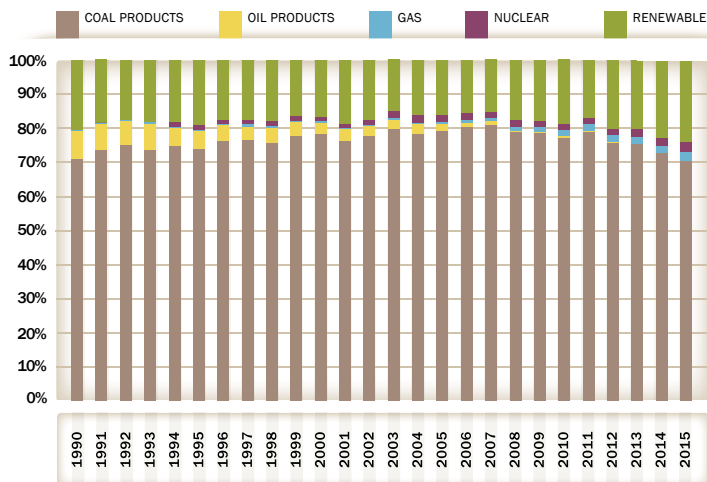
ENERGY MIX BY SOURCE		2000	2015
OIL PRODUCTS		38.8%	29.3%
COAL PRODUCTS		47.0%	22.2%
ELECTRICITY		14.1%	48.6%
of which Fossil		11.6%	35.4%
of which Nuclear		0.2%	1.4%
of which Renewable		2.4%	11.7%

SUMMARY BY SOURCE TYPE		2000	2015
FOSSIL SOURCE		97.4%	86.9%
NUCLEAR		0.2%	1.4%
RENEWABLE		2.4%	11.7%

Note: See Methodology Notes p. 109.

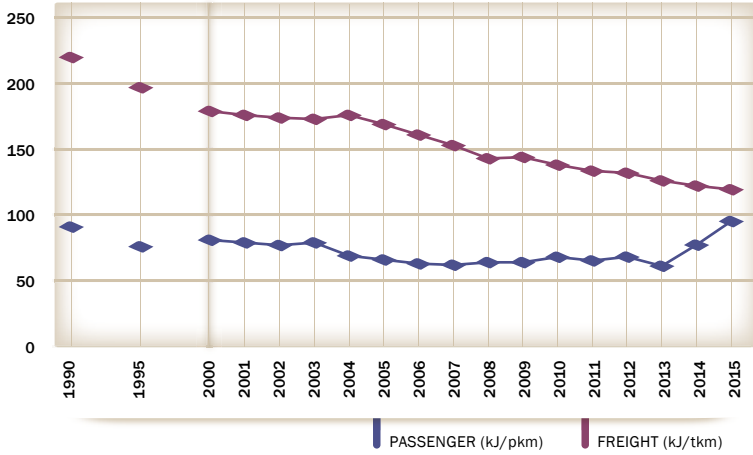
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 87: National electricity production mix evolution, 1990-2015



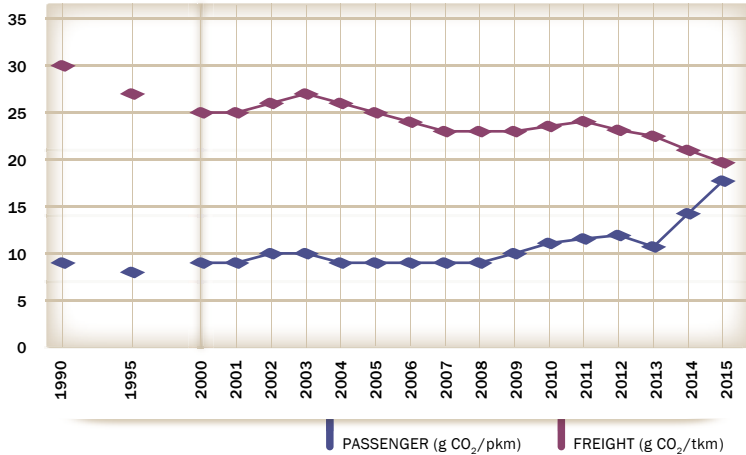
Source: Elaboration by Susdef based on IEA (2017c)

Fig. 88: Railway specific energy consumption, 1990-2015



Note: See Methodology Notes p. 109.

Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)


Fig. 89: Railway specific CO₂ emissions, 1990-2015

Note: See Methodology Notes p. 109.


Source: Elaboration by IEA and Susdef based on IEA (2017b) and UIC (2016a)







**Part II:
Focus on
Passenger
Rail Services**





Introduction, scope and classification issues

80

The focus of this second part of the Railway Handbook is on passenger rail services, including:

- high-speed rail: intercity rail services crossing long distances between stations and having a maximum speed that exceeds 250 km/h;
- high capacity urban rail, including metros and high capacity/high frequency commuter rail services;
- tramways and light rail, i.e. urban guided transport systems with extensive segregated network sections, mostly at-grade; and
- other conventional rail services.

Light rail and tramways, metro and high capacity/high frequency commuter rail are aggregated as urban rail services.

Metros are intended here as urban rail transport services with short headways and high commercial speed operated by vehicles specifically designed for high capacity transport (e.g. including standing passengers and a large number of doors to enable rapid boarding and operations), running on an exclusive right-of-way urban network with regular station spacing, without any interference from other traffic or level crossings, and often developed as an underground and/or elevated network.

Commuter rail includes heavy rail services operating in urban areas and at the boundary between urban and suburban areas, primarily to serve transport needs of commuters needing access to urban environments.

The assessment made here is largely focused on high capacity and high frequency services, typically operated by vehicles specifically designed for rapid boarding operations on networks that are not shared with other rail transport services. This, largely based on data from the International Union for Public Transport (UITP) and the Institute for Transportation and Development Policy (ITDP), is discussed in the section on Urban rail.

Given the nature of the data available (see Box 1 for details), other commuter rail services are not included amongst high capacity/high frequency commuter rail services here, but incorporated under conventional rail and further discussed in a section that builds on specific case studies (*Insights on other commuter rail services*). This section relies on information collected from the International Union of Railways (UIC). This is also the reason why urban rail services identified in this assessment are mostly additional to the rail transport activity reported in Part I of this Handbook, which is entirely relying on UIC statistics for rail transport activity, and covers only a limited portion of high capacity and high frequency urban rail services.

High-speed and other conventional rail services (including intercity and commuter rail complementing the high capacity urban rail category) are interpreted here as non-urban rail services.

The estimates shown in this section cover the whole world with a country-level characterization and rely primarily on data collected by the UIC, the UITP and the ITDP. They were analysed and processed by the IEA in an attempt to respect a common set of definitions.



BOX 1

Data availability and classification

Generally, the classification and definition of rail transport services varies by country and by reporting organization and does not necessarily focus on a distinction between urban and non-urban rail. This is partly due to challenges posed by the country-specific definition of urban areas, by the difference between administrative boundaries and the geographical extent of urban areas, and by the availability of services (often falling under the regional rail category) that include both urban and non-urban portions.

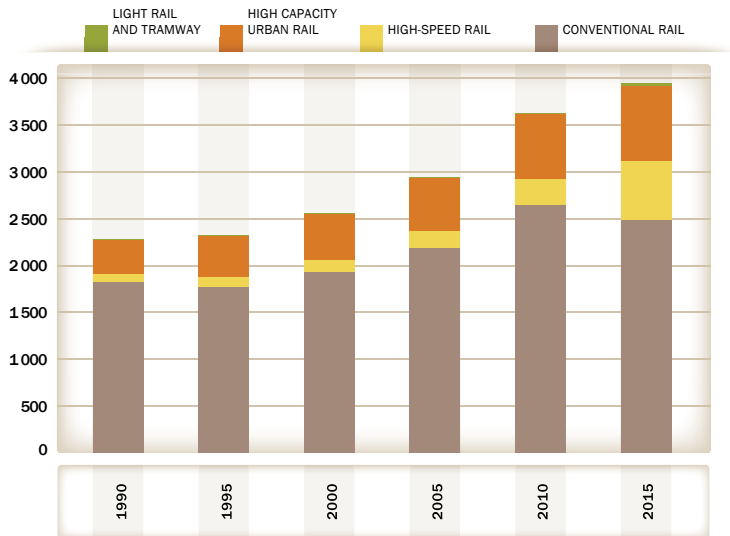
Data on non-urban rail transport services (conventional and high-speed rail), including information on activity, ridership, network extension and other details, are reported to the UIC by operator and by country (UIC 2016a). Similar statistics are available for urban rail transport in International Association of Public Transport (UITP) databases by city, for metro and tramway and light rail services, with varying level of detail over time and by dataset (UITP 2015b). Historical data on urban rail (high capacity urban rail, and light rail and tramway) network extensions, on a line by line basis, are collected by the Institute for Transportation and Development Policy (ITDP) (ITDP 2014). These data are reported according to definitions developed by the ITDP, with the aim to identify high frequency and high capacity commuter rail in addition to metro services.

This assessment builds on the data available from the combination of the three data sources listed above and the definitions they use, and it does not attempt to cover other data that are not reported under this framework.

Passenger rail, an overview of activity and energy use

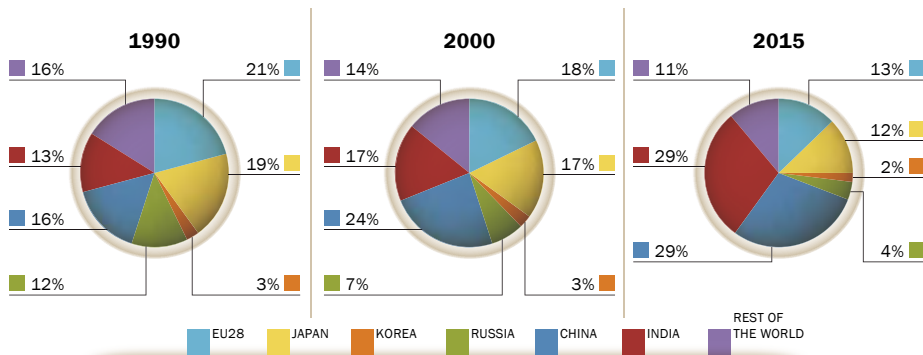
Activity

Fig. 90: Passenger rail by type of service (billion pkm)



Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

Fig. 91: Share of passenger rail activity by geographic area (billion pkm)



Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

Passenger rail transport (including urban rail services) accounted for 9% of global passenger activity (expressed in pkm) in 2015 (IEA 2017b).

Despite a significant increase since 2000, the share of rail pkm in the total of all passenger transport activity declined by one percentage point compared with the year 2000 (IEA 2017b).

Activity on conventional rail declined in recent years, reflecting a shift towards high-speed rail services in China. Whereas activity on urban rail services increased, reflecting a continuous expansion of urban rail networks, especially in Asia.

In 2015, around 75% of the passenger rail activity took place in Asia. The Asian share in total passenger rail activity also grew significantly over the past few decades. Asian economies accounted for around 60% of global passenger rail activity in 2000, compared to 50% fifteen years earlier. Most of this change can be attributed to the development of urban and non-urban (primarily high-speed) rail networks in China and India, which has seen a remarkable acceleration over the past two decades. This change was accompanied by significant increases of rail pkm in Korea and the ASEAN region.

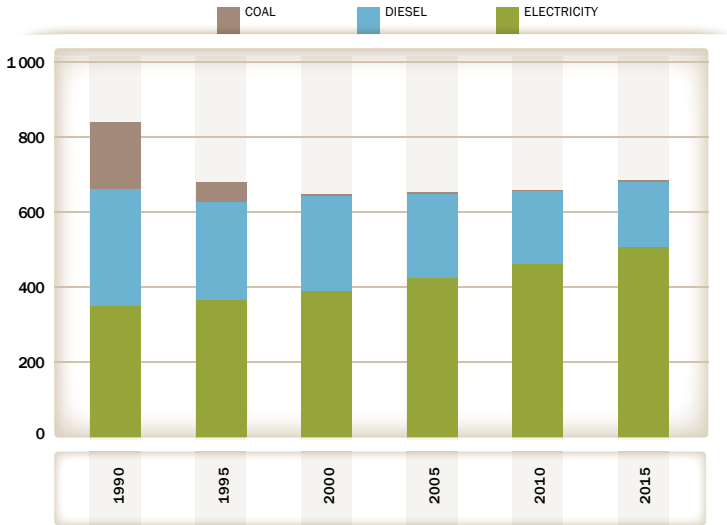
Japan still represented a significant share of the global passenger rail activity (12% in 2015), but passenger rail activity in Japan experienced a much lower growth in the past few decades compared to rapidly growing Asian economies.

Similar to Japan, the European Union accounted for 13% of the global pkm in 2015, down from nearly 20% in 2000.

North American countries account for minor shares of passenger rail services (1%). This reflects the strong dependency on cars in low density urban environments and a limited extension of non-urban passenger rail networks.

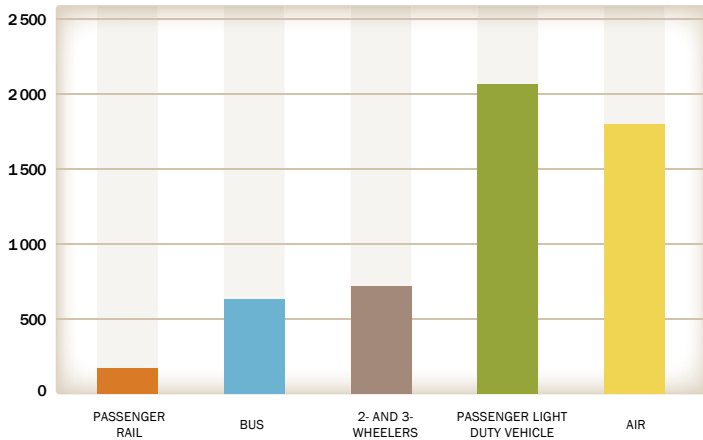
Energy use

Fig. 92: Final energy consumption in passenger rail, by type of fuel (PJ)



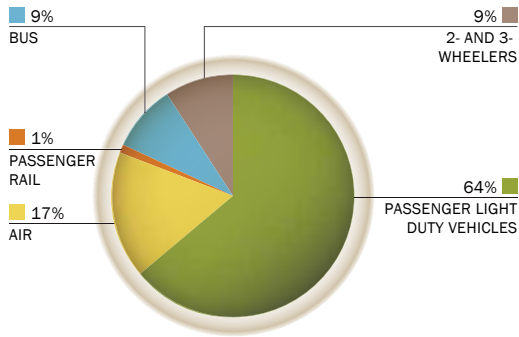
Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

Fig. 93: Energy intensity of passenger transport modes, 2015 (kJ/pkm)



Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

Fig. 94: Share of final energy demand in passenger transport by mode, 2015



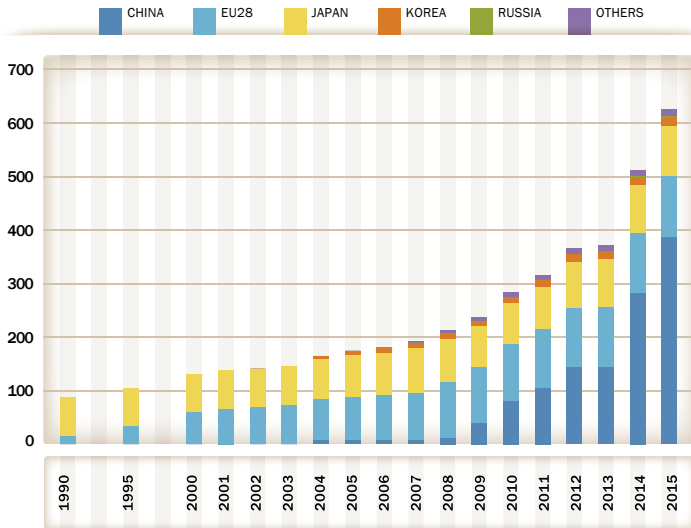
Source: IEA estimates based on IEA (2017b) and IEA (2017c)

In 2015, the passenger rail sector consumed one third of the final energy use across the whole rail sector, close to 700 PJ. Electricity accounted for three quarters of this value, while diesel fuel was used for most of the remaining part. The share of electric energy used for passenger rail is increasing over time. This is consistent with the growth of rail activity in urban and high-speed services, both characterized by a high dependence on electric traction.

Today, passenger rail is the most energy efficient passenger transport mode per pkm. It has a specific energy consumption averaging well below 200 kJ/pkm across all geographical regions and all types of services. Passenger rail requires less than one tenth of the energy needed to move an individual by car or by airplane. This explains why, despite accounting for 9% of the global passenger activity (expressed in pkm) in 2015, passenger rail services only represent 1% of the final energy demand in passenger transport.

High-speed rail activity

Fig. 95: High-speed rail activity by geographic area (billion pkm)



Source: IEA estimates based on UIC (2016a)

High-speed rail (HSR) passenger activity totalled 625 billion pkm in 2015. China, Europe and Japan together account for 95% of the global total. Although construction has started on the first high speed line on the American continent, currently there are no operational services.

HSR activity has been growing rapidly, especially in recent years, making HSR the fastest growing passenger rail transport service. Global high-speed rail activity grew by 14% per year between 2005 and 2015, and increased by nearly 70% between 2013 and 2015.

The large growth of HSR activity in recent years mainly results from a surge in HSR activity in China, which grew by nearly 170% between 2012 and 2015 (Box 2).



BOX 2 HSR development in China

The HSR sector in China has been growing faster and at a larger scale than in any other country. Over the past decade the Chinese share of HSR activity (in pkm) grew from 4% to 62% of the global total, reaching 386 billion pkm in 2015 (UIC 2016a). With nearly 20 000 km of HSR lines in operation in 2016, China also accounts for around 60% of today's global HSR network and 82% of the HSR track km built between 2005 and 2015 (UIC 2017b).

China's high-speed network is most developed in the densely populated Eastern coast, and less developed in Central and Western regions. The government's target is to keep expanding and upgrading the rail network so that all Chinese cities with more than half a million inhabitants, covering 90% of the Chinese population, benefit from rapid rail (maximum speed of at least 160 km/h) services (People's Republic of China Central Government 2008; World Bank 2014a). In 2016, nearly 11 000 km of HSR lines were still under construction and an additional 1 500 km of lines were planned (UIC 2017b). This will raise the total high-speed rail network extension to 31 000 km by 2020, doubling the value of 2014. The "One Belt, One Road" initiative, announced in 2013, and launched in 2015, targets the construction of transport infrastructure connecting China with South-East and Central Asia, the Middle East, Africa and Europe. It also includes plans for the construction of HSR links well beyond the Chinese borders (Yansheng 2014 and Xinhua 2015). Examples include a dedicated HSR line connecting Russia to China (Shuiyu and Xuefei 2017) and another line connecting Thailand and China (Bangkok Post and Reuters 2017).

China is the first country with a GDP per capita below 7 000 USD to invest heavily in a comprehensive HSR network (World Bank 2014a). This has been facilitated by several demographic, geographic and economic conditions. HSR projects need to be accessible to a large volume of passengers in order to be economically sustainable, and are therefore more successful in densely populated areas (Jiao et al. 2014). Many areas of China qualify for this because of their high population densities. Distances between Chinese cities also fall in the distance range (200 to 1 000 km) allowing HSR to be highly competitive with aviation (World Bank 2014a). In several cases intra-city links connect more than one city-pair. The connection of a string of city pairs promotes high capacity utilization thus improving the economic viability of HSR, and is not found in most developing countries (World Bank 2010). China also benefits from collective capacity-building efforts and economies of scale – construction costs of HSR networks in China are estimated to be a third lower than in other countries (World Bank 2014b) – arising from large scale political and economic commitments that include decades-long programs over vast land areas (World Bank 2010).

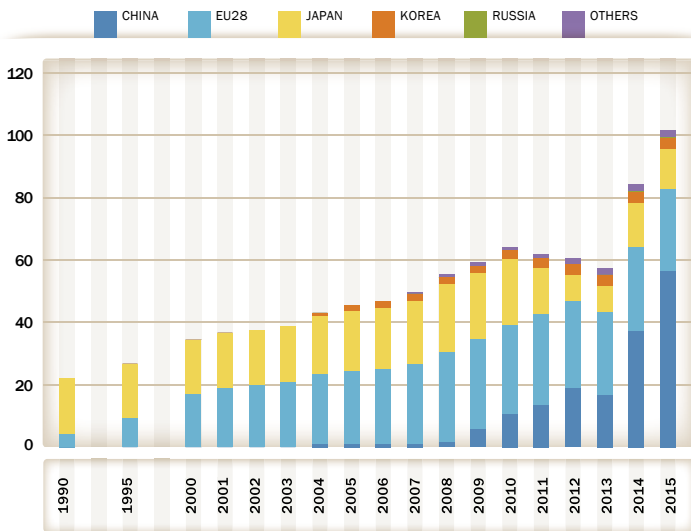
Whether the ridership will arise sufficiently to ensure China recovers its investment costs in HSR has been the subject of much debate (World Bank 2010; World Bank

2014a; Wu et al. 2014). When looking exclusively at the financial performance of HSR projects, only few HSR lines were profitable in 2016: the main examples include the Tokaido Shinkansen line operating between Tokyo and Shin-Osaka, the Paris-Lyon TGV line and the Beijing-Shanghai high-speed rail link (Wu et al. 2014; Yu 2016). Nevertheless, HSR also delivers important economic and environmental benefits that are not directly incorporated in the accounting mechanisms of project financing. Environmental benefits include the capacity to induce modal shifts from aviation, a mode of transport with much higher carbon intensity (see Box 3), and potentially other modes. In China, positive feedbacks on economic growth and industrial competitiveness are also expected from the possibility, enabled by HSR, to create “agglomeration economies” through a network of large, but not oversized, urban agglomerations. This may also lead to wealth redistribution, for example due to lower costs of living in satellite cities (The Economist, 2017).

Recent trends of surging HSR passenger volumes in China also align well with the need to improve energy efficiency and energy diversification of transport. The load factor of Chinese HSR, measuring the number of passengers transported per train-km on average, is three times larger than the European average (UIC 2016a), suggesting a better economic and environmental efficiency potential of Chinese HSR operations when compared with Europe. Large traffic volumes on high-speed rail lines allow for a faster recovery of investment costs, and larger trains for a better energy efficiency per pkm. For example, Japan (together with China, Japan has the highest HSR load factor) encountered some of the highest HSR construction costs (Nash 2014), yet it is one of the only countries today with a profitable HSR connection (Wu et al. 2014).

Energy use and energy intensities

Fig. 96: Final energy use in high-speed rail by geographic area (PJ)



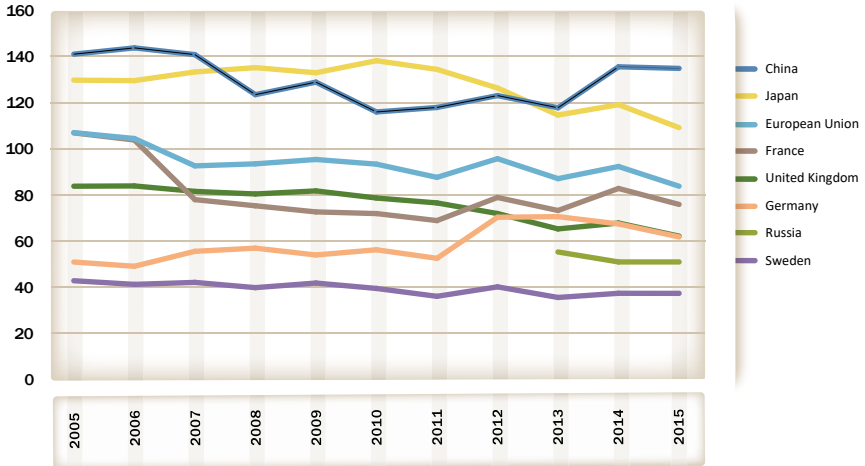
Source: IEA estimates based on Akerman (2011), Lukaszewicz and Andersson 2008, Miyoshi and Givoni 2012, People's Republic of China Central Government (2012), SNCF (2016), UIC (2016a) and UIC (2016c)

In 2015, the HSR sector consumed about 100 PJ of electricity, one fifth of the total electricity demand from passenger rail, and 15% of its final energy use.

High-speed trains do not have the same characteristics across regions. Despite limited data availability, assessments on energy intensity released by selected organizations and studies (Akerman 2011, Lukaszewicz and Andersson 2008, Miyoshi and Givoni 2012, People's Republic of China Central Government 2012, SNCF 2016 and UIC 2016) suggest that European trains use less energy per train-km (up to half) in comparison with Asian high-speed trains.

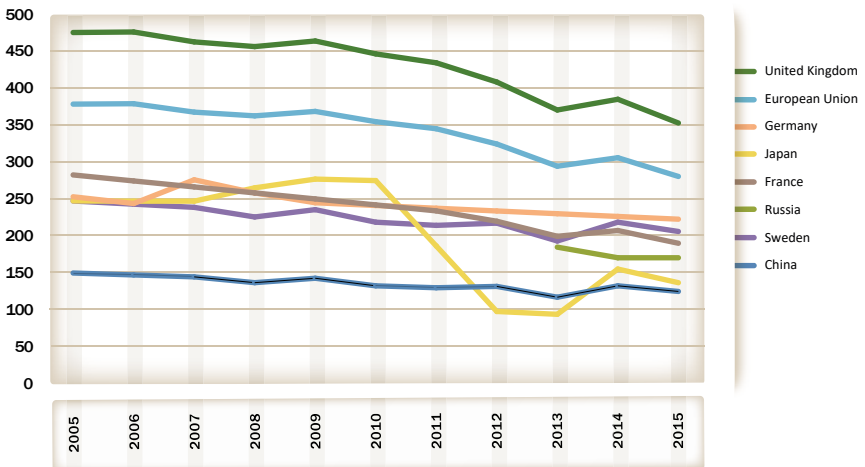
Available data also suggest that high-speed trains in China, Japan and, to a lower extent, Korea have a larger capacity and operate with loads (measured as the number of passengers transported per train on average) that are well above the European average (UIC 2016a). In the case of China and Japan, loads are estimated to be, on average, around three times larger than in Europe, where high-speed trains transport on average 300 passengers. As a result, passenger movements in China and Japan take place at a lower energy intensity per pkm compared with European averages, despite higher energy intensities per train-km.

Fig. 97: Energy intensity of high-speed rail by geographic area (MJ/train-km)



Source: IEA estimates based on Akerman (2011), Lukaszewicz and Andersson (2008), Miyoshi and Givoni (2012), People's Republic of China Central Government (2012), SNCF (2016), UIC (2016a) and UIC (2016c).

Fig. 98: Energy intensity of high-speed rail by geographic area (kJ/pkm)

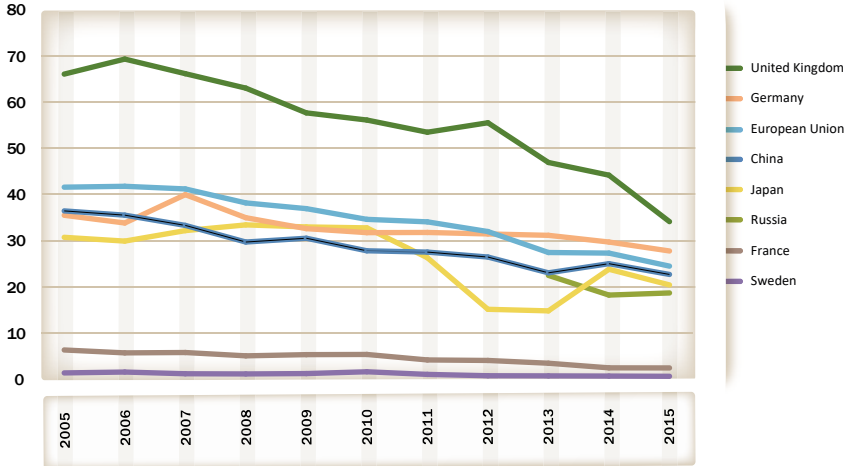


Source: IEA estimates based on Akerman (2011), Lukaszewicz and Andersson (2008), Miyoshi and Givoni (2012), People's Republic of China Central Government (2012), SNCF (2016), UIC (2016a) and UIC (2016c).

The energy use in high-speed rail is the result of changes in activity and the evolution of loads and energy intensities per train-km. Available data suggest that loads were subject to quite some volatility over time, while the energy intensity of high-speed trains tended to improve over the past decades (UIC 2016b).

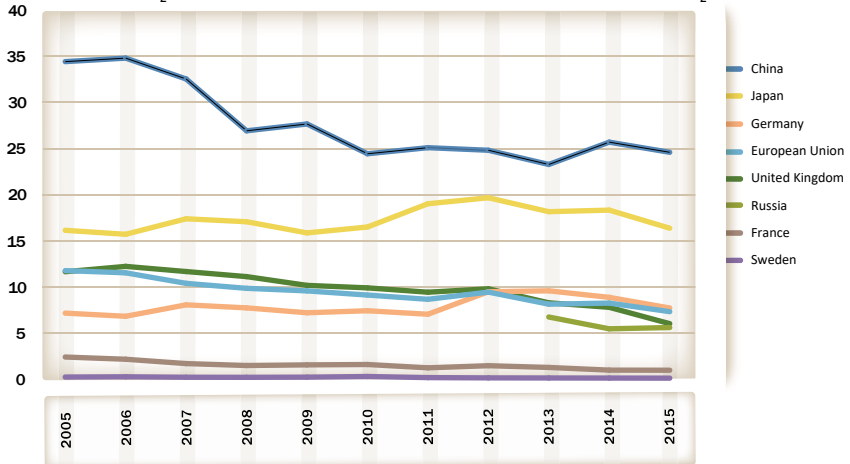
CO₂ emission intensities

Fig. 99: CO₂ emissions of high-speed rail by geographic area (gCO₂/pkm)



Source: IEA estimates based on Akerman (2011), Lukaszewicz and Andersson (2008), Miyoshi and Givoni (2012), People's Republic of China Central Government (2012), SNCF (2016), UIC (2016a), UIC (2016c) and IEA (2017b)

Fig. 100: CO₂ emissions of high-speed rail by geographic area (gCO₂/train km)



Source: IEA estimates based on Akerman (2011), Lukaszewicz and Andersson (2008), Miyoshi and Givoni (2012), People's Republic of China Central Government (2012), SNCF (2016), UIC (2016a), UIC (2016c) and IEA (2017b)

If energy intensities of high-speed rail services are combined with CO₂ emission intensities of power generation, results for China, Japan and the EU average tend to be clustered in the case of carbon intensities per pkm, while they show a greater variability when carbon intensities are measured per vkm (vehicle or train kilometres). This is due to the lower carbon intensity of the European region in comparison with China and Japan. The main outliers are European countries with very low carbon intensities: France and Sweden.



BOX 3 HSR and aviation

The rise of HSR systems has resulted in some induced demand (i.e. trips that would have not been made before the HSR link was in place) and led to changes in modal choices including the displacement of trips from conventional rail, aviation and other competing modes (MTI 2014; Clewlow et al. 2014; Givoni and Dobruszkes 2013; European Commission 1996; Park and Ha 2006; Gundelfinger-Casar and Coto-Millán 2017).

While changes in global aviation activity due to HSR are relatively small, there are several examples of how the introduction of HSR led to significant reductions, or even the curtailment, of air traffic on specific routes. The table below outlines some of the most relevant cases in this respect.

Reduction of air traffic volume after reduction of HSR on a selection of routes

ROUTE	TRAVEL TIME (hh:mm)	YEARS COVERED	DECLINE OF AIR TRAFFIC VOLUME*	SOURCE
Paris - Lyon	01:59	1980-1984	Around 50%	Vickerman (1997)
Madrid - Seville	02:30	1990-1994	57%	EC (1998)
Madrid - Barcelona	02:30	2008-2009	22%	Jimenez and Betancor (2012)
Paris - London	02:15	1993-2010	56%	Givoni and Dobruszkes (2013)
Brussels - London	02:00	1993-2010	58%	Givoni and Dobruszkes (2013)
Taipei - Kaohsiung	01:34	2005-2008	80%	Cheng (2010)
Seoul - Busan	02:37	2003-2011	54%	Lee et al. (2012)
Guangzhou - Wuhan	02:37	2009-2010	48%	Lee et al. (2012)

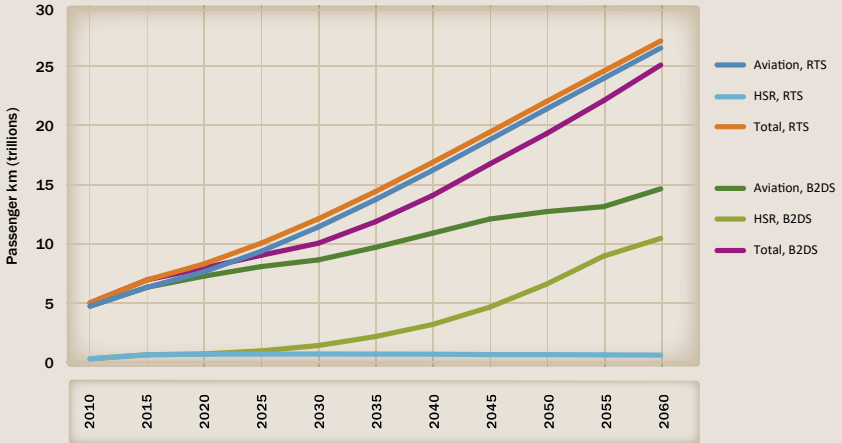
* Volume is measured in number of passengers, except for the Guangzhou-Wuhan route, where volume is measured in number of seats

In the case of Japan, the revenue-pkm (RPK) per capita on aircrafts is well below that of global regions with similar income (IEA 2017b), and the market share of the Shinkansen is always greater than that of airlines on routes of less than 1000 km (Albalade and Bel 2012). This, combined with the large amount of HSR km per capita reached by Japan (750 km per person per year in 2015, comparable only with France), indicates that air traffic can be significantly impacted by HSR once the development of the HSR network is scaled up.

The energy use per pkm of HSR is about 90% lower than aviation, and will remain more efficient even if the aviation sector fulfils their maximum potential for improvement (IEA 2017d). HSR has the potential to emit very low or zero CO₂ emissions in the future, if electricity generation systems manage to decarbonize alongside.

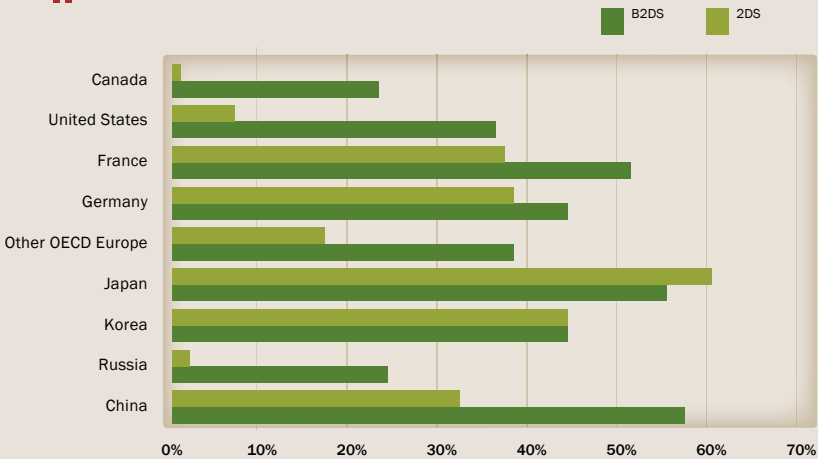
IEA projections of low carbon scenarios (2°C Scenario [2DS] and a Beyond 2°C Scenario [B2DS], consistent with a 50% chance of limiting global warming to 2°C and 1.75°C, respectively) show that a large shift from aviation activity to HSR needs to take place in order to reduce CO₂ emissions. These scenarios indicate that limiting the global average temperature increase below 2°C is unlikely to happen without replacing aviation passenger activity with HSR (IEA 2017d).

Projections on the modal shift from aviation to HSR, according to a reference technology scenario (RTS), a 2°C Scenario (2DS) and a Beyond 2°C Scenario (B2DS)



Source: IEA (2017d)

Share of HSR activity in total HSR + aviation activity, in 2060, 2°C scenario and Beyond 2°C scenario



Source: IEA (2017d)

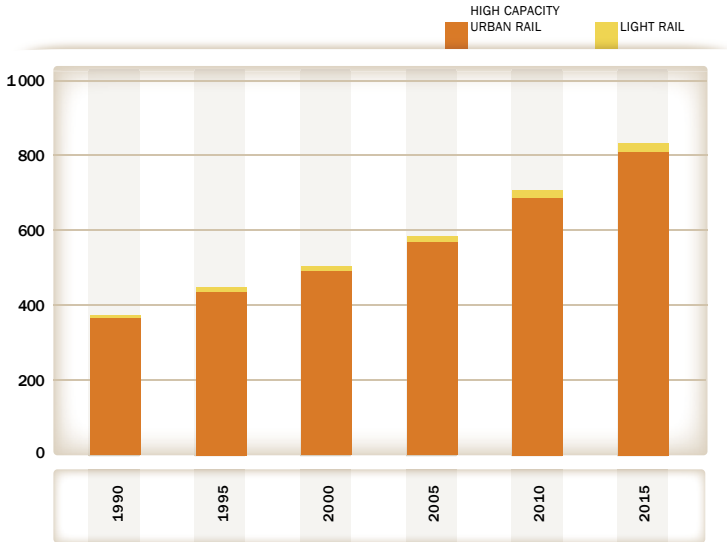
In a scenario aiming to meet the ambition outlined by the Paris agreement (B2DS), and therefore more ambitious in terms of emission reductions than the 2DS, nearly all global aviation activity at short to medium distances (up to 1 000 km) is substituted with HSR by 2060.

Bringing about a shift of this magnitude on a global scale is challenging and requires adding HSR capacity at a rate beyond any observed so far. HSR tends to be competitive when journey times that are shorter than or similar to those offered by aviation, a common feature for distances less than 700 km (Clewlow et al. 2014; Gundelfinger-Casar and Coto-Millán 2017). Station and airport characteristics can also influence journey times, such as waiting times, distance from city centre and accessibility. HSR also tends to be more competitive than aviation in densely populated areas (Clewlow et al. 2014). Japan, where HSR connections are most profitable, has 127 million people living mainly in large cities with high population density along the coastal strip. This allows HSR to connect a chain of large cities so that flows between different cities are combined in a highly efficient network (Nash 2014).

The HSR deployment considered in the IEA B2DS scenario requires an expansion of HSR networks starting in regions with the most favorable conditions, and then expanding into areas which are more challenging, these later projects are likely to require structural subsidies.

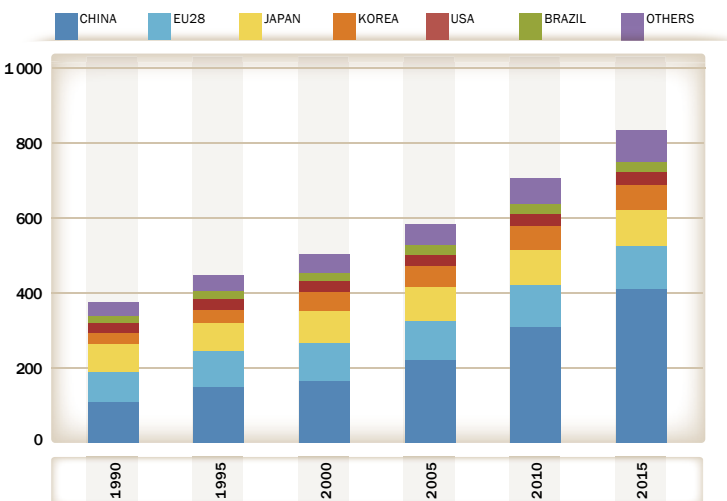
Urban rail Activity

Fig. 101: Urban rail activity by mode (billion pkm)



Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

Fig. 102: Urban rail activity by geographic area (billion pkm)



Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

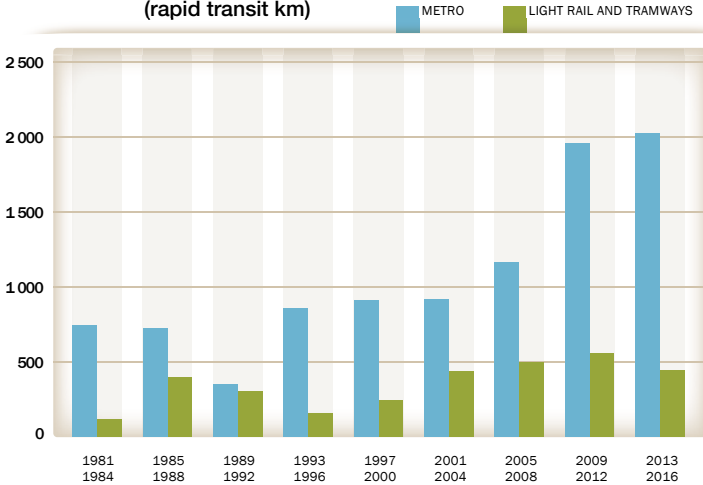
High capacity urban rail services account for the vast majority of the global urban rail activity (estimated in pkm). These services comprise both metros and high capacity/high frequency commuter rail services. The latter are typically operated by vehicles specifically designed for rapid boarding operations and do not share their networks with other rail transport services.

Tramways and light rail account for a small complementary fraction of urban rail. This is explained by the much lower vehicle capacity and operational speeds of tramways and light rail services compared with metros and commuter rail, combined with a network extension that is concentrated in a relatively small fraction of global economies (primarily in some European countries: in 2015, Europe hosted 206 of the 388 tramway and light rail systems in operation globally [UITP 2015a]).

In 2014, 162 cities had a metro system and two-thirds of the world's metro systems were located in Asia and Europe (IEA analysis based on UITP 2015b and ITDP 2014). The geographic distribution of metro systems achieves a good match with the estimation of urban passenger rail activity: in 2015, China accounted for almost half (49%) of the total urban rail transport activity, followed by the European Union (14%), Japan (11%) and Korea (8%).

Urban rail activity increased significantly in recent years, primarily driven by metros and high capacity/high frequency commuter rail networks. Since 2010, these networks grew by more than 600 km a year on average, a third more than in the previous 5 years, and more than double the global annual construction rate occurring in 2000 to 2005 (ITDP 2017). China was the main driver behind the growth of these systems. Activity taking place on networks located in Chinese cities grew by 150% between 2005 and 2015. The expansion of the Chinese high capacity urban rail network translated in an activity growth that exceeded half of the total of all European pkm between 2000 and 2005, and nearly double the total European pkm in the following 10 years.

Fig. 103: Metro, light rail and tramway construction since 1981 (rapid transit km)

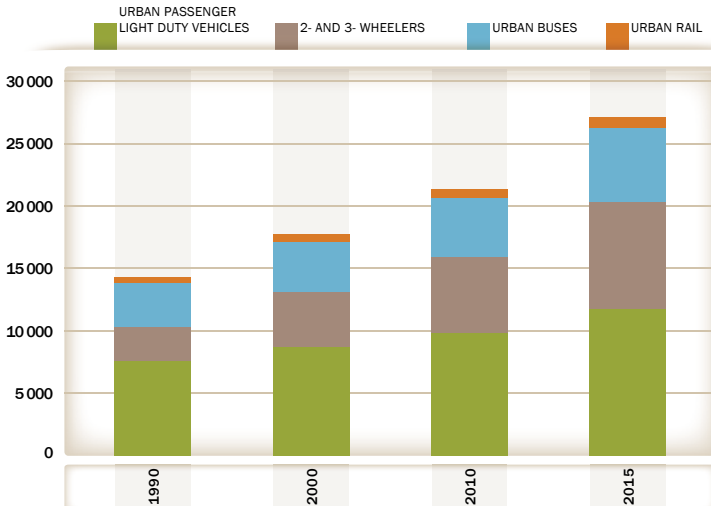


Source: ITDP (2017)

Even though public transport (including rail and buses) accounts for roughly one third of global urban transport demand (Figure 104), and despite the rapid growth experienced in the recent past, urban rail accounts for only 3% of the global urban pkm travelled and 1.6% of total passenger activity.

An estimated 10% of the global population lives in large cities with access to urban rail systems, primarily in Europe and Asia (IEA analysis based on CIESIN 2005). This, combined with the fact that only half of the global pkm takes place in urban environments, confirms the small magnitude of the urban rail transport activity indicated (1.6% of global passenger transport).

Fig. 104: Urban passenger transport activity by mode (billion pkm)



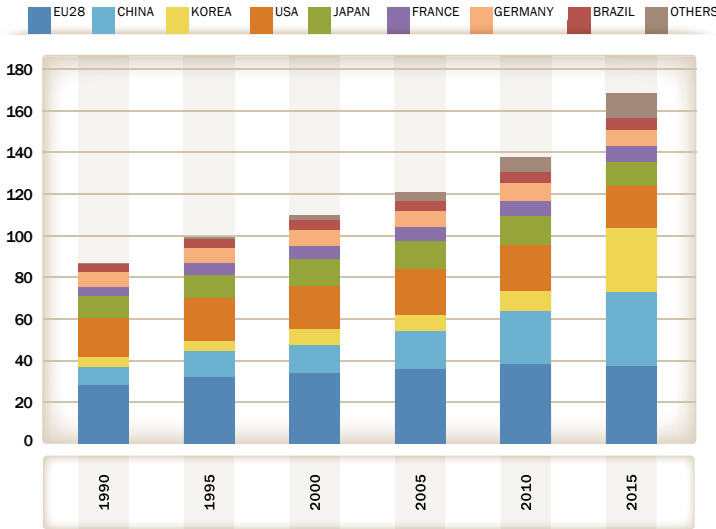
Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

Energy use and energy intensities

Regional differences

In 2015, high capacity urban rail services consumed nearly 160 PJ of energy (mostly electricity), a value of similar magnitude to high-speed rail.

Fig. 105: Final energy consumption in urban rail by geographic area (PJ)



Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

Available data suggest that capacity and occupancy of European high capacity urban rail services is, on average, lower than in Asia: the average number of passengers per train in Europe ranges between 150 and 300, in Japan and Korea the range is 400 to 500 and estimates for China exceed 700 (IEA analysis based on UITP 2002). This is consistent with historical developments and the nature of urban agglomerations. Many of the European systems started to be developed earlier than in Asia, at times when tunnel-boring machines were not yet in use, posing technical and economic challenges to the construction of underground networks accommodating high capacities. The average size and population of European urban agglomerations tends to be significantly smaller than Asian megacities hosting high capacity urban rail networks. Metros in Europe are therefore more likely to be designed to accommodate a smaller flow of passengers, and high capacity/high frequency systems (such as the RER in Paris) are limited to the largest metropolitan areas.

As in the case of high-speed rail, larger train capacities are coupled with higher energy use per train-km in urban rail services. Available data suggest that the gap between Asian and European countries in terms of energy intensity per vkm for high capacity urban rail services is likely to range between 10% and 40% (IEA analysis based on UITP 2002). Given the larger gap in terms of average train loads, the energy requirements per pkm in Asia are, on average, close to half of the energy/pkm needed to move people in European high capacity urban rail networks¹. These considerations largely explain why, despite accounting for 13% of the global activity (in pkm), the European Union consumes about 20% of all energy used globally for high capacity urban rail transport, and why China, Japan and Korea, taken together, absorb around half of the global energy demand to serve two thirds of the global activity.

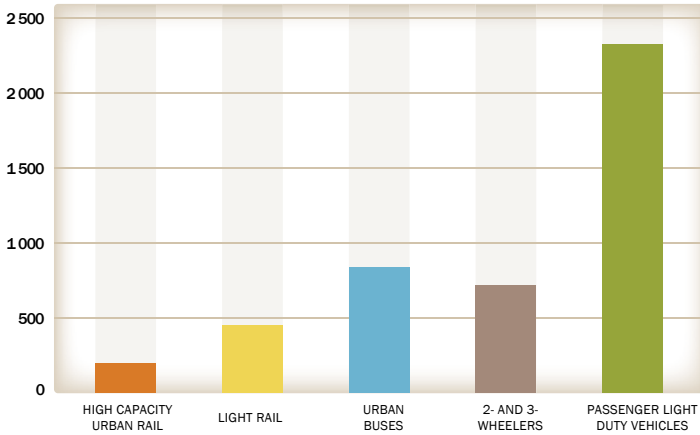
Energy intensity of urban rail compared with other modes

The specific energy consumption of high capacity urban rail, including metros and high capacity/high frequency commuter rail (measured as energy use per pkm) is the lowest of all urban passenger transport modes. Passenger movements taking place on these systems require, on average, less than a tenth of the energy needed to move individuals on urban passenger light duty vehicles (PLDVs). High capacity urban rail is also over two times more energy-efficient per pkm compared to tramways and light rail systems, and likely more energy efficient than other commuter rail services. This is primarily due to higher capacity utilization rates (see the section on Insights on commuter rail for a more detailed discussion).

Due to the share of 3% of urban rail in the total urban transport activity and much lower energy use per pkm compared with all other modes, urban rail services accounted for less than 1% of the total energy demand for urban passenger transport.

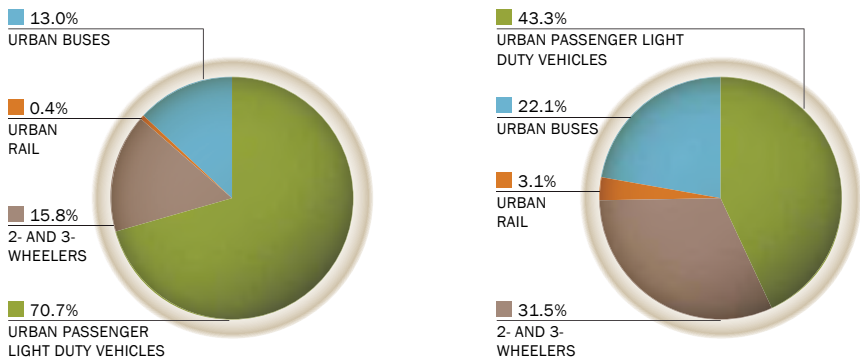
¹ The differences between European and Asian high capacity urban rail transport systems, combined with limited availability of data and the need to collect information that are not consistently reported across all urban rail systems are part of the data-related challenges characterizing the assessment of energy use in urban rail across different countries. This assessment attempts to summarize the best understanding of the authors on the topic, given all limitations imputable to these data-related challenges.

Fig. 106: Energy intensity by urban passenger transport mode (kJ/pkm), 2015



Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

Fig. 107: Share of urban passenger transport final energy demand by mode (left), and share of global urban passenger transport activity by mode (right), 2015

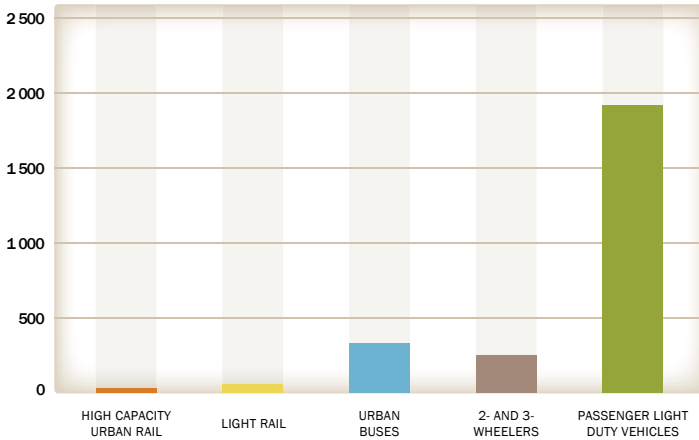


Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

CO₂ emission intensities

The low energy intensities and mainly electric powertrains used for urban rail mobility further strengthen the advantages of urban rail over other transport modes. Today, the CO₂ emission intensity of urban rail is less than one tenth the intensity of urban PLDVs. This reinforces the capacity of urban rail to be part of climate mitigation strategies, besides being an instrument for improving access and reducing congestion in metropolitan areas.

Fig. 108: CO₂ intensity by urban passenger transport mode (gCO₂/pkm), 2015



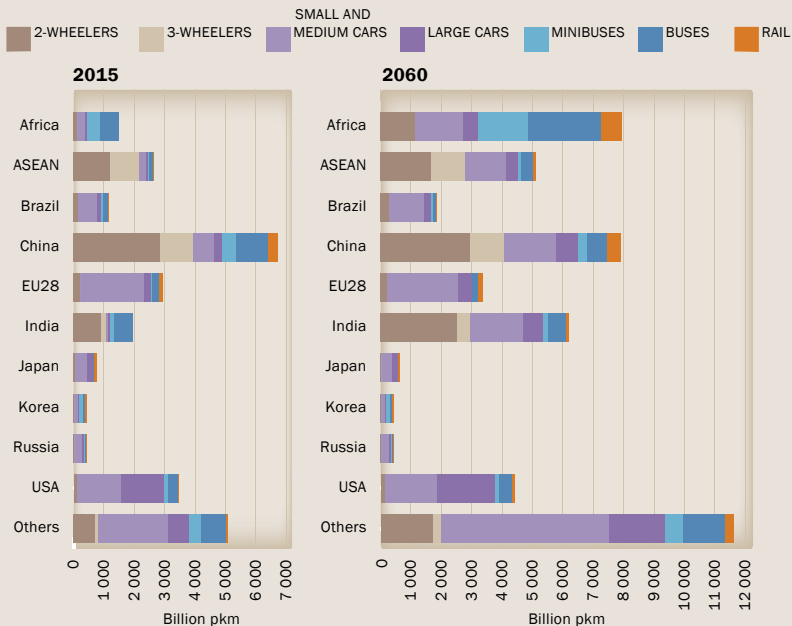
Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)

BOX 4 Prospects for urban public transport in IEA scenarios

Today, about half of total passenger transport activity (measured in pkm) takes place in urban environments, serving a global urban population that exceeded 3.9 billion in 2015. By 2050, urban population is expected to have grown by another 2.5 billion people, reaching 66% of the total global population, up from 54% in 2015 (UNDESA 2014). Urban areas in all global regions are expected to grow, but Africa and Asia, currently the least urbanized regions, together will make up nearly 90% of this increase until 2050 (UNDESA 2014).

This is expected to lead to a significant growth of urban transport activity, primarily in developing economies. Over the past decade, personal vehicles (passenger cars and 2-wheelers) have been responsible for most of the growth (76%) in urban passenger activity. This is consistent with the observed trend that car ownership tends to grow with increasing income levels, affording greater comfort and status (IEA 2016). As incomes continue to rise across a wider range of countries and a broader base of their populations, this trend is expected to continue. Without adequate policies, this may have significant climate and health-related implications, especially given the projected surge in urban transport demand.

Urban passenger transport activity (motorized modes) in the IEA Reference Technology Scenario (RTS), 2015 and 2060

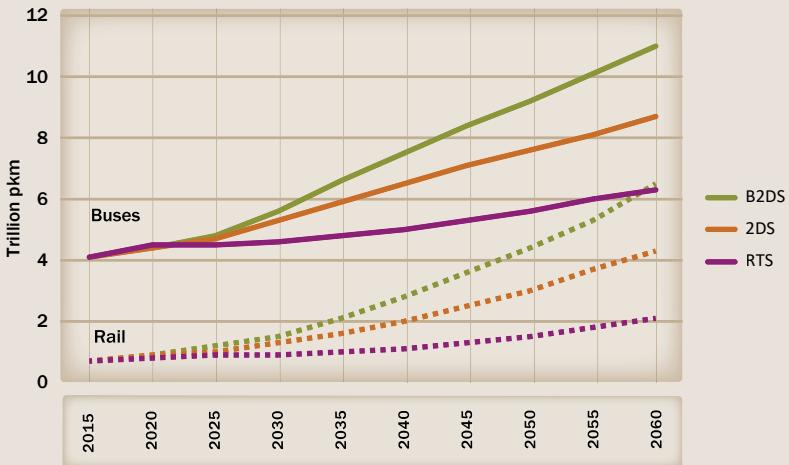


Source: IEA (2017b)

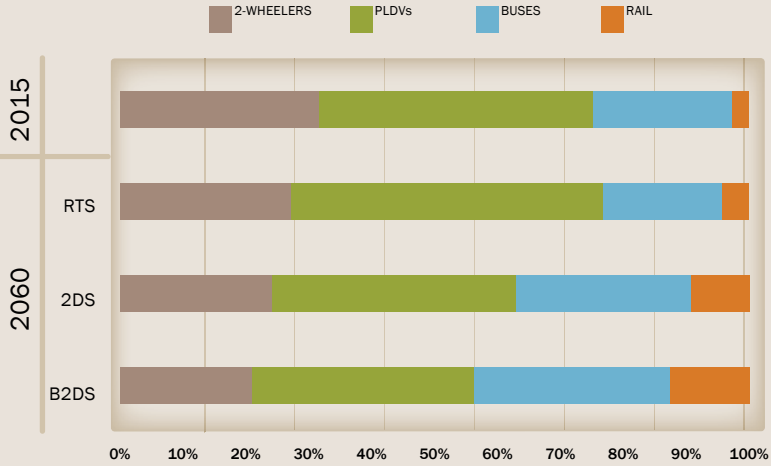
Urban public transport services become increasingly important in low-carbon IEA scenarios 2°C Scenario [2DS] and a Beyond 2°C Scenario [B2DS], consistent with a 50% chance of limiting global warming (to 2°C and 1.75°C, respectively). Between 2015 and 2060, demand for urban rail services is projected to grow by a factor 6 in the 2DS and by a factor 8 in the B2DS, reaching 4.3 and 6.5 trillion pkm respectively in 2060. This is brought about by a significant modal shift from private vehicles (passenger cars and 2-wheelers) to more efficient public transport modes.

This transition needs to be facilitated by significant investments in public transport infrastructure, complemented by local and national policies capable of enhancing its competitiveness. At the local level, these measures include fiscal and regulatory policies designed to manage travel demand and influence choices (such as congestion charges, parking pricing and zero-emission zones), as well as a transition to urban designs capable of reducing the frequency and length of trips (through densification, mixed use and the integration of transport planning, e.g. via transit-oriented development). At the national level, policies supporting a shift to collective urban transport modes need to include an increase in the taxation of fossil fuels, reflecting growing carbon prices. Countries with high taxes on personal vehicles are also amongst the most successful, today, to dissuade consumers from opting for a private vehicle in their urban mobility choices.

IEA projections on urban public transit activity and urban passenger transport shares by mode, according to the RTS, 2DS and B2DS scenario



Source: IEA estimates based on IEA (2017b)



Source: IEA estimates based on IEA (2017a)

The IEA scenario aligned with the Paris agreement (B2DS) assumes that all major world cities will have affordable and attractive high capacity public transit networks in place by 2060. The majority of smaller cities (i.e. those with more than 0.5 but fewer than 2 million inhabitants) will implement a portfolio of progressively more ambitious Transport Demand Management (TDM) measures and invest in alternatives to private cars such as public transit, walking and cycling to achieve the B2DS (IEA 2017d); the roll-out of these networks and policies in the B2DS assumes that current best practices will be universally applied by 2060.



Insights on other commuter rail services

Due to data classification and availability issues (see Box 1), commuter rail services that are additional to the high capacity/high frequency services discussed in the previous section have been classified under conventional rail services. These commuter rail services enable the extension of the capacity of the urban rail network to reach less population-dense urban areas gravitating around larger urban agglomerations.

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To overcome the limitations in scope of this assessment, UIC collected specific information on rail systems that complement those covered in the section on Urban rail and Part I of this Handbook, and are still relevant for urban mobility. For the case studies, characteristics of these rail services were defined as follows:

- distance between stations is less than 5 km (excluding geographic barriers to development, such as mountains and bodies of water);
- average commercial speed: lower than 60 km/h;
- published timetable, may include a range of different termini and stopping patterns;
- frequency under 20 minutes in both directions between 6 a.m. and 10 p.m.;
- double doors to carriages (door opening larger than 1.5 m);
- one-way trip time for average passenger lower than one hour;
- may share infrastructure with other types of rail services (e.g. freight or intercity).

A survey was undertaken among rail operators to investigate activity, energy demand and length of network, over a time span of 5 years (see Appendix A). Respondents include BLS in Switzerland, HZ in Croatia, SNCF (RER/Transilien) in France, Korail (Gyeongwon line) in Korea, PKP (SKM) in Poland and CP (Urbanos de Lisboa and Urbanos do Porto) in Portugal, as well as EuskoTrain, Ferrocarrils Generalitat de Catalunya (FGC) and RENFE (Cercanias) in Spain.

All of these operators are located in Europe and East Asia. The scope of the responses was variable, including systems that are covering a single commuter rail line (such as the Gyeongwon line), systems that are specific to a single urban area (such as the RER/Transilien for Paris), a metropolitan network serving a group of three cities (SKM, linking Gdansk, Sopot and Gdynia) and the services provided by region-specific operators (EuskoTrain, FGC). Two other cases (Portugal and Spain) can also be used to give a national overview.

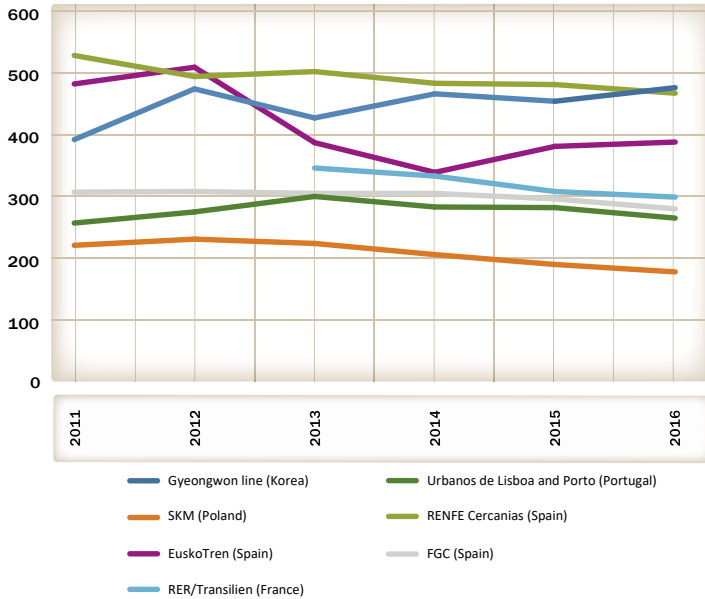
The number of respondents and the level of detail are insufficient to construct a global (or macro-regional) estimate of the volume of suburban rail services. Data limitations constrain insights to the fraction of conventional rail services attributable to commuter rail, complementing the assessment made here for high capacity/high frequency urban rail links. However, the activity data reported in the UIC statistics (UIC 2016a) and in the UIC commuter rail survey for Portugal and Spain (i.e. two of the three cases where the commuter rail systems reported are the most complete nationwide) suggest that large fractions of the pkm (60% in Portugal and 75% in Spain) and the train-km (45% in Portugal and 63% in Spain) of rail services included here in conventional rail could be attributable to commuter rail, even if these systems account for a minor fraction of the national rail network (in the 10% to 20% range). Other examples have a narrower geographical scope and can therefore not be used to assess the magnitudes of these shares.

A study undertaken by the UITP (UITP 2016) also attempted to characterize the role of commuter rail including commuter services that have been classified here as conventional rail. This analysis focuses on the European Union and covers the combination of suburban and regional rail (and in some cases domestic rail). According to the UITP analysis, the volume of rail services in Europe accounted for nearly half of urban mobility, with shares evenly distributed between tramways, metros and other commuter rail services. If compared with the assessment made here, this indicates that, on average and in the European Union, roughly 15% to 30% of the activity that was classified here as conventional rail could be imputable to commuter rail having lower capacity and frequency than metros.

Despite the limitations due to limited detail and scope, the UIC survey on commuter rail also provides initial insights into the energy intensity of commuter rail services. Most of the systems surveyed reported an energy intensity that improved over time, but estimates for the energy intensities of the commuter rail systems surveyed by UIC were rather diverse. In 2015, the specific energy consumption of the respondents fell in the range of 180-480 kJ/pkm². If compared with the high capacity urban rail discussed in the previous section (reflecting an estimation of the global average), this range of values suggests that commuter rail services included in this survey tend to have a higher energy intensity compared with high capacity urban rail and non-urban rail (including conventional and HSR) services, a lower energy intensity than light rail and much lower energy requirements per pkm if compared with passenger cars operated in cities.

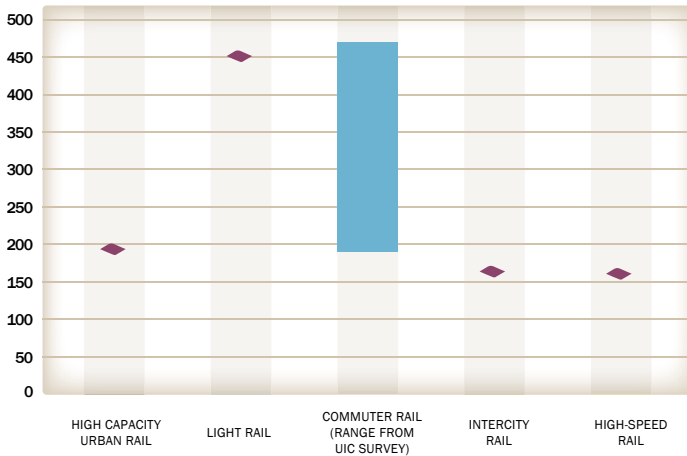
² This result combines information of lines using electricity and diesel. With the exception of the Cercanias line in Spain (partly running on electricity, and partly fuelled by diesel) and the Gyeongwon line in Korea (which uses diesel), all lines use exclusively electricity.

Fig. 109: Energy intensity of commuter rail by network (kJ/pkm)



Source: UIC (2017c)

Fig. 110: Energy intensity of passenger rail modes in 2015 (kJ/pkm)



Source: IEA estimates based on IEA (2017b), ITDP (2014), UITP (2002) and UITP (2015b)



Methodology Notes

Railway specific energy consumption (fig. 15, 28, 40, 52, 64, 76) and specific CO₂ emissions (fig. 16, 29, 41, 53, 65, 77) – indicators building

Railway specific energy consumption and specific CO₂ emissions are mainly based on UIC data. The railway companies provide UIC with their tractive stock's total energy consumption split by electric/diesel and passenger/freight activity. These total energy consumptions are combined with pkm and tkm data (allocated to diesel and electricity according to the repartition of passenger and freight train-km), allowing the calculation of energy intensities for passenger and freight activity where company data are available.

When railway companies do not report any energy consumption to UIC, specific energy consumption is estimated using three representative classes of energy intensities. Such classes represent the range of values observed for countries where data are reported. The selection of the energy intensity class adopted for specific country level estimates is based on an attempt to minimize differences with the rail energy consumption reported in the IEA World Energy Balances. This approach can lead to limited inconsistencies with total energy consumption and CO₂ emissions in rail, as the latter use the IEA World Energy Balances as a source. For a selection of countries/regions – EU, India, Japan, Russia, USA - the availability of direct statistics published by the government or the national rail operator make it possible to calibrate the data resulting from the process described above to this published information. For specific CO₂ emission intensity, the calculated energy intensities are combined with direct CO₂ emissions from fuel combustion (tank-to-wheel CO₂ emissions) and CO₂ emissions resulting from the production and transformation of fuels and electricity (well-to-tank CO₂ emissions). The emission factors used for this purpose are taken from the IEA Mobility Model.

Railway specific energy consumption and specific CO₂ emissions – consistency improvement

In some cases, figures showing specific energy consumption and specific CO₂ emissions differ from the figures in previous Railway Handbook editions. IEA and UIC continue to work together to improve energy and emissions statistics with respect to data reported by UIC members, including specific energy and emissions data for rail tractive stock. From the 2015 edition of the Handbook, pkm and tkm data have been systematically derived from train-km and the corresponding load factors, improving the internal consistency of the data. In addition, energy intensity estimates for passenger rail services benefitted from the revision of specific energy consumption per train-km (see methodology note on railway specific energy consumption and specific CO₂ emissions – indicators building).

Railway final energy consumption by fuel (Fig 13, 25, 38, 50, 62, 74, 86; Table 2, 4, 6, 8, 10, 12, 14):

The railway energy sources mix has been calculated. The railway energy sources mix indicates in what proportion the energy sources are being used for rail traction. By applying the electricity mix to the portion of electric energy used, it is possible to obtain the energy sources mix shown. In this new edition the railway energy mix is also aggregated by type of source (fossil, renewable, nuclear).

Share of CO₂ emissions from fuel combustion by sector (Fig. 17, 30, 42, 54, 66, 78) and share of final energy consumption by sector (Fig. 19, 32, 44, 56, 68, 80)

For this year's edition, navigation and aviation categories do not include the amount of CO₂ emissions and energy consumption relative to the international operations. Considering only domestic aviation and domestic navigation lead to important difference compared to the previous year's Handbook edition.

Scope of data

This booklet intends to provide a global overview of the rail sector, including key world regions. A large amount of effort is dedicated to compile and align different data sources, in order to include the most detailed and accurate indicators for the publication. However, the scope and level of detail may vary from one data source to the other. In particular, it should be noted that:

- Rail energy use and CO₂ emissions data taken from IEA Statistics (sources referred to as "IEA (2017a)" and "IEA (2017b)") cover all national rail operations, including high-speed, intercity, suburban and urban rail services.
- Rail activity, energy use and network extension data are taken from the UIC statistics publication, the Environmental Performance Database (sources referred to as "UIC (2016a)" and "UIC (2016b)") and bilateral communications between the UIC and rail transport operators. Activity data available in the UIC Statistics include primarily high speed and intercity rail services. Suburban or urban rail services are excluded, unless companies also operating long-distance rail services include them in their data submission to UIC. In order to align to the UIC Statistics as closely as possible, suburban and urban rail services are excluded, to the extent possible, from the results reported in part I for the EU, Japan India, Russia, and the USA. That is, those regions where additional data on activity and energy use have been bilaterally collected by UIC (see also the methodology note on "Railway specific energy consumption and specific CO₂ emissions – indicators building"). In future editions, the IEA and the UIC are going to continue to work closely to keep improving the scoping and quality of the data presented in the Railway Handbook.
- For this year's edition, energy consumption of coal in the railway final energy consumption for China (figure 86) is consistent with the values reported in the IEA Energy Balances (IEA 2017c). In last year's edition this number was consistent with the IEA Energy Technology Perspective and the Mobility Model. This change was made in order to avoid inconsistencies between the amount of CO₂ emissions and energy consumption reported.
- China Railway Corporation (CR) is responsible for the administration of the 18 rail bureaus of the State Railways. The data provided by the UIC concerns only CR and by consequence excludes local and other Chinese railways.

**Electrified track**

Track provided with an overhead catenary or a conductor rail to permit electric traction.

Electrified line

Line with one or more electrified running tracks.

Energy consumption by rail transport

Final energy consumed by tractive vehicles for traction, train services and facilities (heating, air conditioning, lighting etc.).

HDV

Heavy Duty Vehicle (gross vehicle weight >3.5 tonnes)

HSR

High-Speed Rail

IEA Mobility Model (MoMo)

The IEA mobility model (MoMo) is a technical-economic database spreadsheet and simulation model that enables detailed global and regional projections of transport activity, vehicle activity, energy demand, and well-to-wheel GHG and pollutant emissions according to user-defined policy scenarios to 2060. It represents all major motorised transport modes (road, rail, shipping and air) providing passenger and freight services.

Joule (J)

Unit of measurement of energy consumption.

Kilojoule: 1 kJ = 1 000 J

Megajoule: 1 MJ = 1 x 10⁶ J

Gigajoule: 1 GJ = 1 x 10⁹ J

Terajoule: 1 TJ = 1 x 10¹² J

Petajoule: 1 PJ = 1 x 10¹⁵ J

OECD

Organisation for Economic Co-operation and Development.

Member countries are: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States of America.

OECD North America: Canada, Mexico and United States of America.

OECD Europe: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

OECD Pacific: Australia, Japan, Korea and New Zealand.

Other OECD: Chile and Israel.

Passenger-kilometre (pkm)

Unit of measurement representing the transport of one passenger over a distance of one kilometre.

PLDV

Passenger Light Duty Vehicle

SUSDEF

Sustainable Development Foundation founded in 2008 by will of companies, business associations and sustainability experts, it is a not for profit think-tank based in Rome aimed at encouraging the transition towards a green economy. The Foundation relies on a network of 100 associated green companies and more than 50 top level senior experts and young talents in the sustainable development field.

Tonne-kilometre (tkm)

Unit of measurement of goods transport which represents the transport of one tonne of goods over a distance of one kilometre.

Tonne of oil equivalent (TOE)

Unit of measurement of energy consumption: 1 TOE = 41.868 GJ

Traffic Unit (TU)

The sum of passenger kilometre and tonne kilometre.

Train-kilometre

Unit of measurement representing the movement of a train over one kilometre.

TTW

Tank to wheel

WTT

Well to tank

WTW

Well to wheel



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