RAILWAY HANDBOOK 2015

ENERGY CONSUMPTION AND CO_2 EMISSIONS

FOCUS ON VEHICLE EFFICIENCY

iea International Energy Agency

uic INTERNATIONAL UNION OF RAILWAYS

INTERNATIONAL ENERGY AGENCY

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.

International Energy Agency
Secure Sustainable Together

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INTERNATIONAL UNION
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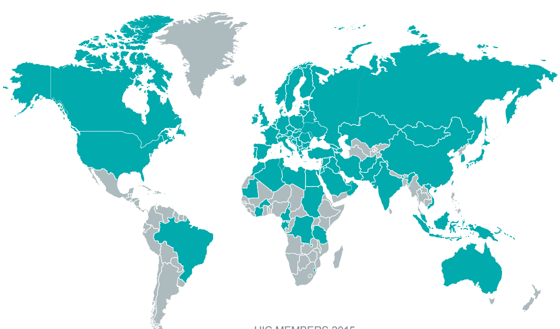
UIC: the international professional association representing the railway sector

UIC, the International Railway Association founded in 1922, counts 24 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 kilometers of tracks, 2900 billion passenger-km, 10000 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 & CO_2, 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 info www.uic.org (http://www.uic.org).

ACCORDING TO THE STATUTES, UIC'S MISSION FOCUSES MAINLY ON:

- Promoting rail transport around the world with the aim to meet current and future challenges of mobility and sustainable development.
- Promoting interoperability, creating new world standards for railways, including common standards with other transport modes.
- Developing and facilitating all forms of international cooperation among members, facilitating the sharing of best practices (benchmarking).
- Supporting members in their efforts to develop new business and new areas of activity. Proposing new ways to improve technical and environmental performance of rail transport, boosting competitiveness and reducing costs.



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Foreword

This publication marks the fourth year of collaboration between the International Union of Railways (UIC) and the International Energy Agency (IEA) in producing a joint data handbook on “Energy Consumption and CO_2 Emissions” in the world railway sector. The very positive response to previous editions, notably special features such as the 2013 focus on the energy mix in the rail sector and the 2014 focus on the impacts associated with rail infrastructure on energy consumption and greenhouse gas (GHG) emissions, has encouraged us to continue this important joint effort.

For the 2015 edition, we highlight energy efficiency in the rail sector. The results of our analysis reveal that the energy intensity of passenger and freight trains is still improving, although some indicators show that the rate of improvement has weakened in recent years. Although rail is already among the most energy efficient transport modes, train manufacturers and public authorities need to keep deploying improvements whenever they are economically viable. Diesel trains are characterized by higher energy use, which can imply energy-related expenditures that are nearly twice as high as those of electric alternatives. Consequently, the electrification of both existing and new lines should be prioritized. This should be coupled with continuous technological innovation of both diesel and electric trains and with operational improvements. Results also suggest that developing high-speed rail in response to growing demand for transport could provide an additional opportunity for a less energy intensive, more sustainable mobility.

To conduct this analysis, we improved the methodology used to calculate specific energy consumption of passenger and goods transport, thus providing more consistent data to the reader, as well as effectively filling data availability gaps. Additionally, specific indicators were developed to provide insights into the energy efficiency of vehicles across different transport modes and to track their evolution through time, thereby allowing a cross-sectorial comparison with rail. Finally, a review of the latest developments in technologies and operational tools for improving the energy efficiency of trains aims to provide railway operators and train manufacturers with an overview of best practices and with insights on the efforts of rail sector to keep developing while limiting its energy use and greenhouse gas emissions.

The quantitative approach developed in this publication supports in a practical and consistent manner the campaign for sustainable development spearheaded by the United Nations post-2015 development agenda and climate change (COP) conferences. The IEA and UIC believe in the capacity of the rail sector to provide sustainable transport services that contribute to economic growth while economizing resources and enhancing energy security. We will continue to collaborate to improve transport sector information and analysis that will aid decision makers in identifying opportunities to support transformations in the transportation sector toward a more sustainable future.

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 CO_2 emissions, and to the IEA Energy Data Centre, which has collected and managed energy balances and CO_2 emissions data from fuel combustion.

The Handbook has been coordinated by Pierpaolo Cazzola and Marine Gorner for the IEA and by Gabriel Castañares Hernandez for UIC.

A special mention goes to the cooperation of Nicholas Craven and Andrea Braschi (UIC) for the completion of this work.

Gratitude is also extended to the Sustainable Development Foundation for its technical support, especially to Raimondo Orsini, Daniele Arena, Valeria Gentili, Stefania Grillo and Luca Refrigeri.

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Railway Handbook 2015

Energy Consumption and CO_2 Emissions

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Introduction

The collaboration of the IEA and the UIC in collecting, elaborating, and presenting activity, energy, and CO_2 emissions data was carried out for the fourth time through the release of the Railway Handbook 2015. The previous editions can be downloaded for free from the UIC website.

For this edition, significant methodological improvements were implemented leading to better consistency between the different indicators presented in this Handbook, in addition to updates of the global data, as well as regional breakdowns for those regions that we consider the most relevant from the point of view of transport activity: European Union, USA, Japan, Russia, India, and China.

This edition devotes particular attention to the energy efficiency of rail vehicles. This is achieved by providing information on the energy efficiency of trains in different world regions, with a richer set of indicators for the European Union. In order to put rail in the context of the broader transport sector, energy efficiency time series are also provided for other transport modes – namely road and aviation. In addition, this year's edition of the Handbook includes a review of recent operational and technological innovations improving the energy efficiency of trains while providing economic benefits.

The data provided in this handbook are the result of the combination of rail infrastructure, activity, and energy use statistics collected by UIC from their member companies (International Railway Statistics - UIC, 2014a – and UIC Environmental Performance Database - UIC, 2014b) with information on energy and CO_2 emissions by end-use sector and fuel from the IEA (CO_2 emissions from fuel combustion – IEA, 2014a - and World Energy Balances – IEA, 2014b). These data are punctually supplemented by sector or region specific databases such as the High-Speed lines in the World database (UIC, 2015).

One of the key figures shown in the statistics shows the global contribution of rail to energy use and CO_2 emissions: in 2012, rail was responsible for 0.6% of global energy consumption and less than 1% of global CO_2 emissions, while an energy share of 21% and a CO_2 share of 17% can be attributed to road transport. Even accounting for the much higher share of passengers transported by road versus by rail, the difference between road and rail energy use and emissions is striking.

The rail sector's energy intensity has declined globally since 1975, achieving in 2012 about half of its original 1975 level for passenger and freight transport. Not only energy intensity has been improving, but the energy sources used in rail have also become cleaner since 1990, with the progressive phasing out of coal and the growing electrification of the sector, enhanced by the growing share of renewable electricity used in rail (IEA/UIC, 2013). This resulted in a drop in specific CO_2 emissions close to 60% for passenger and 41% for freight rail transport since 1975. High-speed lines deployment worldwide reached close to 27 000 km in operation in 2014, 60% of which are located in China. When coupled with findings that high-speed train operation is more energy efficient than conventional train on similar journeys, this represents an opportunity to drive energy intensity even further down.

All regions studied in this handbook have experienced improvements in energy and emissions intensity, as well as in electrification. To date, data show that China has the lowest energy consumption per passenger-km (67 kJ/pkm) while India has the lowest passenger specific CO_2 emissions at 10g CO_2/pkm. India also holds the lowest rate of energy consumption per tonne-km for goods transport by rail (102 kJ/tkm), the lowest specific CO_2 emissions from freight taking place in Russia at 9g CO_2/tkm.

The focus part of the Handbook aims at understanding the long and medium-term evolutions of vehicles energy efficiency in the rail sector. The information shown indicates substantial improvements in train efficiency were achieved since 1975, since both diesel and electric passenger trains in 2012 consumed about one third less energy than they did in the mid-seventies. However, some indicators show that the rate of improvement of the energy efficiency of trains slowed down in recent years: this is the case for the energy use per gross tonnage in Europe and the diesel use per train-km on freight rail, globally. A brief review of innovations for improved vehicle efficiency was carried out for this Handbook as an addition to statistical data. Key items identified in this exercise include amongst others, the development of a drive cycle for a consistent assessment of rolling stock performance, better engine technologies, weight reductions, energy recovery solutions and improvements targeting hotel loads.

The UIC has been undergoing a process of collecting rail rolling stock energy efficiency data directly from railway operators, starting in the European Union. The energy efficiency and CO_2 intensity data displayed for the EU comes from this direct data collection by UIC, while other regions contain figures obtained by combining overall energy consumption and transport activity reported by the different railway operators. The energy efficiency data collection operated by UIC will be extended to railway operators in other world regions in future editions of this Handbook, possibly starting in 2016. The IEA and UIC are undertaking a significant effort to widen the scope of their environmental data collection and to gather data from railways all over the world. The ultimate goal is to release a more accurate and comprehensive edition of the Railway Handbook each year in order to provide policy makers with continuously improved indicators on which to build choices towards sustainable mobility.

Part I:
The Railway Sector Main Data

World

Key Facts

- The transport sector was responsible for 23.1% of global CO_2 emissions in 2012. 3.6% of transport emissions were due to the rail sector, while railways transported over 8% of the world's passengers and goods. The relative contribution of rail to global CO_2 emissions has decreased since 1990 while total CO_2 emissions have risen by almost 50%.

- The rail sector used close to 2 200 PJ of energy in 2012, mostly provided by oil products and electricity, the use of coal becoming marginal at less than 100 PJ.

- Passenger travel on rail increased by 131% between 1975 and 2012, China and India experiencing the largest growth with a seven-fold increase, while EU28 rail passenger activity remained stable since the 1990s.

- Electrification of railway tracks has been constantly increasing in the past decades, accounting for nearly one third of total tracks globally in 2012.

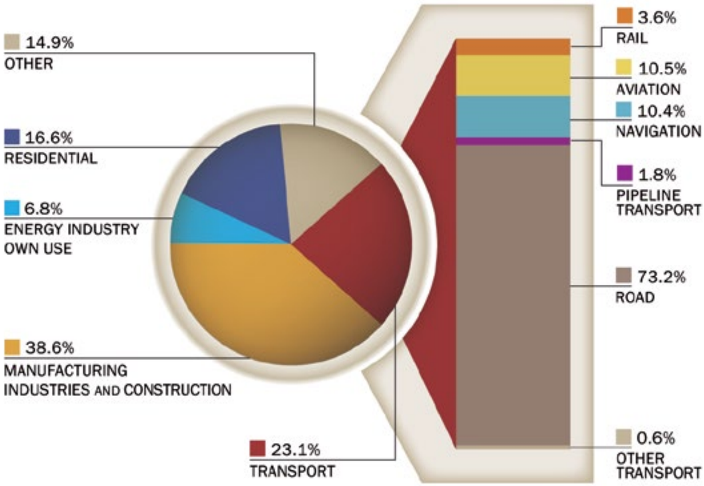
- High-speed rail deployment has been following an even faster growing trend. The total length of high-speed lines in 2014 was 10 times higher than in 1990. China has clearly taken the lead in high speed rail, as it accounts for close to 60% of the length of all high speed lines in 2014.

- Freight activity increased by 78% since 1975. The main global regions using rail for freight transport are North American countries (Canada, USA and Mexico), Russia and China.

- Railway specific energy consumption has been following a downward trajectory since 1975, both for passenger and freight services. From 1975 to 2012, the energy use per passenger-km declined by 62%. In the same time span, the amount of energy needed to move one tonne-km fell by 46%. In 2012, both indicators reached about 150 KJ per passenger-km (for passenger transport) or per tonne-km (for freight transport).

- Specific CO_2 emissions in the rail sector have been following a similar rate of improvement to specific energy consumption, resulting in a CO_2 intensity close to 16 g CO_2 per passenger-km in the case of passenger transport and per tonne-km in the case of freight transport.

Fig. 1: **Share of CO_2 emissions from fuel combustion by sector, 2012**



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

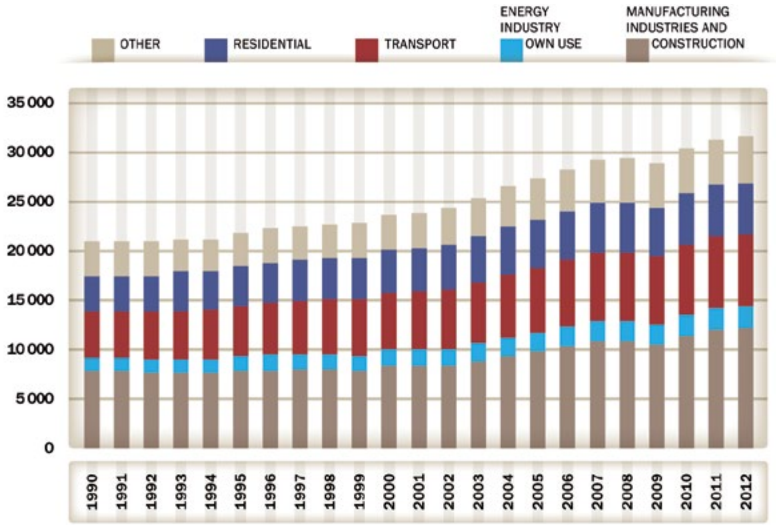
Source: Elaboration by Susdef based on IEA (2014a)

Table 1: **Transport modal share, 2012**

	Passenger PKM	Freight TKM	Total TU
ROAD	82.7%	8.8%	31.3%
AVIATION	10.6%	0.7%	3.7%
NAVIGATION	0.3%	81.5%	56.8%
RAIL	6.3%	9%	8.2%

Source: IEA Mobility Model, UIC (2014a), and UNCTAD (2014)

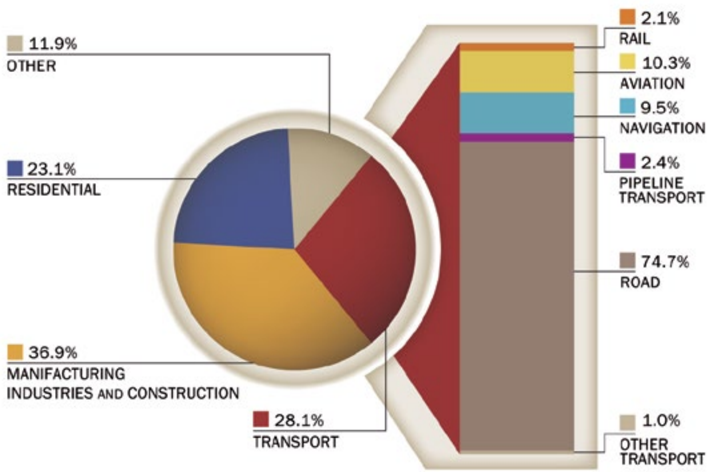
Fig. 2: **Total CO_2 emissions from fuel combustion by sector, 1990-2012 (million tCO_2)**



Note: Electricity and heat emissions are reallocated to the end use sectors. See Methodology Notes.

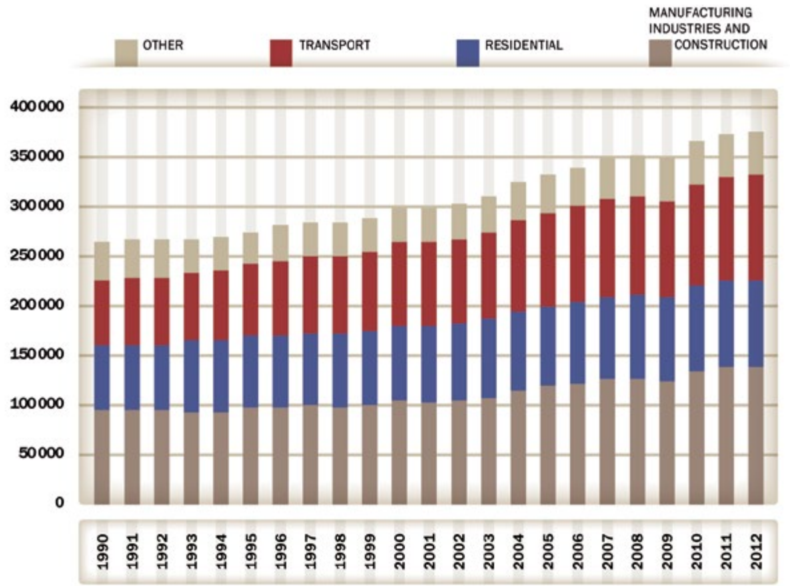
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 3: **Share of final energy consumption by sector, 2012**



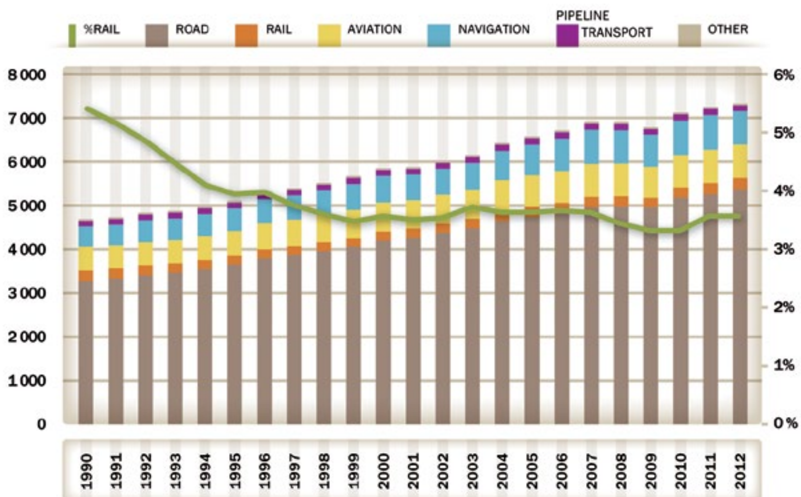
Source: Elaboration by Susdef based on IEA (2014b)

Fig. 4: **Total final energy consumption by sector, 1990-2012 (PJ)**



Source: Elaboration by Susdef based on IEA (2014b)

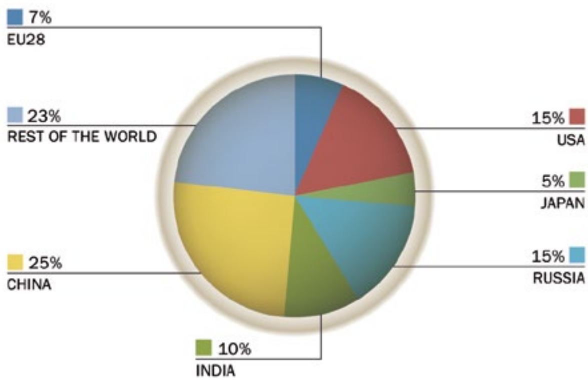
Fig. 5: **Transport sector CO_2 emissions by mode, 1990-2012 (million tCO_2 - left, share of rail over total - right)**



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

Source: Elaboration by Susdef based on IEA (2014a)

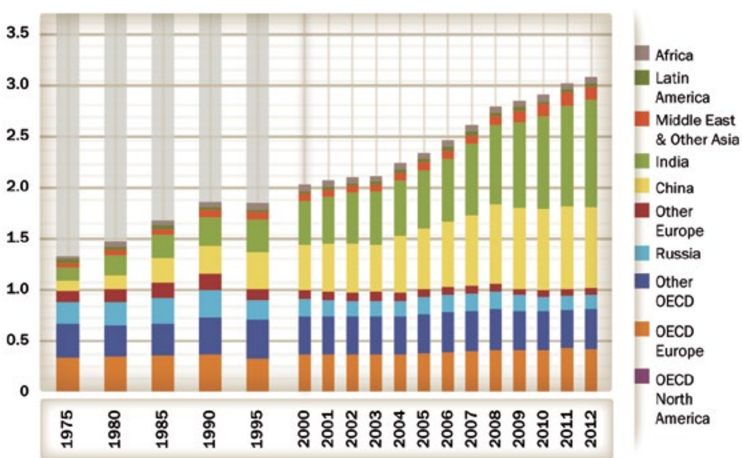
Fig. 6: **Share of railway CO_2 emissions by geographic area, 2012**



Note: All the emissions from electricity/heat production in transport have been reallocated to rail. See Methodology Notes.

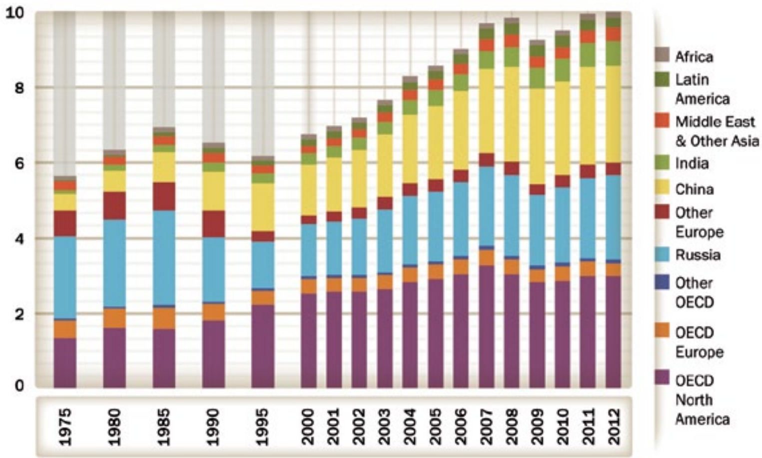
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 7: **Railway passenger transport activity by geographic area, 1975-2012 (trillion pkm)**



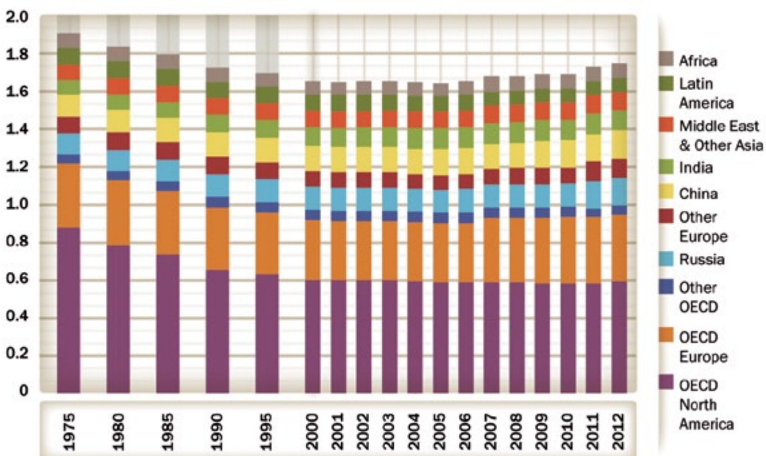
Source: Elaboration by IEA based on UIC (2014a)

Fig. 8: **Railway freight transport activity by geographic area, 1975-2012 (trillion tkm)**



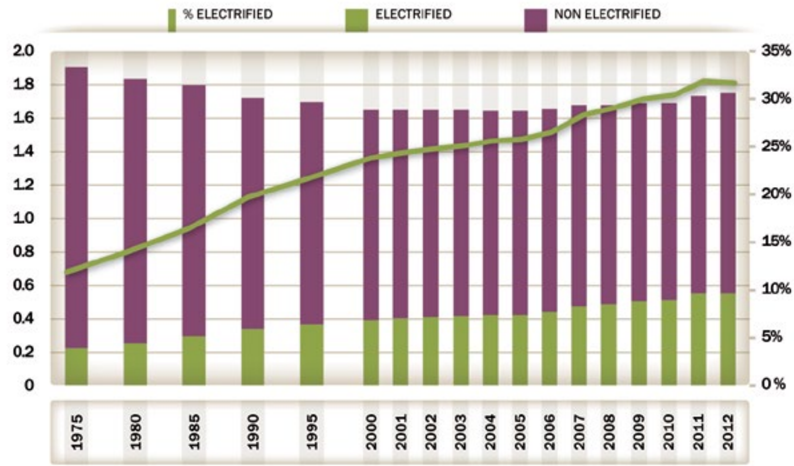
Source: Elaboration by IEA based on UIC (2014a)

Fig. 9: **Length of railway tracks in operation by geographic area, 1975-2012 (million km)**



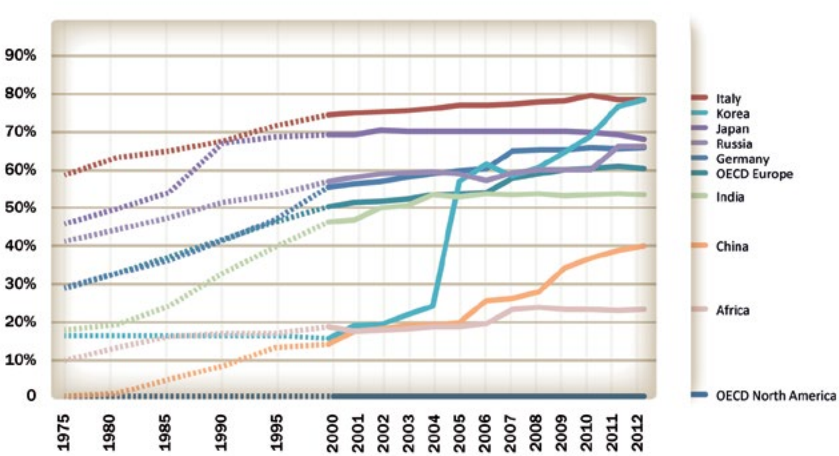
Source: Elaboration by IEA based on UIC (2014a)

Fig. 10: **Length and share of electrified versus non-electrified railway tracks, 1975-2012 (million km – left axis)**



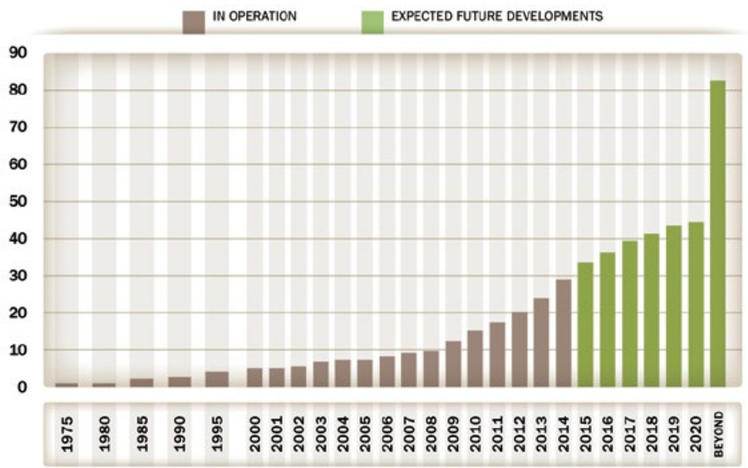
Source: Elaboration by IEA based on UIC (2014a)

Fig. 11: **Share of electrified railway tracks in selected countries and geographic areas, 1975-2012**



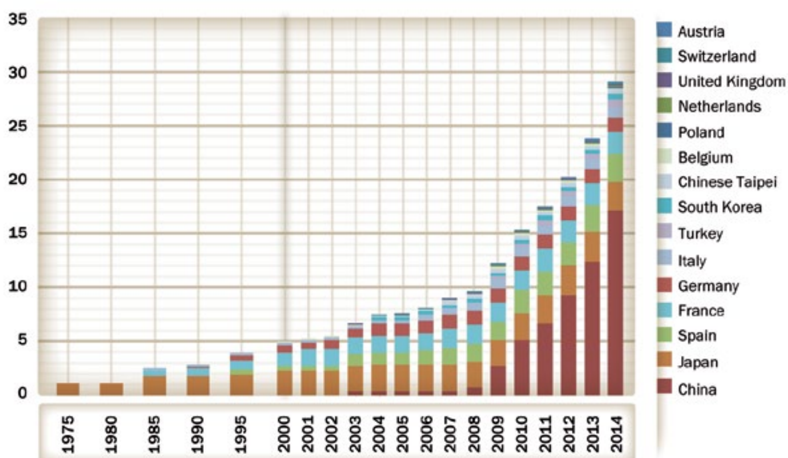
Source: Elaboration by IEA based on UIC (2014a)

Fig. 12: **High-speed lines in operation and forecasted, 1975-2020 and beyond (thousand km)**



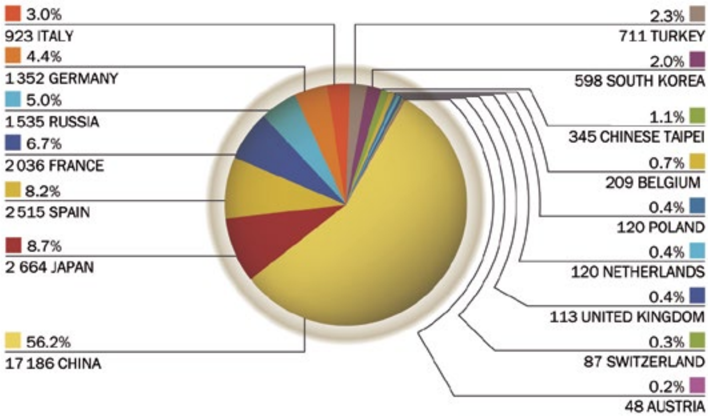
Source: Elaboration by Susdef and IEA based on UIC (2014a) and UIC (2015)

Fig. 13: **High-speed lines in operation by country, 1975-2014 (thousand km)**



Source: Elaboration by Susdef and IEA based on UIC (2014a) and UIC (2015)

Fig. 14: **High-speed lines in operation by country (km) and share of world total (%), 2014**

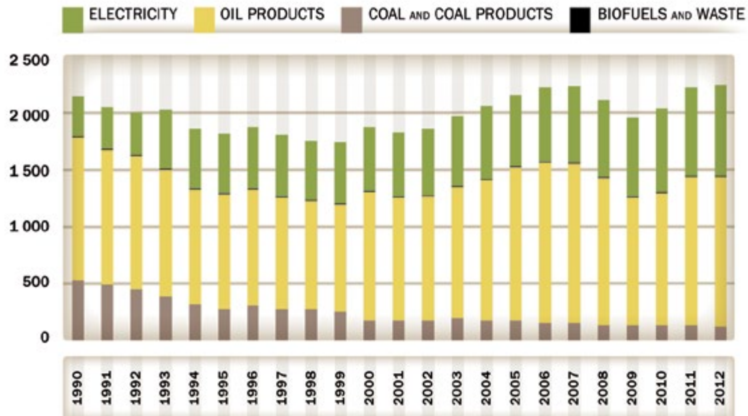


Source: Elaboration by Susdef and IEA based on UIC (2014a) and UIC (2015)

Fig. 15: **High-speed activity as a share of total passenger railway activity, 1990-2012 (billion pkm)**

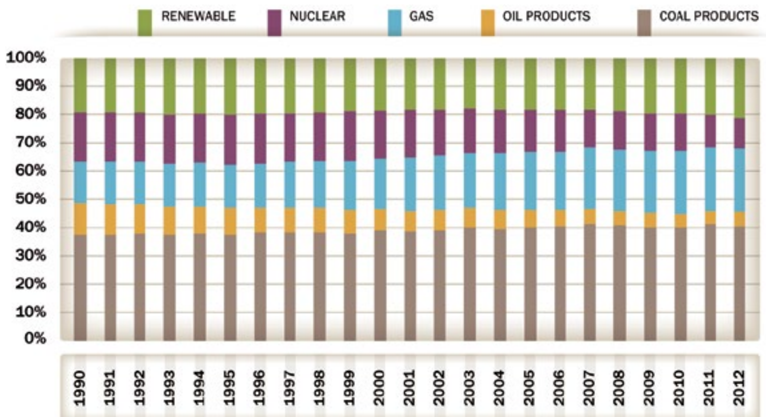
Source: Elaboration by IEA based on UIC (2014a)

Fig. 16: **Railway final energy consumption by fuel, 1990-2012 (PJ)**



Source: IEA (2014b)

Fig. 17: **World electricity production mix evolution, 1990-2012**



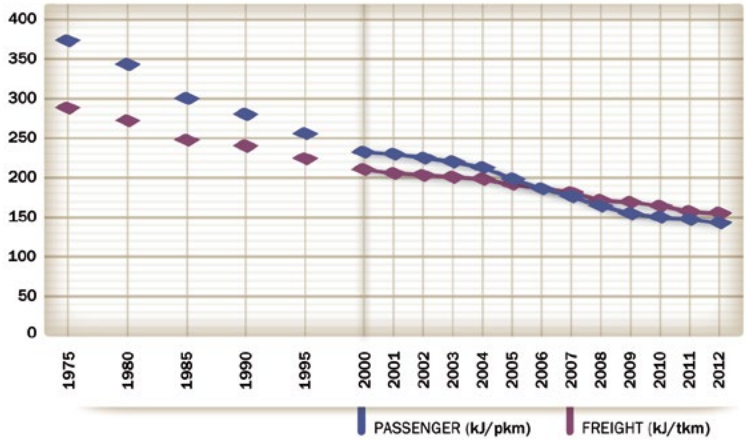
Source: IEA (2014b)

Table 2: **World electricity production mix evolution, 2000-2012**

	2000	2012
COAL PRODUCTS	39%	40%
OIL PRODUCTS	8%	5%
GAS	18%	23%
NUCLEAR	17%	11%
RENEWABLE	18%	21%

Source: IEA (2014b)

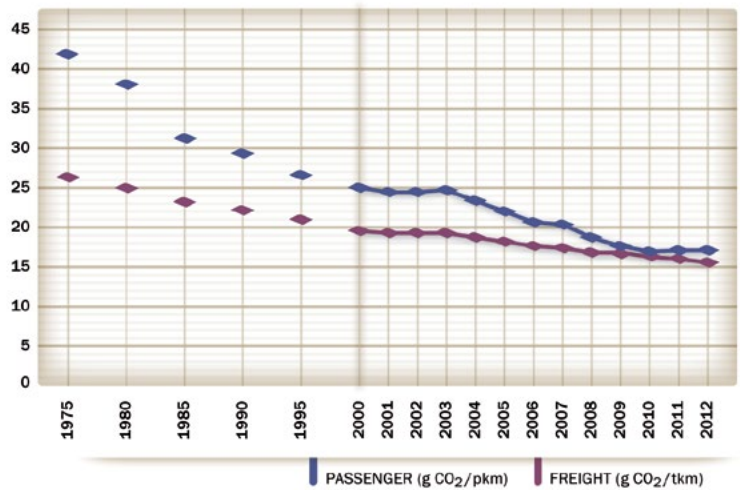
Fig. 18: **Railway specific energy consumption, 1975-2012**



Note: See Methodology p.94

Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

Fig. 19: **Railway specific CO_2 emissions, 1975-2012**



Note: See Methodology p.94

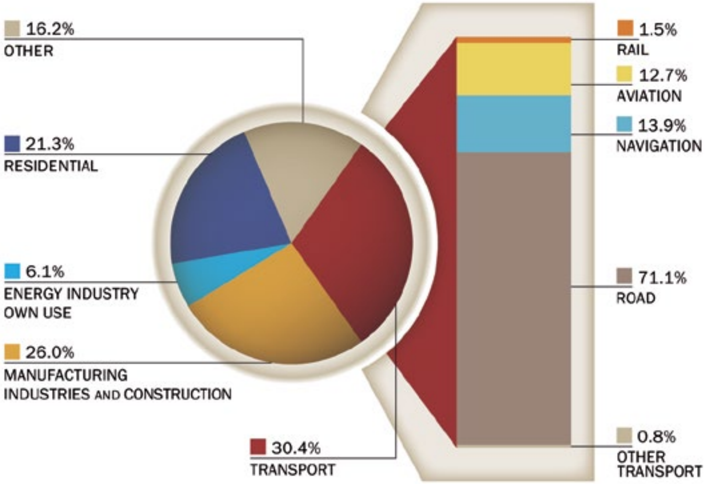
Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

Europe (EU28)

Key Facts

- Rail is responsible for 1.5% of transport CO_2 emissions and 1.3% of energy use. The rail share in transport activity is significantly higher: 7.6% for passenger services and 10.6% for freight.
- Rail contribution to transport emissions has more than halved since 1990.
- Electrification of tracks has doubled since 1975 to reach 60% of total tracks in 2012.
- An increasing share of the energy used in rail is coming from the electric grid and represents about 72% of the fuel used, while the proportion of renewables in the EU electricity mix has also doubled since 1990.
- 390 billion passenger-km were transported by rail in 2012. High speed rail accounted for 28% of this activity, a seven-fold increase since 1990.
- Specific energy consumption of rail reached 400 kJ/pkm and 185 kJ/tkm for passenger and freight transport, respectively, down from 475 kJ/pkm (-16%) and 240 kJ/tkm in 1990 (-23%).
- Specific CO_2 emissions have been falling since 1990. Passenger and freight operations attained, in 2012, 34 g CO_2/pkm (-35%) and 18 g CO_2/tkm (-42%) respectively.

Fig. 20: **Share of CO_2 emissions from fuel combustion by sector, 2012**



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

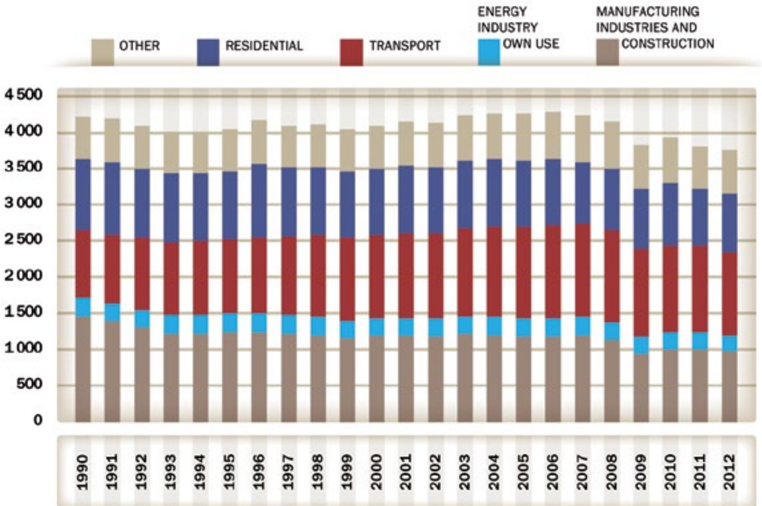
Source: Elaboration by Susdef based on IEA (2014a) and UIC (2014b)

Table 3: **Transport modal share, 2012**

	Passenger PKM	Freight TKM	Total TU
ROAD	82.7%	46.6%	69.6%
AVIATION	9.1%	0.1%	5.8%
NAVIGATION	0.6%	42.7%	15.9%
RAIL	7.6%	10.6%	8.7%

Source: Elaboration by Susdef based on EC (2014) and UIC (2014a)

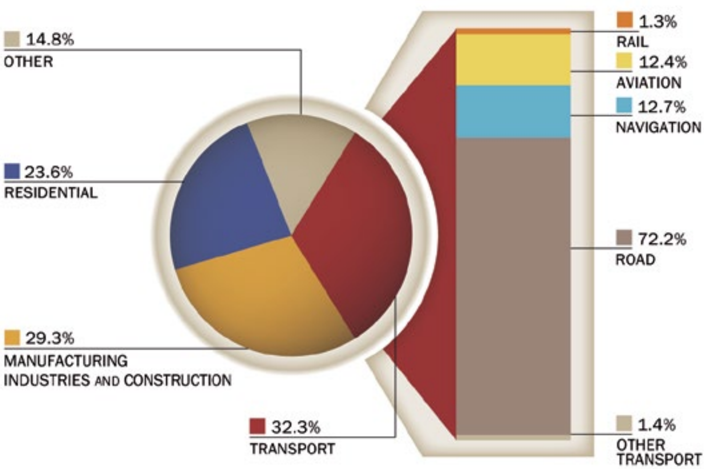
Fig. 21: **Total CO_2 emissions from fuel combustion by sector, 1990-2012 (million tCO_2)**



Note: Electricity and heat emissions are reallocated to the end-use sectors.
See Methodology Notes.

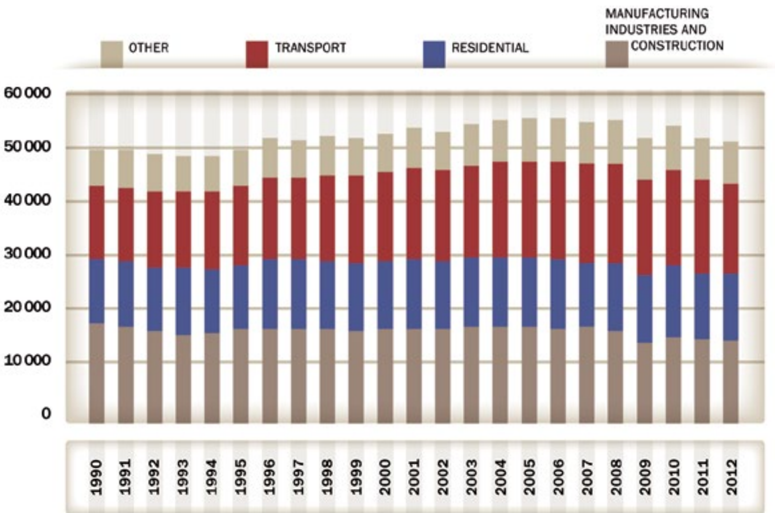
Source: Elaboration by Susdef based on IEA (2014a) and UIC (2014b)

Fig. 22: **Share of final energy consumption by sector, 2012**



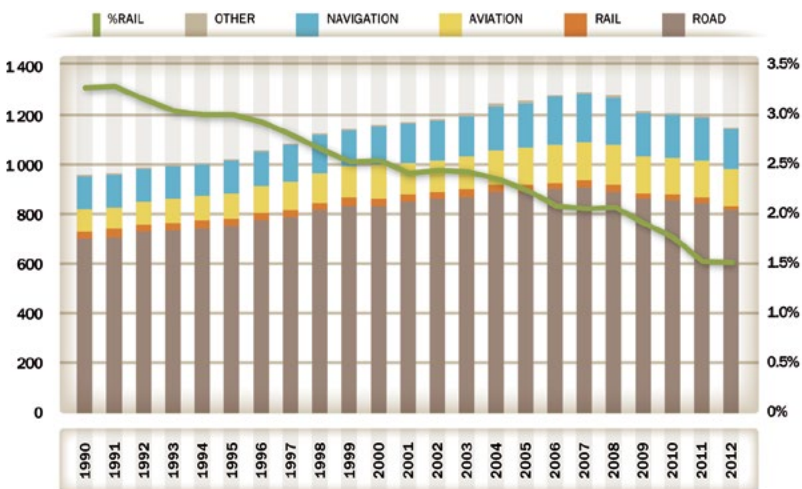
Source: Elaboration by Susdef based on IEA (2014b) and UIC (2014b)

Fig. 23: **Total final energy consumption by sector, 1990-2012 (PJ)**



Source: Elaboration by Susdef based on IEA (2014b) and UIC (2014b)

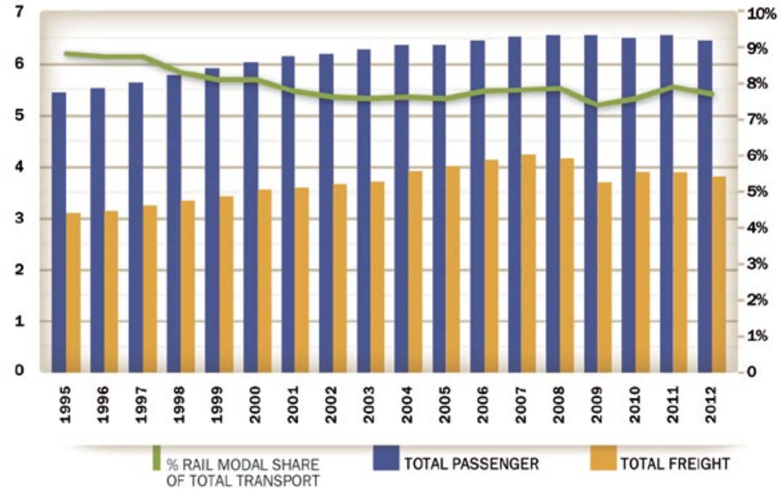
Fig. 24: **Transport sector CO_2 emissions by mode, 1990-2012 (million tCO_2 - left, share of rail over total - right)**



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

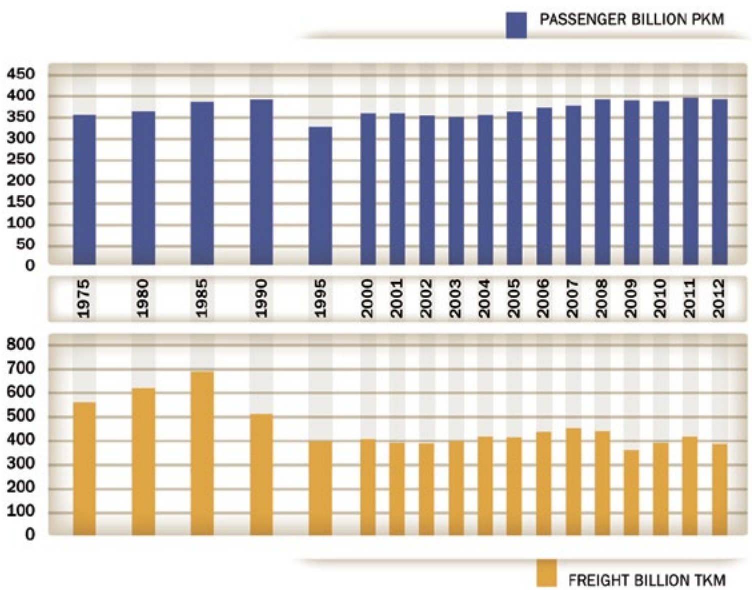
Source: Elaboration by Susdef based on IEA (2014a) and UIC (2014b)

Fig. 25: **Passenger and freight transport activity - all modes, 1995-2012 (trillion pkm and tkm – left, share of rail overtotal - right)**



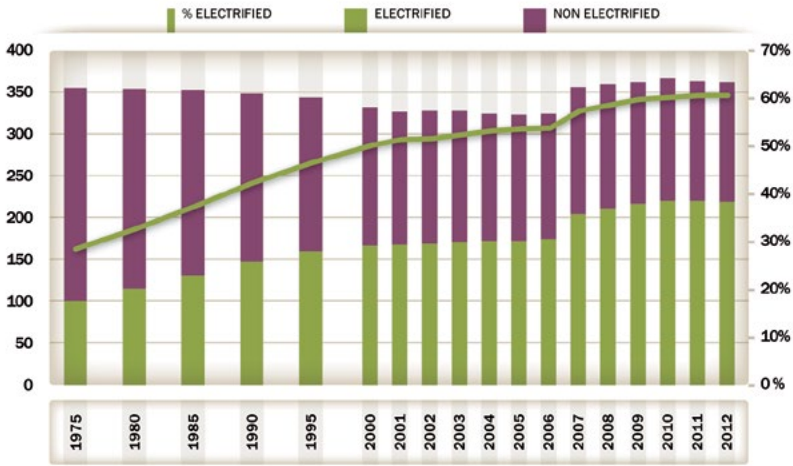
Source: Elaboration by Susdef based on EC (2014) and UIC (2014a)

Fig. 26: **Passenger and freight railway activity, 1975-2012**



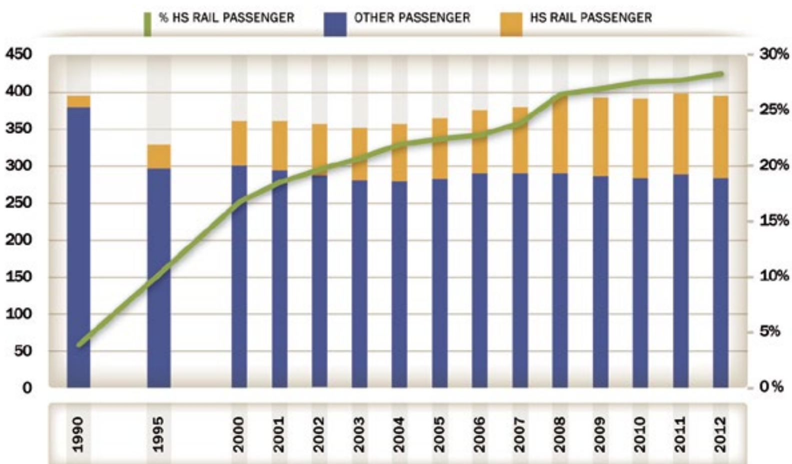
Source: Elaboration by IEA based on UIC (2014a)

Fig. 27: **Length and share of electrified versus non-electrified railway tracks, 1975-2012 (thousand km)**



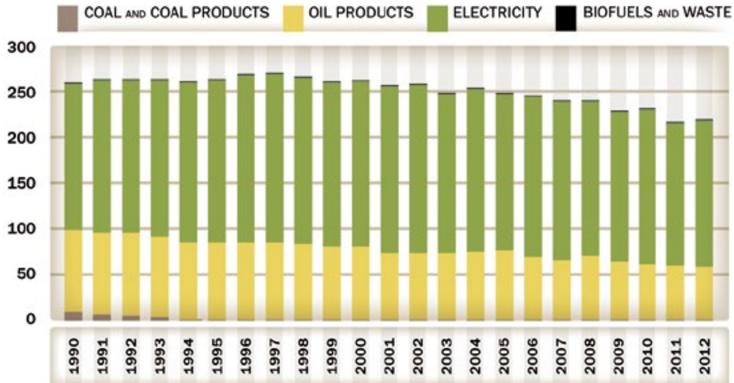
Source: Elaboration by IEA based on UIC (2014a)

Fig. 28: **High-speed activity as a share of total passenger railway activity, 1990-2012 (billion pkm)**



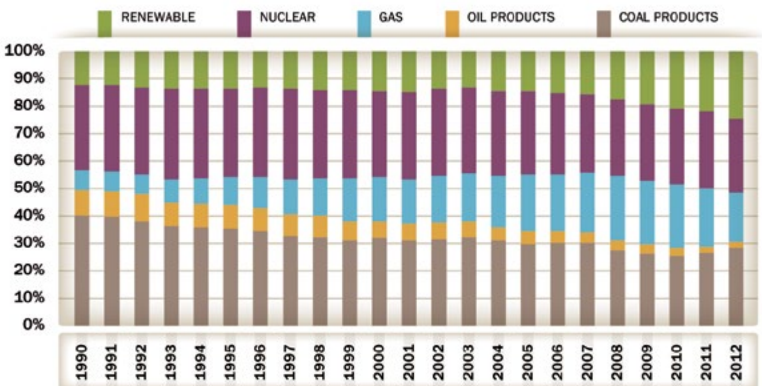
Source: Elaboration by IEA based on UIC (2014a)

Fig. 29: **Railway final energy consumption by fuel, 1990-2012 (PJ)**



Source: Elaboration by Susdef based on IEA (2014b) and UIC (2014b)

Fig. 30: **EU28 electricity production mix evolution, 1990-2012**



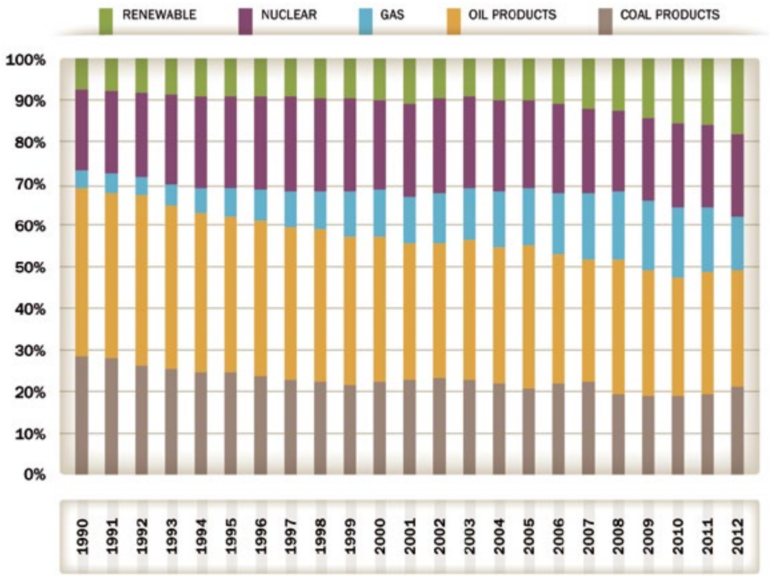
Source: IEA (2014b)

Table 4: **EU28 electricity production mix evolution, 2000-2012**

	2000	2012
COAL PRODUCTS	32%	29%
OIL PRODUCTS	6%	2%
GAS	16%	18%
NUCLEAR	32%	27%
RENEWABLE	14%	24%

Source: IEA (2014b)

Fig. 31: **EU28 Railway energy sources mix evolution, 1990-2012**



Note: See Methodology p.94

Source: Elaboration by Susdef based on IEA (2014b) and UIC (2014b)

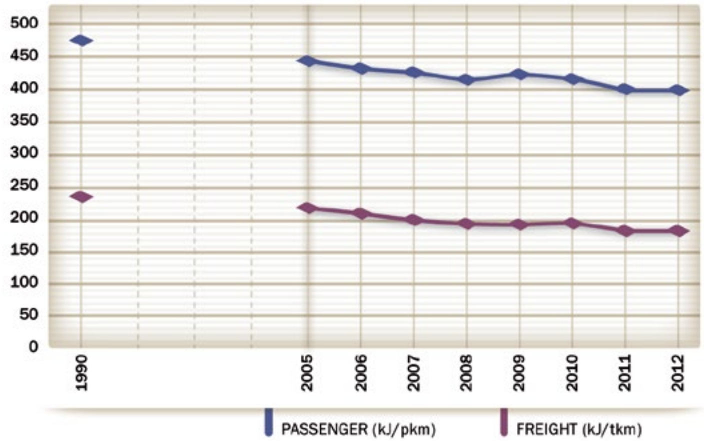
Table 5: **EU28 railway energy sources mix, 2000-2012**

	2000	2012
COAL PRODUCTS	22%	21%
OIL PRODUCTS	35%	28%
GAS	11%	13%
NUCLEAR	22%	20%
RENEWABLE	10%	18%

Note: See Methodology p.94

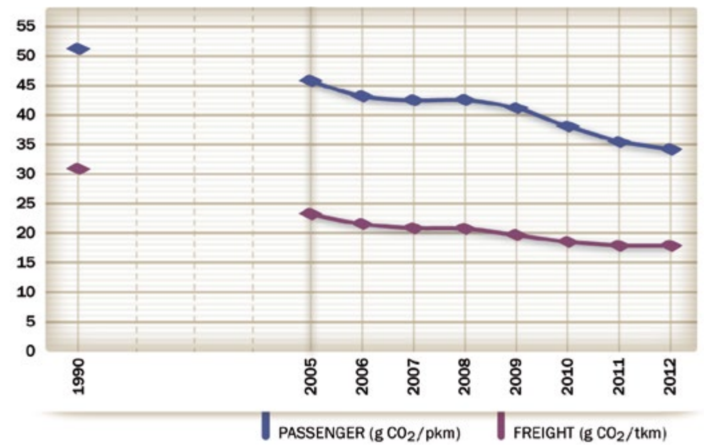
Source: Elaboration by Susdef based on IEA (2014b) and UIC (2014b)

Fig. 32: **Railway specific energy consumption, 1990-2012**



Source: UIC (2014b)

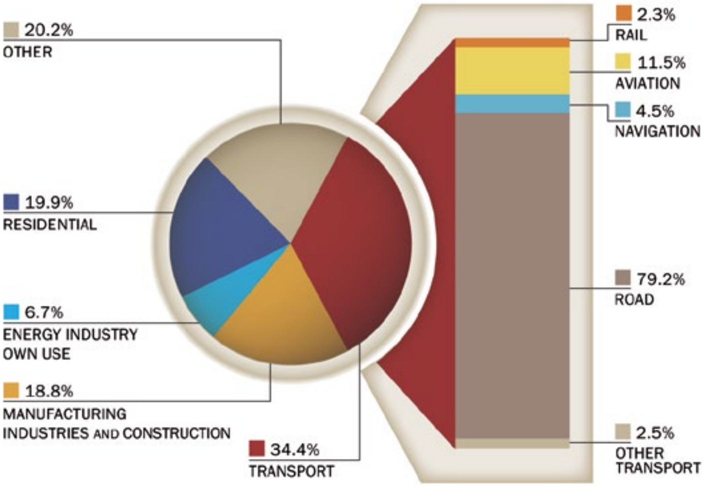
Fig. 33: **Railway specific CO_2 emissions, 1990-2012**



Source: UIC (2014b)

USA

Fig. 34: **Share of CO_2 emissions from fuel combustion by sector, 2012**



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

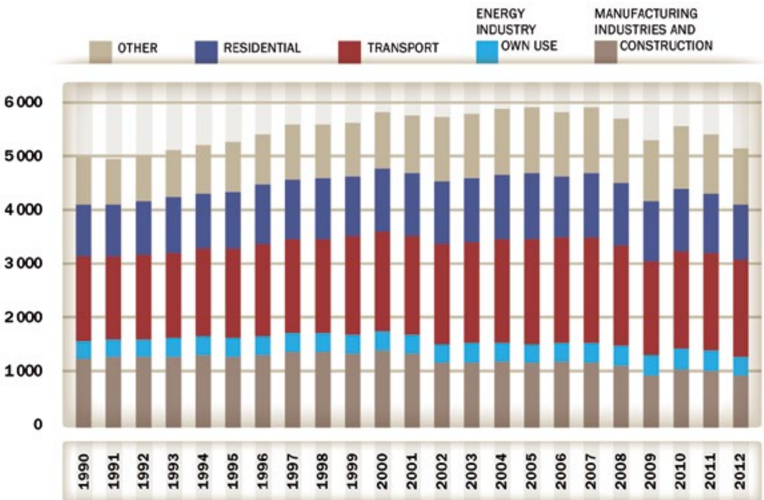
Source: Elaboration by Susdef based on IEA (2014a)

Table 6: **Transport modal share, 2012**

	Passenger PKM	Freight TKM	Total TU
ROAD	87.9%	56.8%	72.4%
AVIATION	12.0%	0.2%	6.1%
NAVIGATION	0%	10.4%	5.2%
RAIL	0.1%	32.6%	16.3%

Source: elaboration by Susdef based on UIC (2014a) and NTS (2015)

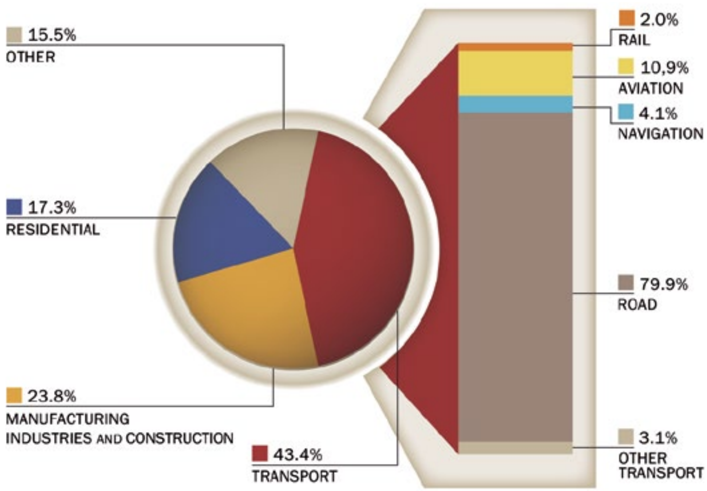
Fig. 35: **Total CO_2 emissions from fuel combustion by sector, 1990-2012 (million tCO_2)**



Note: Electricity and heat emissions are reallocated to the end-use sectors. See Methodology Notes.

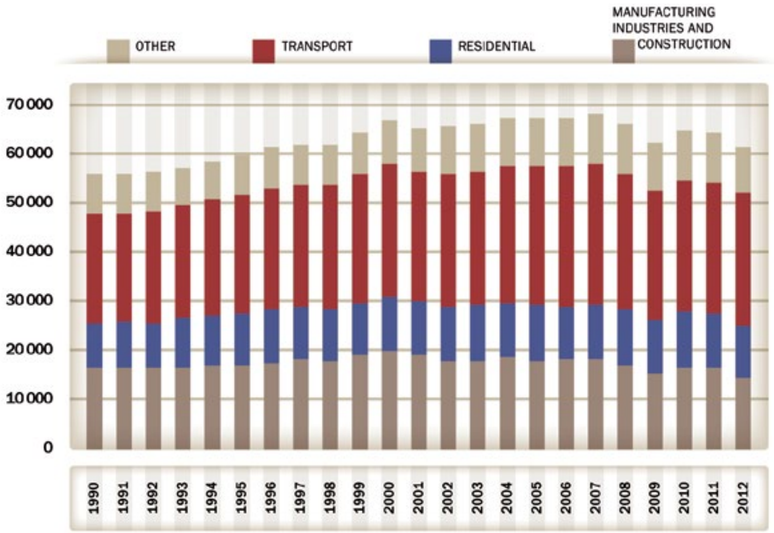
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 36: **Share of final energy consumption by sector, 2012**



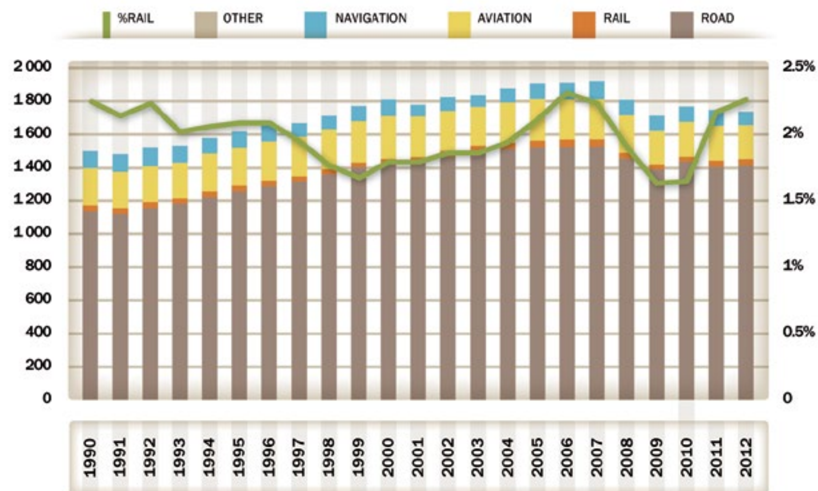
Source: Elaboration by Susdef based on IEA (2014b)

Fig. 37: **Total final energy consumption by sector, 1990-2012 (PJ)**



Source: Elaboration by Susdef based on IEA (2014b)

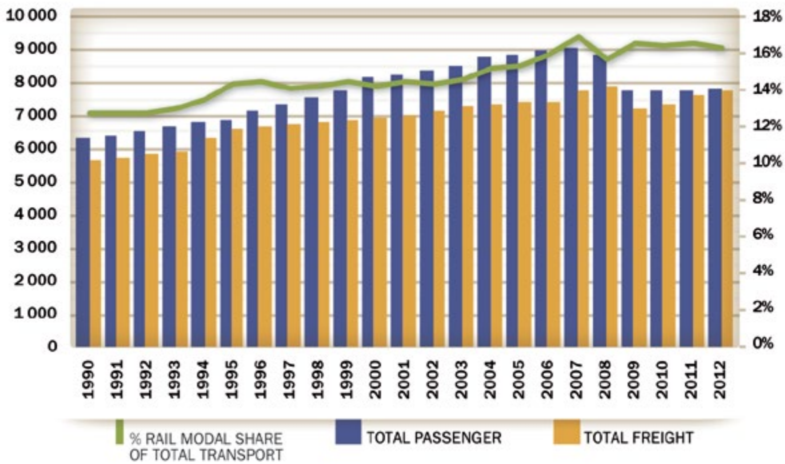
Fig. 38: **Transport sector CO_2 emissions by mode, 1990-2012 (million tCO_2 - left, share of rail over total - right)**



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

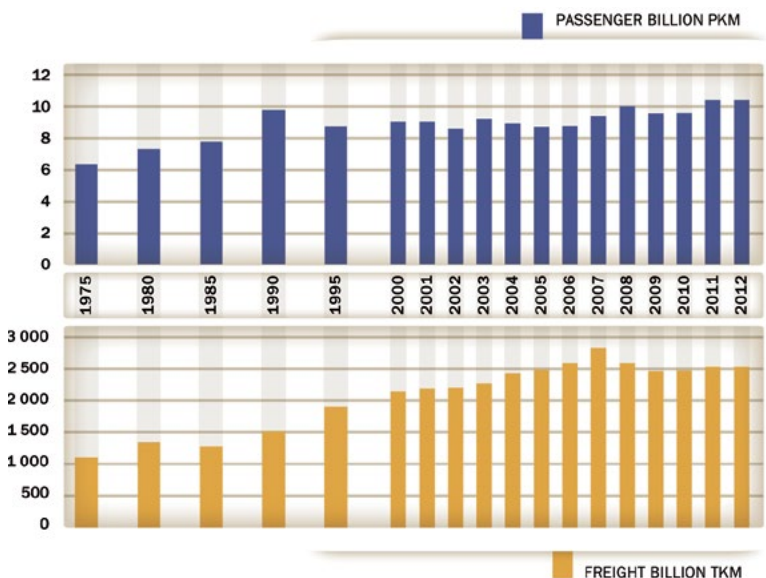
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 39: **Passenger and freight transport activity - all modes, 1990-2012 (billion pkm and tkm)**



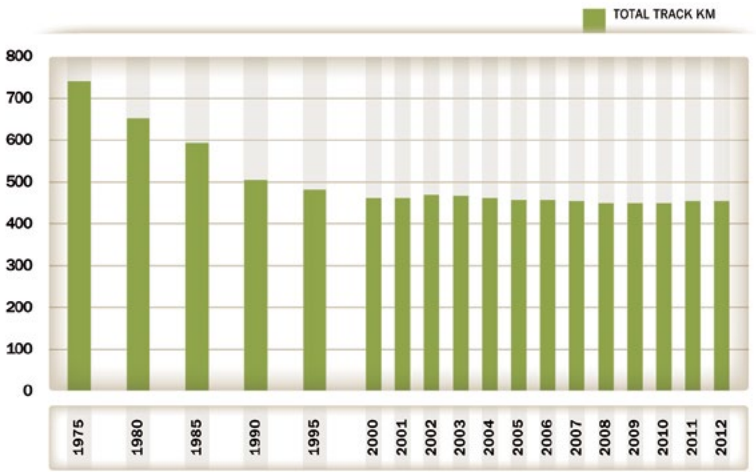
Source: elaboration by Susdef based on UIC (2014a) and NTS (2015)

Fig. 40: **Passenger and freight railway activity, 1975-2012**



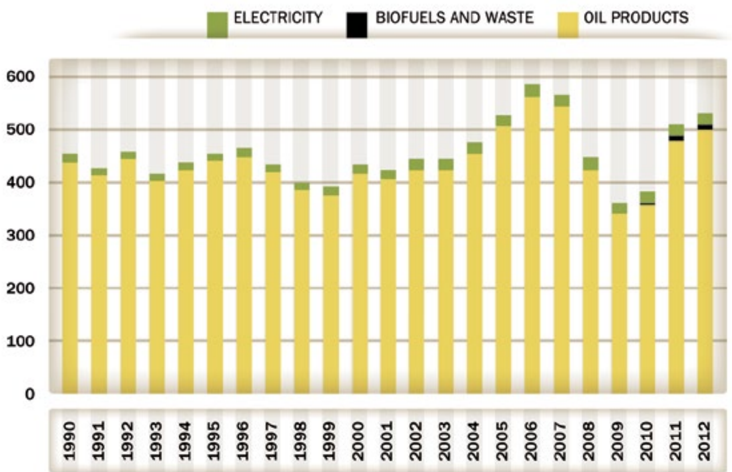
Source: Elaboration by IEA based on UIC (2014a)

Fig. 41: **Length of railway tracks, 1990-2012 (thousand km)**



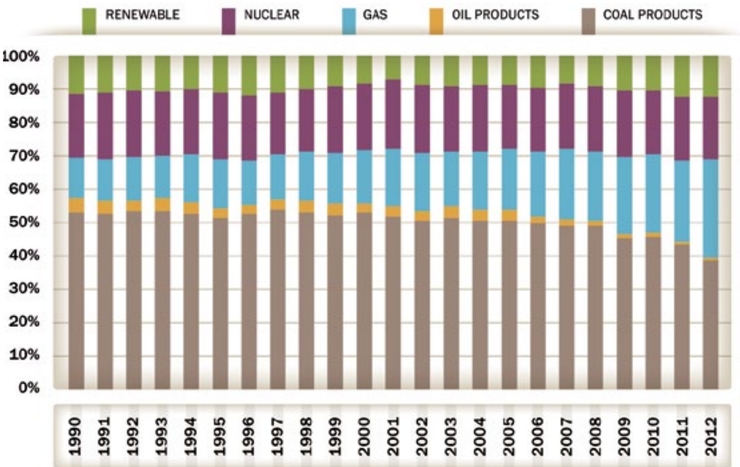
Source: Elaboration by IEA based on UIC (2014a)

Fig. 42: **Railway final energy consumption by fuel, 1990-2012 (PJ)**



Source: IEA (2014b)

Fig. 43: **National electricity production mix evolution, 1990-2012**



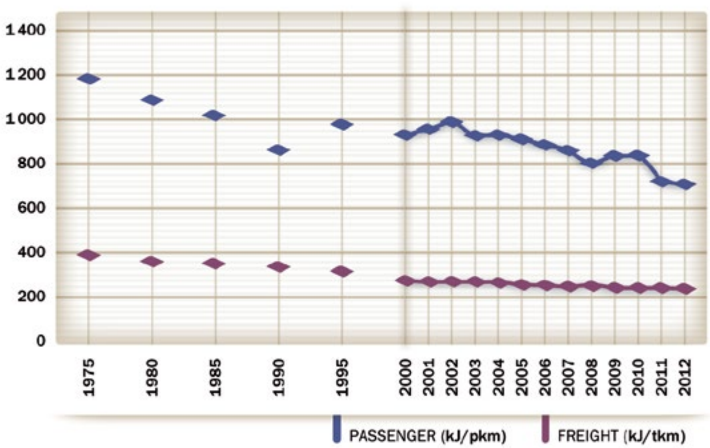
Source: IEA (2014b)

Table 7: **National electricity production mix evolution, 2000-2012**

	2000	2012
COAL PRODUCTS	53%	38%
OIL PRODUCTS	3%	1%
GAS	16%	30%
NUCLEAR	20%	19%
RENEWABLE	8%	12%

Source: IEA (2014b)

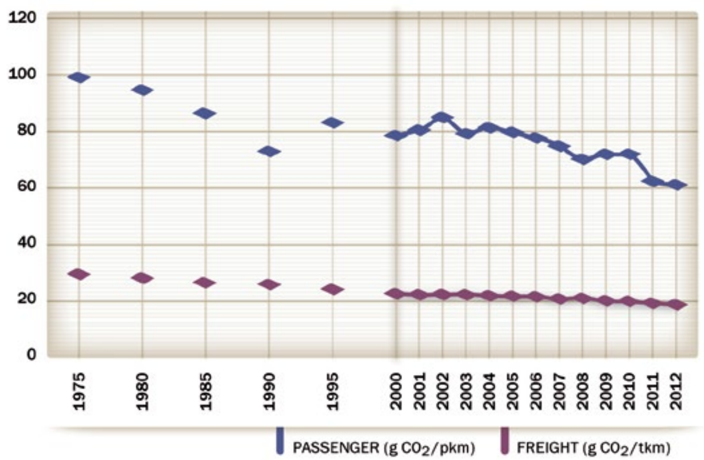
Fig. 44: **Railway specific energy consumption, 1975-2012**



Note: See Methodology p.94

Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

Fig. 45: **Railway specific CO_2 emissions, 1975-2012**

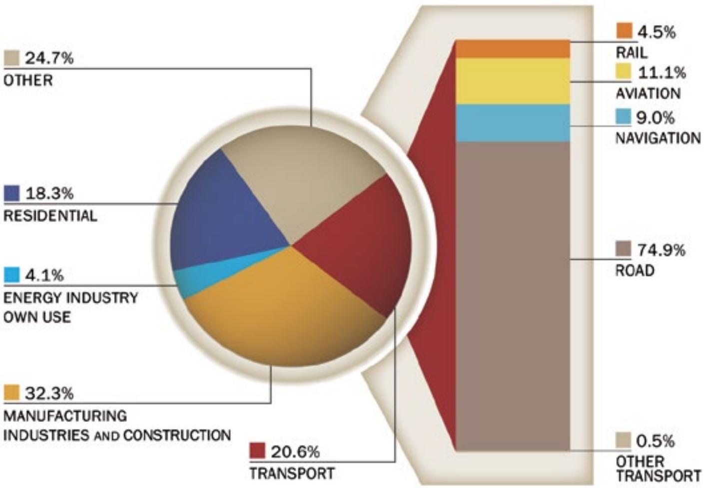


Note: See Methodology p.94

Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

Japan

Fig. 46: **Share of CO_2 emissions from fuel combustion by sector, 2012**



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

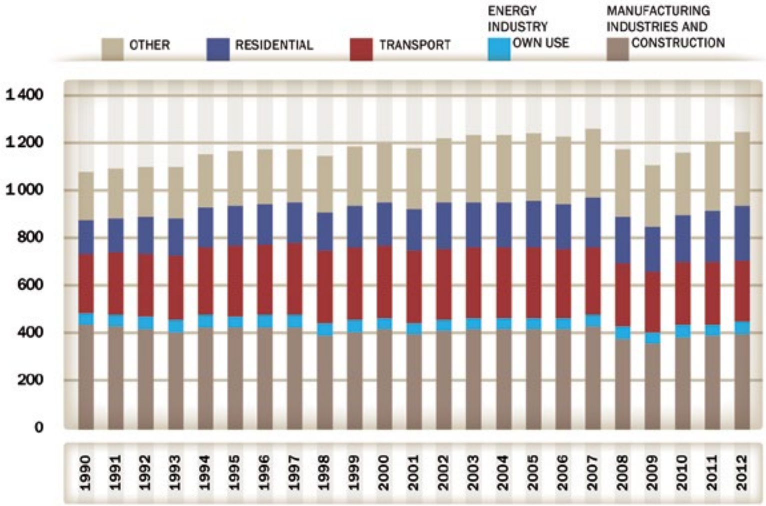
Source: Elaboration by Susdef based on IEA (2014a)

Table 8: **Transport modal share, 2012**

	Passenger PKM	Freight TKM	Total TU
ROAD	69.8%	10.3%	30.8%
AVIATION	8.2%	0%	2.8%
NAVIGATION	0%	89.0%	58.3%
RAIL	22.0%	0.7%	8.0%

Source: estimations from the IEA Mobility Model, including information from UIC (2014a). Navigation activity is estimated from global tkm from UNCTAD (2014) according to shares in energy demand from IEA energy balances (IEA, 2014)

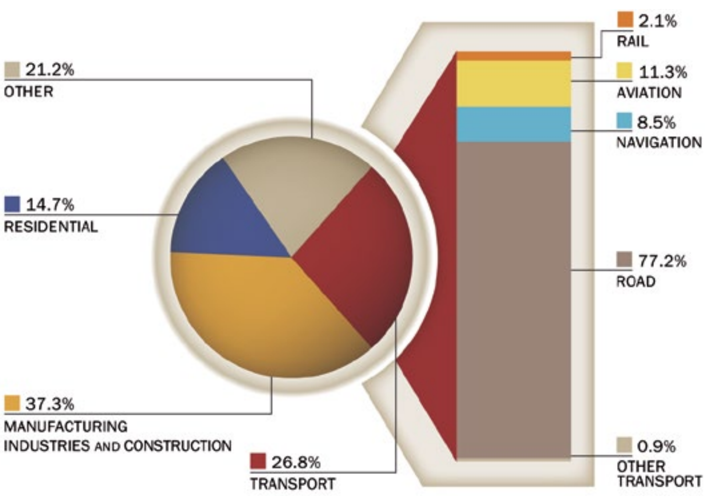
Fig. 47: **Total CO_2 emissions from fuel combustion by sector, 1990-2012 (million tCO_2)**



Note: Electricity and heat emissions are reallocated to the end-use sectors. See Methodology Notes.

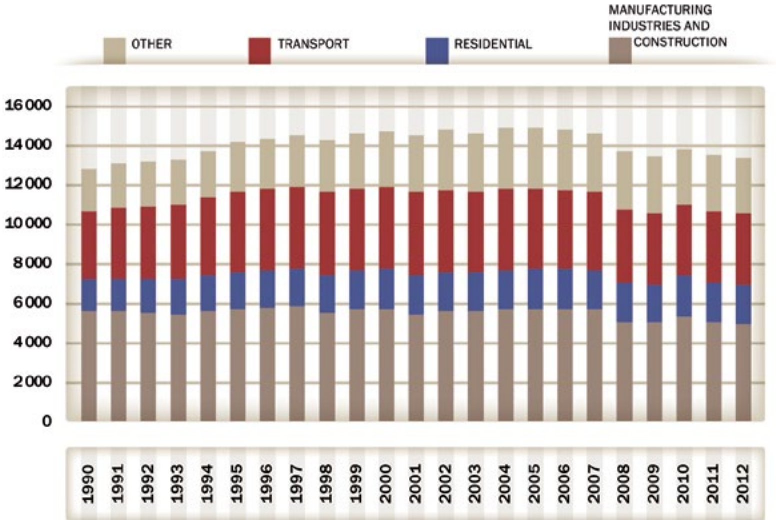
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 48: **Share of final energy consumption by sector, 2012**



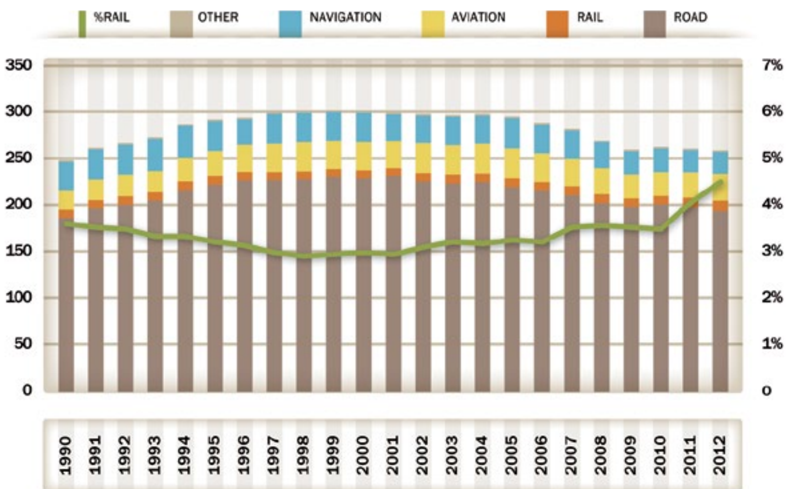
Source: Elaboration by Susdef based on IEA (2014b)

Fig. 49: **Total final energy consumption by sector, 1990-2012 (PJ)**



Source: Elaboration by Susdef based on IEA (2014b)

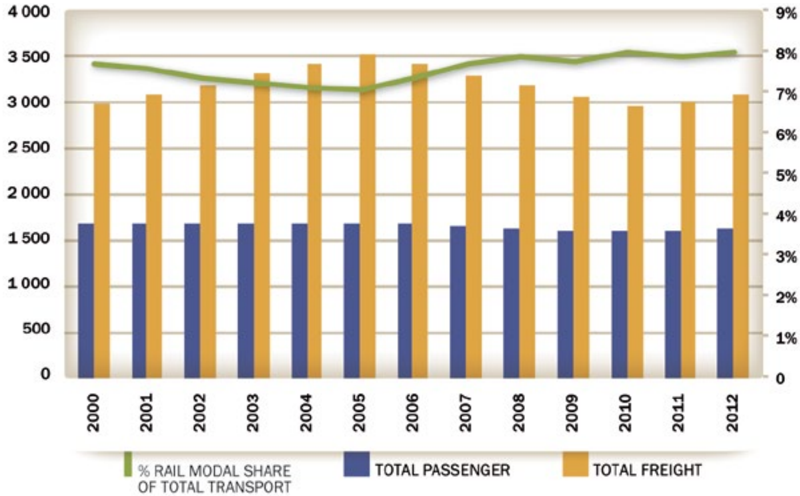
Fig. 50: **Transport sector CO_2 emissions by mode, 1990-2012 (million tCO_2 - left, share of rail over total - right)**



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

Source: Elaboration by Susdef based on IEA (2014a)

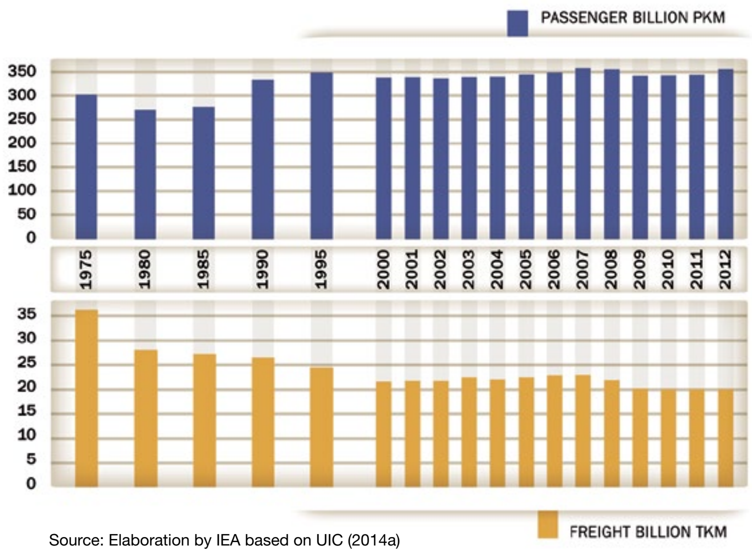
Fig. 51: **Passenger and freight transport activity - all modes, 2000-2012 (billion pkm and tkm)**



Source: estimations from the IEA Mobility Model, including information from UIC (2014a). Navigation activity is estimated from global tkm from UNCTAD (2014) according to shares in energy demand from IEA energy balances (IEA, 2014)

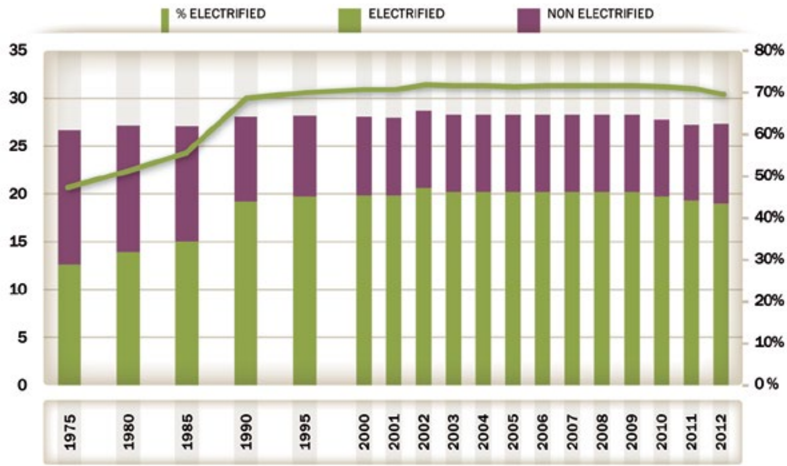
Note: data for years 2001-2004 and 2006-2009 are based on linear interpolations using years 2000, 2005 and 2010 data; 2011 and 2012 data are estimates

Fig. 52: **Passenger and freight railway activity, 1975-2012**



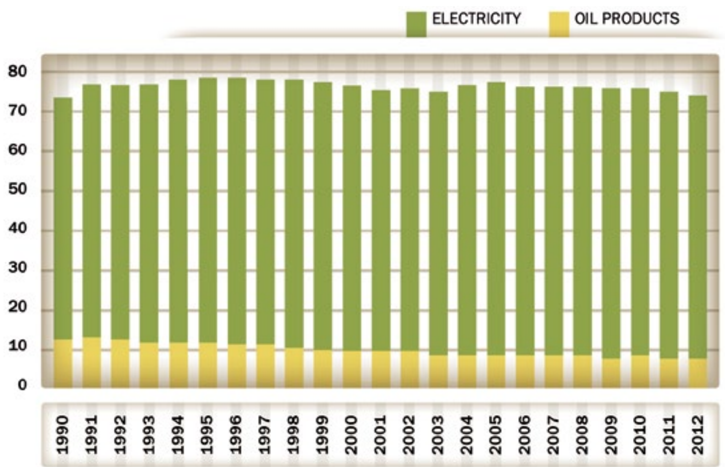
Source: Elaboration by IEA based on UIC (2014a)

Fig. 53: **Length and share of electrified versus non-electrified railway tracks, 1975-2012 (thousand km)**



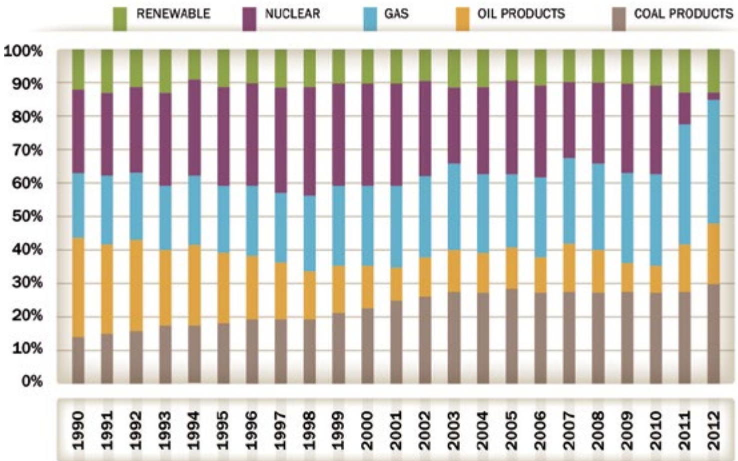
Source: Elaboration by IEA based on UIC (2014a)

Fig. 54: **Railway final energy consumption by fuel, 1990-2012 (PJ)**



Source: IEA (2014b)

Fig. 55: **National electricity production mix evolution, 1990-2012**



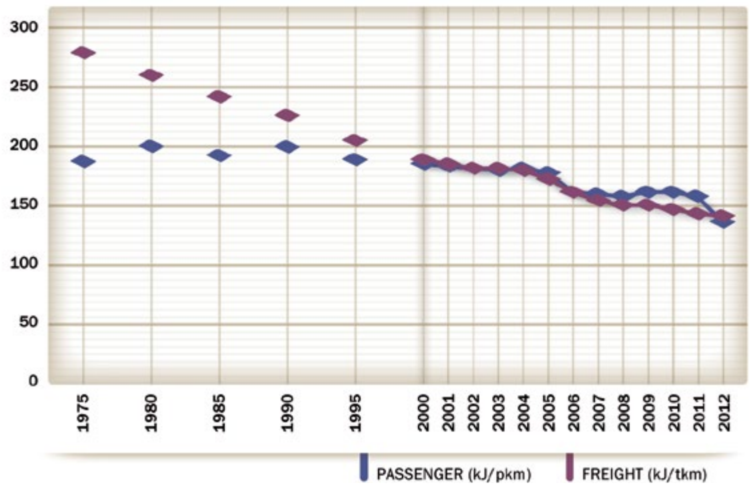
Source: IEA (2014b)

Table 9: **National electricity production mix evolution, 2000-2012**

	2000	2012
COAL PRODUCTS	22%	29%
OIL PRODUCTS	13%	18%
GAS	24%	39%
NUCLEAR	31%	2%
RENEWABLE	10%	12%

Source: IEA (2013b)

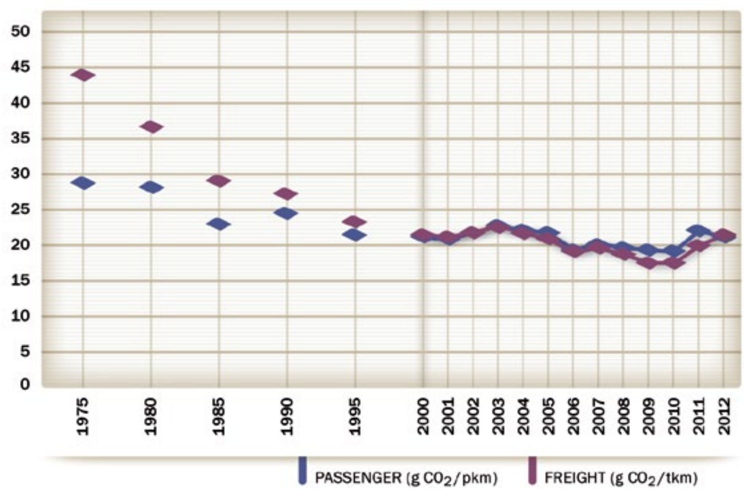
Fig. 56: **Railway specific energy consumption, 1975-2012**



Note: See Methodology p.94

Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

Fig. 57: **Railway specific CO_2 emissions, 1975-2012**

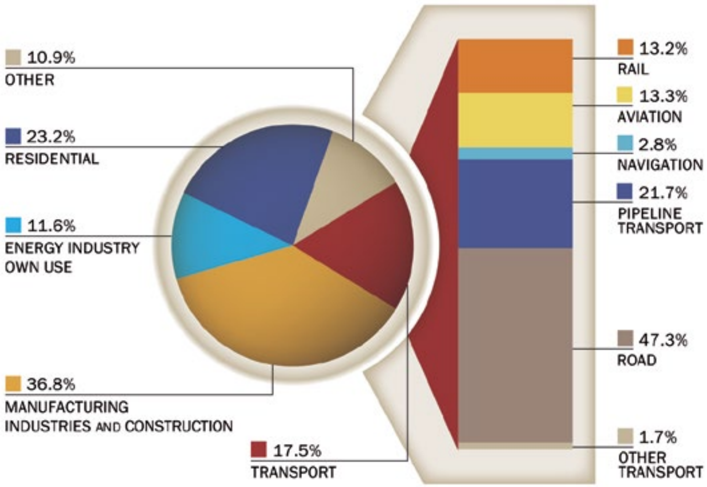


Note: See Methodology p.94

Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

Russian Federation

Fig. 58: **Share of CO_2 emissions from fuel combustion by sector, 2012**



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

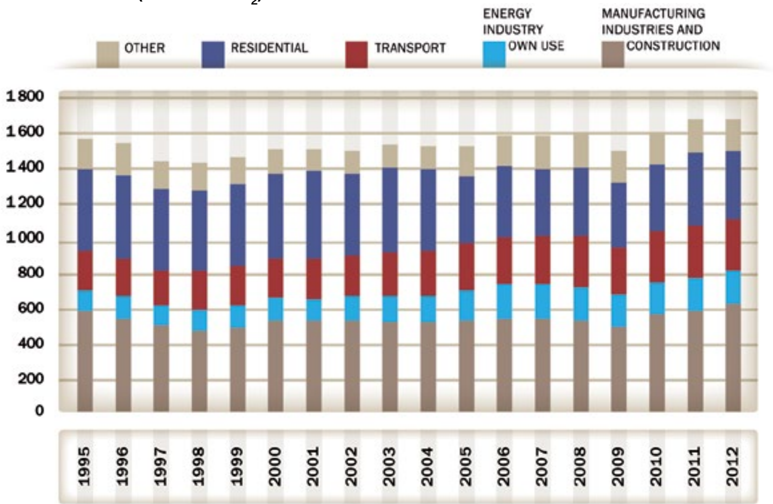
Source: Elaboration by Susdef based on IEA (2014a)

Table 10: **Transport modal share, 2012**

	Passenger PKM	Freight TKM	Total TU
ROAD	28.4%	9.7%	12.6%
AVIATION	41.7%	0.2%	6.7%
NAVIGATION	0.1%	3.2%	2.7%
RAIL	29.8%	86.9%	78.0%

Source: OECD (2015), UIC (2014a) and Rosstat (2015)

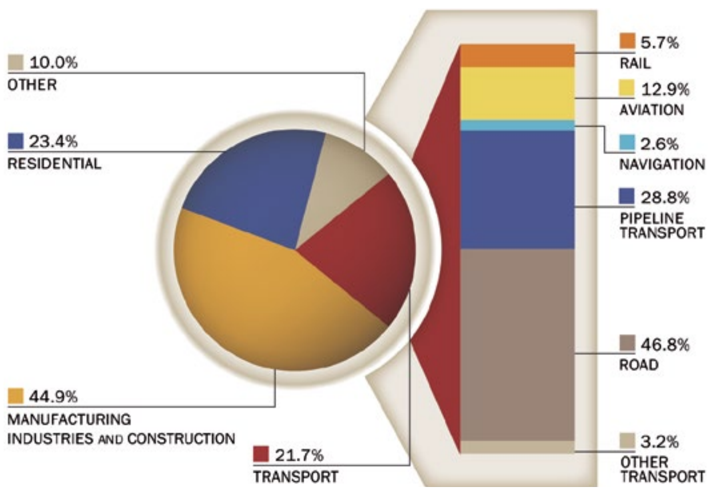
Fig. 59: **Total CO_2 emissions from fuel combustion by sector, 1995-2012 (million tCO_2)**



Note: Electricity and heat emissions are reallocated to the end-use sectors.
See Methodology Notes.

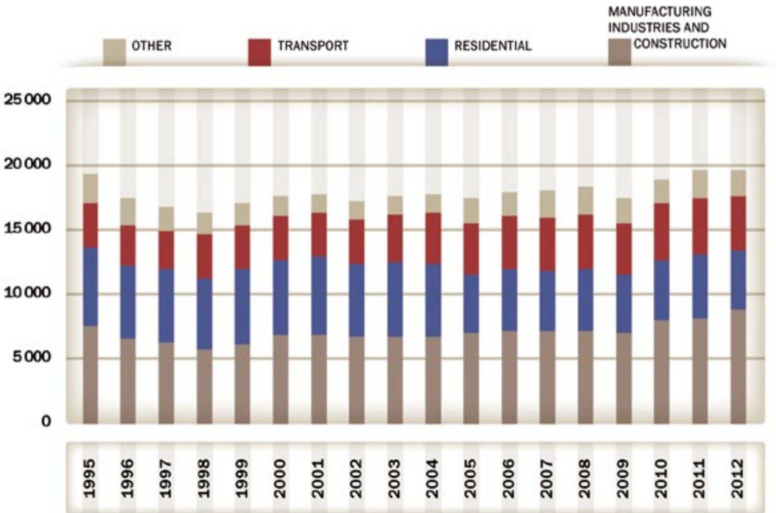
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 60: **Share of final energy consumption by sector, 2012**



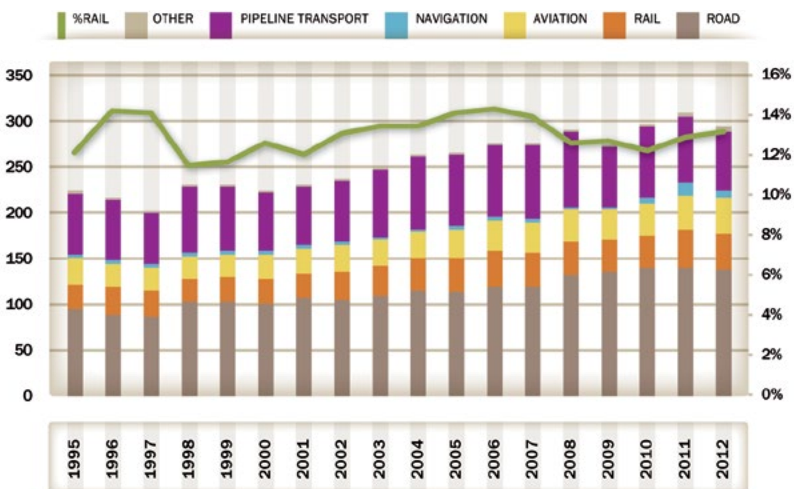
Source: Elaboration by Susdef based on IEA (2014b)

Fig. 61: **Total final energy consumption by sector, 1995-2012 (PJ)**



Source: Elaboration by Susdef based on IEA (2014b)

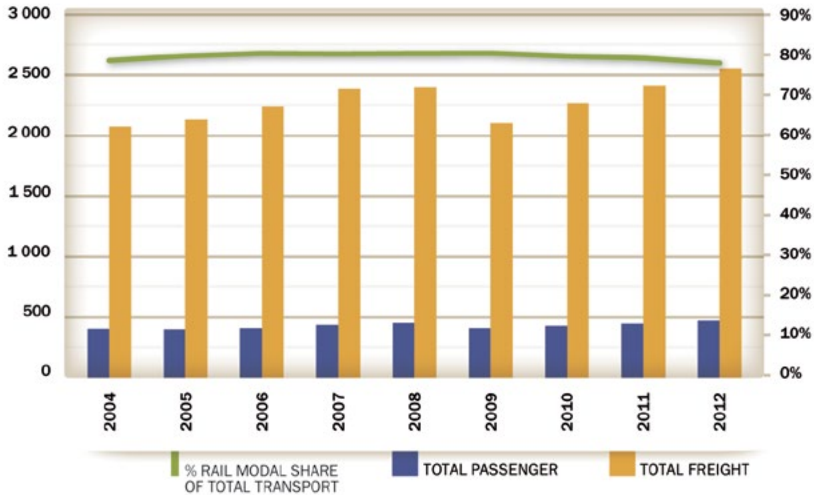
Fig. 62: **Transport sector CO_2 emissions by mode, 1995-2012 (million tCO_2 - left, share of rail over total - right)**



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

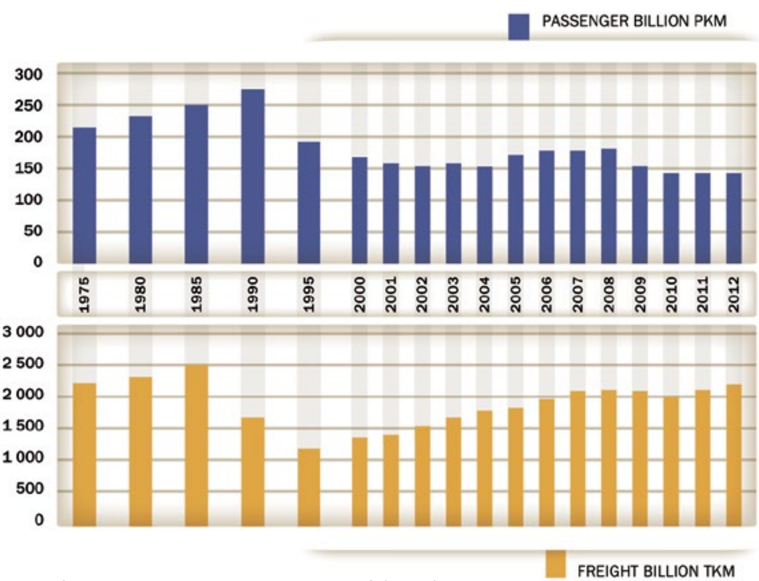
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 63: **Passenger and freight transport activity - all modes, 2004-2012 (billion pkm and tkm)**



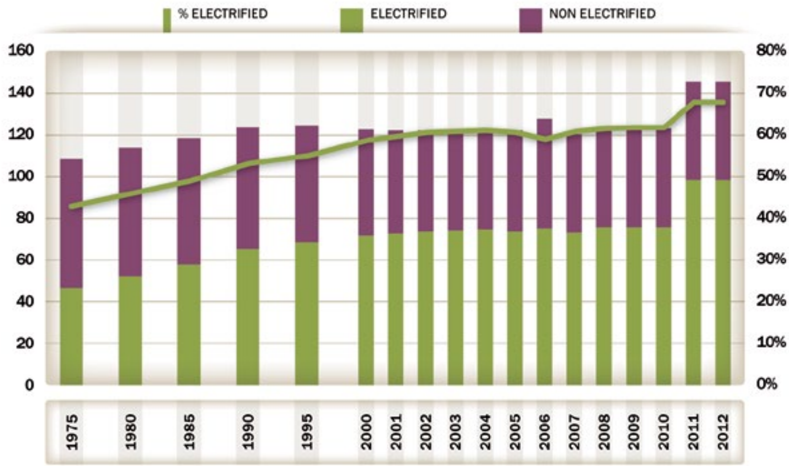
Source: OECD (2015), UIC (2014a) and Rosstat (2015)

Fig. 64: **Passenger and freight railway activity, 1975-2012**



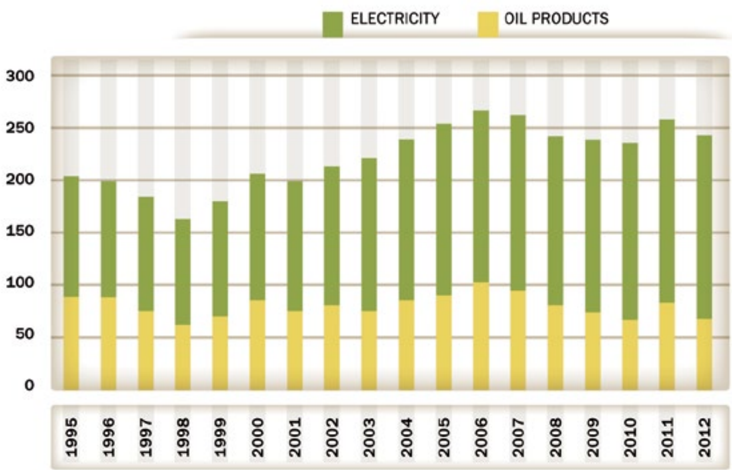
Source: Eleboration by IEA based on UIC (2014a)

Fig. 65: **Length and share of electrified versus non-electrified railway tracks, 1975-2012 (thousand km)**



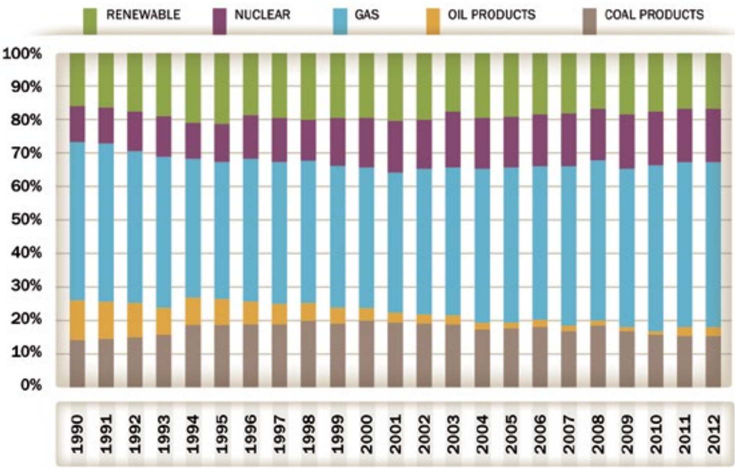
Source: Elaboration by IEA based on UIC (2014a)

Fig. 66: **Railway final energy consumption by fuel, 1995-2012 (PJ)**



Source: IEA (2014b)

Fig. 67: **National electricity production mix evolution, 1990-2012**



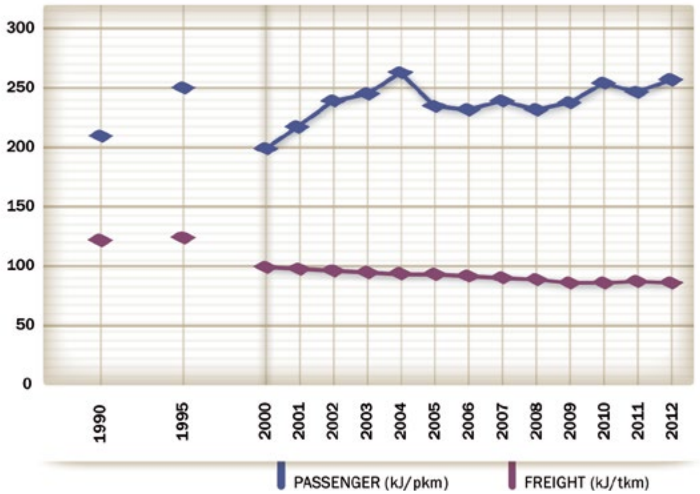
Source: IEA (2014b)

Table 11: **National electricity production mix evolution, 2000-2012**

	2000	2012
COAL PRODUCTS	20%	16%
OIL PRODUCTS	4%	3%
GAS	42%	49%
NUCLEAR	15%	16%
RENEWABLE	19%	16%

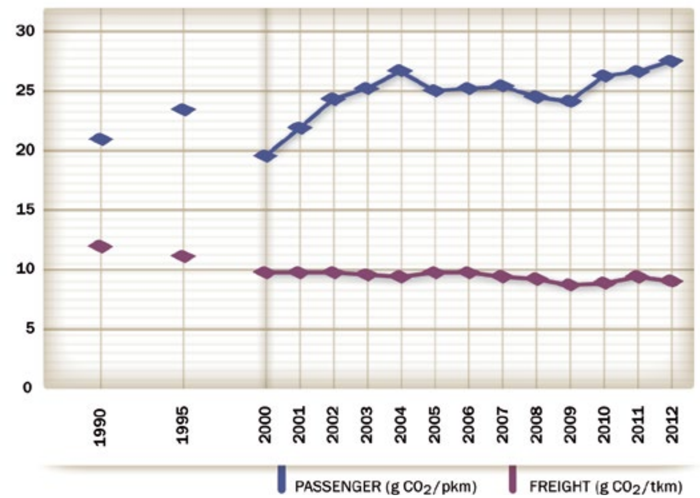
Source: IEA (2014b)

Fig. 68: **Railway specific energy consumption, 1990-2012**



Source: UIC (2014b)

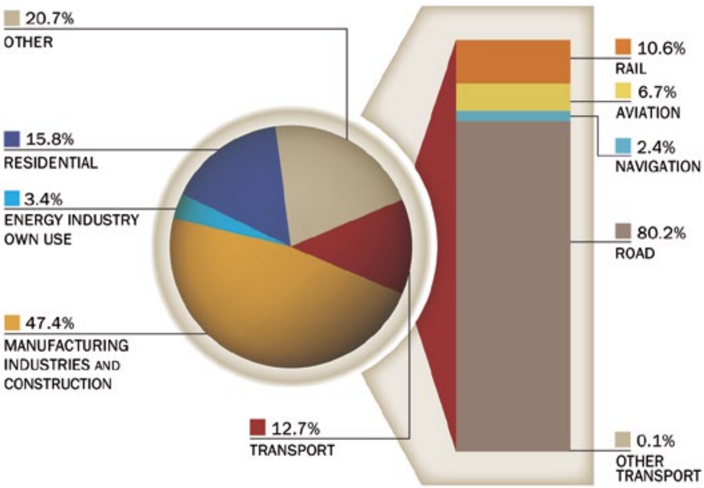
Fig. 69: **Railway specific CO_2 emissions, 1990-2012**



Source: UIC (2014b)

India

Fig. 70: **Share of CO_2 emissions from fuel combustion by sector, 2012**



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

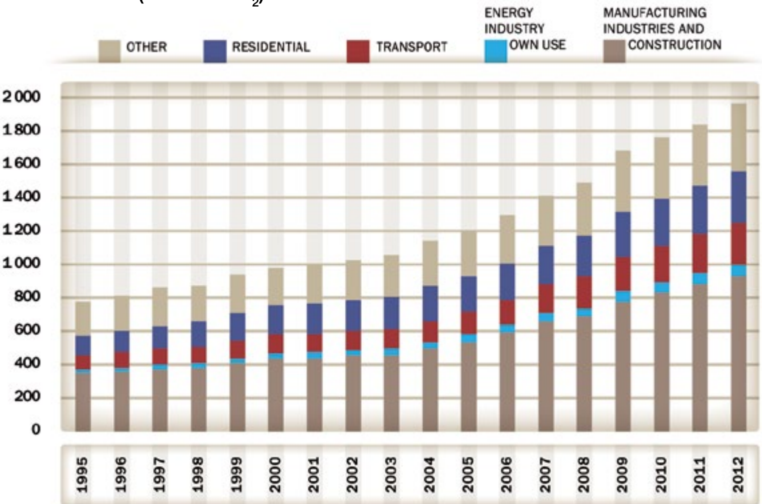
Source: Elaboration by Susdef based on IEA (2014a)

Table 12: **Transport modal share, 2012**

	Passenger PKM	Freight TKM	Total TU
ROAD	85.4%	65.1%	81.4%
AVIATION	1.3%	0.1%	1.0%
NAVIGATION	N.A.	0.2%	N.A.
RAIL	13.3%	34.6%	17.6%

Source: OECD (2015), UIC (2014a) and SYB (2015)

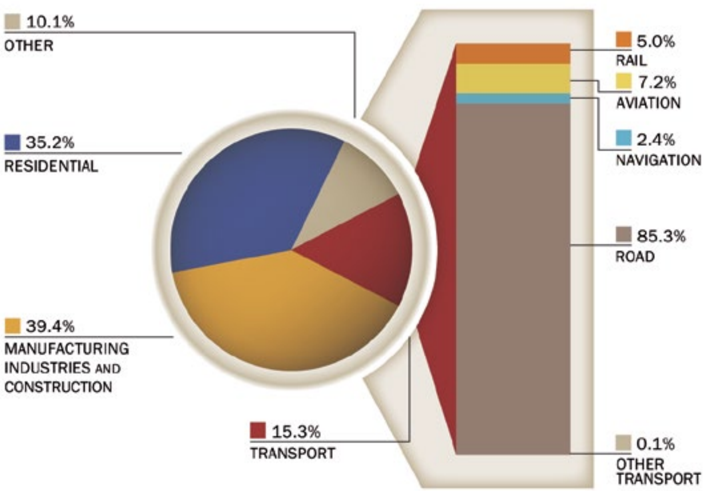
Fig. 71: **Total CO_2 emissions from fuel combustion by sector, 1995-2012 (million tCO_2)**



Note: Electricity and heat emissions are reallocated to the end-use sectors. See Methodology Notes.

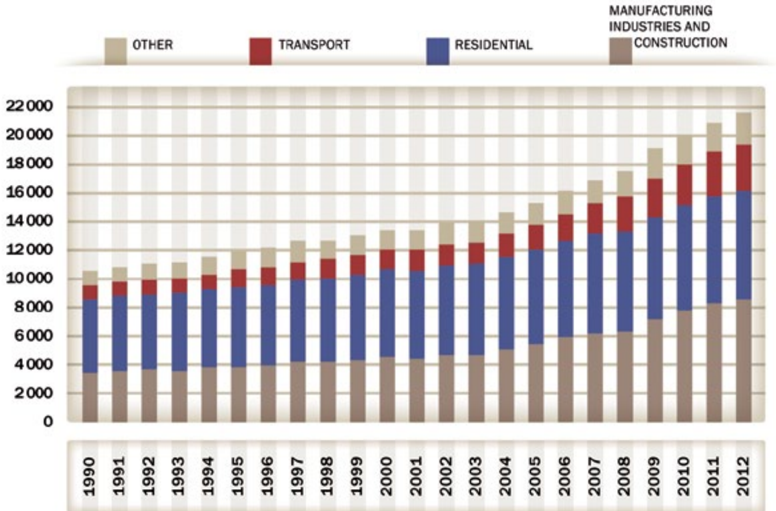
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 72: **Share of final energy consumption by sector, 2012**



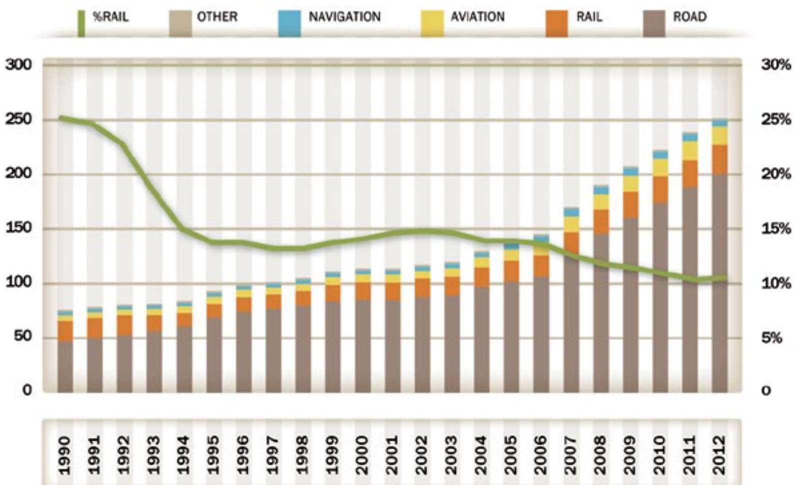
Source: Elaboration by Susdef based on IEA (2014b)

Fig. 73: **Total final energy consumption by sector, 1990-2012 (PJ)**



Source: Elaboration by Susdef based on IEA (2014b)

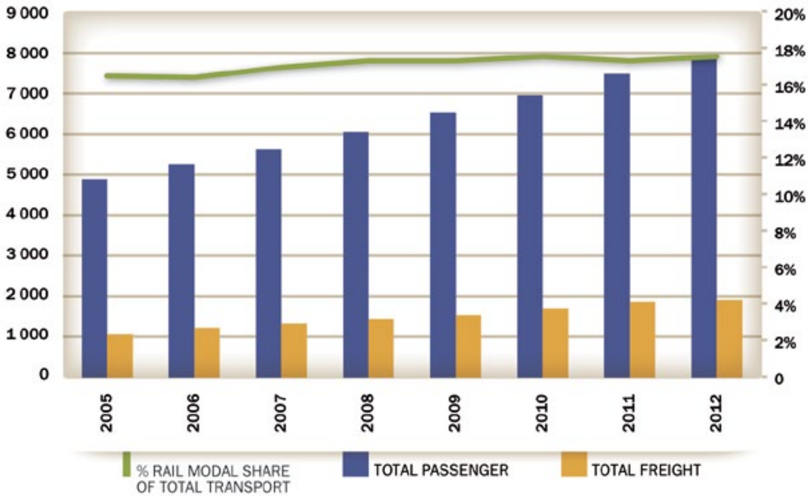
Fig. 74: **Transport sector CO_2 emissions by mode, 1990-2012 (million tCO_2 - left, share of rail over total - right)**



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

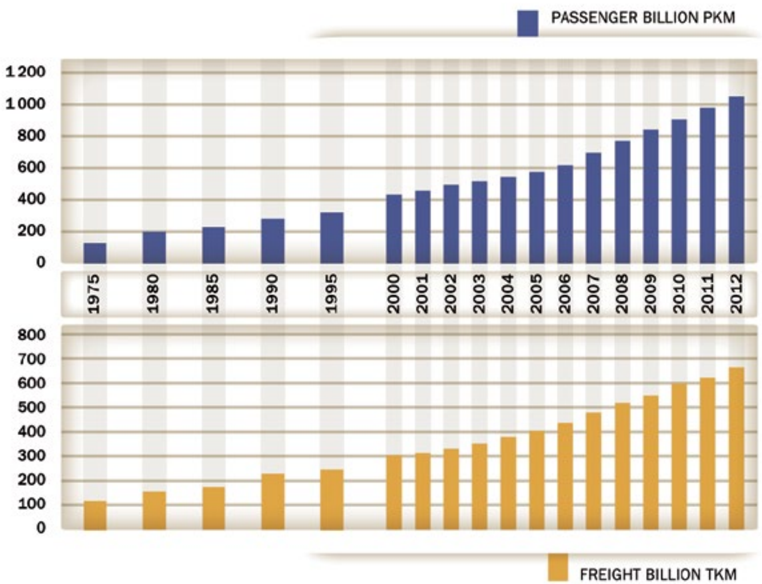
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 75: **Passenger and freight transport activity - all modes, 2005-2012 (billion pkm and tkm)**



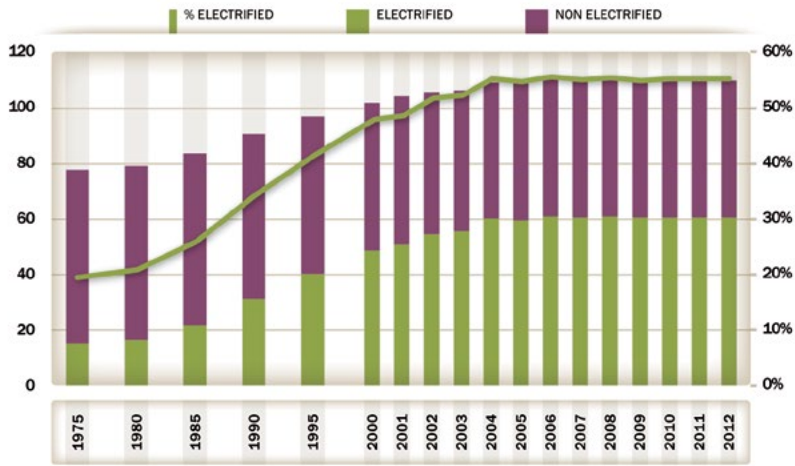
Source: OECD (2015), UIC (2014a) and SYB (2015)

Fig. 76: **Passenger and freight railway activity, 1975-2012**



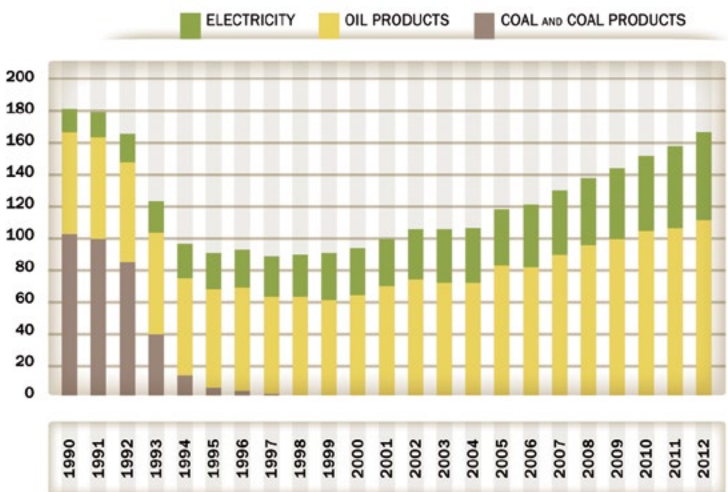
Source: Eleboration by IEA based on UIC (2014a)

Fig. 77: **Length and share of electrified versus non-electrified railway tracks, 1975-2012 (thousand km)**



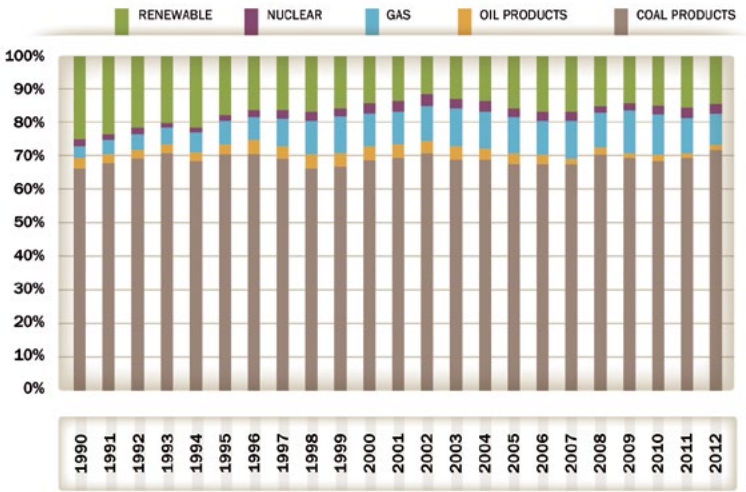
Source: Elaboration by IEA based on UIC (2014a)

Fig. 78: **Railway final energy consumption by fuel, 1990-2012 (PJ)**



Source: IEA (2014b)

Fig. 79: **National electricity production mix evolution, 1990-2012**



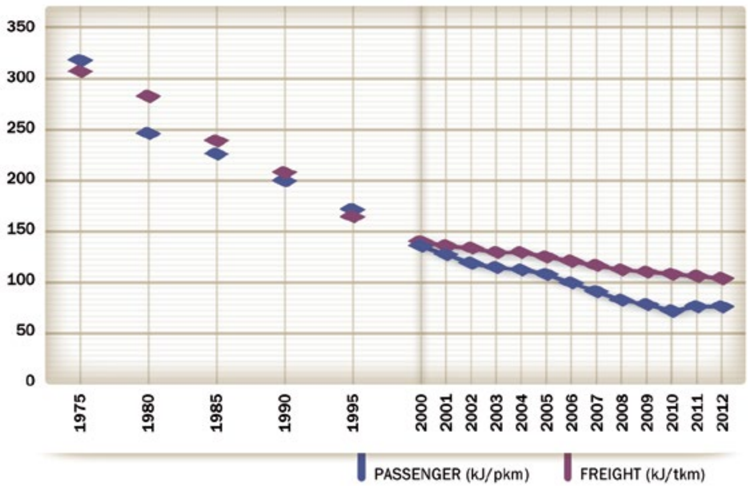
Source: IEA (2014b)

Table 13: **National electricity production mix evolution, 2000-2012**

	2000	2012
COAL PRODUCTS	68%	71%
OIL PRODUCTS	5%	2%
GAS	10%	8%
NUCLEAR	3%	3%
RENEWABLE	14%	16%

Source: IEA (2014b)

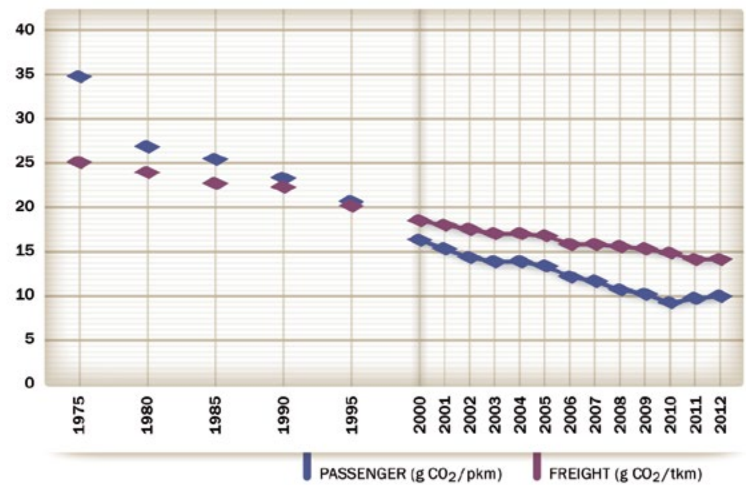
Fig. 80: **Railway specific energy consumption, 1975-2012**



Note: See Methodology p.94

Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

Fig. 81: **Railway specific CO_2 emissions, 1975-2012**

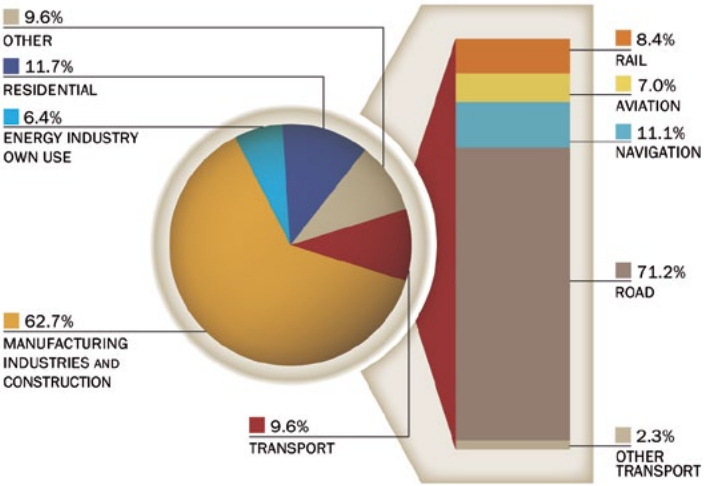


Note: See Methodology p.94

Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

People's Republic of China

Fig. 82: **Share of CO_2 emissions from fuel combustion by sector, 2012**



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

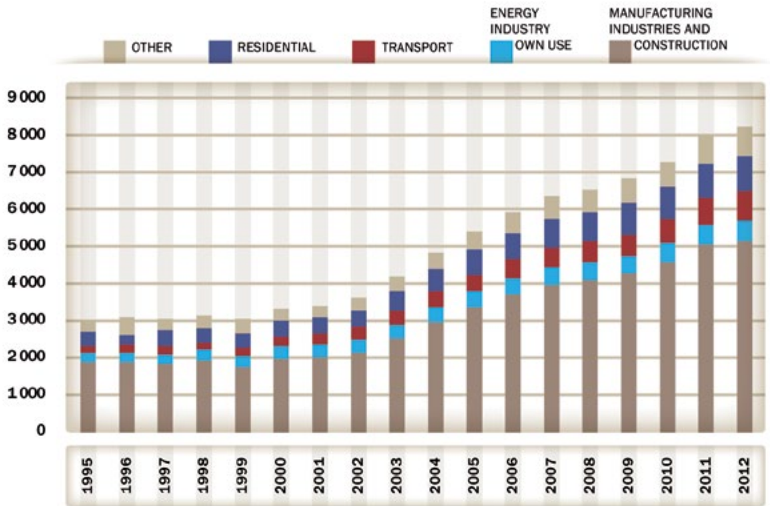
Source: Elaboration by Susdef based on IEA (2014a)

Table 14: **Transport modal share, 2012**

	Passenger PKM	Freight TKM	Total TU
ROAD	58.6%	35.7%	39.3%
AVIATION	15.9%	0.1%	2.6%
NAVIGATION	0.3%	49.0%	41.2%
RAIL	25.2%	15.2%	16.9%

Source: UIC (2014a) and CNBS (2014)

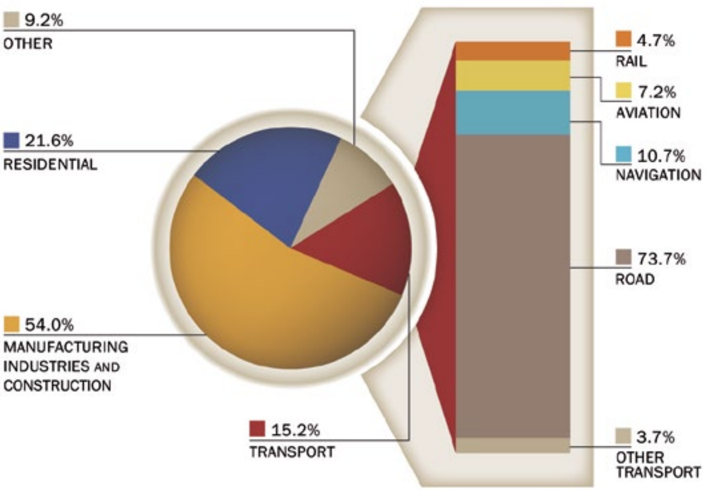
Fig. 83: **Total CO_2 emissions from fuel combustion by sector, 1995-2012 (million tCO_2)**



Note: Electricity and heat emissions are reallocated to the end-use sectors. See Methodology Notes.

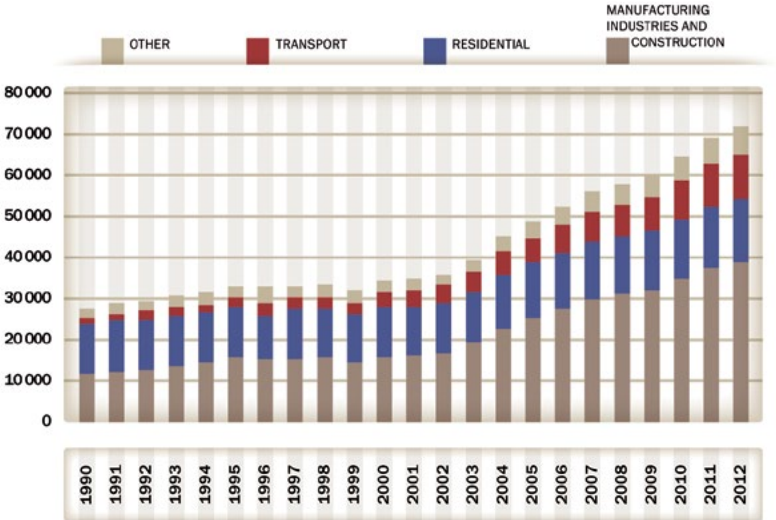
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 84: **Share of final energy consumption by sector, 2012**



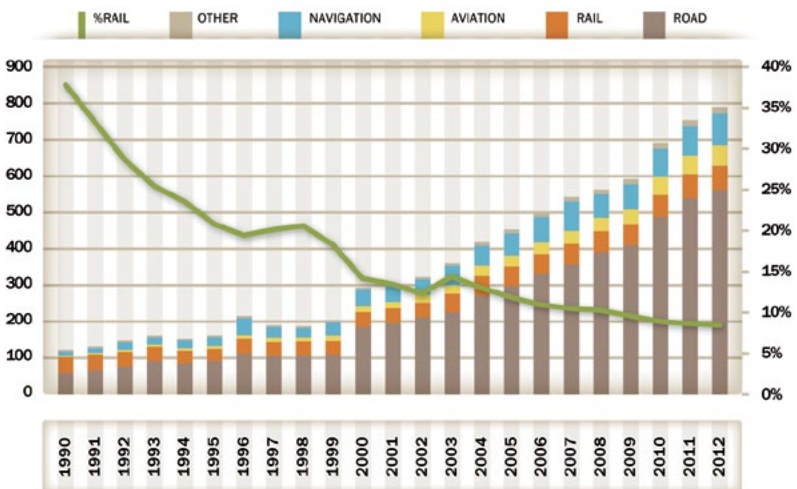
Source: Elaboration by Susdef based on IEA (2014b)

Fig. 85: **Total final energy consumption by sector, 1990-2012 (PJ)**



Source: Elaboration by Susdef based on IEA (2014b)

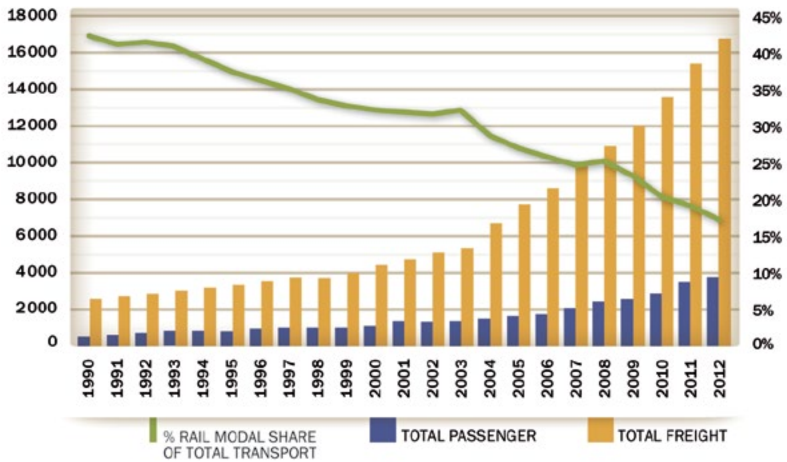
Fig. 86: **Transport sector CO_2 emissions by mode, 1990-2012 (million tCO_2 - left, share of rail over total - right)**



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

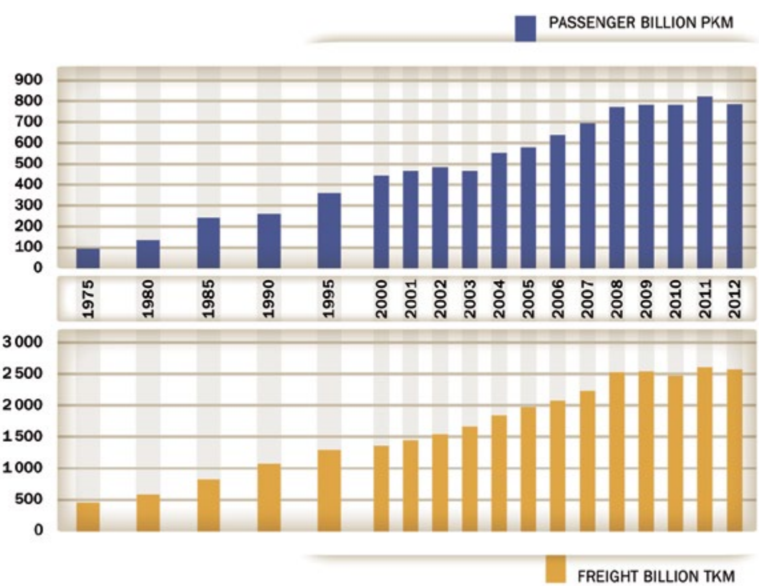
Source: Elaboration by Susdef based on IEA (2014a)

Fig. 87: **Passenger and freight transport activity - all modes, 1990-2012 (billion pkm and tkm)**



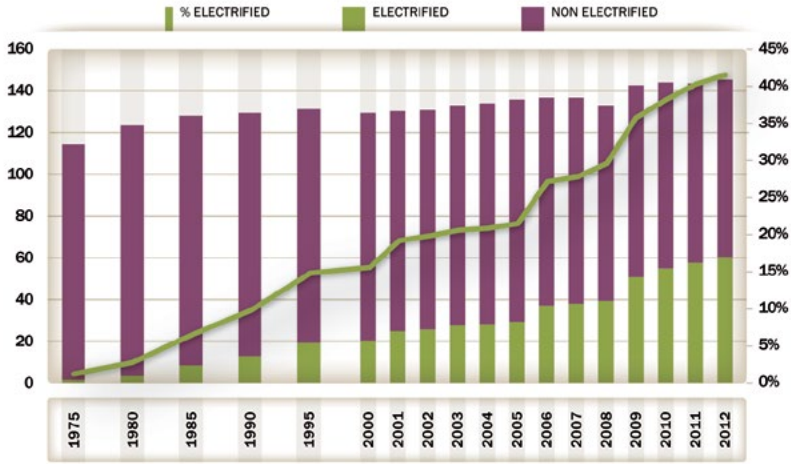
Source: UIC (2014a) and CNBS (2014)

Fig. 88: **Passenger and freight railway activity, 1975-2012**



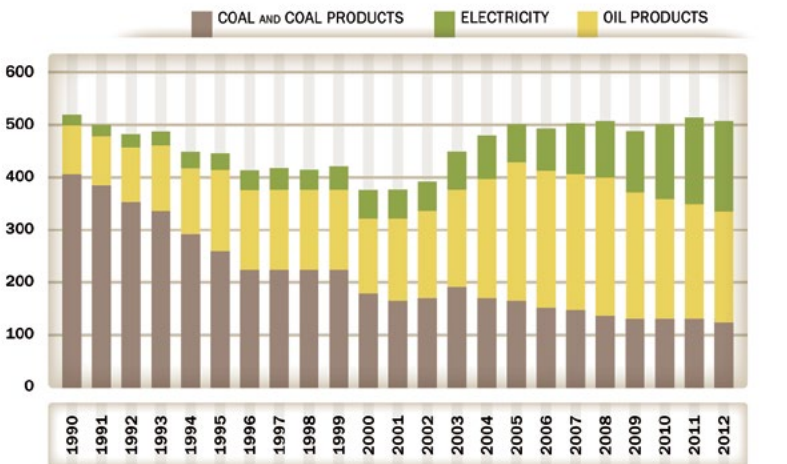
Source: Elaboration by IEA based on UIC (2014a)

Fig. 89: **Length and share of electrified versus non-electrified railway tracks, 1975-2012 (thousand km)**



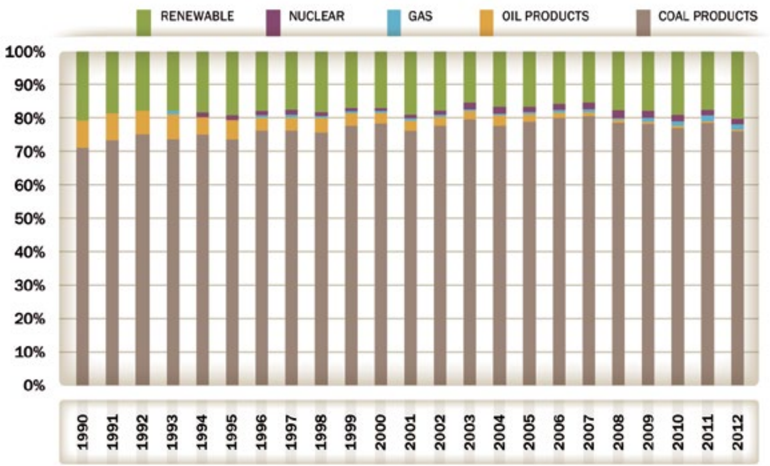
Source: Elaboration by IEA based on UIC (2014a)

Fig. 90: **Railway final energy consumption by fuel, 1990-2012 (PJ)**



Source: IEA (2014b)

Fig. 91: **National electricity production mix evolution, 1990-2012**



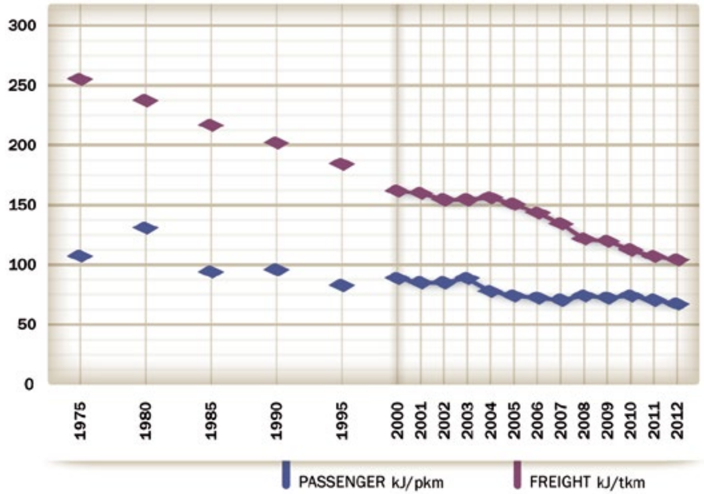
Source: IEA (2014b)

Table 15: **China railway final energy consumption by fuel, 1990-2012**

	2000	2012
COAL PRODUCTS	78%	76%
OIL PRODUCTS	3%	0%
GAS	1%	2%
NUCLEAR	1%	2%
RENEWABLE	17%	20%

Source: IEA (2014b)

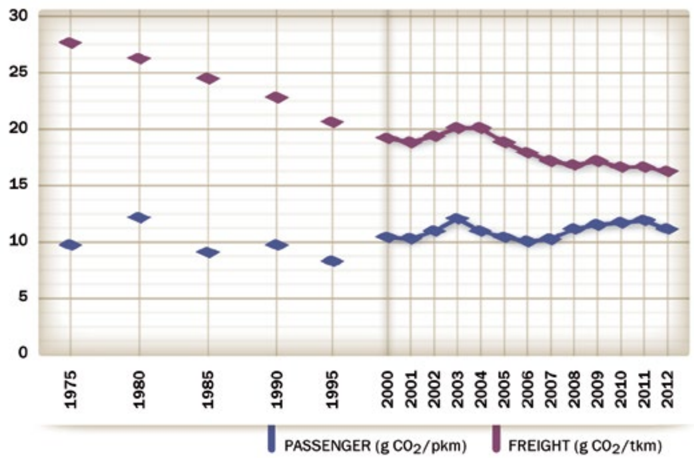
Fig. 92: **Railway specific energy consumption, 1975-2012**



Note: See Methodology p.94

Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

Fig. 93: **Railway specific CO_2 emissions, 1975-2012**



Note: See Methodology p.94

Source: Elaboration by IEA and Susdef based on IEA Mobility Model and UIC (2014a)

The UIC Low Carbon Rail Transport Challenge

At the United Nations Climate Change Summit in September 2014, UIC has presented the “Low Carbon Rail Transport Challenge”, aimed to promote railway transport as a sustainable alternative to other modes of transportation with higher carbon intensity, such as road or aviation.

The three main targets of UIC for world railways are to improve efficiency, decarbonise power and achieve a more sustainable balance of transport modes. In order to reach those goals, railways are developing the electrification of the infrastructure, improving load factors, procuring more efficient rolling stock, developing energy and traffic management systems and efficient driving.

UIC has set internal targets to reduce specific final energy consumption (50% by 2030 and 60% by 2050) and specific average CO_2 emissions from train operations (50% by 2030 and 75% by 2050), all relative to a 1990 baseline.

UIC has also launched a “Modal Shift Challenge”, calling for investments that will increase the modal share of railways at the expense of high carbon transport: the target is for the rail share of passenger transport (in pkm) to achieve a 50% increase by 2030 and a 100% increase by 2050, relative to a 2010 baseline; and for the rail share of freight land transport (in tkm) to be equal with road by 2030 and 50% greater than road by 2050.

Part II:

Focus on Vehicle Efficiency

Key Facts

- The energy performance of light duty vehicles has improved by 14.5% between 2005 and 2013 in terms of fuel consumption per km.

- Fuel burn in aviation has decreased by 49% at representative operational range between 1960 and 2014, with a slower improvement rate since 1985. The improvement rate between 2005 and 2013 was 8%.

- In both passenger and freight rail transport, the energy intensity of vehicles, expressed in MJ/train-km, is at least twice as high for diesel trains compared to electric trains. This is coherent with assessments showing higher energy expenditures in operating diesel trains rather than electric trains.

- At world level, the electric intensity of passenger rail vehicles, measured in MJ/train-km, has improved by 24% between 1975 to 2012, while the electric intensity for freight rail vehicles has improved by 23% over the same timeframe. The improvement rate for these indicators slowed down in recent years.

- European indicators, in particular, show a stagnation of the energy performance of rolling stock in terms of MJ/gross tkm since 2005, both in electric and diesel traction. This can be related to two possible causes: either the energy efficiency of the new rolling stock is only marginally better than the stock average, or the rolling stock replacement rate in recent years was so small, in Europe, that its effect in overall results is negligible. The UIC will investigate this issue in the next years.

- The railway sector is considering or has already implemented several technological solutions that will facilitate energy efficiency improvements in the next decades, such as installing energy meters, recovering energy from braking, implementing Driver Advisory Systems (DAS) or leveraging on better infrastructure management.

Energy efficiency indicators

The most common indicators used to measure the energy intensity of transport are expressed as ratios between energy use and transport activity parameters, for example as kJ/pkm (for passenger travel) or kJ/tkm (for freight). The number of passengers and/or the quantity of goods transported directly affects these indicators: the more the passenger and goods carried using the same amount of energy, the less the energy consumed per unit passenger-km and tonne-km, respectively.

Alternatively, energy intensity can be evaluated as the ratio between energy use and vehicle activity, for example as MJ/train-km, or even more precisely (as the train composition can vary significantly), in MJ/seat-km for passenger transport and in MJ/gross tkm for freight. These types of indicators are independent from the number of passengers and from the quantity of goods transported and instead directly measure energy efficiency improvements across vehicle efficiency, fuel use, and technical operations.

Table 16: **Energy intensity reduction strategies**

Vehicles and fuels	Technical operations	Customer demand for rail services
More efficient energy traction concepts	Optimisation of available space in rolling stock	Load factor increase
Increased electrification	Reduction of empty trips	Marketing strategies for demand increase
Mass reduction	Flexible train composition	
Aerodynamics improvement and friction reduction	Energy efficient driving	
Reduction of conversion losses	Better awareness of energy efficiency in personnel	
Regenerative braking and energy storage	Energy efficient timetabling	
Reduction of hotel loads		
Procurement strategies for more efficient vehicles		

Source: Elaboration by Susdef based on UIC EVENT

Table 16 reports the strategies that the railway sector can adopt in order to improve energy intensity indicators, leveraging on either vehicles and fuels, technical operations, and/or customer demand.

Customer demand factors influence only the indicators calculated as the ratio between energy use and passenger and freight activity parameters (kJ/pkm and kJ/tkm). On the other hand, vehicle technologies, fuels, and technical operations directly impact the energy demand per unit vehicle activity (train-km, seat-km, and gross tkm), influencing all the indicators described above.

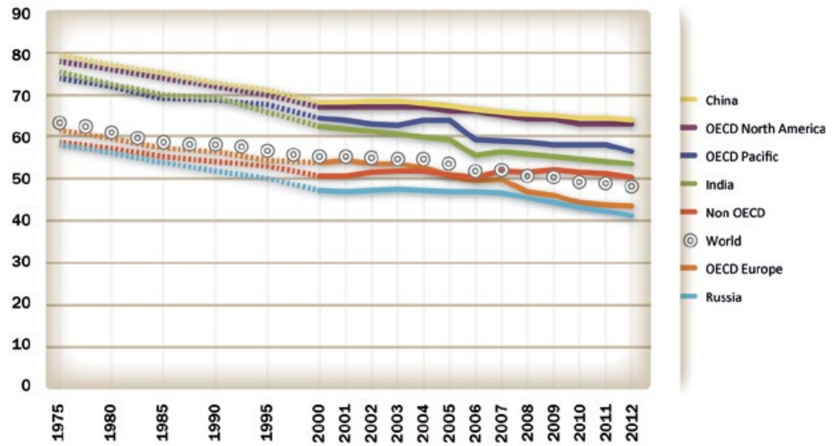
The effectiveness of energy efficiency strategies in railway transport is a subject of continuous study. The EVENT project (Evaluation of Energy Efficiency Technologies for Rolling Stock and Train Operation of Railways), funded by UIC, led to the development of a database of energy efficiency technologies in rail that includes an evaluation of the potential energy efficiency impacts of these technologies.

Enhancing energy efficiency enables the dual benefits of improving the economics of railway operators and of reducing GHG emissions. A 2009 EU-funded project (Hazeldine et al., 2009) attempted to quantify the impact of several energy efficiency measures in different modes of transport, including rail among others, on GHG emissions. For example, the report estimated that regenerative braking could potentially reduce GHG emissions by 10% to 15%, that driver support measures could reduce GHG emissions by 5% to 15%, and that mass-reduction initiatives could achieve more than a 10% reduction in emissions.

Vehicle Efficiency – World data

Passenger

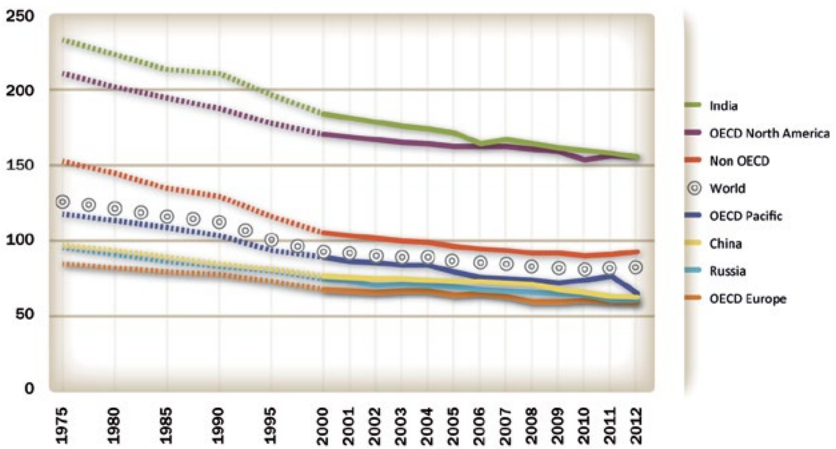
Fig. 94: **Evolution of electric intensity for passenger rail vehicles (including high-speed rail) in selected countries and geographic areas, 1975-2012 (MJ/train-km)**



Note: See Methodology p.94

Source: Elaboration by IEA based on IEA Mobility Model, UIC (2014a), and UIC (2014b)

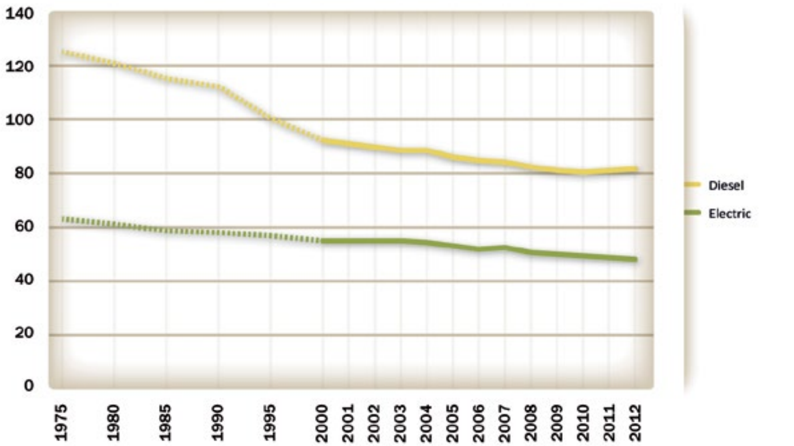
Fig. 95: **Evolution of diesel intensity for passenger rail vehicles in selected countries and geographic areas, 1975-2012 (MJ/train-km)**



Note: See Methodology p.94

Source: Elaboration by IEA based on IEA Mobility Model, UIC (2014a), and UIC (2014b)

Fig. 96: **Evolution of world diesel and electric intensity for passenger rail vehicles (including high-speed rail), 1975-2012 (MJ/train-km)**

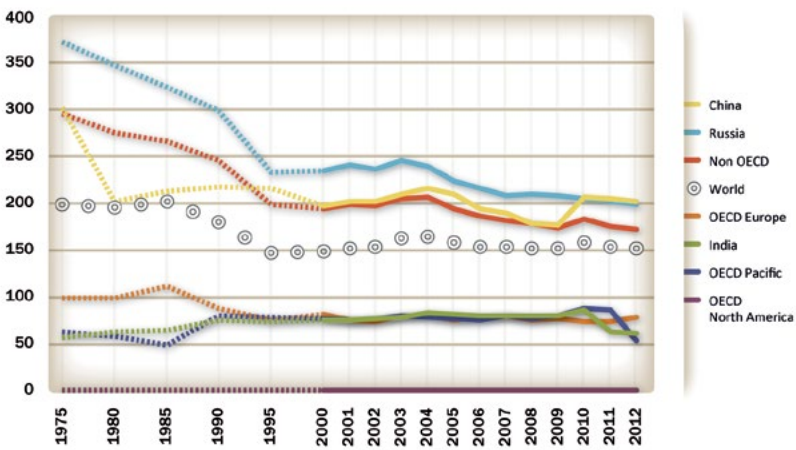


Note: See Methodology p.94

Source: Elaboration by IEA based on IEA Mobility Model, UIC (2014a), and UIC (2014b)

Freight

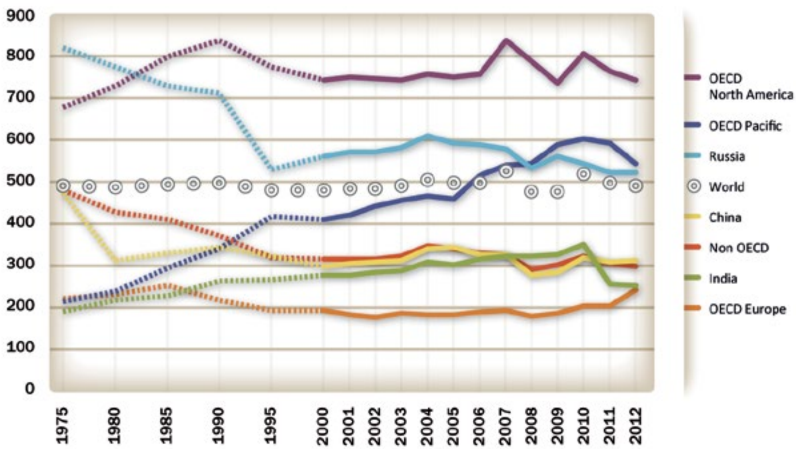
Fig. 97: **Evolution of electric intensity for freight rail vehicles in selected countries and geographic areas, 1975-2012 (MJ/train-km)**



Note: See Methodology p.94

Source: Elaboration by IEA based on IEA Mobility Model, UIC (2014a), and UIC (2014b)

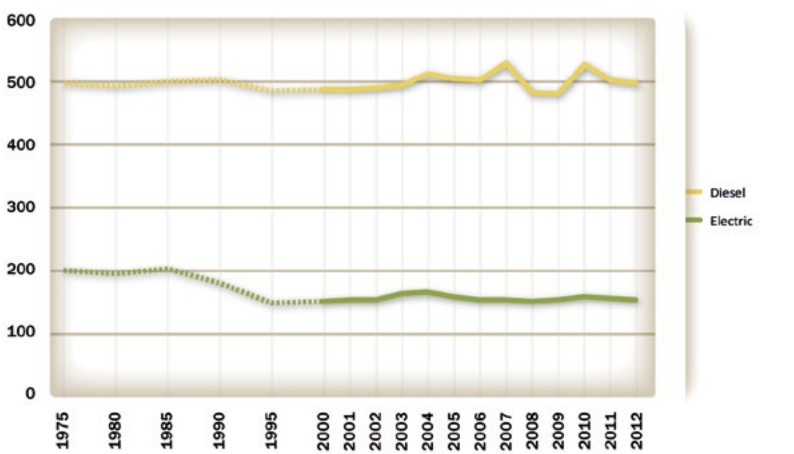
Fig. 98: **Evolution of diesel intensity for freight rail vehicles in selected countries and geographic areas, 1975-2012 (MJ/train-km)**



Note: See Methodology p.94

Source: Elaboration by IEA based on IEA Mobility Model, UIC (2014a), and UIC (2014b)

Fig. 99: **Evolution of world diesel and electric intensity for freight rail vehicles, 1975-2012 (MJ/train-km)**



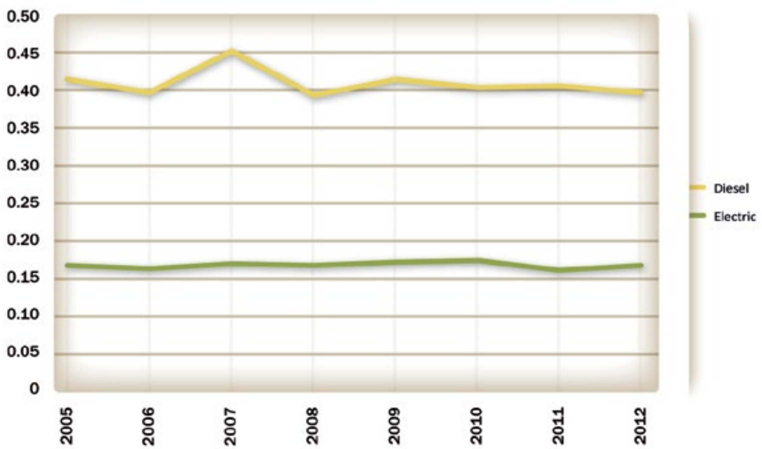
Note: See Methodology p.94

Source: Elaboration by IEA based on IEA Mobility Model, UIC (2014a), and UIC (2014b)

Vehicle Efficiency – EU28 data

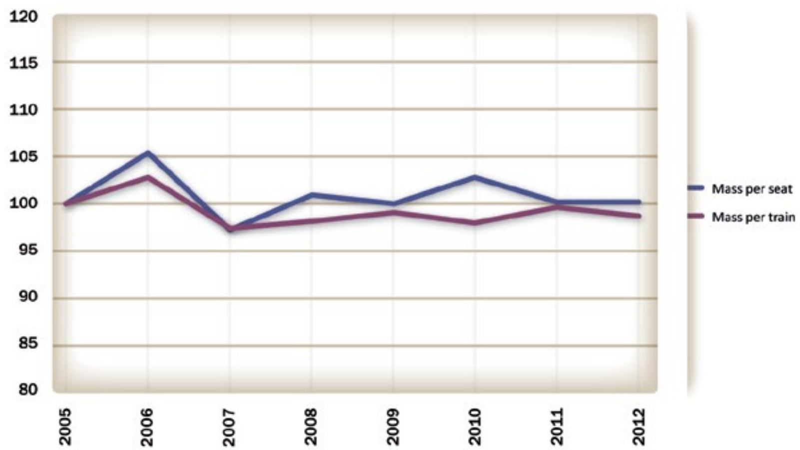
Passenger

Fig. 100: **Evolution of diesel and electric intensity of passenger rail vehicles per gross tonne-km in EU28, 2005-2012 (MJ/gross tkm)**



Source: elaboration by Susdef based on UIC (2014a), UIC (2014b)

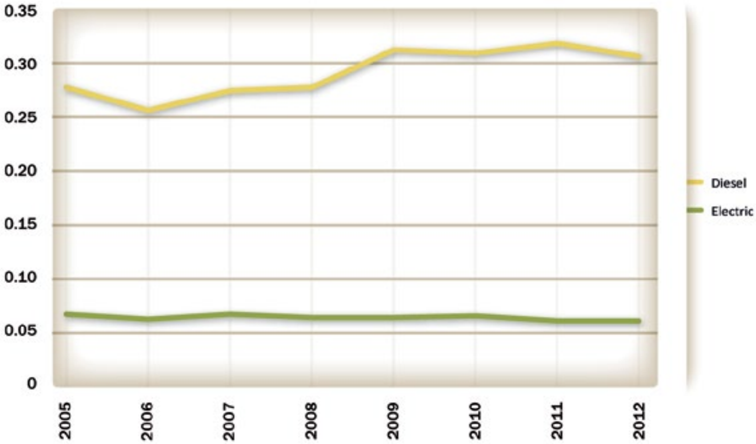
Fig. 101: **Evolution of average mass per seat and mass per train in EU28 passenger trains, 2005-2012 (2005=100)**



Source: elaboration by Susdef based on UIC (2014a), UIC (2014b)

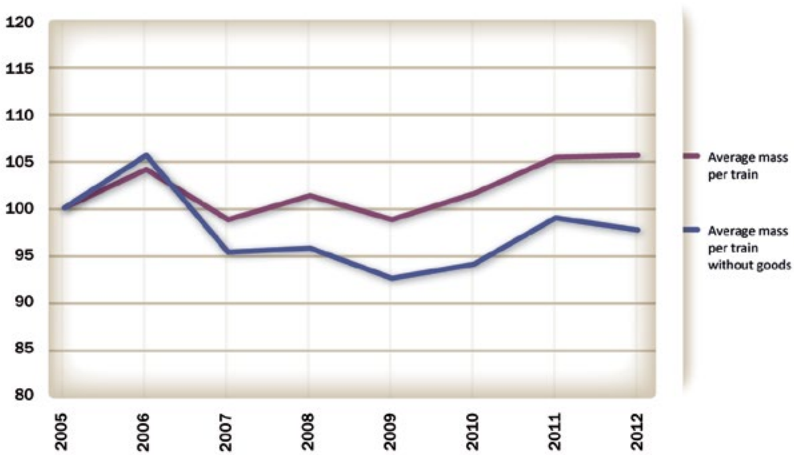
Freight

Fig. 102: **Evolution of diesel and electric intensity of freight rail vehicles per gross tkm in EU28, 2005-2012 (MJ/gross tkm)**



Source: elaboration by Susdef based on UIC (2014a), UIC (2014b)

Fig. 103: **Evolution of average mass per train and mass per train without goods in EU28 freight trains, 2005-2012 (2005=100)**



Note: the mass per train without goods is defined as the gross tonne-km minus the net tonne-km.

Source: elaboration by Susdef based on UIC (2014a), UIC (2014b)

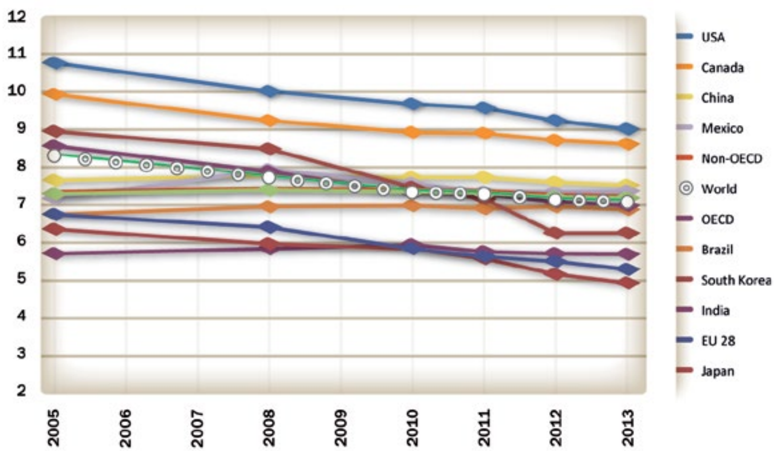
Vehicle Efficiency – Case Studies

Energy efficiency of vehicles in other transport modes[1]

As with rail, the energy efficiency of other transport modes (e.g. passenger cars, freight trucks, and airplanes) has also seen an evolution throughout the years. The Global Fuel Economy Initiative (GFEI) and the IEA have published studies tracking the evolution of fuel consumption in passenger light-duty vehicles, showing a drop of 15% in consumption worldwide from 2005 to 2013. In the case of airplanes, the International Council on Clean Transportation (ICCT) shows a 49% reduction of fuel burn at representative operational range from 1960 to 2014, with most of the reduction happening between 1960 and 1985.

The average fuel burn per seat-km of airplanes (evaluated at operational range) has been declining with varying improvement rates since the mid-1970s. This is consistent, in terms of magnitude, with data on fuel burn at design range for Boeing 737 models. On the other hand, another indicator often used in railways to evaluate energy efficiency – mass per seat – has not been decreasing throughout the years in Boeing 737 aircrafts. This suggests that energy efficiency improvements were not driven, in the case of the 737, by weight reductions per seat, but rather by other developments (e.g. more fuel efficient engines, lower air drag per seat).

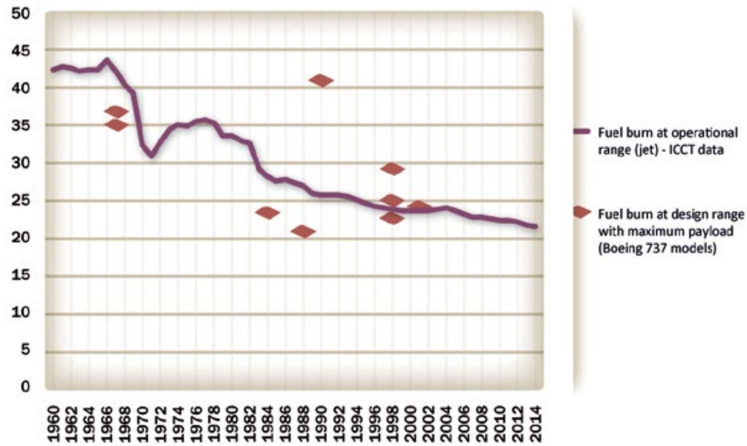
Fig. 104: **Road passenger transport: average new passenger light-duty vehicles (PLDV) fuel economy evolution by country, 2005 to 2013 (litres gasoline equivalent (LGE) per 100 km, normalized to the New European Driving Cycle)**



Source: Global Fuel Economy Initiative 2014

[1] Rail data is based on real energy consumption while the data for other transport modes refer to results from laboratory tests and simulations.

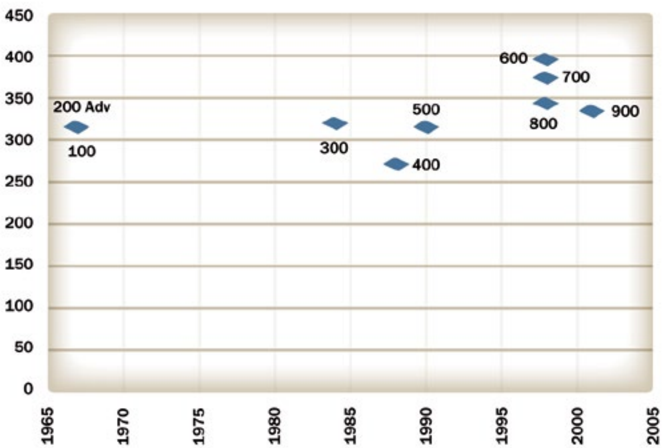
Fig. 105: **Aviation: Evolution of average fuel burn per seat-km, 1960-2014 (g fuel/seat-km)**



Note: ICCT data on fuel burn are at representative operational range. Boeing data are on fuel burn at design range with maximum payload.

Source: Elaboration by IEA and Susdef based on ICCT (2015) and Boeing (2013)

Fig. 106: **Evolution of Zero-fuel Weight per seat in different Boeing 737 Models, ordered by year of production (kg)**



Note: This indicator has been calculated by dividing the Maximum Design Zero-Fuel Weight for the maximum seating capacity.

Standard CENELEC - CLC/TS 50591

"Specification and verification of energy consumption for railway rolling stock"

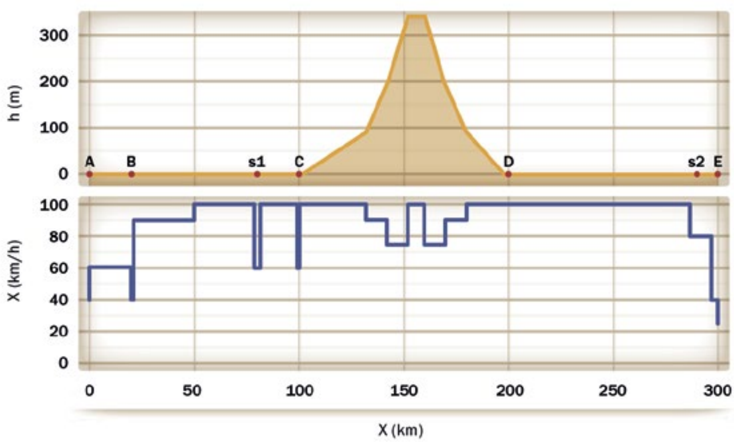
The UIC and the Association of the European Rail Industry (UNIFE) have jointly elaborated and published a document detailing technical recommendations on the "Specification and verification of energy consumption for railway rolling stock", called TecRec 100_001 (UIC/UNIFE 2010). The TecRec 100_001 became a Technical Specification (Standard CENELEC CLC/TS 50591) on November 2013. The standard serves as European Standard and it's planned to become a European Norm (EN) in 2016.

The purpose of this Technical Specification is to provide a methodology to measure energy consumption for rolling stock so that measurements over time or for different types of rolling stock are comparable. This methodology enables measurements of improvements in energy efficiency of rolling stock, and it can further be used as a tool for railways to estimate energy efficiency performance as a consideration in the procurement process. Currently, about ten European railways are using CENELEC-CLC/TS 50591 in this latter capacity, as part of their procurement strategy.

The document defines infrastructure, operational, and environmental conditions in which to conduct a simulation or a real-life energy performance measurement of rolling stock. CENELEC-CLC/TS 50591 also provides a set of standard values for typical service profiles: suburban, regional, intercity, and high-speed passenger traffic.

Figure 107 shows a standard profile of CLC/TS 50591 used for freight mainline over a 300 km route. The profile indicates the linear distance from the departure station (A) to the arrival station (E) with stops in stations B, C, and D and two red signals (s1 and s2). The profile includes a mountain passage, as long-distance freight routes can include considerable variations in altitude.

Fig. 107: **CENELEC-CLC/TS 50591 standard profile for freight main line over a 300 km route. Top: altitude (m), bottom: speed (km/h)**



Source: UIC/UNIFE (2010)

Energy efficiency technologies in new rolling stock

Manufacturers are developing innovative technologies for a more efficient rolling stock. Some of the main innovations concern:

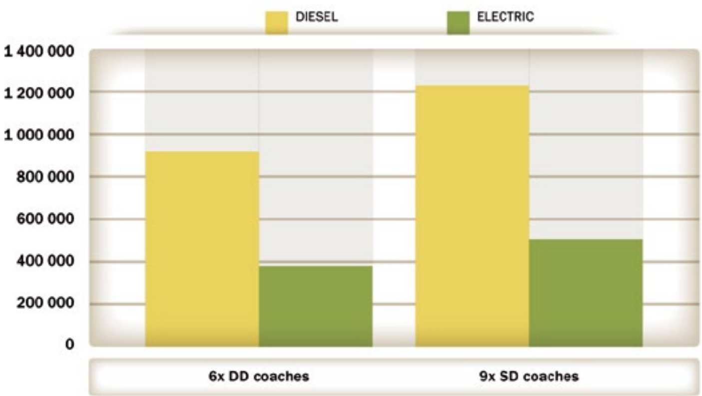
• Aerodynamics: increasing the aerodynamic performance of rail vehicles can reduce energy consumption up to 8% in regional trains and up to 15% in high-speed trains, according to Bombardier (2010).

• Engines: new types of electric engines, such as Permanent Magnet Motors, can improve efficiency and eliminate the need for cooling fans that are required in asynchronous motors. According to Alstom (2015), this can induce up to a 3% increase in energy efficiency. For diesel traction, hybrid engines can significantly reduce energy consumption and costs. According to Siemens, diesel savings at stand still can reach up to 40% (Jony 2014).

• Fuels: the Russian Railways RZD are experimenting with the use of locomotives powered by Liquid Natural Gas (LNG) instead of diesel. According to RZD, GHG emissions of LNG-powered locomotives are drastically reduced – an 80% reduction was observed on a trial operation in Moscow (Lapidus 2011). LNG may result in significant savings and the US Freight Railroad Union Pacific (UP) is evaluating this technology in the new freight locomotives.

• Mass: new materials and composites are being used in the construction of train components, reducing the mass of the train and consequently the energy needed for traction; according to Alstom (2015), the use of Silicon Carbide (SiC) auxiliary converters will allow a 45% reduction in mass and a 55% reduction in volume compared to conventional converters, leading to a 4% reduction in energy consumption.

Fig. 108: **Energy costs per train and per year for electric technology compared to diesel technology for single-decker (SD) and double-decker (DD) trains, according to Bombardier[2] (Euro/year)**



Source: Bombardier (2014)

[2] Assumptions made: identical trains hauled by either diesel or electric locomotives; data used for the comparison: 1.23 Euro/liter diesel fuel; 0.10 Euro/kWh; 1 liter fuel corresponds to 5 kWh (based on simulations); 180 000 km/year

Retrofitting energy meters on european trains

The quantity of energy consumed by diesel trains can be easily derived from the amount of fuel used on board; however, in the case of electric traction, where electricity is supplied by an external grid, trains need to be equipped with an energy meter if their consumption is to be monitored. Installing energy meters in trains, as evidenced by many projects of the UIC railway operators, allows for a more precise measurement of energy consumption, which can in turn ensure energy savings and provide the railway operators with precise indications on the effectiveness of the impact of energy reduction measures. Meters can be retrofitted at relatively low cost on existing rolling stock. The cost is even lower if the meter is installed in new rolling stock.

In a questionnaire issued by UIC and Susdef to European railway operators in 2014, respondents reported that the number of meters installed in their rolling stock will increase three-fold by 2020, as several operators are planning to install meters across their whole fleet. In some countries such as Germany there is a legal obligation to install energy meters in trains. It is estimated that 25 000 energy meters will be installed in European trains by 2020.

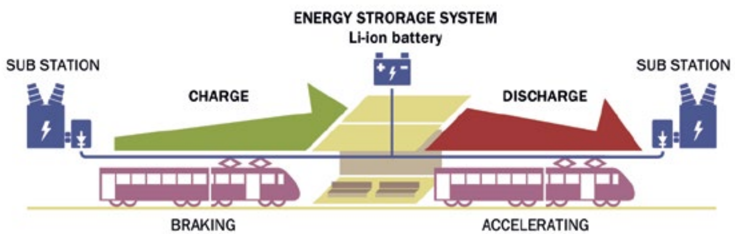
Energy recovery from braking

An increasing number of trains are being equipped with technology to recover electric energy from braking. The energy recovered can be used both internally to the train for the operation of auxiliary systems (e.g. to power lights, air conditioning, door opening and closing, or to charge a battery for later usage when possible) and externally: the recovered electricity can be sent back to the grid and used to power other trains in the same section of catenary.

In the absence of special equipment, part of the energy recovered is lost by dissipation when the electricity both cannot be stored or used inside the train and when there is no train accelerating in the same section of the grid. In these circumstances, specialized equipment can be used to boost the efficiency of energy recovery from braking: reversible substations, for example, are able to collect the recovered electricity and redistribute it on the grid. Many infrastructure managers are working on this issue; for example ADIF (Administrador de Infrastructuras Ferroviarias in Spain) has developed a pilot study in the reversible substation of La Comba (Málaga, Spain) in a DC electrified infrastructure (ADIF 2009).

Japanese Railways (JR) are testing an energy storage system, based on Li-ion batteries, which stores the electricity recovered from braking trains and provides the stored electricity to the next accelerating train passing through the same railway section. The system is placed between two substations and also prevents voltage drop issues (Ashida 2014).

Fig. 109: **JR storage system for energy recovered from braking**



Source: Japan Railway Group (2014)

Energy efficiency in infrastructure

Railway infrastructure managers play a key role in improving energy efficiency by working closely with railway operators. By allowing trains to ride unhindered and at the most efficient speed, well-managed infrastructure can save a significant amount of energy.

Infrastructure managers are adopting advance traffic management systems, which can perform various scheduling and logistic operations and help reduce energy consumption. For example, they can detect and avoid possible conflicts between train journeys, which could cause delays and waste energy due to avoidable braking and stopping of trains; they can assist infrastructure managers in compiling energy-efficient timetables where train trips are optimised, both for passengers (combining the right departure and arrival times) and for freight (to minimise empty trips).

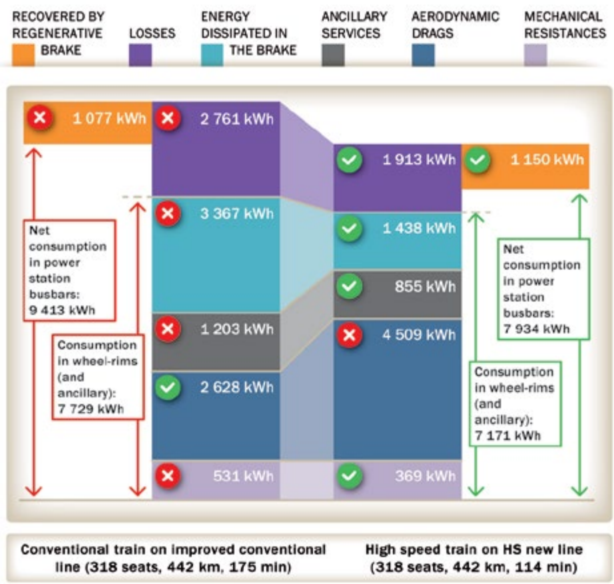
An example is the “Elbrus” traffic management system adopted by Russian Railways RZD, which automatically calculates and allocates journeys according to an energy-saving traffic schedule, and regularly verifies the deviation of actual operations from the forecasted timetables (Vinogradov 2012).

Energy efficiency in high-speed rail

Research commissioned by the UIC (FFE, 2010) examined the energy consumption of high-speed rail through a series of case studies. The paper estimated energy consumption of high-speed trains on high-speed infrastructure and compared it to energy consumption of conventional trains. Both high-speed rolling stock and high-speed infrastructure provide an improvement in energy consumption over conventional trains and conventional lines, with a range of reductions in specific energy intensity ranging from 7% to 28%.

Furthermore, the study stresses how high-speed trains may indirectly impact sectorial energy consumption, for example through mode shift from air travel to high-speed rail, the latter consuming about 1/10th the energy per passenger-km than air travel.

Fig. 110: **Comparison of energy consumption between a conventional train and a high-speed train**



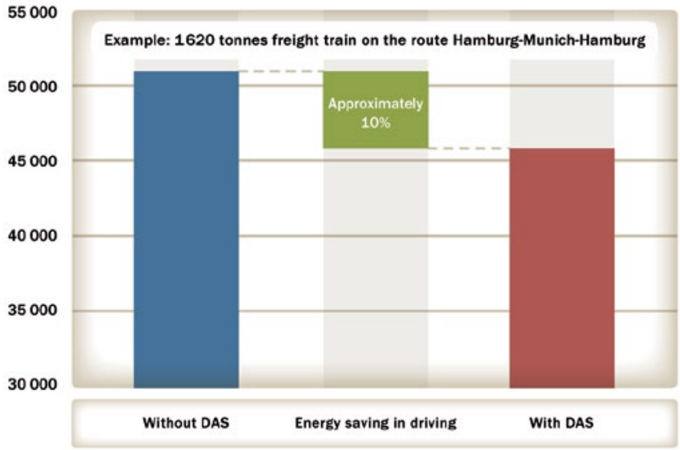
Source: FFE (2010)

Eco-Driving and Driver Advisory Systems

The human factor has a significant impact on the energy efficiency of trains. There are a series of operational measures and best practices that can reduce energy consumption, such as turning off the motive power when acceleration is not needed. Training programs for drivers can lead to several percentage points of reduction in energy consumption.

The use of additional tools like Driver Advisory Systems (DAS) can further augment the energy performance of the driver. The DAS monitors relevant journey characteristics: upward and downward slopes, stops and possible leeway in the timetable, and can also interact with a central system that communicates events happening on the road. After analysing these parameters, the system suggests changes in driving behaviour to reduce energy consumption.

Fig. 111: **Example of energy consumption measurement with and without DAS (kWh)**



Source: Jony (2014)

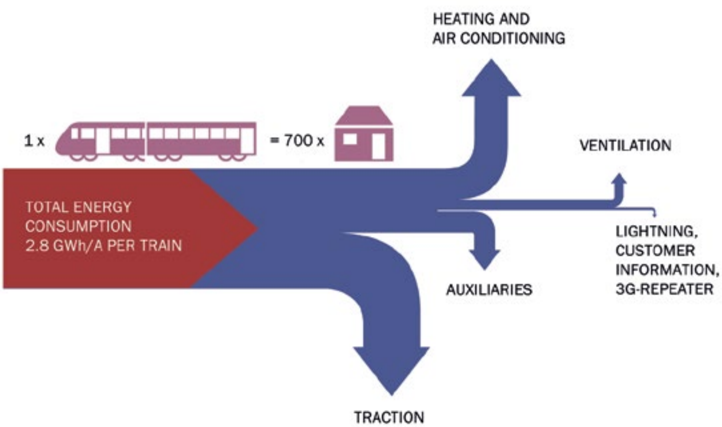
Hotel loads

Not all the energy consumed by a train goes towards traction: part of the energy is needed to operate systems used by passengers and goods carried on the train. For example, energy is needed for heating, ventilation and air conditioning (HVAC), as well as for lighting, power plugs, information screens and the opening and closing of doors. These are called "hotel loads". Estimates on the amount of energy needed for hotel loads range from 10-15% and in some cases up to nearly half of the total train energy consumption (UIC, 2015).

The approaches to improving the energy efficiency of train hotel loads overlap in fact to a large extent with those that have been adopted to improve the energy consumption in buildings. For instance, insulation can reduce the energy consumption of HVAC system, and LED lighting can replace standard lighting to reduce energy use. Innovative technologies such as heat pumps, air cooling, and natural ventilation can also be implemented on trains.

Innovative solutions are being explored to lower the emissions related to hotel loads in trains: Indian Railways are testing to set up photovoltaic power systems for 500 diesel trains to power hotel loads. An average train would accommodate 24 m^2 of panels on a total surface of 40 m^2, and thereby be able to generate 150kWh per year of energy. This production could then reduce the diesel consumption of the rail operator by 90 000 litres per year[3] (IR 2015).

Fig. 112: **Hotel loads in Swiss Railways (SBB/CFF/FSS) ICN trainsets**



Source: SBB (2015)

[3] Estimate based on assumptions of 188 trips per year and 483 litres of diesel used per trip for hotel loads.

Methodology Notes

Railway specific energy consumption (fig. 18, 44, 56, 80, 92, 94, 95, 96, 97, 98, 99) and specific CO2 emissions (fig. 19, 45, 57, 81, 93) – indicators building

Railway specific energy consumption and specific CO_2 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. In particular, EU28 and Russian graphs for specific energy consumption and specific CO_2 emissions are calculated by UIC directly on the basis of the data provided by members.

When railway companies do not report any energy consumption, 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 CO_2 emissions in rail, as the latter use the IEA World Energy Balances as a source. For specific CO_2 emission intensity, the calculated energy intensities are combined with direct CO_2 emissions from fuel combustion (tank-to-wheel CO_2 emissions) and CO_2 emissions resulting from the production and transformation of fuels and electricity (well-to-tank CO_2 emissions). The emission factors used for this purpose are taken from the IEA Mobility Model.

Railway specific energy consumption and specific CO_2 emissions – consistency improvement

In some cases, figures showing specific energy consumption and specific CO_2 emissions differ from the figures in the 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. In this 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 CO_2 emissions). This is the main reason of the revisions of specific energy consumption and specific CO_2 emissions estimates.

Railway energy sources mix (29, 30, 31, table 4, table 5)

For EU28, 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. As seen in Fig. 29, some trains run on diesel (which are oil products) and the rest run on electricity, which is produced from different sources according to the electricity mix used (fig. 30 and table 4). By applying the electricity mix to the portion of electric energy used, it is possible to obtain the energy sources mix shown in fig. 31 and table 5.

Vehicle efficiency – World and EU28 data

Part II (Focus on Vehicle Efficiency) contains graphs on the energy efficiency of railway vehicles both for geographic areas worldwide (where the indicators are measured per train-km) and for EU28 (where the indicators are measured per gross tonne-km). These graphs are obtained by using different datasets; the IEA and the UIC are working to align the datasets and improve their consistency.

Glossary

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.).

Gross tonne-kilometre hauled
Unit of measurement representing the movement over a distance of one kilometre of one tonne of hauled vehicles (and railcars) and contents.

Joule (J)
Unit of measurement of energy consumption.
Kilojoule: 1 kJ = 1 x 10^3 J
Megajoule: 1 MJ = 1 x 10^6 J
Gigajoule: 1 GJ = 1 x 10^9 J
Terajoule: 1 TJ = 1 x 10^{12} J
Petajoule: 1 PJ = 1 x 10^{15} J

Lge/100 km
Litres gasoline equivalent per 100 kilometres

Maximum Design Zero Fuel Weight
The maximum weight of an aircraft (loaded with crew, passengers, baggage and freight) prior to fuel being loaded

Passenger-kilometre (pkm)
Unit of measurement representing the transport of one passenger over a distance of one kilometre.

PLDV
Passenger Light Duty Vehicle

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

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

Transport Unit (TU)
The sum of passenger kilometre and tonne kilometre

TTW
Tank to wheel

WTT
Well to tank

WTW
Well to wheel

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, 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, 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.

SUSDEF
The Sustainable Development Foundation was founded in 2008 by will of companies, business associations and sustainability experts. It is a not for profit think-tank based in Rome aiming 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.

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