Rail Environmental Report

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FOR RAILWAYS

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Commissioner's welcome message

There is no doubting the sustainability of rail and initiatives such as this, that help raising awareness of these credentials, are very welcome. Greenhouse gas emissions per kilometre travelled by each rail passenger are a fraction of those of other transport modes, especially for longer distances. For freight, trains – along with ships and barges – also produce far lower emissions per tonne/km compared with road transport.

We have recognised this in the European Commission, and included ambitious milestones for rail in our Sustainable and Smart Mobility Strategy, presented in 2020. We want to increase freight transport and double high-speed rail passenger traffic by 2030, and triple it by 2050. This is how the rail sector will contribute to the EU's target of carbon-neutrality and reducing transport emissions by 90% by 2050.

What Europe needs is a strong rail sector that is able to attract passengers and freight with accessibility, efficiency and affordability.

We must be honest and say we are not quite there yet. Fortunately, we know what needs to be done and work to implement the necessary measures is already underway.

Innovative solutions such as digital automatic coupling, the Future Railway Mobile Communication System, greater operational efficiency and increased use of renewable energy are some of the answers.

The European Union Agency for Railways plays an important role in supporting rail to become more accessible, efficient, affordable and greener. As system authority for the European Rail Traffic Management System and rail digitalisation, the European Union Agency for Railways is best-placed to deliver technical solutions for the rapid roll-out of modern systems that create efficiency gains in network use and train operations.

This report highlights the ways in which rail is helping to create a more sustainable future, and examines the relationship between rail operations and the environment. It is a valuable contribution to discussions on the role that rail can play in greening transport.

Taking stock of the developments in recent years, the report explains the carbon footprint of rail, and puts forward ways to shrink this footprint further still. I hope that after reading it, you will be convinced as I am of rail's key role in our transport network – today and tomorrow.

Adina Vălean, European Commissioner for Transport

Foreword by the European Union Agency for Railways' Executive Director

Dear reader

It is with great pleasure that I introduce the first edition of the European Union Agency for Railways' rail environmental report, which analyses the environmental performance of railways. This report will contribute to better understanding the environmental impact of our transport system and, more particularly, of the railway sector. The elements contained in this report will allow us to identify the strongest and weakest points of the railway system in relation to the environment.

In our transport system, rail is the mass transport mode with the lowest greenhouse gas emissions and external costs, the highest degree of energy independence (especially if the electricity comes from the EU's renewable sources), the highest efficiency in land-take and the most durable assets. These factors give rail several green competitive advantages over other modes of transport and the potential to become the backbone of a green multimodal transport system.

Even if rail is more environmentally friendly than the other modes of transport, the railway sector still has an impact on the environment; railway noise is the most important effect, with 22 million Europeans exposed. Rail transport also emits greenhouse gases and other pollutants but to a negligible level compared with other modes of transport, producing only 0.4 % of the greenhouse gas emissions in the transport sector. Finally, land is used to build infrastructures, with long-term effects on nature conservation and biodiversity.

Despite being the most sustainable mode of transport, railways have been unable to increase their modal share in the transport mix in the past decade. Therefore, this report also emphasises the importance of a modal shift towards green transport and logistics chains. Rail is the most sustainable, affordable and effective transport mode to meet the goal of decarbonisation. However, trains need to run alongside and in cooperation with other modes of transport to carry goods and people in the most effective way. Such a multimodal approach requires the seamless integration of the transport modes, facilitated by digital technologies.

This report aims to reach a large audience. A total of 9 out of 10 Europeans consider climate change a very serious or fairly serious problem. Climate change is a reality that is affecting European citizens more frequently and more severely. Natural disasters driven by climate change, such as extreme heatwaves and fires, heavy rainfall and flooding, heavy snowfall, and thunderstorms, severely test the transport system's resilience. Those events can become even more challenging to handle when combined with the expected increase in demand for rail transport and the shortage of rail network capacity. From economic and environmental perspectives, a robust, resilient and reliable transport system is fundamental to ensure the welfare and the right to mobility of Europeans. To achieve a resilient transport system, reinforcing multimodality by ensuring the better integration of the transport modes and establishing interoperability at all levels of the transport system is vital.

The report is also an important source of information for decision-making at the EU and Member State levels. Although we do not make proposals in this report, it compiles transport and railway data together with a factual analysis of the environmental dimension of rail transport, which could serve to set political priorities at the European level. In addition, we identified data gaps that could be filled by future editions of this report. I take this opportunity to warmly thank all stakeholders that have contributed to this report: the national safety authorities, the representative bodies, the European Investment Bank, the International Union of Railways and the European Environment Agency.

I hope that you will find this report interesting and a valuable point of reference.

Enjoy reading!

Josef Doppelbauer

Executive summary

The impact of transport on the environment and society is substantial, as it produces approximately 25 % of total EU greenhouse gas (GHG) emissions. GHGs and other air pollutants emitted from the transport sector and other sectors have serious consequences for the health of Europeans. Beyond air pollution, transport is an important source of noise, and the use of land for its infrastructure has a long-term effect on biodiversity. In addition, externalities such as congestion and accidents are negative consequences of the European transport system.

Since the signing of the Treaty of Maastricht of 1992 and the extension of competencies of the EU in the field of transport, the EU has been striving to build the single European transport area. In doing so, it aims to use less and greener energy, to exploit an integrated and multimodal transport network more efficiently and smartly, to promote a modal shift to rail and to establish the polluter-pays principle. The Green Deal – a roadmap to transform the European economy and society and to put it on a sustainable path – was developed by the European Commission in 2019, with a significant transport component. In this communication, the European Commission calls for the acceleration of the shift to a sustainable and smart mobility pattern and for the substantial lowering of the GHG emissions of this key sector. Today's objectives are to double rail freight traffic and triple high-speed rail traffic by 2050.

This is the first rail environmental report by the European Union Agency for Railways, aiming to develop a broader understanding of the relationship between rail activities and the environment, taking into account the experiences of the European Union Aviation Safety Agency and the European Maritime Safety Agency.

In the transport system, rail is the mass transport mode with the lowest GHG emissions and external costs, the highest degree of energy independence (especially if the energy comes from the EU's renewable sources), the highest efficiency in land-take and the most durable assets. This gives rail several green competitive advantages over other modes of transport and the potential to become the backbone of a multimodal transport system.

Despite these advantages and policies put in place to enhance the competitive position of rail transport, its modal share has been stable over the last two decades in both the freight and passenger segments. There are many reasons behind this stagnation: the great flexibility and availability of road haulage, lack of internalisation of external costs, greater investments in European roads than in the rail network and other factors, such as speed, reliability, frequency and price.

Even if rail is more environmentally friendly than other modes of transport, the railway sector still has an impact on the environment; railway noise is the most important effect, with 22 million Europeans exposed. Rail transport also emits GHGs and other pollutants but to a negligeable level compared with other modes of transport, producing 0.4 % of the GHG emissions of the transport sector. Finally, land is used to build infrastructures, with long-term effects on nature conservation and biodiversity.

The railway sector is proactive in tackling the environmental challenge. To mitigate the exposure of European citizens to railway noise, operational and technical measures have been put in place, such as quieter routes and noise protection barriers along tracks. Even though the railway sector's GHG emissions are already relatively low, it aims to become carbon-neutral before 2050, by increasing the electrification of the rail network, using renewable sources of energy to generate the electricity needed and developing trains powered by alternative technologies to eliminate the remaining diesel operations in the sector. The main contribution of rail to the environmental objectives would actually be the increased use of rail with the achievement of the modal shift goals.

Natural disasters driven by climate change, such as extreme heatwaves and fires, heavy rainfall and flooding, heavy snowfall, and thunderstorms, severely test the transport system's resilience. Those events can become even more challenging to handle when combined with the expected increase in demand for rail transport and the shortage of rail network capacity. From economic and environmental perspectives, a robust, resilient and reliable transport system is fundamental to ensure the welfare and right to mobility of Europeans.

To achieve a resilient transport system, reinforcing multimodality by ensuring the better integration of the transport modes and establishing interoperability at all levels of the transport system is vital. In a multimodal approach, all modes of transport have a key role to play, allowing us to make the best use of the strengths of each mode. All modes of transport and their efficient integration are important, including road, rail, waterborne and air transport, and non-motorised transport, such as walking and cycling. Emphasis should, however, be placed on low-carbon-based and energy-efficient modes of transport, and an increased reliance on interconnected transport networks for seamless and 'door-to-door' mobility and connectivity of people and goods. While efforts need to be made to decarbonise each individual mode of transport, political choices need to be made based on the environmental capabilities of each mode. Rail is and will continue to be a major player in the decarbonisation of the EU transport system and ensuring energy independence. Integrated transport chains may also provide the redundancy necessary to increase the resilience of the sector to potential crises and enable its adaptation to climate change.

While the EU is willing to achieve climate neutrality through the long-term establishment of a zero-carbon and climate-resilient economy, the extent to which imperatives of the response to climate change are considered when planning our economic response will greatly influence the GHG emissions trend in the next few decades. This is particularly true for the transport sector.

This rail environmental report is the first produced by the European Union Agency for Railways but will not be the last. The agency is committed to monitoring the railway sector's development in relation to the environmental imperatives and plans to issue this report every 3 years.

Introduction

The impact of transport on the environment and society is very high, as it produces approximately 25 % of total EU greenhouse gas (GHG) emissions. The freight sector produces 30 % of the total GHG emissions of the transport sector, while passenger traffic – mainly private cars – accounts for the remaining 70 %. GHGs and other air pollutants emitted from the transport sector and other sectors have serious consequences for the health of Europeans. Indeed, more than 300 000 Europeans suffered a premature death in 2020 due to bad air quality ([1]). Transport's environmental impact is far from limited to air pollution. Transport is also a significant source of noise, and the use of land for its infrastructure has a long-term effect on biodiversity. Finally, externalities such as congestion and accidents are additional negative consequences of the European transport system. Limiting the environmental impact of transport is challenging when combined with the expected increase in demand for transport, the increase in natural disasters driven by climate change, the shortage of rail network capacity and the policies related to the modal shift to rail, which have not yet reached their goals.

Climate change is currently perceived as a problem by most Europeans. Indeed, in July 2023, a special Eurobarometer on climate change ([2]) was published in which 93 % of European respondents perceived climate change as a very serious (77 %) or fairly serious (16 %) problem. Since 2016, the European Union Aviation Safety Agency (EASA) has analysed the environmental performance of the aviation sector and its necessary changes in relation to its environmental impact. In 2022, EASA published the third edition of its European aviation environmental report. The European Maritime Safety Agency followed with the publication of its first European maritime transport environmental report in 2021, and will publish the second edition in 2024. The European Union Agency for Railways (ERA) decided at the end of 2022 that it was time to conduct a broader analysis of the relationship between rail activities and the environment, benefiting from the experiences of EASA and the European Maritime Safety Agency. This European rail environmental report will contribute to informing Europeans about the environmental impact of rail transport activities, and about measures put in place to limit it.

Chapter 1 of this report provides an overview of rail transport in the EU, including rail transport activity and modal shares, energy use, fleet composition and the state of the infrastructure. It also sets out the EU railway and environmental objectives contained especially in the European Green Deal and the sustainable and smart mobility strategy.

Even though rail remains today the most sustainable mode of mass transport, railway operations generate significant environmental impacts. Chapter 2 evaluates those impacts and, more particularly, noise and vibration, GHG emissions and air pollutants, land occupancy and the impact of new infrastructure and its effect on biodiversity.

The railway sector is active in putting in place measures to overcome or mitigate its environmental impact. Chapter 3 focuses on those measures, including limiting the sector's noise emissions or its GHG emissions through the further electrification of the rail network, enhancing the use of renewable energies and introducing railway innovation. Special attention is also given in this chapter to the importance of the modal shift to rail in limiting the GHG emissions of the transport sector as a whole.

Chapter 4 is dedicated to the challenge of adapting the European transport system in response to climate change, including an evaluation of rail resilience and the need to improve multimodality on a European scale.

([1]) https://www.eea.europa.eu/publications/air-quality-in-europe-2022/air-quality-in-europe-2022.
([2]) https://europa.eu/eurobarometer/surveys/detail/2954.

1. Overview of rail transport in the European Union

A. European objectives for rail transport

Since 1992, the main goal of the EU's transport policy has been to build a single European transport area. That is an important factor in enhancing the four freedoms: the free movement of goods, people, services and capital. The single European transport area should also bring EU citizens closer together, reinforce the competitiveness of the EU within global transport schemes (in terms of the organisation, efficiency and costs of transport and its impact on the environment), protect citizens against risks through enhanced transport safety standards (preventing maritime incidents, ecological disasters, air crashes, and road and rail accidents) and provide better security (by preventing terrorist attacks against air, rail or urban transport facilities).

The diagnosis made in 2011 in the White Paper *Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system* ([3]) has not really changed since: increased competition in the global economy, growing congestion and, more generally, an increase in external costs (including environmental costs), infrastructure gaps in the EU and oil dependency (with an increased price affecting EU sovereignty) are the most important issues the EU is tackling. The share of transport in EU GHG emissions has grown from 19.7 % to 25 % since 2011, and the demand for transport has been continuously growing since the late 2000s (except in 2008 owing to the economic crisis and in 2020 owing to the COVID-19 crisis). The means of reaching European objectives have been similar: using less energy (by designing more efficient vehicles), using cleaner energy (increasing the share of renewable energy in the EU energy mix) and exploiting more efficiently and smartly an integrated and multimodal transport network, promoting a modal shift to rail and considering the polluter-pays principle. The main difference between the situation in 2011 and now is that the targets for reducing GHG emissions have increased, as have the GHG emissions themselves. Nowadays, the EU has more ambitious objectives and less time to achieve them.

One of the greatest challenges ahead for European policies is therefore to reconcile different priorities: facilitating economic development, tackling environmental issues, liberalising the transport sector, and providing fair mobility for all EU citizens and an efficient network for the transport of goods and passengers. The links between environmental policy and transport policy have never been as strong as they are today.

During the 2015 UN Climate Change Conference, held in Paris in December 2015, 195 countries adopted the first worldwide legally binding agreement on the climate. This agreement sets out an international action plan aimed at mitigating the effects of climate change by 'holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels' ([4]). The EU is politically committed to playing a leading role in building an environmental policy at a global level. Indeed, before the EU ratified this agreement in 2016, it adopted legally binding acts to proactively limit the effects of climate change in its 2030 strategy, adopted in October 2014 and reviewed in 2018.

Key targets for 2030

The 2030 climate and energy framework ([5]) includes EU-wide targets and policy objectives for 2021–2030. Member States adopted national energy and climate plans for 2021–2030 on 31 December 2019, with updates published on 30 June 2023, together with national long-term strategies.

([3]) https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52011DC0144.
([4]) https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf.
([5]) https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2030-climate-energy-framework_en.

Through the European Climate Law, adopted in June 2021, the EU raised its ambitions, setting a new target for 2030 of reducing net GHG emissions by at least 55 % instead of 40 % compared with levels in 1990. To reach this goal, two major targets must also be reached:

- increase the share of renewable energy in energy consumption to at least 42.5 %;
- achieve a 36–39 % improvement in energy efficiency for final and primary energy consumption.

In a communication ([6]) from 6 February 2024 on securing Europe's climate target and path to climate neutrality by 2050, building a sustainable, just and prosperous society, the Commission recommends establishing an intermediate target of a 90 % reduction in net GHG emissions. However, this target will have to be decided following the European elections in June 2024. The main goal remains making the EU a carbon-neutral economy by 2050 and the global leader for environmental protection. Finally, the railway sector aims to set this deadline for its own activities.

European Green Deal

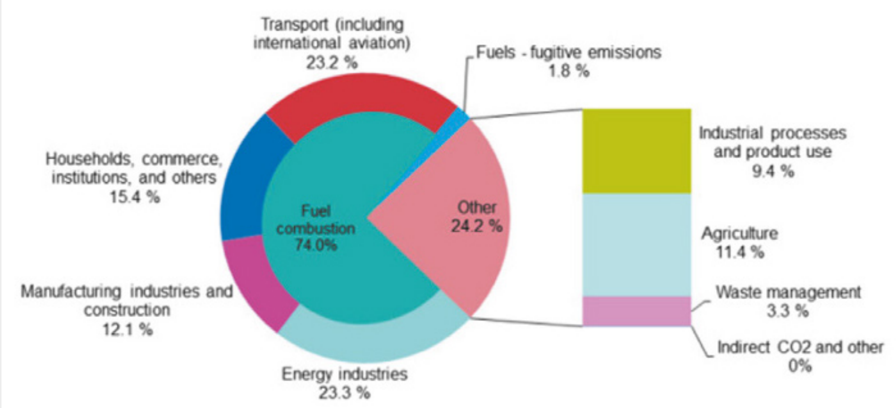
In a communication from December 2019 ([7]), the European Commission developed a global and intersectoral roadmap to reach its key targets and to 'turn an urgent challenge into a unique opportunity'. The main aim of the European Green Deal is to transform the European economy and society and to put it on a sustainable path. This requires a massive public investment programme, together with major efforts to direct private capital towards climate and environmental actions.

The Green Deal includes various targets, such as 'a zero-pollution ambition for a toxic-free environment' and 'mobilising industry for a clean and circular economy'. The strategic goal for the transport sector is 'accelerating the shift to sustainable and smart mobility'. The five sectors with the greatest GHG emissions – energy, industry, buildings, transport and agriculture – have been targeted for substantially lowering emissions. Together with agriculture, the transport sector is largely considered one of the most challenging sectors for decarbonising the economy.

Indeed, the trends in GHG emissions by the main sectors of the EU between 1990 and 2021 demonstrate that transport comes second, after the energy supply sector, in terms of emissions. It produces approximately 23 % of total GHG emissions (Figure 1), with the freight sector producing 30 % of total transport sector GHG emissions, and passenger traffic (mainly private cars) accounting for the remaining 70 %. Despite the declining energy supply, the transport sector's GHG emissions keep increasing.

([6]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2024%3A63%3AFIN.
([7]) https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF.

Figure 1: GHG emissions by sector, EU-27, 1990–2021



Source: EEA, republished by Eurostat (env_air_gge), 2022

To achieve climate neutrality at the EU level, a 90 % reduction in transport GHG emissions is needed by 2050, and all transport modes will have to contribute to the reduction. In addition, a substantial part of the 75 % of inland freight carried today by road should shift onto rail and inland waterways. In this context, in July 2023 the European Commission proposed some measures to increase and better manage railway capacities to improve coordination between railway stakeholders.

Along with reinforcing multimodality, several other workstreams are proposed to reach this objective.

- Digitalisation should enable smarter traffic management and, through automated and connected multimodal mobility, increase transport efficiency. It would also allow the development of 'mobility as a service' solutions.
- Fossil-fuel subsidies should end, including the tax exemptions in the civil aviation and maritime sectors, so that the price of transport reflects the impact it has on the environment and on health and to establish a level playing field between modes of transport. Work to revise the energy taxation directive (Council Directive 2003/96/EC) is ongoing.
- The emissions trading system was extended to the maritime sector from 1 January 2024, and as a result the GHG emissions of airline companies will be reduced in the EU. In addition, the extension of this system to the road sector and correct road pricing should be discussed.
- The EU battery industry will be subsidised, as it provides an alternative transport fuel. By 2025, about 1 million public recharging and refuelling stations will be needed for the 13 million zero- and low-emission vehicles expected on European roads. Regulation (EU) 2023/1804 of 13 September 2023 on the deployment of alternative fuels infrastructure has been adopted to support this process (8).

Obviously, a large volume of investment is necessary to achieve the goals of the Green Deal. The European Commission has estimated that achieving the 2030 climate and energy targets will require EUR 260 billion of additional annual investment, equal to around 1.5 % of EU gross domestic product (GDP) in 2018. To specify how these high-level objectives will be reached, the Commission has adopted two additional documents.

Sustainable and smart mobility strategy

The sustainable and smart mobility strategy (9) was adopted at the end of 2020 and is the guideline aligning the works of the Commission with the objective of implementing concrete actions to reach a 90 % reduction in GHG emissions in the transport sector by 2050.

(8) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1804.
(9) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789.

The success of the European Green Deal depends on the ability of the transport system as a whole to become more sustainable. A list of 82 actions has been developed and will be tackled in 2020–2024. For instance, action 18 on putting forward an action plan to boost passenger rail transport was proposed by the European Commission in December 2021 ([10]), with the aims of, for instance, making the ticketing system more user-friendly and modernising passenger rail infrastructure. Action 19 on putting in place measures to better manage and coordinate international rail traffic and action 25 on intermodal transport are discussed as part of the greening freight transport package.

Various milestones are set out to show the European transport system's path towards achieving the objective of ensuring sustainable, smart and resilient mobility (Table 1).

Table 1: Milestones in the path to ensuring sustainable, smart and resilient mobility

By 2030	By 2035	By 2050
• At least 30 million zero-emission vehicles will be in operation on European roads. • 100 European cities will be climate-neutral. • High-speed rail traffic will double. • Scheduled collective travel of under 500 km should be carbon-neutral within the EU. • Automated mobility will be deployed on a large scale. • Zero-emission vessels will become ready for market.	• Zero-emission large aircraft will become ready for market.	• Nearly all cars, vans, buses and new heavy-duty vehicles will produce zero emissions. • Rail freight traffic will double. • High-speed rail traffic will triple. • The multimodal trans-European transport network, equipped for sustainable and smart transport with high-speed connectivity, will be operational for the whole transport network.

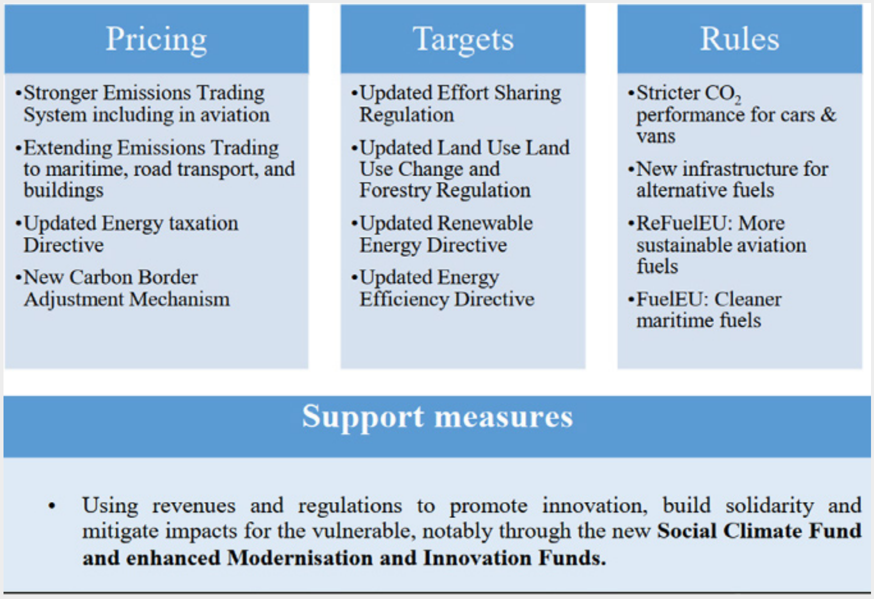
Fit for 55 package

The fit for 55 package ([11]), in reference to the target of reducing emissions by 55 % by 2030, is a very ambitious environment-related package of legal acts that goes far beyond the transport sector, with the ultimate objective of achieving the EU's 2030 climate target on the way to climate neutrality.

The legislative proposals are supported by an impact assessment analysis that considers the interconnectivity of the overall package. The analysis shows that an over-reliance on strengthened regulatory policies would lead to unnecessarily high economic burdens, while carbon pricing alone would not overcome persistent market failures and non-market barriers. The chosen policy mix is therefore a careful balance between pricing, targets, standards and support measures (Figure 2).

([10]) https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM%3A2021%3A810%3AFIN.
([11]) https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal/fit-55-delivering-proposals_en.

Figure 2: Pricing, targets, standards and support measures considered in impact assessment analysis



Greening freight transport package

On 11 July 2023, the European Commission presented its proposal for a greening freight transport package ([12]). Three legislative proposals have been put forward:

- the amendment of the single European railway area directive (Directive 2012/34/EU) on the use of railway infrastructure capacity and repeal of Regulation (EU) No 913/2010 on the European rail network for competitive freight;
- the revision of the weights and dimensions directive (Council Directive 96/53/EC);
- the CountEmissionsEU proposal on the harmonisation of GHG emissions data in transport.

The revision of the combined transport directive (Council Directive 92/106/EEC) is also ongoing.

The proposals on railway infrastructure capacity and on the weights and dimensions directive were voted on in a first reading in March 2024. The plenary vote on the first reading of the CountEmissionsEU proposal was planned for April 2024. The final adoption of the proposals is not envisaged to take place prior to the next European elections, scheduled for June 2024.

([12]) https://transport.ec.europa.eu/news-events/news/green-deal-greening-freight-more-economic-gain-less-environmental-impact-2023-07-11_en.

B. Transport trends in the European Union

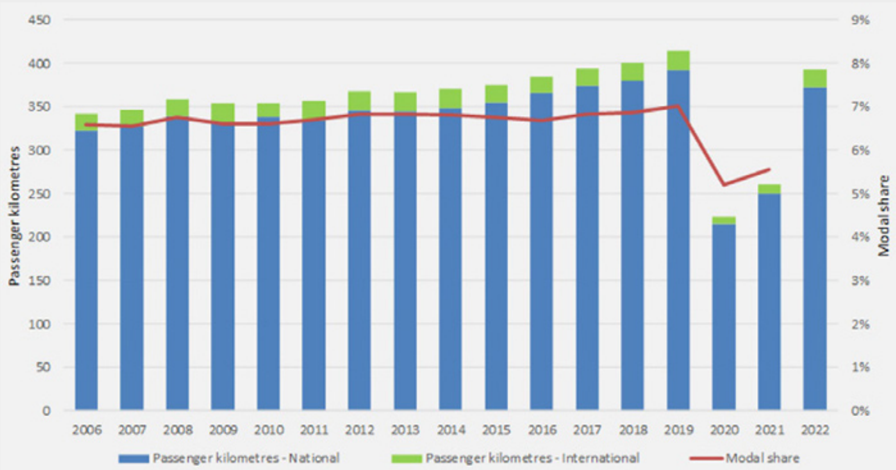
After several decades of losing market shares, predominantly to the road sector, the situation of the railway sector stabilised at the beginning of the 21st century and then increased slightly. The European Commission has been constant in its observation that roads' ultra-dominance of both the passenger and freight land transport markets needs to be balanced, and it advocates the greater use of rail. Various reasons, such as congestion on European roads and the associated costs, the low energy efficiency of cars, oil dependence, air pollution and safety, explain the European Commission's position.

Rail transport activity: passengers/tonnes transported and modal share

European (EU-27) rail traffic increased in 2006–2022, although with different dynamics for passengers and freight. While passenger-kilometres increased slowly but continuously from 2006 to 2019, freight volumes, although varying over the period, remained stable. However, because of COVID-19 and the related travel restrictions, passenger-kilometres decreased notably (by 54 %) in 2020. Freight suffered less as a result of the health crisis, with a slight decrease in the volumes transported. More recent data show an upturn in both passenger traffic and freight volume, recovering to pre-COVID-19 levels.

Rail's modal share ([13]) expressed as a percentage is presented alongside absolute rail transport volumes measured in passenger-kilometres and tonne-kilometres in Figures 3 and 4. In addition, the modal shares are defined considering all modes of transport. For freight, if only inland transport is considered, rail's modal share is 16.1 %.

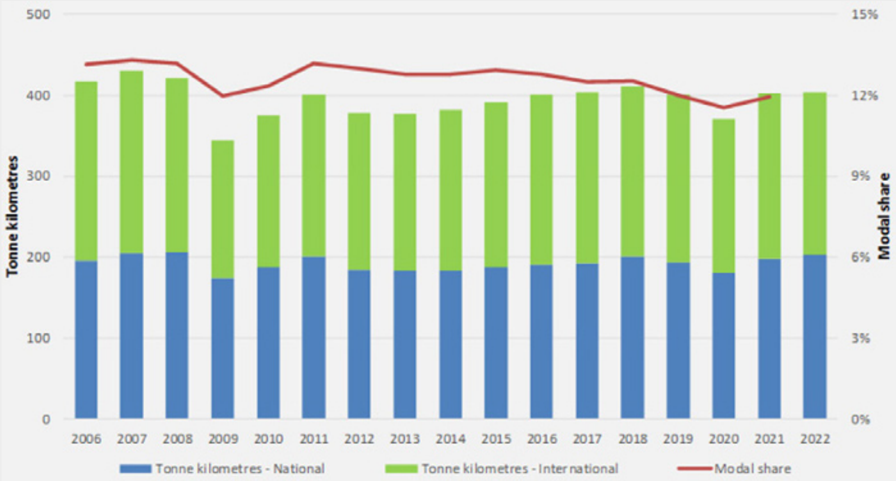
Figure 3: Rail transport of passengers (billion passenger-kilometres) for national (within a Member State) and international (between at least two Member States) traffic and modal share (%), EU-27, 2006–2022



Sources: ERA, based on Eurostat (rail_pa_total), (rail_pa_quartal) and (rail_pa_typepas) and European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

([13]) The modal share is based on transport performance calculated considering road, rail, inland waterway, air and maritime transport (see the Directorate-General for Mobility and Transport's *2023 Statistical Pocketbook*, available at https://transport.ec.europa.eu/facts-funding/studies-data/eu-transport-figures-statistical-pocketbook/statistical-pocketbook-2023_en).

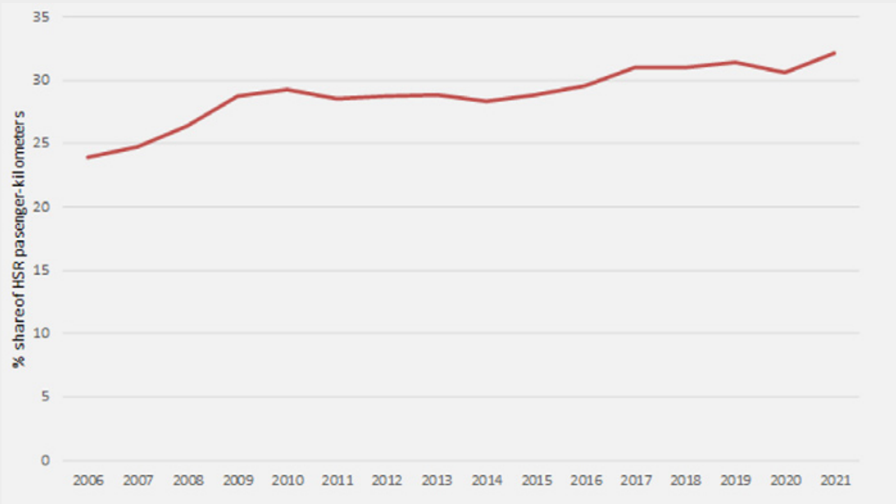
Figure 4: Rail transport of goods (billion tonne-kilometres) for national and international traffic and modal share (%), EU-27, 2006–2022



Sources: ERA, based on Eurostat (rail_go_total), (rail_go_quartal) and (rail_go_typepas) and European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

The slight increase in rail passengers' modal share is strongly linked to the development of the high-speed rail (HSR) network and the continuous increase over time in HSR traffic. As indicated in the European Commission's sustainable and smart mobility strategy, HSR is considered an important element driving the modal shift to rail, and the EU strives to double and triple HSR traffic by 2030 and 2050, respectively. In 2009–2019, HSR demand increased by 28 %. It then decreased by 47 % between 2019 and 2020 as a result of the COVID-19 pandemic, although in 2021 it recovered to a share of 32.2 %, representing 83 846 billion passenger-kilometres (Figure 5).

Figure 5: Share of HSR passenger traffic in passenger-kilometres (%), EU-27, 2006–2021



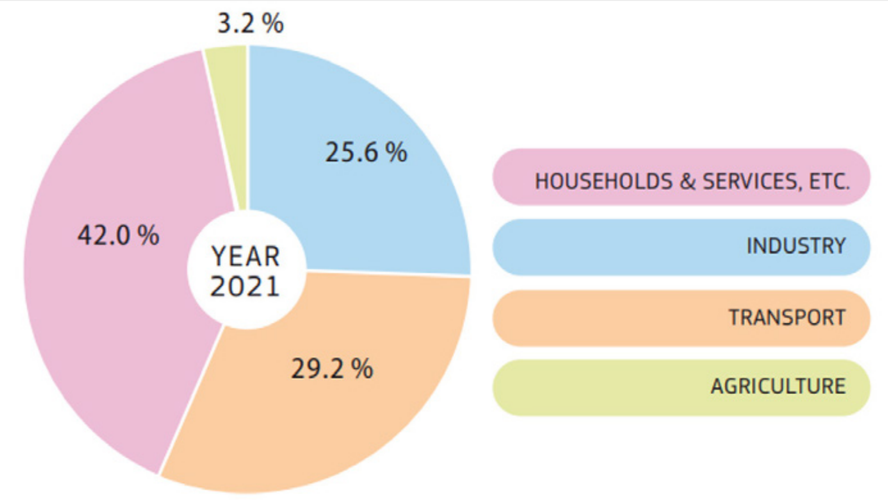
Source: ERA, based on Eurostat (hs_rail) and European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

Despite the policies put in place to enhance the competitive position of the railway sector, rail transport's modal share has been stable over the last two decades. There are many reasons behind this stagnation: the high level of flexibility and availability of road haulage, lack of internalisation of external costs, greater investments in European roads than in the rail network, and other factors, such as speed, reliability, frequency and price.

Rail transport and energy

The transport sector comes second among sectors in terms of final energy consumption (Figure 6), after the households and services sector, and consumes 274.8 million tonnes of oil equivalent (Mtoe) out of a total of 939.9 Mtoe for all sectors together (Figure 7).

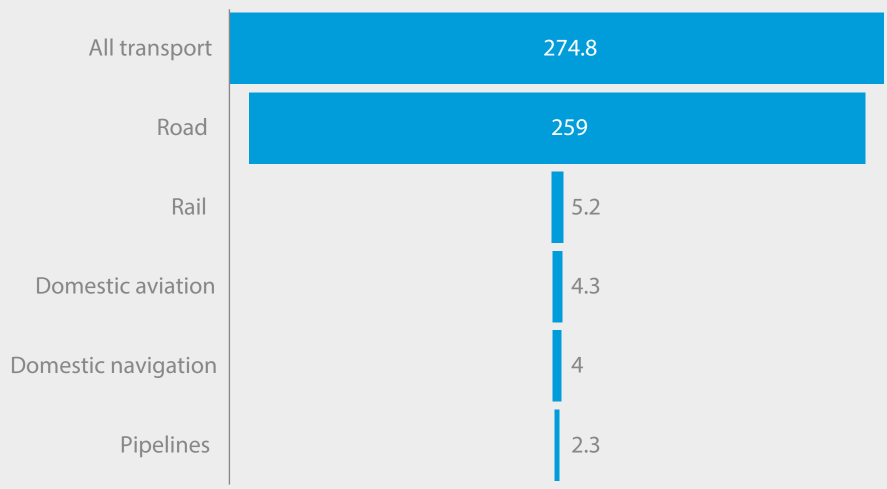
Figure 6: Final energy consumption by sector (Mtoe), 2021



NB: Transport excludes international aviation and international maritime.

Source: European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

Figure 7: Final energy consumption by mode of transport (Mtoe), 2021

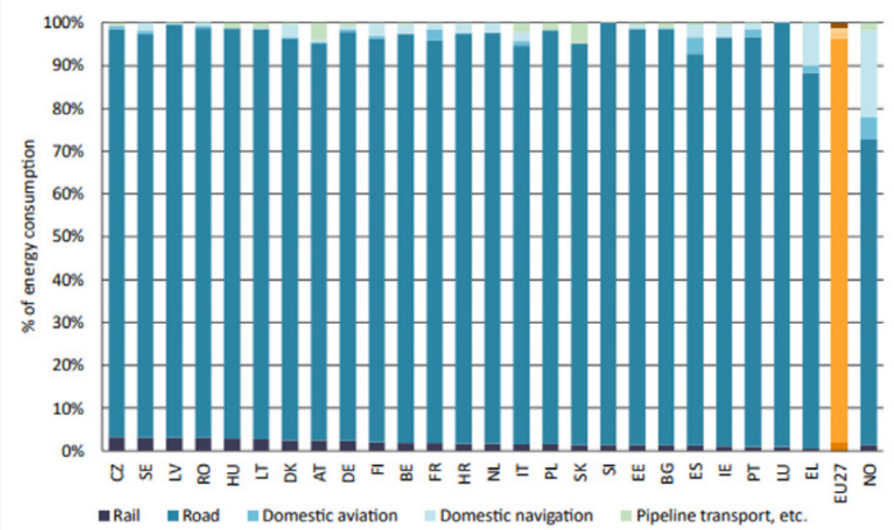


Source: ERA, based on European Commission, Directorate-General for Mobility and Transport (2023), 2023 *Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

Although both trucks and cars have seen their energy efficiency improve over time, the road sector is the mode of transport consuming the most energy by far, at 259 Mtoe ([14]). In contrast, the railway sector consumes only 5.2 Mtoe.

While the EU energy import dependency rate is 55.5 %, the railway sector accounts for 0.55 % of total EU energy consumption in the transport sector (Figure 8). In 2021, rail transport carried 11.9 % of freight and 5.6 % of passengers of all transport modes.

Figure 8: Share of each transport mode in total energy consumption by country and for the EU-27 (%), 2020

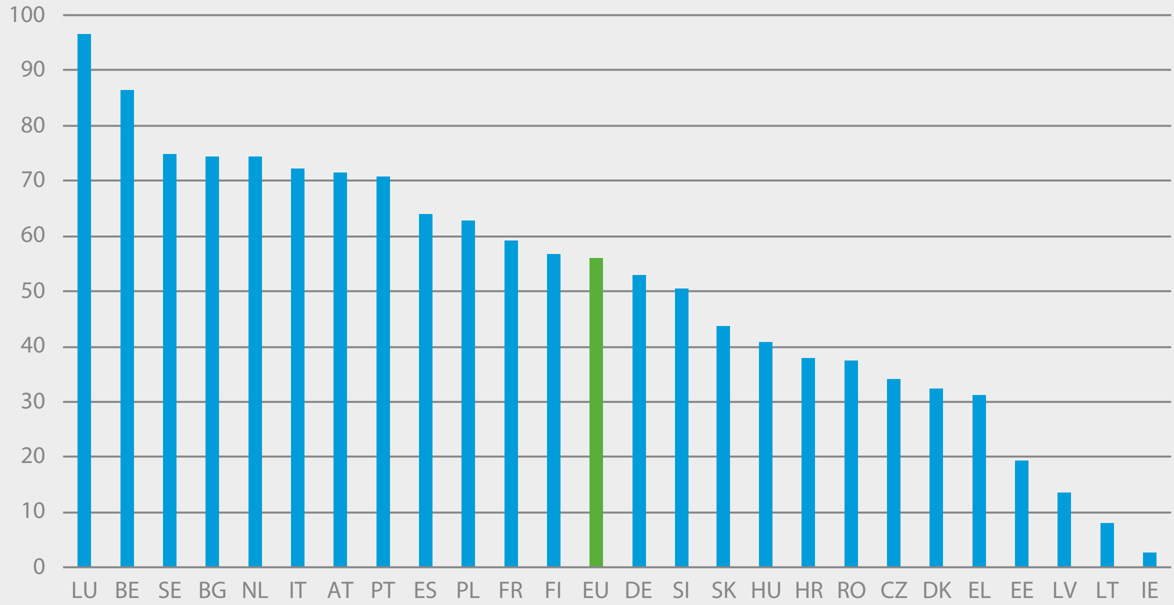


Source: European Commission, Directorate-General for Mobility and Transport (2022), *2022 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

In 2021, 56.1 % of the European rail network was electrified (Figure 9), with a large variety of electrification rates between Member States. However, the electrification rate of the rail network is continuously increasing in the EU, which could result from both electrification projects on existing lines and changes in the length of the network – caused by closing non-electrified lines or building new electrified lines. Finally, according to the latest benchmarking report from the Platform of Rail Infrastructure Managers in Europe, in 2020, approximately 81.6 % of total train-kilometres were travelled by electricity-powered trains ([15]).

([14]) Tonnes of oil equivalent is a unit of energy defined as the amount of energy released by burning 1 tonne of crude oil, and is used to compare energy consumption.
([15]) The GHG intensity of the electricity produced depends on the energy mix of the Member State.

Figure 9: Electrification rate of Member States' rail networks (%), 2021

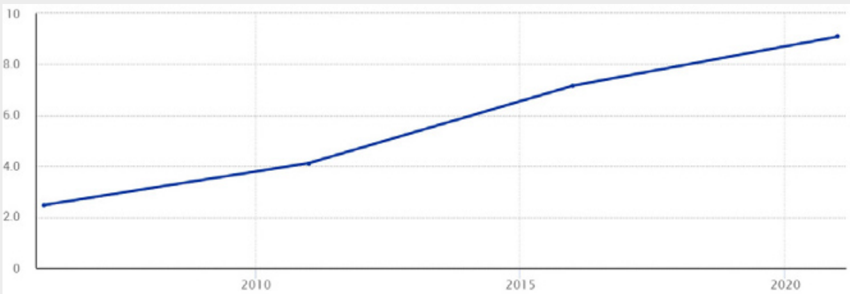


NB: Cyprus and Malta do not have a rail network and are thus not included in this figure.

Source: ERA, based on European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

While the use of renewable energy in the transport sector has increased over time, reaching 9.1 % in 2021 (Figure 10), there is unfortunately no overall figure for the railway sector indicating the share of renewable traction energy for the electrified part of the network. However, some data exist. With regard to the infrastructure managers of the Platform of Rail Infrastructure Managers in Europe, the share of renewable traction energy in relation to the total traction energy in kilowatt-hours is estimated to be 45 % ([16]), with companies such as ProRail ([17]) already at 100 %. It must be noted that most infrastructure managers are aiming to obtain 100 % of their electricity from renewable or low-carbon sources by 2040.

Figure 10: Share of renewable energy in gross final energy consumption in the transport sector (%)

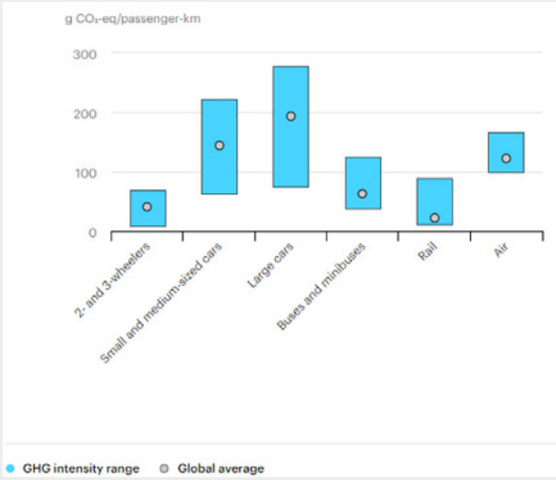


Source: Eurostat (sdg_07_40).

([16]) https://wikis.ec.europa.eu/display/primeinfrastructure?preview=/44167372/93979322/PRIME%20External%20Report%202021.pdf.
([17]) An infrastructure manager in the Netherlands.

Finally, energy efficiency and energy sobriety ([18]) are important to consider ([19]). Electricity sourced from renewable energy is still, for the time being, a scarce and intermittently available resource. In an energy system where a given amount of energy is produced by low-emission technologies and the rest is produced by burning coal, every additional kilowatt-hour produced will have the emission factor of burning coal. Therefore, it is important to use as little electricity as possible. Rail is more energy-efficient than any other mode of mass transport for both passengers and freight (Figures 11 and 12).

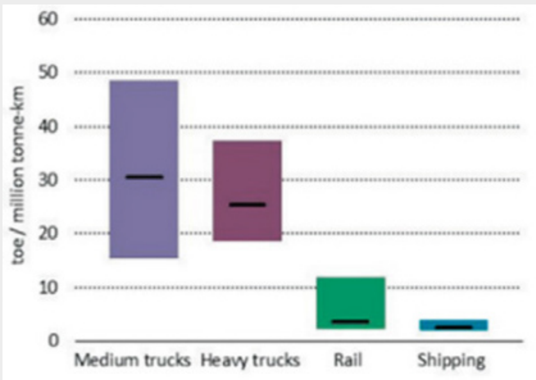
Figure 11: Well-to-wheel GHG intensity of motorised passenger transport modes (gCO_2eq per passenger-kilometre), 2022



NB: Boxes represent average ranges across various countries while dots represent world averages.

Source: International Energy Agency, 'Well-to-wheel GHG intensity of motorised passenger transport modes, 2022' (https://www.iea.org/data-and-statistics/charts/well-to-wheel-ghg-intensity-of-motorised-passenger-transport-modes-2022).

Figure 12: Energy intensity of different modes of freight transport, 2017–2019



NB: Boxes represent average ranges across various countries, while the black horizontal lines represent world averages.

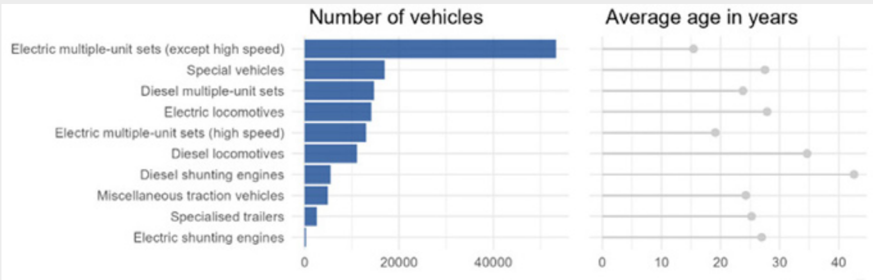
Source: International Energy Agency (2019), *The Future of Rail – Opportunities for energy and the environment*.

([18]) Energy sobriety means setting policies, measures and practices that avoid demands on energy (i.e. voluntarily taking planned actions to reduce energy consumption).
([19]) According to the energy efficiency first principle (see https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-first-principle_en), only the energy really needed is produced, investments in stranded assets are avoided and demand for energy is reduced and managed in a cost-effective way.

C. Fleet composition in the European Union

In 2023, the European rail fleet consisted of 780 000 railway vehicles, of which approximately 137 000 were traction vehicles and 643 000 were freight wagons and passenger coaches. Note that each car within a multiple-unit set is counted as a distinct vehicle. The exact number of multiple-unit sets cannot be easily determined using the European Vehicle Register, as the number of cars can vary from 2 to 10. That said, considering multiple-unit sets as single traction vehicles, it is estimated that there are around 45 000 unique traction vehicles. Also note that a large number of vehicles, while registered, are not actively used for business operations. The numbers below in Figure 13 therefore provide a higher-bounds indication.

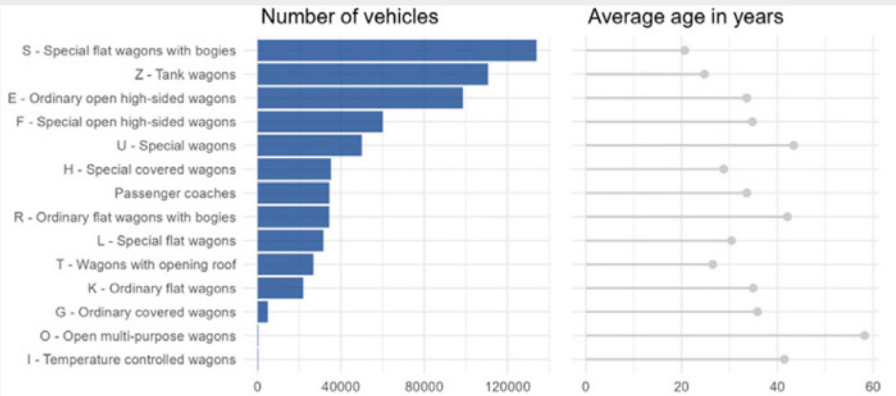
Figure 13: Overview of traction vehicles in Europe, 2023



Source: ERA, European Vehicle Register.

From the Figure 14, the traction source for miscellaneous traction vehicles, special vehicles and specialised trailers cannot be directly determined. Excluding these, about 28 % of the fleet is diesel powered. It is interesting to note that the diesel fleet is also the oldest. On average, the oldest traction vehicles are diesel shunting engines and diesel locomotives, with ages of 42.5 years and 35 years, respectively. These are also the types of traction vehicles that are targeted for replacement with hydrogen, battery or electric alternatives to achieve decarbonisation.

Figure 14: Overview of freight wagons and passenger coaches in Europe, 2023



Source: ERA, European Vehicle Register

The average age of the wagon fleet is equally high. Depending on the class, the average age ranges from 21 to 58 years, illustrating the robustness and sustainability of the fleet. This range also highlights a challenge to system-level innovation, considering that railway vehicles have such a long life cycle compared with road vehicles, with trucks having an average age of 14.2 years ([20]).

The fleet will evolve to cope with recent market developments. Fewer wagons for coal transport are expected to enter the market, whereas the number of wagons for intermodal transport (notably S class wagons) is expected to increase. The size of the fleet is also dependent on the extent to which utilisation improvements are realised, pushed by digitalisation, greater interoperability and increasing market pressures.

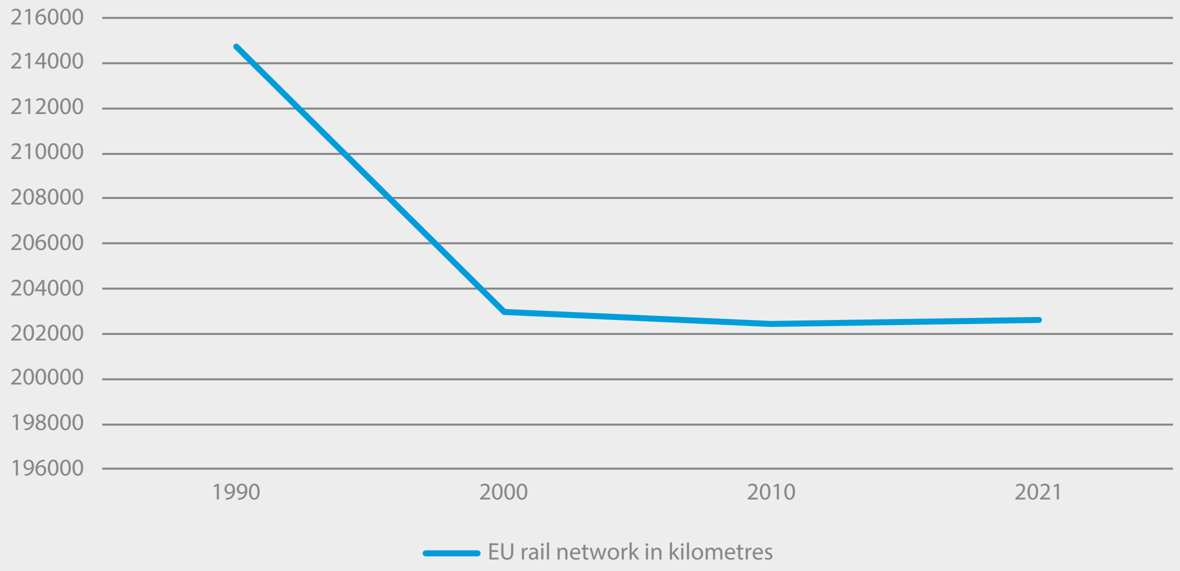
([20]) https://www.acea.auto/figure/average-age-of-eu-vehicle-fleet-by-country/.

D. European Union rail network

European Union rail network length and length of electrified lines

After decades of decreases in the length of the EU rail network, mostly due to a lack of investments and the closure of lines with low traffic, its length started to stabilise at the beginning of the century. The network reached 202 596 km in length in 2021 and was organised around 20 707 stations (Figure 15). Finally, most trains running on the EU rail network use electric traction, and rail transport is currently by far the most electrified transport mode in Europe.

Figure 15: EU rail network (km), 1990–2021



Source: ERA, based on European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

Figure 16: EU rail network (km) by Member State, EU-27, 1990–2021

	1990	2000	2005	2010	2015	2020	2021	km OF WHICH: ELECTRIFIED 2021	% OF WHICH: ELECTRIFIED 2021
EU-27	*214 725*	*202 952*	*202 457*	*202 424*	*201 068*	*202 557*	*202 596*	113 722	56.1
BE	3 479	3 471	3 544	3 582	3 607	3 615	3 612	3 127	86.6
BG	4 299	4 320	4 154	4 098	4 019	4 029	4 031	3 001	74.4
CZ	9 451	9 444	9 614	9 568	9 566	9 542	9 523	3 234	34.0
DK	2 344	2 768	*2 779*	2 092	2 552	2 485	2 485	803	32.3
DE	40 981	36 588	38 206	37 877	38 466	39 773	39 799	*21 100*	53.0
EE	1 026	968	925	1 196	1 164	1 167	1 167	225	19.3
IE	1 944	1 919	1 912	1 927	1 931	2 045	2 045	53	2.6
EL	2 484	2 385	2 576	2 552	2 240	2 345	2 339	731	31.3
ES	12 560	12 310	12 839	13 853	15 384	16 135	16 280	10 428	64.1
FR	34 260	31 397	30 871	*30 335*	28 808	27 213	27 057	16 054	59.3
HR	2 444	2 726	2 726	2 722	2 604	2 617	2 617	994	38.0
IT	*16 005*	15 974	16 225	16 704	*16 752*	16 782	16 832	12 160	72.2
CY	-	-	-	-	-	-	-	-	-
LV	2 397	2 331	2 270	1 897	1 860	1 859	1 859	251	13.5
LT	2 007	1 905	1 771	1 768	1 877	1 911	1 911	152	8.0
LU	271	*271*	*271*	275	275	263	263	254	96.7
HU	7 772	7 668	7 685	7 352	7 197	7 787	7 889	3 221	40.8
MT	-	-	-	-	-	-	-	-	-
NL	2 780	2 802	2 810	3 013	3 031	3 041	3 041	2 264	74.4
AT	5 624	5 563	*5 642*	5 828	5 522	5 607	5 603	4 003	71.4
PL	26 228	22 560	20 253	20 228	19 231	19 383	19 287	12 101	62.7
PT	3 126	2 814	*2 801*	2 843	2 546	2 526	2 527	1 791	70.9
RO	11 348	11 015	10 948	10 785	10 770	10 769	10 764	4 035	37.5
SI	1 196	1 201	1 228	1 228	1 209	1 209	1 209	610	50.5
SK	3 660	3 662	3 658	3 622	3 626	3 627	3 626	1 585	43.7
FI	5 846	5 854	5 732	5 919	5 923	5 918	5 918	3 359	56.8
SE	11 193	11 037	11 017	11 160	10 908	10 909	10 912	8 186	75.0

NB: Estimates are indicated in italic. Vertical blue line indicates a break in horizontal time series.
Source: European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

The rail network has developed differently in different Member States (Figure 16), with France and Poland in particular losing more than 20 % of their rail network between 1990 and 2021, much more than the EU average. In contrast, Spain saw an increase in the length of its rail network by almost 30 % in the same period.

European Union high-speed rail network

Although HSR feasibility requires a substantial passenger volume in order to be viable from a socioeconomic perspective, HSR has been identified as a key lever in the green transition for the transport sector because of its numerous environmental benefits. First and foremost, given its low carbon footprint thanks to its high energy efficiency and full electrification, HSR is much less emission-intensive than aviation or passenger road transport. Moreover, several HSR undertakings provide themselves with green energy (through guarantees of origin and power purchase agreements). Finally, HSR has the potential to stimulate regional economic development by connecting citizens and regional businesses through a fast and competitive alternative to aviation and passenger cars ([21]). The European Commission's HSR traffic targets are to be reached through expanding the EU's HSR network (by constructing new dedicated tracks and upgrading the current network) and making better use of the existing network.

The length of the EU's HSR network has increased considerably during the last two decades (Figure 17). Currently, the network consists of approximately 12 000 km of lines ([22]). However, HSR in Europe remains mainly scattered across the western region; it does not constitute a network yet and is largely non-existent in eastern Europe. Except for Poland, there is currently no HSR infrastructure in the Member States that joined the EU in the most recent enlargement.

Figure 17: EU HSR network (km) by Member State, 1985–2021

km (at end of year)													
	BE	DE	DK	ES	FR	IT	NL	AT	PL	FI	SE	UK	EU-27
1985	-	-	-	-	425	174	-	-	-	-	-	-	599
1990	-	90	-	-	717	194	-	24	-	-	-	-	1 025
1995	-	426	-	471	1 290	238	-	24	-	156	-	-	2 605
2000	72	576	-	471	1 290	238	-	24	-	156	187	-	3 014
2005	137	1 089	-	1 038	1 549	238	-	105	-	882	187	74	5 225
2010	209	1 178	-	2 102	1 912	856	90	121	-	1 120	680	113	8 268
2015	209	1 381	-	3 002	2 058	856	90	237	224	1 120	860	113	10 037
2020	209	1 571	56	3 454	2 735	921	90	254	224	1 120	860	113	11 494
2021	209	1 571	56	3 627	2 735	921	89	254	224	1 120	860	113	11 666

Source: European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

Importance of interoperability

As indicated previously, the modal share of rail transport in Europe is stagnating at quite low levels, with international rail traffic being significant only for freight and very limited for passenger services. This picture is far away from the EU climate and rail policy ambitions, and greater use of rail is critical to satisfy the demand for more sustainable transport.

To achieve the single European railway area, crossing internal EU borders should become a smoother process, enabling an increase in rail's modal share and international traffic. Removing interoperability barriers, deploying the European rail traffic management system (ERTMS) and ensuring the availability of appropriate rolling stock are key to achieving this goal.

The initial independent development of railway systems in different countries led to the adoption of a variety of track gauges and power and signalling systems, which impedes seamless rail operations across Europe.

Although the interoperability of the EU railway system is improving, progress has been slow so far, and it appears to be unequal and uneven across different areas ([23]). Solid progress has been achieved in aligning rules and procedures, whereas improvements in rolling stock and infrastructure have been slow, partly owning to their long life cycles.

([21]) See https://rail-research.europa.eu/publications/smart-and-affordable-rail-services-in-the-eu-a-socio-economic-and-environmental-study-for-high-speed-in-2030-and-2050/.
([22]) https://uic.org/IMG/pdf/uic-atlas-high-speed-2022.pdf.
([23]) See the ERA's annual overview of interoperability (available at https://www.era.europa.eu/content/annual-overview-interoperability-2023) and 2022 biennial report on safety and interoperability (available at https://www.era.europa.eu/content/report-railway-safety-and-interoperability-eu-2022_en). The 2024 update of the biennial report will be published by June 2024.

Rail interoperability is often guaranteed by supplying specific rolling stocks, as it is very costly to change fixed installations, such as track gauges; electrification modes (the voltage or type of current used); and signalling systems. Examples of solutions adopted include the following:

- Talgo and CAF trains can change gauge and therefore run on both standard-gauge high-speed lines and conventional lines with an Iberian gauge;
- cross-border Eurostar trains can be powered by four currents – 25 kV alternating current at 50 Hz, 15 kV alternating current at 16.66 Hz, 3 000 V direct current, or 1 500 V direct current – and are fitted with European train control system (ETCS) level 2, French TVM430 and KVB, German LZB and Belgian TBL2 signalling equipment.

Trans-European transport network

The EU's trans-European transport network (TEN-T) policy is an important instrument for the development of coherent, efficient, multimodal and high-quality transport infrastructure across the EU. It covers railways, inland waterways, short sea shipping routes and roads linking urban nodes, maritime and inland ports, airports and terminals.

The TEN-T policy is based on Regulation (EU) No 1315/2013, which is currently being revised in order to make the EU's transport network greener, more efficient and more resilient, in line with the European Green Deal and the sustainable and smart mobility strategy [24].

As set out in the current regulation, the TEN-T consists of two layers.

- The core network includes the most important connections, linking major cities and nodes, and must be completed by 2030. It needs to meet the highest infrastructure quality standards.
- The comprehensive network connects all regions of the EU to the core network and needs to be completed by 2050.

With the revision of the TEN-T regulation, a third layer – the extended core network – should be added as an intermediate milestone, to be completed by 2040.

The TEN-T regulation sets out infrastructure requirements for the EU rail network, with the aim of harmonising operational practices, signalling systems, electrification, the maximum possible length of a train, operating speed, axle load, loading gauges and track gauges.

As described in a recent ERA study [25], a modal shift will not be the result of rail completely replacing other transport modes. On the contrary, goods and passengers will shift to railways because they are better integrated in the wider transport and mobility systems. Therefore, to increase the share of rail freight transport, it is necessary to develop a green transport logistics chain in which the synergies between modes of transport are optimised. The transport of goods requires simple and efficient transfer/trans-shipment from road to rail [26], as well as from vessels to railways in ports. Meeting this requirement would enable the railway sector to become fully part of the global logistics chain for container traffic. In this context, Annex I of the TEN-T regulation provides a map of ports and rail–road terminals in the TEN-T (Figure 18), and Annex II lists them.

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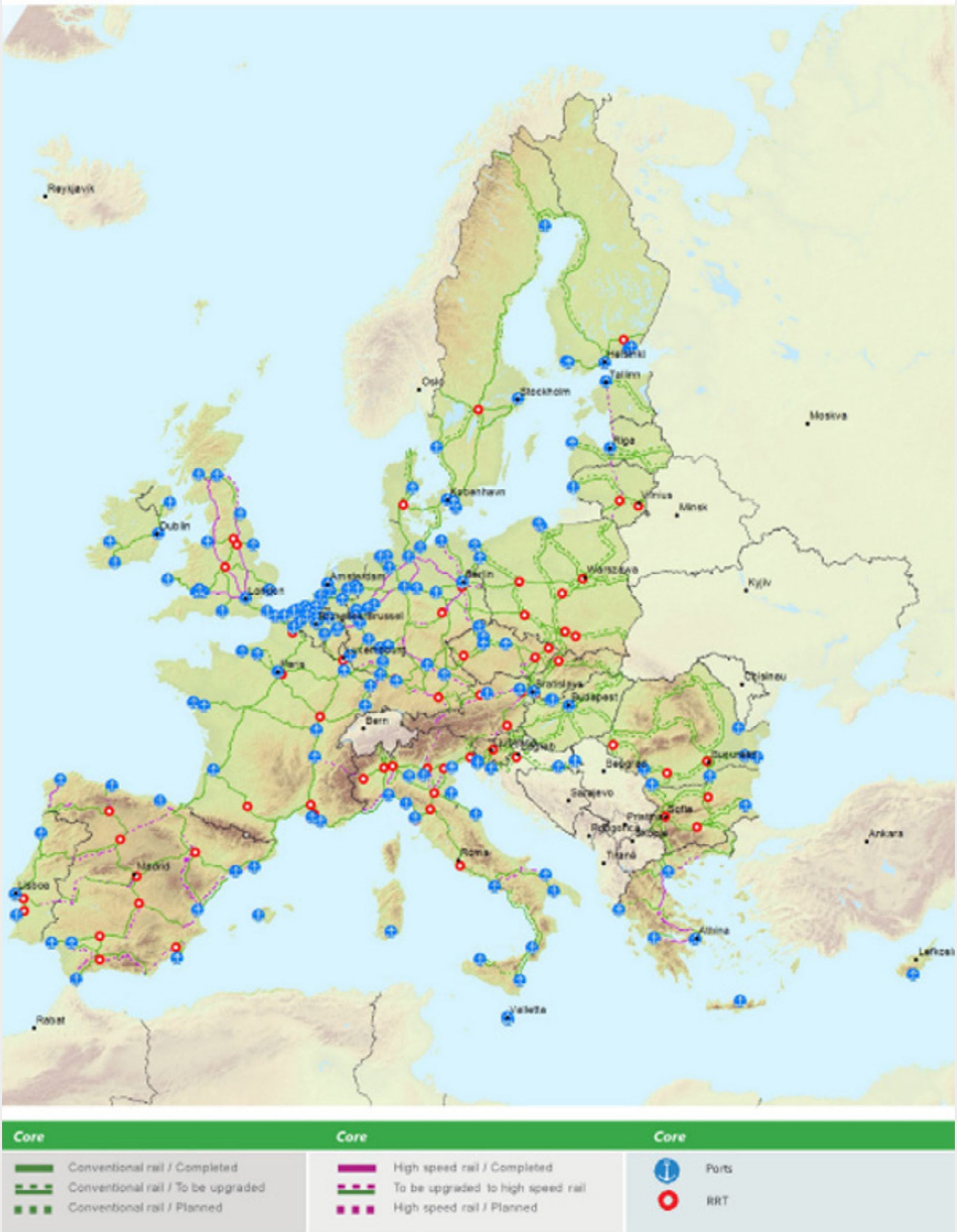
[24] The revised TEN-T regulation should put the transport sector on track to cut its GHG emissions by 90 %. See https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t/ten-t-revision_en.
[25] https://www.era.europa.eu/content/era-report-fostering-railway-sector-through-european-green-deal-part-2-freight_en.
[26] https://ferrmed.com/wp-content/uploads/2023/11/FERRMED-study-summary.pdf.

Figure 18: Map of the ports and rail–road terminals of the core network



Source: Annex I to the TEN-T regulation (EU) No 1315/2013).

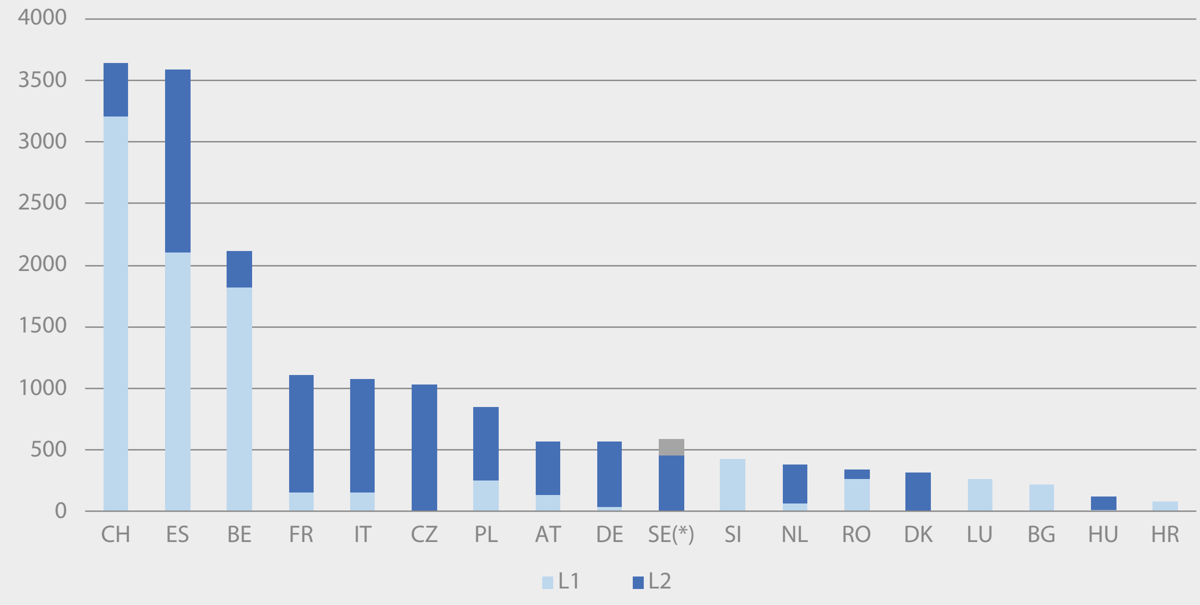
Finally, a recent report (27) from the European Commission provided a comparative evaluation of trans-shipment technologies for intermodal transport and their costs; task 3 of that study aimed to identify the intermodal terminals as well as the TEN-T core network corridor (CNC) infrastructure and corresponding capacity limitations for each combination of trans-shipment technologies and loading units. Based on the Rail Facilities Portal (28) set up by the European Commission and other organisations, the report identified 1 028 intermodal rail terminals in the EU and Switzerland (and their locations and characteristics).

Trackside deployment of the European rail traffic management system

The ERTMS is intended to replace the many incompatible systems currently used by European railways. It provides an interoperable rail network in Europe, and additional benefits in terms of operational efficiency, capacity and safety. Although ideally all core/comprehensive networks (29) in the EU would be equipped with the system, emphasis has been put on nine CNCs, with a view to maximising the return on investment. The long-term target adopted by the European Commission is to have the whole core TEN-T equipped with the ERTMS by 2030 and the whole comprehensive network equipped by 2050.

The deployment of the ETCS in the EU rail network has been slow so far (Figure 19); deployment varies considerably among Member States (reflecting national rail transport policies and investment priorities), and only a few of them have deployed the system on a significant length of lines and/or in a significant part of their network (30).

Figure 19: Length of railway lines equipped with ETCS (km) by ETCS level, EU-27 and Switzerland, end of 2023



NB: L1, level 1; L2, level 2.

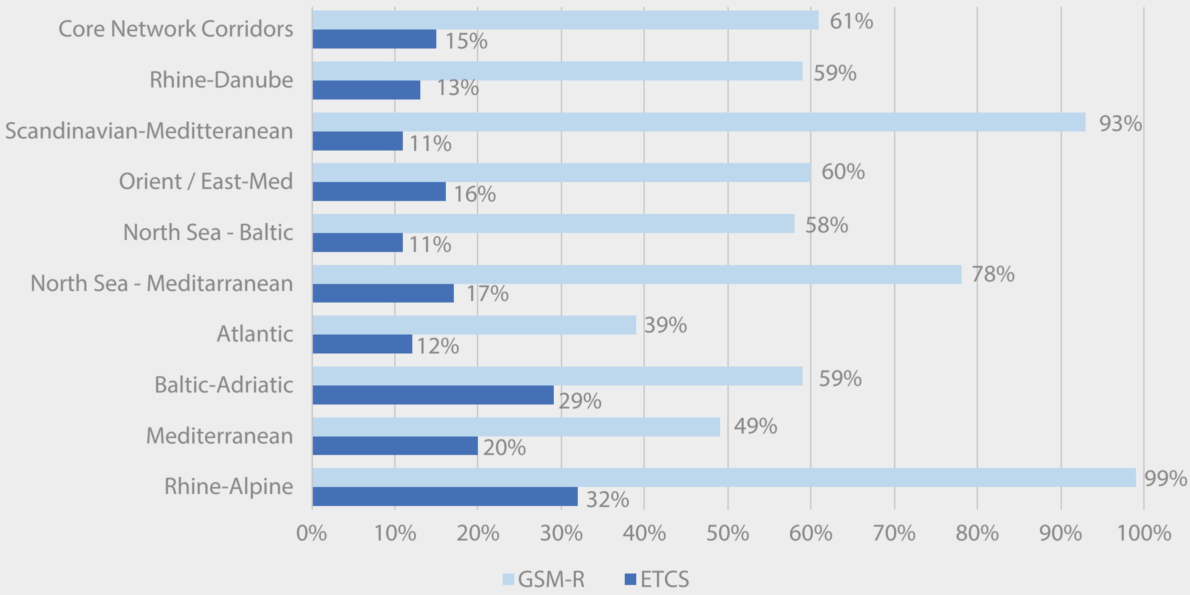
(*) Grey histogram for Sweden refers to an ERTMS regional solution without a train integrity management function implemented on low-traffic lines.

Source: ERA, Register of Infrastructure.

(27) https://op.europa.eu/en/publication-detail/-/publication/d37790ea-b6ef-11ec-b6f4-01aa75ed71a1.
(28) https://railfacilitiesportal.eu.
(29) See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02013R1315-20230709.
(30) See the second work plan (2022) of the European Coordinator for ERTMS (available at https://transport.ec.europa.eu/document/download/275dd7bb-ddad-462a-98aa-61da347351e0_en?filename=ERTMS%20work%20plan%20-%20second%20edition_%20final%20version_20220902.pdf) and ERA's 2022 biennial report on safety and interoperability (available at https://www.era.europa.eu/content/report-railway-safety-and-interoperability-eu-2022_en).

Progress has also been uneven among CNCs, with a substantially greater effort needed to meet the European deployment plan targets. ERTMS deployment on the CNC network had reached 15 % for the ETCS and 61 % for the global system for mobile communications – railway (GSM-R) at the end of 2023; progress was uneven among individual corridors, with the ETCS operational on around 32 % of the Rhine–Alpine corridor and 29 % of the Baltic–Adriatic corridor, compared with 11–20 % of other corridors (Figure 20).

Figure 20: Deployment of the ERTMS (the ETCS and the GSM-R) on CNCs, end of 2023



Source: European Commission, Directorate-General for Mobility and Transport, Tentec information system.

2. Environmental impacts of rail transport

A. Noise and vibration

Noise

According to the UN environmental noise guidelines for the European region ([31]), noise is one of the most important environmental risks to health and continues to be a growing concern among policymakers and the public alike. Exposure to noise can have auditory and non-auditory effects. Through direct injury to the auditory system, noise leads to auditory conditions such as hearing loss and tinnitus. Noise is also a non-specific stressor that has been shown to have an adverse effect on human health, especially following long-term exposure.

Environmental noise is a major issue, considering that at least 20 % of the European population live in areas where traffic noise levels are harmful to physical and mental health and well-being ([32]). Although rail transport is acknowledged as the most sustainable mode of mass transport, noise emissions are a major concern.

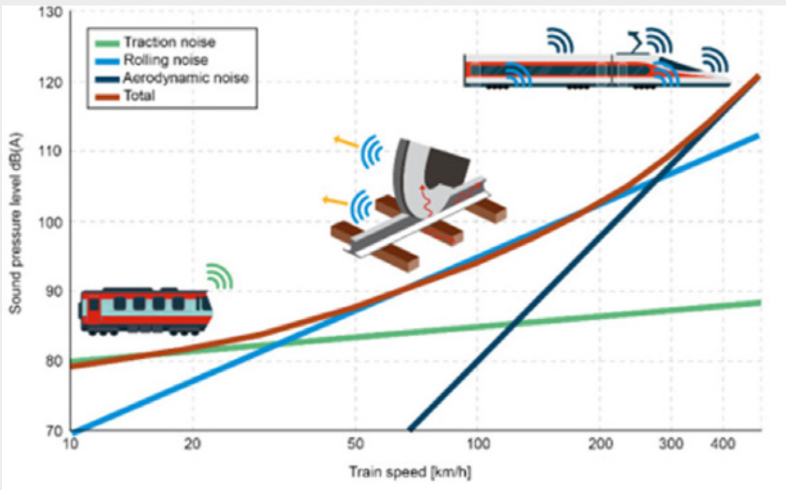
Railway noise ([33]) has three main sources (Figure 21):

- the rolling or pass-by noise due to the mechanical interaction between the rail and the wheel when the rail vehicle is rolling;
- the traction noise deriving from, for example, electric braking, starting and operating a diesel engine or traction components such as compressors;
- the aerodynamic noise created by the airflows around the train.

On specific segments of the railway infrastructure, such as bridges, or at the exit and entrance of tunnels, additional noise emissions can be identified ([34]).

At a given location, the noise level is dependent on both the train type and the distance from the railway track ([35]). For instance, the squealing noise on curves in the track spreads up to 10 m from the track, although it may not occur along the entire length of a curve ([36]).

Figure 21: Sources of railway noise as a function of driving speed, 2021



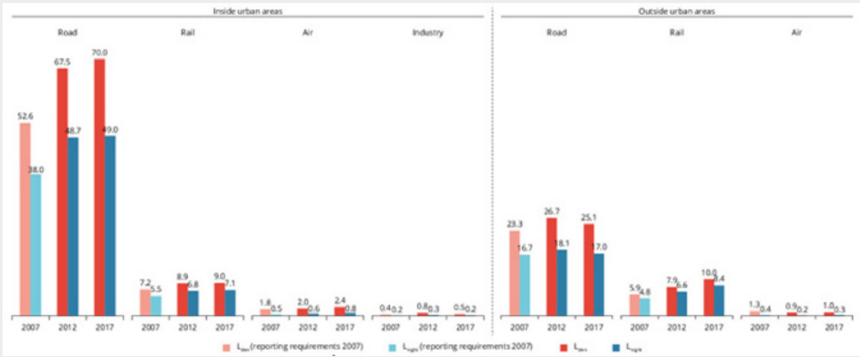
Source: UIC (2021), *Railway Noise in Europe – State of the art report*, Paris.

([31]) https://www.who.int/europe/publications/i/item/9789289053563.
([32]) EEA (2019), *Environmental Noise in Europe – 2020*, Publications Office of the European Union, Luxembourg.
([33]) https://www.sciencedirect.com/book/9780080451473/railway-noise-and-vibration#book-description.
([34]) Zhang, X. and Jonasson, H. G. (2006), 'Directivity of railway noise sources', *Journal of Sound and Vibration*, Vol. 293, Nos 3–5, June 2006, pp. 995–1006.
([35]) https://www.extrica.com/article/14612/pdf.
([36]) https://uic.org/IMG/pdf/railway_noise_in_europe_state_of_the_art_report.pdf.

Railways covered as part of the obligations of the environmental noise directive (END) ([37]) are those with more than 30 000 passages a year. In the EU, there are approximately 39 000 km of major railways covered under the END for which the population's exposure to noise needs to be assessed. Furthermore, the END requires the assessment of noise from non-major railways within urban areas with more than 100 000 inhabitants. However, the END does not cover populations exposed to levels of noise below 50 dB during the night (L_{night}) and 55 dB during the day, evening and night (L_{den}).

The main source of noise pollution in both urban and non-urban areas is road traffic. According to the latest (2017) noise-mapping data, more than 95 million people in the EU are affected by road noise levels of 55 dB L_{den} or more, and more than 65 million are affected by levels of 50 dB L_{night} or more (Figure 22). Noise from railways and aircraft has a much lower impact on the overall population, but both are significant sources of local noise pollution.

Figure 22: Estimated number of people (millions) exposed to harmful noise levels based on the number exposed above the END thresholds (i.e. 55 dB L_{den} and 50 dB L_{night}), EU-27



Source: EEA (2021), 'Exposure of Europe's population to environmental noise' (https://www.eea.europa.eu/en/analysis/indicators/exposure-of-europe-population-to-noise).

Analysing data at the national level, the population exposed to high noise levels (equal to / higher than 55 dB) in areas covered under the 2017 END varies both among countries and among modes of transport.

As opposed to road transport, the proportion of the population exposed to rail transport noise inside and outside urban areas varies to a lesser extent, from 0 % (outside urban areas in Greece, Croatia and Lithuania) to 6.6 % (in Austria) (figure 23). The variability among countries may be due to the noise-mapping methods and approaches to estimating exposure ([38]), the density of transport networks, the completeness of reporting and internal policies related to noise management.

([37]) A map for the 33 member countries of the European Environment Agency (EEA-33) areas is available at https://www.eea.europa.eu/data-and-maps/figures/eea33-coverage.

([38]) For rail transport, RMR (2002) (SRM II), Common Noise Assessment Methods in Europe (2015), Vorläufigen Berechnungsmethode für den Umgebungslärm an Schienenwegen, Nord2000, the Nordic Prediction Method (1996), ONR 30511, NMPB-Routes-2008 and SKM2.

Figure 23: Share of countries' total populations exposed to L_{den} ≥ 55 dB in areas covered by the END (%), 2017

	Inside urban areas				Outside urban areas		
	Road	Rail	Air	Industry	Road	Rail	Air
Austria	24.2	6.6	0.1	0.1	8.2	5.7	0.1
Belgium	14.0*	1.0*	0.6*	0.2*	8.6	2.2	0.6*
Bulgaria	28.8*	0.6*	0.1*	0.0*	1.5		**
Croatia	7.7	0.6	0.0	0.0	2.8	0.0	
Cyprus	49.2*	3.2*	0.9*	1.0*	4.7*		
Czechia	16.7	0.7	0.1	0.0	6.9	1.8	0.1
Denmark	18.5	0.5*	0.1*	0.0*	5.0	1.5	0.0*
Estonia	22.7	0.5	0.2	0.2	0.5		
Finland	8.8	1.6	0.1*	0.0*	2.1	0.6	0.4
France	23.5*	3.6*	0.7*	0.2*	9.8	3.9	0.0*
Germany	6.9*	3.7	0.7	0.1*	3.3	4.0	0.4
Greece	7.9*	1.3*	0.4*	0.1*	0.2*	0.0*	0.0*
Hungary	16.4	1.3	0.0	0.0	1.8	0.9	0.3
Iceland	16.6		0.5*	0.2			0.5
Ireland	14.4	0.6	0.6		4.8	0.3	0.0
Italy	13.7*	0.9*	0.7*	0.1*	12.0*	3.3	0.3*
Latvia	27.0	2.0	0.0	0.7	1.2	0.1	0.1
Liechtenstein					11.4*		
Lithuania	26.3	0.4	0.4	0.3	0.8	0.0	
Luxembourg	24.5	1.5	10.1		11.2	3.3	1.1
Malta	22.4		1.9	0.0	3.7		
Netherlands	19.3	1.3	0.4	0.3	1.0	0.5	0.0
Norway	15.2*	2.2*	0.2*	0.0*	2.6*	0.2	0.1*
Poland	11.6	0.6*	0.1	0.1*	5.7	0.5	0.0
Portugal	5.2	0.4	0.9	0.0	8.6*	1.0	1.3
Romania	13.3*	1.5*	0.2*	1.2*	1.6*	0.1*	0.0*
Slovakia	6.7*	2.4*	0.0*	0.0*	2.9*	2.0*	
Slovenia	9.8	1.2		0.0	5.5	1.1	
Spain	24.8*	1.1*	0.2*	0.2*	4.2*	0.7*	0.3
Sweden	13.2	2.9	0.2*	0.0	3.3	2.7	0.2
Switzerland	30.6	3.4	1.1	0.2*	5.1	2.4	0.0
United Kingdom	14.5	1.9	1.5	0.2	6.5	0.7	0.2*
EEA-33	15.5*	2.0*	0.6*	0.2*	5.9*	2.1*	0.2*

* Data totally or partially estimated; ** Could not be estimated

Percentage of the population exposed to L_{den} ≥ 55 dB

0 50

(*) Data totally or partially estimated.

(**) Could not be estimated.

NB: 'Inside urban areas' means roads, railways, airports and industries inside urbanised areas – called agglomerations – with a population exceeding 100 000 inhabitants and a population density such that the Member State considers it to be an urbanised area. 'Outside urban areas' means major roads with more than 3 000 000 passages/year, major railways with more than 30 000 passages/year and major airports with more than 50 000 movements/year. EEA-33, 33 member countries of the EEA.

Source: EEA, *Environmental Noise in Europe – 2020*, Publications Office of the European Environment Agency, Luxembourg.

To provide a further level of data disaggregation, thanks to the END ([39]), Figure 24 shows the population's exposure to railway noise in Europe during the average day, provided by the Noise Observation and Information Service for Europe (NOISE) of the European Environment Agency (EEA) ([40]). In particular, the interactive map displays the number of

([39]) The END requires EU countries to prepare and publish noise maps and noise management action plans every 5 years for agglomerations with more than 100 000 inhabitants; major roads (those that accommodate more than 3 million vehicles a year); major railways (those that accommodate more than 30 000 trains a year); and major airports (those where there are more than 50 000 take-offs or landings a year, including small aircraft and helicopters).

([40]) It is worth mentioning that data are also available for the average L_{night} at https://eea.maps.arcgis.com/apps/MapJournal/index.html?appid=be745f206c7b4b9fa269f225c6388aec&embed=true. The NOISE population exposure data are based on strategic NOISE maps constructed using reports from the EEA's member countries, in accordance with the END.

people exposed to noise from major railways (travelled by more than 30 000 trains a year) for agglomerations with more than 100 000 inhabitants. Another source of variability can be seen at the subnational level within the same country, showing that some countries are affected more than others.

Figure 24: Average exposure to railway noise in Europe over a day (L_{day}), 2024

Source: EEA, NOISE; data were extracted from the EEA's European Climate and Health Observatory website (https://climate-adapt.eea.europa.eu/en/observatory) on 15 March 2024.

Exposure to railway noise is detrimental to the health and well-being of millions of people in Europe, with those living in residential communities in the vicinity of railways particularly affected. These impacts can include annoyance, sleep disturbance, ischaemic heart disease and even premature death ([41]).

Figure 25 presents data at the European level corresponding to the estimated health impacts of railway noise in Europe, taking into account people living above the END reporting thresholds (i.e. above 55 dB L_{den} and 50 dB L_{night}). In reality, more people may be exposed to unhealthy levels of railway noise than those who can be assessed with the current END thresholds, and it is worth noting that the World Health Organization Regional Office for Europe currently recommends reducing noise levels to 54 dB L_{den} and 44 dB L_{night} for rail traffic ([42]).

According to END-related data reported by Member States, the main health impacts of railway noise are annoyance and sleep disturbance, with an estimated 3.1 million people experiencing high annoyance due to long-term exposure to railway noise and 1.6 million experiencing frequent sleep disturbance. It is estimated that rail noise contributes to 5 600 cases of ischaemic heart disease and 1 500 premature deaths every year (Figure 25).

([41]) WHO Europe (World Health Organization Regional Office for Europe) (2018), *Environmental Noise Guidelines for the European Region*, Copenhagen (https://www.who.int/europe/publications/i/item/9789289053563).
([42]) WHO Europe (2018), *Environmental Noise Guidelines for the European Region*, Copenhagen (https://www.who.int/europe/publications/i/item/9789289053563).

Figure 25: Estimated numbers of people suffering from various health outcomes due to railway noise, EU-27, 2017

Source: Provided by the EEA. Personal communication, email, April 2024

Vibration

Vibration (43), as well as noise, is an environmental and human health concern; both play an important role in lifespan and comfort in urban areas. Although vibration caused by passing trains is mostly far too weak to cause damage to buildings, it has significant effects on people living near railways, causing annoyance or concern.

As reported by the International Union of Railways (UIC) (44), there are different perceptible effects of ground vibration: the structural vibration of a building in response to the ground vibration; and ground-borne noise, which is re-radiated noise inside buildings due to the structural vibration of their surfaces. Moreover, there is a broad range of indicators for calculating the strength of vibration, making it difficult to compare them.

While there is consolidated literature and a homogeneous legal framework on noise, those on vibration have ample room for improvement. In fact, very few countries require compliance with certain vibration thresholds in the railway system. Furthermore, the introduction of monitoring and/or compliance with specific vibration thresholds usually occurs, for example, following the construction of new railway infrastructure near the city centre or a change in key service features, such as the traffic volume and train speed of existing tracks.

The importance of this topic also emerges from the analysis of European Community Research and Development Information Service projects dedicated to rail vibration, including projects that are part of the seventh framework programme for research (a total of 25 786 projects, running from 2007 to 2013) (45), Horizon 2020 (a total of 35 387 projects, running from 2014 to 2020) (46) and Horizon Europe (a total of 10 147 projects, running from 2021 to 2027) (47). shift2rail (now Europe's Rail), within its cross-cutting activity category (which is also dedicated to developing methods of predicting overall noise and vibration performance at the system level), has some projects specifically dedicated to vibration (48). Moreover, it is worth mentioning the 2023 Horizon Europe framework programme call for proposals (HORIZON-ER-JU-2023-EXPLR-01) (49) dedicated to noise and ground vibration, whose deadline was on 7 February 2024. In particular, the topics covered include the on-board measurement of rail acoustic roughness, prediction tools, and requirements and specifications for the ground-borne vibration emission of rolling stock. Regarding ground vibration, as existing regulations such as the END do not mandate vibration mapping with a defined methodology or acceptable exposure limits, there are no technical specifica-

(43) Different standards exist in relation to vibration, such as ISO 2631-1:2014, which is often considered a reference for comfort evaluation; ISO 4866, for measuring and processing data with regard to evaluating vibration effects on structures; and ISO 10137:2007, providing the basis for the design of structures and evaluating the serviceability of buildings and walkways against vibration.
(44) UIC (2017), *Railway Induced Vibration: State of the art report* (https://uic.org/IMG/pdf/uic-railway-induced-vibration-report-2017.pdf), p. 12.
(45) Projects are available at https://data.europa.eu/data/datasets/cordisfp7projects?locale=en.
(46) Projects are available at https://data.europa.eu/data/datasets/cordish2020projects?locale=en.
(47) Projects are available at https://data.europa.eu/data/datasets/cordis-eu-research-projects-under-horizon-europe-2021-2027?locale=en.
(48) Furthering improvements in Integrated mobility management (I2M), noise and vibration, and energy in shift2rail; and soil vibration and auralisation software tools for application in railways.
(49) Available at https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-er-ju-2023-explr-01?tenders=false&programmePart=&callIdentifier=HORIZON-JU-ER-2023-01.

tions for interoperability (TSIs) covering the vibration emission of rolling stock, and there is no standardised procedure for measuring vibration emission. The expected output could be used as an input for possible standardisation (European standards) and/or regulation updates (to parts of the END applicable to vibration and, eventually, TSIs).

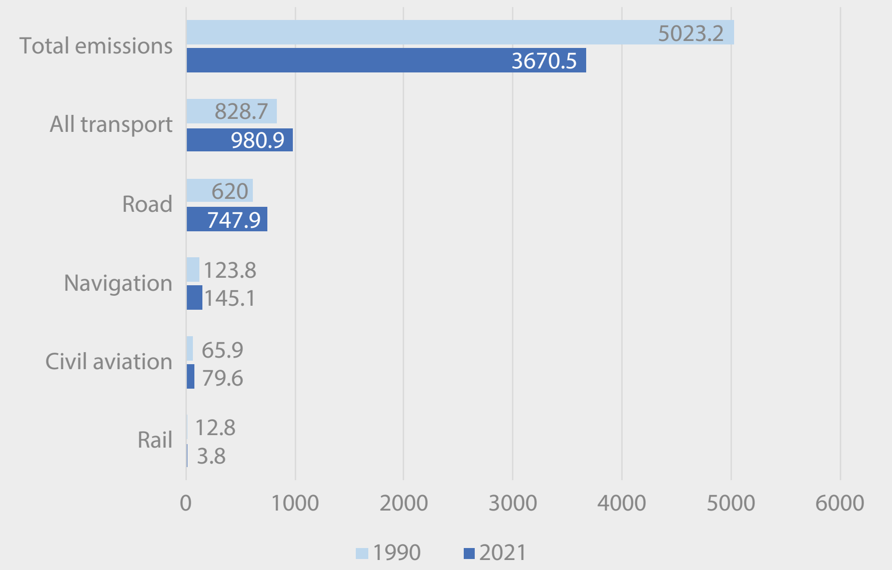
Regarding mitigation measures, as reported by the UIC and the European Rail Supply Industry Association ([50]), in contrast to noise, there are no generally applicable mitigation measures for low-frequency vibration from railways. Therefore, potential measures need to be assessed on a case-by-case basis and taking into account the specific characteristics of the railway system (e.g. track and ground properties). This is also the main reason why forecasting tools for vibration are important, as can be seen from the abovementioned analysis of European projects in which the development of such tools has been the subject of discussion.

([50]) UIC and European Rail Supply Industry Association (2011), *ERRAC Roadmap – WP 01: The greening of surface transport – Towards 2030: Noise and vibrations roadmap* (https://errac.org/wp-content/uploads/2013/06/errac_wp01_roadmap_noise_and_vibration_v06-2.pdf).

B. Greenhouse gas emissions and air pollutants

The trends in the emission of GHGs by the main sectors in the EU between 1990 and 2021 show that transport produces the second highest level of GHG emissions, with slightly less than a quarter of the total EU emissions. More dramatically, even though GHG emissions dropped substantially during the COVID-19 crisis, the transport sector is one of the few sectors for which emissions are increasing. According to the *Statistical Pocketbook 2023*, created by the European Commission's Directorate-General for Mobility and Transport, in absolute terms the transport sector emitted 828.7 million tonnes of carbon dioxide (CO_2) equivalent ($MtCO_2e$) in 1990 out of the 5 023.2 $MtCO_2e$ for total EU GHG emissions, and 980.9 $MtCO_2e$ in 2021 out of 3 670.5 $MtCO_2e$ (Figure 26). Finally, in projections created by the EEA, it was concluded that domestic transport GHG emissions would not decrease to below the 1990 level until 2032, while international transport GHG emissions would continue growing.

Figure 26: Transport emissions ($MtCO_2e$) by mode of transport, 1990 and 2021

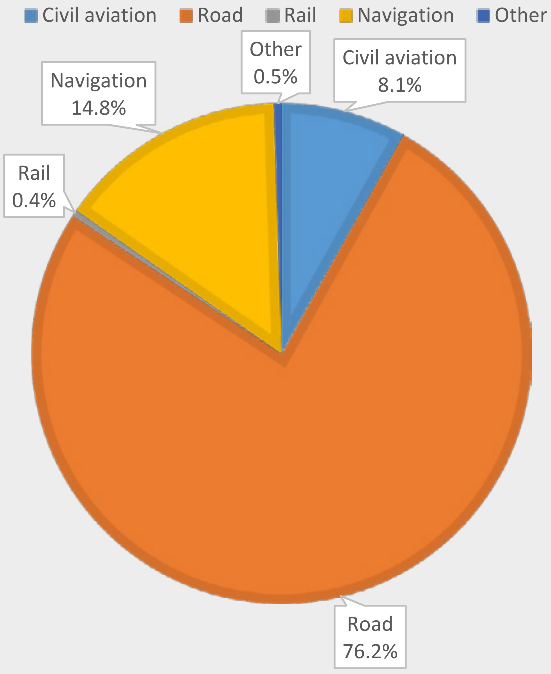


NB: Total civil aviation emissions and total navigation emissions are considered, including international bunkers (international traffic departing from the EU). For railways, indirect emissions from electricity consumption are excluded.

Source: ERA, based on Eurostat (sdg_13_10) and European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

While GHG emissions for all other modes of transport increased between 1990 and 2021, the emissions for the railway sector decreased by approximately 70 %, from 12.8 $MtCO_2e$ to 3.8 $MtCO_2e$. Therefore, in 2021, the railway sector produced 0.4 % of the GHG emissions of the transport sector, while road transport produced 76.2 %, navigation 14.8 % and civil aviation 8.1 % (Figure 27).

Figure 27: GHG emissions by mode of transport as a percentage of total transport emissions, EU-27, 2021



Source: ERA, based on Eurostat (sdg_13_10) and European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

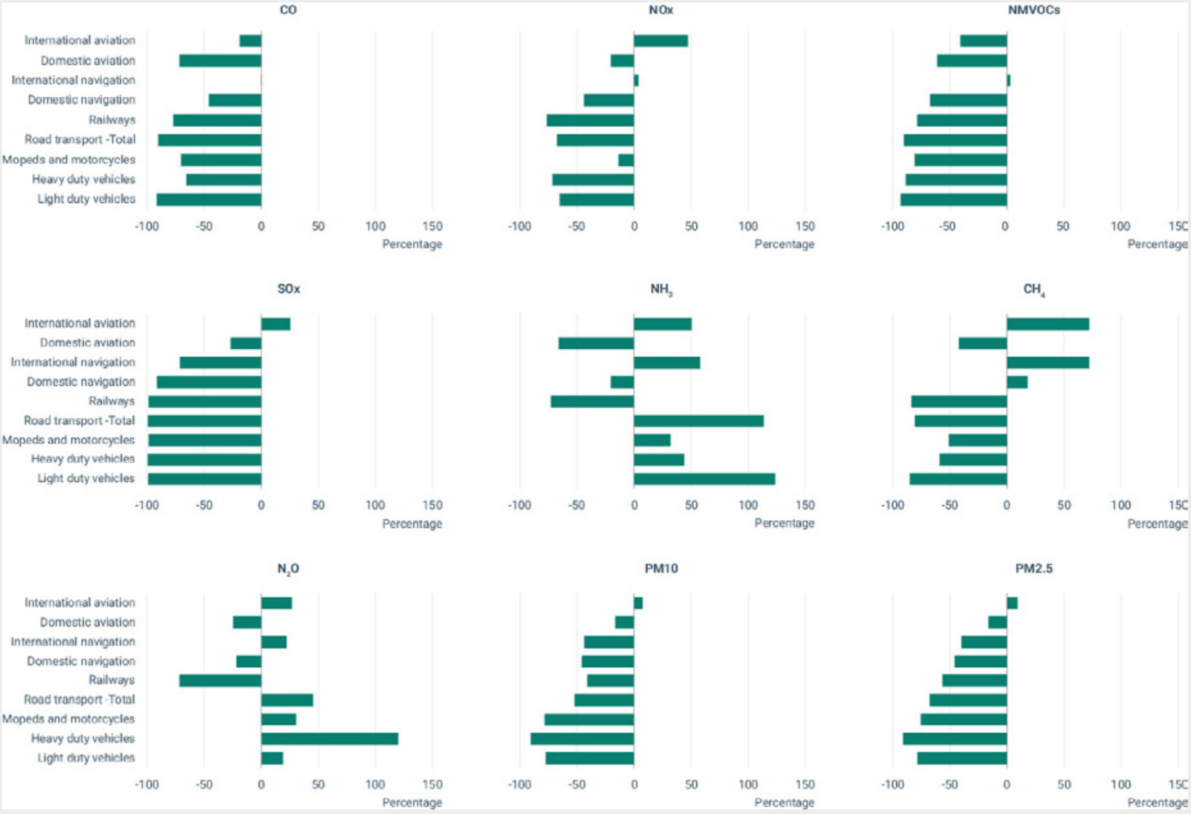
Rail GHG emissions predominantly originate from the use of diesel locomotives, multiple units and shunting engines. These still represent approximately 28 % of the EU railway fleet, as described in Section 1C. However, it must be emphasised that the railway GHG emissions recorded include only the direct emissions. Indeed, indirect GHG emissions from electricity consumption (e.g. emissions from electricity generation from coal) are not considered in the calculation of railway GHG emissions but are included in the emissions of the energy supply sector.

In addition to GHG emissions, air pollutants emitted by the transport sector have an environmental impact, especially on air quality ([51]). Following the adoption of various measures, such as the ambient air quality directives and the establishment of fuel quality requirements, air quality has notably improved over the last two decades. In addition, the European Commission has set an ambitious objective of achieving zero air pollution by 2050 ([52]), which will lead to a continued effort to address air quality issues deriving from transport activities.

According to the EEA, between 1990 and 2020, across the EU-27 the emission of nitrogen oxides (NO_x) by transport decreased by 53 %; sulphur oxides (SO_x) by 77 %; carbon monoxide (CO) by 89 %; and methane (CH_4) and non-methane volatile organic compounds by (PM) 76 % and 90 %, respectively. Between 2000 and 2020, the emission of particulate matter (including non-exhaust emissions) with a particle diameter of 10 µm or less (PM_{10}) and 2.5 µm or less ($PM_{2.5}$) by transport across the EU-27 decreased by 49 % and 55 %, respectively. However, the emission of ammonia (NH_3) increased by 99 % (139 % in 1990–2019), while the emission of nitrous oxide (N_2O) increased by 16 % (38 % in 1990–2019) across the EU-27.

([51]) The Belgian Interregional Environment Agency has provided a global outlook of European legislation on air quality and emissions ceilings, available at https://www.irceline.be/en/documentation/legislation.
([52]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0400&qid=1623311742827.

Figure 28: Variations in the emissions of pollutants (%) from transport by mode, EU-27, 1990–2021



NB: NMVOC, non-methane volatile organic compound.

Source: EEA, (https://www.eea.europa.eu/data-and-maps/figures/variations-1990-2020-2000/fig2-257404-term003-v3.eps/FIG2-257404-TERM003-v3.eps.75dpi.tif/download).

While most pollutant emissions have decreased since 1990, the situation is heterogeneous across transport modes. Road transport has significantly reduced its pollutant emissions, except for NH_3 and N_2O. For aviation, the pandemic in 2020 was almost entirely responsible for the decrease in air pollutants, considering that if calculated for 1990–2019 none of the pollutants decreased apart from non-methane volatile organic compounds and CO. Finally, the railway sector saw all its air pollutant emissions decrease significantly, especially SO_x, NH_3 and CH_4; PM_{10} and $PM_{2.5}$ emissions decreased to a much lesser extent (Figure 28).

C. Land occupancy

Land-take

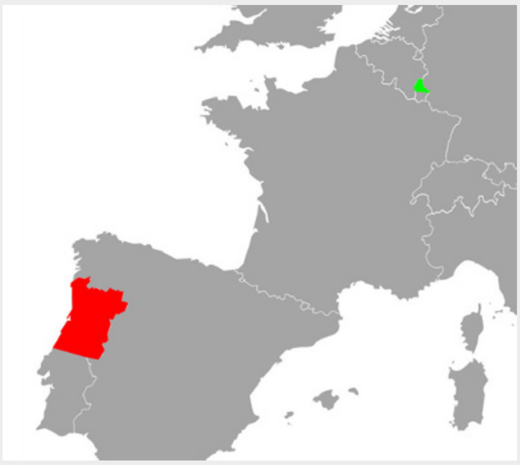
Transport does not only affect the environment in terms of energy consumption and operational pollution; its infrastructure, through land-take, has a permanent and often irreversible impact on the environment. This impact varies depending on the mode of transport. The total land-take of road infrastructure considerably outstrips that of railways and other modes. In 1992, the European Community's road network took 1.3 % of the total land area of the Community, compared with 0.03 % for the rail network ([53]).

In 1993, the EU-12 represented a geographical area of 2 496 174 km^2. With a length of approximately 3 000 000 km, the road network took up 32 450 km^2 of land (approximately the size of Belgium), while the rail network, with 137 236 km of line, took up 749 km^2 of land (approximately twice the size of Malta).

The rail network shrank until the beginning of the 21st century, when it started to stabilise, and comprised 202 596 km of line in the EU-27 in 2021. However, the road network never stopped growing at a relatively fast pace. This is mainly because between 1995 and 2018 the EU-27, Norway, Switzerland and the United Kingdom spent 66 % more of their budgets on extending their motorway networks than extending their railways ([54]). In 15 out of the 30 countries, the lengths of motorways more than doubled. According to the EU statistical pocketbook created by the Directorate-General for Mobility and Transport, the paved road network was 4 473 000 km long in the EU-27 in 2021, with 74 862 km of motorway.

The EU-27 has a geographical area of 4 225 100 km^2. According to Eurostat, in 2021, 125 802 km^2 was used for transport, telecommunications and energy distribution. Based on the same factor used in the 1993 analysis, in 2021–2022, the EU rail network took up 1 172 km^2 of land, 0.027 % of the total land area of the EU and comparable to half the size of Luxembourg. The road network took up 49 193 km^2, 1.16 % of the total EU land area and comparable to half the size of Portugal (Figure 29).

Figure 29: Geographical representation of land used by road networks (in red) and rail networks (in green), 2023



Source: ERA, based on European Commission, Directorate-General for Mobility and Transport (2023), *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

([53]) https://op.europa.eu/en/publication-detail/-/publication/a4c7b3b2-6834-4547-bacf-62133b416f90/language-en.
([54]) T3 Transportation Think Tank and Wuppertal Institute for Climate, Environment and Energy (2023), *Development of Transport Infrastructure in Europe – Exploring the shrinking and expansion of railways, motorways and airports*, Berlin and Wuppertal.

The methodology used to calculate the land-take by these two modes of transport is conservative for railways, as shunting yards are not included in the scope of the rail network; and extremely conservative for roads, as urban streets, the local road network of Germany and parking spaces are not included for lack of data. In addition, the ratio used for 1993 is probably an underestimate ([55]). Considering that 253.3 million passenger cars and 36.5 million commercial freight vehicles are in use in the EU-27, if the infrastructure for parking vehicles were included the total land-take of the road network would increase significantly.

An important measure of land-take is land use in terms of infrastructure needed to move one transport unit, expressed in passengers or tonnes of freight, over a given distance; the land-take transport efficiency is the square kilometres of land used per billion passenger-kilometre / billion tonne-kilometre travelled. Land-take is most efficient for air and sea transport, thanks to the relatively small land-take for a given journey, followed by inland navigation. It is less efficient for rail and least efficient for road.

Table 2: Billion passenger-kilometres and billion tonne-kilometres transported per mode of transport, EU-27, 2021

Passenger transport		Freight transport	
Transport mode	**pkm (billion)**	**Transport mode**	**tkm (million)**
Passenger car	3 742.2	Road	1 862.5
Bus, trolley bus and coach	327	Rail	409.6
Railway	265.2	Inland waterways	136.1
Tram and metro	55.7	Oil pipeline	88.7
Waterborne	13.8	Sea (domestic/intra EU-27)	932.7
Air (domestic/intra-EU-27)	270.1		

NB: pkm, passenger-kilometres; tkm, tonne-kilometres.

Source: ERA, based on Eurostat (tran_hv_ms_frmod and tran_hv_ms_psmod) and European Commission, Directorate-General for Mobility and Transport, *2023 Statistical Pocketbook – EU transport in figures*, Publications Office of the European Union, Luxembourg.

Based on the figures in Table 2, it is possible to calculate the land-take transport efficiency for rail and road. For passenger transport, 12 km^2 of road network is needed to travel 1 billion passenger-kilometres, while 4.4 km^2 of rail network is needed to transport 1 billion passenger-kilometres. Rail is 2.75 times more efficient in land use than road for passenger transport. For freight transport, 26.5 km^2 of road network is needed to travel 1 billion tonne-kilometres, while 2.9 km^2 of rail network is needed to travel 1 billion tonne-kilometres. Rail is nine times more efficient in terms of land use than road for freight transport. If the infrastructure needed to park vehicles were included in the calculation, rail would further increase its land-take transport efficiency compared with road.

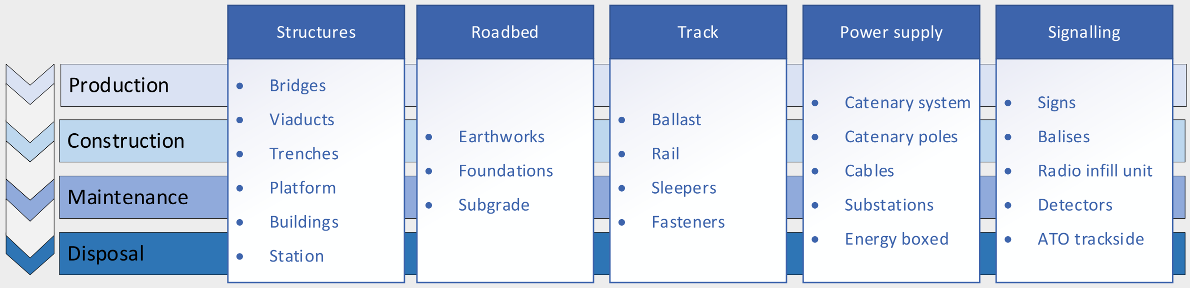
([55]) Several Member States are developing tools to collect much more precise information, which will be available for future editions of this report.

Assessing the greenhouse gas impacts of new infrastructure projects

The total rail network in Europe covers about 202 000 km of lines, 12 000 km of which are high-speed lines. In 2022, this translated into approximately 350 000 km of track ([56]) across the EU and European Free Trade Association countries. These tracks have been built ever since the 19th century. No recent accurate statistics could be retrieved on the number of kilometres of line built each year.

An extensive body of research exists on the GHG impacts of railway infrastructure, although the scope differs in terms of the components that are considered and the life cycle phases assessed. Figure 30 brings together elements of various research studies ([57]) showing key elements to consider when assessing the GHG impacts of railway infrastructure.

Figure 30: Overview of railway infrastructure components



NB: ATO, automatic train operation.

Source: ERA, based on de Bortoli, A., Bouhaya, L. and Feraille Fresnet, A. (2020), 'A life cycle model for high-speed rail infrastructure: Environmental inventories and assessment of the Tours–Bordeaux railway in France', *International Journal of Life Cycle Assessment*, Vol. 25, No 4, pp. 814–830.

Each element depends on raw materials (e.g. concrete, steel and copper) being extracted and produced prior to the construction phase. The challenge in assessing GHG impacts lies in the fact that raw materials may be sourced from around the world. The efficiency with which this process occurs depends on the type of mine and processing plant, as well as the energy sources that are used. A railway line consists of 1 000 subcomponents from various sources, which makes this an arduous exercise. In addition, the annual GHG emissions depend on the economic lifespans of the constructions, but these values vary strongly between countries. Assessing the GHG impacts of existing infrastructure is complicated by the fact that railway infrastructure has been constructed ever since the 19th century, requiring different levels of maintenance and renewal efforts. It is also important to consider that large amounts of the rail network have been removed already, as the European rail network has been considerably shortened. An analysis of historical railway line statistics ([58]) on 20 European countries shows that at least 72 000 km of lines have been removed from the network since 1960. While in the last decade the removal of lines has seemed to decrease, it is important to consider the GHG emissions involved in their disposal.

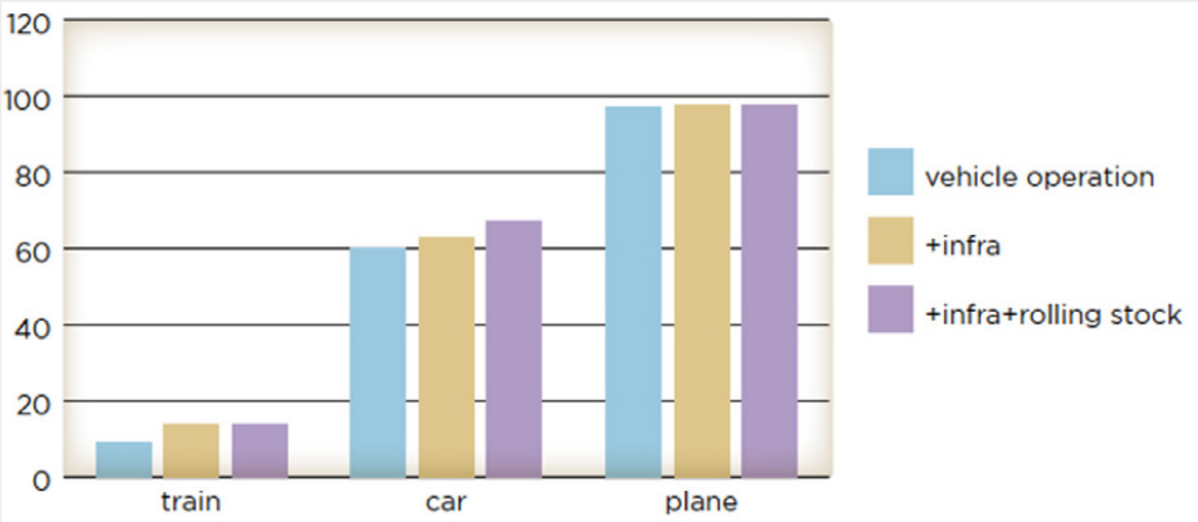
These factors mean that the estimated average annual carbon footprint varies from 50 to 270 tonnes of CO_2 per kilometre of line ([59]). Baron et al. (2016) reviewed 10 methodologies, applying them in three case studies. They concluded that the main factor influencing the GHG impacts of infrastructure is the share of line that consists of bridges and tunnels,

([56]) Eurostat (rail_if_tracks). The 2022 value is 315 000 km of track for the 22 countries for which data are available. It is expected that the number would be approximately 350 000 km if Austria, Denmark, Slovakia and Switzerland were included.
([57]) de Bortoli, A., Bouhaya, L. and Feraille Fresnet, A. (2020), 'A life cycle model for high-speed rail infrastructure: Environmental inventories and assessment of the Tours–Bordeaux railway in France', *International Journal of Life Cycle Assessment*, Vol. 25, No 4, pp. 814–830 Bueno et al., 2017; EEA, 2020; IVL, 2010; Liljenström, 2021; UIC, 2016.
([58]) Eurostat, 2022; IHS, 2013.
([59]) See, for example, Baron et al., 2011, 2016; Bueno et al., 2017; IVL, 2010.

which result in substantially greater CO_2 emissions than the share that does not. If less than 30 % of a line consists of artificial ballastless rail supports, the line's carbon footprint can be estimated to be 50 tonnes of tCO_2/km/year. If more than 30 % of the line consists of support structures, a detailed line-specific assessment is warranted.

Infrastructure-related GHG impacts affect the green performance of rail, but rail remains substantially better performing than road or air transport, as illustrated in Figure 31.

Figure 31: Comparison of CO_2 emissions (kg of CO_2) on a Paris–Amsterdam line by mode of transport, 2014



Source: Operational data from Ecopassenger (2016), *Environmental Methodology and Data Update 2016*, Heidelberg/Hannover.

The results do suggest that the costs of infrastructure in terms of GHG emissions have a comparatively larger impact on rail transport than other modes. Greening rail infrastructure therefore remains an important part of making rail greener. Several measures, such as the use of recyclable sleepers ([60]), should therefore be promoted.

([60]) https://www.railtech.com/infrastructure/2021/03/08/first-recyclable-sulfur-concrete-sleepers-placed-in-belgium/.

D. Nature conservation and biodiversity

Context and legal landscape

Without nature, we have nothing. Without nature, we are nothing. Nature is our life-support system ([61]).

The above statement from the UN Secretary-General, António Guterres, at the UN Biodiversity Conference highlights the importance of biodiversity and its current political relevance. Biodiversity can be understood as the biological diversity of species of plants, animals, fungi and microorganisms in our natural world. When biodiversity is preserved and ecosystems are healthy, they can provide clean air; food, through the maintenance of soil fertility and pollination; medicine; and clean water. All of these are essential to human life.

As expressed well by the researchers Anne and Paul R. Ehrlich, 'species are to ecosystems what rivets are to a plane's wing. Losing one might not be a problem, but each loss adds to the likelihood of a disaster' ([62]). However, biodiversity and associated ecosystems can be weakened, and the delivery of these essential elements of life could then be endangered. This poses a severe risk to humans, especially considering the growing worldwide population. In addition, the impact of biodiversity losses on the economic, social and health systems across the world would be tremendous. According to the Organisation for Economic Co-operation and Development summary and synthesis on biodiversity and finance, a global estimate suggests that ecosystem services provide benefits of USD 125 trillion–140 trillion per year, which is more than 1.5 times the global GDP ([63]).

Given the importance of biodiversity, many countries and international organisations have looked at the endangerment of biodiversity and proposed ways to protect it, such as new legislation, public–private partnerships and consumer sensitisation. The EU has also focused on the topic of biodiversity since its competencies were expanded to include environmental ones. For instance, it adopted the habitats directive ([64]) in 1992, which aims to protect more than a thousand species and 230 habitat types, to halt their decline and enable their long-term recovery. In addition, the EU developed Natura 2000, which is a network for nature protection across the EU. In 2022, this programme celebrated its 30th anniversary, and it currently covers over 18 % of the EU's land and sea territories ([65]). More recently, in 2020, the EU published its biodiversity strategy for 2030, which aims to reinforce resilience to the adverse impacts of climate change, such as forest fires, food insecurity and disease outbreaks. It has committed to, by 2030:

- enlarging the area covered by Natura 2000;
- launching an EU nature restoration plan;
- introducing measures to:
  - enable the necessary transformative change (e.g. funding and better governance),
  - tackle the global biodiversity challenge.

When it comes more specifically to railways, their development and operations are expected to consider the relevant legislation and minimise their impact on biodiversity. For instance, the environmental impact assessment directive (Directive 2011/92/EU) ([66]) specifies that 'Member States shall adopt all measures necessary to ensure that, before consent is given, projects likely to have significant effects on the environment by virtue, inter alia, of

([61]) UN Secretary-General, 'Secretary-General's remarks at the UN Biodiversity Conference – COP15' (https://www.un.org/sg/en/content/sg/speeches/2022-12-06/secretary-generals-remarks-the-un-biodiversity-conference-%E2%80%94-cop15).
([62]) https://www.bbc.com/news/science-environment-48059043.
([63]) https://www.oecd.org/environment/resources/biodiversity/Executive-Summary-and-Synthesis-Biodiversity-Finance-and-the-Economic-and-Business-Case-for-Action.pdf.
([64]) https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en.
([65]) https://environment.ec.europa.eu/topics/nature-and-biodiversity/natura-2000_en.
([66]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32011L0092.

their nature, size or location are made subject to a requirement for development consent and an assessment with regard to their effects'. The construction of lines for long-distance railway traffic is also considered in the aforementioned directive ([67]). Another, more recent, example of legislation is the Recovery and Resilience Facility regulation ([68]), which sets out the facility's aims and the criteria for receiving funding. The technical guidance produced on the 'do no significant harm' principle under this regulation includes the protection and restoration of biodiversity and ecosystems in its assessment criteria and reinforces the importance of environmental impact assessments.

Additional working groups, such as the Taskforce on Nature-related Financial Disclosures ([69]), will become increasingly essential to enable railway companies to monitor the impact of their efforts and actions on nature. Finally, it is important to note that Member States have developed legislation to protect biodiversity at the national and regional levels.

Adverse effects of railways on biodiversity

The development of transport infrastructure usually increases pressure on the local environment. Researchers in the emerging field of railway ecology analyse the impacts of railways on biodiversity in four main areas: wildlife mortality, habitat loss and the exclusion of species from their habitats, exotic species invasions and barriers to them, and impacts of other environmental disturbances related to railway activities (e.g. the use of chemicals to contain vegetation and avoid/limit fire).

Wildlife mortality is most often due to collisions with trains, followed by electrocution, wire strikes and rail entrapment. The mortality of mammals due to train collisions is significant and can have a major impact especially on endangered species, species with large home ranges and low-density populations, and species with a low reproductive rate. Other animals, such as birds, amphibians and reptiles, are also killed in train collisions.

According to the literature, there are four types of barriers to biodiversity conservation.

- **Physical and behavioural barriers.** Physical barriers are structures preventing species from crossing the railway, whereas behavioural barriers occur when species could cross but do not because of unfavourable environmental conditions or risk.
- **Disturbance.** Traffic noise, vibration, chemical pollution and human presence can affect animals living close to railways. The impacts are divided into those related to siting and construction and those related to the operation of the railway line.
- **Mortality.** This is considered a barrier, as it can directly prevent connectivity among subpopulations or reduce their reproductive success.
- **Habitat loss and fragmentation.** Railway construction can result in habitat loss, as the railway bed is not a suitable habitat for many species. Habitat loss can also happen, for example, when a population's territory is bisected by a railway. Habitat changes can occur in railway corridors, as their verges differ from the surrounding landscapes. These changes can also lead to colonisation by invasive species.

Non-native species are those 'species that are moved inadvertently and that are not specific to the commodities being transported' ([70]) and include many organisms, such as mosquitos, fungi, weeds and bacteria. The dispersal of non-native species has recently been rising as a result of the expansion of the transport network and an increase in the exchange of commodities ([71]). They can compete and hybridise with native species, thus altering ecosystem processes and leading to irreversible changes in the diversity and distribution of terrestrial life. In addition, they can cause indirect damage, and many invasive species are vectors of human diseases.

([67]) It should be noted that Court of Justice of the European Union case-law (Case C-227/01, *Commission* v *Spain*, available at https://curia.europa.eu/juris/liste.jsf?language=en&num=c-227/01), establishes that track duplication should be considered to be building a new line and as such requires an environmental impact assessment.
([68]) https://eur-lex.europa.eu/EN/legal-content/summary/european-union-recovery-and-resilience-facility.html.
([69]) https://tnfd.global/.
([70]) https://link.springer.com/book/10.1007/978-3-319-57496-7.
([71]) https://www.sncf-reseau.com/fr/travaux/grand-est/le-programme-reeves.

Transport corridors can function as habitats and venues for the dispersal of non-native species. Therefore, prevention and management actions to contain and eliminate non-native species are crucial. An example of a management action is the inspection of cargo and containers, especially when they are of international origin. Railways have been responsible for several biological invasion events. However, to be able to compare the performance of rail with other transport systems in this area, more research must be conducted ([72]).

Railways can also have some positive effects on biodiversity, by helping to protect and attract wildlife and helping the EU to meet its legal commitments to supporting biodiversity. The first positive effect of railways on biodiversity is the diverse and extensive habitats they provide, for example for lizards and snakes. The second is the refuge for sensitive species provided by restricted access to the lineside, which prevents disruption by humans. The third is railways' indirect positive effects on habitats in the landscapes they pass through (e.g. providing protective buffer zones around adjacent wildlife habitats). Furthermore, the rail network can provide habitat corridors connecting different areas ([73]) or even result in an 'edge' effect ([74]), which can, under certain conditions, increase biodiversity (e.g. if a track crosses a monoculture) (Figure 32).

Figure 32: Benefits and adverse impacts of the rail network on biodiversity

Beneficial effects	Adverse impacts
Provision of habitats and refugia to support species	Habitat loss associated with construction and upgrading infrastructure
	Direct collisions of animals with rolling stock
	Collisions of animals with infrastructure such as overhead cables and windows
	Entrapment of small animals between rails and other infrastructure
Restoration and creation of habitats	Habitat degradation due to lack of management / inappropriate management
Buffering adjacent wildlife habitats in the wider landscape	Pollution of air, water, soil (i.e. exhaust gases, wear emissions, accidental hazardous chemicals)
	Disturbance due to light, noise and vibration
Provision of green corridors for connecting habitats ('ecological connectivity')	Fragmentation of contiguous habitat
	Barriers to the movement of wildlife (depending on train frequency)

Source: UIC (2022), *European Railways: Strategy and actions for biodiversity*, Paris.

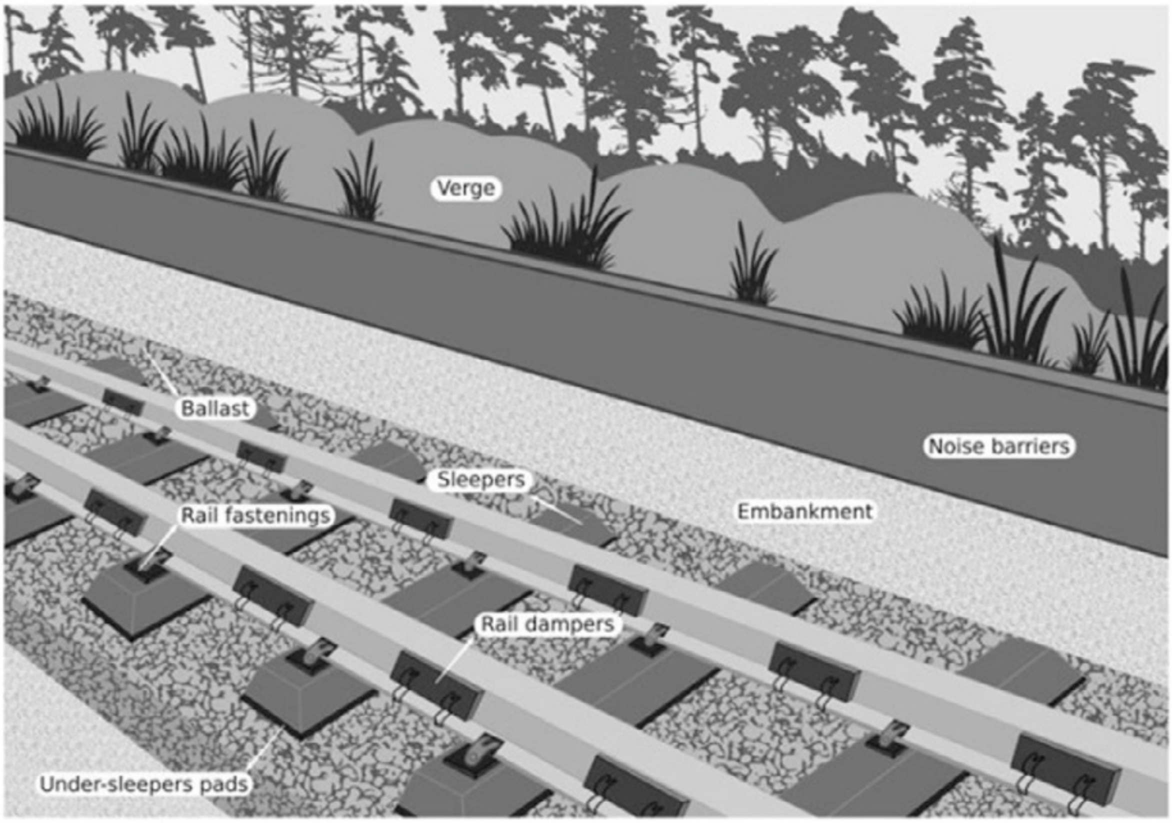
Mitigating the impact of railways on biodiversity

Regarding the reduction of noise, measures could be implemented to decrease the speed of rail vehicles and reduce the intensity of the radiated sound through regular maintenance. Other measures to decrease noise and vibration are rail fastenings, rail dampers,

([72]) https://link.springer.com/book/10.1007/978-3-319-57496-7.
([73]) https://uic.org/IMG/pdf/uic_reverse_strategy_and_actions_for_biodiversity.pdf.
([74]) Change in population structures that occur at the boundary of two or more habitats.

under-sleeper pads and noise barriers. It is important also to consider that the reduction of noise may reduce the ability of wildlife to perceive the arrival of trains, and thus increase the risk of collision (Figure 33).

Figure 33: Examples of noise barriers



Source: UIC (2022), *European Railways: Strategy and actions for biodiversity*, Paris.

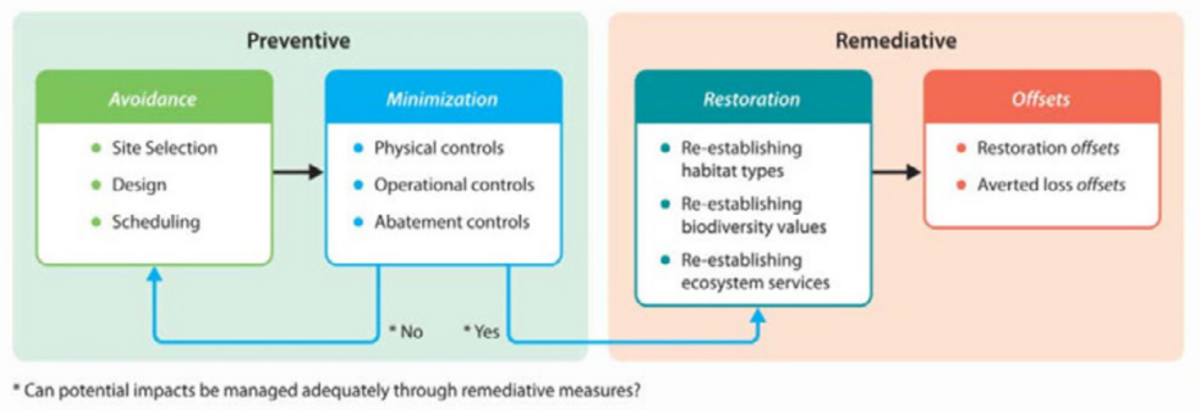
As for soil pollution, a common technique to recycle pollutant components in the surroundings of the rail network is cleaning the ballast. Incinerating, landfilling and recycling the waste are other options. Regarding soil erosion, some common mitigation techniques are planting grass, the use of gypsum, the application of compost/mulch, the use of prefabricated panels and lattice plots, and interception and drainage. In addition, herbicides such as glyphosate are used to manage the vegetation around the railway tracks, which can damage the surrounding environment and biodiversity.

When it comes to habitat fragmentation, railway tracks also create barriers by dividing the natural environment into smaller areas. Items such as fences used to protect the transport network can isolate some species and increase their vulnerability. Some countries have worked on improving the situation by creating wildlife crossings, such as tunnels or bridges, to reduce the impact of transport infrastructure on wildlife.

Evidence is available on the negative effects of noise, light and vibration on insects, amphibians and birds, but further research is needed to understand the effectiveness of the abovementioned measures in reducing the disturbance of wildlife by railways. On a positive note, vegetation on railway verges can overcome noise pollution and attract some birds, reptiles and mammals, partly by providing food availability.

According to a UIC report ([75]), there are four aspects of mitigating the impacts of railways on biodiversity that should be considered when planning any work. These are summarised in Figure 34.

Figure 34: The four levels of mitigating the impacts of railways on biodiversity



Source: UIC (2022), *European Railways: Strategy and actions for biodiversity*, Paris.

The establishment of management plans and collective action are key to protecting and enhancing biodiversity. Mitigating the impact of railways on biodiversity contributes significantly to tackling the climate emergency and biodiversity crisis.

While there is a consensus on the paramount importance of biodiversity for life on Earth, the challenge ahead remains incredibly difficult yet important to tackle. More specifically on railways, it would be essential to gather and consolidate comparable data from railway stakeholders and across Member States.

ERA has contributed to this effort by drafting regulations to reduce the noise emitted by both new and existing rolling stock, but there is still room for many developments and actions. When planning new railway lines, the impact on biodiversity will have to be considered from the start as part of an environmental impact assessment ([76]). For instance, the location of railway tracks can also affect biodiversity, as some areas are more vulnerable and are at a higher risk of biodiversity loss than others. Different solutions can be implemented to allow animals to cross. Considering wildlife tunnels when building new railway infrastructure can also play a role. Railway tracks also contribute to water storage in rural areas and can therefore improve biodiversity, as they can support the restoration of natural habitats in the challenging context of climate change and increasing temperatures globally. In conclusion, a tailored approach considering the location of railway tracks and the types of animals in the surrounding area and their size and behaviour should be considered when developing plans for railway infrastructure.

([75]) https://uic.org/IMG/pdf/uic_reverse_strategy_and_actions_for_biodiversity.pdf.
([76]) https://environment.ec.europa.eu/law-and-governance/environmental-assessments/strategic-environmental-assessment_en.

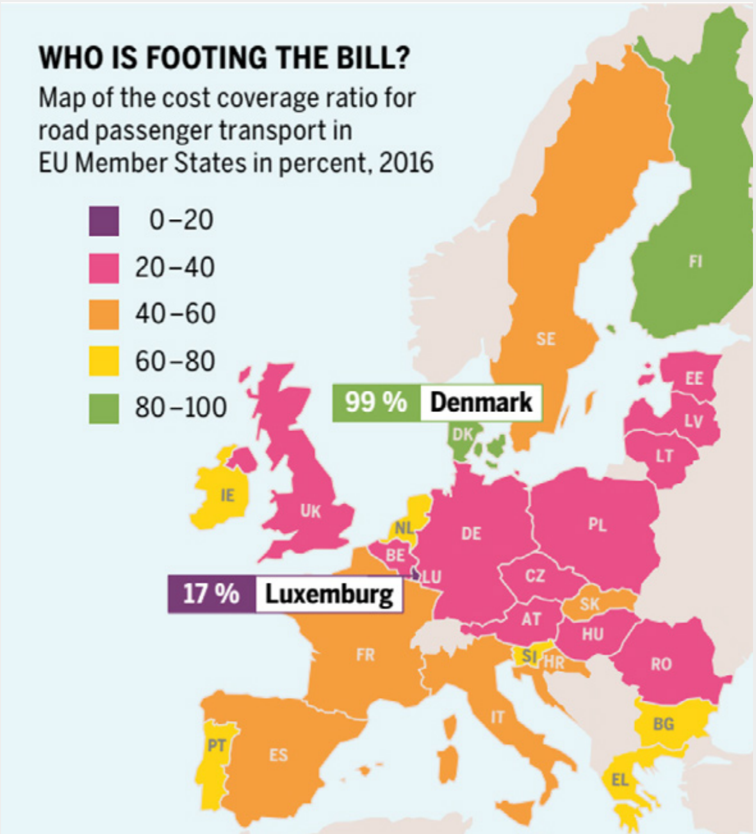
E. Comparison of external costs

External costs of transport are costs generated by transport users and paid not by them but by society as a whole. These costs are borne by third parties, by the general public or by future generations, and they include, for example, damage caused by climate change, air pollution, traffic accidents, noise and congestion.

Practically, the external costs of transport are the difference between the social costs (i.e. all costs to society due to the provision and use of transport infrastructure) and the private costs (i.e. the costs directly borne by the transport user) of transport. Although these costs are caused by mobility, they are not reflected in its price; the market does not provide an incentive to transport users to take external costs into account when taking a transport decision, resulting in suboptimal outcomes. By internalising these costs (through regulation and/or market-based instruments), externalities can be made part of the decision-making process of transport users.

Most users of motorised transport in Europe already pay taxes and charges (energy taxes, taxes for purchasing or owning a vehicle, distance-based tolls, time-based vignettes or urban road-pricing systems, parking fees, etc.). However, when comparing all revenue, taxes and charges with all external costs and infrastructure costs for road passenger transport, only 45 % of the costs were covered on average in the EU-28 in 2021 ([77]). This cost factor significantly varies between Member States, from 17 % in Luxembourg to 99 % in Denmark, based on, for example, their different tax rates (Figure 35).

Figure 35: Cost coverage ratio for road passenger transport



Source: Heinrich-Böll-Stiftung (2021), *European Mobility Atlas – Facts and figures about transport and mobility in Europe*, Brussels.

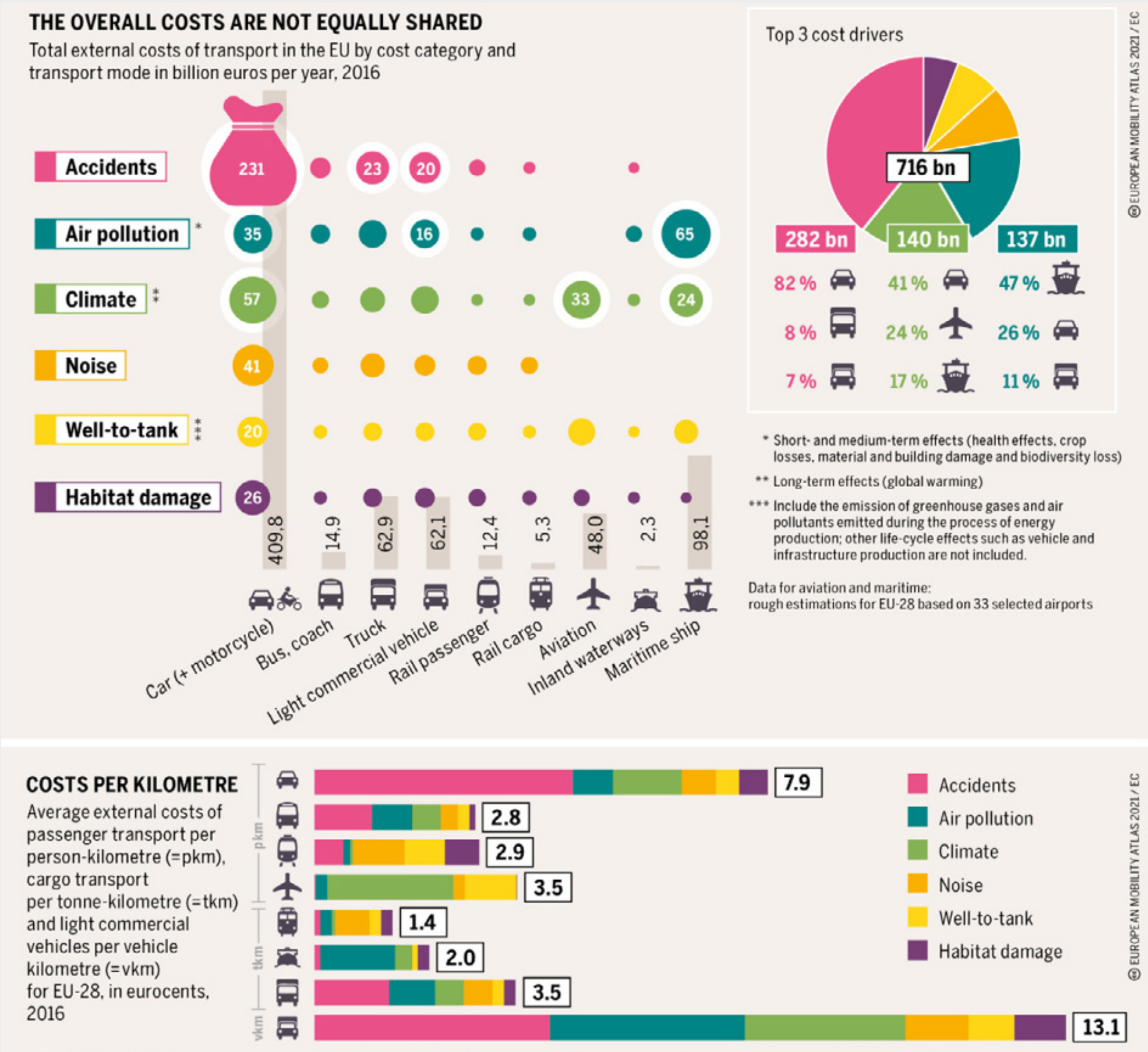
([77]) Heinrich-Böll-Stiftung (2021), *European Mobility Atlas – Facts and figures about transport and mobility in Europe*, Brussels (https://eu.boell.org/sites/default/files/2021-07/EUMobilityatlas2021_2ndedition_FINAL_WEB.pdf).

The internalisation of external transport costs (i.e. by increasing the costs of transport to take externalities into account) is not aimed at punishing people, generating revenue or impeding mobility, and must be performed considering the just transition and social justice. The current transport system is biased and inefficient owing to incorrect prices, resulting in a high level of congestion and severe environmental effects. With correct prices, more environmentally friendly modes of transport may become more attractive.

The total external costs of transport in the EU are not equally shared among transport modes. These differences are evident in the *Handbook on the External Costs of Transport* ([78]) (by a consortium led by CE Delft, commissioned by the European Commission's Directorate-General for Mobility and Transport), for which an update is ongoing. They are also well described and summarised in the related section of the *European Mobility Atlas 2021*.

As is clear from Figures 36–38, rail ranks among the transport modes with the lowest external costs (either in total or per passenger-/tonne-kilometre). The figures are estimated in the handbook based on best practices for the evaluation of externalities.

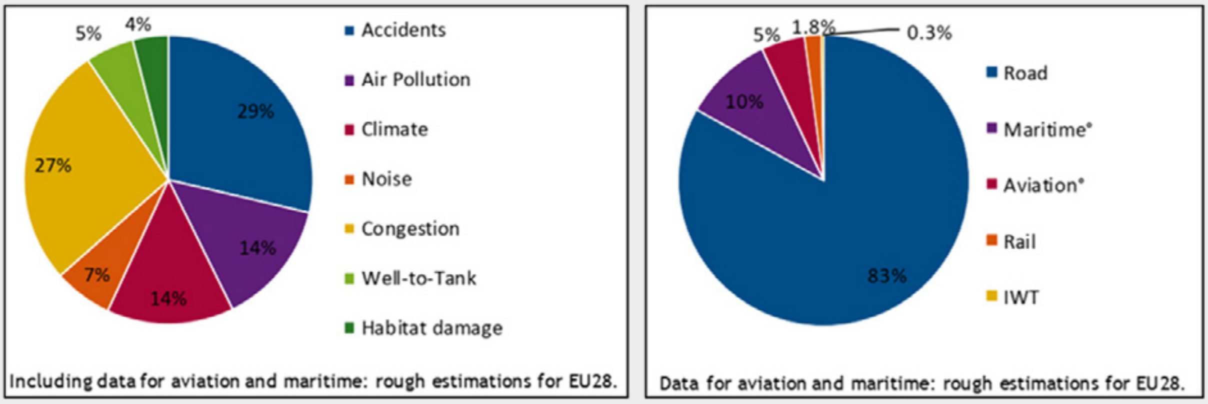
Figure 36: The cost of transport by category and mode



Source: Heinrich-Böll-Stiftung (2021), *European Mobility Atlas – Facts and figures about transport and mobility in Europe*, Brussels.

([78]) European Commission, Directorate-General for Mobility and Transport (2020), *Handbook on the External Costs of Transport*, Publications Office of the European Union, Luxembourg (https://op.europa.eu/en/publication-detail/-/publication/9781f65f-8448-11ea-bf12-01aa75ed71a1).

Figure 37: Share of the external cost by category (left) and mode (right), 2016

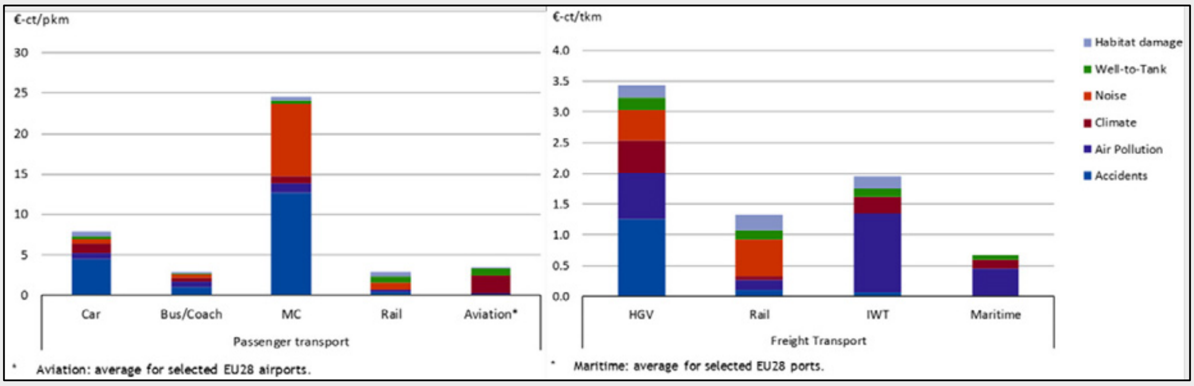


(*) Rough estimations for the EU-28.

NB: The left-hand panel includes data for the aviation and maritime sectors (rough estimations for the EU-28).

Source: European Commission (2020), *Handbook on the External Costs of Transport*, Publications Office of the European Union, Luxembourg.

Figure 38: Average external costs by mode for passenger (left) and freight (right) transport, EU-28, 2016



NB: MC means motorcycle and IWT means Inland waterway transport

(*) Average for selected EU-28 airports.

(**) Average for selected EU-28 ports.

NB: HGV, heavy goods vehicle; IWT, inland waterway transport; pkm, passenger-kilometre; tkm, tonne-kilometre.

Source: European Commission (2020), *Handbook on the External Costs of Transport*, Publications Office of the European Union, Luxembourg.

With regard to environmental costs, all damages as a result of environmental nuisances (e.g. health costs, material damages, biosphere damages and long-term risks) are included in the social costs. The external and social costs are considered the same, except for situations in which some of the social costs are charged and paid for.

As regards accident costs, some of the social costs of accidents are considered internalised by the transport user (as they consider their own accident risk when taking a transport decision) or by insurance. The accident-related damages are estimated based on the damage cost rates. For each EU Member State, the handbook indicates amounts for fatalities as well as minor and serious injuries, which are adjusted to the price level of the country.

Damage costs are also applied for other external cost categories, including air pollution and noise. Noise costs are calculated based on the number of people exposed and on the costs per person exposed. Interesting insights on this externality are provided in a recent UIC study [79]. For the climate costs of transport, avoidance costs are applied – that

[79] UIC (2021), *Railway Noise in Europe – State of the art report*, Paris (https://uic.org/IMG/pdf/railway_noise_in_europe_state_of_the_art_report.pdf).

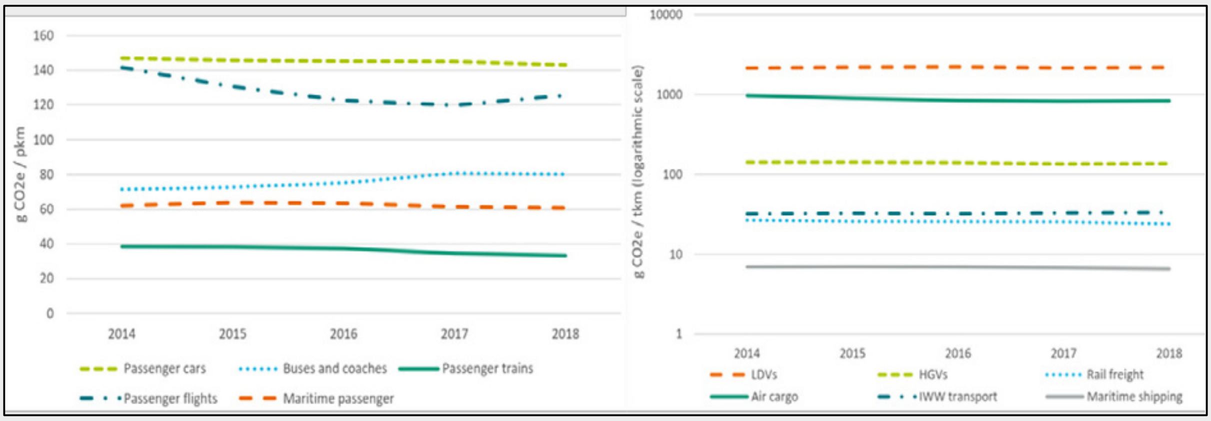
is, the cost rate determines the lowest-cost option for meeting the targets of the Paris Agreement.

Congestion costs arise when a vehicle reduces the speed of other vehicles in a flow of traffic and hence increases their travel time. This externality can be applied to road transport but cannot be expanded to other transport modes, such as rail and air, as they essentially provide scheduled services and are planned based on the allocative capacity of networks and nodes. For congestion costs, only the additional costs to other transport users and society are considered external; own costs (i.e. the costs imposed on the drivers and passengers of the vehicle) are not considered when estimating external congestion costs.

The replacement cost approach is used to estimate the costs of habitat damage – that is, the value of this externality is based on the costs of replacing/repairing the adverse impacts of it.

Some additional interesting insights on the GHG emission efficiency of transport modes (linked to their environmental impacts / externalities) are also provided in a recent study by the Fraunhofer Institute for Systems and Innovation Research and CE Delft commissioned, commissioned by the EEA [80] (Figure 39).

Figure 39: GHG emissions per passenger-kilometre (left) and per tonne-kilometre (right) by transport mode



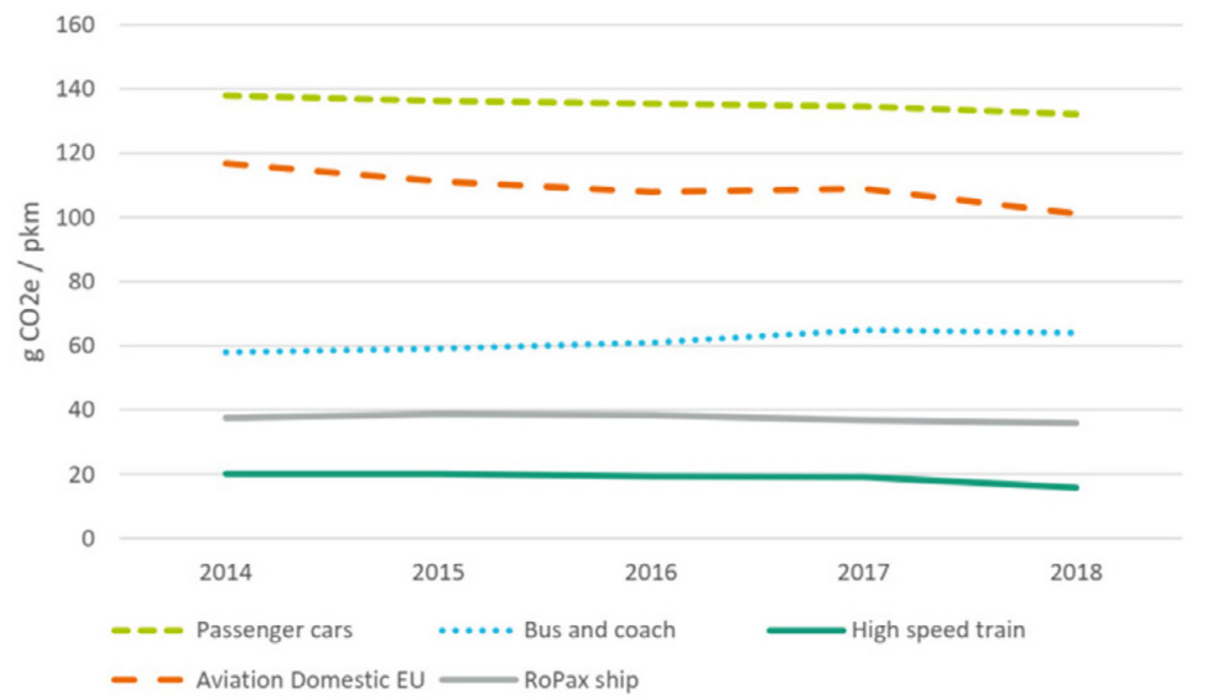
NB: HGV; heavy goods vehicle; IWW, inland waterway; LDV, light-duty vehicle; pkm, passenger-kilometre; tkm, tonne-kilometre.
Source: CE Delft (2020), *Methodology for GHG Efficiency of Transport Modes*, Karlsruhe.

Rail is the most efficient transport mode in terms of GHG emissions per passenger-kilometre (including for long-distance passenger transport – for example, HSR), while in the freight sector specifically it is second after maritime transport.

The efficiency of aviation and rail for passenger transport improved substantially, by 11 % and 13 %, respectively, between 2014 and 2018, while the GHG emissions from car travel declined by only 3 %, and an upward trend is observable for buses and coaches (Figure 40). Freight transport efficiency rates show much greater differences. Improvement rates on GHG emissions per tonne-kilometre from 2014 to 2018 for the EU-27 are highest for air cargo (14 %) and rail freight (11 %). Heavy goods vehicles show a slight improvement, of 3 %, for specific GHG emissions, while emissions from light-duty vehicles increased by 2 %.

[80] https://cedelft.eu/publications/methodology-for-ghg-efficiency-of-transport-modes/.

Figure 40: GHG emissions per passenger-kilometre for long-distance passenger transport by mode of transport



NB: pkm, passenger-kilometre.

Source: CE Delft (2020), *Methodology for GHG Efficiency of Transport Modes*, Karlsruhe.

In conclusion, as reported in a recent ERA study ([81]), rail is the mass transport mode with the lowest GHG emissions and external costs, the highest degree of energy independence (especially if the energy comes from the EU's renewable sources) and the most durable assets.

([81]) ERA (2020), *Fostering the railway sector through the European Green Deal* (https://www.era.europa.eu/content/report-fostering-railway-sector-through-european-green-deal_en).

3. Path to sustainability for railways and transport

A. Measures to reduce railway noise

To reduce the exposure of the European population to railway noise, quieter routes have been created to which specific technical and operational rules are applied. A quieter route means a part of the railway infrastructure with a minimum length of 20 km on which the average number of freight trains operated daily during the night was higher than 12, as defined in national legislation incorporating Directive 2002/49/EC on the assessment and management of environmental noise. On these routes, only freight wagons compliant with Noise TSI requirements will be allowed to be operated from 8 December 2024.

According to Article 5(c)(1) of the EU regulation on the Noise TSI, Member States should provide ERA with a list of quieter routes in a format allowing further processing by the users with IT tools. ERA publishes the quieter routes received in accordance with Appendix D, Section D.1, of the Noise TSI. It also publishes maps illustrating the quieter routes if provided by the Member States and if the Member States have introduced the quieter routes in the Register of Infrastructure. Some Member States do not have quieter routes, such as Bulgaria, Ireland and Greece, and Croatia has not provided data. Finally, in Finland and Sweden, quieter routes will not be applicable until 31 December 2032, and in Baltic states the Noise TSI does not apply to freight wagons.

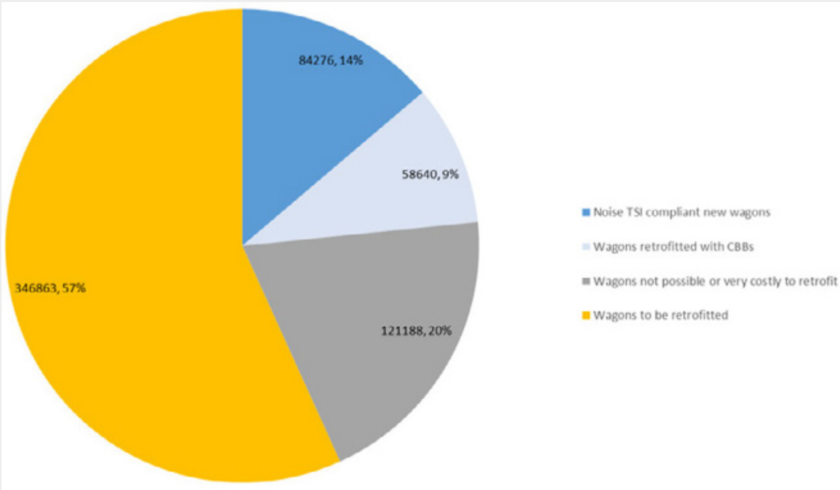
Based on Register of Infrastructure data ([82]), the quieter routes extend to approximately 23 429 km, representing a little more than 11 % of the total EU rail network. However, as these routes contain the main freight corridors, and freight wagons are by nature international, a capillary effect means that the quieter routes have a positive impact on the whole EU network.

In preparation for compliance with quieter routes, the railway sector has made a considerable effort to retrofit freight wagons to make them compliant with the Noise TSI. The Noise TSI facilitates compliance by providing a fast track to retrofit freight wagons with well-proven technical solutions without the need to measure and recertify the retrofitted wagon. These technical solutions consist of replacing the cast iron brake blocks with composite brake blocks or disc brakes, which reduce the pass-by noise level, as they do not increase the wheel roughness as much as the cast iron blocks. The average pass-by noise reduction for a freight wagon if it is retrofitted with composite brake blocks is 8 dB ([83]). Of the two technical solutions, the more cost-effective is replacing the cast iron blocks with composite brake blocks. However, not all freight wagons can be easily retrofitted with composite brake blocks.

The wagons targeted for retrofitting by 2017 comprised 57 % of the EU fleet ([84]). At the time, 58 640 freight wagons had already been retrofitted and 84 276 new wagons were compliant with the Noise TSI (figure 41).

([82]) Data are missing for Denmark and Croatia. For Germany, data are estimates, as they were calculated and not extracted directly from the Register of Infrastructure.
([83]) https://www.era.europa.eu/system/files/2022-10/Recommendation on the amendment of TSI NOISE - Full impact assessment_0.pdf?t=1710421450.
([84]) Including the EU-27, Norway and Switzerland.

Figure 41: Estimated status of Noise-TSI-compliant wagons, EU, Norway and Switzerland, end of 2017

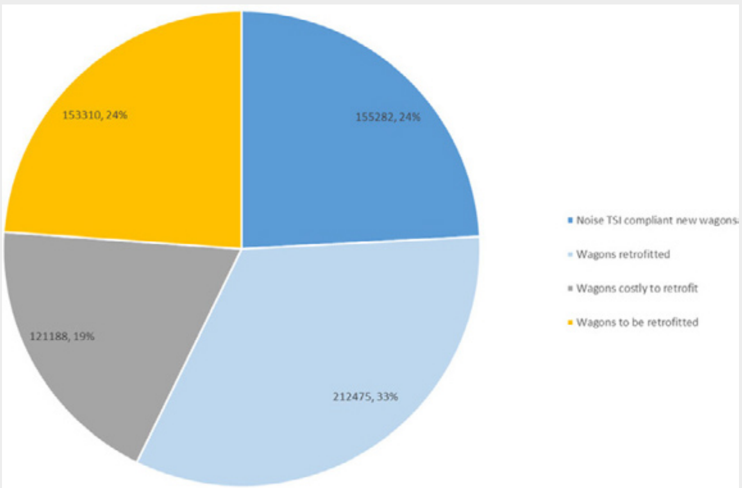


NB: CBB, composite brake block.

Source: ERA, internal resources

The proportion of freight wagons in the EU fleet retrofitted using the Connecting Europe Facility up to 2023 was 33 %. The number of new, TSI-compliant freight wagons is 155 282. Therefore, the number of Noise-TSI-compliant freight wagons represents 57 % of the EU fleet (Figure 42). This percentage is likely to be higher, as many freight wagons have been retrofitted without using the Connecting Europe Facility (e.g. using incentives for supporting the retrofitting provided by individual Member States ([85])). In addition, the retrofitting process has triggered the cleaning up of the wagon fleet, so many freight wagons not used have been decommissioned but are still in the Register of Infrastructure.

Figure 42: Estimated status of Noise-TSI-compliant wagons, EU, Norway and Switzerland, end of 2023



Source: ERA, internal resources

([85]) mobilit.belgium.be/en/rail/professional-railway-transport/grants-and-funding/grant-retrofitting-wagons

At the points in the network where noise has not been reduced enough to achieve the objectives of the END (noise hotspots), additional noise abatement measures involving changes to infrastructure are possible, mainly in urban areas. These include fitting barriers along railway tracks, fitting noise dampeners and acoustic rail grinding.

In the last Noise TSI revision cycle, it was decided that the composite brake blocks must be acoustically certified through the procedure set out in the TSI and meet well-defined limits. In future revisions of the TSI, this acoustic certification will replace the pass-by noise testing of the complete freight wagon.

B. Rail electrification

As indicated in Section 1B, in 2021, 56.1 % of the European rail network was electrified, with a wide variety of electrification rates between Member States, ranging from 2.6 % in Ireland to 96.7 % in Luxembourg. In 2020, approximately 81.6 % of total train-kilometres were operated by electricity-powered trains.

The further electrification of the European rail network has been a major contributor to the reduction of GHG emissions in the railway sector in the last decade. Between 2018 and 2021, more than 2 000 km of lines were electrified. Rail remains the most energy-efficient mode of mass transport. There are no technical obstacles to further electrification, but the costs of upgrading and electrifying the existing rail infrastructure and the expected carbon reduction need to be considered on a case-by-case basis, considering the potential of alternative technologies to power trains.

Although there are no exhaustive data on the amount of investments in the further electrification of the European rail network, several Member States have developed projects or programmes to further electrify tracks. In Germany, the federal government integrated in its coalition agreement from 2021 the objective of achieving a 75 % electrification rate within the German rail network by 2030.

In Belgium, the investment of EUR 50 million in the electrification of the Hasselt–Mol line has allowed the Belgian rail network to reach an electrification rate of more than 90 % (not yet included in European statistics). A study commissioned by the Belgian Federal Public Service Mobility and Transport at the beginning of 2021 concluded that the full electrification of the Belgian rail network would be the best solution in terms of maintenance, energy consumption and achieving the environmental objectives. The use of battery-powered trains could be envisaged in specific situations where the costs of electrifying a line would be too high in relation to the traffic on the line. In addition, at the end of 2022, a public service contract signed with the Belgian National Railway Company and a performance contract signed with Infrabel both set out the objective of eliminating fossil fuel consumption.

In Denmark, the electrification programme of Banedanmark envisages most of the Danish state rail network being electrified between 2014 and 2027. Some 820 km of the state's railway will be electrified (in total, approximately 1 362 km, as most of the sections have double tracks) with an investment of DKK 12 billion (approximately EUR 1.6 billion). The electrification programme includes sections of the network such as the Roskilde–Kalundborg, Fredericia–Aarhus and Aarhus–Aalborg lines.

In Italy, Rete Ferroviaria Italiana will invest more than EUR 2 billion in electrifying 1 100 km of line by 2026 and 340 km after 2026. Those investments should allow Italy's rail network to reach an electrification rate of 78 % by 2026. Lines such as Salerno–Avellino and Reggio Emilia–Guastalla have been electrified, and other lines, such as Aosta–Chivasso and Cagliari–Oristano (in Sardinia) are planned to be electrified.

In Ireland, the Minister for Transport for the Irish government and the Minister for Infrastructure of the Northern Ireland Executive launched in April 2021 the All-Island Strategic Rail Review (AISRR). The AISRR aims to inform policy and future strategies for the railways in both jurisdictions on the island of Ireland. The review examines how the island's railways are currently used, what role rail could play in the future and how the island's railway could better serve the people of both jurisdictions. The AISRR focuses on how the rail network across the island could contribute to the decarbonisation of the island's transport system, promote sustainable connectivity to and between major cities, enhance regional accessibility and support balanced regional development, providing 30 recommendations for achieving these goals. The final report was to be published in spring 2024 and envisaged that 80 % of tonne-kilometres on the island of Ireland would be delivered by electric trains by 2050 (Figure 43).

Figure 43: Proposals for decarbonisation interventions on the rail network, Ireland, 2023

NB: decarb., decarbonisation.

Source: Department of Transport and Department of Infrastructure, AISRR, Draft Report for Strategic Environmental Assessment Consultation, 25 July 2023.

In Austria, ÖBB's framework plan for 2024–2029 involves investing EUR 21.1 billion over the next 5 years, of which EUR 2.5 billion are envisaged to be used for electrification. Approximately 500 km of railway lines are to be electrified by 2030. By then, 85 % of ÖBB's network will be electrified. Priority in the electrification process will be given to the routes for which electrification is the best economic solution, in particular routes of the TEN-T, routes with high passenger traffic and routes crucial for freight traffic. Important diversion routes will also be given priority, in order to develop a more resilient network. The primary objectives of Austria's 2030 mobility master plan [86] are to have railways decarbonised by 2035 and climate-neutral by 2040.

[86] https://www.bmk.gv.at/en/topics/mobility/mobilitymasterplan2030.html.

C. Rail innovation

New rail technologies

While the further electrification of the EU rail network will maintain the positive trend of reducing GHG emissions, it may not be economically sound to electrify some lines. Indeed, with a cost of up to EUR 1.5 million/km, or more if tunnels need to be enlarged, it would be difficult to justify the electrification of lines with low traffic. In other parts of the network, electrification is technically very complicated for topographical or technical reasons. Electrification alone cannot fully mitigate the environmental impacts of railways, while new technologies can play an important role in improving energy efficiency, ensuring the optimal use of current railway assets and limiting railway GHG emissions.

Alternative-technology-powered trains

Several solutions have proven their potential: fuel-cell- and hydrogen-powered trains on the one hand and battery-powered trains on the other ([87]). Recent studies ([88]) show that hydrogen-powered trains offer good technical performance, with similar flexibility and versatility to diesel-powered fleets. They also make economic sense on non-electrified routes of over 100 km for regional passenger transport, on mainline routes with low traffic and on last-mile delivery routes. Plans exist to increase the deployment of hydrogen-powered trains in the years to come, especially in Germany, France and Italy, where hydrogen trains are already in operation. In a communication from July 2020, the Commission presented a hydrogen strategy for a climate-neutral Europe ([89]). Between 2025 and 2030, hydrogen needs to become an intrinsic part of an integrated energy system. Renewable hydrogen is expected to gradually become cost-competitive, and dedicated policies will be needed for industrial demand to gradually include new applications for rail transport.

Fuel cell technology is generally not considered mature enough yet to provide the necessary traction power (300 kN or 202.4 MW). It is estimated that this technology will be used in the future but will probably be implemented first in the United States, as the locomotives are much heavier and transport bigger volumes, so more fuel cell systems can be integrated.

To shunt locomotives in Europe, the priority is to develop dual-mode diesel-electric locomotives that can run on both electrified and non-electrified sections of lines. The next step is to replace diesel with a high-powered battery. This would make it possible to perform shunting movements with battery-powered locomotives, resulting in zero carbon emissions. These types of vehicles would be sufficient to perform last-mile operations. One of the advantages of this technology is its modularity. The battery cells can be placed modularly (in terms of their physical positions and quantity), which can facilitate standardisation. The maintenance costs are also reduced, as currently maintaining diesel engines is quite expensive. However, as in the automotive industry, there is a risk to be considered in accessing the raw materials required to produce the batteries. In addition, circular and ecological means of production will eventually have to be developed so that the electrification of the network as far as possible is still considered the most environmentally friendly solution.

Hydrogen and battery electric rolling stock thus have the potential to allow the elimination of remaining diesel operations. Such alternative-technology-powered trains, whose development is supported by the Europe's Rail Joint Undertaking and Fuel Cells and Hydrogen Joint Undertaking, can eliminate rail's direct CO_2 emissions, decrease air pollution

([87]) https://aerrl.eu/wp-content/uploads/2023/04/AERRL_Report_Study-on-alternatives-on-fossil-diesel-use-in-railways_final-Version_2001232.pdf.
([88]) https://rail-research.europa.eu/wp-content/uploads/2019/04/Final-version_study-on-the-use-of-fuel-cells-and-hydrogen-in-the-railway-environment.pdf.
([89]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301.

and improve rail's multimodal performance (hybrid locomotives can switch from an electrified line to a terminal, eliminating the need for additional shunting locomotives). In a study conducted by the consulting firm Roland Berger (90), it is estimated that fuel-cell- and hydrogen-powered multiple units could replace 30 % of diesel volumes by 2030 in a base-case scenario.

However, despite the critical need for an alternative to diesel, not all locomotives will be replaced by new vehicles, so retrofitting solutions need to be developed as well. Manufacturers are developing technical systems to perform retrofitting on, for instance, shunting locomotives – the oldest type on average by age of the European fleet. These solutions allow us to convert classic shunting locomotives to small diesel hybrid shunting locomotives or even to small emission-free shunting locomotives (Figure 44).

Figure 44: Example of retrofitting a classic shunter into a small diesel hybrid shunter and a small emission-free shunter

NB: HVO , hydrotreated vegetable oil (a biofuel)

Source: Alstom, 'ERA Multimodal Conference 2023' (https://www.era.europa.eu/content/era-multimodal-conference-2023#oe-content-paragraph-2801)

Finally, hydrogen and batteries need electricity to be produced and recharged, respectively. Even if this production is 'green' (produced through wind power, solar power, etc.), there will always be a residual impact. The technology allowing the use of as little energy as possible should be prioritised, and the railways use less energy than any other mode of transport.

Optimal use of current railway assets

Digitalisation has the potential to increase infrastructure capacity by between 20 % and 50 %, depending on the traffic type and signalling used (91). Among the benefits, aside from the higher share of rail in the transport mix and the GHG emissions avoided, are savings from infrastructure investments avoided. Considering that the national legacy control systems are incompatible (producing a patchwork effect due to the lack of a coordinated strategy) and constitute a significant barrier to seamless traffic, deployment of the ERTMS is the core industrial project that will serve to make rail transport safer and more competitive and increase the level of integration of the European railway system. This common European system and its deployment will provide the backbone for a digital railway system and will be the main factor in achieving a single European railway area. Further-

(90) https://www.rolandberger.com/en/Insights/Publications/Fuel-cell-and-hydrogen-trains-An-ultra-green-revolution-for-Europe's-railroads.html.
(91) https://bmdv.bund.de/SharedDocs/DE/Anlage/E/machbarkeitsstudie-digitalisierung-schiene.pdf?__blob=publicationFile; https://op.europa.eu/fr/publication-detail/-/publication/a5c88a67-994f-11e9-9d01-01aa75ed71a1.

more, digitalisation also plays a critical role in terms of the ongoing further optimisation of rail asset management practices, for example through the increased usage of predictive maintenance for rolling stock and infrastructure.

Replacing legacy technology with an advanced train control and signalling system, such as the ERTMS level 2, is a core element of the digitalisation of train control and traffic management. Whereas today's systems may have from 100 to more than 1 000 mechanical and electrical signal boxes, those will be replaced with new digital interlocking and control centres, only a few of which are required to control even the largest rail systems. The ERTMS should also bring advantages in terms of avoiding the need to change locomotives and retrain staff, and lowering costs (because of the larger equipment market). Within the next 10 years, these digital advancements will also allow operators to withdraw most of their trackside equipment, and autonomous train operations will be based on a digital rail infrastructure ([92]). Infrastructure managers and railway undertakings will benefit from much more efficient operations and maintenance. In addition, the lower costs may result in reduced track access charges, from which the train operators will profit. As soon as digital train control and traffic management systems are introduced, the rail system's availability, reliability and punctuality will increase.

Digital automatic coupling (DAC) is another technological solution to increase railway capacity. Coupling and decoupling are two of the main procedures in train operation, particularly for single wagonload traffic, so their automation speeds up railway operations. DAC also couples the air line for the brake and a power and data bus line. This increases productivity by eliminating the manual coupling process and will also provide the technical basis for intelligent freight trains with automated operations such as brake testing, and the continuous monitoring and detection of flat wheels and derailment. DAC is thus expected to increase safety, the speed of operation and the capacity of rail infrastructure.

The continuous deployment of 5G to public customers, with its extremely good latency and throughput close to 1 gB per second, is entering a new phase in the vertical markets of industry, health and transport. This will support the development of critical and operational railway applications. ERA, the UIC and the railway sector are continuing their cooperation with the European Telecommunication Standards Institute and the 3rd Generation Partnership Project to standardise the 5G-based future rail mobile communication system (FRMCS) as the successor to the GSM-R. A first set of specifications (i.e. FRMCS version 1) was defined in the Control Command and Signalling TSI, setting the trend for the adoption of the FRMCS as the only legal replacement system after GSM-R decommissioning. This new communication system should enhance voice and data applications and could be a facilitator for intelligent sensors and smart metering. While the development of 5G would necessitate new equipment (on board and trackside) at a high cost, it is a key enabler of the digitalisation of the railways, as well as a necessary upgrade to cope with the forecasted GSM-R obsolescence. 5G will allow the creation of more predictive maintenance models and the reduction of tele-maintenance and thus the costs of maintenance, to facilitate the development of business applications such as multimodal ticketing and, together with a higher grade of automation, to better manage traffic operations with an increase in capacity. A major step towards the finalisation of FRMCS specifications will be the testing of the adaptability of 5G to railways to determine if some fine-tuning will be necessary. It is also extremely important to secure the spectrum capacity for main railway lines and urban radio communication systems, ensuring a sufficient quality of service for rail transport systems.

([92]) https://www.mckinsey.com/featured-insights/europe/digitizing-europes-railways-a-call-to-action?cid=other-eml-alt-mip-mck&hdpid=a94f5c6b-cdc6-42f9-a6e4-73640083c1da&hctky=9139535&hlkid=d84b7839f0644e6cbd-79299c055be92d.

Improved energy efficiency

This capacity increase can be further improved, together with energy savings, through automatic train operation (ATO) ([93]). Coupled with lighter trains and a higher loading factor, ATO can lead to substantial energy savings. In addition, ATO, coupled with ERTMS/ETCS deployment, will reduce operating costs for railway undertakings and maintenance costs for infrastructure managers, while further improving punctuality. Energy savings can also be obtained through training train drivers on best practices to enhance their capabilities to save energy when driving.

In addition, on-board measurement devices to precisely calculate the traction electricity consumed are an incentive to enhance energy savings. With a better view of the electricity used (and paid for), railway undertakings would be able to determine the energy efficiency of available electric multiple units, identify the optimal point in time for decommissioning/replacing old electric multiple units with more energy-efficient ones, better assess driving style and enhance energy-efficient driving behaviour, and identify points of electricity loss in the infrastructure manager's electricity distribution system. These on-board devices are already on the market in different Member States but are not yet generalised.

Finally, increasing capacity at the train level is also a way to improve energy consumption. Unlike in road transport, in the rail network trains cannot be stored en route because there must be a certain distance between them. Therefore, any capacity bottleneck can rapidly affect the traffic throughout the network. Currently, most of the freight trains circulating in the EU are less than 600 m long. Operating 740 m-long freight trains can increase the capacity by 25–30 % on most rail networks, and these trains have the potential to replace between 50 and 75 trucks.

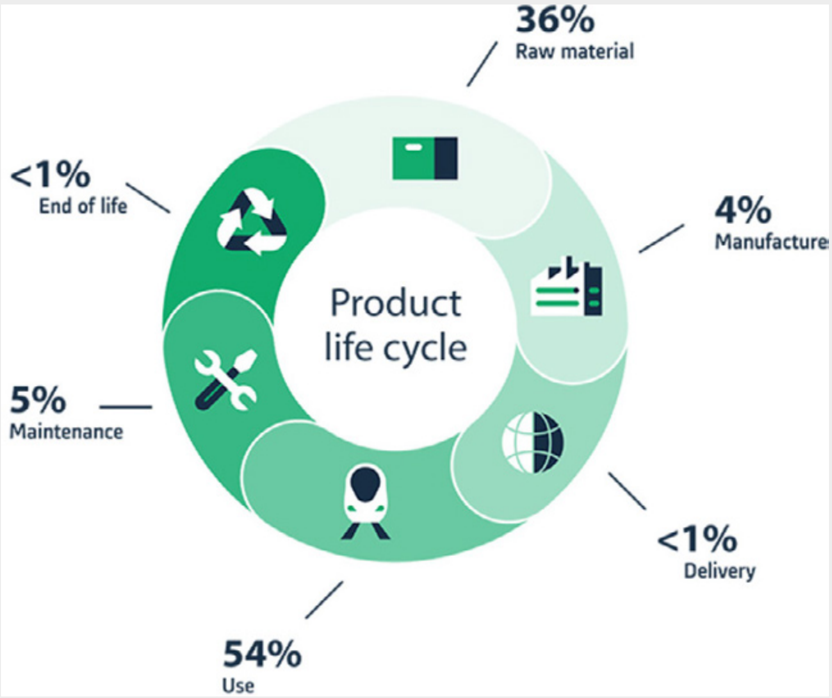
Ecodesign and the circular economy

As described in Section 1C, the life expectancy of the railway fleet is long. Indeed, while the life expectancy of a car, a bus or a truck is estimated to be between 8 and 15 years, and they are able to travel around 250 000 km to 300 000 km in their lifetime, the life expectancy of a railway vehicle is over 40 years, with more intensive use, and even more than 50 years for wagons. For instance, the first high-speed train, named Patrick, put in service in France in 1978 (tested for 3 years and operating its first service in 1981) was released from operation after 41 years of use. The life expectancy of railway infrastructure is equally high. Although the long life expectancy of railway assets may slow down the implementation of innovative solutions, it illustrates their robustness, sustainability and modularity.

In addition to long-lasting products, the railway industry has grasped the need to create a more sustainable framework for its industrial production. Indeed, ecodesign – that is, integrating environmental criteria in the design of a product with a holistic approach across its life cycle to limit its final impact (Figure 45) – is now considered a cornerstone of railway product development. Analysing the raw materials used, the energy consumed during the products' life cycle, the pollution emitted during the construction and delivery of the products and the waste generated by their destruction is key in designing new products. Alstom, for instance, aims to ensure that 100 % of its new products are ecodesigned by 2025, whereas in 2022 only 65 % of newly developed solutions were produced by an ecodesigned process integrated in its research and development strategy.

([93]) As reported in the EEA's Transport and Environment Report 2022 (available at https://www.eea.europa.eu/publications/transport-and-environment-report-2022/transport-and-environment-report/view), 'The lower costs that can be achieved through automation may have significant rebound effects by drastically increasing the demand for transport or by promoting a shift to the transport mode that can deploy autonomous systems quickly (very likely to be the road sector), which may not necessarily be the most sustainable choice. Internalising external costs can be an effective measure to support this transition.'

Figure 45: Product life cycle for the example of a French regional train, with overall environmental impacts expressed as percentages, 2024



NB: The percentage is highly dependent on rolling stock type and the energy mix.

Source: Alstom (n.d.), 'Eco design: A pathway towards sustainable mobility' (https://www.alstom.com/company/commitments/sustainable-mobility/eco-design-pathway-towards-sustainable-mobility).

Ecodesign is one element of shaping production into a more circular model. In the EU's new action plan for the circular economy [94], construction and buildings are targeted in particular, as they represent 50 % of all extracted material used and 35 % of total waste generation in the EU. In addition, the waste framework directive established a waste hierarchy aimed at reducing the generation of waste and improving waste management (Figure 46).

Figure 46: Waste hierarchy as described in the waste framework directive, 2022

Source: European Commission (n.d.), 'Waste framework directive' (https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en).

[94] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN.

Considering ecodesign and the waste hierarchy, in 2021 the UIC released a report on the circular economy in the railway sector through the Sustainable Use of Resources in Railways project (95). In this project, ballast, steel and concrete sleepers were identified by railway stakeholders as the key products that should be subject to closer attention in trying to reduce the consumption of primary raw materials. Those materials are essential for construction and are integrated in the EU action plan for the circular economy.

Track geometry is highly dependent on a good ballast bed, which can be maintained in different ways, either directly on site or through treatment in dedicated waste facilities. Ballast can be sorted, 'cleaned' and reused with the partial addition of new ballast to replace the damaged portion (through tamping). Ballast that cannot be treated can be sold and reused as, for instance, aggregate for road construction. Concrete sleepers are either repaired, if they can be reconditioned, or recycled. Finally, steel is highly recyclable, so recycling is most often preferred to reuse.

Wooden railway sleepers are frequently impregnated with creosote oil, which is an effective but toxic wood preservative. Wooden sleepers are still widely used because of their good technical parameters – including their anti-vibrating characteristics and the efficiency of their use with flexible soil and low-quality ballast – and lower costs. However, without special treatment, the wooden sleepers are not resistant enough to fungal wood decay. Specific attention needs to be given to the recycling of such sleepers by specialised companies. In addition, intensive research into creosote oil substitutes is still under way, and some more environmentally friendly alternatives exist (96).

Finally, the European Rail Supply Industry Association's Sustainable Transport Committee (97) developed product category rules (PCRs) for the assessment of the environmental performance of rolling stock (PCR 2009:05), and the declaration of this performance by an environmental product declaration. A PCR for railway infrastructure (c-PCR-023) was prepared by the Swedish Transport Administration and Tyréns. Those PCRs are now broadly used in the development of new railway solutions.

An industry initiative to develop a systemic approach to sustainable procurement, Railsponsible (98), has been launched, with the aim of continuously improving sustainability practices throughout the supply chain of the railway sector. The initiative is open to all railway operators and companies across the railway sector value chain, along with key sector associations, that share its vision, mission and commitments.

(95) https://uic.org/IMG/pdf/reuse_project_final_report.pdf.
(96) https://www.margaritelliferroviaria.com/it/innovation/.
(97) The companies involved are Alstom, CAF, Siemens, Talgo, Hitachi Rail, Knorr-Bremse, Saft and Voestalpine.
(98) https://railsponsible.group/.

D. Modal shift to rail

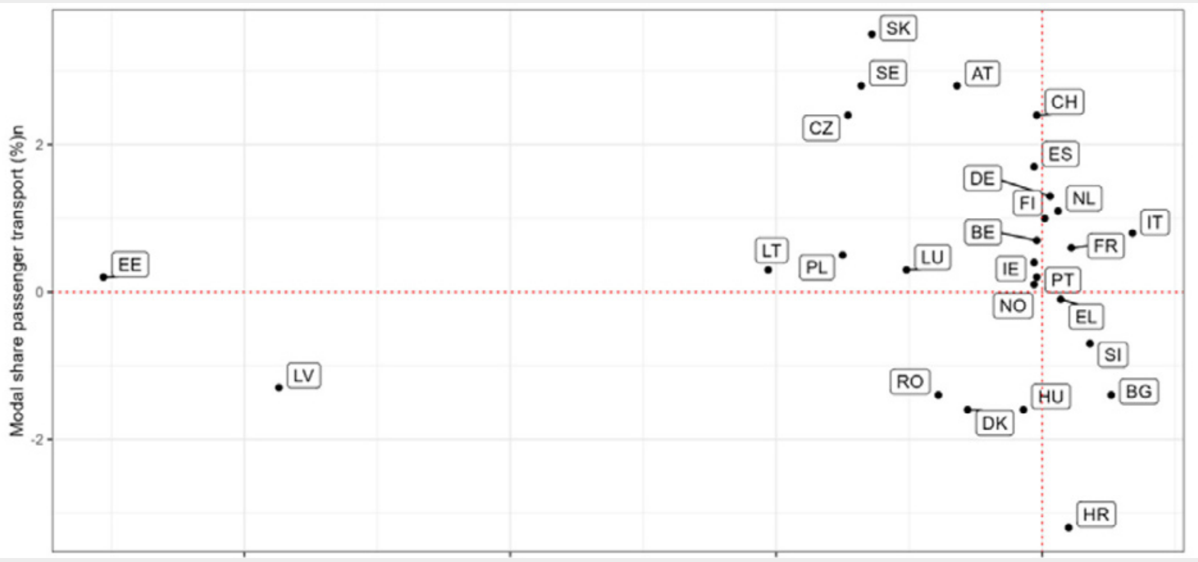
As clarified several times in this report, the substantially lower externalities of rail versus road transport are a key societal argument in favour of rail transport. While it was reasoned above that the externalities of rail itself could be further reduced, it remains key for the transport sector as a whole to shift more transport to rail and other modes, such as inland waterways, to reduce the environmental impacts of transport.

It is important to emphasise that, even if road transport were further electrified, the energy efficiency of rail transport would remain substantially higher and would continue to maintain a strong advantage, owing to its substantially lower costs in terms of congestion and accidents, in the foreseeable future.

In acknowledgement of this situation, many governments have set modal share or modal shift ambitions and have introduced auxiliary measures to realise these goals (99). These range from subsidies, tax breaks in the railway sector, infrastructure investments and the taxation of competing modes of transport. At the EU level, no specific modal share objectives have been set other than an increase in rail traffic both in freight (doubling) and in passenger transport (tripling) by 2050 and the shifting onto rail and inland waterways of a substantial part of the 75 % of inland freight carried today by road.

Despite these actions and aspirations, the modal share of rail remains unsatisfactorily low across the board. Figure 47 (100) shows that the modal share for most countries has remained stable, although the freight sector took some heavy hits due to changing trade relations and the impact of COVID-19.

Figure 47: Change in the modal share for freight and passenger rail transport (percentage points), 2010–2019 (passenger) and 2010–2021 (freight)



Sources: Eurostat (tran_hv_trmod) and (tran_hv_psmod).

(99) International Transport Forum (2022), *Mode Choice in Freight Transport* (https://read.oecd-ilibrary.org/transport/mode-choice-in-freight-transport_3e69ebc4-en#page1).

(100) For rail passenger transport, the timeline 2010–2019 was chosen instead of 2021, as it was disproportionally affected by the COVID-19 pandemic.

As the European Court of Auditors highlighted ([101]), *ex post* evaluations are not systematically carried out to assess the results of modal shift measures, limiting the understanding of what measures work best. That said, research does support the idea that rail transport can attract substantially greater freight volumes by improving its cost position and lowering transit times ([102]). A forthcoming analysis by ERA ([103]) finds that investments in passenger rolling stock and optimised use of the railway capacity can be clearly linked with increased ridership. The main challenge therefore remains, despite a range of measures, profoundly improving the attractiveness and performance of rail itself.

With regard to passenger traffic, investment in HSR infrastructure has had a clear positive impact on the modal shift to rail. About 60–80 % of current HSR activity has been shown to derive from shifts away from conventional rail and planes, with the remainder deriving from avoided road traffic (10–20 %) and induced demand (10–20 %). There is some evidence of substantial, even full, HSR substitution for air traffic, such as for the Paris–Strasbourg connection. More broadly, countries with existing HSR lines tend to have proportionally fewer short-haul flights than countries without HSR lines. This is accompanied in some Member States by a regulatory measure to ban short-haul flights when a frequent, timely and well-connected HSR alternative exists where travel time is less than 2.5 hours (in France, and under discussion in Spain) or 3 hours (in Austria) and taxation measures (EUR 30 extra charge per passenger for flights over a distance of less than 350 km in Austria).

Considering the direct emissions (due to fuel combustion) and the indirect emissions (due to electricity use by operators), according to figures from the EEA, a plane emits on average around 160 grammes of CO_2 equivalent (gCO_2e) per passenger-kilometre, while the amount is less than 20 gCO_2e per passenger-kilometre for HSR (based on the average gCO_2e per passenger-kilometre, well-to-wheel, in the EU-27 in 2018) ([104]). The difference between rail and air transport is much higher when taking into account the net non-CO_2 contributions of aviation ([105]). A modal shift from air to rail with the introduction of new high-speed lines thus has a direct effect on reducing CO_2 emissions. This is especially true considering that fuel consumption is significantly higher on short-haul flights, as take-off and climbing require more energy than cruising.

At the European level, although no rail modal share targets have been set apart from doubling rail freight traffic and tripling high-speed passenger traffic by 2050, changes to the legal framework for combined transport, the TEN-T, TSIs and the rail market pillar should all be seen as enablers of faster and cheaper rail transport, which should eventually support the modal shift process. Finally, for passengers, the modal shift should entail a holistic approach, considering their journeys before and after the train. Combining public transport and active modes of transport is the most sustainable solution. For instance, Article 6 of Regulation (EU) 2021/782 on rail passengers' rights and obligations ([106]) lists the minimum requirements for railway undertakings in relation to carrying a bike on a train in order to facilitate this multimodal approach.

([101]) https://www.eca.europa.eu/en/publications?did=63659.
([102]) Jourquin, B. and Beuthe, M. (2019), 'Cost, transit time and speed elasticity calculations for the European continental freight transport', *Transport Policy*, Vol. 83, pp. 1–12.
([103]) ERA's compelling vision for 2024 will be released by the end of 2024.
([104]) https://www.eea.europa.eu/data-and-maps/figures/ghg-efficiency-of-different-transport.
([105]) https://www.sciencedirect.com/science/article/pii/S1352231020305689.
([106]) https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ%3AL%3A2021%3A172%3ATOC&uri=uriserv%3AOJ.L_.2021.172.01.0001.01.ENG.

4. Adapting the transport system to the climate evolution

A. Rail resilience

Importance

Our society is highly dependent on critical infrastructure systems, including those for rail. Any kind of unexpected event, especially an extreme one, may have a significant impact on the reliability of these systems and the provision of transport services. This has been demonstrated by recent events in which the rail transport system proved essential to the organisation and well-functioning of our society and economy. The railway sector has indeed demonstrated its resilience in reorganising travel and logistics chains in the face of an ash cloud, a pandemic and a war. However, the EU is still in an unprecedented situation characterised by an ongoing military conflict and energy, food and material supply issues, overlapping with trends such as climate change and sociopolitical instability. In particular, natural disasters driven by climate change (e.g. extreme heatwaves and fires, heavy rainfall and flooding, heavy snowfall and thunderstorms) severely test the system's resilience, given the complexity of the events, and adaptability in guaranteeing transport connections for passenger and goods. The scenario is even more challenging when combined with the expected increase in demand, the shortage of rail network capacity and ineffective rail modal shift policies.

The importance of a robust and reliable transport system from an economic and welfare perspective has led to considerable research into the interrelationships that create its vulnerability, to find ways to both make it more robust and mitigate the impact of disruptions ([107]).

Definition

The most widely accepted definition of 'resilience' is proposed by the UN: 'The ability of a system, community or society exposed to hazards to resist, absorb, accommodate … and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions' ([108]).

Considering the numerous recent studies on the resilience of various transport domains ([109]), no single definition of resilience ([110]) has emerged. However, some similarities can be observed across the different definitions of resilience ([111]), as shown in Figure 48.

([107]) Mattsson, L.-G. and Jenelius, E. (2015), 'Vulnerability and resilience of transport systems – A discussion of recent research', *Transportation Research Part A: Policy and Practice*, Vol. 81, pp. 16–34.
([108]) UN (2009), *UNISDR – Terminology on disaster risk reduction* (https://www.preventionweb.net/files/7817_UNISDRTerminologyEnglish.pdf?_gl=1*1c10d84*_ga*MTczNzUzMjE1NS4xNzAxNjk3NDUz*_ga_D8G5WXP6YM*MTcwMTY5NzQ1OS4xLjAuMTcwMTY5NzQ1OS4wLjAuMA.), Geneva.
([109]) Examples can be found in the following networks.

- air: Janić, M. (2015), 'Reprint of "modelling the resilience, friability and costs of an air transport network affected by a large-scale disruptive event', *Transportation Research Part A: Policy and Practice*, Vol. 81, pp. 77–92
- road: Wang, D. Z. W., Liu, H., Szeto, W. Y., and Chow, A. H. F. (2016), 'Identification of critical combination of vulnerable links in transportation networks – A global optimisation approach', *Transportmetrica A: Transport Science*, Vol. 12, No 4, pp., 346–365
- supply chain: Ponomarov, S. Y., and Holcomb, M. C. (2009), 'Understanding the concept of supply chain resilience', *The International Journal of Logistics Management*, Vol. 20, No 1, pp., 124–143
- waterborne: Mansouri, M., Sauser, B., and Boardman, J. (2009,), ' Applications of systems thinking for resilience study in maritime transportation system of systems. 2009 3rd Annual IEEE Systems', Conference, Vancouver, BC (pp. 211–217). IEEE; 23–26 March 2009, pp. 211–217; rail: Khaled, A. A., Jin, M., Clarke, D. B., & Hoque, M. A. (2015). Train design and routing optimization for evaluating criticality of freight railroad infrastructures', *Transportation Research Part B: Methodological*, Vol. 71, pp., 71–84.

([110]) Zhou, Y., Wang, J., and Yang, H. (2019), ' Resilience of transportation systems: Concepts and comprehensive review', *IEEE Transactions on Intelligent Transportation Systems*, Vol. 20, No 12, pp., 4262–4276. doi:10.1109/ TITS.2018.2883766
([111]) Bešinović, N. (2020), 'Resilience in railway transport systems: A literature review and research agenda', *Transport Reviews*, Vol. 40, No 4, pp. 457–478.

Figure 48: Definitions of resilience in transport systems, 2020

Definition	Reference
Ability to recover quickly from a disruption	Bababeik, Khademi, Chen, and Nasiri (2017), Chan and Schofer (2016), Lu (2018), Saadat, Zhang, Zhang, Ayyub, and Huang (2018), Adjetey-Bahun, Planchet, Birregah, and Châtelet (2016), Jenelius and Cats (2015), Janić (2015), D'Lima and Medda (2015)
Remaining system's performance during a disruption	Khaled et al. (2015), Diab and Shalaby (2019), Ferranti et al. (2016), Dawson et al. (2016), Dorbritz (2011)
Described with four properties: robustness, redundancy, resourcefulness and rapidity (based on Bruneau et al., 2003)	Beiler, McNeil, Ames, and Gayley (2013), Bocchini, Frangopol, Ummenhofer, and Zinke (2014)
A function of system's vulnerability against potential disruption, and its adaptive capacity in recovering to an acceptable level of service within a reasonable timeframe after being affected	Mansouri et al. (2009), Saadat et al. (2018), Zhang et al. (2018)

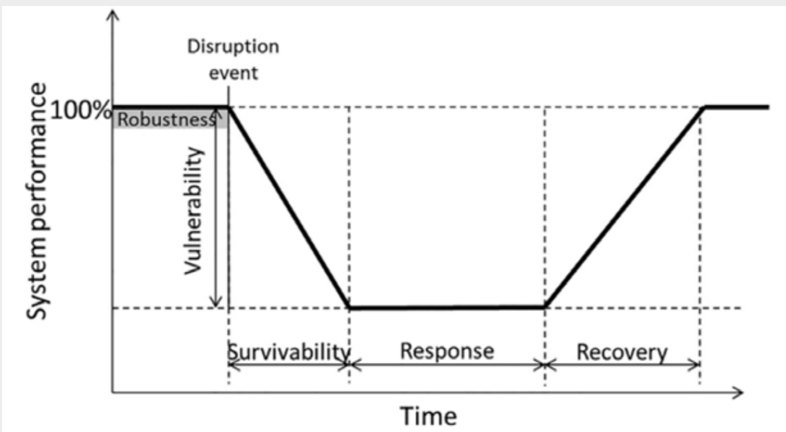
Source: Bešinović, N. (2020), 'Resilience in railway transport systems: A literature review and research agenda,' Transport Reviews, Vol. 40, No 4, pp. 457–478.

Resilience is defined as the ability of a railway system to provide effective services in normal conditions, and to resist, absorb, accommodate and recover quickly from disruptions. It covers specific building characteristics that represent distinct system states.

- Vulnerability is defined as how much performance remains during a disruption ([112]) or society's risk of transport system disruptions and degradations ([113]). Similarly, robustness is the ability of a system to mitigate various delays caused by disturbances; this definition is typical for rail transport and may differ for other transport modes.
- Survivability is the ability of a system to adapt during disruptions to planned system performance.
- Response is the contingency plan implemented in response to a disruption to provide the best level of service possible during the disruption, ensure public safety, provide alternative travel options to enable passengers to reach their destinations and meet the basic subsistence needs of the people affected.
- Recovery is the ability of a system to return to its original condition.

An overview of the abovementioned characteristics is provided in Figure 49.

Figure 49: Aspects of the resilience of rail transport systems, including vulnerability, survivability, response and recovery



Source: Bešinović, N. (2020), 'Resilience in railway transport systems: A literature review and research agenda', *Transport Reviews*, Vol. 40, No 4, pp. 457–478.

([112]) Khaled, A. A., Jin, M., Clarke, D. B., and Hoque, M. A. (2015), ' Train design and routing optimization for evaluating criticality of freight railroad infrastructures', *Transportation Research Part B: Methodological*, Vol. 71, pp. 71–84
([113]) Jenelius, E. and Mattsson, L.-G. (2015), 'Road network vulnerability analysis: Conceptualization, implementation and application', *Computers, Environment and Urban Systems*, Vol. 49, pp. 136–147.

Features of the rail system

Railway infrastructure systems, owing to a lack of capacity, limited possibilities for rerouting trains, the presence of single-line tracks, their highly integrated nature and the need to maintain safe operations ([114]), are particularly vulnerable to disruptions caused by extreme climate events and other threats, which have economic and non-economic consequences.

Quantification of extreme climate events

Especially in recent years, there have been an increasing number of extreme-weather-related events with significant impacts on the railway system, the transport services provided, passengers and people in the vicinity of the rail network ([115]). This is also demonstrated by the increased attention on this topic in academia, with only one publication in 2008 but 12 in 2018.

A recent survey, jointly launched by the Swiss national safety authority (NSA) the Federal Office of Transport and the French NSA Etablissement Public de Sécurité Ferroviaire, of NSA concerning the impact of climate change on railway systems showed that 87 % of respondents (seven NSAs) registered major railway-related occurrences caused by exceptional weather events in the past 5 years, demonstrating visible signs of climate change.

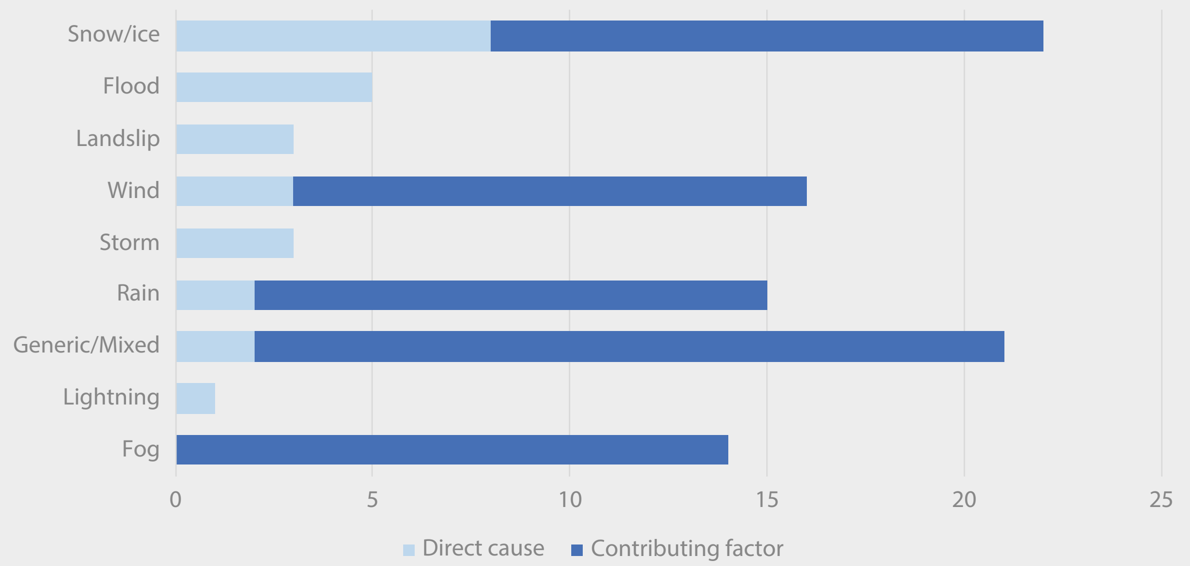
Using the accident investigation reports notified/sent to ERA ([116]), it is possible to provide an overview of weather-related rail accidents/incidents investigated by the national investigation bodies. In total, 100 accident investigations launched following weather-related occurrences from 2007 to 2023 have been reported; in 27 cases, weather conditions are indicated as direct causes, while for the other 73 occurrences they are considered contributing factors.

The most frequent weather conditions directly causing rail accidents are snow/ice (eight occurrences), floods (five occurrences), and landslips, wind and storms (three occurrences each). In addition, rain can cause incidents (three occurrences), especially in combination with other severe weather conditions.

If we consider weather conditions as a factor contributing to rail accidents, snow/ice is one of the most frequently reported weather-related factors (14 occurrences), together with wind (13 occurrences). Fog (14 occurrences), more than one weather condition or an unspecified condition (19 occurrences) and rain (13 occurrences) are also reported as factors contributing to rail accidents (Figure 50).

([114]) Palin, E. J., Oslakovic, I. S., Gavin, K. and Quinn, A. (2021), 'Implications of climate change for railway infrastructure', *WIREs Climate Change*, Vol. 12, No 5, e728.
([115]) Dawson, D., Shaw, J. and Roland Gehrels, W. (2016), 'Sea-level rise impacts on transport infrastructure: The notorious case of the coastal railway line at Dawlish, England', *Journal of Transport Geography*, Vol. 51, pp. 97–109.
([116]) Accident investigation reports sent to ERA are available at https://www.era.europa.eu/domains/accident-incident/rail-accident-investigation_en.

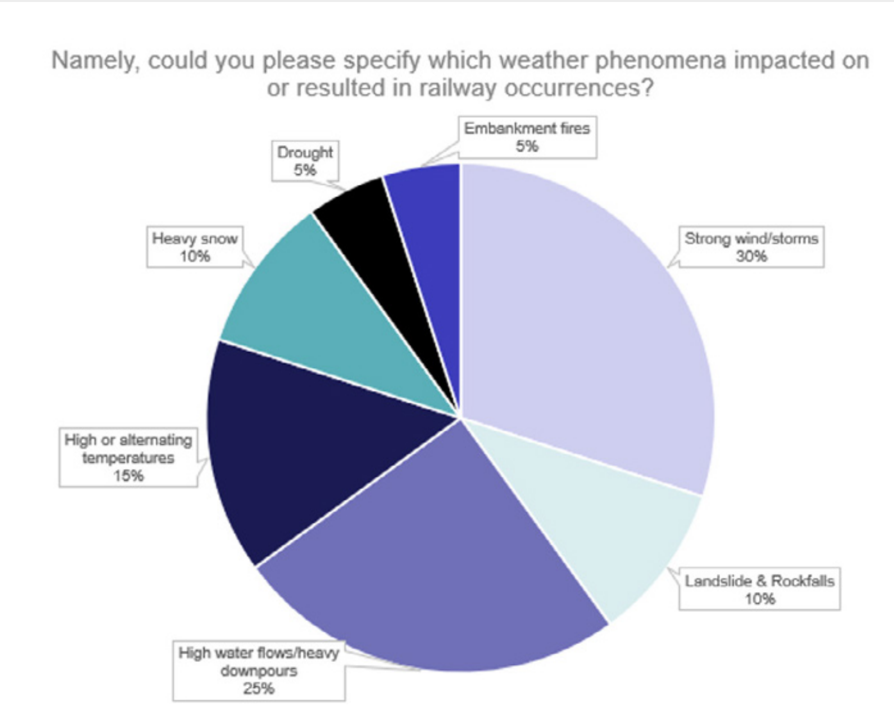
Figure 50: Number of weather-related occurrences by cause type



NB: 'Generic/mixed' means the weather event is not specified and/or more than one weather condition is reported.
Source: ERA, European Railway Accident Information Links (ERAIL), 2007–2023.

Although the results differ in terms of periods and samples, they are confirmed by the findings of the NSA survey launched by the Swiss NSA and the French NSA, concerning the impact of climate change on railway systems (Figure 51).

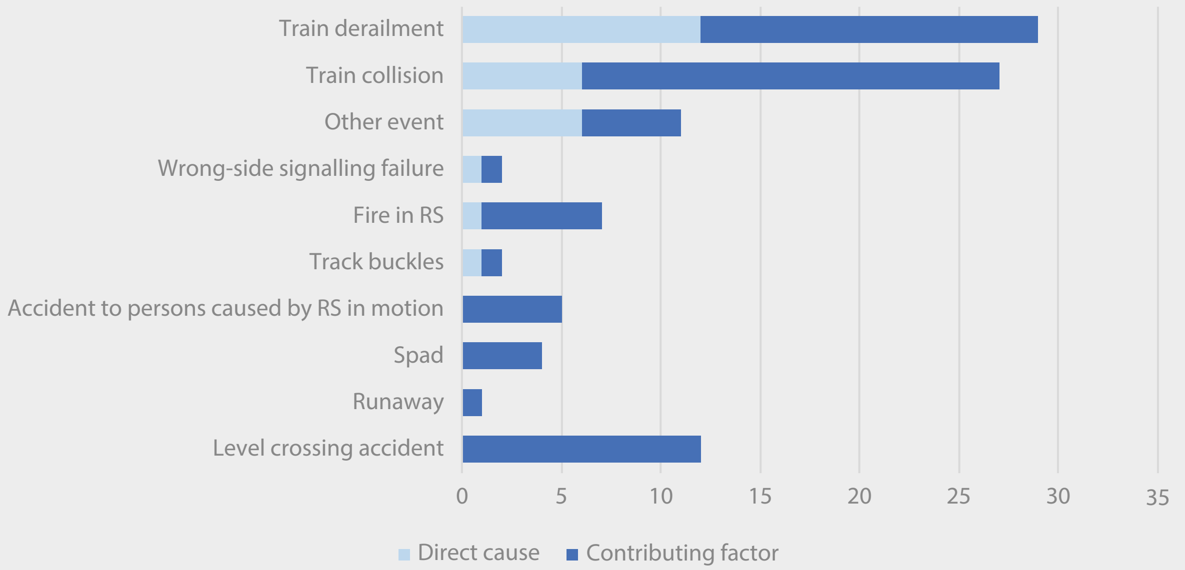
Figure 51: Railway occurrences by weather event



Source: Presentation by the Federal Office of Transport and Etablissement Public de Sécurité Ferroviaire, 2023.

With regard to occurrence type, the most frequent occurrences directly related to weather conditions are train derailments (12 occurrences) and train collisions (6 occurrences), while considering weather-related contributing factors the numbers of level crossing accidents (12 occurrences) and accidents to people caused by rolling stock in motion (5 occurrences) appear to be significant (Figure 52).

Figure 52: Number of weather-related accidents by occurrence type



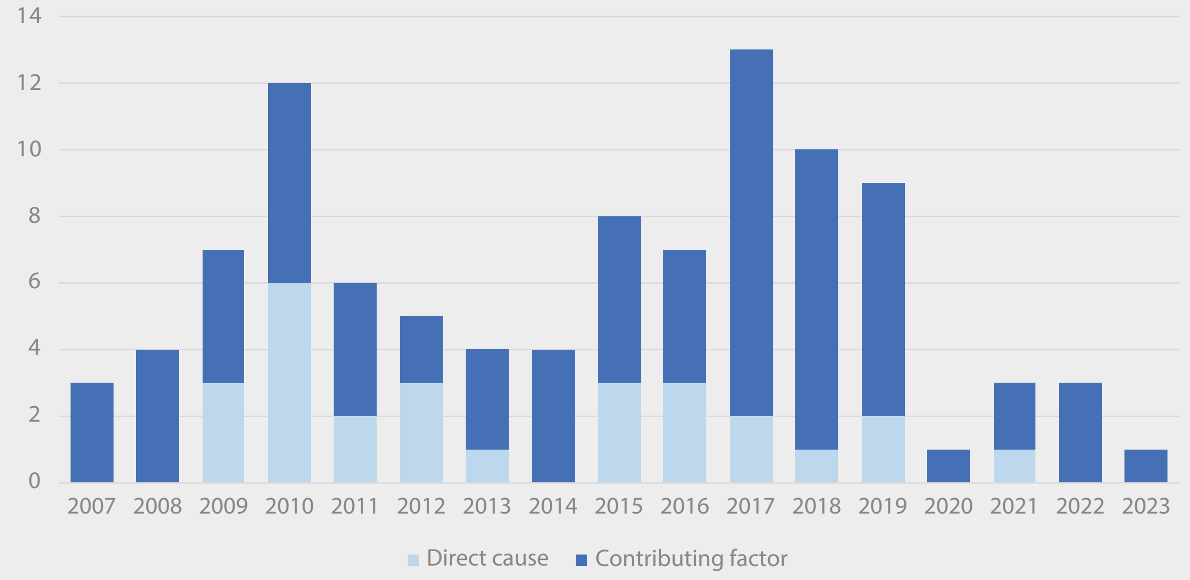
NB: RS, rolling stock; Spad, signal passed at danger.

Source: ERA, ERAIL, 2007–2023.

The change in the number of weather-related accidents does not show a clear pattern over the entire period considered. A certain number of occurrences are investigated every year, although the trend does not appear to be increasing, probably because there are non-mandatory requirements/obligations to launch an investigation in several cases. This leads to a sample of occurrences in the ERAIL database that does not truly represent the total number of accidents.

It is worth mentioning that for 2022 and 2023 only closed investigations have been analysed (often in the reports there is no clear indication of the causes or weather-related aspects of incidents), and the lower number of occurrences recorded in 2020–2022 (particularly 2020 and 2021) was caused by the global COVID-19 pandemic (Figure 53).

Figure 53: Change in the number of weather-related accidents



Source: ERA, ERAIL, 2007–2023.

Impact of weather-related incidents and extreme climate events

Concerning weather-related rail occurrences, several events occurred recently in several European countries that drew public attention.

- A train carrying around 120 passengers derailed in eastern Sweden, as the heavy rain partly washed away the railway embankment. Three people were injured (August 2023) ([117]).
- A storm caused two train derailments on narrow-gauge lines in north-western Switzerland, causing 15 injuries in total (end of March 2023) ([118]).
- A landslide occurred in the commune of Saint-André (between Saint-Michel-de-Maurienne and Modane), resulting in rail and road traffic disruption (the Fréjus road tunnel was also closed to heavy-duty vehicles). Landslides occur regularly in this region and, although there were no injuries, the consequences of this event are very important, as rail traffic between France and Italy was also interrupted at the Maurienne valley and will be so until the end of 2024 (August 2023) ([119]).
- Flooding in Austria interrupted traffic on multiple lines; traffic was halted in Tyrol, and long-distance traffic on the Tauern line between Salzburg and Spittal-Millstättersee/Klagenfurt was also suspended (August 2023) ([120]).
- Because of mudslides, the Brenner railway line between Innsbruck and Brennero station in Italy was closed to train traffic, and because of flooding the west line was closed to train traffic between Imst-Pitztal Bf and Schönwies (August 2023) ([121]).

([117]) More information is available at https://www.reuters.com/world/europe/train-derails-roads-flood-sweden-norway-hit-by-torrential-rain-2023-08-07/.
([118]) More information is available at https://www.thelocal.ch/20230401/fifteen-hurt-as-two-swiss-trains-derail-in-storm.
([119]) More information is available at https://www.railtech.com/infrastructure/2023/08/28/no-trains-for-days-between-france-and-italy-after-alps-rock-slide/.
([120]) More information is available at https://www.railtech.com/infrastructure/2023/08/29/flooding-in-austria-interrupts-traffic-on-multiple-lines/.
([121]) More information is available at https://www.railtech.com/infrastructure/2023/08/29/flooding-in-austria-interrupts-traffic-on-multiple-lines/.

- A storm and heavy rain caused a railway bridge on the Norwegian Dovre line to collapse. Trains from Trondheim to Oslo were diverted after the bridge collapse, but the alternative route was also damaged by extreme weather (August 2023) ([122]).
- Extreme flooding severely affected the Greek rail network, as parts of the infrastructure were destroyed (September 2023) ([123]).
- Significant snowfall in Bavaria led to numerous train cancellations and breakdowns (December 2023) ([124]).
- Extreme flooding in the north of France damaged the tracks on several lines, and two lines were closed to traffic for several months (November 2023, January 2024) ([125]).

An analysis of these events in newspapers shows that adverse weather events affect European railway systems indiscriminately and often even jointly, making the rescheduling of transport services even more complex. Adverse climate events have different types of impacts (e.g. economic and operational) and they result in accidents, incidents, and rail transport service delays or cancellations.

Within the analysis of ERAIL weather-related accidents, with regard to the impacts of rail accidents in terms of fatalities and serious injuries from directly weather-related accidents, the data analysed do not seem to show an important effect. However, considering weather conditions as factors contributing to rail accidents, the numbers of rail accidents with at least one fatality or at least one seriously injured person are 13 and 9, respectively.

In addition, it cannot be overlooked that these events also have a major impact in economic terms. This was demonstrated by a recent rail accident in Greece in which an extreme flood severely affected 50 km of railway infrastructure. The reconstruction works are estimated to cost EUR 50 million ([126]).

With the increase in climate-related events and risks, it is reasonable to expect:

- an increase in costs to maintain a safe and serviceable network (owing to more frequent and extensive construction, maintenance, repair and renewal work) and because of the requirement for new solutions (e.g. the costs of design and materials, components and construction);
- an increase in the costs and time required to rebuild damaged or destroyed infrastructure;
- an increase in business management costs (owing to a need for more staff, more frequent events and more research into ways of coping with climate change).

From an economic point of view, there are both direct costs of repair and hidden elements that should be considered whose costs can be estimated (e.g. where flooding occurs, there may be significant cleaning costs associated with contamination from sewage; or equipment may be more susceptible to failing again in future or have a reduced lifetime after repairs) ([127]).

([122]) More information is available at https://www.railtech.com/infrastructure/2023/08/22/sj-diverts-trains-trondheim-oslo-after-bridge-collapse-but-alternative-route-also-damaged-by-extreme-weather/.
([123]) More information is available at https://www.railfreight.com/railfreight/2023/09/08/floods-put-greece-underwater-piraeus-stranded-from-rail-services/?utm_source=newsletter&utm_medium=email&utm_campaign=Newsletter%20week%202023-36&gdpr=accept.
([124]) More information is available at https://www.theguardian.com/world/2023/dec/04/german-travel-chaos-blamed-on-lack-of-investment-in-railways.
([125]) More information is available at https://www.francebleu.fr/infos/transports/inondations-dans-le-pas-de-calais-les-lignes-de-ter-fermees-rouvriront-en-fevrier-et-en-avril-5190325.
([126]) More information is available at https://www.railfreight.com/railfreight/2023/09/11/greece-50-km-of-destroyed-tracks-require-50-million-euro-investments/.
([127]) UIC (2017), *Rail Adapt – Adapting the railway for the future*, Paris (https://uic.org/IMG/pdf/railadapt_final_report.pdf).

Measuring the resilience of the rail transport system

In the literature, there are four approaches to estimating the resilience of rail transport systems ([128]).

- **Data-driven.** The quantification of rail system resilience is based on historical data that have greatly increased with the advancement of data acquisition and storage, typically used for assessing *ex post* effects of disruptions (e.g. using historical traffic realisation data, passenger/ridership data and weather-related data).
- **Topological.** This approach uses graphical representations and most often involves performing network-wide assessments, mainly modelling either the infrastructure network or the services network.
- **Simulation.** This approach evaluates the performance of the rail network in a stochastic environment.
- **Optimisation.** Mathematical optimisation methods have been used with network-wide and scenario-specific approaches.

The NSA survey launched by the French and Swiss NSAs, concerning the impact of climate change on railway systems, investigated methods to identify weather risks, and whether NSAs had some interfaces with other organisations involved in identifying and/or analysing risks linked to extreme weather. The findings show that 40 % of NSAs have interfaces with other organisations, and 30 % of them have developed or are developing some methods of identifying weather risks. For example, in Sweden there is a project facilitating cooperation between the competent authorities (meteorological authorities, hydrological authorities, civil protection authorities, decision-makers, climate change specialists, etc.) for the warning and prediction of natural events at the national level. In Poland, these skills are directly developed within railway companies. In Germany, natural-hazard-driven risk analysis and cross-modal analysis (with roads and waterways) are run.

Adaptation to climate events

Among the challenges described in the 2013 EU adaptation strategy package, adapting rail transport infrastructure to climate change was envisaged for both existing infrastructure (with the goal of making it more climate-resilient by retrofitting and/or ensuring that maintenance regimes promote resilience to the impacts of climate change over its lifetime) and new infrastructure ([129]). The European Commission updated its strategy on adaptation to climate change on 24 February 2021, with the goal of becoming climate-resilient by 2050. The Paris Agreement has set a global objective for adaptation, namely to improve our capacity to adapt, strengthen our resilience and reduce our vulnerability to climate change. As set out in the guidelines on Member States' adaptation strategies and plans produced by the European Commission ([130]), the EU finances adaptation to climate change through a wide range of instruments, such as the Cohesion Fund, by investing in the environment and the TEN-T. In particular, transport infrastructure is said to strengthen the protection of critical services and critical infrastructure (an example of a specific, measurable, achievable, relevant and time-based objective), confirming its important role in the climate change mitigation process. On this, the EEA ([131]) describes the relevance of the EU's actions to facilitate systems-level assessments of current/future climate risks to critical infrastructure and related services.

([128]) Bešinović, N. (2020), 'Resilience in railway transport systems: A literature review and research agenda', *Transport Reviews*, Vol. 40, No 4, pp. 457–478.
([129]) eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013SC0137.
([130]) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023XC0727(01).
([131]) https://www.eea.europa.eu/en/newsroom/news/europe-is-not-prepared-for?utm_medium=email&_hsmi=84201387&_hsenc=p2ANqtz--Bh1FnMTzdJvTK-29ePlnFW0seKsfZ6klCV-XSDH_B0vTllKPROzBG8lgjnvL_fdVBg-bL9vJJWB-S-3EV86Qb1AGfTGEC76eIsvZSMa5MqfjivLlU&utm_content=84201387&utm_source=hs_email.

B. Multimodality

Mobility and transport are vital to meet citizens' fundamental personal and societal needs, for example for education, work, leisure, food and material supply. They also come at a price, affecting the environment and the climate. However, climate change has an impact on critical infrastructure (especially energy and transport infrastructure) and can affect nearly all aspects of society, from human health to the wider economy and the financial system. Infrastructure assets and networks are often interconnected, so a failure at one point in the network can cascade to other regions and countries. The EU transport policy aims to ensure mobility is sustainable, energy-efficient and respectful of the environment.

Integrated transport and transit systems that optimise the advantages of each mode of transport are crucial to achieving the sustainable transport of passengers and freight within and between countries. Planning such transport systems, including long-distance, cross-border transport corridors, requires well-coordinated integration across modes ([132]).

The European Commission hence pursues a policy of multimodality by ensuring the better integration of transport modes and establishing interoperability at all levels of the transport system. For example, in line with the objectives of the European Green Deal and the sustainable and smart mobility strategy, the revision of the TEN-T aims to increase the use of more sustainable forms of transport, and provides a greater focus on multimodality and interoperability between transport modes and nodes and facilitates the better integration of urban nodes into the TEN-T.

The mobility of tomorrow will need to be provided by a fully integrated multimodal transport system that gets people and goods from A to B as quickly as possible with a minimal impact on the environment, from a GHG emission and energy efficiency point of view.

All modes of transport have a key role to play in the multimodal logistic chain, allowing us to make the best use of the strengths of each mode. All modes of transport and their efficient integration are important, including road, rail, waterborne and air transport, and non-motorised transport such as walking and cycling; emphasis should, however, be placed on low-carbon-based and energy-efficient modes of transport, and an increased reliance on interconnected transport networks for seamless and 'door-to-door' mobility and connectivity of people and goods.

While efforts need to be made to decarbonise each individual mode of transport, political choices need to be made based on the environmental capabilities of each mode of transport. Rail has been a major player in the decarbonisation of the EU transport system and ensuring energy independence. It has the potential to become the backbone of a multimodal transport system with a holistic perspective but cannot work in isolation from other modes. Ports and airports, for example, are key for international connectivity; they should become multimodal mobility and transport hubs, linking all the relevant modes ([133]).

Integrated transport chains may also provide the redundancy (i.e. the ability to use backup facilities to provide services during disruption) necessary for resilience (both in view of crises and from a climate perspective). Natural disasters driven by climate change (e.g. extreme heatwaves, heavy rainfall and flooding, heavy snowfall and thunderstorms) can be expected to cause more frequent disruption of the transport network; redundancy in the integrated and multimodal transport system can prevent the interruption of mobility/services and help in guaranteeing transport connections for passengers and goods.

([132]) UN (2021), *Sustainable Transport, Sustainable Development*, Department of Economic and Social Affairs (https://sdgs.un.org/publications/interagency-report-second-global-sustainable-transport-conference?_gl=1*f6lx9l*_ga*MTI1ODgyNTM1MS4xNzAwOTAwNjMz*_ga_TK9BQL5X7Z*MTcwMTA4OTMzMS4yLjAuMTcwMTA4OTMzMS4wLjAuMA..), p. 42.
([133]) European Commission, Directorate-General for Mobility and Transport (2021), *Sustainable & Smart Mobility Strategy – Putting European transport on track for the future* (https://transport.ec.europa.eu/system/files/2021-04/2021-mobility-strategy-and-action-plan.pdf), p. 6.

In periods of crisis, the railway sector has demonstrated its high resilience in reorganising travel and logistics chains, whether in the face of an ash cloud, a pandemic or a war. For instance, while access to the Black Sea was blocked, rail proved to be the only reliable transport mode for delivering support to Ukraine and ensuring its export of grains.

Transport was one of the sectors hit hardest by the COVID-19 pandemic, and many businesses in the sector experienced immense operational and financial difficulties; rail freight traffic, although severely affected, was able to continue to operate, with adaptations. The COVID-19 pandemic demonstrated how increased multimodality is crucial to improving the resilience of our transport system and how ready the public is to embrace sustainable alternative modes of travel ([134]).

Some actions/measures to enable/support multimodality are reported in the following sections.

Improved connections between airports and the rail network

Over short and medium distances, rail and aviation are often perceived as being in competition. It is true that when new HSR infrastructure is built the new line can shift passengers from air to rail, as has been the case, for instance, between Rome and Milan. New lines can even generate a full substitution effect like the one between Paris and Strasbourg ([135]), where air connections have been terminated. But we can also perceive this substitution effect as positive for both the railway and the aviation sectors; complementarity can be exploited between air and rail by connecting major airports to the long-distance rail network and offering integrated booking options. Good connections between rail infrastructure and airports are particularly important in building synergies between the two modes of transport. For longer distances, new routes have recently been opened or reopened for night trains.

If airports are well connected to the rail network, new integrated rail and air products can be developed, with trains playing the role of feeder services. The railway sector could thus be seen more as a partner to replace feeder flights to major hubs and better complement long-haul journeys, a segment of the market where the benefits are higher for airlines.

Rail can also be helpful in reaching cities not served by regular direct flights. For example, to go from Brussels to Florence, passengers often need two flights. By combining a flight to Bologna or Pisa with a train connection to Florence, you can reach the capital of Tuscany in roughly the same time and at a similar cost but with half the GHG emissions. Customers will only choose these more sustainable options if they can easily find and book these connections and if they are adequately covered by passenger rights. The Commission's initiatives on multimodal digital services and on multimodal passenger rights are important in this respect.

Combining road and rail for efficient freight operations

Improving consumers' information is also relevant to freight, together with continued support for key enabling rail technologies (this includes the use of the ERTMS and DAC and the development of a good network of terminals for loading and unloading goods).

Nowadays, the transport of goods by freight trains results in six to eight times less GHG emissions than transport by trucks. As indicated in a recent study by the Commission ([136]), a key element of reducing GHG emissions from the European transport system is limiting the number of trucks travelling distances of over 700 km. There is significant potential for a modal shift: a 90 % reduction in road freight traffic travelling distances over 700 km has the

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([134]) See European Commission, Directorate-General for Mobility and Transport (2021), *Sustainable & Smart Mobility Strategy – Putting European transport on track for the future* (https://transport.ec.europa.eu/system/files/2021-04/2021-mobility-strategy-and-action-plan.pdf), p. 3.
([135]) See ERA (2022), *Fostering the railway sector through the European Green Deal* (https://www.era.europa.eu/system/files/2022-09/Report - Fostering the railway sector through the European Green Deal.pdf), p. 17.
([136]) See ERA (2022), *Fostering the railway sector through the European Green Deal – Part 2: Freight* (https://www.era.europa.eu/system/files/2022-09/Fostering the railway sector through the European Green Deal %E2%80%93 Part 2 Freight.pdf), p. 20.

potential to lead to a market share of rail of 36 %, while saving approximately 40 million tonnes of CO_2 annually.

In addition, a study from the Commission ([137]) looking at options for more competitive intermodal transport confirmed that, if we considered environmental performance, most intermodal transport chains would have lower external costs at 600 km than road-only transport.

The proposal for the revision of the combined transport directive, as part of the greening freight transport package, aims to make freight transport more sustainable by improving the competitiveness of intermodal freight – the transport of goods using two or more transport modes – vis-à-vis road-only transport. In addition, the European Commission is promoting the multimodal paperless exchange of data in order to reduce administrative costs in the transport and logistics sector ([138]).

Combined transport is a solution to reduce the environmental impact of road freight and increase the share of goods transported by rail where the benefits inherent to each mode of transport are optimised. It is a sort of intermodal transport combining the flexibility of road transport, which would still be used for the first/last leg of a journey to ensure that any location in the EU can be reached, with the environmental performance of rail, inland waterways or short sea shipping for the main leg of the journey.

Rail–port synergies

A good network of terminals is also important for the maritime sector, because they allow the hinterland transport of goods to shift from road to rail. For most ports, rail activities are considered strategic.

As indicated in a recent study by ERA ([139]), the current level of connection of rail to the ports and presence of rail inside ports is on average rather good (despite a large variation between ports with a modern infrastructure and those with an ageing infrastructure that needs significant investment to modernise it). Many ports consider that their competitiveness will increasingly be judged by their railway connectivity. Therefore, most ports are investing in increasing their rail capacity and rail modal share through the development of the railway infrastructure. The diversification of hinterland transport is seen as the main commercial driver for the ports.

Practically, a key element of fostering synergies between the railway sector and ports is clearly the state of rail infrastructure in ports and their connection with the main rail network; the development and modernisation of the railway infrastructure is considered a key factor in increasing rail's modal share. Another important development in reinforcing the synergies between the railway sector and ports is digitalisation. A lack of communication and data exchange is often perceived as an important barrier to developing further rail activities. Therefore, many ports are investing in the development of specific IT tools that facilitate coordination between different port stakeholders, with the aim of speeding up processes and the control of rail operations. Most ports have a digitalisation strategy including smart customs procedures, but there is also a great need to ensure data availability and data interoperability for the logistics chains in general, for example for track and trace systems. We also see that, to compensate for a lack of information exchange, shipping companies are investing in railway operators or setting up new ones to vertically integrate themselves in the logistic chain.

([137]) https://transport.ec.europa.eu/news-events/news/study-analyses-transhipment-options-more-competitive-intermodal-transport-and-terminal-capacity-ten-2022-05-05_en.
([138]) https://www.eea.europa.eu/publications/transport-and-environment-report-2022/transport-and-environment-report/view.
([139]) https://www.era.europa.eu/system/files/2022-10/fostering_the_railway_sector_through_the_european_green_deal_-_rail-ports_synergies_1.pdf.

The first and last miles as key to sustainable urban transport

Making a transport system efficient means bringing together people or goods as early as possible in their journey. However, people or goods rarely travel between two mass transport hubs or stops. The first and last legs of the trip are referred to as the first mile / last mile. First-mile and last-mile ([140]) mobility options allow people or goods to travel between their starting point (origin) and a starting hub and/or between an end hub and their destination. In the case of freight transport, last-mile delivery is defined as the movement of goods from a transport hub to the final delivery destination.

However, public transport, which is an environmentally friendly transport mode, rarely provides a door-to-door solution and is also less flexible. Although bus and rail services may cover the main part of a trip, people need to first walk, drive or use another mode of transport to get to and from their nearest station or stop.

Good first- and last-mile options can make it easier to cover the distance before and after the main part of the trip and increase the flexibility of the supply of sustainable transport modes, thereby improving their attractiveness and increasing their service area.

The proposed revision of the TEN-T regulation, in line with the EU urban mobility framework, underlines the importance of multimodal urban nodes ([141]). Intermodal connections between long-distance and last-mile freight logistics are essential; urban freight must contribute to the efficient integration of urban nodes in the network by promoting seamless multimodal flows. This requires a holistic approach, including but not limited to technological developments; for example, digital solutions (e.g. real-time public transit information and integrated multimodal information) are very important in enhancing/enabling multimodality. Thanks to digital connectivity, customers will be able to book their journey in a few clicks, and will be offered a wealth of information before, during and after their journey about the best travel options and services. The objective is to develop an efficient and fully connected transport network that plays a large part in our decarbonised economy and offers affordable and safe travel and transport options to Europe's citizens.

Ensuring interconnectivity to enhance the resilience of multimodal public transport systems

Extreme weather events resulting from climate change create challenges for the transport system in handling related unforeseen disruptions. Understanding the resilience of interconnected infrastructure systems is important to effectively manage such disruptions. Interconnected transport systems may improve resilience by reducing topological vulnerabilities, integrating vulnerable systems to improve their robustness, and enhancing post-disruption interoperability and intermodal transfer. Strengthening interconnectedness among modes of public transit may foster a safe-to-fail system (with a resilience-by-design approach complementing the conventional resilience-by-intervention approach).

The importance of redundancy as one of the key elements/factors in ensuring better resilience to climate change was also highlighted through the UIC's Rail adapt project ([142]).

([140]) https://www.eea.europa.eu/publications/the-first-and-last-mile/file.
([141]) https://publications.jrc.ec.europa.eu/repository/handle/JRC130426.
([142]) https://uic.org/IMG/pdf/railadapt_final_report.pdf.

Conclusions

Our house is burning and we are looking elsewhere.

Jacques Chirac, 4th Earth Summit, Johannesburg, 2002

Since 2002, the level of awareness of the climate emergency has greatly increased among European citizens, and this is reflected in the ambitious political goals set in the European Green Deal. While we have been looking to tackle this existential threat more seriously (especially since the signing of the Paris Agreement), the fire is far from being extinguished, as the UN estimates that the limit of 1.5 °C warming could be reached as soon as 2025. During the peak of the COVID-19 crisis, the annual decrease was estimated by several organisations (Nature Climate Change, the International Monetary Fund and the International Energy Agency) to be around – 4.2 to – 7.5 %. This is an order of magnitude comparable to the rates of decrease needed year on year in the following decades to limit climate change to a 1.5–2 °C warming. This indicates the importance of making efforts to reach the objectives of the Paris Agreement and the European Green Deal.

Surface transport accounted for nearly half of the decrease in GHG emissions during the various lockdowns all around the world. This is another indicator that transport is a key sector to decarbonise in this strategy, on top of the fact that it produces one quarter of EU GHG emissions across all sectors and its emissions are still increasing. Despite its environmental impact, especially in terms of noise, rail remains the most environmentally friendly mode of mass transport, and will have an important role to play in achieving European environmental goals.

For passenger transport in an urban context, public policies should always consider the sustainable transport hierarchy, where active modes of transport (walking and cycling) are privileged, followed by public transport, including rail, then car-sharing and, finally, the (preferably electric) private car. Rail / public transport, walking and cycling therefore comprise the smart urban mobility triptych. For longer distances, rail has green competitive advantages over other modes of transport. Indeed, rail is the mass transport mode with the lowest GHG emissions and external costs, the highest degree of energy independence (especially if the energy comes from the EU's renewable sources), the highest efficiency in land-take and the most durable assets. This gives rail the potential to become the backbone of a multimodal transport system.

Rail also has a future in the freight sector. Each time rail is used to transport goods, even in a multimodal approach, we are getting closer to reaching the 2050 objective of a 90 % reduction in GHG emissions in the transport sector. Accelerating the modal shift to rail for the transport of goods would not only be a way to contribute to the decarbonisation of the EU economy but also reinforce its energy independence, as rail is and will remain substantially more energy-efficient than road transport.

Rail electrification, the implementation of the ERTMS, and the development of rail innovations such as alternative-technology-powered trains and further digitalisation will not only reduce the environmental impact of rail but also actively contribute to European wealth. Indeed, the European railway sector employs around 2.3 million people and represents approximately 1.1 % of the GDP of the Member States ([143]). A growth in rail-related employment would benefit the whole of society. Rail industries, from track equipment to rolling stock, are important technology clusters spread across almost all EU Member States. They create jobs that are spread throughout the EU territories, including less-favoured areas. This is particularly important in ensuring a just transition. Furthermore, railways are important with regard to the training of skilled staff and play a key role in avoiding youth unemployment and in securing a skills supply for the industry. However, rail still needs to make efforts to become more attractive, especially for women. With the continuous absolute growth of rail transport in the EU, it is expected that employment in the sector will continue to grow.

([143]) https://errac.org/wp-content/uploads/2019/03/122017_ERRAC-RAIL-2050.pdf.

While the EU is willing to achieve climate neutrality through the long-term establishment of net-zero carbon emissions and a resilient economy, the extent to which imperatives of climate change are considered when planning our economic response will largely influence the CO_2 emissions trend in the decades to come, and this is particularly true for the transport sector. This rail environmental report is the first of its kind produced by ERA but will not be the last. The agency is indeed committed to monitoring the evolution of the railway sector in relation to the environmental imperatives, and plans to issue the report every 3 years.

Annexes

Annex 1. Abbreviations

AISRR	All-Island Strategic Rail Review
ATO	automatic train operation
CH_4	methane
CNC	core network corridor
CO	carbon monoxide
CO_2	carbon dioxide
DAC	digital automatic coupling
EASA	European Union Aviation Safety Agency
EEA	European Environment Agency
END	environmental noise directive
ERA	European Union Agency for Railways
ERAIL	European Railway Accident Information Links
ERTMS	European rail traffic management system
ETCS	European train control system
FRMCS	future rail mobile communication system
gCO_2e	grammes of carbon dioxide equiva
GDP	gross domestic product
GHG	greenhouse gas
GSM-R	global system for mobile communications – railway
HSR	high-speed rail
L_{den}	day, evening and night noise level
L_{night}	night noise level
$MtCO_2e$	million tonnes of carbon dioxide equivalent
Mtoe	million tonnes of oil equivalent
N_2O	nitrous oxide
NH_3	ammonia
NOISE	Noise Observation and Information Service for Europe
NO_x	nitrogen oxides
NSA	national safety authority
PCR	product category rule
PM	particulate matter
SO_x	sulphur oxides
TEN-T	trans-European transport network
TSI	technical specifications for interoperability
UIC	International Union of Railways

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Annex 3. Data gaps

Data	Relevance	Potential provider
Share of renewable energy in gross final energy consumption by the railway sector	Provide a better understanding of the indirect emissions from the consumption of electricity by the railway sector	Infrastructure managers
GHG emissions from the electricity used by the railway sector at the EU level and the Member State level (based on the energy mix) (*)	Provide a better understanding of the indirect emissions from the consumption of electricity by the railway sector	Infrastructure managers
Weather-related occurrences affecting railway activities without necessarily leading to an incident or an accident	Allow the determination of some trends in the impact of climate change on rail transport activities	Infrastructure managers
Land use for parking spaces and shunting yards	Allow the refinement of the analysis of transport's land-take efficiency	—

(*) These data would also be valid for the road sector with the enhanced electrification of this mode of transport.

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