



The future of sustainable railway transport in Europe

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Final report

This study examines the possible long-term trajectories of the European railway system by analysing the trends, drivers, and uncertainties shaping its evolution towards 2050. It explores how emerging technological, regulatory, economic and societal developments may influence the role of rail within a sustainable, resilient, and competitive European transport system. The analysis considers a range of plausible future configurations for the sector, assessing their implications for mobility, energy use, climate objectives, territorial cohesion, and infrastructure needs. Attention is given to the potential relevance of innovative transport solutions, including hyperloop and maglev, within different development pathways, considering their technical feasibility, regulatory requirements, and system-level impacts.

The study draws on scientific and grey literature and integrates insights from relevant stakeholders to capture diverse perspectives on the future of rail. By identifying policy options, the work aims to support long-term transport planning and investment decisions at EU level. The findings are intended to inform ongoing policy discussions on the transformation of the European rail sector and its contribution to the Union's wider competitiveness, sustainability, and connectivity goals.

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Executive summary

The study is situated within the EU's long-standing objectives of promoting sustainable mobility, competitiveness and territorial cohesion through rail transport. Over recent decades, successive legislative packages and policy initiatives have progressively shaped the Single European Railway Area, supported by measures addressing market opening, interoperability, safety and infrastructure development. More recent initiatives, including reforms to railway capacity management and the revised TEN-T framework, have reinforced these ambitions while also exposing persistent structural challenges, notably fragmented governance, incomplete cross-border integration and uneven implementation across Member States. Further policy reflections underline the widening gap between strategic ambition and the institutional, financial and operational capacity of the EU's rail system.

Against this background, this study aims to support the European Parliament by providing a forward-looking assessment of how the European railway system could evolve towards 2050 under different policy, investment and technological pathways. The analytical approach combines a systematic mapping of trends, drivers and uncertainties across demand, supply, policy and regulation, technology, and funding and financing, with scenario analysis and stakeholder perspectives. The study adopts a foresight perspective to inform strategic decision-making at EU level, highlighting the importance of coherent sequencing of reforms, investment priorities and innovation to strengthen the contribution of rail to a sustainable, resilient and integrated European transport system.

Mapping of trends, drivers, and uncertainties

The analysis identifies a set of interrelated trends, drivers and uncertainties shaping the future performance and competitiveness of rail transport in Europe, structured around demand, supply, policy and regulation, technology, and funding and financing.

On the demand side, rail passenger traffic has recovered strongly since the COVID-19 shock, yet its modal share remains structurally constrained by generalised travel costs, reliability and ease of use, particularly for cross-border journeys. Rail is most competitive on medium-distance intercity routes, long-distance regional commuting and metropolitan mobility, where door-to-door travel times, service frequency and reliability are decisive. In freight transport, rail continues to face declining modal share, driven by short average haul distances, limited flexibility and operational fragmentation, despite growth potential in intermodal and low-carbon logistics segments.

On the supply side, the EU's railway system is characterised by a diverse service mix and an extensive but ageing infrastructure base. While the high-speed network has expanded significantly, capacity constraints, maintenance backlogs and temporary capacity restrictions increasingly limit performance, particularly on cross-border corridors. Electrification has progressed unevenly across Member States, reinforcing geographical disparities, while ageing assets and workforce shortages raise concerns about long-term reliability and resilience. Climate risks, including heatwaves and flooding, are emerging as a structural challenge, increasing lifecycle costs and reinforcing the need for systematic adaptation of infrastructure and operations.

Policy and regulatory developments continue to shape market structure and system performance. Progressive market opening has stimulated competition in selected passenger and freight segments, delivering efficiency gains and service improvements in specific contexts, but outcomes remain uneven across Member States. Fragmented governance, persistent national rules and slow progress on interoperability continue to hinder seamless cross-border operations. Recent legislative initiatives on capacity management, digitalisation and the revised TEN-T framework aim to address

these shortcomings, yet their effectiveness depends on coordinated implementation and sustained national commitment.

Technological developments are identified as critical enablers rather than standalone solutions. The deployment of the European Rail Traffic Management System (ERTMS), digital capacity management tools, automation and data-driven maintenance offers substantial potential to increase capacity, reliability and safety, but progress remains slow and fragmented. General-purpose digital technologies, including artificial intelligence and smart energy systems, are increasingly relevant for operational efficiency and decarbonisation, while emerging rail-specific technologies such as digital automatic coupling are particularly important for freight competitiveness. More radical innovations, including maglev and hyperloop, are assessed as long-term or niche options, with significant uncertainty regarding costs, interoperability, capacity and governance implications.

Funding and financing emerge as the dominant cross-cutting constraint. Rail infrastructure remains highly capital-intensive, with track access charges covering only a limited share of total costs, necessitating substantial public support. While EU instruments such as CEF, RRF and EIB lending play an important role, overall investment levels remain insufficient relative to identified needs, particularly for maintenance, resilience and cross-border projects. Long-term funding stability, cost overruns and delivery risks are highlighted as major uncertainties affecting future system performance.

Overall, the analysis highlights that the future trajectory of European rail is less constrained by technological feasibility than by governance coherence, investment capacity and effective system integration. Addressing these structural factors is central to improving rail's competitiveness and enabling a sustained contribution to Europe's mobility, climate and cohesion objectives.

Future scenarios and their implications

The study develops four stylised future scenarios to explore how different combinations of governance arrangements and technological trajectories could shape the European railway system towards 2050. The scenarios are not forecasts but coherent foresight constructs, designed to highlight structural trade-offs, enabling conditions, and constraints. Each scenario reflects a distinct configuration along two core dimensions: the degree of governance centralisation at European level and the nature of technological development, ranging from incremental to more transformative pathways.

Scenario I focuses on decentralised corridor implementation and incremental technology adoption. It reflects a continuation of the current institutional setting, in which EU-level objectives are pursued primarily through national implementation and corridor-based coordination. While incremental improvements are achieved through existing policy instruments and technological upgrades, fragmented planning, funding and execution limit network-wide optimisation. Progress in interoperability, capacity utilisation and cross-border continuity remains uneven, and EU-level ambitions translate into system-level outcomes only gradually, depending largely on national execution capacity.

Scenario II assumes central network planning and centralised network implementation. It explores a future characterised by stronger European-level coordination within an otherwise incremental technological trajectory. Centralised approaches to network planning, standard-setting and funding enable a system perspective across Member States, reducing coordination failures and strengthening cross-border continuity. Under this scenario, mature rail technologies deliver more robust and scalable gains in reliability, capacity utilisation and resilience, allowing the conventional rail system to perform more coherently as a European network without reliance on disruptive innovation.

Scenario III considers decentralised rail policies implementing national projects of transformative technology. It assumes a pathway in which technological ambition increases in the absence of stronger EU-level governance. Member States pursue advanced or edge technologies independently, reflecting national priorities and innovation agendas. While such projects may generate local or corridor-specific benefits, limited coordination risks reinforcing fragmentation, creating interoperability challenges and weakening network effects. In this scenario, technological progress alone does not overcome structural constraints related to governance, funding and system integration.

Scenario IV assumes a centralised high-speed rail system with most advanced technology. It represents a highly ambitious long-term configuration in which transformative technologies are developed as a dedicated European system layer, supported by centralised planning, regulation and funding. This scenario offers the greatest potential for profound travel-time reductions and new network effects at European scale, but it also entails substantial uncertainty, financial commitment and institutional complexity. It highlights trade-offs between investing in novel system layers and maintaining focus on the performance, maintenance and optimisation of the existing rail network.

Across all scenarios, the analysis consistently highlights that governance coherence and investment coordination are the primary determinants of system-level performance, outweighing the specific level of technological ambition pursued. The scenarios show that technological progress delivers meaningful benefits only where planning, funding and operational coordination are sufficiently aligned, and where reforms are sequenced in a way that first addresses structural fragmentation. In this sense, strengthening governance frameworks and ensuring stable, coordinated investment emerges as a precondition for realising its system-wide value. The scenario analysis therefore provides a structured lens for assessing policy options under different future conditions and for clarifying how current strategic choices can shape the long-term contribution of rail to a sustainable, competitive and integrated European transport system.

Policy options

The study identifies five policy options that illustrate distinct strategic pathways for the future development of the European railway system. These policy options are then stress-tested to reveal their performance in relation to the scenarios.

Policy Option 1 – Implementation and System Delivery focuses on closing the gap between existing EU ambitions and actual system performance by accelerating implementation, interoperability and operational consistency. It prioritises execution capacity, predictable delivery and the removal of cross-border bottlenecks within the current rail system, without requiring a fundamental institutional redesign.

Policy Option 2 – European High-Speed Rail Integration aims to maximise modal shift by developing high-speed rail as a coherent European network rather than a set of nationally fragmented projects. It emphasises corridor-level planning, cross-border continuity and network effects, positioning high-speed rail as a system tool that complements conventional passenger and freight services.

Policy Option 3 – Digitalisation and Operational Optimisation seeks to unlock additional capacity, resilience and freight competitiveness through coordinated digital tools, automation and data governance. It focuses on making better use of existing infrastructure by improving traffic management, capacity allocation, automation and interoperability across borders.

Policy Option 4 – Demand-Led Multimodal Integration addresses rail performance from the demand side by improving door-to-door journeys for passengers and logistics chains for freight. It prioritises seamless integration with other transport modes through interoperable ticketing, coordinated timetables, multimodal hubs and improved information continuity.

Policy Option 5 – European Ultra-High-Speed Strategic Infrastructure explores the development of ultra-high-speed systems as a distinct, EU-level network layer, fully planned, funded and regulated at European level. It represents a long-term, high-risk strategy aimed at transformational travel-time reductions on selected high-demand corridors, while explicitly complementing rather than replacing conventional rail.

The stress test shows that the performance of all policy options depends primarily on governance conditions rather than on technological ambition alone. Scenarios with stronger EU-level centralisation consistently enable better system-wide outcomes by addressing coordination failures in planning, funding and operations. A centralised but incremental pathway proves particularly robust for strengthening conventional rail, while policies underperform in decentralised scenarios due to persistent fragmentation, even when technology advances rapidly. Highly transformative futures offer additional long-term potential, but also introduce trade-offs, notably the risk that new technologies draw resources and attention away from maintenance, interoperability and optimisation of the existing rail system. Overall, the results underline the importance of sequencing governance reform ahead of, or in parallel with, technological ambition.

Conclusions

Looking towards 2050, the future of European rail will be influenced by major external pressures, including climate objectives, energy security, demographic change, digitalisation and geopolitical considerations, all of which are likely to increase rail's strategic importance. The analysis suggests, however, that technological progress alone is unlikely to address long-standing structural challenges. Without changes in how network planning, capacity management, interoperability and funding are organised, investments may continue to deliver uneven results. Scenarios characterised by stronger EU-level centralisation tend to enable more coherent system outcomes, while more fragmented settings remain exposed to coordination failures. At the same time, highly transformative pathways introduce uncertainties and potential trade-offs, particularly if attention shifts away from the performance and maintenance of the existing network. Overall, the findings highlight the importance of governance arrangements and sequencing in shaping how policy ambition translates into system-level outcomes over time.

Central to improving the performance of the European rail system is a shift towards more coordinated implementation, stronger EU-level fiscal capacity, and incentive-based regulatory frameworks. Greater centralisation of project appraisal and delivery, particularly through joint evaluation standards, can reduce persistent delays and cost overruns by aligning Member States around the wider European benefits of rail investments. At the same time, enhanced EU fiscal capacity is needed to address coordination failures and uneven distribution of costs and benefits, especially for cross-border infrastructure and emerging high-risk technologies. Finally, a regulatory approach based on managed (yardstick) competition, which rewards compliance with common standards rather than relying primarily on sanctions, can help overcome resistance from incumbent operators and accelerate convergence towards a more integrated European Single Rail Area.

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List of abbreviations

Abbreviation	Definition
AC	Alternating Current
AFIR	Alternative Fuels Infrastructure Regulation
AI	Artificial Intelligence
ARRT	Autonomous Rail Rapid Transit
ATO	Automatic Train Operation
CEF	Connecting Europe Facility
CER	Community of European Railway and Infrastructure Companies
CINEA	Climate, Infrastructure and Environment Executive Agency
DAC	Digital Automatic Coupling
DC	Direct Current
DER	Distributed Energy Resources
DMI	Driver Machine Interface
DNSH	Do No Significant Harm
ECA	European Court of Auditors
EEA	European Environmental Agency
EHP	European Hyperloop Centre
EIB	European Investment Bank
ERA	European Union Agency for Railways
ERDF	European Regional Development Fund
ERTMS	European Rail Traffic Management System
ESF+	European Social Fund Plus
ESIRS	European Simplified and Integrated Railway System
ESG	Environmental, Social, and Governance
ESS	Energy Storage Systems
ETCS	European Train Control System
ETF	European Transport Workers' Federation
EU-Rail	Europe's Rail Joint Undertaking
FRMCS	Future Railway Mobile Communication System

Abbreviation	Definition
GoA	Grade of Automation
GSM-R	Global System for Mobile communications for Railways
HDP	Hyperloop Development Programme
HICP	Harmonised Index of Consumer Prices
HTS	High-temperature superconducting magnets
IoT	Internet of Things
JNR	Japan National Railways
JNRSC	Japan National Railway Settlement Corporation
JR	Japan Railways
JRTT	Japan Railway Construction, Transport, and Technology Agency
LTE	Long-Term Evolution (communication standard)
LSM	Linear Synchronous Motor
MaaS	Mobility-as-a-Service
MDMS	Multimodal Digital Mobility Services
MFF	Multiannual Financial Framework
NTC	National Train Control
OA	Open Access
OJEU	Official Journal of the European Union
PaP	Pre-arranged train path
Pax-km	Passenger-kilometre ¹
PRIME	Platform of Rail Infrastructure Managers in Europe
PSO	Public Service Obligation
R2G	Railway-to-Grid
RBC	Radio Block Centre
RFC	Rail Freight Corridor
RNE	Rail Net Europe
RRF	Recovery and Resilience Facility

¹ A passenger-kilometre is a unit of measurement that represents the transport of one passenger over a distance of one kilometre. It is calculated by multiplying the number of passengers by the distance travelled and is used to quantify the overall volume of passenger transport activity, considering both the number of travellers and the length of their journeys.

Abbreviation	Definition
RRP	Recovery and Resilience Plan
RSST	Railway Static and Stationary Transformers
RTO	Remote Train Operation
SERA	Single European Railway Area
SWL	Single wagonload transport
TAC	Track access charges
TCR	Temporary Capacity Restriction
TEE	TransEuropeExpress
TEN-T	Trans-European Transport Network
TFI	Transport Flagship Initiative
TGV	Train Grande Vitesse
TMS	Traffic Management System
Ton-km	Tonne-kilometre ²
TRL	Technology Readiness Level
TSI	Technical Specifications for Interoperability
UIC	Union internationale des chemins de fer
WCSPE	Wireless Charging combined with Photovoltaic Energy

² A tonne-kilometre is a unit of measurement that represents the transport of one tonne of goods over one kilometre. It is calculated by multiplying the weight of freight transported (in tonnes) by the distance travelled and is used to measure the total volume of freight transport activity, reflecting both cargo weight and transport distance.

1 Introduction

1.1 Contextualisation

Over the past three decades, the European Union has progressively positioned rail as a cornerstone of sustainable mobility, safety, and territorial cohesion. The policy trajectory began in the 1990s with a strategic turn towards market opening, competition, and the functional separation of infrastructure and operations. The [1996 White Paper](#) (Commission of European Communities 1996) on revitalising rail set the direction for interoperable technologies and investment, with an explicit aim to shift traffic from road to rail; the [2001 White Paper](#) (Commission of European Communities 2001) reinforced this vision, advocating a competitive, resource-efficient railway within a unified European system, integrated with other modes to raise efficiency and connectivity.

This strategic vision was implemented through four successive legislative packages. The [First railway package](#) (2001) introduced competition in freight, improved financial transparency, and set fair access to infrastructure. The [Second railway package](#) (2004) accelerated liberalisation and strengthened safety and interoperability, establishing the European Union Agency for Railways (ERA) to harmonise standards across borders. The [Third railway package](#) (2007) advanced international passenger services and enhanced passenger rights, including certification standards for train drivers and frameworks for service quality and compensation. Together, these measures laid the legal foundations for the Single European Railway Area (SERA), consolidated by the Recast Directive 2012/34/EU (OJEU 2012) on infrastructure management, licensing, and charging. The [Fourth railway package](#) (2016) removed remaining market barriers: its 'market pillar' opened domestic passenger services to competition and mandated competitive tendering for public service contracts, while its 'technical pillar' harmonised safety and vehicle authorisation, further empowering the ERA.

As implementation advanced, the EU assessed performance and refined strategies. The Commission's 2018 review of Regulation (EU) No 913/2010 (OJEU 2010) noted the limited usage and unmet goals of the Rail Freight Corridors, despite improvements in cooperation and multimodal competitiveness; experience during the COVID-19 pandemic highlighted additional potential for cross-border rail freight. Subsequently, the 2021 Action Plan to boost long-distance and cross-border passenger rail (European Commission 2021c) proposed measures for better capacity allocation and traffic management, laying the groundwork for updated track access charging guidance.

Building on these evaluations, the EU proposed in July 2023 a new regulation to improve the use of railway infrastructure capacity, amending Directive 2012/34/EU and repealing Regulation (EU) 913/2010, to harmonise technical standards and operational procedures, optimise traffic management, and address planning challenges arising from Temporary Capacity Restrictions (TCR). In parallel, the [revised TEN-T Regulation](#) (OJEU 2024) strengthens the framework set by Regulation (EU) No 1315/2013 (OJEU 2013) by introducing a three-layer network structure and clearer completion deadlines, notably for the core, extended core and comprehensive networks. It enhances sustainability, interoperability and resilience requirements, aligning infrastructure development with the Green Deal's objectives. A key change is the replacement of the previous Core Network Corridors and Rail Freight Corridors with the [European Transport Corridors](#), ensuring a more coherent approach to both infrastructure and operations. These corridors now guide strategic cross-border investments and multimodal development across the EU. Complementary initiatives include the legislative proposal for [Multimodal Digital Mobility Services](#) (MDMS) to improve travel option comparison and booking, and the Action Plan on Military Mobility (2022) (European Commission 2022), all supporting the broader objectives of SERA.

The strategic and legislative framework aligns increasingly with wider efforts to strengthen single market competitiveness and cohesion. However, both the [Draghi](#) and [Letta](#) reports ((Draghi 2024) and (Letta 2024)) underline that the EU's railways still require substantial modernisation to meet the Union's competitiveness, connectivity, and sustainability goals, stressing the need for major investment in (high-speed) rail infrastructure, digitalisation, and interoperability. The Draghi report highlights persistent fragmentation, noting that hundreds of national rules and divergent operational requirements hinder seamless cross-border rail services. The Letta report, likewise, identifies structural barriers to a genuine SERA, pointing to obstacles for open-access operators and incomplete interoperability frameworks.

Both reports conclude that insufficient EU-level coordination remains a systemic constraint and call for stronger and centralised EU-level governance, harmonised signalling (ERTMS), and integrated ticketing frameworks, as key enablers to achieve the Green Deal's targets on modal shift and, ultimately, to ensure that rail can function as an efficient, continent-wide backbone of sustainable mobility. This direction is mirrored in the mission letter of the President of the European Commission to the Commissioner for Transport (von der Leyen 2024b), calling for further advancement of the [Trans-European Transport Network](#) (TEN-T) network and support for breakthrough technologies, such as Hyperloop, as part of a forward-looking strategy for sustainable, high-speed European rail connectivity.

Considering technology pathways, the Commission has tasked transport leadership to promote cutting-edge innovations. Hyperloop and Maglev systems are highlighted as potential complements to conventional rail, offering ultra-high speeds with low emissions and the capability to carry time-sensitive goods, combining the speed of aircraft with the convenience of trains. To explore and mature such innovations, the EU is funding research through [Europe's Rail Joint Undertaking](#) (EU-Rail) and Horizon Europe, with programmes such as the [Hyperloop Development Programme](#) (HDP) and projects like [Hyper4Rail](#), [MaDe4Rail](#), and [MagRail](#) examining scalable pathways to deployment.

Taken together, the policy, legislative, and research actions provide a coherent foundation for the present study. They articulate a long-term EU ambition: a digitally integrated, interoperable, and decarbonised railway that can sustainably expand its modal share in both passenger and freight markets, reduce external costs, and enhance competitiveness at the European scale. Within this context, the study's foresight perspective examines how governance integration, capacity optimisation, technology adoption, and corridor development can be sequenced to realise the benefits envisaged by the EU's evolving framework, while ensuring consumer-friendly, cross-border connectivity and resilience by design.

1.2 Aim and methodological approach

The principal aim of this study is to support the European Parliament in shaping a long-term vision for a sustainable, interconnected, and competitive railway sector across Europe. In alignment with the EU's climate objectives, economic cohesion, and strategic connectivity goals, including the completion of the Trans-European Transport Network (TEN-T) by 2030, the study seeks to anticipate and analyse multiple plausible futures for European rail transport. This will be achieved by systematically identifying and evaluating key trends, drivers, uncertainties, and potential disruptions that may influence the sector's evolution.

The study's specific objectives are as follows:

- Construct and analyse contrasting scenarios for the future of European rail. These scenarios will explore the implications for governance and coordination, network performance and capacity use, modal shift and demand response, technology pathways and system integration, and investment needs.

- Identify and assess strategic policy options and innovation pathways that can shape desirable outcomes for the sector, ensuring alignment with EU legislative and strategic frameworks.
- Examine the potential roles, feasibility, and system impacts of emerging transport technologies, such as Hyperloop and Maglev, within various future scenarios, taking into account technical, regulatory, financial, and societal factors.
- Incorporate perspectives from policymakers, industry, and civil society to capture diverse visions, expectations, and concerns regarding the future of sustainable railway transport.
- Provide actionable and foresight-informed recommendations to guide long-term EU transport strategies, investment priorities, and competitiveness agendas up to 2050.

To systematically explore the future of sustainable railway transport in Europe, the study adopts a thematic framework comprising five interrelated themes: (i) supply side, (ii) demand side, (iii) policy and legislative framework, (iv) technology, and (v) funding and financing. These themes serve as analytical lenses, enabling a comprehensive assessment of the trends, drivers, uncertainties, and opportunities that will shape the railway sector's evolution. Each theme is examined in terms of prevailing trends, key challenges, and potential opportunities for disruption, providing a robust foundation for scenario development and policy analysis.

The **supply side theme** addresses the evolution of rail services and infrastructure, the harmonisation of standards, and the optimisation of capacity and traffic management. The European railway system encompasses a diverse range of services, including high-speed, long-distance, regional, and night trains, as well as various freight operations (i.e. bulk, intermodal, and container). The development of both high-speed and conventional infrastructure, alongside progress in standards harmonisation (i.e. signalling, communication, and track gauge), is central to enhancing interoperability and efficiency. However, much of the EU's railway infrastructure is ageing, with sections facing congestion and maintenance backlogs. Workforce shortages, particularly in technical and operational roles, are becoming acute, and climate resilience is an increasing concern as infrastructure is exposed to more frequent extreme weather events. Investment cycles are often inconsistent, tied to political priorities rather than long-term planning, and freight capacity is constrained by mixed-use lines and outdated terminals.

Opportunities for transformation are emerging through automation and digitalisation. The deployment of driverless trains and automated yards can reduce costs and improve reliability, while predictive maintenance using general-purpose technologies (e.g. Artificial Intelligence (AI) and Internet of Things (IoT)) can extend asset life and minimise downtime. Modular rolling stock allows for flexible deployment and easier upgrades, and robotics and drones may further streamline inspection and repair processes, enhancing operational efficiency.

The **demand side theme** focuses on the factors influencing passengers and freight users in their choice of rail as a transport mode. For passengers, determinants such as travel time and cost, reliability, safety, information systems, comfort, and entertainment play a pivotal role. The integration of rail into the broader multimodal transport chain, particularly through integrated ticketing and digital travel platforms, has become increasingly significant, as it enhances the attractiveness and convenience of rail journeys. For freight, users are mainly influenced by fixed time and monetary switching costs, but also reliability, sustainability, and the degree of integration within the multimodal and logistics chain. However, the European railway market remains fragmented, with varying degrees of liberalisation and competition across Member States. While rail does not need to compete with road and air transport for every type of journey, it must continue to foster a unified customer experience across operators and reinforce its competitiveness on those segments where it provides a genuinely effective and sustainable alternative for modal shift, most notably mid-distance intercity travel, long-distance regional commuting, and mobility within major

metropolitan areas. The COVID-19 pandemic has further introduced uncertainty, altering demand patterns for both passenger and freight services.

Despite these challenges, there are notable opportunities for disruption. While the early expectations around Mobility-as-a-Service have not yet materialised at scale ((ITF 2021) and (van 't Veer, et al. 2023)), the progressive unification of ticketing and journey information systems across operators and modes remains a highly relevant enabler of seamless passenger mobility, supported by increasingly data-driven approaches to forecasting and service planning.

The entry of open-access operators and new market players is already demonstrating its ability to enhance competitiveness in the EU rail market, with evidence showing noticeable reductions in passenger fares (e.g. 31 % in Italy) and lower freight transport costs. In several Member States, competitive pressure has also contributed to more frequent services (e.g. 41 % rise in frequency in Austria's open-access market) and improvements in overall service quality, as illustrated by marked increases in train frequency in both open-access and tendered PSO markets. These developments indicate that market opening can stimulate innovation, deliver more attractive service offers, and generate operational efficiencies (de Rose, Trier Jørgensen and Doklestic 2024).

Furthermore, the development of cross-border and domestic high-speed rail corridors can complement aviation by reducing the need for short feeder flights, particularly where high-speed services offer competitive journey times and robust standalone demand (Rothengatter 2017). In such cases, rail can strengthen the overall multimodal network while contributing to the EU's connectivity objectives.

The **policy and legislative framework theme** examines the evolution of EU and national policies that have progressively liberalised and integrated the railway sector. As illustrated in the background section, successive railway packages have opened markets, promoted competition, and harmonised technical and safety standards, positioning rail as the backbone of green and connected mobility in Europe. Recent legislation has placed a strong emphasis on digitalisation, sustainability, and cross-border efficiency. Nevertheless, the regulatory landscape remains complex, with slow progress on harmonisation and interoperability. National safety and technical standards still vary, complicating cross-border operations and creating administrative burdens for new entrants. The pace of regulatory adaptation often lags behind technological innovation, and the high cost of compliance can deter investment and innovation.

There are, however, significant opportunities for regulatory innovation. The creation of a unified EU digital rail governance framework could streamline operations and reduce compliance costs, while regulatory sandboxes may allow for safe experimentation with new technologies. Open data initiatives can foster service and analytics innovation, and simplified licensing and certification processes would lower barriers for new operators. Stronger alignment with the European Green Deal could accelerate incentives for modal shift, supporting the EU's decarbonisation agenda.

The **technology theme** encompasses both the deployment of standard technologies and the adoption of emerging, potentially disruptive innovations. The roll-out of the [European Rail Traffic Management System](#) (ERTMS) and the European Train Control System (ETCS) is central to enhancing interoperability, safety, and efficiency. In addition, emerging technologies such as the Future Railway Mobile Communication System (FRMCS), Automatic Train Operation (ATO), and [Digital Automatic Coupling](#) (DAC) contribute to the transformation. Maglev and Hyperloop are considered technologies with the potential to disrupt the railway system. Despite this progress, many rail systems continue to rely on legacy technologies that are difficult to upgrade or integrate. Interoperability between national systems remains a major hurdle, and cybersecurity risks are increasing as digitalisation expands. The adoption of advanced technologies is often slowed by complex procurement rules and risk aversion.

Nonetheless, the potential for technological disruption is considerable. The deployment of 5G-enabled signalling and real-time traffic management can enhance infrastructure capacity, while autonomous train trials could redefine operations, particularly in freight systems. AI-powered analytics can optimise scheduling, energy use, and incident response. The development of alternative fuels and autonomous vehicles is advancing the sustainability agenda.

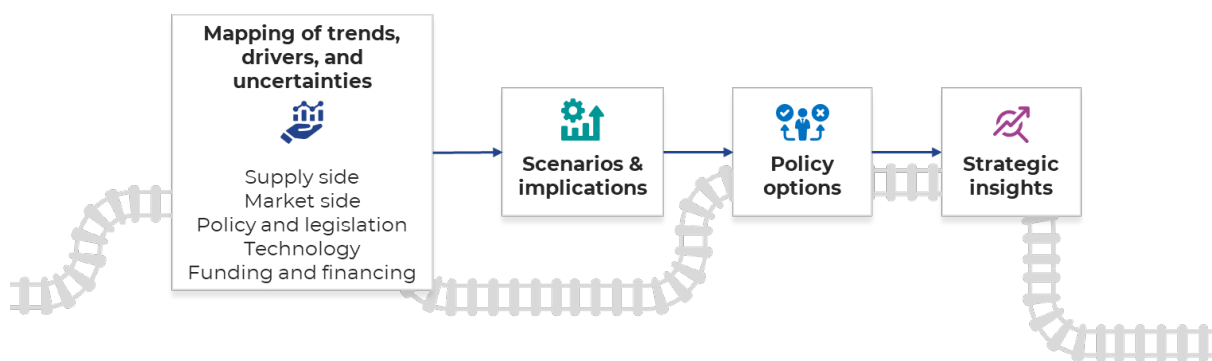
The **funding and financing theme** addresses the utilisation and absorption of EU and national funding instruments, including the Connecting Europe Facility (CEF), the European Regional Development Fund (ERDF), the Recovery and Resilience Plan (RRP), Horizon Europe, the European Investment Bank (EIB), and national promotion banks. Rail infrastructure projects are inherently capital-intensive, with long payback periods, and public funding is often constrained by political cycles. Cost overruns and delays are common, eroding stakeholder confidence, and traditional funding models may not align with the needs of innovation-driven projects.

Opportunities for innovation in funding and financing are emerging. Green bonds and climate-linked finance can attract Environmental, Social and Governance (ESG) investors, while blended finance models combining public and private capital can de-risk large projects. Outcome-based contracts may incentivise performance and innovation, and EU-level funding instruments such as CEF and InvestEU can support the development of strategic corridors. Crowdfunding and community investment models may also emerge for local or niche services, broadening the base of support for railway investment.

Taking stock of the mapping of the assessment of the trends, drivers, uncertainties, and opportunities identified in the framework of the five themes, the study adopts a stepwise methodological approach, beginning with the development and assessment of future scenarios for the European railway sector. These scenarios integrate technological, economic, and policy dimensions, informed by both quantitative and qualitative analysis. Building on this foundation, the study systematically evaluates strategic policy options and innovation pathways, ensuring their relevance and feasibility within the evolving European context.

Figure 1 provides a schematic presentation of the methodological approach of the study.

Figure 1 – Methodological approach of the study



Source: Elaboration by the authors.

A literature review and desk research on the five themes was complemented by interviews with various stakeholders and organisations relevant to the railway sector. The bibliography offers a detailed overview of the reviewed documents and sources of information. Interviews enriched the literature review with more qualitative information and case study highlights. The interviews were targeted to elicit views on the analysis and to validate or update the literature findings.

Through a multidisciplinary approach combining desk research, expert analysis, and stakeholder consultation, the study aims to deliver original analysis and strategic insights that will inform the European Parliament's contribution to a resilient, forward-looking transport system for Europe.

1.3 Overview of the study

Beyond this initial chapter, the study is organised as follows.

- Chapter 2 presents the analysis of key trends in the European railway sector, detailing how each trend is influenced by other trends and external drivers.
- Chapter 3 describes the suggested scenarios for potential futures of railways as a combination of technological, economic, and policy futures. The scenarios differ in terms of the degree of governance coordination, investment concentration and technological ambition shaping the European railway system.
- Chapter 4 presents policy options building on the analysis of trends and drivers, as well as the scenarios.
- Chapter 5 concludes this study.
- The bibliography presents the list of documents cited throughout the study.
- Annex I gathers the supporting evidence to the analysis presented in the previous chapters.
- Annex II presents the overview of the drivers.
- Annex III presents the synopsis of the stakeholder consultation activities.
- Annex IV presents insights on Hyperloop.

2 Mapping of trends, drivers, and uncertainties

Chapter 2 provides a mapping of the key trends, drivers, and uncertainties shaping European railway transport. It examines developments on the supply and demand sides, the policy and regulatory landscape, technological progress, and funding and financing conditions. By analysing how these elements interact and evolve, the chapter identifies the forces most likely to influence rail performance and competitiveness. This assessment forms the analytical basis for the future scenarios developed in Chapter 3.

2.1 Supply side

2.1.1 Services

In 2025, there were in total over 1 200 licensed railway undertakings operating in either freight or passenger transport (ERA 2025a). Of all active railway undertakings, 72 % offered freight services, and about 33 % offered passenger services (some railway undertakings offer both). In almost all Member States, the number of railway undertakings operating in freight is higher than those operating in passenger rail. This reflects the earlier opening of the freight market to competition. While both freight and passenger railway undertakings have grown in the period leading to 2025, the increase is especially marked for freight rail undertakings (Gardner, Brambilla and Matheus 2023) (see also Figure A.10 and Figure A.12). Especially in Germany, many of these freight railway undertakings are held by small companies, which are not involved in mainline freight (see also Table A.2).

Regarding long-distance cross-border passenger trains, the number of weekly train connections remained relatively stable between 2001 and 2019, at about 4 500 train connections. Of this total, high-speed connections almost doubled, while cross-border night trains were reduced by almost 66 %, or about 800 connections, from 2001 to 2019 (see also Figure A.1 and Figure A.2). In the same period, around 250 conventional cross-border train connections were added. This pronounced shift from night trains to high-speed trains is traceable to infrastructure changes in Spain, France, and Italy, with a large expansion of the high-speed network, which captured night-train passengers. For Eastern Member States, poor infrastructure conditions and disruptive maintenance and renewal are contributing factors to the decline of night-train connections. Other reasons include insufficient new rolling stock to replace ageing fleets (Steer 2021).

Despite the growth of the high-speed rail network since 2010 (UIC 2023), fewer than half of Member States offer passenger services with commercial speeds over 200 km/h (see also Figure A.7). On medium-distance routes (less than 500 km) connecting mid- and large-size cities, 30 % of services still operate below 60 km/h, with only 3 % above 150 km/h. This can partly be attributed to regional disparities, with most speed limitations happening in the Eastern Member States. The urban spatial structure and geographical obstacles also play a role, where rail connections between major cities are not suited to high-speed lines due to the demand for frequent stops and difficult terrain (Droes and Rietveld 2014) and (Shomik Mehndiratta 2024)).

Cross-border connections are 16 times more likely to face lower speeds than internal connections. A key reason for this is ineffective capacity management and allocation, due to prioritisation of railway capacity for national travel, which negatively impacts cross-border availability. Indeed, even in European countries which already have high-speed lines, on large parts of the infrastructure, trains cannot yet run at their maximum speed, either through line speed limitations or additional stops planned. It is important to consider, however, that these internal additional stops are useful in serving passengers outside major European urban areas. Additionally, interoperability limitations often also result in cross-border connections generally having lower speeds than internal

connections (Martijn Brons 2023). The effective management and allocation of rail capacity is a crucial driver for the competitiveness of rail transport, and in particular for cross-border traffic (Ecorys, TRT, and Hacon 2023).

Regarding rail passenger operations, public service obligations (PSOs) still accounted for a significant portion of 2023 operations. On average, PSO passenger services accounted for 64 % of total pax-km, down from 67 % in 2019 (IRG 2025). This suggests a progressive move towards a more competitive rail market (see also Figure A.11), driven by competitive tendering of PSOs, which has increased and is expected to continue to increase in the years to come, improving service quality and cost efficiency (European Commission 2025g).

EU rail freight transport performance in train-km decreased slightly in 2024, falling by 1.4 % compared with 2023 (see Figure A.20). The main category of goods transported by rail remained metal ores in 2024 (mostly driven by Poland, Germany and Sweden) (Eurostat 2025b). In 2023, freight load factor decreased by 3 % compared to 2019, after several years of growth. The average freight punctuality was above 65 % in 2023. Although the network shows a moderate level of utilisation (see Figure A.8), the main reasons for low punctuality can be traced to congestion in the nodes for intersecting traffic, unplanned diversions, maintenance works, vehicle technical problems, priority given to passenger trains in case of traffic disruptions, and staff shortages (ERA 2025a).

Rail remains the least carbon-intensive mode in the EU, accounting for only 0.3% of transport-related GHG emissions in 2023, compared with 73% from road transport and significantly higher intensities from aviation. European Commission monitoring shows that rail transport has consistently reduced its emissions since 1990, unlike most other modes (European Commission 2025d). Studies by the European Environment Agency (EEA) further confirm rail's superior GHG efficiency, with emissions per passenger-km and tonne-kilometre far below those of road and air transport (EEA 2021).

Rail also remains among the safest transport modes, although recent data shows 1 588 significant accidents in 2024, slightly lower than the previous two years and, except for a reduction in 2020 and 2021 due to the COVID-19 pandemic, in decline since 2014 (see also Figure A.19). Safety is a crucial concern, especially at level crossings and in regard to worker safety. Ageing infrastructure and years of underinvestment have increased maintenance needs and reduced reliability, with networks relying too much on reactive repairs rather than predictive maintenance (ERA 2025a).

Against this background, stakeholders representing railway undertakings, public authorities and workforce organisations converged in highlighting that service performance is increasingly constrained by operational reliability and workforce availability rather than by market structure alone. Interviewees underlined that staff shortages, ageing workforce and increasing complexity of operations are already affecting service robustness, particularly during disruptions and periods of intensive maintenance. From a service perspective, interviewees also emphasised that reliability and predictability have become decisive performance attributes for both passenger and freight services. While digital tools and new operating concepts offer potential efficiency gains, interviewees cautioned that service quality remains dependent on human presence, clear operational responsibilities and well-maintained assets, especially in mixed traffic and node intensive parts of the network.

2.1.2 Infrastructure

The total EU railway network length consists of more than 200 000 km (see also Table A.1 and Figure A.5). The total network length has remained relatively stable since 2010, and about 56 % of the network is now electrified (Chamaret 2023). Around half of Member States have increased their national network length in the period 2018–2022, with Spain leading with an increase of more than 5 % (European Commission 2025g). Although many countries are close to achieving full electrification (see also Figure A.9), a clear division remains between Eastern and Central/Western

countries, with some local exceptions, such as Denmark with low electrification and Bulgaria with high electrification.

The push for further electrification will continue, with core TEN-T lines required to be electrified by 2030. Achieving full electrification will substantially increase electricity demand, especially traction electricity, which already accounts for nearly 87 % of railway energy use. Current distribution grids face constraints on capacity and stability, while old 3 kV DC systems limit power throughput on several corridors. Strengthening substations, converting networks to 25 kV AC, and deploying stabilising technologies such as Static Frequency Converters and High Voltage Boosters are important actions for supporting a fully electrified European rail system (Vernova 2024).

The total high-speed rail network length has grown to more than 12 000 km, a significant increase from the 9 % of 2010. There are plans for an additional 1 600 km to be developed by 2035. Spain again leads in high-speed network length with close to 4 000 km, followed by France, with more than 2 700 km, and Germany with more than 1 600 km (European Commission 2025d) (see also Figure A.6). Stakeholders consider high-speed rail expansion as a tool to free capacity on conventional networks.

The share of single-track lines has declined from 62 % in 2010 to 59 % in 2020. This downward trend can be explained by the closure of single-track lines on underused lines, rather than conversion into double-track. There are close to 40 000 train stations in the EU, on average 2 800 per Member State (ERA 2025a).

On freight traffic, a slight downward trend can be observed in the number of freight terminals available. This is mostly driven by numbers in Germany, where a strong reduction of smaller terminals has taken place in recent years. However, this mostly affected smaller terminals, while new, larger, and more efficient ones were being built. The proportion of intermodal terminals (serving at least two modes) has remained stable at around 22 % of the total terminals (IRG 2025).

Regarding track gauge, the majority of EU Member States uses a standard track gauge of 1 435 mm. Some peripheral countries use a broader gauge, due to historical reasons: Finland, Latvia, Lithuania and Estonia use tracks of approximately 1 520 mm, Ireland operates on 1 600 mm gauge, and Spain and Portugal use a gauge of 1 688 mm. Many of these countries have begun converting their network or are constructing new lines in the 1 435 mm gauge. Track gauge difference is still a big physical barrier to cross-border connectivity, although this is a localised problem, only affecting outer states (Transport & Environment 2025). Spain has mitigated this gauge barrier through the adoption of variable-gauge passenger rolling stock, including Talgo's gauge-changing technology and Renfe's variable-gauge Alvia services.

European railway infrastructure is exposed to climate hazards such as heatwaves, flooding, and other extreme weather events, which can directly impact tracks, bridges, earthworks, electricity systems, and signalling (Quinn, et al. 2017), leading to service disruptions (European Environment Agency 2024). According to the EU railway sector, these disruptions led to an estimated €2 billion in costs in 2024-2025 (CER 2026). For these reasons, climate resilience has become a priority for railway infrastructure, as evidenced by the EU Strategy on Climate Adaptation, which estimates a need for an additional 3% of upfront costs for climate-resilient infrastructure (European Commission 2021). The incorporation of the 'Do No Significant Harm' (DNSH) principle in public funding programs also ensures that climate mitigation and adaptation dimensions are incorporated into railway infrastructure public investments (OJEU 2020). Member State authorities also confirm that climate resilience is part of their national priorities. Still, much of the existing European railway infrastructure remains vulnerable, and upgrading the existing assets will continue to be a necessary point of attention in the future.

The overall picture is corroborated by stakeholder views, with representatives of infrastructure managers, national administrations and research bodies consistently stressed that the EU railway

network is facing a growing maintenance and renewal backlog. The interviewees warned that decades of underinvestment are progressively constraining reliability and available capacity, with effects becoming most visible on heavily used corridors and at major nodes. There was strong agreement that sustained investment in maintenance and systematic renewal constitutes a foundational driver of system performance and safety. Interviewees noted that deferred maintenance often results in cumulative degradation, masking risks in the short-term while increasing long-term costs, capacity restrictions and exposure to service disruptions. Stakeholders also converged on the view that infrastructure modernisation is inseparable from climate resilience and highlighted that modernised assets recover more rapidly from extreme weather events, whereas ageing infrastructure remains particularly vulnerable to heat stress, flooding and power supply failures. In addition, the stakeholders broadly agreed that high-speed rail can generate system level benefits by providing competitive long-distance services while freeing capacity on conventional lines. However, interviewees underlined that these benefits materialise only where high-speed investments are aligned with sufficient funding, timely permitting, industrial capacity, and integration with the wider network and local services.

2.1.3 Costs and revenues

2.1.3.1 Infrastructure managers

Across the EU, infrastructure managers face operational costs between €50 000 and €190 000 per track-km per year, with an annual average of €120 000 per track-km. The total operational expenditure, though variable, shows an annual growth from 2018 to 2022. This can mostly be attributed to price increases since after the COVID-19 pandemic, reinforced by the economic effects of Russia's war on Ukraine. The largest operational cost categories are maintenance and traffic management, while finance and power consumption costs constitute a smaller share. Operational costs are driven by several different factors, including the size and complexity of the networks, train utilisation, condition and age of the assets, and traffic management. As the services provided by infrastructure managers vary significantly, the different technologies and the amount of human resources needed determine the level of expenditures for each infrastructure manager (PRIME 2022).

Regarding capital expenditure, the annual average per infrastructure manager stands at €145 000 per track-km, with a maximum of €340 000. Most infrastructure managers' capital expenditure shows a growth over the period 2018-2022, though there is a lot of variation, as capital expenditures are often linked to major (re-)investment programmes (see also Figure A.15). The largest share of capital expenditures is reported for renewals. Indeed, capital costs are driven by network complexity and are highly dependent on the budget and financing of each infrastructure manager (PRIME 2022). A clear division also remains between Western European countries, and Central and Eastern countries. The latter show lower levels of investment, due to lower capital intensity and labour productivity (Hana Fitzová 2024).

In 2023, infrastructure managers grossed €23.4 billion from track access charges (TAC) for the minimum access package, as defined in point 1 of Annex II of Directive 2012/34 of the European Parliament and the Council. About 90 % of all European TACs derive from passenger services. The average TAC per passenger train-km was €5.13 (see also Figure A.17). However, this indicator varies substantially between European countries. Passenger TAC revenue declined during the pandemic but again sits at 10 % above 2019 levels. Freight TAC revenue, on the other hand, showed only partial recovery and remained 5 % below 2019 levels (see also Figure A.18).

The study on the state of play of internalisation in the European transport sector concluded that the revenues from TAC alone do not cover the full costs of maintaining and operating EU's rail infrastructure (van Essen, et al. 2019). The study concluded that the overall infrastructure cost coverage of TAC averaged only around 19 % of the overall infrastructure costs and 102 % of the

variable infrastructure costs, respectively. The ratios reflect the dominance of fixed costs in the rail system, which constitute the bulk of the total infrastructure expenditure and the fact that, in general for the Member States, the TAC schemes cover the variable infrastructure costs, being based (at least partially) on the marginal cost pricing principle. Consequently, the TAC alone do not ensure sustainable financing of the railway infrastructure, requiring complementary public funding mechanisms through general taxation. In this regard, in 2023, 64 infrastructure managers reported receiving almost € 47 billion of external funding, more than twice the revenues from TAC. Major sources of external funds come from state and regional budgets, which make up about 80 % of the share of external funds, and European funds, which cover around 10 %, and loans (IRG 2025). Section 2.5 provides further insight into funding and financing in the railway sector.

These findings are reinforced by stakeholder input. Infrastructure managers, public authorities and research organisations broadly agreed that current cost and revenue structures reflect the capital-intensive nature of rail infrastructure and the dominance of fixed costs. In this respect, interviewees emphasised that TAC alone cannot ensure sustainable financing of maintenance, renewal and resilience investments, particularly in highly utilised networks. Moreover, several stakeholders cautioned that pressure to contain TAC, while politically necessary to support service affordability and modal shift, risks reinforcing underinvestment if not accompanied by stable and predictable public funding. Interviewees therefore highlighted the importance of long-term financing frameworks capable of balancing affordability objectives with infrastructure sustainability.

2.1.3.2 Railway undertakings

In 2023, the average revenue for passenger railway undertakings was €24.2 per train-km (increase of 7 % from 2022) and €0.17 per passenger-km (decrease of 3 % from 2022). The increase in revenue per train-km was driven by the increase in revenue from fares, while PSO compensations mostly remained unchanged. On the demand side, while PSO revenue per passenger-km decreased by 6 %, non-PSO unit revenue rose by 4 % from 2022 to 2023, signifying a shift towards non-PSO services or longer trips (IRG 2025).

Regarding freight railway undertakings, in 2023 their average revenue was €25.6 per train-km and €0.045 per ton-km. Both these values mark a strong increase from previous years, 12 % and 15 % respectively. This increase in average revenue per train-km was driven by cost inflation in countries with high freight transport volumes, such as Poland, Germany, and France (IRG 2025).

The market share of new entrants in the EU-27 rail freight sector reached 49 % in 2022, continuing an upward trend from 39 % in 2018. In passenger rail, new entrants had a 12.6 % market share in 2022, nearly double the 6.6 % recorded in 2020. In the national PSO passenger market, competitors held a 21 % market share in 2022, marking a significant increase from 18.5 % in 2020. These share increases for new entrants can be traced back to market liberalisation policies, which have stimulated competition in the rail sector (European Commission 2025g).

2.1.4 Capacity and traffic management

Railway capacity is higher in core countries of the network, such as France, Germany and Poland, as there is a need for more double-track lines to accommodate more freight traffic. Population density also affects the necessary network capacity, as in high-density countries such as Belgium and the Netherlands. Denmark, Austria, the Netherlands, and Germany had the highest capacity utilisation, with over 28 000 train-km per track-km each year. Countries with low utilisation should prioritise resolving bottlenecks and station upgrades before expanding capacity (Transport & Environment 2025).

Electrified lines show significantly more utilisation than non-electrified lines, with the electrified 56 % of the network carrying around 80 % of the total annual train-km. Although there are variations by country, the share of traffic carried by the electrified lines is higher than the electrified share of

the network in all countries. However, since electrification is not essential for a functioning railway, it can be lower in the priority list for Member States with limited investment capacity, provided they invest in zero-emission rolling stock for non-electrified and low-density lines (Transport & Environment 2025). The cost of electrification is proportional to track-km but the benefits are proportional to train-km. Therefore, it is less worthwhile the lower the traffic density.

The congestion on EU railway tracks in 2022 was over 6 711 km, of which 3 523 km of rail freight corridors, showing a slight decrease from previous years. In case of congestion, Member States most often prioritise services under a PSO, followed by international passenger services. Freight traffic is rarely given top priority (European Commission 2025g).³

For freight traffic on the Rail Freight Corridors (RFCs), the capacity requested by railway undertakings is often much lower than the offered capacity. This low attractiveness of the RFCs can be attributed to a lack of flexibility and market orientation, which arise from limited resources and tools for capacity management of cross-border freight traffic (Ecorys, TRT, and Hacon 2023) (see also Figure A.3).

Furthermore, railway undertakings have a general tendency to safeguard capacity by placing requests via the annual process just to book capacity, as there is no guarantee of receiving high-quality capacity via ad-hoc requests. However, as the actual capacity needs details emerge at later stages, modifications and cancellations are frequent. Between 20 % and 25 % of freight train path requests are stable, and the remaining requests have to be modified, resulting in a big waste of resources (time and costs) on both railway undertakings and infrastructure managers' sides (see also Figure A.4). Notably, the number of changes or modifications of annual timetable requests registered by infrastructure managers and freight companies is more than two times higher than the number of requests, and the changes are significantly higher for the freight applicants than for the passenger applicants (Ecorys, TRT, and Hacon 2023). Freight traffic is much less predictable than passenger traffic, which sticks to a published timetable.

On infrastructure capacity and traffic management, interview findings echo the desk-based evidence. Stakeholders representing infrastructure managers, railway undertakings and EU level bodies converged on the conclusion that capacity constraints are no longer a future risk but rather a binding structural condition across significant parts of the European network. In this context, the interviewees stressed that congestion at nodes and on core corridors already limits the system's ability to accommodate additional passenger and freight demand. Stakeholders emphasised that digital traffic management and capacity allocation tools offer substantial potential to optimise existing infrastructure. However, interviewees consistently underlined that real system level benefits depend on cross-border coordination and federated implementation of national systems, rather than fragmented or corridor specific solutions.

Generally, inefficiencies in rail capacity management often result from uncoordinated planning and execution of infrastructure works, which cause temporary capacity restrictions (TRCs). TRCs have a significant impact on cross-border rail freight traffic. TCRs are essential for the maintenance, renewal, or upgrade of the rail network. The stable planning of TCRs, however, is hindered by multiple factors that negatively impact network capacity and service quality. These factors include planning modifications between initial announcements of TRCs and their execution, and the absence of a comprehensive network approach which considers not only the affected railway lines, but the neighbouring ones as well. Driving these issues are maintenance planning and tendering processes, which are often incompatible with TCR coordination timelines, as infrastructure managers do not

³ A problem in the EU network is the allocation of infrastructure capacity between passenger and freight traffic. As rail freight transport is not bound by a fixed schedule like passenger transport, the usage infrastructure by freight operators is subordinated to passenger operators, unless there is sufficient overcapacity (e.g. for mobility restrictions during COVID-19 pandemic) or dedicated tracks for each mode (RNE 2025).

always organise detailed maintenance planning and tendering processes in a way that allows them to provide detailed execution information at that stage, leading to subsequent modifications (Ecorys, TRT, and Hacon 2023).

In this respect, interviewees concern was expressed regarding inefficient capacity use in freight operations. Interviewees noted that over reservation of train paths and frequent late modifications, the insufficient coordination of TCRs result in lost capacity and increased costs for both infrastructure managers and rail operators. Addressing this inefficiency was seen as a major opportunity to improve performance without immediate large scale physical expansion, although stakeholders agreed that capacity optimisation alone will not suffice in the medium- to long-term.

2.2 Demand side

2.2.1 Passengers

Rail passenger traffic volumes have followed an increasing trajectory from 2015 to 2019, followed by a steep drop due to the COVID-19 pandemic in 2020 and 2021, and a strong increasing trend from 2022 through 2024. Of the over 350 billion pax-km recorded in 2022, about 93 % came from domestic travel,⁴ and the rest was international.⁵ An all-time high value of over 440 billion pax-km was reached in 2024 (see also Figure A.21 and Figure A.22). Though also on the rise after 2020, railways make up about 8 % of the passenger land transport modal split. Travel by passenger cars is the dominating land passenger transport mode with a stable share of 72 % or above. Air transport slightly increased up to about 10 %, while trams and metros, and buses and coaches, faced minor modal share reductions from 2018 to 2023 (European Commission 2025d) (see also Figure A.23 and Figure A.24).

Stakeholder consultation revealed climate awareness and service preferences as strong drivers for rising passenger demand. In particular, stakeholders from passenger organisations, public authorities, and operators converged in emphasising that rising climate awareness contributes to renewed interest in rail, particularly for long distance services. At the same time, interviewees consistently underlined that affordability, reliability, booking simplicity and door-to-door travel times remain the decisive determinants of sustained modal shift. In parallel, the interviewees cautioned that environmental considerations alone are insufficient to change travel behaviour in the absence of competitive generalised costs. Stakeholders therefore stressed that policies focused exclusively on high speeds or flagship services risk limited impact if reliability, frequency and integration with local and regional networks are not addressed simultaneously.

Mode choice is generally explained by generalised costs, combining monetary cost (i.e. fares, subsidies, and taxes), travel time (i.e. in-vehicle, access/egress, and waiting), reliability and frequency, and convenience factors (i.e. interchanges, comfort, luggage, ticketing). A modal shift to rail occurs when these generalised costs fall below competing modes, but the elasticities differ by trip purpose and distance (Luh 2024) and (Wardmann 2025)). The German €9-ticket experiment demonstrated that large, simple fare reductions can trigger short-term modal shift and generate traffic, particularly from car to regional rail, although persistence depends on service quality and capacity (Chapuis 2023). For long-distance business travel, price incentives have limited impact unless accompanied by time or convenience improvements (Bursa 2024) and (Chapuis 2023)). In this context, improving onboard experience (e.g. through reliable Wi-Fi, ergonomic seating, quiet

⁴ The desk research showed that for domestic passenger rail transport there is no EU-wide official dataset providing detailed indicators to elaborate further by distance class (i.e. regional or long distance).

⁵ The pandemic reinforced the domestic nature of passenger rail traffic. Before COVID-19, international passenger services accounted for around 7% of total rail traffic, but this share dropped to less than 4% in 2020 due to mobility restrictions. By 2022, the proportion of international rail passenger services recovered to 7%.

zones, catering, and seamless digital services) can enhance rail's attractiveness, particularly against aviation, where travel time includes non-productive segments (i.e. check-in, security, and boarding) and where onboard productivity is limited.

Reductions in door-to-door travel times are among the most powerful drivers of modal shift, especially against air and car. High-speed rail corridors in Europe show that when rail achieves city-centre to city-centre times of under 3–4 hours, rail can capture 50–80 % of market share from air, even without large fare subsidies (ERA 2024) and (European University Institute 2022)). Moreover, improving reliability and frequency can be as effective as reducing travel time, especially for regional travel and commuting. Poor punctuality and low frequency systematically undermine price-based modal shift policies (ERA 2024). However, passengers value the total journey time, rather than in-vehicle speed alone (Wardmann 2025). Therefore, improvements in station-to-station speeds without corresponding reductions in access, interchange, or reliability deliver limited modal shift, especially outside dense metropolitan cores. Modal shift strategies relying mainly on very high-speed intercity links between major hubs are less effective in countries with polycentric settlement patterns, as access and feeder travel dominate door-to-door time (ERA 2024).

Average punctuality for passenger rail stands at around 87 % in 2023, on an increasing trajectory from previous years (ERA 2025a) (see also Figure A.13). A European Commission study has found that, across a variety of cases, ticket prices have generally decreased, and the quality of the rail passenger service has increased, since the introduction of Open Access (OA) competition (see also Figure A.25). Specifically on pricing, OA competition has provided a variety of ticketing options to passengers. Regarding service quality, competition has also promoted the upgrade of amenities aboard trains, as non-incumbents aim to win over passenger shares, and these service enhancements have incentivised incumbents to follow. These effects on pricing and service quality have resulted in railways becoming more attractive to passengers, thereby increasing demand for rail, and shifting passengers to rail from competing modes, as is especially clear in case studies from Spain and Italy. Here, the introduction of competition on high-speed lines has contributed to high-speed rail outcompeting aviation on domestic connections and capturing the majority of the mode share (European Commission 2024).

However, from the perspective of a rail traveller, there are still several barriers to tackle, especially for international travel. First, travel time can make trains attractive compared to other options, but in practice, on large parts of the infrastructure, trains cannot yet run at their maximum cruising speed, either through line speed limitations, insufficient capacity, or non-optimal timetable design. Second, travel cost is perceived as higher than air travel, though often additional costs of air travel (such as parking fees and travel to and from airports) are not accounted for. Third, direct train connections (or lack thereof) also play a role in passenger mode choice criteria. This is especially true when considering delays or cancellations, which can leave passengers stranded and seemingly without support, or with unclear passenger rights. Last, the poor integration and user-friendliness of the booking system compared to other modes of transport negatively influences mode choice when booking a trip with multiple legs (Witlox 2022).

The shift from other modes to rail transport, especially on medium distances, can be driven by network development and competition. On network development, there is some evidence that high-speed rail contributes to modal shift, though this is not sufficiently consistent. The upgrade of existing conventional lines is also a driving factor. Competition benefits the modal shift to rail, both through internal price competition and through price competition against rival air and coach options (Pastori 2018).

2.2.2 Integration in the multi-modal passenger chain

Regarding rail passenger transport integration with other modes, the following trends are expected to have the greatest potential in Europe. The increase of urbanisation and congestion can increase

the competitiveness of rail, where private cars do not perform so well. In dense urban areas, rail can serve as the backbone of a multimodal transport system. This trend is reinforced by Mobility-as-a-Service (MaaS), which gives access to an integrated interface for intermodal trips, allowing seamless switching between modes. The MaaS market was valued at €15.44 billion in 2024 and is expected to grow to almost €140 billion by 2033 (Business Wire 2025). Finally, growing demand for intra-EU leisure trips and environmental awareness influence the demand for rail transport (CE Delft 2018).

Despite comprehensive data on integrated ticketing services not easily retrievable, national integrated ticketing platforms have grown steadily. Early leaders like the Netherlands, Sweden and Germany set the trend toward single-ticket access across multiple transport modes. Other countries (like Austria, Belgium, Denmark, and Ireland) have since developed similar nationwide smart-card or digital systems. This trend towards wider integration is driven by digitalisation and passenger demand for seamless multimodal travel. Transport operators' reluctance to share dynamic fare and travel data can hinder progress on integrated ticketing systems (European Commission 2019b).

2.2.3 Freight operations

Freight traffic volumes decreased from 421 billion ton-km in 2018 to 397 billion ton-km in 2020, before recovering to 416 billion ton-km in 2022. This value is divided at around 223 billion ton-km per year for international rail, and 193 billion ton-km per year for domestic rail (see also Figure A.26 and Table A.5). In terms of train-km, rail freight saw over 792 million train-km in 2022. However, the freight modal share has been slightly declining since the COVID-19 pandemic, from almost 19 % in 2019 to less than 17 % in 2023 (see also Figure A.27). This decrease indicates a continuation of the shift towards road transport. The overall decline was particularly pronounced in Latvia, Estonia, and Lithuania, where freight volumes dropped significantly due to reduced exchanges with Russia. Intermodal rail transport performed relatively better than bulk materials and single wagonload transport (SWL) (European Commission 2025d).

In freight transport, modal choice depends on generalised logistics costs, typically including monetary cost (transport price, handling, subsidies), transit time (door-to-door), reliability and variability (buffer time, inventory costs), frequency and flexibility, and network and terminal access. Unlike passenger transport, the value of time is indirect, expressed via inventory holding costs, production disruption risk, and service commitments (Jonkeren 2023) and (Takman 2021)). In EU freight transport, modal shift to rail is driven primarily by trade distances, reliability, capacity, and end-to-end service quality, while monetary incentives act as enabling rather than decisive factors. Subsidies are most effective where rail is already close to competitiveness, particularly on medium- and long-distance corridors (Takman 2021). The modal competition is primarily between rail and road transport, with breakeven distances between unimodal and multi-modal freight transport estimated to be 600–650 km, depending on the size of the area around rail logistics stations (Zgonc, Tekavčič and Jakšič 2019).⁶

Various future trends influence the rail market. First, the phase-out of coal transport, which has fallen almost by half from 2015 to 2024, negatively impacts the bulk market segment. Second, the rise of just-in-time logistics regimes will drive a decline in SWL transport, which will in turn impact the conventional goods market. Growth in maritime, intermodal transport, and demand for low-carbon freight transport puts rail freight in a competitive position. A reduction of cross-border difficulties, mainly low speeds and interoperability problems, could significantly improve the competitiveness and demand for freight rail (CE Delft 2018).

⁶ Elaborations based on Eurostat data on distance-class split and type of good reveal that about 60 % of all EU freight distances are too short to shift to rail transport. Moreover, the slight changes in the distance distribution over the past four years also point to reduced opportunities for modal shift from road to rail freight transport.

Regarding pricing, both intra- and intermodal competition can influence rail freight pricing. In Germany, for instance, intra- and intermodal competition has led to noticeable improvements in quality and price reductions on the railways, but without a sustainable increase in rail's share of the market. In Poland, there is specialisation in the haulage of specific types of freight rather than geographic specificity regarding particular routes. This specialisation in types of freight suggests that internal competition has less impact on margins and revenues than external competition from road transport. Many customers, mainly from outside the minerals and raw materials sector, are very price-sensitive and hence better able to switch mode of transport in the event of a rate increase. Overall, transport prices across all modes are expected to increase in the future. This is due to the increase of energy price, shortage of drivers for both trucks and trains, and the fact that rail locomotives are becoming increasingly expensive (European Commission 2024).

2.2.4 Integration in the multi-modal logistic chain

A set of technical, organisational, and market facing drivers influence the effective integration of rail into the multi-modal logistic chains. Cross-border interoperability is key, covering infrastructure standards such as track gauge, axle load, voltage and harmonised timetables. The quality of the network (i.e. its proximity to productive areas and the road network, efficient terminal operations, capacity to handle different types of cargo) and the density of the rail network are drivers in advancing multi-modal logistics integration. Additionally, without renewed efforts and investments in multimodal freight terminals, the overall terminal offer in the EU is likely to deteriorate over time rather than improve (European Commission 2026a).

The organisational complexity of the freight transport chain, which requires cooperation and communication between a multiplicity of stakeholders (i.e. shippers, infrastructure managers, terminal operators, railway undertakings, wagon keepers), can be a barrier to multimodal rail freight services. The effective cooperation on operations (including sharing of information) between the involved stakeholders of the multimodal transport chain is generally still limited, especially with respect to interface at terminals and involvement of end customers (Ecorys, TRT, and Hacon 2023). This can become an operational barrier, both internally as lack of real time information exchange between rail undertakings, and on the customer side due to lack of knowledge of market opportunities, and a lack of competence to develop supply chain projects involving multimodal solutions (Pastori 2018).

Focusing on the import of maritime containers, defined by low-density, high-value goods (such as electronics and conditioned goods), there is potential for freight rail to gain market on this segment. Drivers for acquiring a market share are defined by the required services in this market, namely delivery time, punctuality, and technical services such as real time track-and-trace (CE Delft 2018).

2.3 Policy and legislative framework

2.3.1 EU rail policy

2.3.1.1 Strategic policy context for rail

European transport policy has undergone a gradual but significant transformation since the early 1990s. The [1992 Transport White Paper](#) (Commission of European Communities 1992) initiated a new policy direction centred on opening transport markets and establishing the foundations of a competitive internal transport system. In 2001, the Commission signalled a shift towards managing transport growth more effectively across all modes, emphasising the need to rebalance transport demand and to reduce congestion and environmental impacts. The [2008 Greening Transport Package](#) (Commission of the European Communities 2008) further reinforced the commitment to decarbonisation and placed rail transport at the heart of efforts to reduce the environmental footprint of the transport sector.

A decade after the [first White Paper](#) (Commission of European Communities 2001), the [2011 White Paper](#) (European Commission 2011) expanded the vision to a comprehensive long-term strategy. It framed rail transport as a central pillar of the transition towards a competitive, resource-efficient and integrated transport system. The 2011 White Paper called for a substantial increase in rail transport share of long-distance passenger and freight modes, supported by structural reforms, including high-quality infrastructure and greater cross-border interoperability. However, the European Court of Auditors has repeatedly warned that the EU's high-speed rail development remains an "ineffective patchwork" of poorly connected national projects, marked by cost overruns, construction delays and the absence of a coherent EU-wide strategic approach (ECA 2018).

The policy momentum was further reinforced by the [Sustainable and Smart Mobility Strategy](#) of 2020 (European Commission 2020), which defined rail transport as a backbone of Europe's future sustainable mobility system. It set ambitious modal shift objectives, including doubling high-speed rail by 2030 and tripling it by 2050, and emphasised the importance of electrification, including hydrogen-based solutions, alongside advanced technologies such as digital automatic coupling (DAC) and further automation of rolling stock. The Sustainable and Smart Mobility Strategy also underscored the need to update Technical Specifications for Interoperability (TSIs) and accelerate the deployment of the European Rail Traffic Management System (ERTMS). In 2021, the Commission published its [Action Plan to Boost Long-Distance and Cross-Border Passenger Rail](#) (European Commission 2021c), identifying actions required to remove barriers to international passenger services, including improved capacity allocation and more coordinated traffic management across Member States.

Digital transformation has become a cornerstone of more recent policy efforts. Beginning with the [2010 Digital Agenda](#) (European Commission 2010) and strengthened through subsequent communications such as [Digitising European Industry](#) (European Commission 2016) and the [European Data Economy Communication](#) (European Commission 2017), the EU set the basis for data-driven transport systems and digital interoperability. The 2021 [Digital Compass](#) (European Commission 2021b) introduced a vision for a digitally integrated transport landscape by 2030, including interoperable data spaces for mobility, enhanced automation and improved digital tools supporting rail transport operations and multimodal traveller services.

Broader political guidance also shapes EU rail policy. The 2025 [European Compass for resilience and competitiveness](#) (European Commission 2025c) the [Political Guidelines](#) of President von der Leyen (von der Leyen 2024a) and her [letter to Commissioner Tzitzikostas](#) to pursue sustainable mobility (von der Leyen 2024b), all reinforce rail's strategic importance. Parallel work on a [European high-speed rail network plan](#) (European Commission 2025b) complements the revision of the [TEN-T Regulation](#) (OJEU 2024) and supports the long-term objective of creating a fully interconnected European rail area.

Lastly, the Joint Communication on [Military Mobility](#) (European Commission 2025f) underscores the dual use requirements of strategically located rail infrastructure, emphasising the need to align design standards with military load bearing parameters and to address vulnerabilities to cyber and hybrid threats. The Joint Communication further highlights persistent shortages in critical rail related capabilities, such as flatbed wagons suitable for heavy and outsized equipment, which remain essential for large scale military transport. It calls for harmonised and accelerated cross border procedures, ensuring interoperability of rolling stock and signalling systems, supported by a strengthened role for the ERA in facilitating safety, authorisation and regulatory convergence. Moreover, the Joint Communication stresses the importance of integrating rail with other transport modes in a resilient multimodal logistics chain, enabling swift transfers between rail, road, inland waterways and ports, and contributing to the establishment of an EU wide Military Mobility Area by 2027. Finally, it underlines that upgraded dual use rail elements within the TEN T are indispensable for ensuring rapid and secure movement of military personnel and materiel across the EU.

2.3.1.2 Legislative framework directly relevant to rail

The process of liberalising and integrating Europe's rail market began with [Directive 91/440/EEC](#) (Official Journal of the European Communities 1991), which separated infrastructure management from operations and laid the groundwork for competition in the sector. This process advanced through four successive railway packages, each expanding market access and strengthening the EU's role in safety, interoperability and cross-border coordination.

The [First Railway Package](#) (2001) introduced non-discriminatory access to the trans-European freight network. The [Second Railway Package](#) (2004) liberalised all rail freight services by 2007, established common procedures for investigating accidents and created National Safety Authorities while reinforcing the role of the ERA. The [Third Railway Package](#) (2007) extended open access rights to international passenger services, introduced a European train driver licence and strengthened passenger rights. The reform process culminated in the [Fourth Railway Package](#) (2016), which completed the internal market for rail by opening domestic passenger services to competition and creating streamlined vehicle authorisation and safety certification procedures. This framework is underpinned by the SERA [Directive 2012/34/EU](#) (OJEU 2012), the cornerstone of EU railway market legislation.

Against this regulatory background, the effectiveness of market opening depends not only on formal liberalisation, but also on the practical conditions of access to infrastructure and the behaviour of market actors. The existing literature on rail market organisation, notably for passenger rail transport, highlights that incumbents operating in contexts characterised by vertical integration or strong control over the infrastructure, may retain informational and strategic advantages that influence capacity allocation, access price, and technical standards, potentially affecting non-discriminatory market openness and the conditions for new entrant railway undertakings. More broadly, the literature has pointed to concerns regarding non-discriminatory and unbiased access to the railway infrastructure to adequately reflect the needs of non-incumbent railway undertakings in sector-wide planning processes ((IRG 2025) and (E.CA Economics 2024)).

In addition to the four railway packages, several other legislative acts directly affect rail. [Regulation \(EU\) 913/2010](#) (OJEU 2010) established the Rail Freight Corridors, creating a legal framework for coordinated cross-border freight capacity and operational management. The revision of the TEN-T Regulation modernised the requirements for the core and comprehensive rail networks by reinforcing cross-border commitments, aligning infrastructure standards and including provisions for the possible integration of innovative technologies such as Hyperloop, Maglev and alternative propulsion systems. The Connecting Europe Facility (CEF) [Regulation \(EU\) 2021/1153](#) (OJEU 2021) provides financial support for projects that improve rail infrastructure, digitalisation and cross-border connectivity.

The Commission has also proposed a [Regulation on railway capacity management](#), which would repeal Regulation (EU) 913/2010 and integrate its provisions into Directive 2012/34/EU (European Commission 2023b). Its objective is to ensure more efficient and coordinated capacity allocation, particularly for international traffic. Parallel the initiative of the [Revised Intelligent Transport Systems Directive](#) (European Commission 2023a) contribute to creating a more integrated and digital mobility system, indirectly supporting rail. The Delegated Regulation (EU) 2024/490 on [Multimodal Digital Mobility Services](#) (OJEU 2024) reinforces the importance of interoperable digital platforms for passengers, enabling seamless journey planning and ticketing across borders.

2.3.1.3 Cross-border aspect of EU rail policy

Cross-border interoperability remains a central objective of EU rail policy. The SERA framework, the TEN-T Regulation and the proposed capacity management regulation all aim to remove barriers to international rail traffic. Harmonised TSIs and the deployment of ERTMS underpin a consistent technical architecture across Europe, while Rail Freight Corridors have created an institutional

structure for coordinated capacity allocation and traffic management. Social and training legislation facilitates the movement of train drivers and other mobile workers across borders. Despite this progress, challenges persist. Differences in operational rules, legacy national signalling systems and administrative complexity continue to hinder seamless cross-border services. Addressing these barriers remains a priority under ongoing legislative revisions and implementation efforts.

Technical legislation is also central to completing the SERA. The 2023 revision of the TSIs replaced earlier rules, including [Regulation \(EU\) 2016/919](#) (OJEU 2016), and aims to accelerate the harmonisation of standards and the deployment of ERTMS (Transport & Environment 2025). Additional legislative measures address the phasing out of rear-end signals, improved data collection on railway markets and other technical updates that support interoperability.

Social and training legislation further facilitates cross-border rail services. [Directive 2005/47/EC](#) (Official Journal of the European Union 2005), based on an agreement between the European Transport Workers' Federation (ETF) and the Community of European Railway and Infrastructure Companies (CER), sets minimum standards for working time and rest periods for mobile rail workers. [Directive 2007/59/EC](#) (OJEU 2007) harmonises the minimum qualifications and certification requirements for train drivers, enabling mutual recognition of licences across Member States. Since 2011, drivers engaged in cross-border services have been required to hold such certificates. The Commission launched a review of the Directive in 2022 with the aim of improving driver mobility and reducing administrative burden.

In relation to this, stakeholders from governance and operational backgrounds expressed concern that fragmented responsibilities and divergent national implementation practices continue to undermine the effectiveness of EU-level rail legislation. Interviewees emphasised that technical interoperability alone does not guarantee seamless cross-border operations in the absence of coordinated approaches to capacity allocation, timetabling, public service contracts and investment planning. Divergent views emerged on the role of competition and market opening. Stakeholders linked to new entrants and parts of the supply industry highlighted remaining barriers to cross-border service development and innovation. Despite these differences, there was strong convergence on the need for enhanced cross-border European coordination beyond voluntary mechanisms. The interviewees questioned whether the current cooperation frameworks are sufficient to address system level challenges, while broadly favouring hybrid governance models that combine national operational responsibility with stronger EU level steering.

2.3.1.4 Legislative and strategic instruments indirectly relevant to rail

Beyond rail-specific legislation, several broader policy areas have a significant indirect impact on rail. The [European Green Deal](#) (European Commission 2019a) frames rail as a key low-emission mode and creates strong incentives for modal shift. In 2021, the '[Fit for 55](#)' package included measures on emissions trading, energy taxation and alternative fuels that influence the operating conditions for rail. The Alternative Fuels Infrastructure Regulation (AFIR) (OJEU 2023) supports the deployment of electric and hydrogen refuelling infrastructure, which can be relevant for non-electrified rail lines and for new forms of propulsion.

Digital policy instruments such as the [Data Governance Act](#) and the Data Act (OJEU 2022) enhance data availability, interoperability and security, underpinning the development of digital platforms for rail operations and multimodal mobility. The [Urban Mobility Framework](#) (European Commission 2021a) encourages integrated solutions in metropolitan areas, strengthening the connection between rail and other sustainable mobility modes.

2.3.1.5 Emerging technologies

Although hyperloop and maglev technologies are at an early stage of development, they are increasingly considered within the EU's strategic discussions on long-distance mobility. The revised

TEN-T Regulation allows for the incorporation of innovative transport modes where they contribute to network objectives, enabling the potential future alignment of such systems with European infrastructure planning. CEF funding can support feasibility studies, pilot projects and research activities related to breakthrough technologies, reflecting the EU's openness to emerging forms of high-speed mobility.

While no dedicated regulatory framework yet exists for hyperloop or maglev, the principles governing rail interoperability, safety and cross-border coordination may provide a foundation for future regulation. The Commission continues to assess how such technologies could complement existing transport modes while upholding sustainability, safety and interoperability standards.

2.3.2 National rail policy

Desk research shows that most EU Member States have developed dedicated national railway development strategies, and these plans often include explicit cross-border and TEN-T corridor priorities. These national plans are increasingly aligned with EU objectives, especially regarding (i) high-speed rail expansion, (ii) ERTMS and digitalisation, (iii) cross-border corridor improvements, (iv) freight interoperability, and (v) sustainability and modal shift targets. Also, desk research from national policies and EU funding programmes shows that railway development has become a structural part of nearly all national transport plans.

The Member States that represent the core EU rail transport activities have adopted national rail development frameworks that converge with EU-level objectives.

Germany's strategy is particularly embedded in the SERA framework and emphasises cross-border interoperability and synchronised timetabling under initiatives such as the [TransEuropExpress 2.0](#) (TEE 2.0) and [Deutschlandtakt](#) (BMVI 2020), reflecting its central role in long-distance passenger and freight flows.

France, Italy and Spain continue to expand high-speed networks (UIC 2023) and digital signalling upgrades, in line with TEN-T requirements for higher speeds, ERTMS deployment and the reduction of bottlenecks. These countries, together representing most of the EU's high-speed and long-distance services, also integrate national electrification, capacity expansion and modal-shift targets in line with EU ambitions for a climate-aligned rail system.

Poland, meanwhile, prioritises cross-border freight corridors and interoperability upgrades to support both TEN-T cargo flows and wider EU rail-market liberalisation dynamics (Ministry of Infrastructure 2019) and (Lisewski, Gorzelanczyk and Luptak 2025)). Belgium is preparing for restructuring the rail system as EU-mandated market opening will require competitive tendering of passenger services by 2033, signalling a shift in national rail-sector governance (Inno-V, Trans-Mimsisons and KCW 2024). The Netherlands is also aiming at liberalisation dynamics, with the national operator expected to adapt to an increasingly open and competitive European rail landscape.

Furthermore, the [Rail Baltica](#) project illustrates how national policies in Estonia, Latvia and Lithuania are deeply integrated with EU priorities, supported by substantial CEF funding and a newly adopted EU implementation decision that sets binding milestones for full cross-border connectivity by 2030.

In relation to the national rail policies, it is also worth mentioning that the [Recovery and Resilience Facility \(RRF\) Regulation](#) (OJEU 2021) establishes that Member States Recovery and Resilience Plans (RRPs) should contribute to the green transition and digitisation, hereby including ERTMS. The RRP have already been set out by Member States, and the funding has started. Rail development comprises about 40 % of the transport-related reforms and investments of the RRP (i.e. €38.4 billion). The RRP of Austria, Belgium, Bulgaria, Czechia, Estonia, Greece, Finland, France, Hungary,

Croatia, Italy, Netherlands, Poland, Latvia, Slovenia, Slovakia, and Sweden contain various measures to support the upgrade and modernisation of railway infrastructure, including the roll-out of ERTMS.

2.4 Technology

Technological developments are a central driver for changes in the European railway system. The development and deployment of the technologies introduced in this section are closely intertwined, leading to a complex developing technology landscape.

Cybersecurity is a cross-cutting topic across the technological developments. Increasing digitalisation and connectivity (including signalling, maintenance, rolling stock, ticketing systems, real-time information systems) expands the attack surface, making infrastructure-level disruptions more likely. The railway sector is a strategic sector and part of activities of vital importance. Therefore, cybersecurity concerns go beyond ICT risk and relate directly to national and European security and societal functioning. Despite this, the railway safety regulatory framework contains no specific provisions for cybersecurity and lacks integration with cybersecurity authorities. Moreover, Member States adopt different approaches to cybersecurity, which do not always guarantee an equivalent level between actors (EPSF 2021).

2.4.1 Standard technologies

2.4.1.1 European Rail Traffic Management System

The ERTMS is a European signalling and speed control system to ensure interoperability of national railway systems. ERTMS is composed of the European Train Control System (ETCS), the global system for mobile communications for railways (GSM-R) and operating rules (ERA 2025b). Of the 201 315 km of railway lines in the EU, 15 124 km are equipped with ETCS Level 1 or 2. The EU countries with the highest ERTMS deployment are Belgium (2 782 km) and Spain (3 574 km) (see also Figure A.29). Switzerland has 5 734 km of ERTMS-equipped lines (Eurostat 2025a).

There are three ERTMS levels in use. Level 0 entails an ETCS-equipped train running on a non-equipped line, providing basic safety, but no ETCS supervision. In Level NTC (i.e. National Train Control), the ETCS onboard interfaces with the country's legacy system. Level 1 is an add-on system built on conventional lines with existing signals and detection. Communication between the track and the train is achieved through dedicated balises ('Eurobalises'). The main benefits of Level 1 are interoperability between suppliers and countries and safety due to the automatic braking of the train if the maximum speed is exceeded. Level 2 is a radio-based system. The Radio Block Centre (RBC) directly communicates movement authority, thus eliminating the need for physical signals. In addition to the benefits of Level 1, Level 2 brings capacity increases, lower maintenance, and cost savings (UNIFE, WHAT IS ERTMS? 2025). How major the capacity increases can be is controversial, especially without additional attention to junctions and other bottlenecks.

While the technology is conceptually mature, implementation remains slow and fragmented across Europe. Research so far has focused heavily on technical aspects, with limited attention to managerial and organisational challenges. Despite the interoperability goals, rollout has been hindered by national differences in business models and safety philosophies (Morin 2024). Stakeholders interviewed for this study agree that ERTMS remains foundational, but slow and fragmented deployment limits its benefits. From a system perspective, the interviewees stressed its potential to enhance safety, interoperability and capacity, while consistently attributing its limited impact to slow and fragmented deployment, high transition costs and unstable governance rather than to technical shortcomings.

2.4.1.2 European Train Control System

ETCS is a key element of ERTMS. The in-cab system monitors train speed and can stop the train if limits are exceeded. It receives track data via Eurobalises or radio signals, calculates permitted speeds, and displays them to the driver through the Driver Machine Interface (DMI), which the driver uses to confirm changes manually (UNIFE, WHAT IS ERTMS? 2025). Currently, 19 % of European rolling stock is equipped with ETCS (SCI Verkehr 2025).

ETCS is central to simplifying and harmonising European rail operations under the European Simplified and Integrated Railway System (ESIRS) flagship initiative. The focus is on ETCS Level 2-only operations, eliminating legacy hybrid systems to reduce complexity and cost. The expected impacts of ETCS include improved punctuality and reliability, cost effectiveness, and resilience (Europe's Rail 2025a).

2.4.1.3 Capacity allocation and traffic management tools

Various capacity allocation and traffic management tools are provided by RailNetEurope (RNE), an association of European rail infrastructure managers. It serves as an umbrella organisation that helps coordinate its members' international processes in the areas of capacity management, traffic management, corridor management, IT and sales and legal matters. RNE was set up in 2004 to help meet the challenges faced by the international rail sector. RNE facilitates the operational international business of its members by providing solutions that benefit all RNE members as well as their customers and business partners. RNE's role is also to provide support as regards compliance with the European legal framework. This entails developing harmonised international business processes, templates, handbooks, and guidelines. In short, RNE's mission is to help its members meet the challenges of the rapidly-changing railway sector in Europe and to promote international rail traffic.

RNE's IT strategy has been developed over several years in close collaboration with the IT managers of RNE's members. While its main pillars have existed since the beginning, new challenges, such as the Rail Freight Regulation, are being taken into account as they arise. The facilitation of use, development and implementation of software tools according to changing business demands is a major part of RNE's IT strategy, which is based on the following three main digitalisation domains and tool:

- Digital Infrastructure Information (Customer Information Platform and Rail Facilities Portal).
- Digital Capacity Management (Path Coordination System and Temporary Capacity Restriction tools).
- Digital Train Information (Train Information System tool).

All these tools are mainly for international passenger and freight services in terms of capacity and traffic management between infrastructure managers, allocation bodies and railway undertakings.

2.4.2 Emerging rail-specific technologies

2.4.2.1 Future Railway Mobile Communication System

The legacy technology for communication in railways is GSM-R. For future smart rail operations, Long-Term Evolution (LTE) and 5G are the preferred backbones due to their superior throughput, latency, and availability. LTE is currently being piloted, while 5G is emerging with trials in high-speed corridors (Kljaić 2023). 5G is the basis for the FRMCS, a system designed to replace GSM-R to enable advanced applications like Automatic Train Operation (ATO) and higher levels of ERTMS for the digital transformation of the railway sector. In addition to ATO, FRMCS can enable predictive maintenance, real-time video surveillance, and passenger services (Carranza Ruiz de Loizaga 2024).

The strengths of this technology are its high capacity and reliability, low latency, and interoperability potential. Weaknesses include spectrum scarcity (i.e. increasing demand outpaces the availability of radio frequencies), high deployment costs, and regulatory and legacy integration complexity. In addition, 5G coverage is difficult in tunnels and depots. Opportunities related to this technology arise from digitalisation, new revenue streams, and improved railway safety (e.g. through accurate positioning and cooperative operations). Threats emerge in relation to cybersecurity, radio interference, and technology gaps (Carranza Ruiz de Loizaga 2024) and (Kljaić 2023)).

The implementation of FRMSC requires collaborative efforts among industry stakeholders, regulators, and research institutions. To overcome the scarcity of available frequencies, a viable solution is to create hybrid networks using 5G network slicing (i.e. the creation of multiple virtual networks for dedicated purposes using the same physical infrastructure). These hybrid networks would allow commercial service providers to supplement the required capacity for railway applications (Carranza Ruiz de Loizaga 2024).

2.4.2.2 Automatic Train Operation

Automatic Train Operation (ATO) is described by four Grades of Automation (GoA):

- GoA1: The train driver manually operates the train, potentially assisted by driving advisory systems.
- GoA2: Acceleration, deceleration, and stopping are automated, but the train driver actively monitors and retains responsibility.
- GoA3: The ATO system operates independently. The driver may be outside the cab and engage in other tasks.
- GoA4: The ATO system operates autonomously. No driver is onboard. Disruptions are managed remotely or by a maintenance team.

ATO is widely used in metro systems, but the adoption in mainline rail is minimal. National pilot projects are currently being used as learning platforms. ATO promises major benefits in relation to costs, capacity, efficiency, and emissions, but implementation faces safety, acceptance, and organisational challenges (Morin 2024). ATO is increasingly viewed as a structural response to workforce shortages, particularly shortages of train drivers and other operational staff, rather than only as a technological upgrade. Stakeholders emphasised that ATO should be understood as a capacity and resilience tool, not primarily as a speed-enhancement measure. Also, stakeholders broadly agreed on its long-term potential to improve energy efficiency, capacity utilisation and resilience, particularly in response to workforce shortages. At the same time, interviewees expressed caution about large-scale deployment timelines on mainline passenger networks, citing regulatory, interoperability and social acceptance challenges. Automation is framed as a way to sustain service levels and network performance under growing operational constraints, rather than as a replacement of the rail system's fundamentals. Hereby, remote train operation (RTO) can be considered as both a standalone solution with immediate applicability and a stepping stone towards higher grades of automation.

2.4.2.3 Digital Automatic Coupling

DAC is considered a central enabler for modern, digitalised rail freight in Europe, replacing the 150-year-old manual screw coupling still widely used. Europe has developed five types of automatic coupling, but only Types 4 and 5 qualify as DAC because they support automatic mechanical coupling, brake pipe connection, power lines, and data lines. Large-scale tests in Sweden, Germany, Austria, France, and Poland show that DAC is technically viable, including in ice and snow (Djordjević 2025).

The potential benefits of DAC for the railway system include processing time reduction, improved safety, capacity gains, higher competitiveness, and sustainability. In addition, DAC is a key enabler

for digital rail operations. These clear benefits, along with a strong EU-level push and successful test, indicate a good potential to scale up and implement this technology. However, financial, technical, and operational challenges pose barriers to implementation (Djordjević 2025) and (Europe's Rail 2025a)). Stakeholders view DAC as particularly critical for freight, reducing hazardous manual tasks. In this respect, stakeholders from freight operators, workforce representatives and research bodies strongly converged in viewing DAC as a pivotal enabler for rail freight modernisation. The interviewees highlighted its potential to improve safety, operational efficiency and automation, while stressing that its benefits depend on synchronised deployment across countries and operators to avoid fragmented implementation.

DAC is a technology with a strong impact on railway workers. On the positive side, DAC eliminates key risks of falling or crushing, reduces physical strain, improves working conditions, and can lead to higher productivity. However, some manual roles may reduce or shift in nature, which requires intensive reskilling for workers. Therefore, there is a need to negotiate new roles, skills, and safety protocols, and to prepare organisations for the changes (Djordjević 2025).

2.4.2.4 Maglev

Maglev has been under development for nearly 100 years, but today only six commercial systems operate globally. All these systems are low- to medium-speed (100–110 km/h), except for one high-speed line, the Shanghai Transrapid (430 km/h). In addition, another high-speed maglev application is in advanced testing, with the Chuo Shinkansen (500 km/h) under construction. The technology works without rail-wheel contact, thus eliminating rolling resistance and adhesion limits, and reducing noise, vibration, and maintenance. Linear electric motors are used for propulsion, while magnetic levitation is used for support and guidance (Liu 2022).

The main benefit of Maglev is its high speed, which could reduce travel times between major cities significantly. Further, maglev uses less energy per seat-km than high-speed rail at same speeds and operates with lower noise levels and has less track wear. Despite these benefits, maglev faces significant challenges. Firstly, the infrastructure costs associated with Maglev systems are exceptionally high, often exceeding those of conventional high-speed rail. The Shanghai Transrapid project illustrates this clearly: its 2003 construction costs, when updated to 2023 price levels, amount to an estimated €69 million per km, reflecting the substantial engineering requirements of an elevated urban corridor. Similarly, for Japan's Chuo Shinkansen, inflation-adjusted figures widen the gap between successive project estimates, with the 2021 revision indicating a cost of approximately €172 million per km, largely driven by tunnel-intensive construction through mountainous terrain and rising material prices. By contrast, benchmark estimates for the German system fall within the range of €17–23 million per km, demonstrating how geographical conditions, design standards and project scope can significantly influence overall capital expenditure. Secondly, traditional maglev systems require entirely new, fully segregated infrastructure (Liu 2022). However, recent technological advances (e.g. Nevomo MagRail system) demonstrate that magnetic propulsion and levitation technologies can be integrated onto upgraded conventional rail lines, enabling mixed operation with existing rolling stock and reducing the need for a wholly new network.

Its reliable operation at 500–600 km/h for intercity travel holds potential to scale up. So far, Japan is the only country currently scaling towards a full network with the Chuo Shinkansen (286 km by 2027, extended to 505 km by 2037). China has stated plans for 600 km/h commercial Maglev, but it is still in the prototype and testing stage. Barriers to scale include the capital cost, the need for fully dedicated infrastructure, technical complexity, and market feasibility. Maglev adoption depends heavily on political commitment, long-term investment ability, and high traffic demands and is likely to remain niche or corridor-specific, not a broad replacement for rail (Liu 2022).

About maglev, stakeholders from infrastructure, policy and research communities expressed broadly cautious views on its role in the future European transport system. The interviewees

acknowledged the technological maturity and operational performance demonstrated in non-European contexts, but emphasised that high infrastructure costs, limited interoperability with existing rail networks and corridor-specific demand profiles significantly constrain large-scale deployment in Europe. Maglev was therefore generally viewed as a niche or corridor-specific option rather than a systemic alternative to high-speed rail, with relevance primarily in very high-demand links where conventional rail solutions face physical or operational limits.

2.4.2.5 Hyperloop⁷

The emergence of Hyperloop can be traced to a white paper conceptualising it (Musk 2013). The concept, which is still in development, is a proposed high-speed transportation system (i.e. operational target of 1,000 km/h) that consists of pods or capsules that use magnetic levitation technology to move across low-pressure tubes (Hyper4Rail 2024b, Kurstjen, van Haken and van Mil 2022).

Hyperloop systems and subsystems (i.e. guideway infrastructure, the vehicle or pod, propulsion and levitation, stations, energy systems, and operating, safety, and emergency components) are at different Technology Readiness Levels (TRLs, between 1 (low) and 9 (mature)), usually TRL 6 or lower (Nøland 2024, Vesjolijs, Stukalina and Zervina 2025). Different initiatives exist focusing on setting standards, development, and testing of different elements of the system. A recent study published by the European Commission (Ramboll Management Consulting, TIS, CETH, SINTEF 2025) notes that some components may be adapted from other industries, like rail or aviation, and some components may be considered at TRL 7 if only minor adaptations are needed to integrate them in hyperloop. Still, a hyperloop concept design could be considered at TRL 2, and some key subsystems could be validated only at TRL 4 by the end of 2026 (Hyper4Rail 2024a).

Several companies and research programmes have emerged to develop hyperloop technology and integrate the required systems. In Europe, examples such as Hardt Hyperloop, Zeleros, the Institute of Hyperloop Technology (University of Applied Sciences Emden/Leer), Swisspod Technologies (Swiss-American), the Hyperloop Development Program, Neoways, and the TUM Hyperloop research program (Technical University of Munich) are examples of this. Additionally, physical assets have also started to emerge, such as the 420-metre test track from the European Hyperloop Center in the Netherlands (European Hyperloop Center n.d.), a 320-meter test track in Toulouse (HyperloopTT 2024), and a potential upcoming track in Italy (Hyperloop Italia 2024). At the moment, the United States, China, (Ramboll Management Consulting, TIS, CETH, SINTEF 2025) and South Korea (Ministry of Land, Infrastructure and Transport of the Republic of Korea 2025) are also investing in hyperloop research and testing, with dedicated test tracks already present in the United States (Swisspod 2025).

The technical concept for hyperloop, with small pods that can be individually controlled, could enable the offer of non-stop high-frequency services for passengers (point-to-point), but this setup could be more technically complex than a network where passengers interchange at hubs, or continuous services with intermediate stops. Advocates for hyperloop argue that an independent hyperloop system could compete with air travel (and rail), especially for trips of over 1 000 km. Other possibilities are as a complement to high-speed rail on missing links (Hyperloop Development Program 2022b), or as a feeder service to main airports (substituting some short-haul flights). A model with independent infrastructures may be easier to manage in the near term and may overlap with the concept of feeder service to airports, but in the long term, hyperloop as a complement to high-speed rail may be more desirable. Hyperloop is expected to have less passenger capacity when compared to high-speed rail, but it has been suggested that hyperloop infrastructure costs (€ 33 million/km) could be slightly lower than those of high-speed rail (€37 million/km) and thus provide an

⁷ For more details on Hyperloop's concept and characteristics, please see Annex IV.

advantage (Hyperloop Development Program 2024b) that could make it suitable for lower-demand routes. Still, cost estimates for hyperloop are highly uncertain at this stage, especially the cost of stations and operational costs.

It is possible that some long-distance hyperloop services could be in operation in Europe in 20 years along selected corridors, but there does not seem to be an expectation for a European Hyperloop network before 2050, rather that it develops increasingly in the years after that (Ramboll Management Consulting, TIS, CERTH, SINTEF 2025) (see also Figure A.46). This is specially the case since hyperloop infrastructure is not interoperable with existing rail networks, so the network would have to be newly developed. Still, European entities have spent considerable effort in leading hyperloop development and testing, which, if maintained, could provide opportunities to deploy and export the technology.

Stakeholder engagement revealed a high level of scepticism regarding the medium-term system relevance of hyperloop for European rail transport. While interviewees recognised the innovation and research value of ongoing hyperloop initiatives, they consistently highlighted substantial uncertainties related to technical readiness, costs, safety frameworks, governance models and integration with existing networks. Stakeholders broadly agreed that hyperloop is unlikely to play a significant role before 2050 and should be understood, at this stage, as a long-term exploratory technology that may complement, but not substitute, investment in conventional and high-speed rail infrastructure.

2.4.3 Emerging general-purpose technologies

Across stakeholder categories, general-purpose technologies such as Artificial Intelligence, data analytics and advanced communications were consistently viewed as enabling tools rather than standalone solutions. Interviewees emphasised that their contribution to rail performance depends critically on effective integration with rail specific systems, operational processes and governance frameworks. Stakeholders identified data sharing, cybersecurity and skills availability as key constraints on large scale adoption. While predictive maintenance and traffic decision support applications were seen as mature and cost effective, interviewees cautioned that fragmented data governance and inconsistent standards risk limiting system wide benefits.

Several general-purpose technologies have the potential to disrupt the European railway system. For each technology, this section presents the state of the art, expected impact on the railway system, and the potential to scale up and implement.

2.4.3.1 Artificial Intelligence

Artificial intelligence (AI) has disrupted and will continue to disrupt many industries. For the railway sectors, AI has the potential to advance the automation of various processes. Currently, AI is being introduced for predictive maintenance, anomaly detection on infrastructure and rolling stock, and traffic management. AI has a growing role in autonomous or remote driving and human-automation cooperation (Kljaić 2023).

A key strength of this technology is the return on investment for maintenance applications by reducing unplanned downtime, demonstrated by commercial applications. In addition, using the data of multiple sensors can enhance safety. Weaknesses include interoperability challenges due to data quality and data labels, and the explainability and validation for safety-critical contexts. The main opportunities for this technology lie in autonomous operations and virtual coupling, and the integration with IoT and 5G for real-time optimisation. Threats include cybersecurity risks to the AI pipeline and data integrity, and regulatory hurdles (Kljaić 2023).

If the strengths of AI can be mobilised while also overcoming its pitfalls, it has the potential to positively impact the railway system through higher availability and reliability, energy savings

through optimised driving, and capacity gains by reducing headways under virtual coupling and platooning. Especially, platooning is expected to have a significant impact on capacity. The implementation pathway of AI into the railway system has already started with predictive maintenance applications. Applications can be further developed to include traffic-decision support and continue towards autonomy with human-machine cooperation. Barriers for this deployment include safety certifications, data governance, and workforce skills (Kljaić 2023).

2.4.3.2 Industry 4.0 and 5.0

Industry 4.0 represents a systemic transformation rather than a single technology. It merges classical industry with digital technologies through IoT (Internet of Things), big data, cyber-physical systems, and smart factories. The adoption of Industry 4.0 remains at an early stage; most processes remain manual or semi-digital (Gerhátová 2021). Industry 5.0 complements this concept by shifting the focus from purely digital automation and efficiency to a human-centric, sustainable, and resilient system (CoP 5.0 2024).

Applications so far include Autonomous Rail Rapid Transit (ARRT) pilots, virtual tracks, digital order processing and customer portals, and sensors and cameras for technical inspections (Gerhátová 2021) and (Kljaić 2023)). In addition, there are many potential use cases, such as mobile apps and electronic ticketing, predictive maintenance platforms for rolling stock and infrastructure, remote-controlled operations, and digital freight documentation (Gerhátová 2021).

Industry 4.0 has several strengths, such as efficiency, sustainability, safer operations, holistic mobility-energy integration, and the ability to support data-driven business models. However, it faces notable weaknesses such as high initial costs, reliance on legacy infrastructure and dependencies, and complex governance involving multiple stakeholders. There are significant opportunities arising from EU digitalisation, AI-based optimisation, improved KPIs, multimodal advantages, and smart grid integration. At the same time, the system must address threats like workforce adaptation challenges, cybersecurity risks, and standardisation issues (Gerhátová 2021) and (Kljaić 2023)).

The potential impacts on the railway system are increased operational efficiency and reduced processing times, enhanced interoperability between carriers, customers, and infrastructure managers, and the potential for real-time monitoring and predictive analytics to minimise downtime (Gerhátová 2021). In addition, Industry 4.0 has the potential to increase safety and sustainability (Kljaić 2023).

The pathway for implementation is gradual, with modular adoption of smart logistics solutions, the digitalisation of subsystems, integration of IoT and Big Data platforms, and gradual automation of technical inspections and documentation processes. High investment costs, the need for employee training, interoperability challenges in relation to legacy systems, and regulatory challenges pose barriers to the adoption of Industry 4.0 (Gerhátová 2021). Hereby, human-machine interaction is most relevant, especially in the context of AI (CoP 5.0 2024).

2.4.3.3 Renewable energy and smart grid

Railways are increasingly integrating renewable energy systems and are treated as cyber-physical systems integrated with smart grid architectures. Current deployments include Railway Static and Stationary Transformers (RSST/ISST) for efficient traction power conversion, Energy Storage Systems (ESS) and Distributed Energy Resources (DER) (e.g. Photovoltaic, wind) connected to rail substations, and Railway-to-Grid (R2G) converters enabling bidirectional energy flows. Maturity is medium to high for energy recuperation and storage and emerging for full smart grid orchestration and market participation. There are several business models, such as rail operators acting as energy market participants (ESO/EMO interaction), energy-as-a-service for stations and multimodal hubs

and partnerships with utilities for demand response and ancillary services ((Kljaić 2023) and (Gore 2023)).

Currently, energy storage systems are deployed at substations and onboard trains. In addition, recuperation systems can be used to reduce peak demand and energy costs. In the future, full smart grid orchestration across rail corridors, dynamic energy trading and real-time optimisation, and integration with multi-modal transport energy systems could be possible (Kljaić 2023). This solution offers several strengths, including the ability to cut operating expenses by 22 to 30 %, support renewable energy integration, and enhance power reliability. However, it also carries weaknesses such as high initial costs for energy storage systems and converters, along with complex governance and integration requirements. There are notable opportunities for generating new revenue through energy markets, and the approach aligns with Industry 4.0 initiatives and digital energy management systems. On the other hand, it faces threats such as increased cyber risks and regulatory challenges related to grid interaction (Kljaić 2023).

Smart grid solutions impact the railway system's energy efficiency, sustainability, operational resilience, and costs and revenues. A gradual implementation pathway starts from deploying energy storage systems at substations and rolling stock and can develop to enable market participation and dynamic optimisation. Barrier to adoption include standards compliance, cybersecurity maturity, regulatory approval for energy trading, and workforce skills (Kljaić 2023).

Several avenues for scaling renewable energy and smart grid in rail are emerging. First, renewable energy sources can be integrated with traction power. Examples include co-locating solar or wind farms⁸ with railway infrastructure or hybrid power systems for stations and depots. Second, intelligent energy storage deployment can be used to store regenerative braking energy, reduce traction peaks, and improve supply stability. Third, potential smart grid features include smart metering for granular traction load data, automated power flow and dynamic load balancing, and substation automation and digitalisation. Fourth, AI can be employed to optimise power consumption and forecast demand in real-time (Gore 2023).

2.4.4 Rolling stock

The EU rolling stock industry is mature, globally competitive, and export-oriented. The fleet in Europe developed as follows between 2015 and 2023: locomotives and railcars increased (+16 %), coaches remained unchanged (+0.5 %), and freight wagons increased (+11 %), reflecting market consolidation (see also Figure A.28). The sector is undergoing a transition towards sustainability, digitalisation, automation and advanced materials and designs ((Gardner, Brambilla and Matheus 2023) and (European Commission 2025d)).

Rolling stock manufacturing is heavily concentrated. In 2021, Germany, China, and the US amounted to one third of global supply (Gardner, Brambilla and Matheus 2023). The top 10 manufacturers by revenue in 2024 were in China, the European Union, Russia, the US, and Japan, with the EU producing around 40 % of the revenue of the top 10, and China around 30 % (Novak 2025).

Electric traction remains the backbone where infrastructure is electrified. Currently, 56 % of the EU network is electrified, covering 80 % of the passenger-km (Gardner, Brambilla and Matheus 2023). In addition, several technologies are emerging for low-carbon operations on non-electrified lines: battery trains, hydrogen trains, hybrid diesel-battery trains, and alternative fuels (see also Figure A.30). Battery trains are suitable for non-electrified regional lines, with an average range of 85 km. In addition, battery trains are useful for intermodal terminals in which overhead catenary systems cannot be used due to their interference with cranes loading and unloading wagons. Viable

⁸ A concept from Switzerland envisions solar panels directly on the tracks, see [Sun-ways | Des panneaux entre les rails](#).

prototypes exist for rail yard switching and light to medium cargo hauling in industrial railway sidings and logistics terminals.

Hydrogen trains have been explored as an option for longer, non-electrified routes where the cost of full electrification is high. However, market developments indicate that the technology's deployment trajectory has slowed, with some early adopters reconsidering their plans and pilot programmes being phased out. Although hydrogen traction remains technically feasible, its maturity level and commercial outlook are less certain than anticipated. Depending on tank capacity, hydrogen train ranges can reach 600–1 000 km, but large-scale viability continues to depend on efficient, low-carbon hydrogen production and distribution, as well as the achievement of economies of scale. In parallel, hybrid locomotives, combining diesel with battery or electric traction, are increasingly used for last-mile and yard operations. Hybridisation can also be used to enable a silent mode without diesel for entering cities (Chamaret 2023) and (Kljaić 2023)).

Overall, stakeholder engagement shows that rail operators, manufacturers and public authorities highlighted rolling stock availability and renewal cycles as an increasingly critical constraint on system performance. The interviewees underlined that long procurement, certification and retrofit timelines require anticipatory investment, particularly in the context of rising demand, ageing fleets and expanding interoperability requirements. Moreover, there was strong convergence that rolling stock investments must be closely coordinated with infrastructure upgrades and digital deployment. Lastly, stakeholders emphasised that misalignment between infrastructure programmes and fleet renewal risks creating bottlenecks and underutilised capacity.

2.5 Funding and financing

Rail operations are costly and require large sums of funding and financing. National public budgets are the primary funding source for rail infrastructure expenditure, accounting for 70 % in 2022. EU co-financing provided 8 % while the remaining 22 % were covered by other sources such as loans, equity financing and charges (European Commission 2025g). During the stakeholder consultation, financing constraints were widely identified as the strongest driver shaping rail sector development.

Various funding sources are available at the EU level, especially for infrastructure and rolling stock. Under the Connecting Europe Facility (CEF), the European Commission granted €13.2 billion in grants to railway projects between 2021 and until the elaboration of this report. These investments are largely directed towards infrastructure construction, upgrades, and management across the TEN-T core and extended networks, and in a smaller capacity (i.e. around 3% of the funding) to rolling stock retrofits, especially for ERTMS deployment⁹. Over the same period, the European Regional Development Fund (ERDF) provided €1.9 billion to projects including rail,¹⁰ covering infrastructure (i.e. about two-thirds of the funding) and rolling stock (i.e. about one-third of the funding). Cohesion Fund investments also amounted to €3.9 billion, mostly towards infrastructure projects, over the same programming period. Finally, for rolling stock, the European Company for the Financing of Railroad Rolling Stock (EUROFIMA) also funded rolling stock leases worth €2.8 billion.

From 2021 the European Investment Bank (EIB) also provided loans worth €27.5 billion for railway infrastructure (i.e. roughly two-thirds) and rolling stock (i.e. roughly one-third). The EIB offers lending either directly to public and private project promoters or indirectly through its intermediaries (EIB

⁹ CEF funding criteria emphasise EU added value, cross-border relevance, and TEN-T compliance, but in practice, often prioritise project maturity, readiness, and implementation feasibility. EU studies show that national appraisal practices dominate project selection, which can lead to the undervaluation of cross-border spillovers and network benefits (European Commission 2018).

¹⁰ Programmes under this fund often include multiple sectors and transport mode, making rail-specific figures hard to obtain (European Commission 2025e).

2021). National promotion banks may provide additional funds as partners of the EIB. National promotion banks are state-owned or partially state-owned financial entities that provide support to specific socioeconomic objectives for which private investment is insufficient (European Commission 2025h).

The Recovery and Resilience Facility (RRF), a temporary instrument and the centrepiece of the EU's plan to emerge stronger and more resilient from the COVID-19 crisis, also provided funding for railway projects, given their inclusion in Member States' Recovery and Resilience Plans (European Commission 2026b). This amounted to €38.7 billion in grants and loans to railway infrastructure (largely capacity expansions and other upgrades) and, to a much smaller degree, rolling stock.

Horizon Europe funds research and innovation projects mainly via the European Rail Joint Undertaking. The Joint Undertaking's latest call for proposals included total EU funding of €148 million, for expected projects worth €245 million (Europe's Rail 2025b). Horizon Europe funding has amounted to €298 million since 2021 for research and innovation projects in railways.

In total, funding instruments have provided around €32.4 billion in grants since 2021, and €56.0 billion in loans, of which most has gone to infrastructure (i.e. upgrades, and to a lesser degree, completely new construction, amounting to €70.7 billion) and rolling stock (i.e. purchase and retrofits, amounting to €17.0 billion). The final €729.7 million has gone towards research and innovation.

Some funded projects are explicitly linked to defence. Military mobility, dual-use infrastructure, and other defence-related terminology appear in projects totalling €737.8 million. However, defence-related investments often correspond with links and nodes of the TEN-T network, citing that infrastructure works also have certain defence value, so it is not clear that this funding is additional to what would otherwise be funded as purely civil infrastructure works.

In some cases, funded projects specifically highlight technological developments. For example, projects that explicitly mention ATO amount to €419.3 million of the funding, largely corresponding with funding of ERTMS-enabled rolling stock, and only a small fraction (i.e. €52.1 million) in research and innovation for related ATO-enabling technologies. Research and innovation funding has also gone towards hyperloop (i.e. €5.0 million) and maglev (i.e. €4.2 million) over the same period.

It is worth noting that the research and innovation funding tends to be captured by incumbent railway companies. While hyperloop development is a notable exception (with startups receiving European funding), for other railway technologies like ATO, startups seem to be dependent on private funding alone, which may place them at a disadvantage compared to incumbent Original Equipment Manufacturers (OEMs). This is despite ATO having a clearer and more immediate use case in European railways. Similarly, rolling stock financing is largely captured by railway incumbents, while new entrant railway undertakings report difficulties in purchasing new and used rolling stock to support railway services, and have difficulties accessing private finance due to the lack of long-term guarantees that state incumbents have.

For the upcoming period, the Commission's Communication on high-speed rail outlines that delivering the core high-speed network by 2040 will require substantial and coordinated investment, supported in the Multiannual Financial Framework 2028-2034 by the proposed € 51.5 billion CEF III transport envelope. Within this, € 17.5 billion is earmarked for military mobility, reflecting the dual-use nature of upgraded railway infrastructure and the need to remove bottlenecks relevant for defence logistics. Expenditures will need to cover major cost components such as high-speed line construction, cross-border tunnel and bridge upgrades, ERTMS deployment, digital capacity enhancements and interoperable rolling stock, alongside reinforced nodes and last-mile links that ensure network resilience. European Commission's estimates suggest that to finalise the currently planned TEN-T high-speed rail network by 2040, € 345 billion will be required. Moreover, market

opportunities for the rail supply industry have been estimated at € 18.2 billion for ERTMS on the TEN-T core network alone.

The scale of the investment envelope implies major expenditures for new high-speed alignments, large civil-engineering works, ERTMS deployment, digital capacity upgrades and interoperable rolling stock fleets. As public funding alone is insufficient, blended frameworks will be necessary to support the network's development. CEF can support leveraging additional public and private sources, including guarantees and long-term lending by the EIB. Also, innovative funding solutions combining EU grants, EIB loans, national promotional-bank instruments and enhanced private-capital mobilisation will strengthen the bankability of rolling stock investments.

However, beyond the availability of financing instruments, the mobilisation of private capital at scale depends critically on the underlying risk allocation and revenue framework of rail investments. While emerging instruments such as green bonds and blended finance offer potential to mobilise private capital, their effectiveness in the rail sector remains conditional on the underlying allocation of risks and the predictability of revenue streams (UNECE 2013). Evidence from rail PPPs indicates that bankable projects typically rely on a balanced sharing of demand risk, the presence of minimum revenue or availability-based payment mechanisms, and stable long-term regulatory frameworks (ADB Institute 2026). Where these conditions have been absent, projects have been exposed to cost overruns, traffic shortfalls and renegotiations, as documented in the European Court of Auditors' assessment of high-speed rail investments, which highlights weaknesses in demand forecasting, project appraisal, and delivery discipline (European Court of Auditors 2018). More broadly, the structural characteristics of the rail sector, with high fixed costs, long asset lifecycles and strong dependence on public support, limit the extent to which pure demand-risk models can attract institutional investors at scale. In this context, while EU State aid rules limit direct revenue guarantees and selective advantages, they allow for support mechanisms aligned with PSO, infrastructure funding and risk-sharing frameworks, provided they ensure proportionality and avoid undue market distortion. Strengthening clarity and predictability in the application of these rules, alongside more standardised PPP frameworks, may be a condition for scaling up private capital participation in rail investment (Rotellar-García 2024).

Across all stakeholder categories, long-term funding stability emerged as a decisive precondition for the effective delivery of rail investments. Interviewees consistently highlighted that fragmented, short term and project-based funding frameworks undermine maintenance planning, capacity expansion and technology deployment, particularly for cross border and system level projects. Stakeholders stressed that the capital intensive and long-lived nature of rail infrastructure requires governance and financing arrangements capable of extending beyond electoral and budgetary cycles. In this context, stronger alignment between EU funding instruments, national investment programmes and corridor level priorities was widely viewed as essential to translating policy ambition into tangible system performance improvements.

2.6 Overview of drivers and trends

Based on the literature analysis, reinforced by stakeholder views, a full overview of drivers can be found in Annex II (see also Table A.6). The analysis shows that the future performance of the European railway system is less constrained by technology than by infrastructure condition, funding capacity, and governance coherence. While demand for rail is strong, modal shift depends primarily on reliability, affordability, and door-to-door travel times rather than environmental awareness alone. Digitalisation and automation are widely recognised as essential enablers, yet their benefits remain limited by slow deployment and fragmented implementation. Chronic underinvestment in maintenance and renewal, combined with misalignment between political and infrastructure time horizons, emerges as the dominant structural constraint. Stakeholders consistently stress that

stable, long-term public funding and stronger European coordination are indispensable to translating policy ambition into system-wide performance gains.

Overall, stakeholder engagement confirms that the future performance of the European rail system is shaped less by the absence of technological solutions than by structural constraints related to infrastructure condition, capacity, governance, and long-term financing. The interviewees consistently emphasised reliability, coordination and investment stability as decisive factors across passenger and freight markets. While digitalisation and innovation are widely seen as necessary enablers, the stakeholders underlined that their impact depends on coherent system-level integration. Taken together, the findings highlight that effective coordination and sustained funding frameworks remain central to translating policy ambition into tangible improvements.

Table 1 provides an overview of the most important drivers and trends for each theme.

Table 1 – Key trends and drivers for each of the themes

Dimension	Key trends	Key drivers
Supply	Ageing infrastructure, capacity bottlenecks, renewal needs, workforce shortages, growing market opening	Underinvestment, fragmented planning, long delivery times for infrastructure vs. short political cycles, climate impacts
Demand	Strong demand, limited modal share	Reliability, door-to-door service and travel time, pricing, service frequency, punctuality, integration in multi-modal chains
Technology	Digitalisation, slow deployment, automation	Capacity constraints, interoperability needs, labour constraints, resilience needs
Funding	Investment gap, public funding dominance	Capital intensity, long asset lifecycles
Policy	Persistent fragmentation of governance, growing recognition for the need for EU-level steering	Fragmentation, EU climate and cohesion goals

Source: Elaboration by the authors, based on the analysis of Chapter 2 and stakeholder consultation.

External contextual drivers influence rail primarily through policy and governance choices, funding and financing conditions, and the deployment of technology. These enabling drivers are constrained by structural barriers identified in the analysis and stakeholder consultation. Together, they shape core system characteristics, such as infrastructure capacity, market structure and competition, service quality, costs and interoperability, which ultimately determine rail's competitiveness and its ability to support modal shift and broader EU policy objectives. Competition is considered a system characteristic, shaped by policy and regulatory choices and influencing prices, service quality and efficiency, rather than as an external driver in its own right. Outcomes feed back into the rail system over time: changes in demand, modal share and competitiveness influence prices, service quality, capacity utilisation and investment needs, thereby shaping subsequent system performance.

3 Future scenarios and their implications

3.1 Background

3.1.1 State of the sector and policy objectives

The scenarios provide a picture of the future role of railway transport against the background of the general policy objectives of the EU. Railway transport has recently found greater interest in EU policy making. Rather than arguing its importance by merely aspiring to shorter travel times, high speed passenger transport has earned the status of a catalyst for European integration. The Letta report assigns a particularly important role to faster rail transport: *"The establishment of a comprehensive, pan-European high-speed rail network, seamlessly linking all EU capitals and major urban centres, would represent an unparalleled opportunity to revolutionise European travel and catalyse EU integration"* (Letta 2024). The Draghi report also emphasises the role of transport to integration and competitiveness. Specifically, the transport chapter opens *"Well-functioning transport networks and services and a prosperous transport industry are crucial to the competitiveness of the entire EU economy. Transport systems ensure access to goods, services, and resources (including knowledge and innovation), in the process driving economic development, territorial and social cohesion"* (Draghi 2024). It points to the importance of rail connectivity for innovation and the growth of knowledge. The intensity of European business travel indicates the importance of face-to-face communication in research and development. The top six markets for business travel in the Europe, Germany, the UK, France, Italy, Spain, and the Netherlands, record 17.7% of global business travel expenditures (Meeting Spotlight 2025).

While volumes of passenger transport have been flat for other transport modes, the pax-km numbers of road, rail and air transport have increased. The increases translated into stable modal shares for road and rail but into a strongly increasing share of aviation.

The second objective for a greater role of rail relative to road and air transport is the potential in CO₂ emission savings. A modal shift to rail transport looks imperative in view of the EU risking to fail its decarbonisation commitments for the transport sector. Rail transport emitted less greenhouse gases than other modes and has been the only mode that has significantly reduced emissions over the last decades.

Figure A.38 underlines what motivates the demand for a modal shift towards rail transport. The achievements in reducing carbon emission by road transport fuel substitution have not resulted in significant reductions in emissions overall. While decreasing since the beginning of this decade, the road sector is still responsible for about 73% of overall carbon emissions. The strong increase in aviation traffic has caused a strong increase in carbon emissions. The difficulties of future fuel substitution in aviation support the demand to replace intra-European aviation by rail transport to meet the sector's climate policy objectives. Railways' share in overall emissions was 0.3% in 2023 (with about 10% of the pax-km supplied), down from 0.8 % 13 years ago. The modal competition with aviation provides the rationale for the focus on speed. As discussed in chapter 2, the driver of modal demand is the so-called "generalised costs", mainly composed of ticket prices and door-to-door travel times. The specific objective of EU and national rail policies of some Member States to achieve the modal shift is often a maximum station-to-station speed instead.

The European Commission's recent Communication reflects this sketch of the sector's policy background, adding additional dimensions: *"A European high-speed rail network will boost our economy, create quality jobs, foster cohesion, bring citizens together, decrease air pollution, and help deliver on our climate goals. High-speed rail is key to making Europe more united and future-ready, while strengthening the competitiveness of European industry. A high-speed rail network connecting capitals and other major cities in the EU can offer a convenient and clean alternative*

for travelers to short-to-medium-haul flights, and a fast and comfortable alternative to individual car or bus rides." (European Commission, 2025). It adds the claim on local connectivity that *"Better connections can help reduce the demographic pressure on large urban areas, notably on the housing market, while preserving the depopulation of smaller cities."* (ibid).

3.1.2 Member State status quo

Railway policies cast a long legacy shadow, as rail infrastructure has a standard lifetime of about 70 years. Hence, EU Member States face different starting points for the adjustment to conceivable and feasible railway futures.

3.1.2.1 Differences in striking the balance between policy objectives

National railway policies are influenced by each country's history of infrastructure investment. They follow from the historically grown density of the rail networks and the size of countries. Small countries, like the Benelux or the Baltic countries, have no commercial domestic flights. Therefore, national policies pay little attention to substitute air passenger travel by rail transport. Depending on existing capacity they prioritise the connection of regions. If high-speed rail stations are spaced closely together, the costs in terms of infrastructure and rolling stock per travel time unit saved drastically increase. Even the required minimum speeds for TEN-T core and extended core routes become too high to deliver reductions in travel time values that balance the costs of speed increases.

National rail policies have assigned different importance to rail connectivity in correspondence to national economic geographies in terms of population density and urban structure. The more disperse the urban structure, the greater the interest of national policies in regional and local connectivity relative to the high-speed connections between "all EU capitals and major urban centres" (see also Figure A.39 and Figure A.40).

3.1.2.2 Different financing models

Railway policies of the Member States adopt different rules to fund infrastructure investment and the costs of operations. When economic policies emphasise market liberalisation, railway policies often pursue the modal objective of creating quasi markets for rail transport services. Such concepts demand Infrastructure companies cover investment costs through access fees, and operators to cover the full costs of rail services through ticket prices. Public finance economics suggests that ticket prices should only cover marginal costs of operations, coupled with multi-part tariffs or tax finance, to avoid an underutilisation of the infrastructure capacity (OECD/European Conference of Ministers of Transport, 2007). EU Member States have adopted different regimes of infrastructure funding, with operators often contesting the infrastructure charges. It has led the European Commission to issue "Interpretative Guidelines on the setting-up of charges for the used of rail infrastructure" to interpret the Single European Railway Area Directive 2012/34/EU and the Implementing Regulation (EU) 2015/909 on how to calculate "direct costs".

Current policy debates on funding favour a different pricing and funding model, the "Regulatory Asset Base Framework" (RAB). (Makovsek and Veryard, 2016; Montero and Petrozziello, 2025) Instead on the optimal use of fixed infrastructure resources it centres on price regulation, granting a fair rate of return to investors. The controversies on the definition of direct costs are replaced by controversies on how to evaluate infrastructure assets and what is "fair". It is subject to all the criticism of rate-of-return regulation, and incentives to overinvest (Katz, 1983; Ponti, 2011).

3.1.2.3 National rail technology interests

Like the legacies in infrastructure, national policies to support technological development have created systems that reach their replacement point in 15 to 20 years. The European Court of Auditors cast the ERTMS, for example, as a "strategic political choice with no cost estimate". The European Deployment plans did not require commitments to decommissioning. Consequently, there were at

times thirty parallel technical systems to ensure interoperability. (European Court of Auditors, 2017)

The switch to one technical system creates private costs for operators, which leads to resistance against political change. The EU-Rail Joint Undertaking seeks to make the switch palatable by offering profitable solutions at the company level. Rail undertakings potentially benefit from network and company size economies and therefore anticipate a loss in protection and an increase in competition intensity from harmonizing technical standards and management systems.

3.2 Construction of the scenarios

Building on the mapping of trends, drivers and uncertainties presented in Chapter 2, Section 3.1 outlined the analytical logic underpinning the scenarios and the key dimensions along which future developments of the European railway system may diverge. The scenario framework deliberately abstracts from short-term policy debates and instead explores plausible long-term configurations of the European rail sector, reflecting different combinations of governance arrangements and technological trajectories.

The four scenarios should be understood as stylised foresight environments, rather than forecasts or normative policy choices. They are constructed to illustrate how structural drivers identified earlier in the study may interact over time and shape system-level outcomes up to 2050. None of the scenarios is presented as inherently desirable or undesirable; their value lies in highlighting trade-offs, boundary conditions and systemic implications for rail performance, integration and resilience.

To ensure transparency and comparability, the scenarios are organised along two core axes. The first axis relates to the degree of governance and coordination in the European railway system, ranging from predominantly decentralised, Member State-led approaches to more centralised forms of European integration. The second axis concerns the nature of technological development, distinguishing between incremental evolution of established rail technologies and more transformative pathways centred on emerging or edge technologies. Table 2 presents four contrasting future scenarios.

Table 2 – Future scenarios

Axis		Governance	
		Decentralised	Centralised
Technology	Incremental/Conventional	Scenario I: Decentralised corridor implementation and incremental technology adoption	Scenario II: Central network planning and centralised network implementation
	Transformative/Edge technologies	Scenario III: Decentralised rail policies implement national projects of transformative technology	Scenario IV: Centralised high-speed rail system with most advanced technology

Source: Elaboration by the authors.

The following sections present the four contrasting scenarios in detail. Each scenario is described in a structured and consistent manner, covering implications for technology and infrastructure, costs and investment dynamics, and rail policy coordination and governance. Taken together, the four scenarios provide a coherent basis for the subsequent analysis of the policy options in Chapter 4, where different strategic choices are assessed against a range of possible future system conditions.

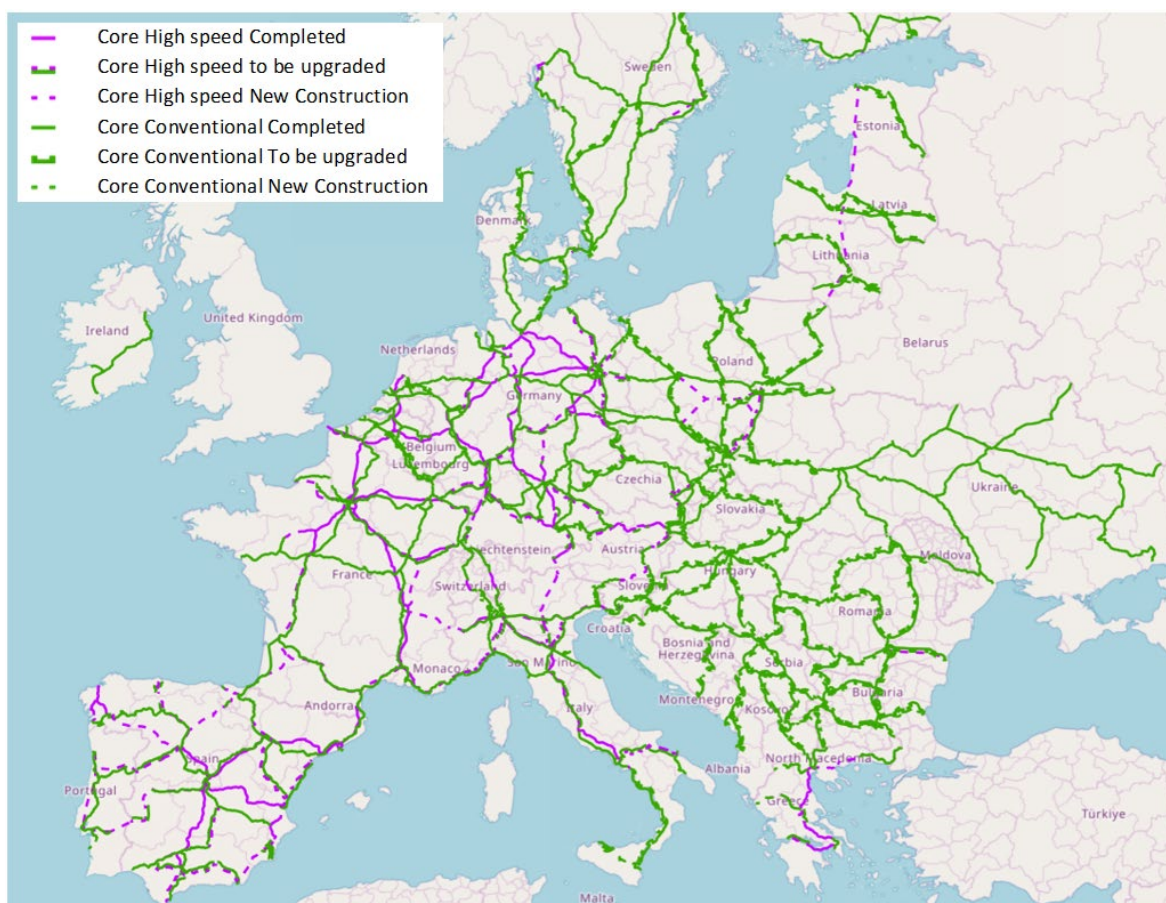
3.3 Scenario I: Decentralised corridor implementation and incremental technology adoption

Scenario I describes the future of railways with the current assignment of responsibilities in railway policies, as described in the above chapters.

3.3.1 EU target setting and planning of railway infrastructure

Scenario I can be considered the business-as-usual case, in which rail infrastructure planning remains centralised. EU Regulations continue to set the targets for rail connectivity. It defines a core, an extended and a comprehensive network with connecting routes and speed targets, as set out in Figure 2. The 2024 revision of the 2013 regulation introduced an extended core network as an intermediate layer to accelerate strategic links. The revision tightens the deadlines.

Figure 2 – TEN-T rail core network



Source: TENtec map viewer webpage.

The core network includes the most important connections between major cities and nodes. Minor extensions have been added in the TEN-T Regulation revision 2024 to define the extended network. A comprehensive network includes full EU-wide connectivity. The completion deadlines are 2030, 2040 and 2050, respectively. The core and extended core rail networks mandate operators to achieve minimum speeds of 160 km/h. The sparser high-speed rail network, as published in the high-speed rail communication of November 2025, targets a minimum speed of 200 km/h. It foresees new lines from Paris to Madrid and Lisbon, and from Warsaw to Tallinn, with completion deadlines between 2030 and 2040. As Figure 3 shows, the high-speed rail network focuses on connecting EU capitals.

Figure 3 – The European high-speed rail network



Source: (European Commission 2025b).

3.3.2 Decentralised implementation leads to slow realisation of EU roadmaps

The greater ambition to complete pan-European networks, is not matched with faster progress in implementation. In contrast to the network ambitions, implementation is subdivided into corridors (see also Table 3). Member state governments complete the corridors by sequenced projects. Corridor coordinators establish work plans for the cooperation between the national authorities involved.

The Baltic Sea-Black Sea-Aegean corridor has only been added to the list with the 2024 revised TEN-T regulation and is therefore unlikely to match the target timeline. Major infrastructure gaps in linking Romania, Bulgaria and Greece will remain beyond 2030. The coordinators see also the overall completion of the North Sea-Baltic Corridor and the Mediterranean in critical state. In four of the original eight corridors, they state critical cross-border gaps: The Scandinavian-Mediterranean Corridor records critical delays for the Brenner Tunnel and the Fehmarn belt. The North Sea-Baltic Corridor considers Rail Baltica to be a crucial gap. The Atlantic corridor suffers from unresolved high-speed rail connections between France and the Basque region. For the Mediterranean Corridor the Lyon -Torino Base Tunnel will not be completed by 2030. The Baltic Adriatic Corridor faces bottlenecks at the border between Poland, the Czech Republic and Slovenia (E59 rail line).

Table 3 – TEN-T corridors, updated with Regulation

Corridor	Geographic scope
Atlantic	Portugal, Spain, France, Germany
Baltic Sea – Adriatic Sea	Poland, Czechia, Slovakia, Austria, Italy, Slovenia
Mediterranean	Spain, France, Italy, Slovenia, Croatia, Hungary, Ukraine

Corridor	Geographic scope
North Sea – Baltic Sea	Finland, Estonia, Latvia, Lithuania, Poland, Germany, Netherlands, Belgium
Baltic Sea – Black Sea – Aegean Sea	Greece, Bulgaria, Romania, Hungary, Slovakia, Poland
Western Balkans – Eastern Mediterranean	Greece, Bulgaria, North Macedonia, Serbia, Bosnia and Herzegovina, Croatia
North Sea – Rhine – Mediterranean	Netherlands, Belgium, Luxembourg, Germany, France
Rhine – Danube	Germany, Austria, Slovakia, Hungary, Romania, Bulgaria
Scandinavian – Mediterranean	Finland, Sweden, Denmark, Germany, Austria, Italy, Malta

Source: European Commission (2024).

Analysing the completion of the TEN-T core network in its 2026 update of the 2020 special report (see also Figure 2), the Court of Auditors (European Court of Auditors, 2026) concludes that the completion deadline will not be met, as is detailed in Table 4. For all the transport flagship projects assessed by the Court of Auditors the completion forecasts have significantly worsened in comparison to the 2020 special report, except for the Fehmarn belt.

Table 4 – Expected delays to transport flagship projects

TFI	Original Plans ¹¹		Special report 10/2010	Status in November 2025		
	Implementation timeline (years)	Estimated opening year	Estimated opening year	Revised estimated opening year	Delay compared with special report (years)	Delay compared with original plan (years)
Lyon – Turin rail link	7	2015	2030	2033	3	18
Brenner Base Tunnel	9	2016	2028	2032	4	16
Fehmarn Belt link	10	2018	2028	2029	1	11
Basque Y	4	2010	2023	2030 ¹²	7	20
Rail Baltica	10	2026	2030	n. a. ¹³	Yes	>4
E59 railway line	Varies by section			n. a.	n. a.	n. a.

Source: European Court of Auditors (2026).

3.3.3 Decentralised harmonisation of technical standards and management procedures risks holdups

In a decentralised rail policy system efforts to establish high-speed connections across jurisdictional borders depend on harmonising research on up-to-date technical standards, finding a consensus on

¹¹ The original plans are the earliest that exist for each TFI, which can correspond to a different scope or level of maturity of its design.

¹² While the Commission has indicated 2030 as a likely completion date, information from the project promoters points to a 2035 completion date.

¹³ No estimated opening year is available for the full TFI. The first phase of the TFI is estimated to open in 2030.

different components of a system for train control, safety, and communication.¹⁴ It also requires credible commitments to implement agreed joint features.

For the EU, the search for such a system began under the auspices of the Union Internationale des Chemins de fer (UIC) in the 1980s. At that time, trains in Europe operated under more than 20 incompatible protection systems.¹⁵ Harmonisation efforts have been undertaken in the EU through the European Rail Traffic Management System (ERTMS), which includes the following components:

- European Train Control System (ETCS), an automatic train protection and control layer with continuous speed supervision, movement authority management,
- A radio communication layer, which is in the process of being changed from GSM-R to FRMCS,
- An automatic train operation system (ATO), which supports automatic driving with or without driver supervision,
- Traffic Management System integration (TMS) for conflict detection, automatic route setting and real-time rescheduling.

The first Directive on interoperability for high-speed rail defined the characteristics of ERTMS (Official Journal of the European Communities 1996). It introduced the concept of an interoperable control and command system and signalling. UNISIG, an organisation of European signalling companies, produced the first technical specifications for interoperability in 2000.¹⁶ It was translated to European interoperability standards by the Commission Decision 2002/731/EC (Official Journal of European Communities 2002).

Table 5 shows the agreed timelines for the roll-out of ERTMS, as it has been redefined in Article 18 of the new TEN-T Regulation of 2024. Exceptions from the timeline are defined in Article 8(5), based on project maturity or availability of financial resources. Derogations are possible, if competent authorities can present a negative outcome of a socio-economic cost-benefit analysis as part of an interoperability impact assessment, or because of coordination difficulties with neighbouring countries.

Table 5 – Timelines for the roll-out of ERTMS according to the new TEN-T Regulation

Obligation according to Article 18	Deadline
ERTMS implementation on core networks	2030
ERTMS implementation on extended core networks	2040
ERTMS on comprehensive network	2050
Radio-based ETCS obligatory on new lines	2030
Radio-based ETCS obligatory on upgraded lines	2040
Radio-based obligatory for all ERTMS	2050

Source: Elaboration by the authors, based on (Ruete, 2026).

¹⁴ The digital interfaces for traffic management and the traffic management system add additional layers of technical train protection and control for automated train operations, and standards for transponders signalling location as well as secure communication protocols.

¹⁵ Anecdotal evidence shows that, today, train operators on international routes like Eurostar must still have six to eight different train protection system.

¹⁶ UNISIG is a consortium of European railway signalling companies responsible for developing and maintaining technical specifications for the ERTMS.

The ERTMS efforts go back to 1995, defining its implementation as a precondition for the implementation of the European Rail Network. In 2009 the first ERTMS deployment plan marked an additional milestone for ERTMS. It included mandatory deadlines ranging from 2015 to 2020 depending on the line sections. The European Commission published the latest version of the ERTMS European Deployment Plan in 2017. Industry stakeholders signed letters of intent to renew their commitment for the development of ERTMS. Member states were asked to draw up National Implementation Plans.

The long process of consensus building between Member States and the different authorities lead to complicated governance structures with time-consuming internal coordination processes. Since 2021 the EU Rail Joint Undertaking is tasked to develop a unified system architecture, accelerate deployment of digital and automated solutions and to fund large flagship research projects under Horizon Europe.

The ERTMS coordinator points to an active process of improving governance between the Commission, the ERTMS coordinator, the ERA, the research organisation EU-RAIL as well as the sector's representative stakeholders. But he rates the efforts "*... still seem to fall short, and a more structured, streamlined and strengthened governance framework appears warranted*" (Ruete, 2026). Still, the European coordinator proposes to newly establish an ERTMS task force and to consider an EU-level deployment manager.

The coordinator's assessment of the status of the deployment raises the question whether deadlines remain meaningful. Figure A.41 shows the rate of deployment of ETCS in member states. Seven of the 27 Member States has not begun the implementation. Large countries like Spain, Italy, France and Germany had deployment rates of 28, 17, 10 and 5 percent on the core network in 2024.

Despite the agreed ERTMS timeline, Member State plans to deploy ETCS covers only about 50% of the core network, as Figure A.42 shows. Large countries like France, Germany, Spain and Italy commit only to deployment rates of 20, 33, 46 and 69 percent for the core network by 2030. The Court of Auditors sees the lack of deadlines for a decommissioning of the legacy systems as the main barrier to ending the limited and patchy deployment of ERTMS (European Court of Auditors, 2017). The adoption of joint technical and management systems as developed by the Rail Joint Undertaking is predicated on ERTMS serving the business interest of the operators. This requires that business opportunities are seen to be greater with greater cross-border competition than the current situation of protection.

3.3.4 Differences in country geographies lead to gaps in decentralised investment in faster rail network connectivity

With decentralised funding investment in modernisation and high-speed rail is governed by national interests. These national interests derive from country size, the size and density of urban centres and the distances between urban centres. For short distances speed increases do not generate significant time savings for passengers. Without larger and dense cities high-speed trains do not generate sufficient demand to justify the investment costs. It implies that Member States do not target the completion of a European network but the optimised resource use for a national rail network. This becomes obvious from the review of high-speed rail funding for the programming periods 2000 to 2020 by the European Court of Auditors (European Court of Auditors, 2018a).

Under shared management, a system under which responsibility for spending the budget is shared with the Member States, the Commission establishes guidelines for planning operational programmes. The Commission negotiates, approves and monitors the implementation of the operations proposed by the Member States. Budget contributions are provided through the European Regional Development Fund (ERDF) and the Cohesion Fund. The European Commission is responsible for approving the EU's contribution to transport projects with a total eligible cost higher than €75 million. In direct management, applications for EU co-funding are made through the

Connecting Europe Facility (CEF) in response to periodic calls for proposals. Proposals are evaluated by the Commission in cooperation with the Innovation and Networks Executive Agency (INEA).

Figure A.43 shows that investment in high-speed rail has been uneven across countries and over time. Smaller countries like Belgium, Czechia, the Netherlands and Slovenia invested less than 1 % of the grand total of investments. The same holds for the Nordic countries. They lack the metropolitan areas and distances between them that could generate a high value of time savings by investing in higher rail speeds. For the programming period from 2014 to 2020 they had investment shares in the grand total of less than 0.1 %.

At the time of the 2025 audit of the Court of Auditors, the accumulated investment volumes for the Transport Flagship Initiatives (with volumes of larger than €1 billion) amounted to about €50 billion. As reported above, all of them (except for the Fehmarn belt) are not expected to be completed in line with the TEN-T deadlines (European Court of Auditors, 2026). Figure A.44 shows the dramatic cost overruns compared to initial cost estimates. ECA traces them back to complicated bureaucratic procedures in the member states, duplication of implementation efforts and weaknesses in the cost-benefit analysis processes. Remarkably, the expenditures for the E59 rail line (upgrading rather than new investment) are lower than originally estimated.

3.3.5 Decentralised funding maintains national legacies of national railways' differences in rail policy objectives

In addition to the differences in investment efforts in high-speed rail lines due to different urban geographies, larger countries are constrained in station-to-station speeds by urban settlements along the lines and policy intent to connect regions. High station-to-station speeds depend on connecting large metropolitan centres and the availability of large and fast feeder systems to generate sufficient demand for high-speed rail. As Table 6 shows, these factors have led to significant differences between national rail policies, reflected in differences in (maximum) effective station-to-station speeds.

Table 6 – Selected best performing national high-speed rail lines

Link between centres	Distance (km)	Best travel time (minutes)	Maximum station to station average speed (km/h)	Minimum number of stops
Paris-Marseille	862	205	252	0
Paris-Bordeaux	537	122	264	0
Paris-Strasbourg	490	106	275	0
Strasbourg-Stuttgart	109	78	90	1
Hamburg-Munich	613	340	108	11
Berlin-Munich	623	250	150	2
Frankfurt Airport-Cologne	151	45	200	0
Brussels-London St. Pancras	321	120	161	0
Barcelona-Madrid	621	150	250	1

Link between centres	Distance (km)	Best travel time (minutes)	Maximum station to station average speed (km/h)	Minimum number of stops
Milano–Roma	570	175	195	0

Source: Elaboration by the authors, based on information collected from timetables of railway operators.

The top speed connections in Europe reveal the difficulties to make them economically viable. Trenitalia operates the routes Paris Bordeaux and Paris Marseille since 2021. According to newspaper reports, both routes have accumulated triple digit million Euros losses since then, with 70% capacity utilisation rates. It shows that even with large and dense Paris being one of the nodes, it is difficult to generate sufficient demand to achieve economic viability.

Table 6 also reflects differences in objectives to connect medium-sized cities by high-speed rail. It shows how the number of stops reduces average station-to-station times. Both the Berlin-Munich connection and the Frankfurt-Cologne connection have track infrastructure that allows for speeds greater than 250 km/h.

The smaller the cities connected and the more dispersed these are, the higher are the demands on the local urban transport systems to increase the potential demand for high-speed rail connectivity. Large catchment areas and high-speed connections to the railway stations are required to achieve door-to-door travel times that can compete with aviation. The TEN-T Regulation 2024 picks up the need to connect urban planning to the long-distance railway planning.

3.4 Scenario II: Central network planning and centralised network implementation

Scenario II changes the fundamentals that are barriers to the realisation of a Single European Railway Area. It assumes that the rail technology ambitions do not deviate from the evolutionary path that EU operators have followed for train technologies.

It takes from Scenario I that in a decentralised system of implementation the sunk costs of switching from infrastructure and technology legacies, and of leaving research histories from national research institutions stands in a way of a unified Single European Railway Area. Additional barriers are the social costs of changing or giving up established institutions in the railway sector, and the resistance to shoulder adjustment costs to a new market structure. With a new distribution of competences, the vision for a pan-European high-speed rail system as set out in the recent communication of the European Commission could become reality. This concerns centralisation of:

- selection and implementation of railway infrastructure policies.
- the setting and implementation of technical standards and management procedures.
- funding of railway infrastructure.
- a unified regulatory regime for all operators.

The changes presented in these scenarios require big institutional adjustment including the transfer of infrastructure planning competences and fiscal competences from the member states to the EU institutions. The scenario is mindful of the scale and network economies that may emerge in a unified railway market with the potential of a dominant natural-monopolistic operator. To avoid the associated market and political power, the proposed regulatory regime will contain market

distortions resulting from a local monopoly position¹⁷ and reward compliance with the centralised market setting.

3.4.1 Centralised infrastructure implementation overcomes the disregard for network benefits

The map of the TEN-T core network high-speed connections to be upgraded or build, the list of the TEN-T flagship projects that are delayed and the announced start of the subset of national high-speed rail projects that serve cross-border traffic only after 2030 (i.e. 6 out of 16) (European Commission, 2025, p. 81) show a bias against the completion of a European network, creating deep uncertainty on the completion of even the TEN-T network links.

This bias is a natural consequence of the impact assessments of the projects being done with national net benefits in mind. The centralisation of impact assessments that count benefits regardless of where they occur within the EU would change the ranking of railway infrastructure projects. Only such a change would capture wider benefits of transport in the form of lower cross-border trade costs in all member states connected to transactions, in terms of monetary costs and transport times. It would account for the resulting impact on productivity and competitiveness. This would counter the evaluation deficit in implementing TEN-T network completion as identified by the Special Report of the Court of Auditors (European Court of Auditors, 2018b).

3.4.2 Centralised setting of technical and management standards is a necessary condition for harmonisation

Technical standards are set after consulting with stakeholders and an impact assessment on best practice and the most promising perspective on technical development. This could become a role of a permanent institution like the Rail Joint Undertaking.

This will create different legacy costs, depending on the rail density of service supply. It will also depend on the history and the state the equipment. The parties of the EU-Rail Joint Undertaking agree on a path of decommissioning the equipment. The costs of implementation will be covered by central fiscal support for equipment that is part of the infrastructure and operator revenues that is a function of the regulatory regime explained below. A European rail agency will oversee the implementation.

Such a change would end the postponing of the implementation of ERTMS agreements into an unpredictable future. It would remove the holdup opportunities of member state governments and railway companies. The regulatory regime will reward compliance and speed of adjustment that leads to higher adjustment costs. It also ends the situation that the adoption of agreed standards depends on increased profits under incumbent business models. The regulatory regime will also solve the weak sanctioning powers of EU institutions that have helped non-compliance in the past.

3.4.3 Centralised funding of railway infrastructure will increase the efficiency of capacity choice and allocation

As reported in Scenario I, different models exist across member states, how the costs of railways are covered. The controversies around the topic of what "direct costs" are allude to the rule of normative public finance that prices should only cover marginal costs. Marginal costs are those that go up or down with higher or lower usage. If the TACs include other elements, fixed infrastructure resources will be underused, leading to higher unit costs of infrastructure services. Whether fixed costs should be covered by (annual) fixed charges for users or by government "grants" depends on whether the infrastructure creates benefits only (or mainly) for the users or for the European society

¹⁷ See for example, European Commission: DG for Mobility and Transport and KPMG (2025).

at large. Apart from the efficiency argument, pricing rules to make modernised railways "self-financing" will reduce opportunities for shift from more carbon intensive modes.

The central fiscal funding also helps to reduce the conflicts between Member States because of different geographies, different infrastructure investment legacies and different interests in modernisation because they are of different sizes. Member States could be supported in accordance with their contribution to the network benefits achieved through more effective implementation of agreed network-wide infrastructure and equipment choice. Small countries would have incentives to support high-speed rail build-up that is not in their national interest, large countries with dense rail infrastructure, like France and Germany, can be incentivised for faster infrastructure change.

The importance assigned to fast railway connectivity for competitiveness and overall European integration like in the Letta and Draghi reports suggests that its benefits are "wider benefits" that go far beyond the users. This holds first for the benefits of trade in goods and services that are made possible by lower rail transport costs. It also holds for the reduction of environmental damage, the reduction of safety risks and carbon emissions that are higher for competing modes.

The greater social than individual benefits of European rail transport do again not accrue at the national level. The recognition of the wider benefits of fast railway connectivity is a strong argument for central European fiscal competences to switch to a European network policy rather than the corridor project decisions in direct and shared management.

Central fiscal competences would also facilitate to ease local resistance against upgrading of infrastructure and the sunk legacy costs it entails. In many cases where local adjustment costs are higher than local benefits, impact assessments in a network perspective will show an overall social net benefit.

3.4.4 Centralised regulation can balance network economies and contain incumbents' market powers

The expansion of railway services creates scale and network economies. The larger railway operators and the more railway links they serve the greater will be their competitive advantage. On track competition leads to high coordination costs and mutual holdup opportunities for competing railway companies. Without a proper regulatory regime, the scale advantages at the company level are likely to lead to cost inflation and rents driving up prices. Where dominant railway suppliers exist, they also wield political power to establish protection. Both would again decrease the potential for a shift from modes with higher external costs.

One way to ensure efficiency is yardstick competition (Shleifer, 1985). Yardstick competition introduces competitive pressure on natural monopolies by subjecting them to benchmarking against undertakings in similar conditions. The mechanism rewards user serving or cost reducing change by allowing successful companies to earn temporary profits. The mechanism provides laggards with incentives to catch up or leapfrog and earn temporary innovation rents.

In the European context it would mean to form suitable border-crossing regions of low interdependence of demand with (emerging) dominant suppliers who are the most successful in achieving economies of scale at the operator level. The interfacing between geographic regions of operations has to make sure that the balancing of a reduced potential of network economies and the containment of monopoly powers is balanced at least costs. In this respect the mechanism can also avoid the blockage of cooperation in infrastructure capacity utilisation.¹⁸

¹⁸ This concerns, for example, the non-progress on the Commission's proposal on rail infrastructure capacity use. COM(2023) 443/2. The Regulatory Scrutiny Board has given a green light despite doubts on the discarding of a policy

Yardstick competition may offer opportunities to allow for regulated vertical integration that avoids the friction that has occurred between operators and infrastructure companies. The yardstick competition would extend to the efficiency of the scale and organisation of maintenance, avoiding also the moral hazard in ensuring railway safety.

3.5 Scenario III: Decentralised rail policies implement national projects of transformative technology

There is no initiative from Member States for cross-border networks using transformative rail technologies. A small number of project ideas are studied for urban mobility. Metropolitan areas like Paris, Berlin, Milano or the Rhine Ruhr area could use the maglev or hyperloop technologies to relief land pressure within a polycentric setting of suburban agglomerations. None of the implemented projects has pursued such an objective.

Most prominent in these plans is the German-developed high-speed monorail train which was developed and marketed by Siemens and Thyssen Krupp. The super-speed maglev system runs on magnetic force between linear arrays of electromagnetic coils. One side of the coil is on the vehicle, the other in the track guideway, functioning together as a magnetic dipole. During levitation and travelling operation, the maglev vehicle floats on a frictionless magnetic cushion with no mechanical contact with the track guideway. The maglev technology can therefore run faster and at lower energy consumption than traditional rail systems. The German Transrapid allows maximum speeds of 550 km/h.

Infrastructure cost figures are available for the Shanghai maglev. The line was built between 2001 and 2004, with infrastructure costs of US\$1.33 billion (i.e. €2 billion in current prices) for a track of 30 km. The distance from Pudong International Airport to downtown Shanghai takes about 8 minutes, reaching a top speed of 431 km/h.

Based on the published rolling stock data of Transrapid Australia, rolling stock costs about €72.200 per sqm of floor area, compared to the costs of €31.540 per sqm of floor area of a current ICE. The rolling stock estimates are above double the rolling stock costs of current ICEs.

There are no decisions on maglev urban transport projects in Europe. Plans are considered for Berlin and Nürnberg. They are connected to a licence of the Federal Government of Germany to the company Transport System Bögl. The licence follows a long history of folded maglev urban transport planning projects in EU Member States:

- connection from Milano airport to Bergamo and Brescia proposed in 2008.
- a connection from Pisa airport to Prato and Firenze in 2011.
- a two-line 120 km long line was proposed for Tenerife to connect the island capital Santa Cruz in the north with Costa Adeje in the south and Los Realejos in the northwest at an estimated costs of Euros 3 billion (2011 prices).
- in Switzerland a systemic deployment was planned between Geneva, St. Gallen, Luzern and Basel, construction to be started after 2011 and the trains in operation by 2020.
- the maglev technology was also supposed to be used to connect major Swiss cities underground, the Swissmetro AG, tasked to implement the plans were handed over to the EPF Lausanne after dissolution.
- in the UK three maglev lines were proposed, the London-Glasgow line, rejected by the government in 2007 and implementing company closing down in early 2013, the Glasgow-Edinburgh line with works supposed to start in early 2008 but never started, and the line

option requiring greater coordination between member states. (European Commission, 2023) It has not move forward through Parliament and Council.

Liverpool-Hull proposed in 2017, linking Liverpool, Manchester, Leeds and Hull, also not taken forward by the UK government or the agency Transport for the North.

- in Germany the link between the city centre of Munich and Franz-Josef-Strauss airport earned a lot of attention due to the strong support from the government of Bavaria, promising to half the travel time from 40 to 20 minutes, a contract of €1.9 billion was signed and the project scrapped in 2008 because of dramatic cost overruns.
- a plan to build a Berlin-Hamburg connection was cancelled due to the lack of funds, and the upgrading of the ICE to reach 230 km/h of top speed.
- Metrorapid, a 79 km maglev line to connect Düsseldorf with Dortmund via Duisburg, Essen and Bochum in 37 minutes, cancelled in 2003 for financial reasons.
- a test facility in the Emsland used by Thyssen Krupp, Siemens and Transport System Bögl. The facility was complete in 1984. On the test track of 31.8 km, it achieved maximum speeds of 450 km/h. In 2006 23 people were killed in the Lathen maglev train accident due to a collision between a visitor passenger train and a maintenance vehicle. The licence expired in 2011 and the licence was not renewed. The demolition and reversion plan was approved in 2012; demolition began in 2016. Federal public grants had accumulated to estimated EURO 800 million between 1970 and 2008. Universities of Lower Saxony have expressed interest in converting the site for research on the hyperloop system.

Two projects are active:

- A 5 to 7 km line in Berlin connecting Spandau with the city centre was proposed in 2023 by the city Senate, the connection is planned to use the Transport System Bögl. The Berlin Senate is committed to support the project with a grant of €80 to €85 million. Earlier, in 2020 a plan for a connection from the city centre to the Airport Berlin Brandenburg has been launched, being delayed by disputes over the possible routes.
- A 4 km maglev line in Nürnberg has been proposed by the Minister-President of Bavaria, from the University of Nürnberg to a fairground and a hospital. The Bögl company is located in Sengenthal, southeast of Nuremberg where the company runs an 850 m long test track. The project would use the TSB technology. A comparative feasibility study found that costs of the maglev line would be similar to those of a conventional tram extension, but that the conventional tram system would attract more passengers due to easier access to the system.

The Federal Railway Agency has granted a licence to operate maglev systems to Transport System Bögl in November 2025. TSB has completed a trial in Chengdu in China, in cooperation with Chengdu Xinzhu Road & Bridge Machinery Co Ltd. The rolling stock was built by the company HeiterBlick in Leipzig. The top speed achieved was 169 km/h, a new record for the TSB. In December 2021 Chinese authorities announced the production of TSB carriages in China. The Chengdu partner company has a TSB production and marketing monopoly in China. We cannot exclude that greater scale of deployment in China inducing a steep learning curve reduces the costs of maglev projects to lead to a renaissance in Europe.

For hyperloop only one local project is proposed.¹⁹ Hyperloop shuttles are planned to connect Schiphol Airport to the smaller airports Lelystad Airport in the northeast, Rotterdam-The Hague in the southwest and Eindhoven Airport in the southeast. The study explicitly rejects the objective of substituting air travel by high-speed rail transport.²⁰ Unrelated to objectives of European connectivity and sustainability of transport, the proposal seeks to increase the capacity of the

¹⁹ See [Amsterdam Airport Schiphol Study](#).

²⁰ "Despite previous suggestions for high-speed rail as a short-haul flight substitute, it has been deemed inadequate due to issues like cost overruns and protracted infrastructure lead times." They do not seem to be expected for the proposed hyperloop connections. [Amsterdam Airport Schiphol Study](#).

Netherlands to handle intercontinental flights. The hyperloop links are planned to relieve the gap between burgeoning demand and stringent capacity restrictions. Social net benefits are measured in being able to accommodate a maximum of 58.3 million passengers in 2050 who would like to use Schiphol Airport but are excluded from its services due to noise and flight time restrictions. The greater air transport capacity of the Netherlands is expected to be essential for the vitality of the Dutch aviation sector and to generate wider benefits.

Project ideas to foster aviation apart, ultra-high-speed rail connectivity could help to relieve land pressure for large metropolitan areas with a polycentric structure that clearly separated large and densely populated sub-agglomerations. In such cases local maglev or hyperloop connections. None of the European cases studies of the Hardt hyperloop study series seem to fit this picture.

All the local ultra-speed systems of today are not economically viable. The largest traffic is registered by the Shanghai Pudong Airport connection to Longyang Road. Longyang Road is a peripheral metro interchange, not a centre of Shanghai station. It has never been profitable.²¹ The press statement of the vice president at the time of inauguration suggests that it was planned to serve as a showcase for longer-distance transrapid connections than as a standalone project.²² In contrast, the Chinese government pursued the objective to create large and dense urban subcentres by locating high-speed and ultra-speed stations outside cities.

European mega-centres could adopt the same strategy to relieve land pressure and the associated high land and housing rents in large metropolitan inner cities. To generate enough demand for the short connections the newly created sub-centres would have to be large and dense, including the supply of local services for the inhabitants of sub-centres.

If successful, the local transformative projects would mainly generate local benefits. A greater local tax base would have to cover a major part of the increased local tax burden. Transfers to the large metropolitan areas depend on wider trade and agglomeration benefits.

3.6 Scenario IV: Centralised high-speed rail system with most advanced technology

In this scenario, the hyperloop system is expected to represent a paradigm shift for European infrastructure: no longer just a high-speed transport system, but an integrated, highly efficient energy network. The key to hyperloop's energy superiority lies in the reduction of aerodynamic drag provided by the low-pressure environment inside the tubes. This physical parameter allows the system to operate with a much lower amount of energy than that required by aviation, but with speeds that are even higher. Table A.8 in Annex IV presents the main components of the Hyperloop system.

The adoption of a network of the most advanced hyperloop technology requires a central regulatory and funding regime. The great hopes for a quantum leap by hyperloop are based on theoretical top speed estimates. They range from 700 to 1 200 km/h. One of the national promoters, the Dutch Hardt hyperloop company, estimates the top speed to be 700 km/h. On short test tracks, the highest speed of 463 km/h has been achieved by the Technical University of Munich's hyperloop in the SpaceX Pod competition. There is no estimate of the speed that could be achieved in actual network operations. They depend first on passenger comfort impacted by the maximum acceleration and second on the infrastructure characteristics determining relative acceleration and

²¹ This also holds for the Chengdu project of Transport Systems Bögl.

²² All plans for Chinese long-distance transrapid connections have been cancelled, the Shanghai-Beijing connection being the most prominent one. Similarly plans of a transrapid connection between Berlin and Hamburg have been dropped in view of the high costs for the achievable travel time reductions.

deceleration phases, station spacing, safety margins and network integration. The European Tech companies estimate a realistic speed of 300 to 500 km, unless distances between stations are longer than 200 km. On routes smaller than 100 km, tech promoters do not expect a speed advantage relative to conventional high-speed trains.

There is no definitive discussion so far on the likely or desirable pan-European network. The European Hyperloop Development Program (a public-private partnership on hyperloop development) has recently published the network envisaged by 2050, as presented in Figure 4.

Figure 4 – European Hyperloop network projected for 2050



Source: (Ramboll Management Consulting, TIS, CETH, SINTEF 2025), based on (Sanchez, et al. 2022).

The Hyperloop Development Program expects the hyperloop corridors to be complementary to current high-speed routes. The map could be highly provisional as, for example, a paper of the Royal Technical Institute of Sweden advocates adopting hyperloop if technical uncertainties were removed (Magnusson 2022).

It is still a matter of debate where stations were to be located. Some promoters prefer inner cities; others plead for intermodal hubs at airports. Without an agreement on the network configuration, it is not yet possible to estimate average travel times and their impact on modal shift.

The main technical challenges discussed are the configuration of tubes, the availability and use of carbon-neutral and fully circular materials, and the positioning, communication and control systems (see Table 7). At this stage, the desk research shows that there is no agreement among the partners of the Hyperloop Development Program (HDP). Moreover, as Table 8 illustrates, the promoters of the hyperloop system do not expect the infrastructure to be available before 2050. Partners of HDP expect the rollout to start in 2035.

Table 7 – Main perceived challenges for the development of hyperloop

Challenge	Explanation
Tube configuration	The challenge concerns the diameter and pressure of the tubes. This is critical if the priority is to achieve interoperability between different hyperloop technologies.
Development of carbon-neutral and fully recyclable materials	The challenge lies in developing materials that maintain a net-zero carbon footprint across their entire lifecycle, encompassing production, disposal, and the ability to be reused, recycled, or composted within a closed-loop system.
Positioning, communication and control systems	The challenge is to create real-time hyperloop control systems by developing a new model to develop algorithms for operation control.

Source: (Ramboll Management Consulting, TIS, CETH, SINTEF 2025).

Table 8 – Projected Hyperloop network operational per year

Infrastructure available	2035	2040	2045	2050	2055	2060
Network kilometres added by year	120	160	1 200	1 200	1 200	1 200
Cumulative network kilometres	120	720	4 060	10 060	16 060	22 060

Source: (Ramboll Management Consulting, TIS, CETH, SINTEF 2025).

3.6.1 Investments need centralisation of funding responsibility

Estimates of infrastructure costs vary by a large margin. The average estimate of capital costs per km is €36.6 million, with a range of estimates by hyperloop promoters from €34 million to €37 million. This is double the capital cost in 2024 prices that the European Commission's Assessment of Unit Costs for Rail Projects estimated for high-speed rail.⁸ At the EU level, these estimates would lead to a total infrastructure expenditure of €808 billion by 2050. This excludes the construction costs of stations.

The European Hyperloop Centre (EHP) promoters estimate that a hyperloop vehicle would cost about €10 million. One promoter projected demand for vehicles is 15 000 by 2050. Estimates of the total costs of rolling stock vary dramatically from €70 million to €425 million, depending on the network configuration.

In light of the cost increases seen from early estimates to final cost figures 25 years later, total costs could be substantially higher. There are no concrete models on how to finance a European rail future with a hyperloop network. The experience of privatisation and the experience of Japan National Rail indicate the need for centralised public sector finance.

A lower estimate of the per km tube costs are €30 million. A rough estimate of the infrastructure costs connecting the European capitals in line with Figure 4 would lead to a total of €386 billion, excluding costs for stations and pods.

Table 9 shows the costs of the individual links and the time savings relative to the travel time estimates in the Commission's Communication, assuming optimistic station-to-station speeds of 400 km/h. The total infrastructure costs would be significantly higher, as much of the modal shift would be from aviation but from conventional high-speed rail, creating unused capacity at least on some links. The assumed speed of 400 km/h is higher than any station-to-station speed that has been achieved in practice. As Table 9 suggests, it marks a benchmark for rail competitiveness in terms of travel times relative to aviation for connecting intra-European capitals.

Table 9 – Hyperloop infrastructure cost and time savings estimate, connecting EU capitals

Links of the high-speed rail map	Estimated operational distances	Costs (€ million)	Travel times for high-speed rail (minutes)	Travel times hyperloop no stops, at 400 km/h (minutes)	Time savings (minutes)
Lisbon – Madrid	510	15,300	180	77	104
Madrid – Paris	1,050	31,500	360	158	203
Rome – Paris	1,420	42,600	525	213	312
Rome – Berlin	1,500	45,000	615	225	390
Athens – Sofia	820	24,600	360	123	237
Sofia – Bucharest	460	13,800	360	69	291
Bucharest – Budapest	830	24,900	375	125	251
Zagreb – Budapest	350	10,500	255	53	203
Budapest – Vienna	250	7,500	100	38	63
Ljubljana – Vienna	380	11,400	270	57	213
Vienna – Berlin via Prague	410	12,300	270	62	209
Vienna – Warsaw	680	20,400	255	102	153
Amsterdam – Berlin	650	19,500	330	98	233
Brussels – Berlin	770	23,100	280	116	165
Berlin – Warsaw	570	17,100	255	86	170
Berlin – Copenhagen	440	13,200	240	66	174
Warsaw – Vilnius	520	15,600	240	78	162
Copenhagen – Stockholm	650	19,500	240	98	143
Vilnius – Riga	300	9,000	120	45	75
Riga – Tallin	310	9,300	105	47	59
Total	12,870	386,100			

Source: Elaboration by the authors.

3.6.2 Rail policy coordination and governance

The technical minimum distance requirements for a technically viable hyperloop connectivity indicate that a European network defies national systems in Europe and will require centralised public sector funding. The harmonisation of technical systems and the development of control systems is still a matter of debate among the tech companies developing hyperloop in Europe. There is anecdotal evidence that there are disagreements between protagonists. The European Commission supports technical and regulatory harmonisation by the Hyper4Rail project promoted by the EU-Rail Joint Undertaking, and efforts to align hyperloop plans with TEN-T.

A pan-European hyperloop system to connect European capitals would generate the time savings reported in Table 9. In view of these time savings, air travel is likely to be substantially reduced. It would also reduce high-speed rail even with high station-to-station speeds on the current rail tracks. If, for example that hyperloop connection from Paris to Rome would stop in Marseille, the current demand for the Trenitalia line between the two cities would disappear.

Table 9 shows the investment costs of the tube infrastructure only. Additional investments are needed for new stations and the passenger pods. Whether these investments can be justified depends on:

- the modal shift of air traffic between connected cities.
- the modal shift from current high-speed rail to hyperloop (through strong reduction in high-speed travel).
- potential shift from road transport (minor shift in view of the long distances).

The larger the modal shift, the higher will be additional opportunity costs in the form of current infrastructure losing value.

Whether the benefits created by the hyperloop system justifies, the high investment expenditures depend on the value of time savings, relative to the fastest alternative. If the fastest connection is by aviation, the travel time savings would be smaller than those indicated in Table 9. It is unlikely, to be assessed in a separate study, that modal shift volumes and the value of time of future passengers would suffice to justify the connections.

The CO₂ emission savings generated by hyperloop connections would mainly depend on demand attracted from aviation. There are no publicly available origin-destination data for passenger flights. Guessing passenger numbers from the number of flights and the current capacity utilisation rates, there are, for example, 700 passengers per day who could switch from aviation to hyperloop per day in each direction between Paris and Berlin today. The equivalent value for the connection between Paris and Rome would be 1 100 passengers per day. The investments would also require large wider integration benefits, but they need to be further specified.

4 Policy options

This chapter outlines a set of policy options to guide the long-term development of the European railway system. These options are designed to inform political debate and support decision-making by illustrating how governance choices, investment priorities, and regulatory approaches could shape the future performance of rail transport in Europe.

The policy options build directly on the identified trends, drivers and uncertainties, as well as on the scenarios developed earlier in the study. They recognise that the future of European rail is not constrained primarily by technological feasibility, but by the coherence of governance arrangements, the scale and predictability of investment, and the capacity to integrate national systems into a genuinely European transport network.

The mapping exercise highlighted persistent structural challenges across all five analytical themes, including fragmented governance, uneven infrastructure quality, limited cross-border capacity, slow deployment of interoperable digital systems, and sustained dependence on public funding. At the same time, it identified strong enabling factors, notably rail's favourable environmental performance, growing demand for sustainable mobility, and the availability of mature and emerging technologies capable of improving capacity, reliability and user experience.

If no additional policies are put in place beyond existing commitments, the European railway system is likely to continue along an incremental, nationally driven trajectory. Persistent structural constraints, such as fragmented governance, uneven implementation of EU rules, and chronic underinvestment in maintenance, renewal and digitalisation, would continue to limit system-level performance and European network effects. Cross-border connectivity and interoperability would improve only gradually, as slow and fragmented deployment of interoperable systems, notably ERTMS and coordinated capacity management, constrains reliability and capacity gains. From a demand perspective, rail would struggle to achieve a sustained modal shift, as door-to-door travel times, reliability, ease of use and pricing, particularly for cross-border services, remain insufficiently competitive against road and aviation. At the same time, ageing assets, growing maintenance backlogs and increasing exposure to climate risks would progressively undermine network resilience, reinforcing a pattern of delayed delivery, rising lifecycle costs and uneven service quality across Member States.

Across all policy options, funding is a recurring element. For each policy option, an RRF-like rail fund is described, each with a distinct strategic focus. All build on core RRF design principles: EU-level borrowing, milestone-based disbursement, reform-investment linkage, and performance monitoring. This approach reflects the need for a stronger EU-level governance framework to advance investments of shared European interest.

To illustrate the policy options' performance under varying governance and technology conditions, we describe how they would perform under each of the four scenarios.

4.1 Policy option set for European rail policy

4.1.1 Option 1: Implementation and system delivery

The analysis shows that despite a mature EU legislative framework, the European railway system continues to underperform due to slow and uneven implementation of agreed rules, persistent interoperability gaps, and fragmented operational practices across Member States. Key instruments such as ERTMS deployment, harmonised capacity management, and coordinated handling of Temporary Capacity Restrictions (TCRs) remain delayed, limiting reliability, cross-border continuity and capacity utilisation. The core issue is not a lack of policy ambition, but a widening execution gap between EU objectives and system-level outcomes.

The objective of this policy option is to rapidly close the implementation gap between existing EU ambition and real system performance. This objective is in line with stakeholders stating that execution and predictability matter more than new rules. This policy option includes the following measures:

- Accelerate deployment of interoperable standards through ERTMS roll-out on core and extended TEN-T network, including rolling stock funding and financing. In addition, the elimination of hybrid and legacy signalling systems on priority corridors is time-bound.
- Operational interoperability is made a priority. This includes harmonised capacity allocation rules, coordinated management of infrastructure Temporary Capacity Restrictions, and common digital traffic management tools for cross border services.
- The regulatory capabilities upgrade entails a stronger role for EU level technical bodies (e.g. ERA) in authorisation, certification, and system compatibility.

A fund specific to this policy option would favour projects with an advanced planning and permitting status, a demonstrated construction time reduction, clear absorption capacity and procurement readiness. The focus lays on cross-border bottlenecks, missing links, and capacity upgrades on the TEN-T core network. This fund would have a short eligibility window, a high prefinancing share, and milestones focused on physical delivery of projects rather than exploratory studies.

EU action concentrates on stronger steering, enforcement and prioritisation. This includes:

- Strengthening the role of EU technical bodies (notably ERA) in authorisation, certification and interoperability.
- Deploying an RRF-style rail delivery fund with short eligibility windows, high pre-financing and milestone-based disbursement focused on physical delivery rather than studies.
- Using EU funding conditionality to reward implementation speed, absorption capacity, and cross-border impact, while maintaining national responsibility for project execution.

Positive expected impacts are as follows:

- Rapid and tangible improvements in reliability, capacity and cross-border performance of the existing rail system.
- High political and institutional feasibility.
- Clear contribution to climate and cohesion objectives through faster delivery of already-agreed investments.

The cons of this policy option include:

- Risk of achieving only incremental gains if not accompanied by sufficient investment in maintenance and capacity.
- Limited ability to overcome deeper structural coordination failures in a predominantly decentralised governance setting.
- Does not fundamentally alter long-term investment fragmentation across Member States.

4.1.2 Option 2: European high-speed rail integration

The analysis showed that rail captures market share when it substitutes aviation on 3–4 hour corridors, yet high-speed rail expansion remains nationally fragmented and uneven, resulting in disconnected networks, weak cross-border continuity and lost network effects. Investments are often evaluated on national cost-benefit logic, undervaluing European-wide connectivity and capacity-release benefits for conventional rail.²³ In addition, stakeholders raised the concern about

²³ Standard cost-benefit analyses focus on domestic benefits and do not fully capture wider effects of a transport intervention, such as network-wide benefits (e.g. agglomeration effects, trade facilitation, and improved accessibility)

incumbent operators using joint undertakings to define business cases in their favour, undermining new entrants' interests.

The objective of this policy option is to maximise modal shift from air and road transport by completing a coherent European high-speed rail network instead of disconnected national lines. This policy option includes the following measures:

- Prioritisation of cross-border and missing link investments on trajectories with sufficient demand creates a targeted expansion where rail can credibly replace short haul flights.
- High-speed rail is regarded as a system tool to free capacity on conventional lines for suburban, regional and freight services.
- Rail-air substitution packages include integrated ticketing, coordinated timetables, and airport rail interfaces to actively displace short haul flights.

A fund specific to this policy option would require high-speed rail expansions to reduce end-to-end travel times across borders, to improve network connectivity and transfer quality, and to contribute to European service patterns. Each funding request will have to demonstrate sound cross-border demand estimates, timetable coordination, and rolling stock and operational compatibility. In addition, a network-wide cost-benefit analysis is proposed as an eligibility criterion for EU co-financing, requiring corridor-level appraisal instead of project-level appraisal, prioritising projects with high EU-wide benefits, and integrating cross-border externalities, interoperability gains, and wider system effects. These funding criteria emphasise end to end performance and cross-border travel times and network effects, not isolated national benefits. Moreover, these criteria should also reflect the needs of non-incumbents to ensure non-discriminatory and unbiased access for new entrant railway undertakings.

An investment committee could set common criteria and perform evaluations²⁴. Joint National Rail plans are encouraged (or required) for cross-border sections. Technical standards and timetabling assumptions would be coordinated at EU-level.

EU involvement shifts from project-by-project support to corridor- and network-level planning, including:

- Corridor-based funding assessment, focusing on end-to-end travel times, continuity and network effects rather than national benefits.
- Stronger EU-level coordination of technical standards, timetabling assumptions, and service patterns.
- Incentivising or requiring joint cross-border national plans for high-speed sections, while maintaining national construction responsibility.

The following positive impacts are expected:

- Modal shift from short-haul aviation where door-to-door travel times fall below competitive thresholds.
- Strong European integration and cohesion effects through improved cross-border connectivity.
- Capacity release on conventional networks, benefiting regional services and freight.

across borders) (Laird 2014) and wider impacts on the economy (e.g. distribution and production patterns, market areas served, and labour market catchment areas and labour supply) ((The World Bank 2005) and (OECD 2008)).

²⁴ InvestEU can serve as an example for such an investment committee. The InvestEU governance model includes an independent Investment Committee that approves projects based on compliance with EU objectives and investment guidelines, and an Advisory Board that provides recommendations on market conditions, project design, and investment priorities. This model demonstrates the feasibility of centralised, rules-based investment screening using common criteria.

Cons include:

- High reliance on governance coordination and sustained political alignment across Member States.
- Risk of overemphasising speed at the expense of reliability, maintenance, and feeder systems.
- High capital intensity and long delivery timelines increase exposure to delays and cost overruns.

4.1.3 Option 3: Digitalisation and operational optimisation

Large parts of the European rail network suffer from capacity constraints and operational inefficiencies, not because of physical limits, but due to fragmented capacity management, slow adoption of digital tools, and workforce shortages. Existing infrastructure is often underutilised, particularly for freight, undermining reliability and competitiveness.

Large capacity gains are available without large new infrastructure, if operations are coordinated coherently. The objective of this policy option is to maximise usable capacity, resilience and freight competitiveness through digital and organisational levers. The following policy measures are included:

- Digital capacity management at scale entails the mandatory use of coordinated digital tools for capacity allocation, real time traffic management, and TCR planning.
- Automation becomes a staffing strategy through progressive deployment of ATO (GoA 2-3) and remote train operation where operationally justified. Hereby, automation is a response to workforce shortages, not labour replacement.
- The freight system modernisation package includes accelerated EU coordinated rollout of DAC.
- EU data governance for rail ensures standardised data sharing, cybersecurity rules, and digital interfaces across operators and infrastructure managers.

A rail digitalisation fund would prioritise deployment of high ERTMS levels, digital tools, and traffic management systems, demonstrating measurable gains in capacity, punctuality, asset utilisation, and interoperability across borders. The fund set-up includes strong EU-level technical guidance and common architecture. Funding conditionality on data sharing, cybersecurity frameworks, and cross-border operations ensures well-designed digital systems prioritising network effects over isolated pilots. Milestones would be linked to operational outcomes, not installation alone.

EU action centres on common architecture and conditional funding, including:

- Establishing EU-level technical guidance and a shared system architecture for digital rail solutions.
- Linking funding eligibility to demonstrable operational outcomes (capacity, punctuality, asset utilisation), not installation alone.
- Strong conditionality on interoperability, data sharing, and cross-border applicability.

Positive expected impacts include:

- Significant capacity and punctuality gains without major new infrastructure investment.
- Strong benefits for freight competitiveness and network resilience.
- Scales effectively under centralised governance conditions.

Cons of this policy options are as follows:

- High dependence on coordination and organisational change management.
- Requires substantial reskilling and social dialogue.

- Benefits are limited if deployment remains fragmented or confined to national pilots.

4.1.4 Option 4: Demand-led multimodal integration

The analysis showed that rail's modal share is constrained less by speed than by poor door-to-door performance, fragmented ticketing, weak integration with other modes and inconsistent customer experience, especially for cross-border journeys and freight logistics.

This policy options aims to maximise rail's modal share by integrating it seamlessly into multimodal passenger and logistics chains. The following measures are included:

- Integrated ticketing and journey planning becomes the default through the full implementation of multimodal digital mobility services. Participation of rail operators in interoperable booking and information platforms becomes mandatory.
- Rail-air complementarity is achieved through integrated rail-air tickets and coordinated timetables. High-speed rail is positioned as a substitute for short haul flights where door-to-door times fall below thresholds.
- Freight logistics integration is enhanced through intermodal terminals, last-mile links, and real-time track-and-trace for high-value freight.
- The onboard experience is improved through service quality standards, including onboard connectivity, availability of workspace-suitable seating, and basic services (e.g. cleanliness, accessibility, and catering).

Funding criteria would emphasise integration with urban public transport, long-distance buses, active modes (i.e. walking and cycling), and airports (e.g. rail-air connections). The focus lays on improvements in transfer times, ticketing interoperability, and information continuity to achieve a strong modal shift impact. The set-up of this fund requires joint planning between rail, regional, and urban authorities. Eligible projects include stations as multi-modal hubs, digital ticketing solutions, and timetable coordination. Monitoring does not only focus on infrastructure, but also passenger experience and network-wide benefits.

EU action focuses on framework setting and cross-sector coordination, including:

- Full implementation of Multimodal Digital Mobility Services.
- Funding criteria prioritising transfer times, information continuity, and customer experience.
- Joint governance arrangements involving rail, regional, and urban authorities.

Expected positive impacts include:

- Strong potential for sustained modal shift through improved door-to-door performance.
- Better user experience and higher system value of existing rail assets.
- Reinforces rail's role as the backbone of sustainable mobility.

On the other hand, the following cons are expected:

- Requires coordination beyond the rail sector, increasing governance complexity.
- Benefits take time to materialise and depend on stakeholder cooperation.
- Less effective without parallel improvements in reliability and capacity.

4.1.5 Option 5: European ultra-high-speed rail

Incremental innovation improves performance but may not be sufficient for long term competitiveness, while Europe risks losing leadership in next generation mobility technologies. At the same time, ultra-high-speed concepts (hyperloop, maglev) remain highly uncertain and incompatible with decentralised planning.

The objective of this policy option is to develop an EU-level ultra-high-speed transport layer (e.g. hyperloop-type systems) as a strategic European infrastructure, complementing conventional rail and aviation on the highest-demand long-distance corridors. Hereby, ultra-high-speed systems are treated as pan-European backbone infrastructure, comparable to electricity grids or digital networks. Planning, regulation, funding, system architecture, and operations are fully centralised at EU-level. Member States act solely as hosts (e.g. for land use and permitting support) and providers of feeder connections.

The economic rationale is based on very high utilisation on selected corridors, transformational travel-time reductions, and long-term public investment capacity, but not short-term profitability. Conventional rail is structurally complemented, not displaced.

This option represents a high risk, high commitment strategy contingent on sustained political consensus and fiscal capacity at EU level. The following measures are necessary for such a system:

- Hyperloop and maglev are continuously explored as potential future network layers, not substitutes for conventional rail.
- Part of EU R&I funding is shifted from exploratory research to system-level pilots, testing, and cost validation.
- EU-level regulatory sandboxes allow for regulatory experimentation related to safety, certification, and interoperability of breakthrough technologies.
- The EU would position itself as a norm-setter rather than late adopter, even if deployment remains long term.

Funding would be corridor-specific based on EU-level assessment of long-distance, high-demand travel flows, potential travel-time reductions versus aviation and high-speed rail, and system-wide network effects (not local accessibility gains). Projects must demonstrate integration with European high-speed rail and air hubs, scalability to an EU-wide network over time, and technological maturity beyond experimental pilots. Isolated national segments or standalone demonstrations are not eligible.

Setting up this fund requires a single EU implementing authority, either a new agency or an expanded role for an existing one. The entire system is financed and governed at EU level. The multi-decadal investment horizon operates outside standard national budget cycles. Disbursement is linked to corridor-level milestones (not national) and system performance benchmarks (speed, reliability, safety). Harmonising the regulatory framework ex-ante at EU-level avoids national divergence.

This option requires the highest degree of EU centralisation, including:

- EU-level planning, funding, regulation and ownership of infrastructure.
- A single EU implementing authority and multi-decadal financing outside national budget cycles.
- Corridor-level funding decisions based on European demand and network effects.

Expected impacts include the following pros:

- Potential for transformational travel-time reductions on selected corridors.
- Preserves European leadership in next-generation mobility technologies and standards.
- Long-term strategic option aligned with future competitiveness narratives.

These cons are to be expected:

- Extremely high financial risk and long delivery horizon.
- High uncertainty on costs, demand and system integration.

- Significant risk of crowding out investment and political attention from maintenance and performance of the existing rail network.
- An additional risk is the misinterpretation of ultra-high-speed rail as a near-term solution.

4.2 Comparison of the policy options

Table 10 compares the five policy options.

Table 10 – Comparative table of policy options

	Option 1: Implementation and system delivery	Option 2: European high-speed rail integration	Option 3: Digitalisation and operational optimisation	Option 4: Demand-led multimodal integration	Option 5: European ultra-high-speed rail
Problem addressed	Uneven implementation, fragmentation	Nationally fragmented high-speed rail development	Capacity constraints, low performance	Barriers in multi-modal integration	Incremental innovation
Objective	Close implementation gap	Complete a coherent European high-speed rail network	Increase usable capacity, resilience, and competitiveness	Seamless integration into multi-modal chain	Develop an EU-level ultra-high-speed transport layer
Time horizon	Short to medium term	Medium to long term	Short to medium term	Medium term	Long to very long term
Expected benefits	• Faster and more consistent deployment of interoperable systems across the TEN-T core and extended core network • Improved reliability, capacity and cross-border performance through harmonised operational practices and digital traffic management • Tangible improvements in service quality without requiring new legislation or system redesign	• Modal shift from short-haul aviation and road on corridors with sufficient demand • Improved end-to-end travel times and continuity across borders due to network-level planning • Release of capacity on conventional rail lines for regional passenger services and freight	• Increased usable capacity and punctuality without major new infrastructure investment • Improved freight competitiveness through DAC, flexible capacity products and priority paths • Better resilience and asset utilisation through real-time traffic management and data-driven operations	• Higher rail modal share due to improved door-to-door performance • Better passenger experience through integrated ticketing, seamless transfers and information continuity • Stronger integration of rail into freight logistics chains via intermodal terminals and last-mile connections	• Potential for transformational reductions in long-distance travel times on selected high-demand corridors • Preservation of European leadership in next-generation mobility technologies and standards • Creation of a new strategic transport layer with pan-European network effects
Funding criteria	• Project readiness and permitting maturity • Time-to-delivery reductions	• End-to-end cross-border travel time gains • Network effects and corridor connectivity	• Deployment of interoperable digital rail technologies	• Improved transfer times and ticketing integration • Connectivity with urban transport and aviation	• High-demand long-distance corridors • Transformational travel-time reductions

	Option 1: Implementation and system delivery	Option 2: European high-speed rail integration	Option 3: Digitalisation and operational optimisation	Option 4: Demand-led multimodal integration	Option 5: European ultra-high-speed rail
	Removal of TEN-T bottlenecks and missing links	Service integration, not national benefits	- Measurable capacity, punctuality and reliability gains - Cross-border compatibility	Customer experience improvements	System-wide European network effects
Funding set-up	- National Rail Plans with strong reform conditionality - Fast disbursement, high pre-financing - EU oversight, national implementation - Reliance on public funding and fragmented PPPs, with low bankability	- Corridor-level assessment and funding - Joint cross-border planning encouraged - EU coordination of standards and service logic - Large-scale investment needs with limited adaptation of risk/revenue frameworks, constraining private capital	- EU technical architecture and guidance - Milestone-based funding tied to operational outcomes - National implementation within EU framework - Introduction of more standardised risk sharing - Lower capital intensity, but limited relevance for private infrastructure financing models.	- Joint governance across transport authorities - Funding for hubs, digital platforms and coordination - Performance monitored via user indicators - Improved demand conditions, but funding structures largely unchanged.	- Fully centralised EU planning, funding and regulation - EU ownership and long-term financing - Member States host assets and feeder links - Highly capital-intensive with high risk, requiring strong public backing and limited private bankability.
Key risk	Achieving only incremental gains if not combined with parallel investments	Overemphasis on speed at the expense of maintenance, feeder systems, and reliability	Strong dependence on coordination and need for change management and reskilling	Cooperation with rail and non-rail actors under central coordination	Funding requirements, long time horizon
Role relative to existing system	- Optimises and stabilises the current rail system by closing the implementation gap - Builds on existing infrastructure, technologies and regulatory frameworks rather than introducing new system layers - Acts as a performance-maximising option for today's network	- Adds a stronger, more coherent high-speed layer to the existing rail network - Functions as a system tool that complements conventional rail rather than replacing it - Relies on the existing network for feeders, distribution and resilience	- Enhances the performance of the existing rail network by modernising operations - Leverages existing infrastructure more efficiently rather than expanding it - Acts as a multiplier for other investments, especially in infrastructure and interoperability	- Positions rail as the backbone of multimodal passenger and freight transport - Does not alter the core rail infrastructure, but reshapes how it interfaces with other modes - Strengthens the system value of existing rail assets through better connectivity	- Explicitly complements rather than replaces conventional rail and aviation - Conventional rail remains essential for distribution, feeder services and freight - Represents a separate, centrally planned infrastructure layer with limited overlap in function

Source: Elaboration by the authors.

4.3 Policy options across future scenarios

The policy options are stress-tested against four scenarios that reflect different assumptions about governance and technological development in European rail.

Scenario 1 assumes continuity in the current institutional framework: Member States honour existing commitments, but governance remains largely national, with EU influence relying on legislation, planning obligations and co-financing rather than fiscal or regulatory centralisation. Performance gains therefore depend primarily on national execution capacity rather than institutional reform.

Scenario 2 rests on a qualitatively different setting, in which strategic planning, funding and pricing are centralised at EU level, rail infrastructure is treated as a European public asset, and coordination failures are addressed structurally through central fiscal capacity and incentive-based regulation.

Scenario 3 combines high technological ambition with decentralised governance, assuming that Member States pursue advanced digital and mobility technologies independently, resulting in uneven deployment, interoperability risks and limited network effects.

Scenario 4 assumes both strong EU-level centralisation and high technological ambition, with ultra-high-speed systems developed as a distinct European network layer, fully planned and funded at EU level, complementing but not replacing the conventional rail system.

Against this background, the stress test explores how each policy option performs under different combinations of governance centralisation and technological ambition, and where trade-offs emerge, particularly regarding the balance between transformative investments and the performance of the conventional rail network. Table 11 gives an overview of how the policy options perform in relation to the scenarios.

Among all options, Implementation and system delivery (Option 1) emerges as the most robust and no-regret policy choice. It performs consistently well across all scenarios, including both decentralised and centralised futures, and under both incremental and transformative technology pathways. Its strength lies in directly addressing structural weaknesses that are present in all scenarios, notably slow implementation, fragmented operational practices and delayed interoperability.

Even under more ambitious technological futures, this option remains valuable as a stabilising backbone, ensuring that the existing rail system delivers reliable performance and absorbs investments effectively. Given that the most likely future trajectories resemble incremental or moderately centralised developments, this option stands out as the most resilient foundation for EU rail policy, regardless of how governance and technology evolve. However, this option is the least transformative and may only lead to incremental performance gains.

Digitalisation and operational optimisation (Option 3) also performs strongly across multiple scenarios, particularly those characterised by incremental technological development and increasing governance centralisation, which align closely with current policy trajectories. Its effectiveness does not depend on breakthrough technologies, but on coordinated deployment, data governance and organisational change, making it highly relevant in the short to medium term.

The stress-test shows that this option delivers meaningful benefits even in decentralised settings, though its full system-wide potential is only realised under stronger EU-level centralisation. As such, it represents a low-regret, high-return option, especially when combined with implementation-focused measures. Like Option 1, it strengthens the performance of the existing system rather than betting on uncertain future technologies.

Table 11 – Performance of policy options under alternative scenarios

Policy option	Scenario 1 (Decentralised / Incremental)	Scenario 2 (Centralised / Incremental)	Scenario 3 (Decentralised / Transformative)	Scenario 4 (Centralised / Transformative)
Option 1: Implementation and system delivery	Moderate fit. Enables targeted delivery improvements, but fragmented governance constrains system-wide consistency and enforcement.	Very strong fit. Centralisation directly reinforces predictable delivery, uniform standards and enforcement, yielding rapid gains in conventional rail performance.	Moderate fit. Helps contain fragmentation risks but faces competition from nationally driven technology agendas.	Strong but potentially secondary fit. Effective as a stabilising backbone, though attention and resources may increasingly shift toward more transformative investments.
Option 2: European high-speed rail integration	Limited fit. National planning limits network coherence and cross-border continuity.	Strong fit. Centralised planning and funding support the build-out of a coherent European high-speed system anchored in conventional rail.	Limited to moderate fit. Technological ambition without governance alignment risks incompatible systems and weak integration.	Very strong fit, with trade-offs. Benefits from integrated planning and advanced systems but may face strategic tension if ultra-high-speed concepts dominate long-distance priorities.
Option 3: Digitalisation and operational optimisation	Partial fit. Delivers local efficiency gains, but fragmentation limits interoperability and scaling.	Very strong fit. Centralisation enables digital tools to optimise the existing rail network, maximising capacity, resilience and freight performance.	Moderate fit. High innovation potential, but risks duplication, incompatibility and uneven uptake.	Strong fit, but with balance risks. Advanced automation and data systems deliver major gains, yet complexity and ambition may divert focus from pragmatic optimisation of conventional operations.
Option 4: Demand-led multimodal integration	Limited fit. Fragmented responsibilities across modes and territories impede seamless door-to-door performance.	Strong fit. Centralised frameworks support consistent multimodal integration while keeping rail as the backbone of mobility systems.	Moderate fit. Digital platforms help integration, but lack of governance alignment limits system effects.	Moderate fit, but conditional. Integrated governance enables deep multimodal links, though rail's role risks dilution if focus shifts toward breakthrough technologies over service integration.
Option 5: European ultra-high-speed rail	Very weak fit. Fragmentation makes EU-wide planning and funding infeasible.	Limited fit. Centralisation supports governance, but incremental technology constrains transformative impact.	Weak fit. High technological ambition without central control creates very high risk of fragmented and stranded assets.	Context-dependent fit. Governance and technology conditions are aligned, but there is a clear risk of crowding out investment, political attention and legitimacy for conventional rail.

Source: Elaboration by the authors.

Demand-led multimodal integration (Option 4) performs moderately well across scenarios, with its effectiveness less sensitive to the level of technological ambition than to institutional alignment across transport modes and governance levels. It delivers clear benefits under more coordinated scenarios and remains relevant in decentralised settings, although fragmentation limits its system-level impact.

The stress-test suggests that this option is rarely a primary driver of system performance on its own, but works best as a complement to stronger implementation, digitalisation and capacity improvements. It is therefore best understood as a supporting no-regret option, enhancing the impact of other policies rather than substituting for them.

European high-speed rail integration (Option 2) shows a much more differentiated performance across scenarios. It performs strongly under centralised governance conditions, where corridor-level planning, funding coordination and EU-level prioritisation allow network effects to materialise. Under decentralised scenarios, however, its impact is limited by nationally driven planning, uneven implementation and incompatible investment choices.

This makes Option 2 a high-impact but higher-risk strategy, whose success is contingent on governance evolution. The stress-test indicates that it is not a no-regret option in isolation, but becomes significantly more attractive once implementation gaps are closed and coordination mechanisms are strengthened. Its feasibility therefore depends on sequencing: it works best after or alongside Options 1 and 3, rather than as a standalone priority.

The stress-test confirms that European ultra-high-speed rail (Option 5) is the least robust policy option. It only performs credibly under the most ambitious scenario combining strong EU-level centralisation and transformative technology deployment. In all other futures, it is either ineffective or poses substantial risks of fragmentation, stranded assets, and diversion of attention and funding from the conventional rail system.

As a result, this option represents a long-term, speculative strategic bet, whose relevance depends on political willingness to centralise governance and sustain large-scale investment over several decades. The stress-test underlines the importance of clearly distinguishing this option from near-term system improvement priorities.

Taken together, the stress-test highlights that robustness across scenarios is driven more by addressing structural system weaknesses than by technological ambition. Options focused on improving implementation, coordination, digitalisation and operational performance (Options 1 and 3) consistently perform well across all or most scenarios and align most closely with likely future conditions.

In contrast, options with higher transformative potential (Options 2 and especially 5) are more scenario-dependent and sensitive to governance assumptions. This suggests that the central strategic choice is not between incremental and transformative policies, but how to sequence them. Strengthening the performance, reliability and integration of the existing rail system emerges as a necessary precondition for more ambitious long-term investments to deliver value.

5 Conclusions

This study has examined the long-term trajectories of the European railway system by analysing the key trends, drivers, and uncertainties shaping its evolution towards 2050, complemented by scenario analysis and stakeholder perspectives. The analysis shows that the future performance of rail in Europe is less constrained by technological feasibility than by governance choices, investment capacity, and system integration.

5.1 Key insights from the analysis

Across all analytical dimensions, the findings point to a persistent gap between strategic ambition and delivery capacity. Over recent decades, the EU has established a comprehensive policy framework for rail, underpinned by the objective of completing the Single European Railway Area and reinforced by successive railway packages, the revised TEN-T Regulation and the Sustainable and Smart Mobility Strategy. At the same time, implementation remains uneven, with fragmented governance, limited cross-border coordination, and chronic underinvestment in maintenance and renewal continuing to constrain system performance.

On the supply side, the European rail network is extensive but ageing, with growing capacity bottlenecks, maintenance backlogs and increasing exposure to climate risks. While high-speed rail has expanded significantly, this expansion has been uneven and predominantly nationally oriented, limiting the emergence of a coherent European network. The analysis highlights that further network expansion alone is unlikely to deliver the desired system-wide benefits unless accompanied by improved capacity management, stronger cross-border coordination and effective integration with local and regional feeder systems.

From a demand perspective, rail demonstrates strong attractiveness where it can offer reliable, frequent and time-efficient door-to-door journeys, particularly on medium-distance intercity routes, long-distance regional commuting and metropolitan mobility. Modal shift is driven primarily by reductions in generalised travel costs, including travel time, reliability and ease of use, rather than by environmental awareness alone. Improvements in interoperability, digitalisation and service integration therefore emerge as decisive enablers of future demand growth. This tension is particularly relevant when considering the 2050 pathway for European rail, and especially the development of high-speed rail as a European system. The evidence suggests that fragmented national investment decisions and market structures alone are unlikely to deliver a coherent, integrated high-speed rail network, while fully centralised approaches raise questions around implementation capacity, political feasibility, and the role of incumbent operators. Indeed, differences in national railway models, investment priorities, and market openness continue to shape system performance and constrain cross-border integration.

A central strategic tension emerging from both the desk research and the stakeholder consultation relates to the balance between market liberalisation and coordinated public investment in the rail sector. On the one hand, competitive dynamics, where successfully introduced, have improved service quality and efficiency. On the other hand, the structural characteristics of rail (i.e. as a network industry with capacity constraints, high fixed costs, and strong interdependencies) limit the effectiveness of pure market mechanisms and require coordinated planning, public funding, and standard-setting at European level. This creates a fundamental policy choice: whether to prioritise decentralised, competition-led development of rail services, or to move towards more centralised, network-based planning and investment frameworks.

Technological developments, including ERTMS, digital capacity management tools, automation, and data-driven maintenance, are widely recognised as critical enablers of higher capacity, reliability and resilience. However, their deployment remains slow and fragmented. Stakeholder views consistently

underline that technology delivers value only when embedded in a coordinated system, supported by stable funding, aligned incentives and clear governance responsibilities.

Hyperloop can be a long-term strategic bet, both from economic or competitiveness perspective and as a complement to the HSR system, although it is still highly uncertain. Support can focus on resolving the uncertainty and defining the cost and funding structure of the needed infrastructure, on the basis of which policy decisions can be made.

Funding and financing emerge as the dominant cross-cutting constraint. Rail infrastructure remains highly capital-intensive, with limited cost recovery through user charges and a strong dependence on public funding. So far, infrastructure funding is largely aligned with supporting European objectives such as requirements for the TEN-T network. While EU instruments such as CEF, RRF, and EIB lending play an important catalytic role, overall investment levels remain insufficient relative to identified needs, particularly for maintenance, resilience and cross-border projects. The analysis suggests that the predictability, coordination, and strategic targeting of funding are at least as important as its absolute volume. Regarding R&I investments, a clear choice emerges between supporting technologies with a clear European application (e.g. ATO) and supporting long-term bets (e.g. hyperloop). Related to this, there is a choice towards ensuring startups and new entrants also have access to funding, or that at least mechanisms are in place for them to overcome their barriers (e.g. supporting sale of used rolling stock, new state aid rules that supposedly also target new entrant rolling stock, flanking support towards new technologies and startups, etc).

Taken together, the evidence indicates that the main challenge facing European rail is not whether the system can be modernised, but how governance and funding choices shape the pace and direction of that modernisation.

5.2 Implications of the policy options

This study presents five policy options that illustrate strategic pathways for the long-term development of the European railway system. Their performance and feasibility depend strongly on the institutional and technological context in which they are deployed.

Policy Option 1 – Implementation and System Delivery focuses on closing the gap between existing EU ambition and actual system performance by accelerating execution, interoperability and operational consistency. Its primary strength lies in improving the reliability, capacity and cross-border performance of the current rail system without requiring major institutional redesign. The stress test shows that this option performs particularly well in centralised governance settings, where enforcement, funding predictability and standardisation can be applied consistently. However, in more transformative scenarios it risks being deprioritised if political attention shifts towards breakthrough technologies.

Policy Option 2 – European High-Speed Rail Integration seeks to maximise modal shift by developing high-speed rail as a coherent European network rather than a collection of national lines. Its performance is highly sensitive to governance arrangements. Under centralised scenarios, it benefits from corridor-level planning, harmonised standards and network-wide optimisation, delivering strong cross-border effects. In decentralised or technology-driven scenarios, by contrast, fragmentation and incompatible investment choices substantially weaken its impact.

Policy Option 3 – Digitalisation and Operational Optimisation aims to unlock capacity, resilience and freight competitiveness through coordinated digital tools, automation and data governance. The stress test indicates that its effectiveness depends less on technological ambition per se than on governance coherence. Centralised scenarios enable digital solutions to generate system-level capacity gains, while decentralised settings risk uneven deployment, limited interoperability and reduced returns on investment.

Policy Option 4 – Demand-Led Multimodal Integration addresses the demand side by improving door-to-door performance through seamless integration of rail with other passenger and freight modes. This option performs best where governance frameworks allow joint planning across transport authorities and consistent implementation of integrated ticketing, timetabling and information services. While technological innovation can support this option, its success depends primarily on institutional alignment rather than on transformative technologies.

Policy Option 5 – European Ultra-High-Speed Strategic Infrastructure represents a qualitatively different trajectory, centred on the development of ultra-high-speed systems as a distinct European network layer. The stress test shows that this option is viable only under conditions of strong EU-level centralisation and sustained technological ambition. Even in that context, it entails significant risks, including high fiscal exposure, long delivery horizons and the potential diversion of funding and political attention away from maintenance, interoperability and performance of the conventional rail system.

The stress test confirms that centralisation of governance is the decisive enabler across all policy options. Scenario 2, combining EU-level centralisation with incremental technological development, emerges as the most favourable context for strengthening conventional rail performance and achieving reliable, scalable gains. Scenario 4 offers the greatest long-term transformative potential, but also introduces strategic risks, notably the possibility that ultra-high-speed or breakthrough technologies overshadow continued investment in the existing network. Scenarios characterised by decentralised governance consistently underperform, regardless of technological ambition, due to persistent fragmentation and weak network effects. Overall, the results suggest that durable progress in European rail depends less on the pace of technological change than on the strength, coherence, and sequencing of governance reform.

5.3 Future outlook

Looking ahead to 2050, the trajectory of European rail will be shaped by a combination of strategic choices and external pressures. Climate objectives, energy security concerns, demographic change, digital transformation and geopolitical considerations, including military mobility and supply-chain resilience, are likely to reinforce the strategic importance of rail within Europe's transport system. However, the analysis cautions against assuming that technological leaps alone can resolve structural weaknesses. In the short to medium term, incremental improvements within existing governance structures will not be sufficient to unlock the full potential of rail. Without stronger coordination in network planning, capacity management, interoperability and funding alignment, even well-intended investments risk reinforcing fragmentation rather than integration.

At the same time, the analysis cautions against assuming that more radical technological solutions, such as ultra-high-speed systems, can substitute for addressing structural constraints in the existing network. Emerging technologies may play a complementary role in the long term, but their viability depends on scale, governance and integration with established rail systems. Premature large-scale deployment risks creating new stranded assets and undermining the utilisation of existing infrastructure.

The most robust pathway identified by the study lies in a progressive strengthening of EU-level centralisation, particularly in network planning, capacity management, interoperability and funding decisions, while allowing limited flexibility in national and regional implementation. This approach enables learning, sequencing and adjustment over time, while keeping open the possibility of deeper integration as political and fiscal conditions evolve.

Ultimately, the future of European rail will depend on the ability to align long-term policy ambition with credible implementation pathways. This requires not only technological innovation, but sustained political commitment, stable investment frameworks, and governance arrangements

capable of translating European objectives into tangible system-level improvements. We conclude with three steps forward:

First, measures to centralise implementation are essential to reduce delays and cost overruns associated with already agreed projects. The evidence discussed in the report suggests that fragmentation in project appraisal and delivery remains a key source of inefficiency, with delays often arising from misaligned national priorities and weak coordination mechanisms. A pragmatic step forward would be the establishment of joint evaluation standards for railway investments, enabling Member States to better capture the wider European benefits of integration beyond narrow national cost-benefit considerations. By making these system-wide benefits more visible and comparable, such a framework would strengthen commitment to implementation and help prevent the recurring cycle of delayed execution of jointly agreed infrastructure projects.

Second, stronger central fiscal capacity at EU level can help balance inherent differences in Member States' policy preferences and investment priorities. Rail investments are characterised by high upfront costs and uneven distribution of benefits across countries, which can create coordination failures and underinvestment in cross-border infrastructure. In this context, enhanced EU-level funding capacity can act as a balancing mechanism, aligning incentives and enabling projects that would not be pursued under purely national decision-making logics. At the same time, the experience of emerging technologies, such as ultra-high-speed systems, illustrates that early-stage innovation often requires longer-term public financial support, as high risks and uncertain returns limit the ability of private capital markets to step in at scale.

Third, a regulatory regime based on managed (yardstick) competition could accelerate harmonisation and convergence towards a European Single Rail Area. Resistance from incumbent operators remains a significant barrier to reform, particularly where changes are perceived as threats to existing organisational structures or employment. A shift from sanction-based enforcement towards a system that rewards compliance with jointly agreed standards and progress towards interoperability could reduce opposition and foster more constructive engagement. By benchmarking performance and incentivising convergence rather than penalising divergence, such a framework would support gradual but effective alignment of national systems, thereby facilitating the long-term objective of a seamless and integrated European rail network.

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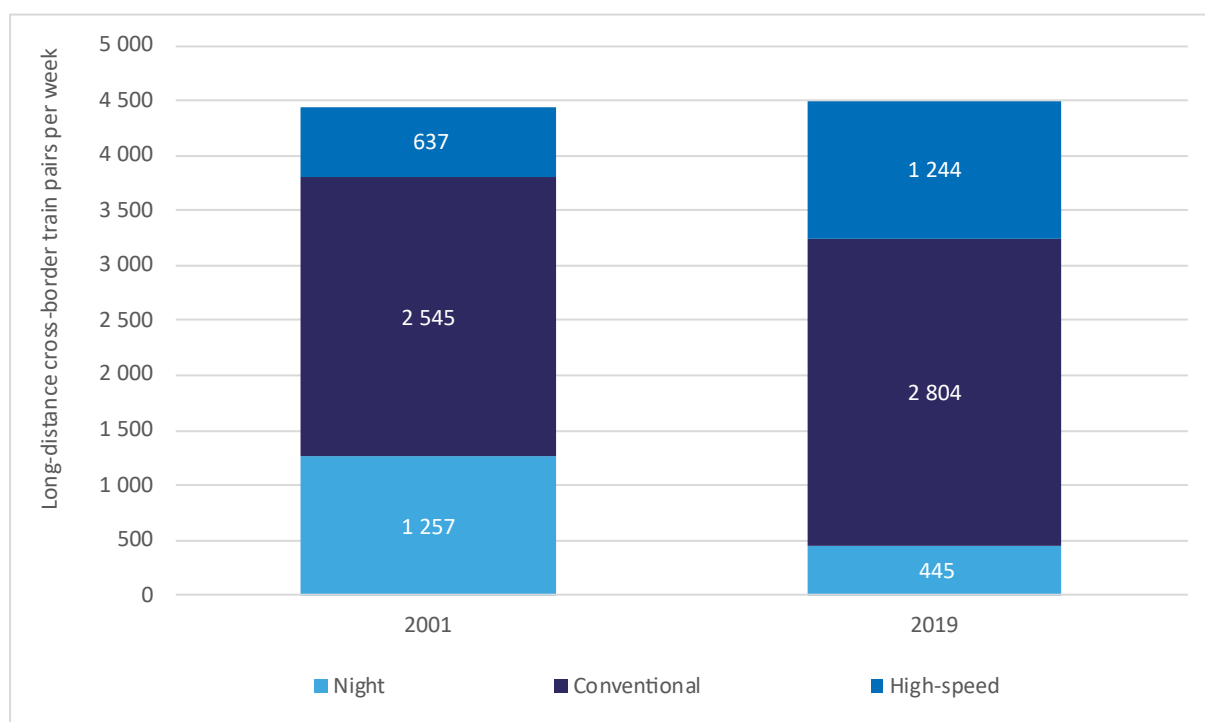
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Annex I – Supporting evidence to the analysis

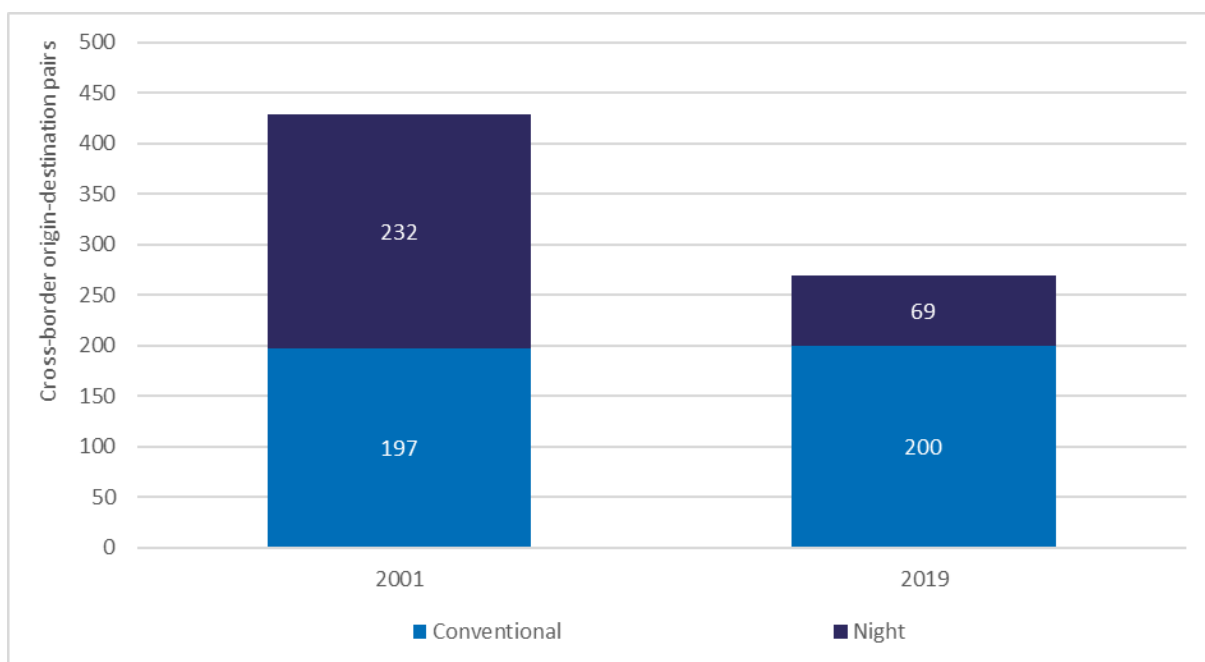
Supply side

Figure A.1 – Long-distance cross-border trains pairs per week (2001 and 2019)



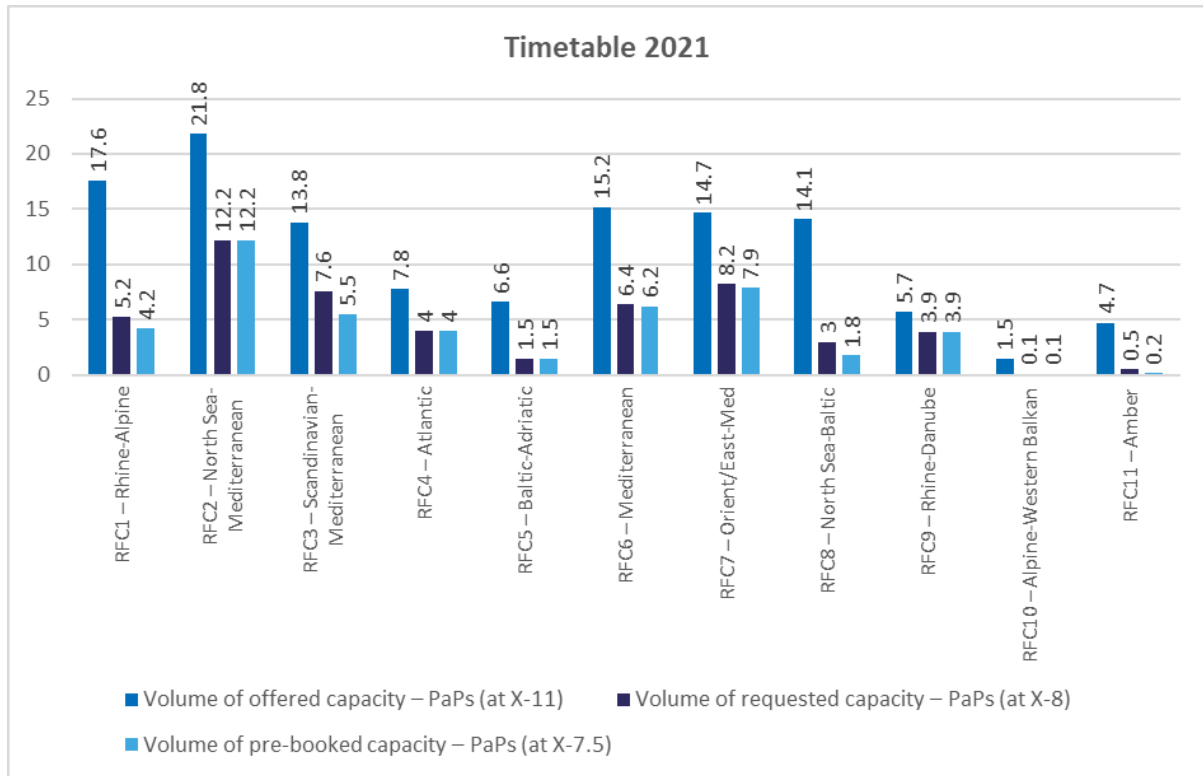
Source: Elaboration based on (Steer 2021).

Figure A.2 – Long-distance cross-border origin-destination pairs served (2001 and 2019)

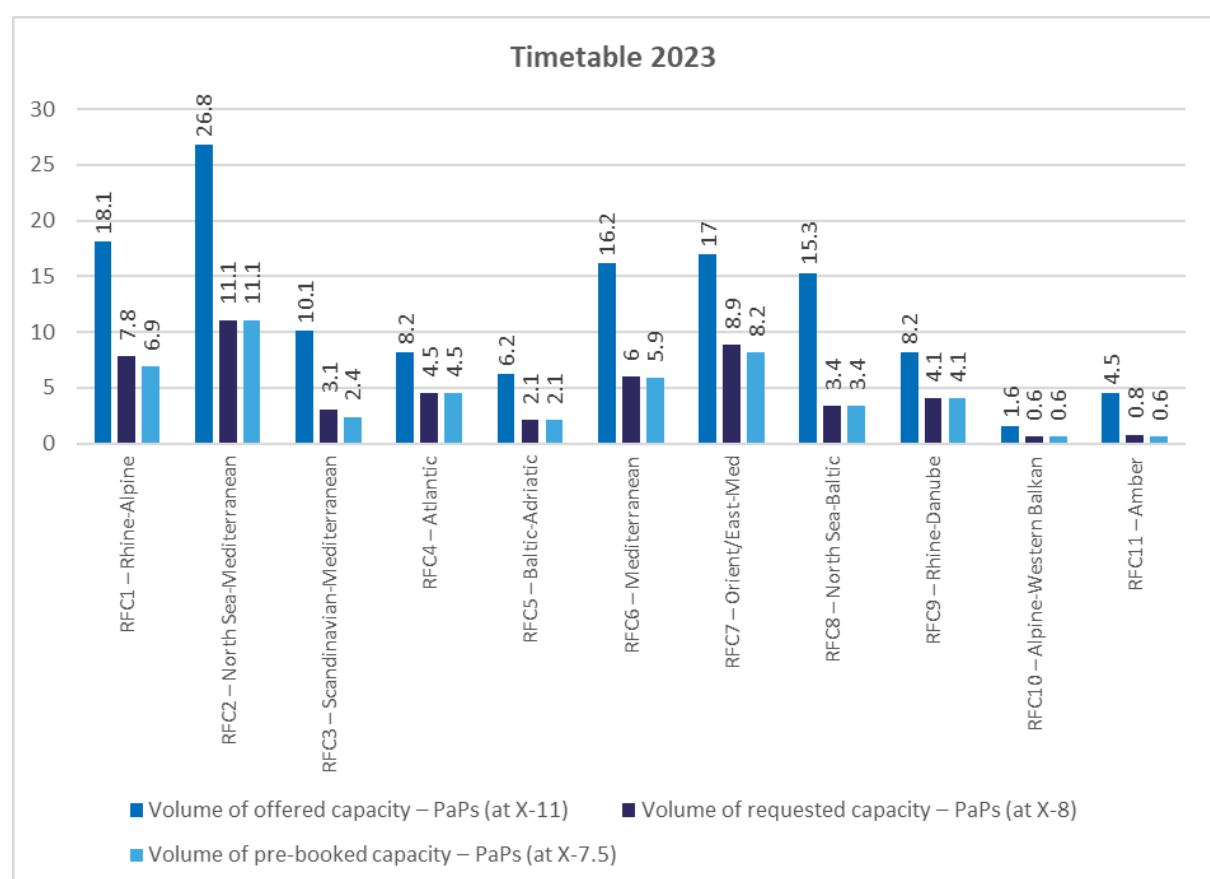
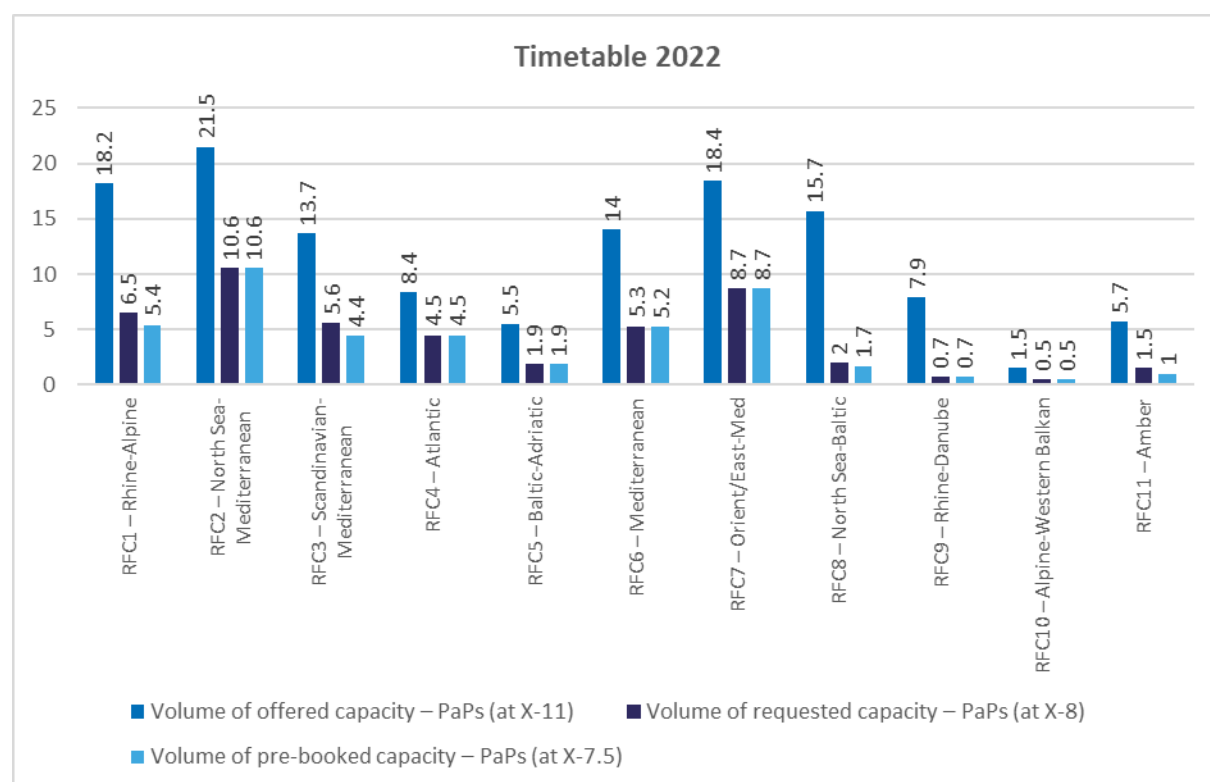


Source: Elaboration based on (Steer 2021).

Figure A.3 – Volume of offered, requested and pre-booked, pre-arranged capacity of RFCs (timetables of 2021, 2022, and 2023)²⁵

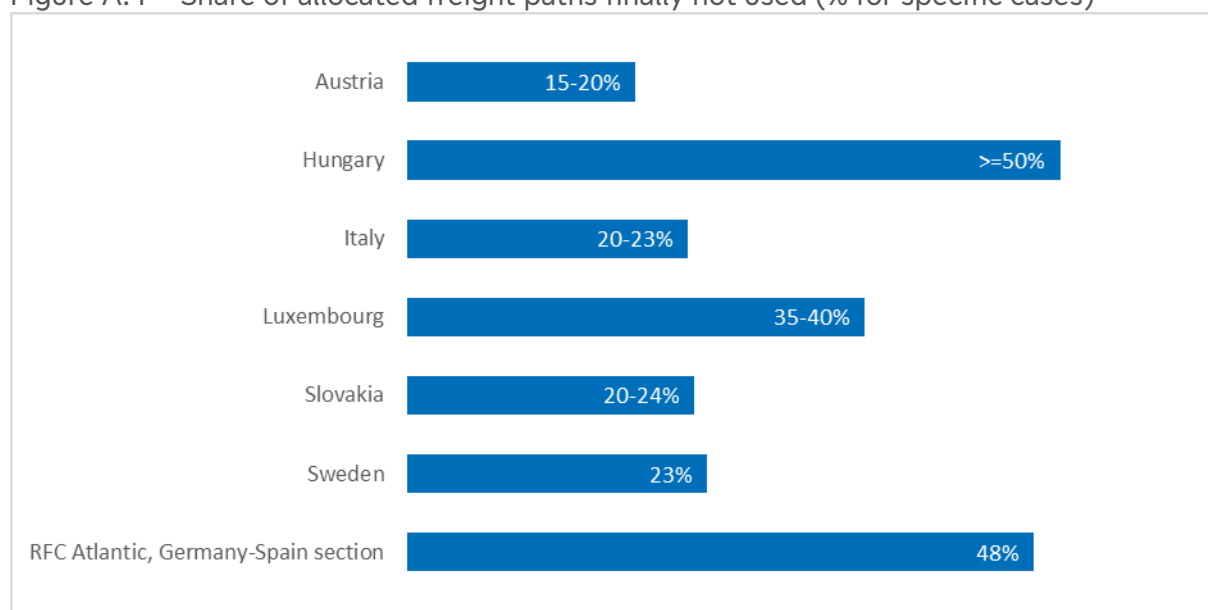


²⁵ In the legend of the figures, PaP means a pre-allocated (or pre-arranged) train path, which is an international, pre-constructed freight train path that is planned in advance by the infrastructure managers along a RFC and made available to applicants before the annual timetable is finalised. These paths are offered as a standardised "off-the-shelf" capacity product for cross-border rail freight services.



Source: Elaboration based on (Ecorys, TRT, and Hacon 2023).

Figure A.4 – Share of allocated freight paths finally not used (% for specific cases)



Source: Elaboration based on (Ecorys, TRT, and Hacon 2023).

Table A.1 – Length of conventional and high-speed rail lines in use by Member State (km, 2018–2022) and percentage electrified lines (2022)²⁶

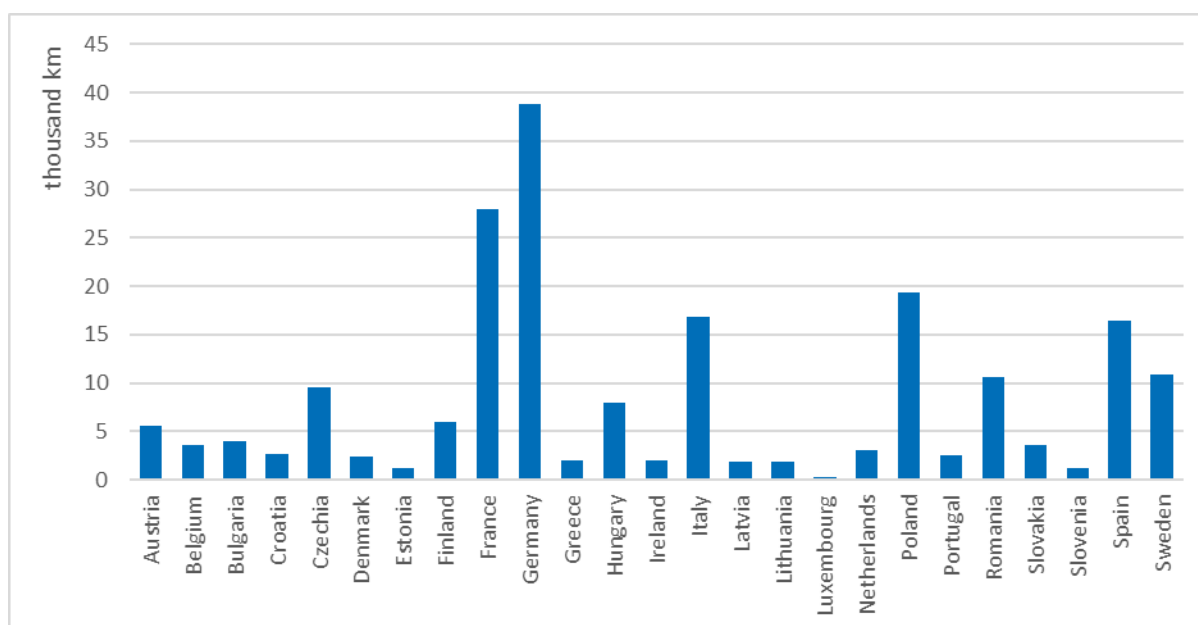
Member state	2018	2019	2020	2021	2022	of which electrified lines (%)
Austria	5 526	5 615	5 607	5 603	5 575	72
Belgium	3 607	3 614	3 615	3 612	3 619	88
Bulgaria	4 030	4 030	4 029	4 031	4 029	75
Croatia	2 604	2 617	2 617	2 617	2 617	38
Czechia	9 572	9 562	9 542	9 523	9 521	34
Denmark	2 481	2 536	2 485	2 485	2 448	33
Estonia	1 161	1 167	1 167	1 167	1 175	12
Finland	5 926	5 923	5 918	5 918	5 918	58
France	28 461	28 350	28 080	27 924	27 812	60
Germany	38 995	39 068	38 800	38 783	38 836	55
Greece	2 293	2 280	2 345	2 339	1 990	37
Hungary	7 732	7 743	7 787	7 889	7 907	41
Ireland	2 045	2 045	2 045	2 045	2 045	3
Italy	16 781	16 779	16 782	16 832	16 829	72

²⁶ Cyprus and Malta are not included in the analysis, as they do not operate railway networks.

Member state	2018	2019	2020	2021	2022	of which electrified lines (%)
Latvia	1 860	1 860	1 859	1 859	1 865	14
Lithuania	1 911	1 911	1 911	1 911	1 919	8
Luxembourg	271	271	271	271	271	97
Netherlands	3 040	3 040	3 041	3 041	3 041	75
Poland	19 196	19 359	19 383	19 287	19 355	63
Portugal	2 546	2 526	2 526	2 527	2 527	71
Romania	10 765	10 759	10 769	10 764	10 615	38
Slovakia	3 627	3 629	3 627	3 626	3 626	44
Slovenia	1 209	1 209	1 209	1 209	1 208	50
Spain	15 449	16 006	16 135	16 280	16 468	65
Sweden	10 906	10 899	10 909	10 912	10 914	75
Total	201 993	202 798	202 459	202 456	202 131	57

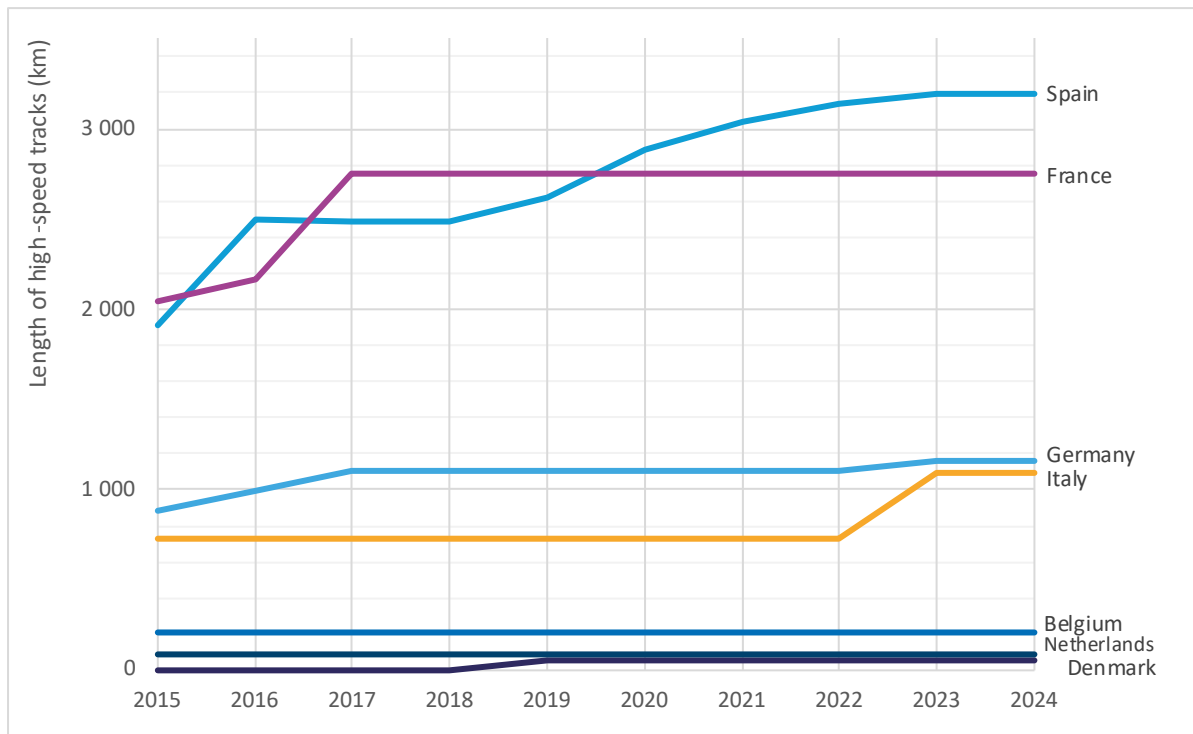
Source: Elaboration based on (European Commission 2025a).

Figure A.5 – Length of national networks by Member State (thousand km, 2022)



Source: Elaboration based on (European Commission 2025g).

Figure A.6 – Length of dedicated high-speed lines in EU countries (2015–2024)²⁷

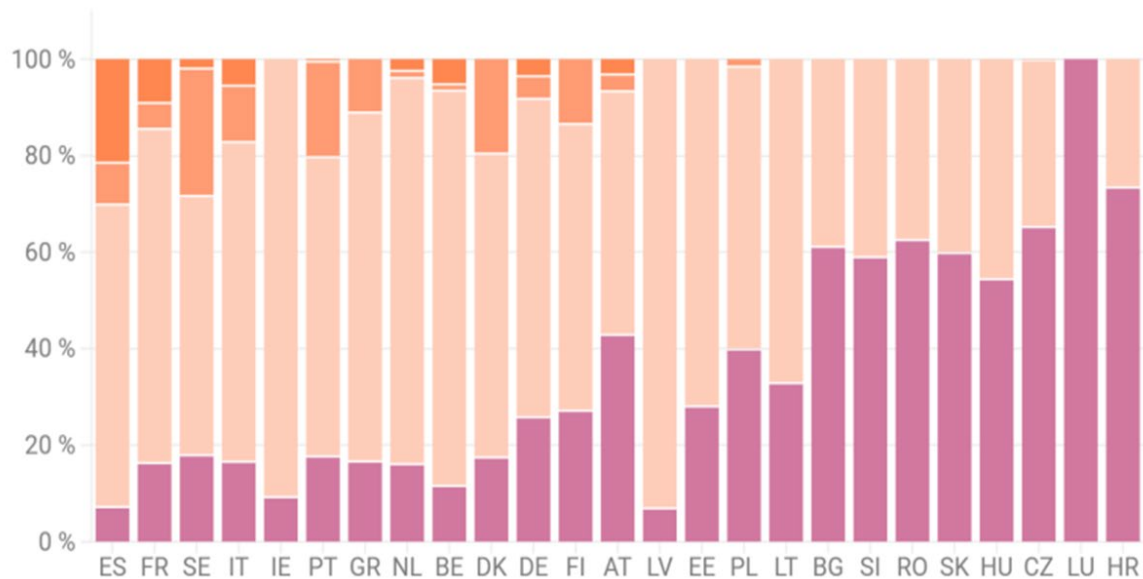


Source: Elaboration based on (Transport & Environment 2025).

Figure A.7 – Speed limitations in the European railway network (km/h)²⁸

■ <80 ■ <160 ■ <240 ■ >240

Share of the national rail network

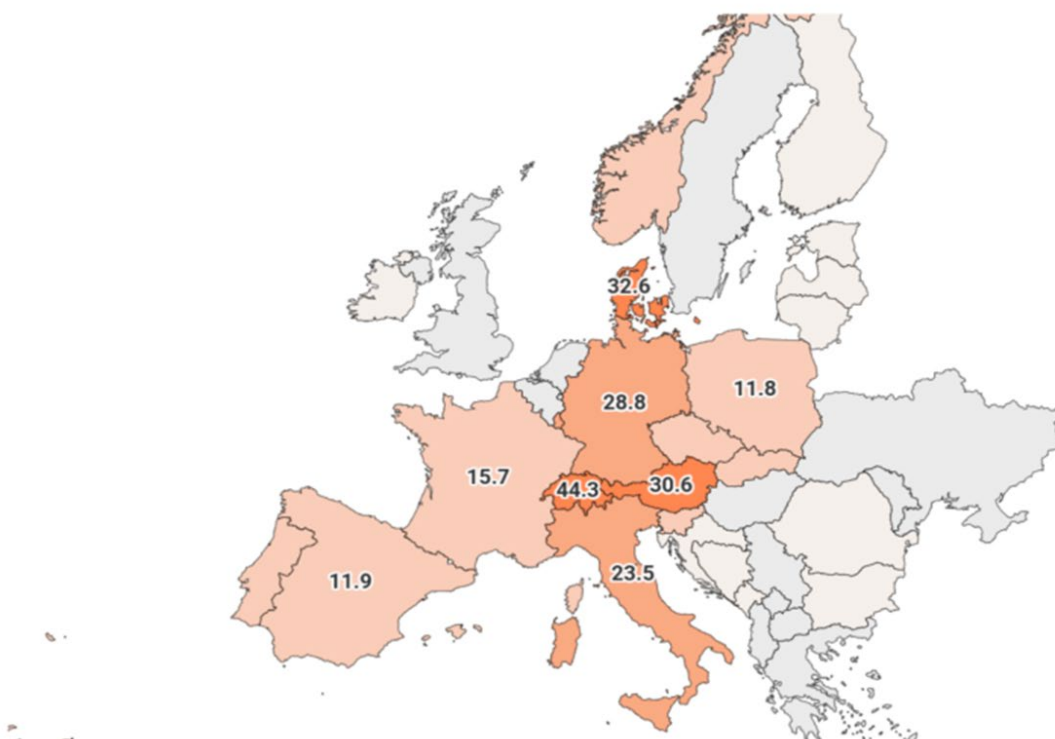


Source: Elaboration based on (Transport & Environment 2025).

²⁷ Lines with speed ≥ 250 km/h.

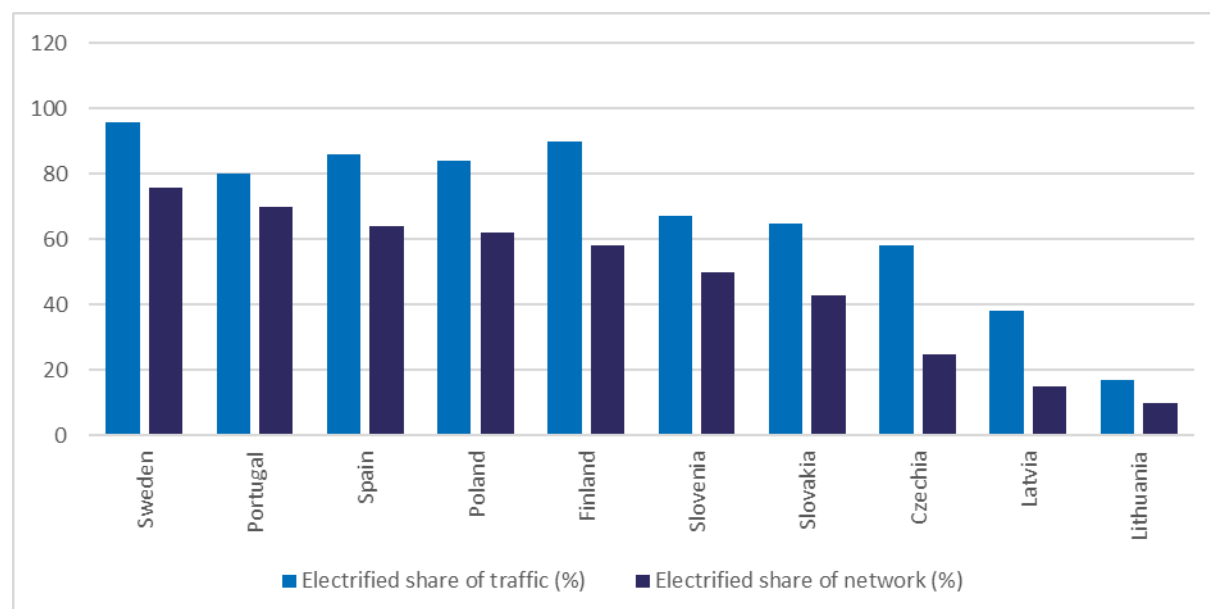
²⁸ Average speed decreases from left to right.

Figure A.8 – Railway network utilisation (average thousand train-km per track-km per year)²⁹



Source: Elaboration based on (Transport & Environment 2025).

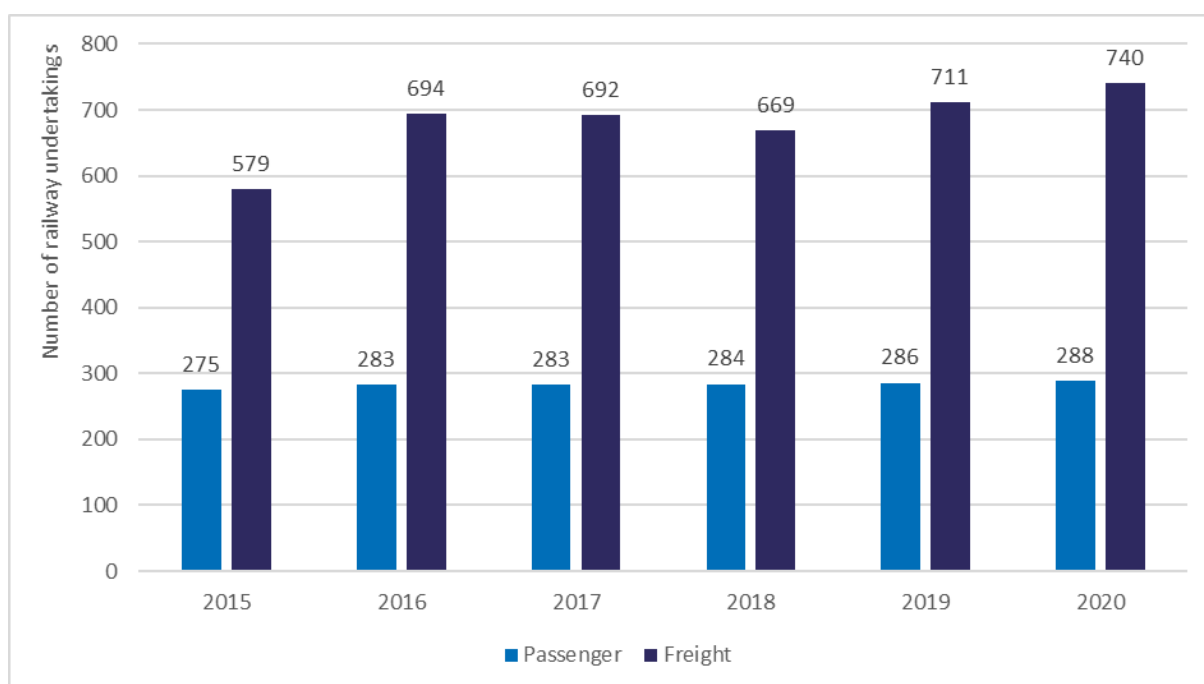
Figure A.9 – Share of electrified traffic and share of the electrified railway network



Source: Elaboration based on (Transport & Environment 2025).

²⁹ Train-km per track-km is an indicator of network utilisation, expressing the average intensity of train traffic carried by each kilometre of railway infrastructure over a given period.

Figure A.10 – Passenger and freight railway undertakings in the EU (2015–2020)



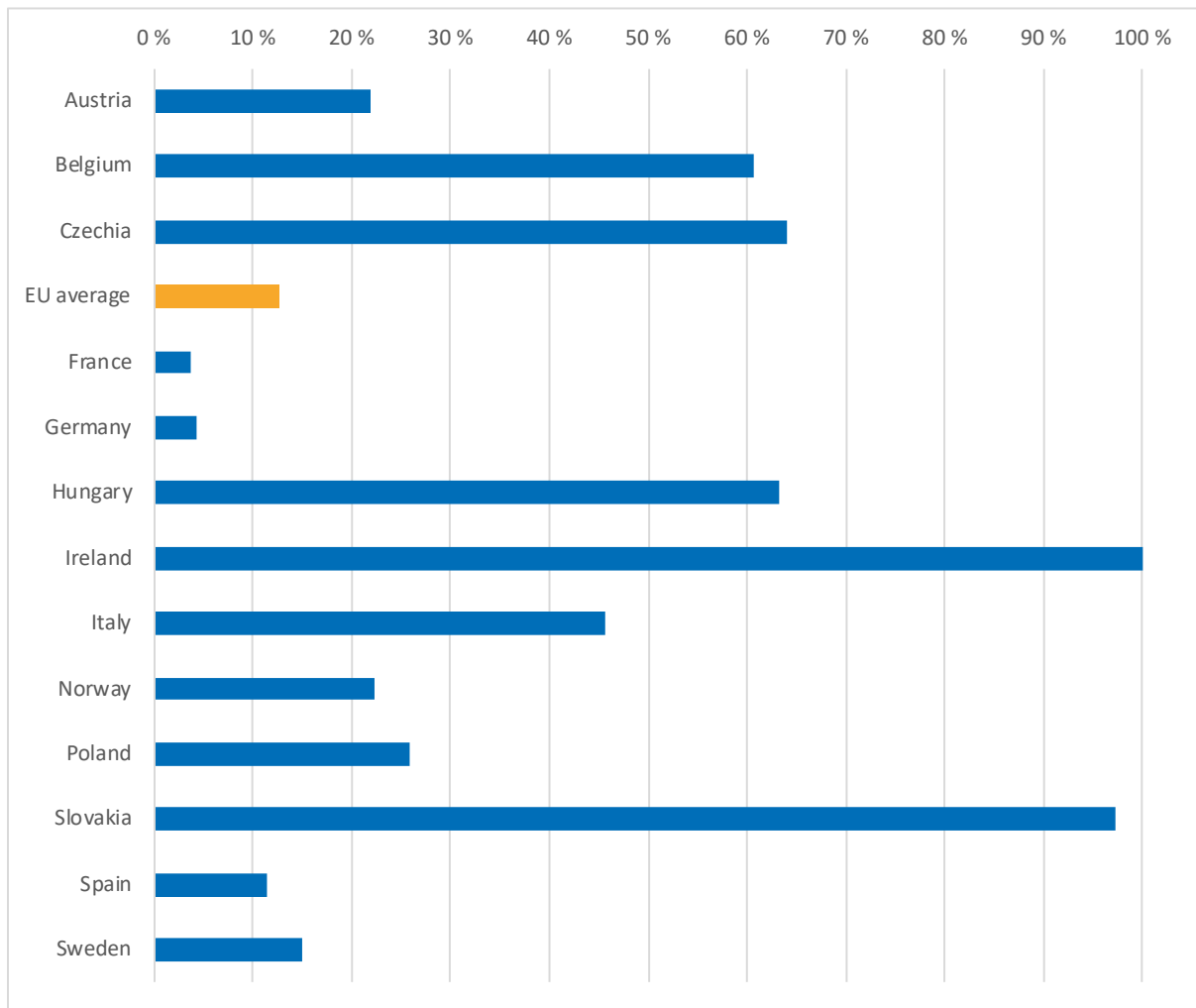
Source: Elaboration based on (Gardner, Brambilla and Matheus 2023).

Table A.2 – Passenger and freight railway undertakings by Member State (2025)

Country	Number
Austria	20
Croatia	1
Czechia	46
Denmark	3
Finland	1
France	3
Germany	223
Greece	1
Ireland	1
Italy	7
Netherlands	8
Norway	2
Poland	18
Romania	3
Slovakia	6
Slovenia	1
Spain	12
Sweden	5
Total	361

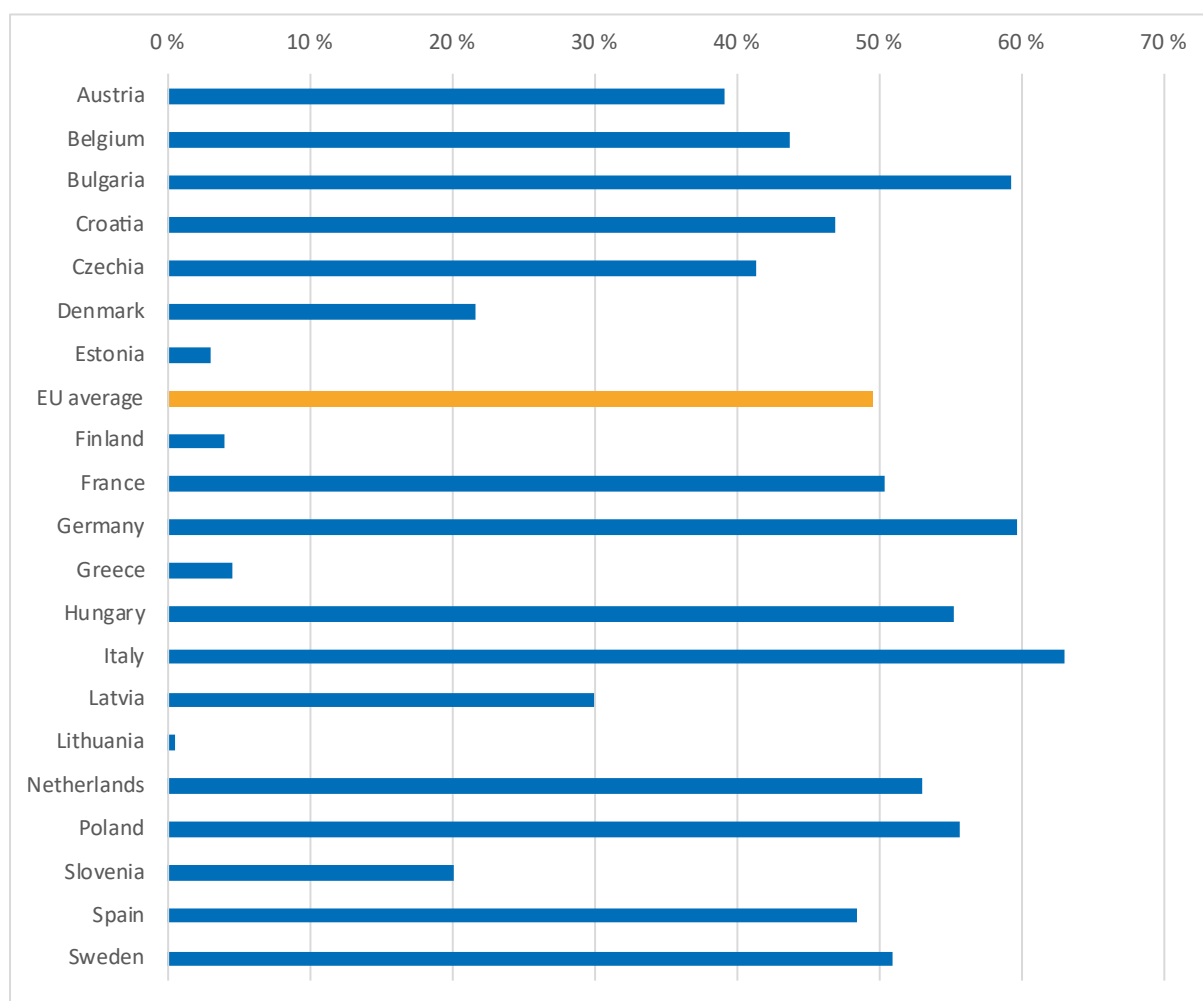
Source: Elaboration based on ERA data (see [here](#)).

Figure A.11 – Competitors' market share in the commercial passenger market by Member State (% of pax-km, 2022)



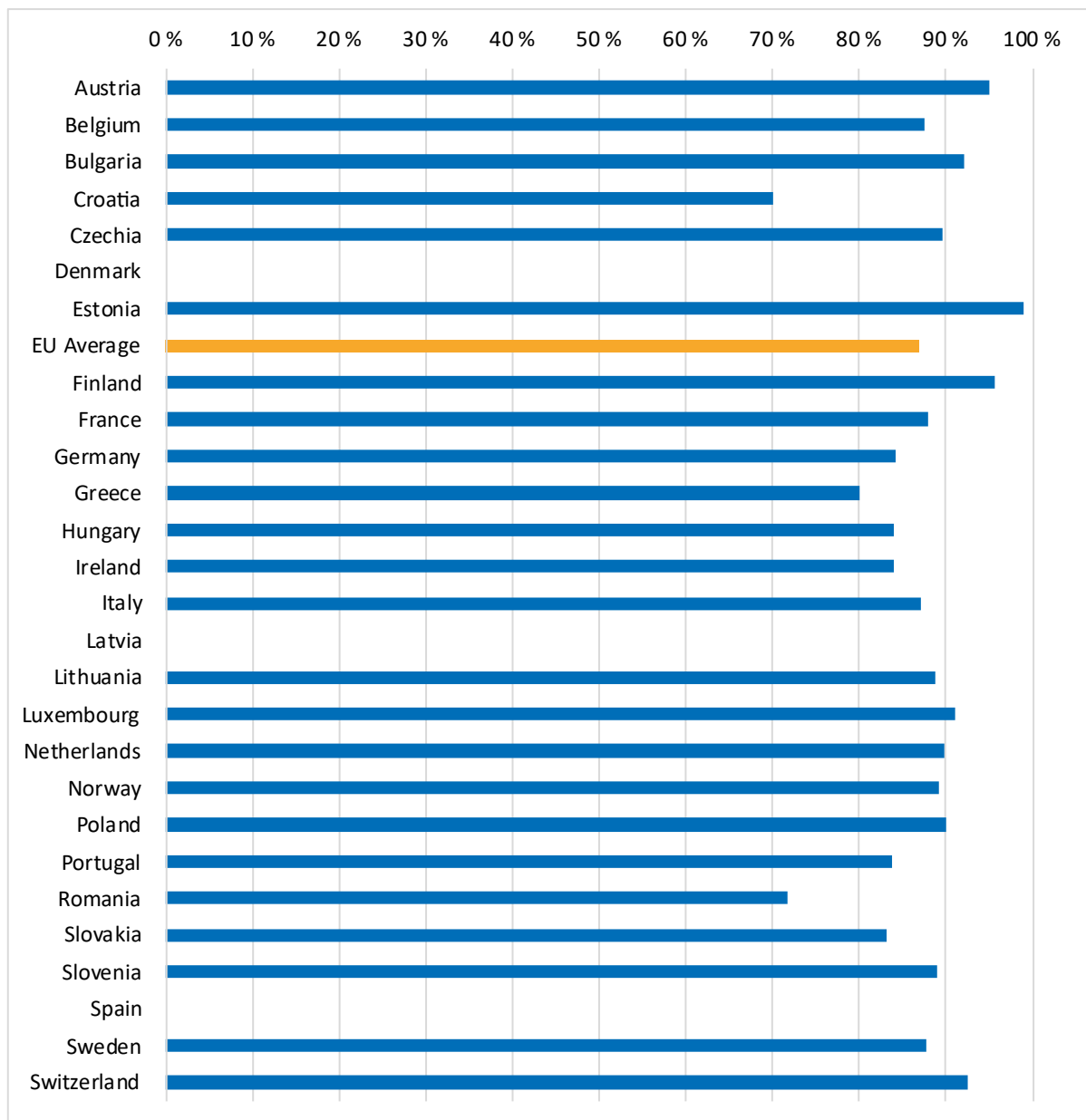
Source: Elaboration based on (European Commission 2025g).

Figure A.12 – Competitors' market share in the rail freight market by Member State (% of ton-km, 2022)



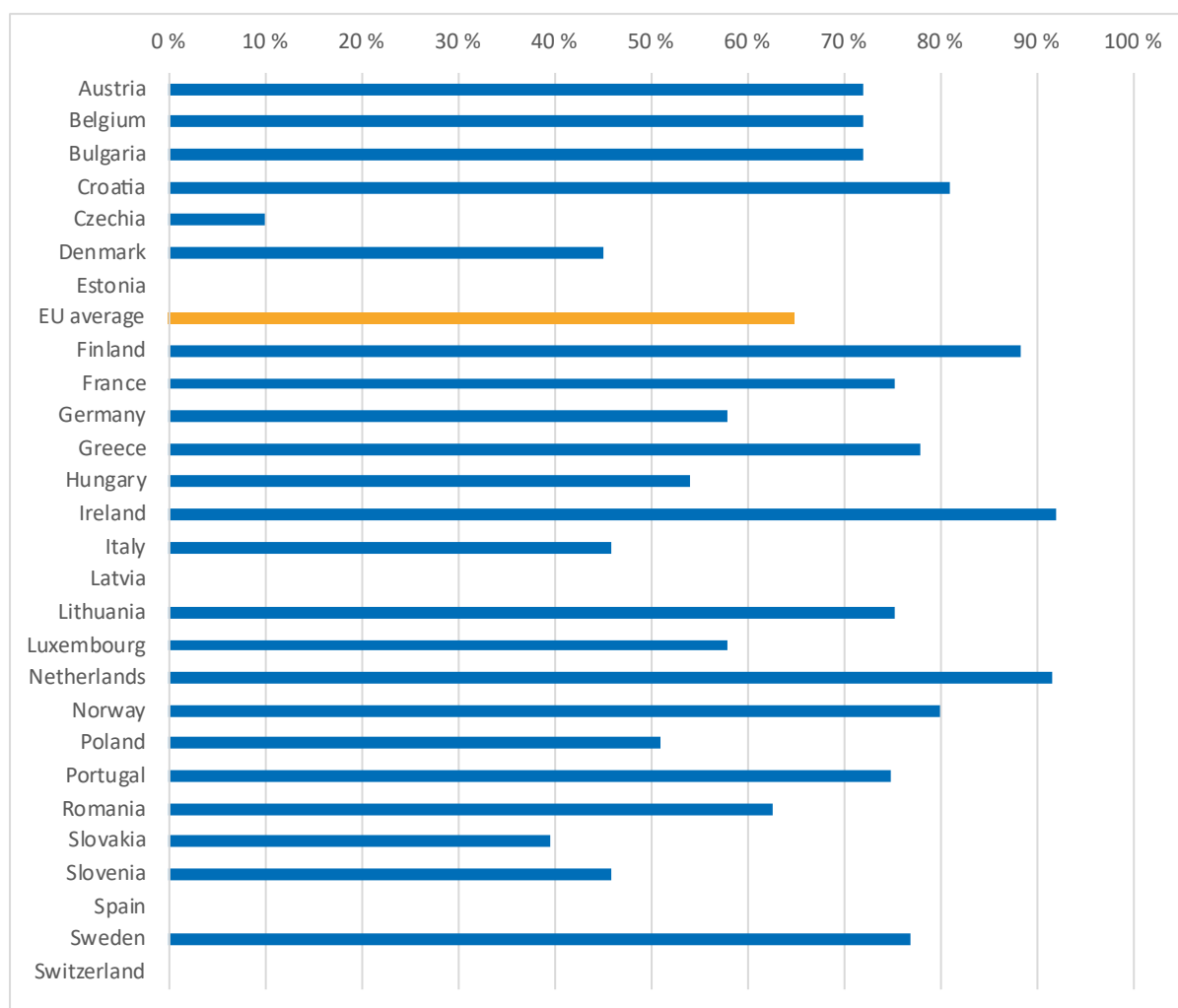
Source: Elaboration based on (European Commission 2025g).

Figure A.13 – Passenger rail transport punctuality by Member State (2023)



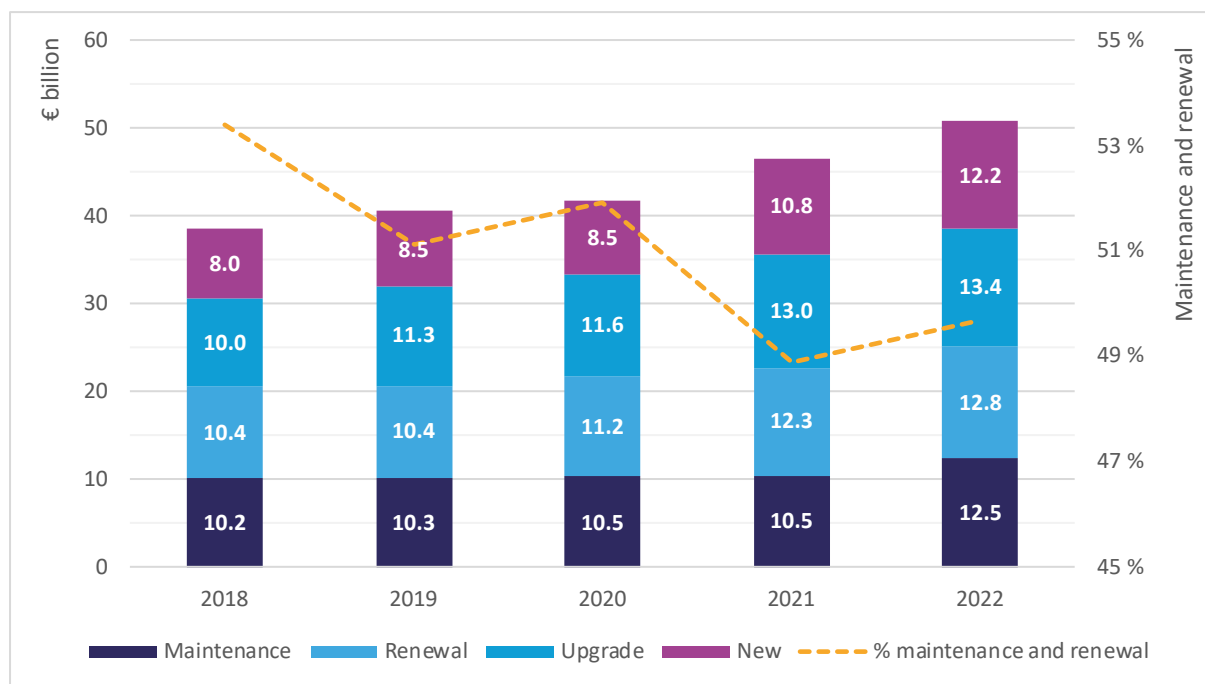
Source: Elaboration based on ERA data (see [here](#)).

Figure A.14 – Freight rail transport punctuality by Member State (2023)



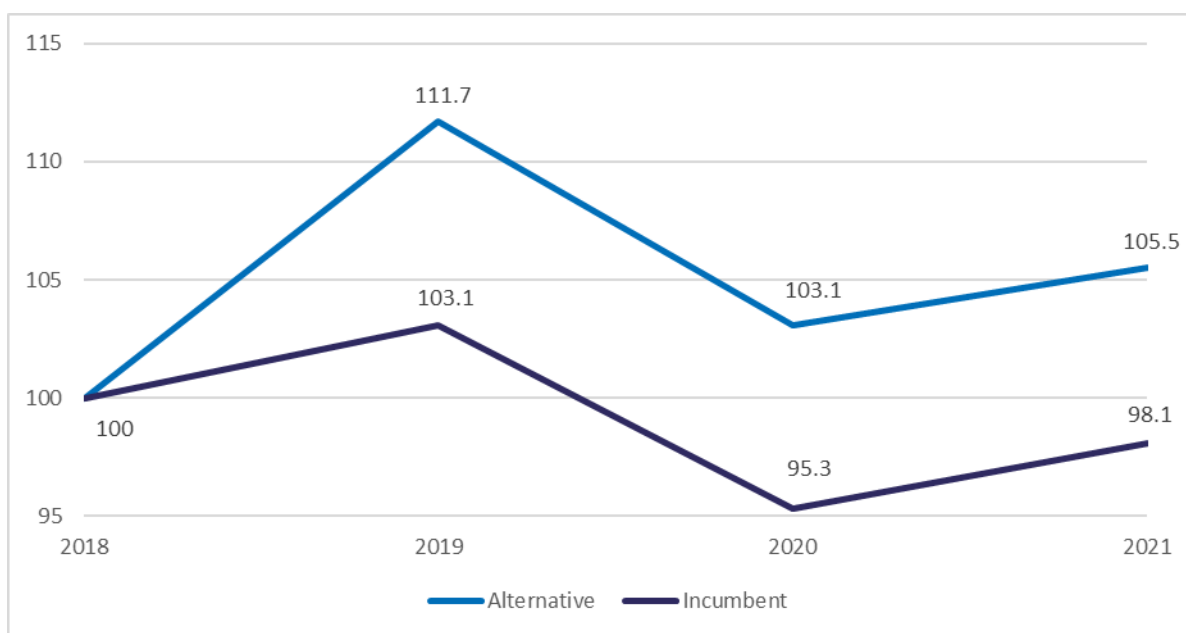
Source: Elaboration based on ERA data (see [here](#)).

Figure A.15 – Total expenditure on rail infrastructure (EU-27, 2018-2022)



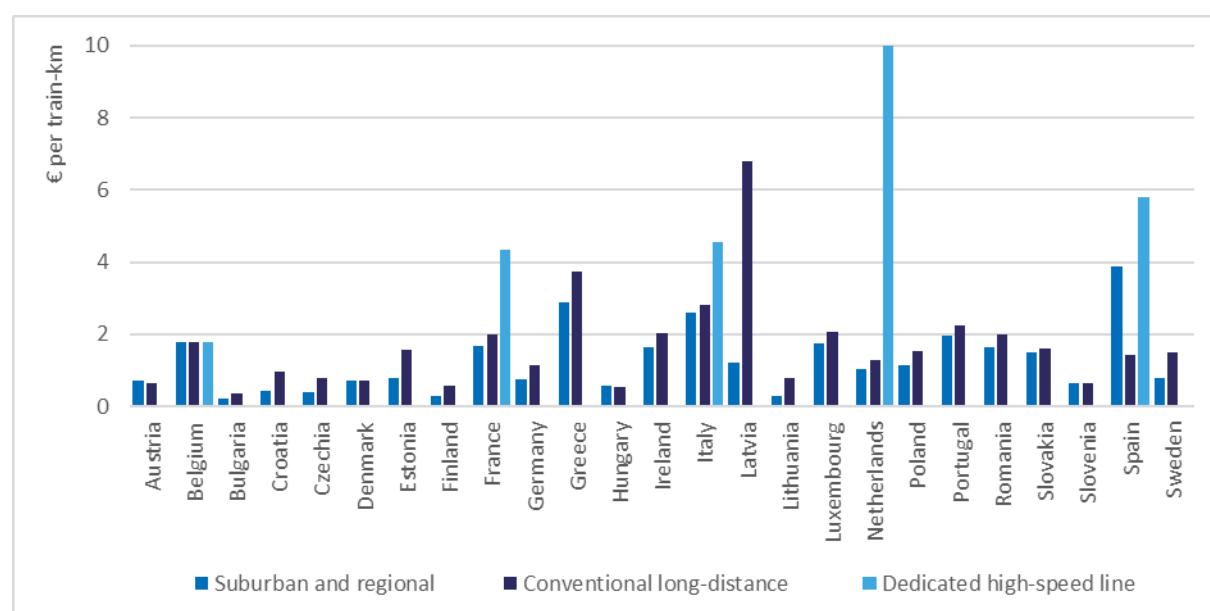
Source: Elaboration by the authors, based on (European Commission 2025g).

Figure A.16 – Total expenditure at EU level for passenger operators, index base 100 (2018 value = 100)



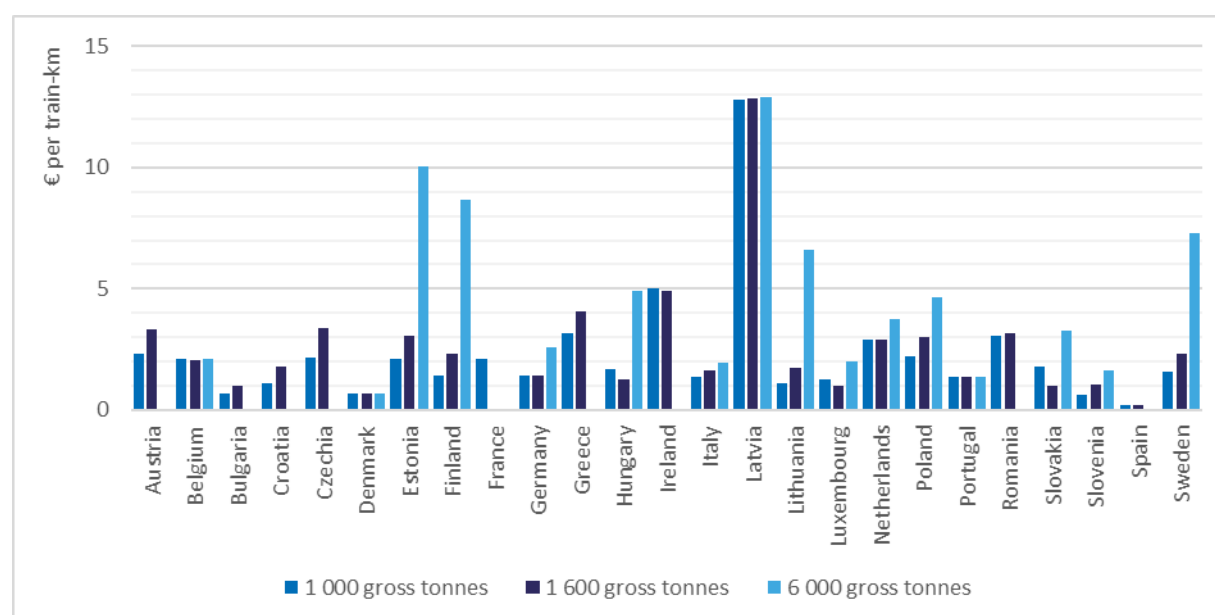
Source: Elaboration based on (KPMG and VVA 2023).

Figure A.17 – Track access changes (excluding markups) for different categories of passenger trains by Member State (€ per train-km, 2022)



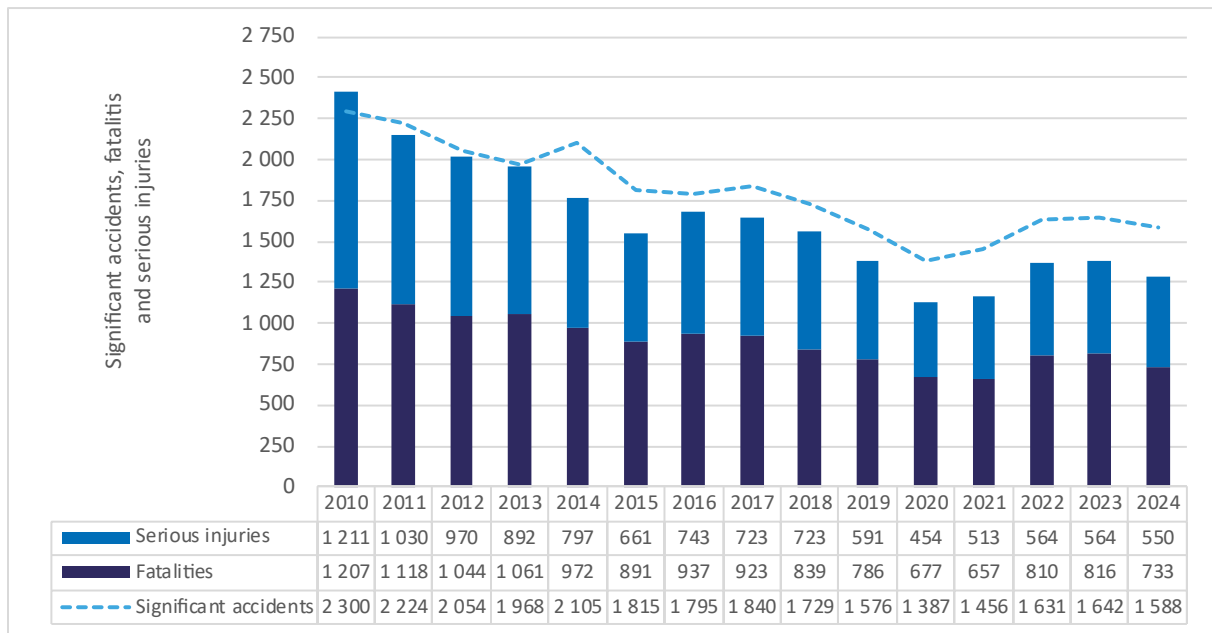
Source: Elaboration based on (European Commission 2025g).

Figure A.18 – Track access changes (excluding markups) for different categories of freight trains by Member State (€ per train-km, 2022)



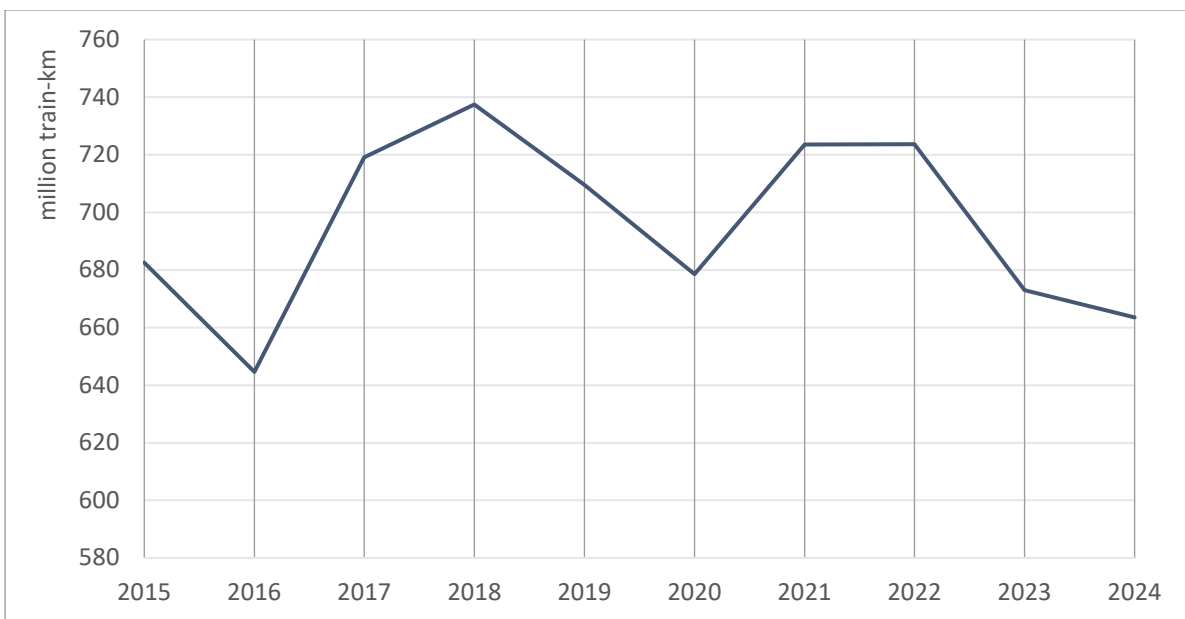
Source: Elaboration based on (European Commission 2025g).

Figure A.19 – Rail transport safety level (EU-27, 2010–2022)



Source: Elaboration based on ERA data (see [here](#)).

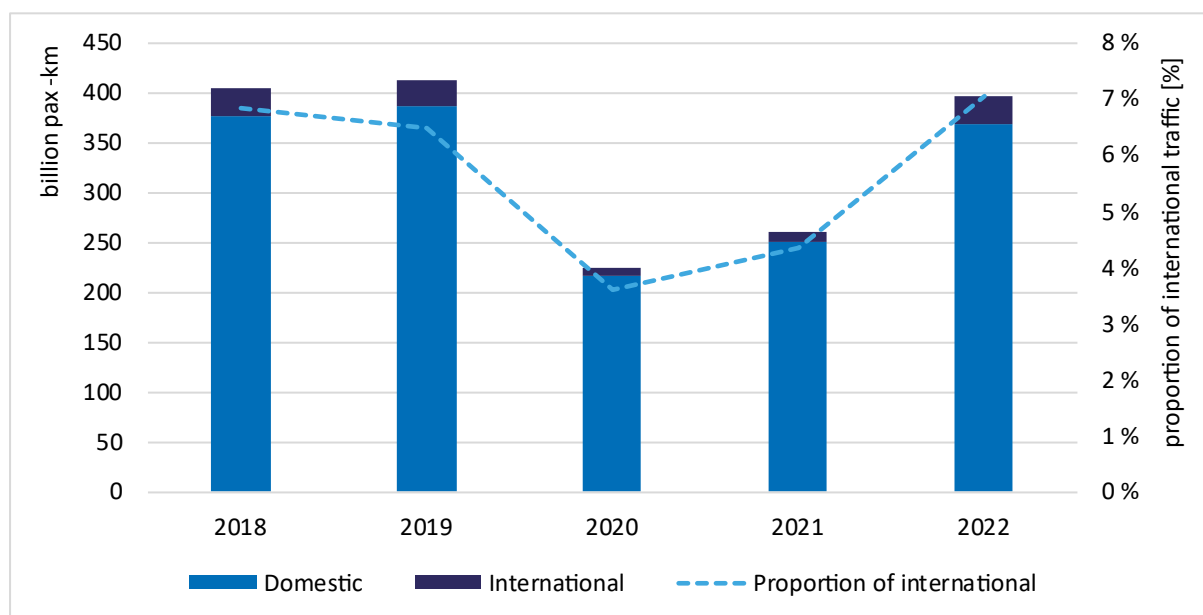
Figure A.20 – Evolution of freight rail transport in the EU (million train-km, 2015–2024)



Source: Elaboration based on Eurostat data (see [here](#)).

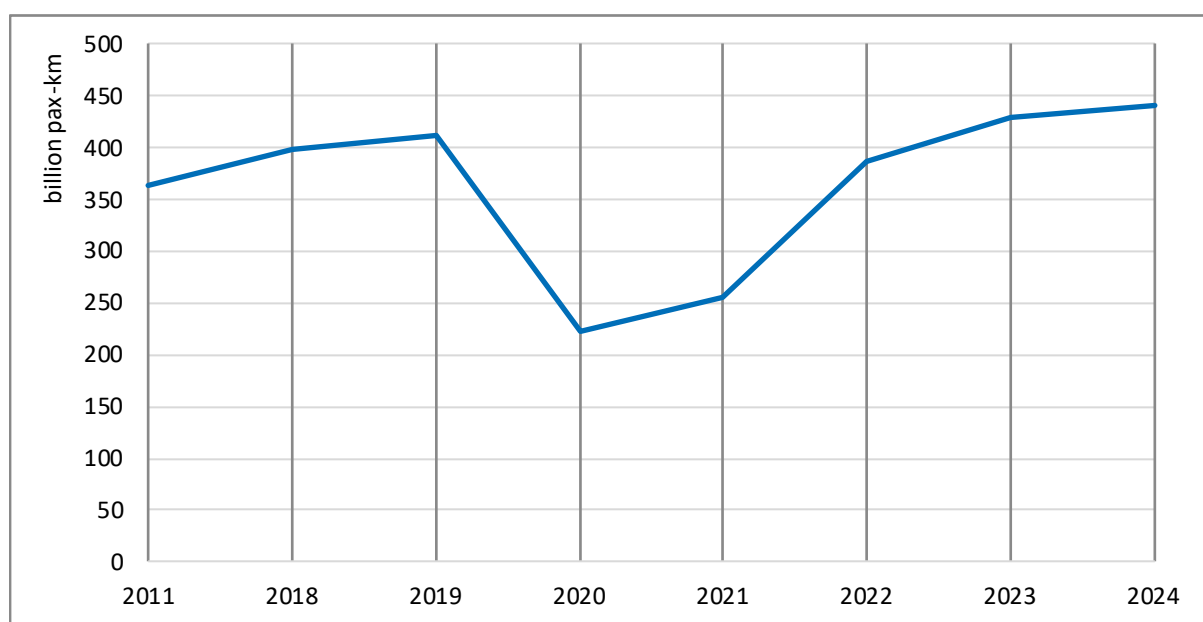
Demand side

Figure A.21 – Evolution of passenger rail transport (domestic, international and proportion of international in total traffic) (billion pax-km, 2018–2022)



Source: Elaboration based on (European Commission 2025a).

Figure A.22 – Evolution of passenger rail transport in the EU (million pax-km, 2011–2023)



Source: Elaboration based on ERA data (see [here](#)).

Table A.3 – High-speed rail transport (billion pax-km, 1990–2023)

Year	Austria	Belgium	Czechia	Finland	France	Germany	Italy	Netherlands	Poland	Portugal	Slovenia	Spain	Sweden	EU-27
1990		-	-	-	14.92	-	0.30	-	-	-	-	-	0.01	15.23
1995		-	-	-	20.94	8.70	1.10	-	-	-	-	1.29	0.42	32.45
2000		0.87	-	0.07	35.19	13.93	5.09	0.11	-	-	-	1.94	2.05	59.24
2005		0.98	0.01	0.31	43.42	20.85	8.55	0.69	-	0.49	-	2.32	2.33	79.96
2010	0.21	1.06	0.27	0.65	53.91	23.90	11.34	0.29	-	0.52	0.02	11.72	2.94	106.82
2011	0.46	0.91	0.29	0.71	55.19	23.31	12.28	0.31	-	0.47	0.01	11.23	2.83	107.98
2012	0.48	0.91	0.27	0.71	55.19	24.75	12.79	0.32	-	0.46	0.01	11.18	2.95	110.02
2013	0.51	0.91	0.25	0.76	54.91	25.18	13.34	0.36	-	0.47	0.01	12.74	3.06	112.48
2014	0.51	0.91	0.25	0.65	54.87	24.32	13.67	0.24	-	0.54	0.01	12.79	3.23	111.98
2015	0.52	1.20	0.57	0.57	55.20	25.28	14.28	1.00	0.47	0.57	0.01	14.13	3.37	117.16
2016	0.58	1.50	0.70	0.61	54.76	27.21	14.28	0.37	1.44	0.61	0.00	15.06	3.48	120.60
2017	0.58	1.56	0.77	0.68	59.65	28.50	14.56	0.41	1.44	0.65	0.00	15.54	3.60	127.95
2018	0.60	1.56	0.79	0.80	56.06	31.07	15.18	0.40	1.55	0.66	0.00	16.13	3.52	128.33
2019	0.60	1.56	0.88	0.81	58.93	33.20	15.48	0.45	1.68	0.70	0.00	16.07	3.90	134.27
2020	0.33	1.00	0.54	0.33	33.06	18.15	6.09	0.14	0.76	0.22	0.00	5.61	1.80	68.03
2021	0.38	1.35	0.55	0.34	43.52	19.57	7.58	0.14	1.12	0.27	0.03	6.37	1.94	83.16
2022	0.59	1.45	0.58	0.39	61.38	33.99	12.72	0.20	1.40	0.55	0.04	9.75	3.03	126.05
2023	0.66	1.57	0.62	0.44	64.57	37.96	14.99	0.45	1.62	0.60	0.10	9.93	3.19	136.70

Source: (European Commission 2025d).³⁰

Table A.4 – Share of high-speed rail transport in total pax-km in rail transport (%)

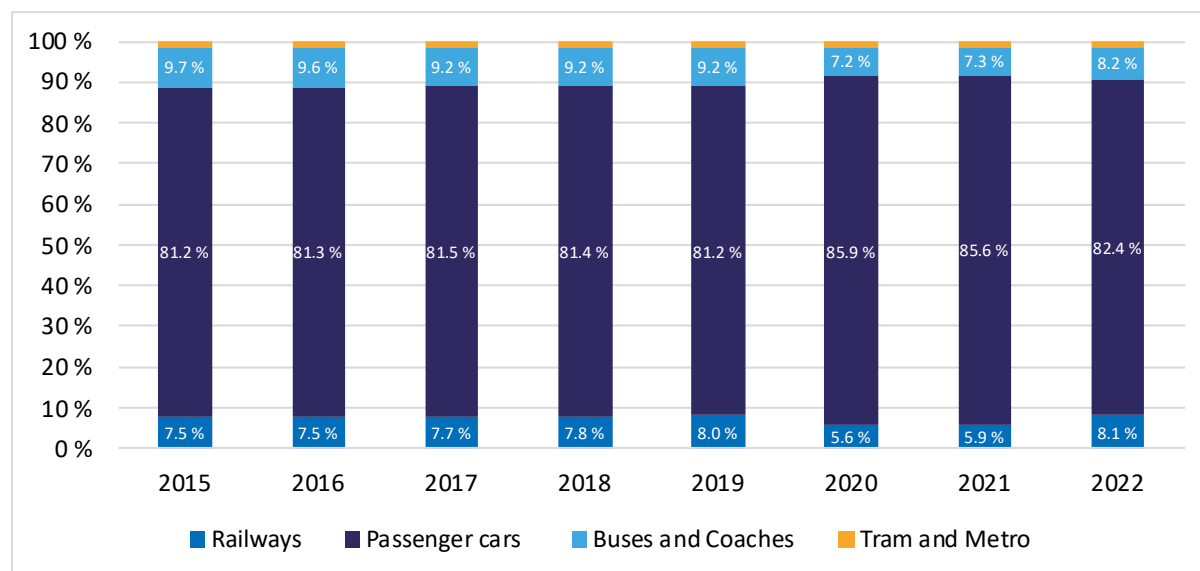
Year	Austria	Belgium	Czechia	Finland	France	Germany	Italy	Netherlands	Poland	Portugal	Slovenia	Spain	Sweden	EU-27
2000		11.2	-	2.1	47.0	18.5	10.3	0.8	-	-	-	9.6	24.8	17.4
2005		11.5	0.1	8.9	52.7	27.2	17.1	4.5	-	12.9	-	10.7	26.2	23.4
2010	2.1	10.1	4.1	16.4	58.4	28.5	24.0	1.7	-	12.6	2.1	52.2	26.3	29.4
2011	4.3	8.5	4.3	18.3	57.7	27.3	26.2	1.7	-	11.0	1.9	49.3	24.8	28.5

³⁰ High-speed rail transport covers all traffic with high-speed rolling stock (including tilting trains able to run 200 km/h).

Year	Austria	Belgium	Czechia	Finland	France	Germany	Italy	Netherlands	Poland	Portugal	Slovenia	Spain	Sweden	EU-27
2012	4.3	8.3	3.8	17.5	57.6	27.9	27.4	1.8	-	12.1	1.8	49.7	25.0	28.8
2013	4.3	8.3	3.3	18.7	57.7	28.1	27.4	1.9	-	12.7	1.6	53.6	25.8	28.9
2014	4.3	8.3	3.2	16.8	58.1	26.7	27.4	1.2	-	14.0	1.2	51.0	26.6	28.4
2015	4.3	11.4	7.0	13.9	58.3	27.8	27.4	5.7	2.7	14.4	0.9	54.0	26.4	28.8
2016	4.6	15.0	8.0	15.8	58.3	28.5	27.4	2.0	7.5	14.4	0.6	56.5	27.2	29.6
2017	4.6	15.1	8.2	15.9	59.5	29.8	27.4	2.2	7.1	14.5	0.3	56.5	27.0	31.0
2018	4.6	13.3	7.8	17.5	59.3	31.6	27.4	2.1	7.4	14.5	0.3	56.7	26.0	31.0
2019	4.5	13.0	8.1	16.5	59.6	33.1	27.4	2.3	7.6	13.8	0.3	55.7	26.7	31.4
2020	4.5	12.7	8.1	11.5	58.3	31.4	27.4	1.5	6.0	8.7	0.1	46.5	22.1	30.5
2021	4.5	17.1	8.1	11.7	58.7	34.0	27.4	1.3	7.1	9.3	5.4	37.5	24.2	32.1
2022	4.6	12.7	6.2	8.5	60.5	36.8	27.4	1.2	5.9	12.5	6.0	35.5	23.5	32.0
2023	4.6	12.7	6.2	8.5	60.4	37.4	27.4	2.4	6.3	12.4	12.8	28.7	24.0	31.3

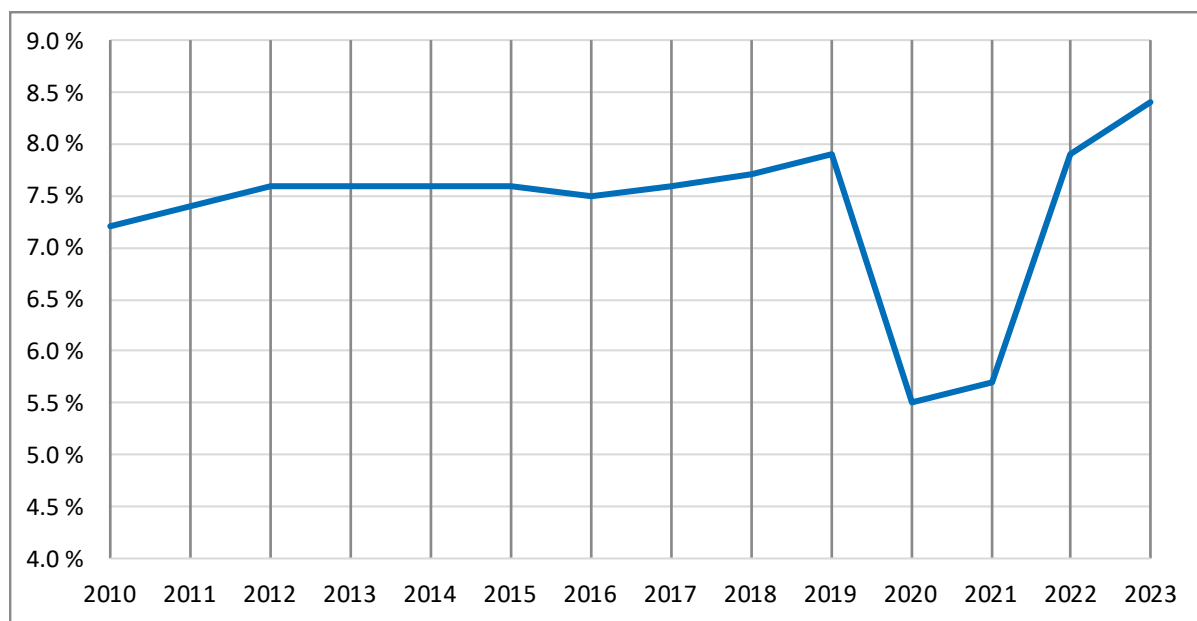
Source: Elaboration based on (European Commission 2025d).

Figure A.23 – Passenger land transport modal split



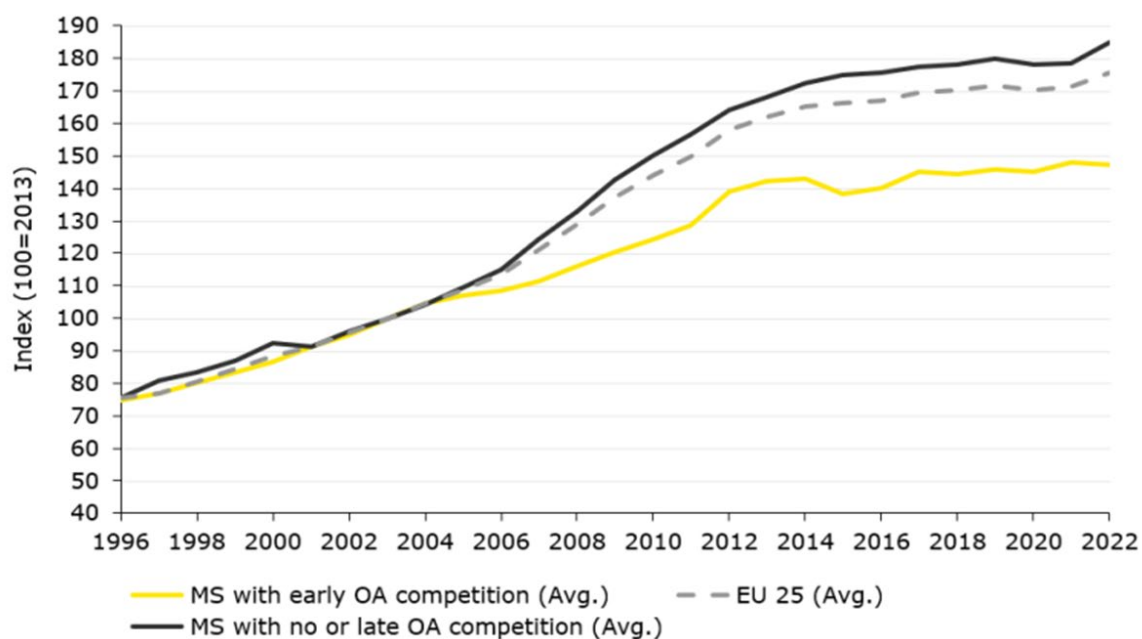
Source: Elaboration based on (European Commission 2025a).

Figure A.24 – Passenger rail transport modal share in the EU (2010–2023)



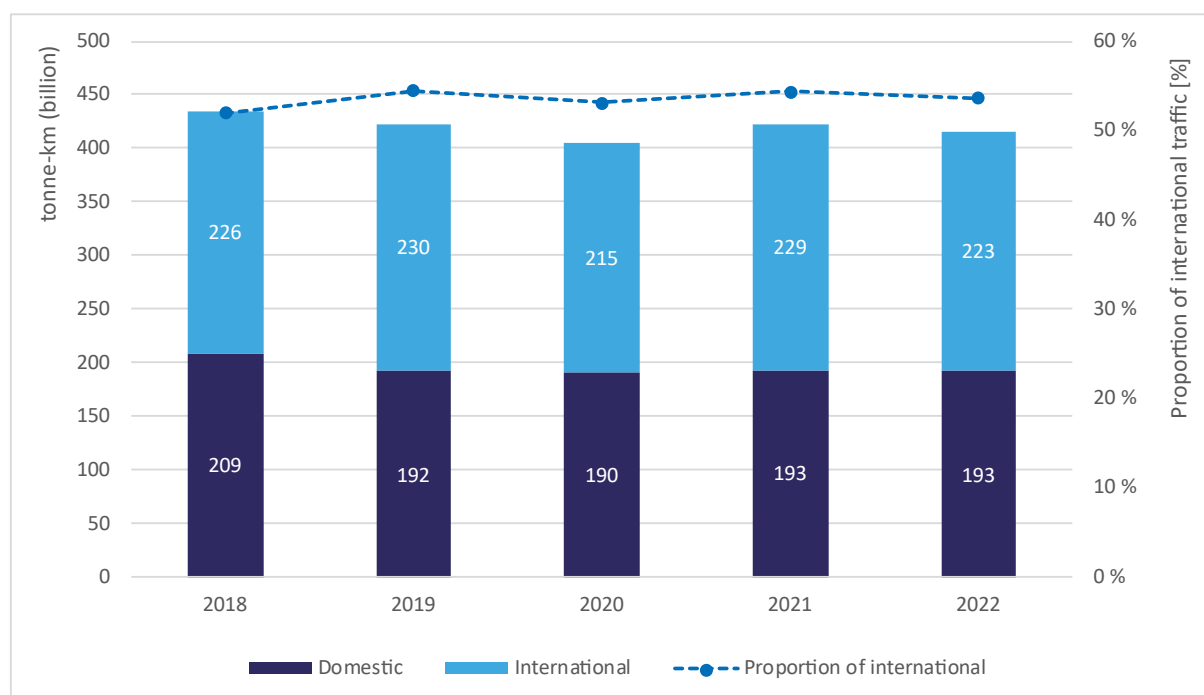
Source: Elaboration based on ERA data (see [here](#)).

Figure A.25 – Average Harmonised index of Consumer Prices (HICP) for passenger transport by railway for selected groups of EU Member States (index 100=2003)



Source: (de Rose, Trier Jørgensen and Doklestic 2024).

Figure A.26 – Evolution of freight rail transport in the EU (domestic, international, and proportion of international traffic) (billion ton-km, 2018-2022)



Source: Elaboration based on (European Commission 2025g).

Table A.5 – Evolution of freight rail transport in the EU at Member State level (billion ton-km, 1995-2023)³¹

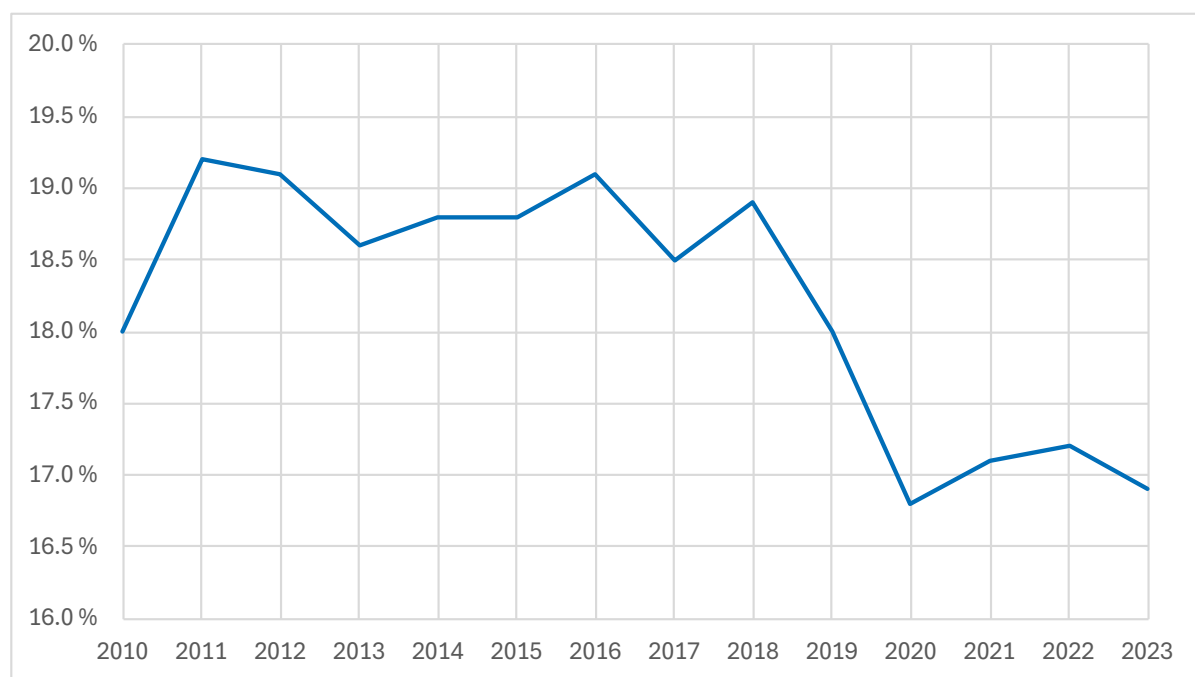
Member State	1995	2000	2005	2010	2015	2020	2023	% variation 2022-2023
Belgium	7.3	7.7	8.1	7.5	13.9	13.4	11.9	17.2
Bulgaria	8.6	5.5	5.2	3.1	3.7	4.5	4.6	-13.1
Czechia	22.6	17.5	14.9	13.8	15.3	15.3	15.0	-8.1
Denmark	2.0	2.0	2.0	2.2	2.6	2.5	1.9	-13.8
Germany	70.5	82.7	95.4	107.3	114.3	109.2	129.1	0.4
Estonia	3.8	8.1	10.6	6.6	3.1	1.7	0.8	-40.0
Ireland	0.6	0.5	0.3	0.1	0.1	0.1	0.1	-6.2
Greece	0.3	0.4	0.6	0.6	0.3	0.6	0.2	-53.9
Spain	11.0	12.2	11.6	8.9	11.0	8.9	10.0	-5.6
France	48.3	57.7	40.7	30.0	36.3	31.3	29.4	-16.7
Croatia	2.0	1.8	2.8	2.6	2.2	3.3	3.1	-10.9

³¹ Cyprus and Malta are not included in the analysis, as they do not operate railway networks.

Member State	1995	2000	2005	2010	2015	2020	2023	% variation 2022-2023
Italy	21.7	22.8	22.8	18.6	20.8	20.8	22.7	-6.7
Latvia	9.8	13.3	19.8	17.2	18.9	8.0	5.2	-29.9
Lithuania	7.2	8.9	12.5	13.4	14.0	15.9	6.3	-14.5
Luxembourg	0.5	0.6	0.4	0.3	0.2	0.2	0.2	4.2
Hungary	8.4	8.8	9.1	8.8	10.0	11.6	10.5	-7.8
Netherlands	3.1	4.5	5.9	5.9	6.5	6.7	6.5	-9.5
Austria	13.2	16.6	19.0	19.8	20.8	20.5	20.2	-8.9
Poland	68.2	54.0	50.0	48.7	50.6	51.1	61.1	3.0
Portugal	2.0	2.2	2.4	2.3	2.7	2.3	2.3	3.3
Romania	17.9	16.4	16.6	12.4	13.7	12.3	12.9	-3.3
Slovenia	3.1	2.9	3.2	3.4	4.2	4.7	4.6	-6.1
Slovakia	13.8	11.2	9.5	8.1	8.4	6.9	7.5	-4.5
Finland	9.6	10.1	9.7	9.8	8.5	10.1	7.9	-11.0
Sweden	19.4	19.5	21.7	23.5	20.7	22.1	22.0	-5.2
EU-27	374.8	378.9	394.6	375.0	402.8	383.7	395.8	-4.3

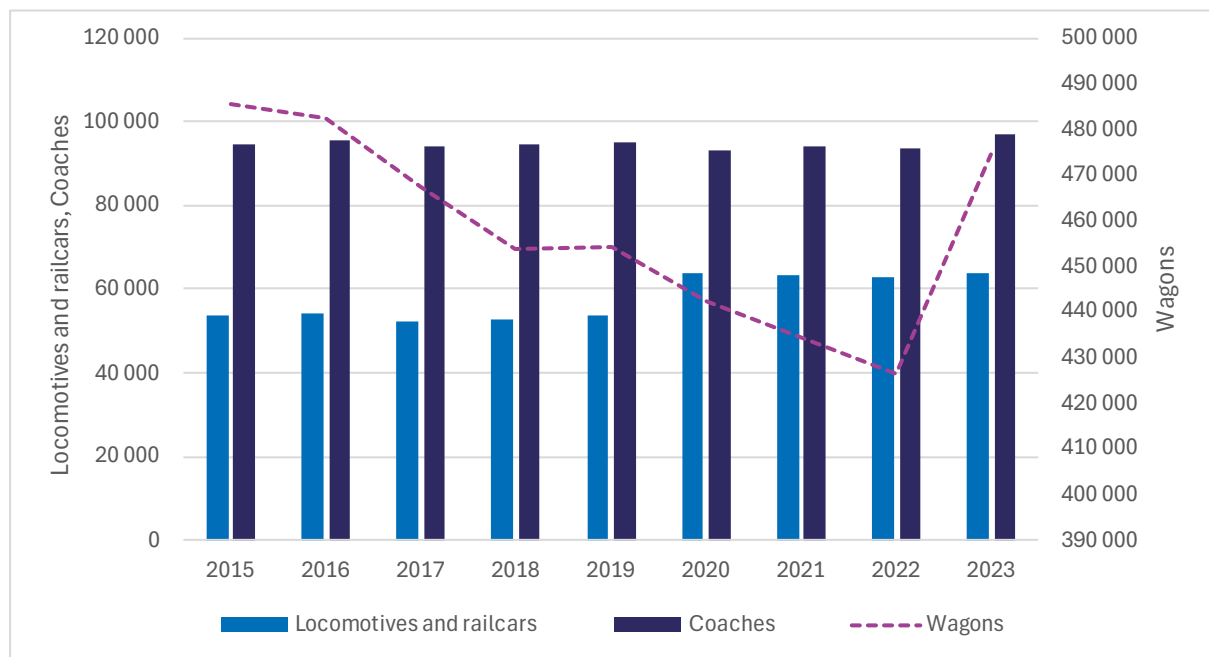
Source: Elaboration based on (European Commission 2025d).

Figure A.27 – Freight rail transport modal share in the EU (2010-2023)



Source: Elaboration based on ERA data (see [here](#)).

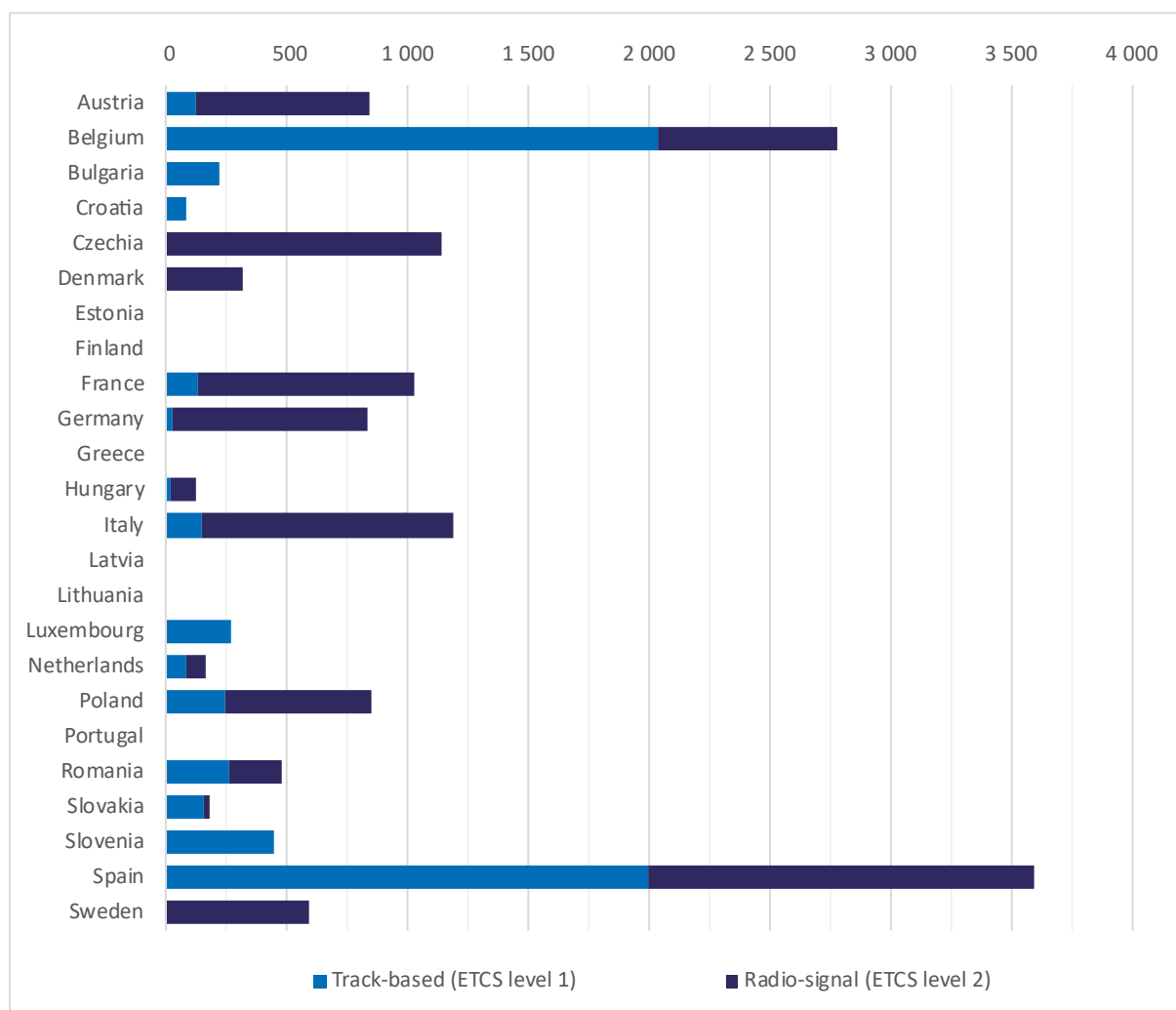
Figure A.28 – Volume of rolling stock in the EU (locomotives and railcars, coaches, and wagons)



Source: Elaboration by the authors, based on (European Commission 2025d).

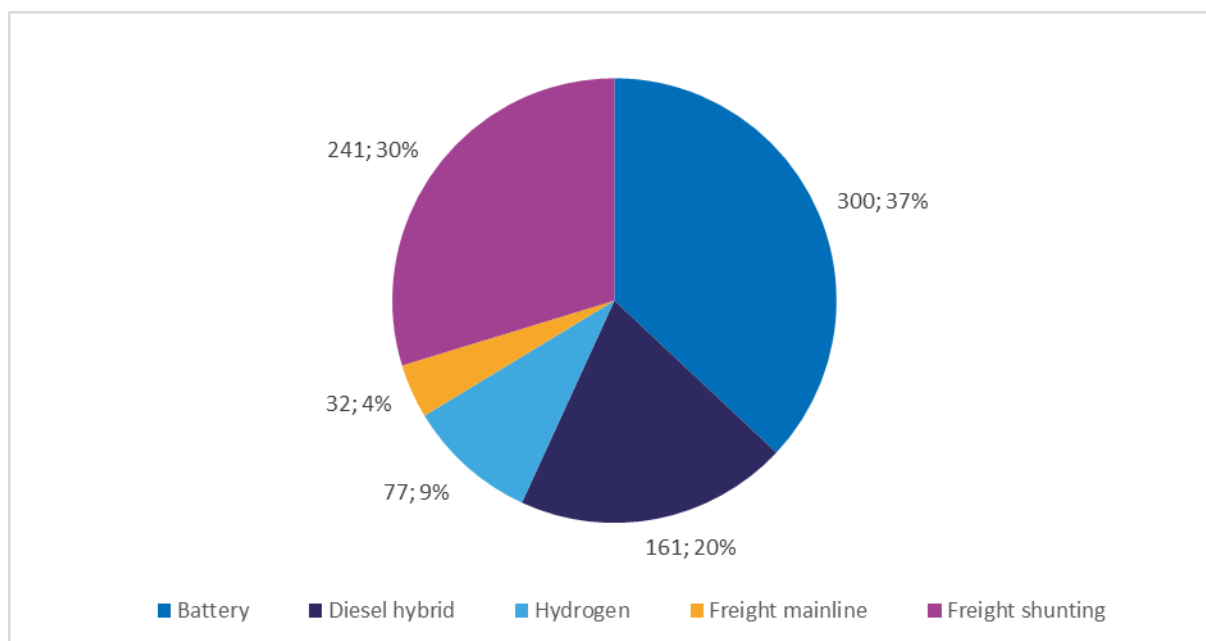
Technology

Figure A.29 – Length of railway lines equipped with ERTMS by Member State and type of signalling system (km)



Source: Elaboration based on Eurostat data (see [here](#)).

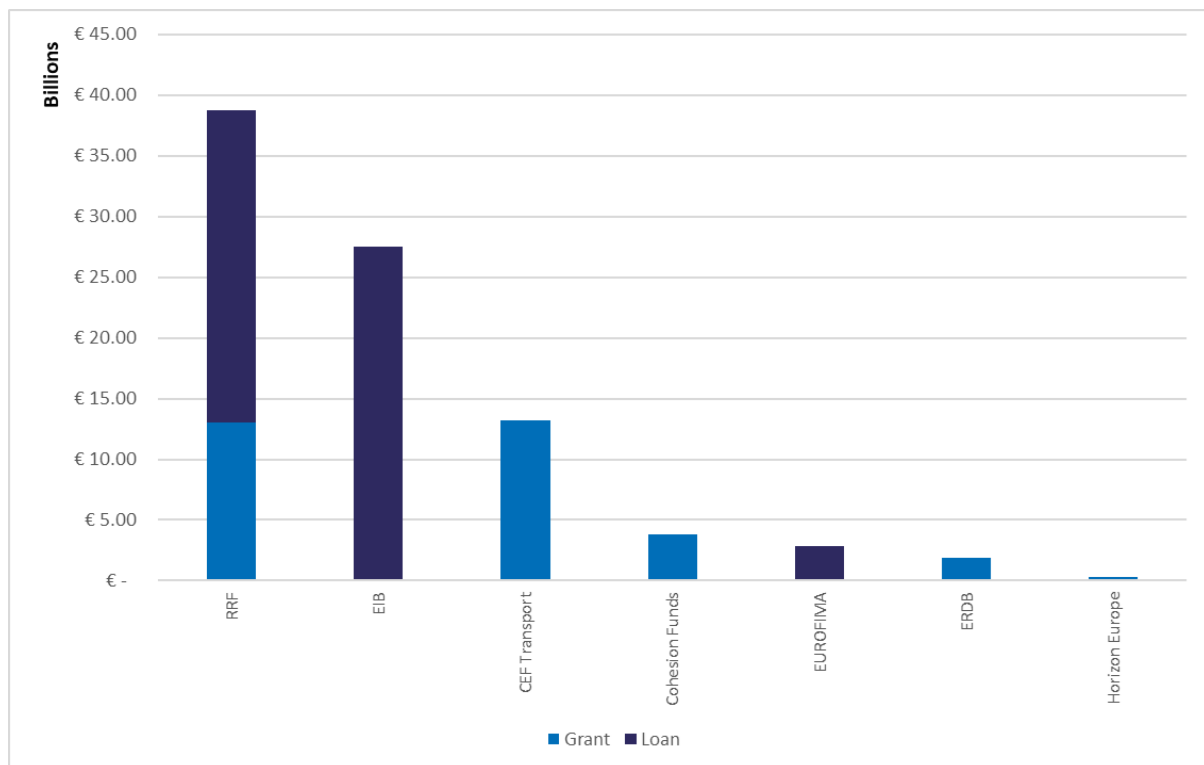
Figure A.30 – Alternative drive trains in Europe (in service and order)



Source: Elaboration based on (Chamaret 2023).

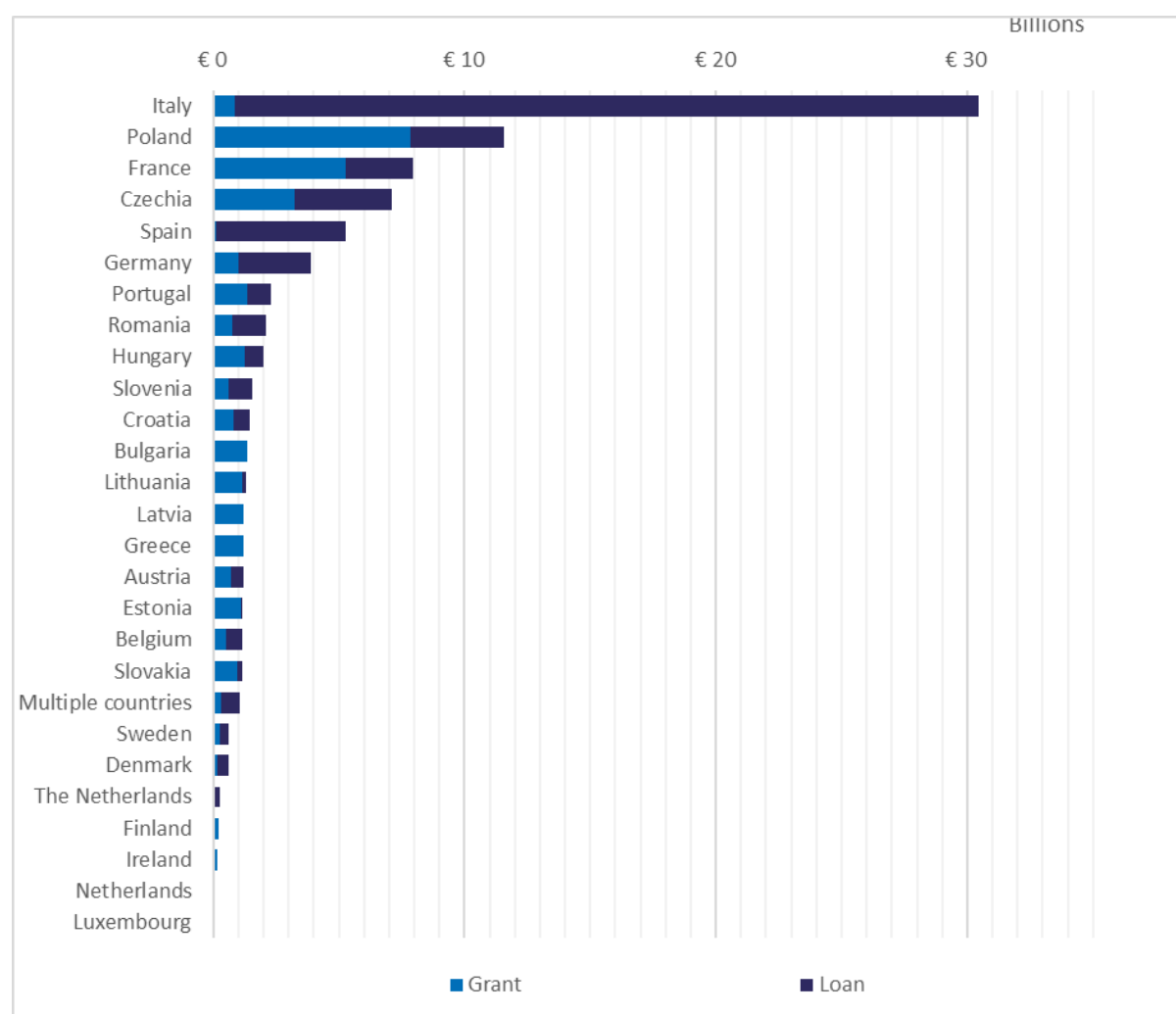
Funding and financing

Figure A.31 – EU funding provided between 2021 and 2026 to railways, per instrument

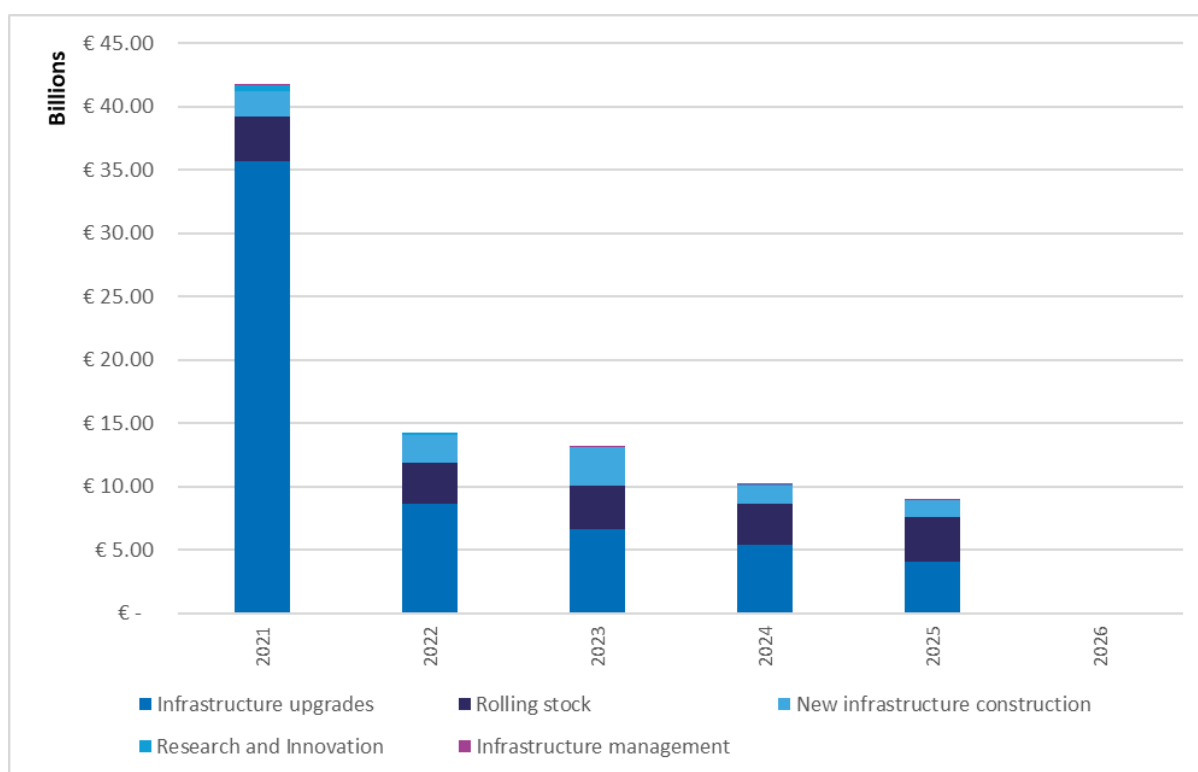


Source: Elaboration based on EU funding programmes data until February 2026.

Figure A.32 – EU funding provided between 2021 and 2026 to railways, per country

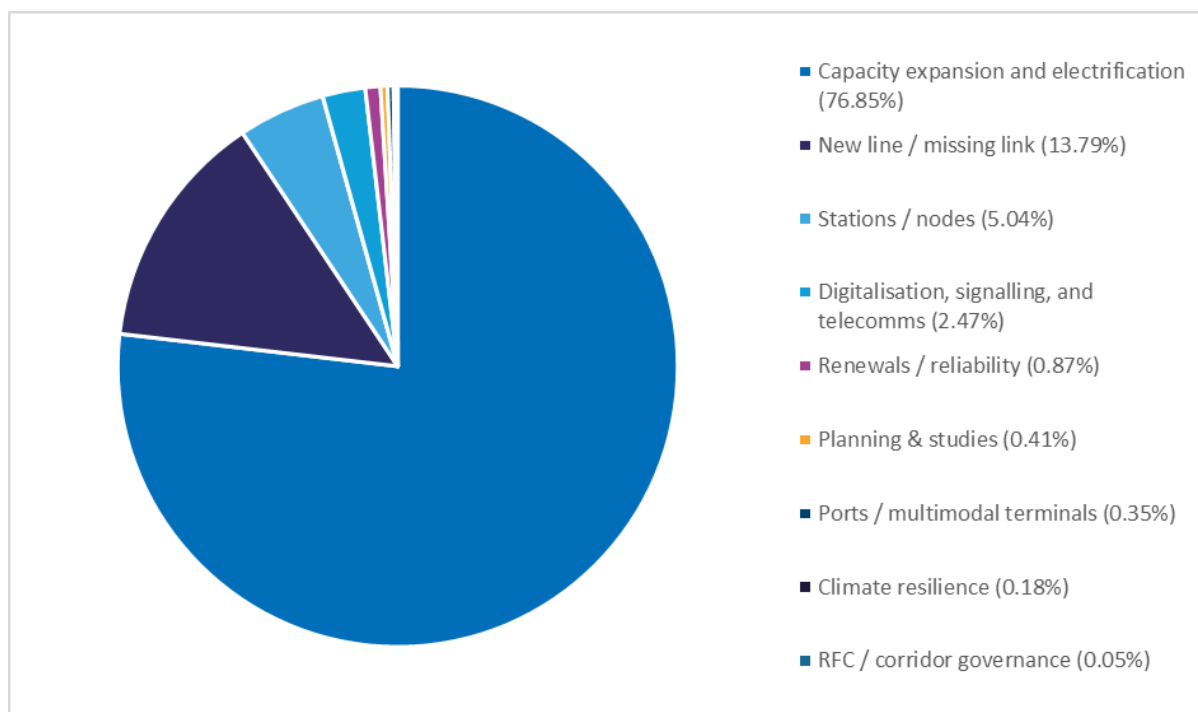


Source: Elaboration based on EU funding programmes data until February 2026.

Figure A.33 – EU funding provided between 2021 and 2026 to railways, per type of project³²

Source: Elaboration based on EU funding programmes data until February 2026.

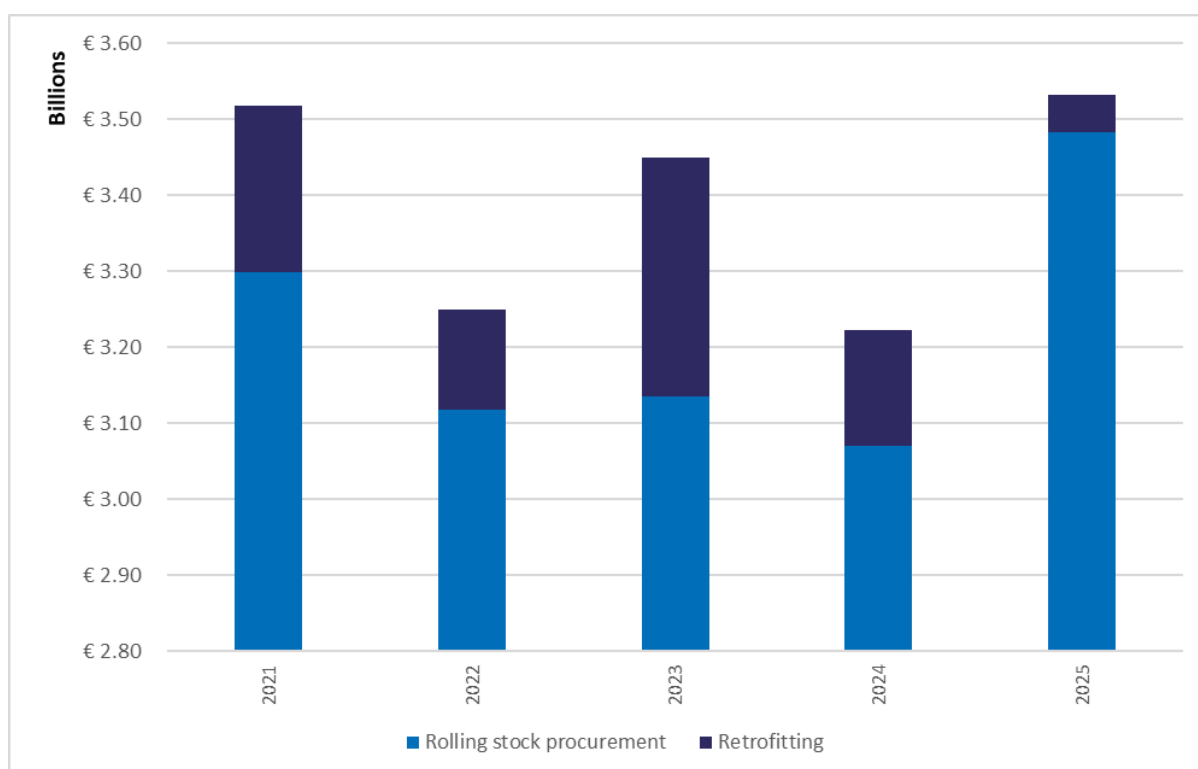
Figure A.34 – Distribution of infrastructure investments from EU-funded projects



Source: Elaboration based on EU funding programmes data until February 2026.

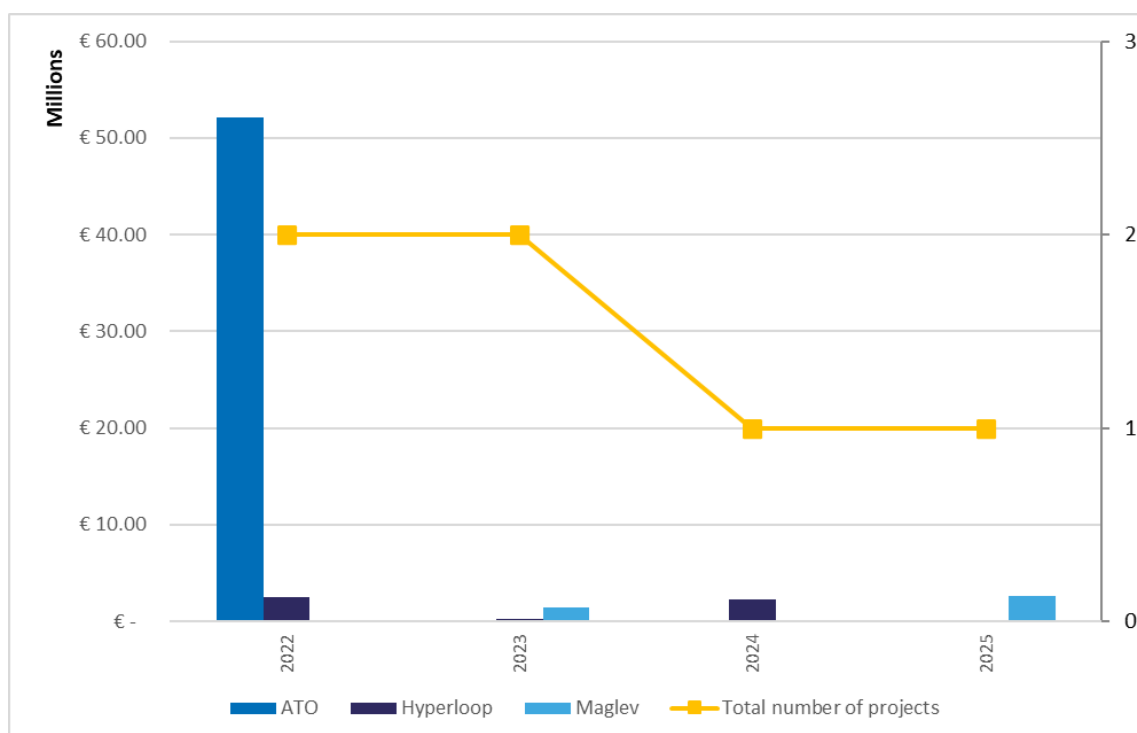
³² The RRF heavily skews the data towards 2021.

Figure A.35 – EU funding for rolling stock procurement and retrofitting



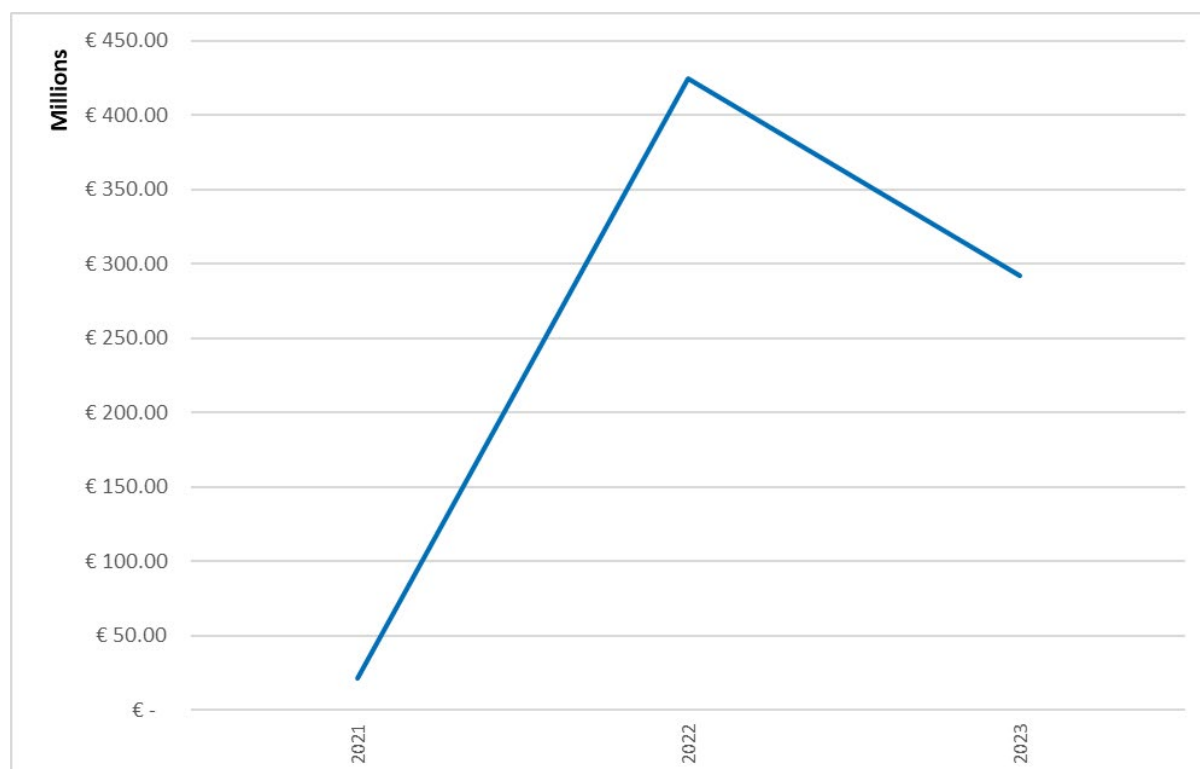
Source: Elaboration based on EU funding programmes data until February 2026.

Figure A.36 – Research and Innovation funding for rail-specific technologies



Source: Elaboration based on EU funding programmes data until February 2026.

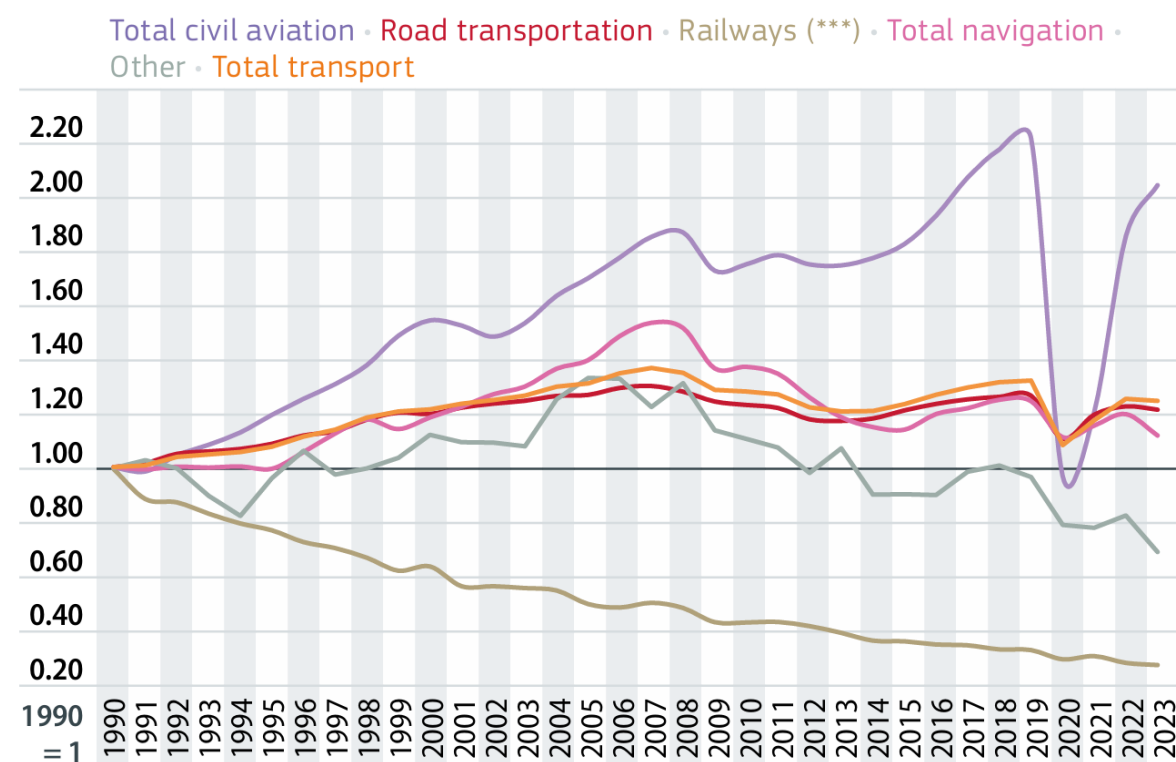
Figure A.37 – EU funding for projects explicitly labelled as relevant for military mobility



Source: Elaboration based on EU funding programmes data until February 2026.

Future scenarios

Figure A.38 – Greenhouse gas emissions from transport in the EU-27, in million tonnes CO₂ equivalent



- NB:** (*) Excluding international bunkers (international traffic departing from the EU)
 (**) Including international bunkers and indirect CO₂ but excluding LULUCF (land use, land-use change and forestry).
 (***) Excluding indirect emissions from electricity consumption.
 (****) Combustion emissions from all remaining transport activities including pipeline transportation, ground activities in airports and harbours, and off-road activities.

Source: (European Commission 2025d).

Figure A.39 – Density of the national railway networks in 2023, in metres of railway line per km

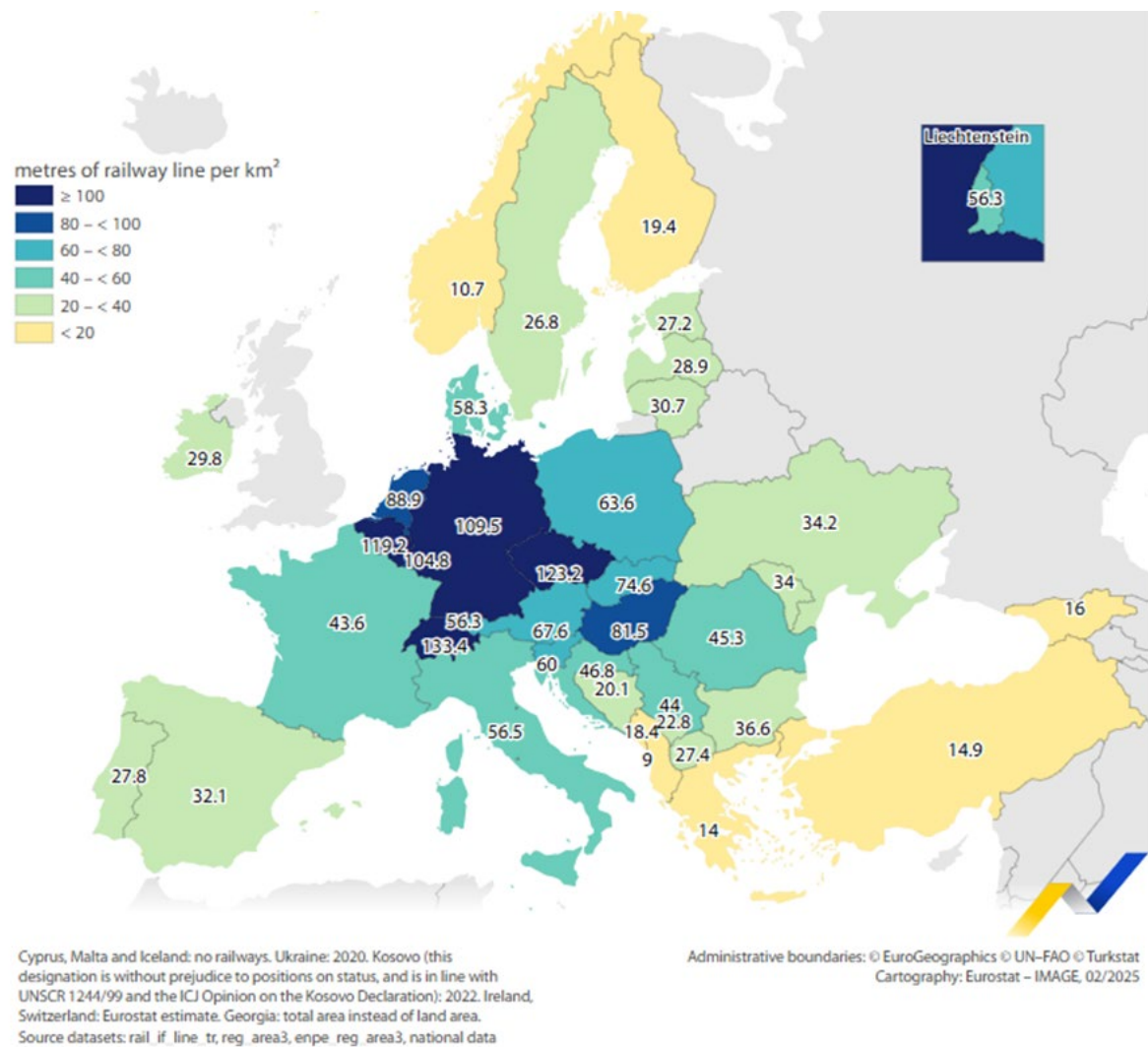
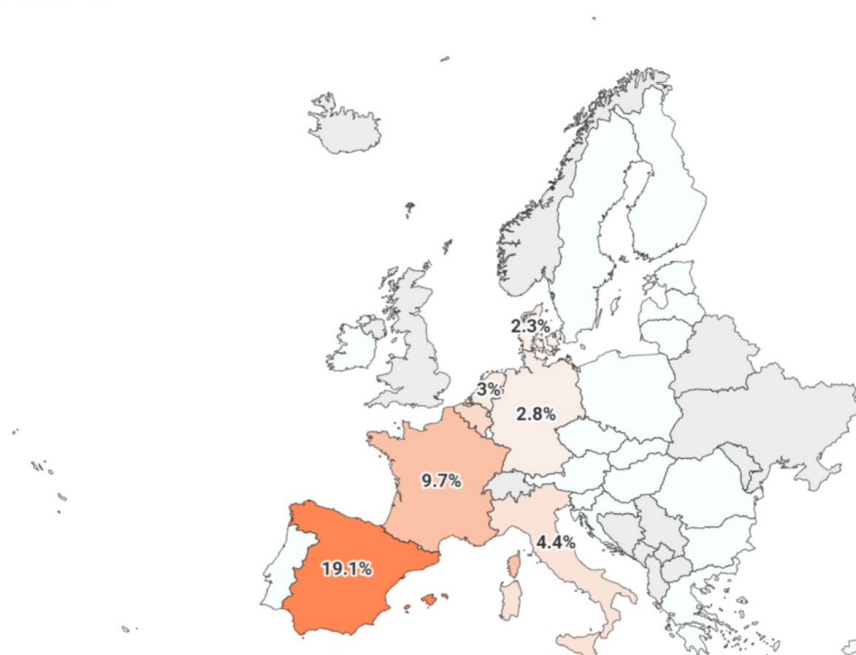


Figure A.40 – Share of high-speed rail lines as negative mirror image of rail infrastructure density

0 30 %



Source: Rico and Heyl (2025).

Figure A.41 – ETCS status per type of network and Member State, 2024

MS	TEN-T network (km)	ETCS in operation end 2024 (km)	Length commissioned with ETCS 2022 - 2024 (km)	ETCS in operation - Core (%)	ETCS in operation - Extended Core (%)	ETCS in operation - Comprehensive (1) (%)
Luxembourg	216	207	0	92%	100%	100%
Belgium	2 387	1 683	854	79%	66%	58%
Slovenia	987	389	0	72%	24%	0%
Czechia	3 200	1 062	554	46%	14%	17%
The Netherlands	2 513	354	0	36%	0%	3%
Austria	3 028	456	106	34%	5%	0%
Denmark	1 076	386	272	33%	N/A	56%
Hungary	3 667	597	255	29%	6%	6%
Spain (*)	14 672	3 011	505	28%	0%	7%
Slovakia	1 578	135	0	19%	0%	0%
Italy	11 622	998	186	17%	1%	0%
Sweden	5 240	588	126	15%	N/A	0%
Poland	10 261	737	143	15%	0%	0%
Bulgaria	2 437	209	0	12%	0%	0%
France	17 560	1 076	50	10%	3%	2%
Croatia	2 048	54	0	9%	0%	0%
Germany	15 116	445	102	5%	0%	0%
Romania	5 742	40	0	1%	0%	0%
Portugal (*)	3 216	0	0	0%	0%	0%
Greece	3 047	0	0	0%	0%	0%
Estonia (*)	1 158	0	0	0%	0%	0%
Lithuania (*)	1 986	0	0	0%	0%	0%
Latvia (*)	1 623	0	0	0%	0%	0%
Finland (*)	3 813	0	0	0%	0%	0%
Ireland (*)	1 796	0	0	0%	N/A	0%
TOTAL EU-27	119 988	12 426	3 153	17%	3%	3%

(*) Member States having most lines that are isolated networks

(1) Comprehensive network without considering Core or Extended Core network

Source: Ruete (2026).

Figure A.42 – ETCS deployment envisaged by Member State by 2030

MS	TEN-T network (km)	ETCS planned to be equipped by 2030 (km) - Core	ETCS planned to be equipped by 2030 (%) - Core	ETCS planned to be equipped by 2030 (km)	ETCS planned to be equipped by 2030 (%)
Luxembourg	216	117	100%	216	100%
Slovenia	987	475	100%	522	53%
Belgium	2 387	1 225	99%	2 261	95%
Austria	3 028	1 171	96%	1 629	54%
Denmark	1 076	875	93%	1 003	93%
Poland	10 261	4 479	92%	5 177	50%
Romania	5 742	2 561	89%	2 770	48%
Czechia	3 200	1 631	89%	2 565	80%
Slovakia	1 578	632	87%	632	40%
Portugal (*)	3 216	1 020	71%	1 222	38%
Italy	11 622	3 976	69%	5 908	51%
Hungary	3 667	997	60%	1 125	31%
Greece	3 047	979	55%	1 011	33%
Estonia (*)	1 158	212	52%	212	18%
Spain (*)	14 672	4 573	46%	4 972	34%
Lithuania (*)	1 986	344	40%	344	17%
The Netherlands	2 513	307	36%	354	14%
Germany	15 116	3 131	33%	3 676	24%
Bulgaria	2 437	566	33%	701	29%
Latvia (*)	1 623	271	29%	271	17%
Ireland (*)	1 796	127	29%	191	11%
Sweden	5 240	880	23%	880	17%
Croatia	2 048	132	21%	150	7%
France	17 560	1 733	20%	1 991	11%
Finland (*)	3 813	109	8%	596	16%
TOTAL EU-27	119 988	32 524	51%	40 378	34%

(*) Member States having most lines that are isolated networks

Source: Ruete (2026).

Figure A.43 – Overview of high-speed rail funding since 2000 by Member State and management mode

Member State	Grand Total		Programming Period 2000-06				Programming Period 2007-13				Programming Period 2014-20			
			Dire ct Mgm t	Shar ed Mgm t	Total	Total in %	Dire ct Mgm t	Shar ed Mgm t	Total	Total in %	Dire ct Mgm t	Shar ed Mgm t	Total	Total in %
Belgium	95.5	0.4 %	76.0	-	76.0	0.9 %	19.0	-	19.0	0.2 %	0.5	-	0.5	0.0 %
Bulgaria	259.4	1.1 %	-	-	-	-	-	259.4	259.4	2.7 %	-	-	-	-
Czech Republic	0.3	0.0 %	-	-	-	-	0.3	-	0.3	0.0 %	-	-	-	-
Denmark	90.4	0.4 %	8.4	-	8.4	0.1 %	82.0	-	82.0	0.8 %	-	-	-	-
Germany	2 693.9	11.4 %	377.9	12.2	390.1	4.5 %	492.3	351.8	844.1	8.6 %	1 459.7	-	1 459.7	27.8 %
Greece	1 050.9	4.4 %	-	241.9	241.9	2.8 %	1.0	308.3	309.3	3.2 %	499.7	-	499.7	9.5 %
Spain	11 232.2	47.3 %	197.5	6 175.8	6 373.3	73.3 %	299.4	4 264.3	4 563.7	46.6 %	295.2	-	295.2	5.6 %
France	2 004.7	8.4 %	252.9	-	252.9	2.9 %	814.7	101.6	916.3	9.4 %	835.5	-	835.5	15.9 %
Italy	2 042.5	8.6 %	195.7	241.0	436.7	5.0 %	608.1	-	608.1	6.2 %	997.6	-	997.6	19.0 %
Netherlands	104.6	0.4 %	98.3	-	98.3	1.1 %	6.3	-	6.3	0.1 %	-	-	-	-
Austria	996.6	4.2 %	39.6	-	39.6	0.5 %	308.7	-	308.7	3.2 %	648.3	-	648.3	12.3 %
Poland	1 996.7	8.4 %	-	-	-	-	1.9	1 710.6	1 712.5	17.5 %	-	284.2	284.2	5.4 %
Portugal	917.9	3.9 %	36.3	543.2	579.4	6.7 %	43.0	102.9	145.9	1.5 %	192.5	-	192.5	3.7 %
Slovenia	0.7	0.0 %	-	-	-	-	0.7	-	0.7	0.0 %	-	-	-	-
Finland	5.0	0.0 %	-	-	-	-	5.0	-	5.0	0.1 %	-	-	-	-
Sweden	6.6	0.0 %	-	-	-	0.0 %	4.6	1.9	6.6	0.1 %	-	-	-	-
United Kingdom	232.7	1.0 %	185.0	8.5	193.5	2.2 %	-	-	-	-	39.2	-	39.2	0.7 %
Not attributable	1.5	0.0 %	1.5	-	1.5	0.0 %	-	-	-	-	-	-	-	-
Grand Total	23 732.1	100.0 %	1 469.2	7 222.6	8 691.8	100.0 %	2 687.1	7 100.8	9 787.9	100.0 %	4 968.2	284.2	5 252.4	100.0 %

Note: Values in million euro in February 2018; paid / allocated amounts; cross-border projects' amounts allocated equally between the concerned Member States; in order to stay coherent across the table, the data are as recorded by the European Commission. Therefore, due to different methodologies, for audited Member States, they may differ from the values in the text of the Special Report; data exclude ERTMS support and EIB lending.

Source: (ECA 2018), see Annex II.

Figure A.44 – Cost overruns of rail flagship projects as part of the TEN-T core network

Transport Flagship Infrastructure	Special report 10/2020		Status in November 2025		
	Original estimate (in 2019 values) (a) ¹	Latest estimate (in 2019 values) (b)	Revised estimate (in 2019 values) (c)	% increase compared to SR 10/2020 estimate (c/b – 1)	% increase compared to original estimate (c/a – 1)
Rail Baltica ²	4 648	7 000	18 189	+ 160 %	+ 291 %
Lyon-Turin rail link	5 203	9 630	11 828	+ 23 %	+ 127 %
Brenner Base Tunnel	5 972	8 492	8 373	- 1 %	+ 40 %
Fehmarn Belt fixed link ³	5 016	7 711	7 630	- 1 %	+ 52 %
Basque Y	4 675	6 500	6 888	+ 6 %	+ 47 %
E59 railway line ⁴	2 113	2 160	1 737	- 20 %	- 18 %

Notes:

All cost figures have been reindexed at 2019 values using the year-appropriate price deflator from the Commission's [AMECO database](#).

¹ The original estimate is the earliest existing one for each TFI, which can correspond to a different scope or level of maturity of its design. As an example, the Lyon-Turin rail link was initially envisaged as a single-tube tunnel and afterwards designed as a two-tube tunnel; similarly, the estimate presented for the Canal Seine Nord Europe was identified before feasibility studies were conducted.

² The revised estimate refers to the completion of the entire TFI by 2030. The project has since been split into phases ([Box 1](#)).

³ The estimate was not revised by the project promoter since our 2020 special report. The different new value reflects only the indexation.

⁴ Costs excluding the Świnoujście-Szczecin section as in our 2020 special report.

Source: European Court of Auditors (2026).

Annex II – Overview of drivers and barriers

Table A.6 – Overview of the drivers

Driver	Section	Influence on
Market liberalisation	2.1.1, 2.1.3	Number of railway undertakings, market share of new entrants
Expansion of the high-speed network	2.1.1	Number of high-speed train connections
Competition	2.1.1	Service quality and cost efficiency
Effective management and allocation of rail capacity	2.1.1	Competitiveness of rail, in particular cross-border traffic
Electrification	2.1.2	Energy demand
Cost inflation	2.1.3	Average revenue per train-km of freight
Size and complexity of the network	2.1.3	Operational costs
Train utilisation	2.1.3	Operational costs
Condition and age of assets	2.1.3	Operational costs
Traffic management	2.1.3	Operational costs
Technologies used	2.1.3	Operational costs
Human resources needed	2.1.3	Operational costs
Network complexity	2.1.3	Capital expenditure
Capital intensity	2.1.3	Level of investment
Labour productivity	2.1.3	Level of investment
Limited resources and tools for cross-border capacity management	2.1.4	Lack of flexibility and market orientation
Introduction of OA competition	2.2.1	Decrease in ticket prices, increase in the quality of service, upgrade of amenities aboard trains
Decrease in ticket prices, increase in the quality of service	2.2.1	Attractiveness/demand for rail
Internal price competition and against rival air or coach options	2.2.2	Modal shift to rail
Urbanisation and congestion	2.2.2	Competitiveness of rail
Demand for intra-EU leisure trips	2.2.2	Demand for rail
Environmental awareness	2.2.2	Demand for rail
Digitalisation	2.2.2	Integrated ticketing platforms
Passenger demand for seamless multi-modal travel	2.2.2	Integrated ticketing platforms

Driver	Section	Influence on
Phase-out of coal transport	2.2.3	Negative impact on Bulk-market segment
Rise of just-in-time logistics	2.2.3	Decline in SWL transport
Decline in SWL transport	2.2.3	Conventional goods market
Growth in maritime and intermodal transport	2.2.3	Competitiveness of and demand for rail freight
Demand for low-carbon rail transport	2.2.3	Competitiveness of and demand for rail freight
Reduction of cross-border issues (low speeds and interoperability problems)	2.2.3	Competitiveness of and demand for rail freight
Intra- and intermodal competition	2.2.3	Rail freight pricing
Increase of energy prices	2.2.3	Increase in prices (across all modes)
Shortage of drivers for both trucks and trains	2.2.3	Increase in prices (across all modes)
Rail locomotives are becoming increasingly expensive	2.2.3	Increase in prices (across all modes)
Quality of the network	2.2.3	Advancing multi-modal logistics integration
Density of the network	2.2.3	Advancing multi-modal logistics integration
Four railway packages	2.3.1	Liberalisation and integration
Rail Freight Corridors Regulation	2.3.1	Coordinated cross-border freight and operational management
Connecting Europe Facility (CEF)	2.3.1	Financial support for rail projects
Social and training legislation	2.3.1	Facilitation of the movement of train drivers and other mobile workers
Technical legislation	2.3.1	Harmonisation of standards and the deployment of ERTMS, technical updates that support interoperability
European Green Deal	2.3.1	Incentives for modal shift
Fit for 55 package	2.3.1	Operating conditions for rail
Alternative Fuel Infrastructure Regulation (AFIR)	2.3.1	Deployment of electric and hydrogen refuelling infrastructure
Digital policy instruments	2.3.1	Data availability, interoperability, and security
Urban Mobility Framework	2.3.1	Integrated solutions in metropolitan areas
European Rail Traffic Management System (ERTMS)	2.4.1	Interoperability, punctuality, reliability, cost effectiveness, resilience
Future Railway Mobile Communication System (FRCMS)	2.4.1	Higher levels of ERTMS, ATO

Driver	Section	Influence on
Digital Automated Coupling (DAC)	2.4.1	Processing time reduction, improved safety, capacity gains, higher competitiveness, sustainability
Artificial Intelligence (AI)	2.4.3	Advance the automation of various processes (predictive maintenance, traffic management), ATO, reducing unplanned downtime, safety
Platooning	2.4.3	Significant impact on capacity
Industry 4.0	2.4.3	Efficiency, sustainability, safety, interoperability
Smart grid solutions	2.4.3	Energy efficiency, sustainability, operational resilience, cost and revenues

Source: Compilation by the authors.

Table A.7 – Overview of barriers

Barrier	Section	Influence on
Geographical obstacles	2.1.1	Suitability for high-speed lines
Speed limitations or additional stops	2.1.1	High-speed operation on cross-border connections
Interoperability limitations	2.1.1	High-speed operation on cross-border connections
Track gauge difference	2.1.2	Cross-border connectivity
Travel time	2.2.1	Attractiveness/demand for rail
Travel cost	2.2.1	Attractiveness/demand for rail
Lack of direct train connections	2.2.1	Attractiveness/demand for rail
Unclear passenger rights	2.2.1	Attractiveness/demand for rail
Poor integration and user-friendliness of the booking system	2.2.1	Attractiveness/demand for rail
Transport operators' reluctance to share dynamic fare and travel data	2.2.2	Integrated ticketing systems
Organisational complexity of the freight transport chain	2.2.4	Multi-modal freight services
Differences in operational rules	2.3.1	Seamless cross-border transport
Legacy national signalling systems	2.3.1.	Seamless cross-border transport
Administrative complexity	2.3.2	Seamless cross-border transport
Differences in business models and safety philosophies	2.4.1	ERTMS rollout
Safety certifications, data governance, and workforce skills	2.4.3	AI rollout, Industry 4,0 rollout
Regulatory challenges related to grid interaction	2.4.3	Smart grid adoption

Financial constraints	2.5	Lack of investment
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Source: Compilation by the authors.

Annex III – Synopsis of stakeholder consultation activities

The stakeholder consultation aims to collect diverse viewpoints on the future of railway transport in Europe from relevant stakeholders and experts in the railway sector. The interviews were conducted between December 2025 and March 2026. The stakeholder interviews covered a broad spectrum of actors across the European rail ecosystem, including EU-level research and coordination bodies, sector associations, regulators, social partners, national ministries, railway undertakings, technology providers, and academic experts. This ensured balanced coverage of policy, operational, social, technological, and passenger perspectives.

Trends

Stakeholders broadly agree that Europe's rail sector is experiencing strong **demand growth**, particularly in long-distance passenger markets, stated by nine interviewees, but that this momentum is **constrained by infrastructure capacity, maintenance backlogs and declining reliability**. Ten interviewees stressed that insufficient infrastructure capacity and chronic capacity backlog are the main constraint to rail growth. Without major renewal and selected new lines, demand growth cannot be absorbed. Six stakeholders mentioned that that passenger demand is strong and growing, especially for long-distance and high-speed rail, but that poor reliability and delays threaten this momentum. Moreover, five interviewees mention capacity scarcity as a systemic issue, affecting passenger services, freight competitiveness, military mobility, and modal integration.

Digitalisation and interoperability are widely recognised as essential enablers, yet their benefits are delayed by fragmented implementation and limited European coordination. Eight stakeholders mention that ERTMS, digital capacity management, automation and system integration are critical enablers of future capacity, efficiency and safety. Implementation is considered slow, fragmented, and institutionally complex by six stakeholders. Several stakeholders stress the need for stronger European coordination. Five interviewees argued that national optimisation still dominates, preventing effective cross-border services and a truly integrated European rail market.

Infrastructure renewal and resilience, including climate adaptation and security considerations, are increasingly shaping investment priorities. Interviewees consider climate adaptation and resilience (linked to security, cyber risks, and supply chains) relevant across short-, medium-, and long-term horizons. Five stakeholders urge to make climate resilience and adaptation integral to future rail systems.

Stakeholders express divergent views on **market organisation**, with tensions between competition-driven models and the conception of rail as a public service. Three interviewees see liberalisation and competition as essential for innovation, service quality, and cross-border growth, particularly in high-speed passenger markets). One stakeholder argued that rail should be treated primarily as a public good, not a competitive market and considers liberalisation as contributing to instability, especially in freight. Moreover, one stakeholder argued that resources should focus on high-density corridors and that underused or politically motivated lines should be reconsidered, while another stated that closing regional lines undermines climate goals and pushes travellers back to cars, arguing that basic network functionality must come first.

Regarding **rolling stock manufacturing and industrial policy**, three stakeholders argue that industrial consolidation has reduced competition, innovation and capacity, leading to higher prices and long delivery times. Global suppliers are seen as a necessary corrective. Conversely, two stakeholder think that maintaining a strong European rail industry is framed as strategically important, requiring coordinated European investment rather than reliance on global suppliers. Four

stakeholders raise concerns regarding rolling stock availability, highlighting high prices, long delivery times, and disproportionate impacts on new entrant operators.

Overall, interviewees highlight a growing gap between policy ambition and system capacity, calling for a stronger focus on execution, reliability and pan-European network thinking.

Drivers

Eight stakeholders identify **financing constraints** as the dominant driver shaping the rail sector's development, limiting the pace and scale of modernisation, digitalisation and expansion. They state that investment needs exceed available public resources, therefore limiting ambitions. Long-term maintenance funding is critical, as underinvestment leads to systemic degradation and declining reliability.

Policy and regulatory choices, particularly on pricing, taxation and infrastructure funding, are viewed as more influential than public environmental awareness alone. Seven interviewees argue that policy choices, rather than traveller preferences alone, ultimately determine modal outcomes. Pricing structures, taxation asymmetries and access charges strongly shape competitiveness, as stated by five interviewees. Climate ambition depends on enforceable regulation and sustained funding. Public interest in low-carbon travel is real, but price and service quality dominate behaviour.

Cost competitiveness and affordability remain decisive for rail demand, reinforcing calls to address asymmetries with competing modes. Five stakeholders highlight affordability as a primary driver of rail use, outweighing environmental motivation. Competition can reduce fares initially, but long-term effects are limited without complementary policy measures. Internalising external costs in competing modes is seen as critical.

Capacity expansion, including high-speed rail, is seen as essential to enable growth across passenger and freight markets by seven stakeholders. High-speed rail supports passenger demand while freeing conventional capacity for freight and commuters. Without new infrastructure, growth in both passenger and freight traffic will be constrained. Permitting, financing and industrial capacity are key bottlenecks.

EU-level coordination is considered a critical enabling driver. Five stakeholders stress that EU-level coordination and instruments are decisive drivers for overcoming fragmentation. National priorities often undermine TEN-T implementation, especially cross-border projects. EU co-financing levels influence Member State alignment. Joint Undertakings and EU-wide procurement are seen as mechanisms to reduce costs and scale innovation.

Digitalisation and automation are widely recognised as drivers, but their impact depends on large-scale, coordinated uptake rather than pilots alone, state five interviewees. **Research, innovation, and pre-deployment** are essential for long-term competitiveness, according to five stakeholders. Fragmented innovation efforts reduce European competitiveness. Universities and foundational research are often undervalued. Pre-deployment bridges are needed to move from prototypes to operations.

Workforce and skills shortages increasingly shape feasibility. Workforce and culture are critical but under-recognised assets according to five stakeholders. Three stakeholders mention human capital constraints are emerging as a binding driver for sector development. Shortages in operational and technical skills affect reliability and modernisation. Automation and digital coupling are partly driven by labour scarcity. Skills bridging legacy systems and new technologies are particularly scarce.

Divergent views persist on the role of **competition and market openness**, with tensions between efficiency-driven and public-service-oriented approaches. Six stakeholders see competition as the strongest driver for efficiency and cost reduction, provided system-level coordination mechanisms

exist. Three stakeholders argue that sustainability depends primarily on political commitment and funding, with competition playing a secondary role.

Uncertainties

Stakeholders identify **long-term funding stability** as the most critical uncertainty affecting the future of European rail. Nine stakeholders cited uncertainty concerns about whether sufficient, stable funding can be mobilised and sustained over long-time horizons to deliver rail ambitions. Rail investment cycles of over 20 years are misaligned with political cycles. Even where a special budget exists, funding remains insufficient. Underfunding risks delaying or scaling back high-speed rail, ERTMS, and capacity upgrades.

Significant doubts persist over the **timely and cost-effective delivery of the TEN-T network**, particularly for complex cross-border projects, as noted by five interviewees. Repeated delays and cost overruns undermine credibility. Cross-border projects are vulnerable to shifting national priorities, and long-term political commitment is seen as fragile.

Fragmented governance and divergent national priorities remain unresolved risks for system integration. Six stakeholders refer to this uncertainty as affecting performance, safety and efficiency. Split responsibilities between infrastructure, operators, and stations risk loss of system knowledge. The significant differences between national governance models complicate coordination, and voluntary cooperation between Member States is considered unreliable.

Four interviewees voice concern that **decarbonisation policies may outpace rail's capacity to respond to the demand**, potentially undermining modal shift objectives. Carbon pricing may shift demand faster than rail can respond. Without sufficient rolling stock, maintenance and capacity, rail may fail to deliver modal shift. Freight customers may revert to road if reliability declines.

Workforce ageing and skills shortages add further layers of uncertainty. Four stakeholders highlight human capital as a strategic uncertainty for system resilience and service continuity. The challenges include a large share of the workforce nearing retirement, difficulties attracting younger and more diverse talent, and skills gaps affect both operations and adoption of new technologies. Automation is seen as a partial mitigation, but several stakeholders stress that human presence remains critical for safety, service quality and passenger trust.

Five stakeholders mentioned **external and systemic uncertainties beyond the rail sector**: energy prices and energy availability; climate impacts and extreme weather; geopolitical instability and military mobility needs; and competition from other modes and emerging technologies.

Diverging views persist regarding **liberalisation and system stability**. Two interviewees adopt a critical view of liberalisation, citing excessive competition and fragmented responsibilities as risks to safety, flexibility and affordability, with reference to negative experiences in the UK. Four other interviewees are implicitly pro-market or neutral, focusing on funding and coordination failures rather than competition itself, suggesting liberalisation is not the primary uncertainty.

Technology is seen as a risk or opportunity. On one hand, two stakeholders view technological developments as opportunities with risks relating mainly to asset lifecycles and renewal. On the other hand, global competition (notably from Asia) and high-cost technologies such as maglev and hyperloop are seen as sources of strategic uncertainty.

Technology

Stakeholders broadly agree that **digitalisation and interoperability** are the most critical technological levers for improving rail capacity, safety and cross-border performance. Seven interviewees emphasise digitalisation – anchored in interoperable European systems – is the most

impactful technological pathway for rail. ERTMS/ETCS is considered foundational for capacity, safety and cross-border operations by ten interviewees. Digital capacity management, traffic management and automation depend on full ERTMS deployment. Fragmentation, governance and programme management, not technical maturity, are the main bottlenecks.

The main barriers to technological impact are not technical readiness but **fragmented deployment, governance complexity and investment constraints**. Six interviewees stress that most key technologies already exist or are maturing, but benefits are delayed by slow, fragmented deployment. Frequent change requests and unstable baselines undermine ERTMS rollout. Data-sharing barriers prevent full use of AI and predictive maintenance. Building on legacy systems and national divergence raise costs and risks.

Automation, including ATO and digital automatic coupling, is widely viewed as essential for addressing workforce shortages and improving operational efficiency, particularly in freight. Seven interviewees emphasise this point. While automation is welcomed for freight, shunting and urban rail, two stakeholders stress that human presence remains essential for long-distance passenger services, particularly for safety perception, assistance and resilience.

General-purpose digital technologies such as AI and digital twins offer significant benefits but raise concerns around certification, cybersecurity, energy use, and working conditions. Six stakeholders consider these technologies critical enablers as long as they are deployed responsibly. Digital twins and harmonised data models support lifecycle management and resilience. AI is valuable for maintenance and operations but faces certification, trust and energy concerns. Hereby, cybersecurity is becoming central as rail digitalises.

Seven stakeholders argue that **upgrading existing rail technologies** offers far higher returns than deploying radically new systems. High-speed rail is technologically mature; future gains lie in integration and operations. Moving block, ERTMS Level 3 and virtual coupling are seen as high-potential innovations. Battery-electric trains are already viable for regional non-electrified lines. In relation to traction, two stakeholders adopt a battery-first view stating that battery-electric trains combined with partial electrification are seen as more suitable for Europe than hydrogen. Conversely, two other stakeholders prefer hydrogen as a long-term option that remains on the agenda but faces cost, efficiency, and scale challenges. Energy scarcity and rising demand reinforce the importance of energy-efficient technologies such as ATO and optimised operations.

Radical alternatives such as hyperloop and maglev divide opinion and are generally seen as long-term, or niche options compared with upgrading existing rail technologies. Seven stakeholders consider hyperloop and maglev as costly, difficult to integrate, and likely to divert resources from core rail upgrades. Key concerns include the lack of interoperability with existing networks, high costs, long development timelines, uncertain sustainability benefits and limited network effects. Two stakeholders voiced exploratory or conditional support, seeing a potential for niche or long-term applications, with possible spillovers to rail, but only after standardisation and cost clarity.

Scenarios

Stakeholders converge on **strengthened coordination between Member States** as the most realistic and effective scenario for the future of European rail. Nine interviewees consider formalised coordination between Member States as the most realistic and effective scenario for the European rail system, preferable to both purely national approaches and full centralisation.

Full centralisation is widely seen as politically and operationally unfeasible by seven interviewees. Long asset lifetimes and local specificities require decentralised management. National ownership and responsibility are seen as unavoidable. Centralisation risks losing flexibility and local adaptation.

Corridor-based integration and cross-border prioritisation are viewed as the most promising pathway to deliver European added value by six stakeholders. Cross-border passenger and freight corridors deliver the highest EU value. Implementing decisions under the TEN-T Regulation are seen as promising tools. Poor coordination of works across borders is a persistent weakness.

Five stakeholders stress that European integration cannot succeed if national rail systems remain unreliable. **Failures in national performance** spill over to cross-border services. Investment in maintenance and operations remains essential.

International best practices offer inspiration but are not directly transferable. Five stakeholders caution against copy-paste models from Switzerland or Japan as their success is context-specific (geography, density, culture, governance). European systems differ fundamentally in spatial structure and legacy. Therefore, lessons should be adapted, not replicated.

Divergent views persist on the **role of alternative systems such as hyperloop**. Seven stakeholders view Hyperloop and maglev as, at best, complementary or niche elements, not central pillars of future European rail scenarios. Three stakeholders express that hyperloop and maglev could contribute disruptive ideas or serve specific corridors in the long term, depending on standards and economics. Four stakeholders state that high-profile alternative systems risk diverting attention and resources from pressing rail investments and advocate for prioritising completing and upgrading conventional and high-speed rail networks before pursuing radical new systems.

Additional divergence occurs in relation to how strongly **freight** should be prioritised within future scenarios. Only one interviewee explicitly advocated for stronger freight rights. Other stakeholders primarily focus on passenger integration.

Investment

Stakeholders broadly agree that **infrastructure renewal and selective capacity expansion** are the most urgent investment priorities for European rail. Ten stakeholders identify infrastructure investment, both renewal and selective expansion, as the most urgent and impactful use of funds. Large maintenance backlogs undermine reliability and capacity. Expansion is needed on high-demand corridors, especially where bottlenecks constrain growth. Digitalisation and rolling stock upgrades cannot compensate for poor infrastructure quality.

Public funding is seen as indispensable, given the long- time horizons, risk profile and public-service nature of rail investments. Nine stakeholders emphasise that public funding must remain the backbone of rail investment. Long asset lifetimes, high risks and public-service obligations limit the role of purely private finance. Rail investments deliver social, environmental and cohesion benefits beyond financial returns. Private capital can complement but not replace public leadership.

Rolling stock renewal and availability are emerging as binding constraints alongside infrastructure bottlenecks, as noted by six interviewees. Long procurement and testing cycles risk becoming a binding constraint. Modern rolling stock improves energy efficiency and system performance. Moreover, dual-mode and specialised freight wagons support resilience and military mobility.

European coordination, including joint procurement and pre-deployment investment, is viewed as key to improving efficiency and value for money by five interviewees. Pre-deployment phases reduce risk and accelerate uptake. Joint procurement can lower unit costs and align national roll-outs, with European financing instruments supplementing national budgets. One interviewee raised concerns about current EU funding structures, which may favour large incumbents and create vendor lock-in.

Four stakeholders call for renewed political attention to **freight** investment as port connections, terminals and last-mile links remain weak. Without public support, freight competitiveness will continue to erode.

Views diverge on the role of **public-private partnerships**. Three stakeholders adopt a critical view, stating that public-private partnerships risk higher fares, reduced accessibility and contractual rigidity that hinders long-term network evolution. Three stakeholders voice conditional support, noting that public-private partnerships and private capital can play a role in specific contexts if contracts remain flexible and risks are shared appropriately.

Regarding **investment in high-speed rail**, two stakeholders advocate for a cautious approach, stating that large-scale continental expansion risks overinvestment in politically motivated projects with limited demand. Three stakeholders support strategic expansion on high-demand corridors with strong political consensus and long-term planning.

Hyperloop and other experimental systems spark scepticism, with most stakeholders prioritising conventional rail investments, and only one interviewee stating exploratory interest.

Policy

Seven stakeholders emphasise that **stronger European coordination and coherent policy frameworks** are essential to unlock rail's full potential. Cross-border services require harmonised technical standards (ERTMS, rolling stock). Fragmented national approaches increase costs and slow deployment. Policy coherence across transport, climate, digital, competition and finance is critical.

Long-term policy stability is viewed as more important than short-term initiatives by five stakeholders, reflecting the long investment and innovation cycles of rail. Rail investment and innovation cycles extend beyond electoral terms. Multiannual instruments (e.g. CEF) are positive but insufficient on their own. Enduring governance frameworks are needed to de-risk innovation and deployment.

Cooperative models between operators are seen as more effective than competition alone in delivering cross-border passenger services by four interviewees. Pilot projects show that viable cross-border services often rely on cooperation. Market opening alone does not guarantee new international connections. Governance frameworks must allow both competition and cooperation.

Policy increasingly frames **rail as a strategic industrial sector**, linking transport objectives with competitiveness and resilience, according to three stakeholders. Rail is seen as a sector where Europe can maintain global leadership, but dependence on external suppliers poses risks in cybersecurity, signalling and rolling stock. Coordinated European demand can reduce costs and support industry scale.

Social acceptance and workforce involvement are seen as critical for innovation by three stakeholders, emphasising that innovation policies must actively involve workers to succeed. Technologies such as DAC are welcomed for safety benefits. Automation raises concerns about skill erosion and oversight. An ageing workforce makes upskilling and inclusion essential.

Stakeholders diverge on the role of **competition versus cooperation**. Three stakeholders adopt a cooperation-oriented view, stating that cooperation between operators can deliver cross-border services more effectively than competition alone. Two other stakeholders see competition as present but not the main policy constraint; capacity and finance matter more.

Divergent views persist on the role of **radical innovations such as hyperloop**. Four stakeholders hold a cautious or sceptical view, stating that hyperloop and maglev are unlikely to play a major role

in Europe's transport system in the coming decades and risk distracting from core rail needs. Two interviewees support continued research primarily for spillover and industrial benefits, while opposing large-scale deployment in the near to medium term. One stakeholder advocates for stronger political backing to avoid Europe losing technological leadership to Asia; Hyperloop could complement rail and aviation under hub-and-spoke models. Regarding the distributional impacts of innovation, one stakeholder stresses that the cost of innovation falls unevenly across Member States, with Eastern Europe facing greater financial strain. Another interviewee noted that benefits outweigh costs across stakeholder groups if cost-benefit allocation is fair and well designed.

Annex IV – Hyperloop

Hyperloop concept

The emergence of Hyperloop can be traced back to Elon Musk's white paper conceptualising it (Musk 2013), who did not further develop it. The idea, still under development by other actors, is a very high-speed transport system (i.e. over 1 000 km/h) consisting of capsules that exploit magnetic levitation to move seamlessly through low-pressure tubes (Hyper4Rail, 2024b).

More precisely, the main features expected by the system, are:

- transonic speed: the operational target should reach 1 200 km/h.
- high comfort: no turbulence or mechanical vibrations thanks to levitation.
- energy efficiency: drastic reduction in aerodynamic drag thanks to the low-pressure environment.
- operational sustainability: native integration with renewable sources and reduced maintenance costs due to the absence of rolling friction.

These are the main characteristics of the Hyperloop concept in its abstract form. In the following of this section, we will discuss how these concepts are (or could) become reality. To do that, we adopt three viewpoints: (1) Hyperloop as a technology to be developed, (2) as a transport network to be planned and operated, and (3) as a business model for enterprises developing it. Avoiding seeing Hyperloop only as a technology is important to define a European strategy, involving also substantial decisions on how network must develop and which is the preferable governance to be pursued.

Hyperloop as a technology

The Hyperloop system is expected to represent a paradigm shift for European infrastructure: no longer just a high-speed transport system, but an integrated, highly efficient energy network. The key to Hyperloop's energy superiority lies in the reduction of aerodynamic drag provided by the low-pressure environment inside the tubes. This physical parameter allows the system to operate with a much lower amount of energy than that required by aviation, but with speeds that are even higher.

Table A.8 shows the main components of the Hyperloop and sub-systems.

Table A.8 – Main components of Hyperloop systems and sub-systems

Guideway infrastructure	
Low-pressure tubes	Linear structure that connects hubs and maintains a near-vacuum environment (around 100 Pa) to minimise aerodynamic drag.
Support structures	Tubes can be built above ground on pillars, at ground level, or underground.
Magnetic switches (Turnouts)	Infrastructure components that allow pods to change lines or exit the main corridor at high speeds without slowing down.
Vacuum pumps	Electric pumps distributed along the track to extract air and maintain the operational low-pressure environment.
The vehicle (Pod)	
Pressurised capsule	The actual vehicle transporting passengers or cargo. It features an aerodynamic design to manage shock waves at high speeds.
Bogie	The part of the pod that houses the magnets and interaction systems for levitation and propulsion.
Environmental Control System (ECS)	onboard system that manages cabin pressure, oxygen levels, temperature, and air filtration, similar to aircraft life-support systems.
Propulsion and levitation systems	

Magnetic levitation	Devices using electromagnetic forces to eliminate physical contact with the track, reducing friction.
Linear motors	The propulsion system, typically either a Linear Induction Motor (LIM) or a Linear Synchronous Motor (LSM), which accelerates and decelerates the pod using magnetic fields.
Station systems	
Airdocks (Airlocks)	Specialised station interfaces that allow passengers or cargo to move between the pressurized pod and the ambient environment without compromising the vacuum inside the entire tube.
Stations	Points of entry and exit of passengers and cargo into the system, through the airdocks.
Energy systems	
Solar panels	Often integrated into the exterior of the tubes to provide clean energy, potentially making the system energy-sufficient.
Energy storage and recovery	Including onboard batteries and regenerative braking systems that return energy to the track or storage units during deceleration.
Operating, safety and emergency components	
Operating and control system	System that coordinates pod movements, manages headways, and handles pod-to-pod communication for safety, similarly to rail signalling systems.
Emergency exits and safe havens	Designated sections of the tube where pods can stop during a failure. These areas can be isolated and rapidly repressurized to allow passengers to evacuate safely.
Pressure valves	Located throughout the infrastructure to allow for controlled air intake in emergency scenarios.
Onboard emergency equipment	Including emergency oxygen masks, lighting, and communication links to the control centre.

Source: Elaborated by the authors.

The central element of this new transport system is the **low-pressure tube** through which the capsules can move at very high-speed. Maintaining low pressure conditions inside the tube is necessary to eliminate aerodynamic drag and achieve extremely high speeds (Galindo, et al. 2025). Therefore, the development of efficient and safe void machines is essential for the feasibility of the system.

Design optimisation, particularly the geometry of the **pod**, is crucial to mitigating pressure gradients. With reduced fluid dynamic resistance, the system must incorporate suspensions capable of eliminating residual mechanical friction (Abdulla, et al. 2025).

In addition to the geometry of the tube, minimising friction is fundamental in this transport system. The system therefore adopts **Maglev technology**, which is essential for ensuring contact-free movement, eliminating material wear and noise pollution. Electrodynamic Suspension (EDS) systems use high-temperature superconducting (HTS) magnets (Kurstjen, van Haken and van Mil 2022) and (Cho, et al. 2025)), capable of generating stable and powerful magnetic fields, ensuring operational safety at speeds exceeding 1 000 km/h. A Linear Synchronous Motor (LSM) is used for propulsion. Due to the characteristics of the system, a low-pressure environment and the capsule moving at very high speed, the use of pantographs and traditional overhead lines is technically impractical due to mechanical instability and the formation of electric arcs. From an energy perspective, power is supplied by WCSPE (Wireless Charging combined with Photovoltaic Energy) technology.

A critical component is the interface between the depressurized volumes of the tubes and the stations where passengers and operators move. The idea is that pods enter in **airdocks** where pressure is modified to let passengers board safely. Airdocks require switches and turnouts to deviate the pod from the main tube (Sanchez, et al. 2022).

To further reduce energetic impact, the outer surface of the tube can also be used to install flexible **photovoltaic panels** capable of supplying the system with the necessary energy (Chung, Hwang and Lee C. Y. 2025). The infrastructure is then transformed into an active power generator thanks to the integration of renewable systems on the vast surfaces of the track. Analysis of the energy potential shows that the outer surface of the tubes (diameter 2.5 metre) offers kilometres of space for the installation of photovoltaic systems. A stable foundation and a precise superstructure are essential requirements to support the load of the solar panels and the associated vibrations without compromising the magnetic alignment. This precision transforms Hyperloop into an asset capable not only of self-powering itself, but also of redistributing clean energy, dramatically improving the economic feasibility of the system (Hyperloop Development Program 2023a).

All of these components are at different TRL levels, usually TRL 6 or lower in the consulted sources ((Nøland 2024) and (Vesjolijs, Stukalina and Zervina, assessment of Socio-Economic Impacts of Hyperloop Technology on European Trade Routes 2025)). Apart single initiatives, there are programmes to push the development of the components at earliest stages, such as Hyper4Rail project. It is specifically designed to move missing or low-maturity subsystems from TRL 2 (i.e. basic principles) to TRL 4 (i.e. laboratory validation) by the end of 2026 (Hyperloop Development Program 2025a).

Hyperloop as a network

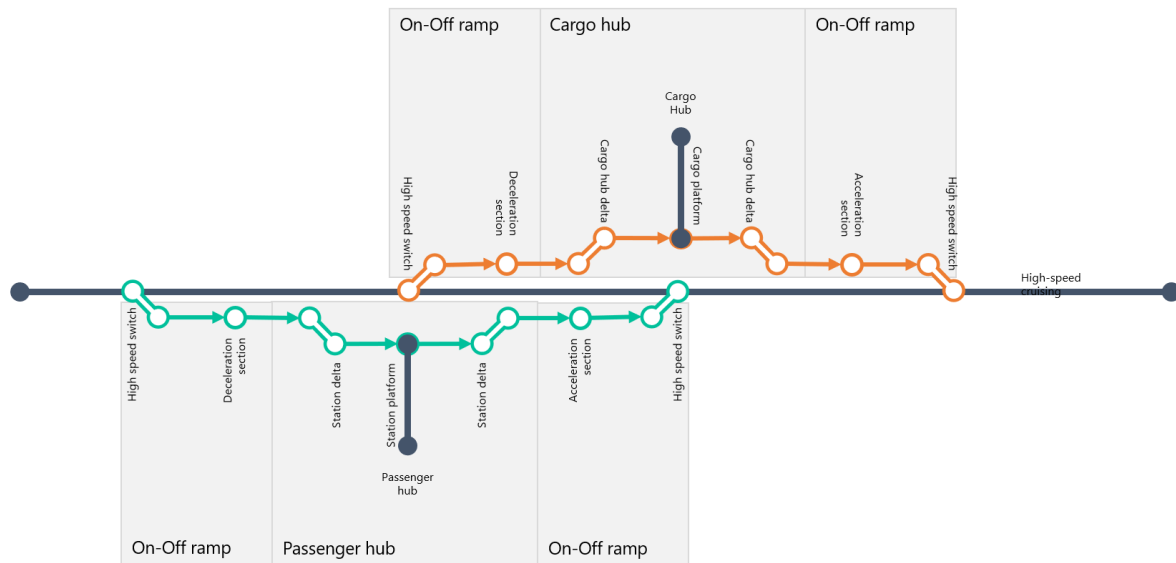
Hyperloop is conceived as a long-distance transport mean, potentially substituting or integrating both air and high-speed rail transport. Apart the technological aspects, how the network is structured and developed is of utmost importance for the functionality of the system and must therefore be conceived as soon as possible in the strategic phase.

Most of consulted resources focus on technological aspects. However, a few studies (mainly from Hyperloop Development Program) foresee how the combination of network and operations could look like, especially in consideration of the trade-off between maximum speed and stop distance.

In these studies, the segments of the system are specialised for HS cruise operations and for lower speed urban penetrations and interconnections. The assumption is that the pods can operate more freely than a train in terms of speed and routing, thanks to the existence of efficient switches allowing them to leave seamlessly the high-speed sections (at 700 km/h, (Hyperloop Development Program 2022a) and enter in the decelerating sections of the distribution subnetwork. **How these switches influence capacity and how long they should be, however, is not discussed yet**, but it is of utmost importance in the light of how rail capacity is impacted by line interconnections.

Assuming that the system will operate in this way, the typical Hyperloop operation will look as Figure A.45 shows: off-ramps extract pods from the main high-speed line, decelerate it up to a disembarking dock where passengers get off and on, and relaunch it in the mainline again. These features would allow to design the networks more freely, relaxing the need to have the stations along the high-speed tubes and consequently more freedom to define the alignments.

Figure A.45 – Passengers and cargo access processes



Source: (Hyperloop Development Program 2022a).

Different service concepts and network can be conceived. A first difference is between:

- a pure point-to-point service, comparable to that of low-cost airlines, connecting directly as much as possible OD pairs that have sufficient demand to be sustainable
- a network of legs not necessarily continuously connected, where the passenger's origin-destination (OD) network is composed by interchanging at hubs.
- continuous services, that include intermediate stops, similarly to a metro line.

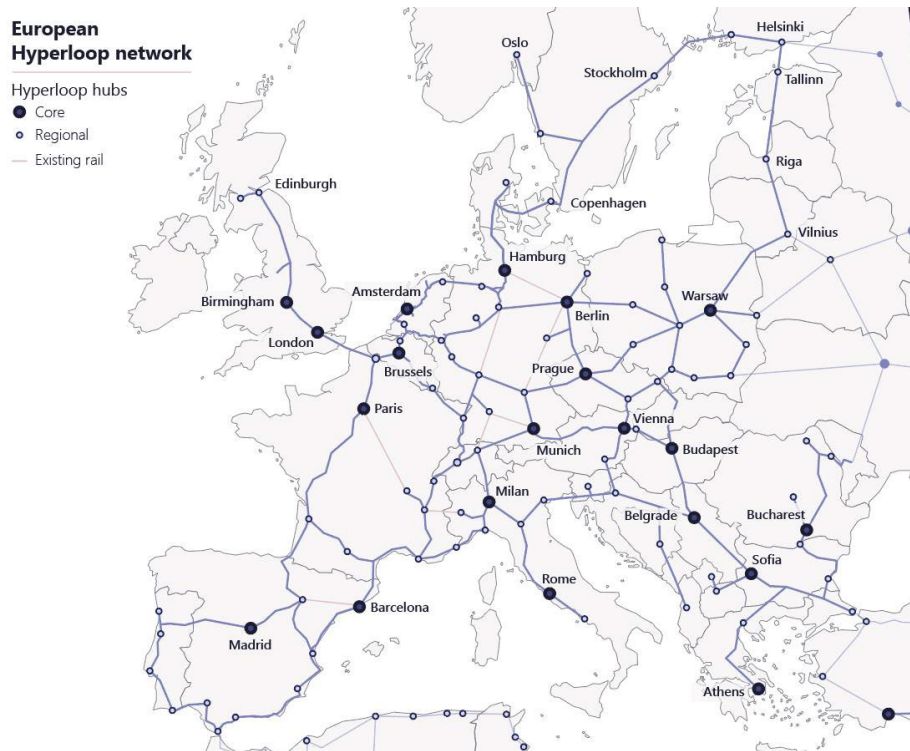
The low capacity of pods would suggest that the P2P model is preferable, as it would be the pod to switch among lines to destination and not the passenger. The drawbacks of this model are that not all OD pairs would be feasible and that capacity requirements (and thus network complexity) are much higher, not to mention the unjustifiable infrastructure cost if the demand is thin.

A second strategic choice is about infrastructural network and intramodality:

- Hyperloop as an independent system, competing with rail and air.
- Hyperloop as a complement of high-speed rail on missing links (Hyperloop Development Program 2022b).
- Hyperloop as an integrator of air transport, as feeder to main airports.

While the third model would look more feasible in the short run, consisting of potentially independent infrastructures easier to manage, the second model seems preferable in the long run, taking advantage of the lower capacity of Hyperloop making it more suitable as a complement of the European network where rail is not feasible. As Figure A.46 shows, this is the concept developed by the Hyperloop Development Program (Hyperloop Development Program 2022b), where the inclusion criterion is to be a 100 000 inhabitants city along main corridors.

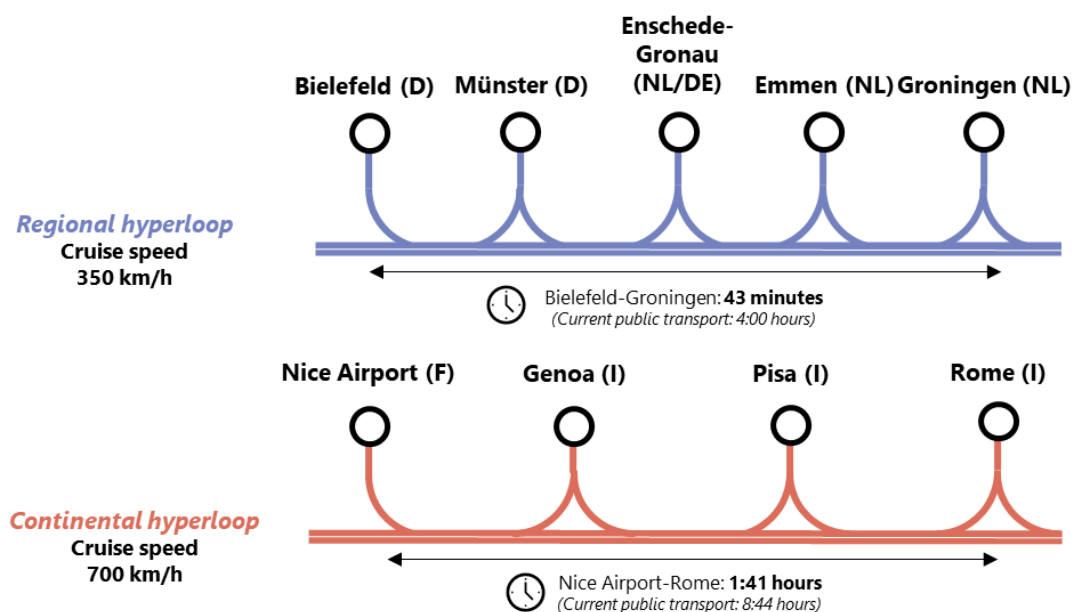
Figure A.46 – Proposed European Hyperloop network



Source: (Hyperloop Development Program 2022b).

While some references to "regional Hyperloop" operating at 350 km/h exist (Hyperloop Development Program 2023b), the technical and cost characteristics seem to go in the direction of a fast long-distance system, with a market overlapped to that of air transport (see Figure A.47). This poses the question of **intermediate territories**, that would be once again skipped by high-speed systems or whose connectivity is left to intermodal connections whose actual design is not yet at stake.

Figure A.47 – Regional and continental scale examples of Hyperloop services



Source: (Hyperloop Development Program 2023b).

A last question regarding the network is the way cities are physically connected. Recognised that, in European context, a system "far" or at the border of population hubs is not optimal as it would replicate one of the main limits of air transport, the possibility of deviating pods efficiently towards lower-speed last-mile sections make possible to leave main tubes out and at the same time guarantee urban penetrations. Figure A.48 depicts the concepts for one topology case (Hyperloop Development Program 2023b), where one secondary branch equipped with one terminal station serves the city centre without the need to cross the built area with the main tube. Again, whether this is feasible (the length of the decelerating sections must not be underestimated) and its impact on system's capacity are key issues still to be solved.

Figure A.48 – City network concept 2A: one Hyperloop station in the centre



Source: (Hyperloop Development Program 2023b).

Hyperloop as an enterprise

Hyperloop technology is not currently configured as a single and consolidated solution, but several companies and research programmes have emerged to develop it independently by integrating the required systems.

In Europe, Hardt Hyperloop, Zeleros, the Institute of Hyperloop Technology (University of Applied Sciences Emden/Leer), Swisspod Technologies (Swiss-American), the Hyperloop Development Program, Neoways, and the TUM Hyperloop research program (Technical University of Munich) are examples of this. In addition, physical assets have also begun to emerge, such as the 420-metre test track at the European Hyperloop Centre in the Netherlands. Currently, the US, China and South Korea are also investing in Hyperloop research and testing, with dedicated test tracks already in place in the United States. At the end of 2025, the following organisations were active (Hyperloop Development Program 2025a). Table A.9 presents the overview of the companies and research programmes developing Hyperloop systems.

Table A.9 – Overview of companies and research programmes developing Hyperloop systems

Category	Structure / Organisation	Place
Operational	European Hyperloop Center (EHC)	Netherlands
	goTube test facility (Università di Emden/Leer)	Germany
	ITT Madras test track	India
	TUM Hyperloop test track	Germany
	Datong Shanxi test track	China
	Nevomo test track	Poland
	Swisspod test track	Swiss
	Tubitak	Türkiye
Under construction	Chengdu test track	China
	DemoTube	Swiss
	Swisspod test track (Colorado)	USA
Planned	Progetto Veneto (Venice-Padua)	Italy
	Ciudad Real	Spain

Source: (Hyperloop Development Program 2025a).

A relevant European actor is the Hyper4Rail project, launched with the aim of standardising the system and harmonising technology. Funded by the Europe's Rail joint undertaking (EU-Rail) and coordinated by the Hyperloop Development Programme, the Hyper4Rail project brings together a consortium of 27 public and private organisations. Its main objectives are as follows ((Hyperloop Development Program 2024) and (Hyperloop Development Program 2025b)).

- to assess technological convergence towards a single European standard.
- to define a roadmap for industrialisation and market readiness by the end of 2026.
- develop a harmonised operations concept and common safety objectives inspired by railway and aviation regulatory frameworks.

Expected characteristics

Speed

The high hopes for a quantum leap in Hyperloop technology are based on theoretical estimates of maximum speeds ranging from 700 km/h to 1 200 km/h. The aim of the technology is to achieve very high operating speeds drastically reducing travel times over long distances (Kurstjen, van Haken and van Mil 2022). However, the standard cruising speed envisaged for the trans-European network called "Hyperconnected Europe" is 700 km/h. This speed is considered the optimal balance for connecting the continent's major cities, allowing it to compete directly with aviation in terms of door-to-door travel times ((Hyperloop Development Program 2022b) and (Hyperloop Development Program 2025a)) and acceleration and deceleration phases.

Despite these objectives, the development is not yet such to allow to estimate today the speed that could be achieved in actual operations. These conditions depend firstly on passenger comfort, which is influenced by the maximum acceleration that the capsule can achieve, secondly on the characteristics of the infrastructure, and ultimately by the circulation management in case of intensive use of the tubes. These parameters generally determine the acceleration and deceleration phases, the distance between stations, safety margins and network integration. European manufacturers of this technology estimate a realistic speed of between 300 and 500 km, unless the distances between stations exceed 200 km. On routes shorter than 100 km, technology promoters do not expect any speed advantage over conventional high-speed trains.

Table A.10 shows some tests that have been carried out on short tracks. They have shown that high speeds can be achieved, albeit far from the final target (Hyperloop Development Program 2023a) and (Hyperloop Development Program 2024b)).

Table A.10 – Tests carried out on short test track of Hyperloop

Organization/test	Result (year)	Location	Technical detail
CASIC	50+ km/h (2023)	Datong, China	210-metre tunnel test
CASIC	600+ km/h (2024)	Shanxi, China	2-km track record
Hardt Hyperloop	300 km/h (2023)	The Netherlands	Onboard propulsion prototype

Source: (Hyperloop Development Program 2023a) and (Hyperloop Development Program 2024b).

Infrastructure costs

Estimates of infrastructure costs vary by a certain margin, even if the optimistic estimates of early sources (Musk 2013) have been largely overcome. Recent sources estimate capital costs around €30 million per km of tube, but the type of alignment and the cost of stations induce significant additional variability (Hyperloop Development Program 2024b). This suggests that Hyperloop remains cheaper (i.e. €33 million per km) than high-speed railway (i.e. €37 million per km), however the immaturity of the technology should also suggest caution and total costs could be substantially higher. Table A.11 provides the overview of the estimates of infrastructure cost of the Hyperloop infrastructure.

Table A.11 – Estimates of infrastructure cost per km of tube

Infrastructure capital cost (per km of tube)	Primary source	Secondary source
€ 11.5 million	Musk, 2013	(Kurstjen, van Haken and van Mil 2022)
€ 25.7 – € 38.4 million	AECOM, 2020	
€ 12.3 – € 45.2 million	Delft Hyperloop V, 2021	
€ 33 million	Hardt Hyperloop, 2022	(Hardt Hyperloop 2022)
€ 39.2 million	Based on € 981 billion estimate for 25 000 km of lines	(Hyperloop Development Program 2022a)

Source: See primary and secondary sources indicated in the table.

At the EU level, these estimates would lead to a total infrastructure cost of €800–1 000 billion by 2050 for a complete Hyperloop network, excluding the construction costs of stations, which could be very relevant in function of local urban conditions, and the pods (i.e. the vehicles).

Estimates of the operating costs are even more uncertain, not depending only on the cost side, but also on the demand side. Delft Hyperloop has assumed the maintenance costs of the hyperloop tube alone to be €50 000–150 000 per km per year for an above ground tube and € 210 000–370 000 per km per year for an underground tube (Kurstjen, van Haken and van Mil 2022). An estimate of the total operating cost can be derived by (Hyperloop Development Program 2022a). They hypothesise €48 billion per year for the maintenance of a mature network of 25 000 km, which makes €1.9 million per km including operation. Taking for good their guesses of a demand of 1.3 trillion pax-km and 0.38 trillion of ton-km per year, it makes a unit operating cost of €0.003 per unit-km, much lower than high-speed rail. Clearly, this estimate is valid only if the expected 1.3 billion passengers travelling 1 000 km each truly materialise, but these figures look quite optimistic (especially the average distance).

Capacity

The capacity of the Hyperloop system would depend, as for rail, on the combination of vehicle capacity and vehicle frequency. According to currently available sources, there are several types of capsules, which may have different capacities (Sanchez, et al. 2022):

- Hyperloop S (Small): represents the lower limit feasible for passenger and freight transport, designed to assess the feasibility of a service in a 2.5-metre diameter tube. These capsules have a reduced capacity of approximately 8 passengers.
- Hyperloop M (Medium – Baseline Model): this is the model recommended as the reference standard (called M_EVO). Specifically, the M_EVO layout provides for a total of 42 seats: 24 in the standard cabin, 12 in business class and 6 seats reserved for passengers with reduced mobility (PRM) and their companions. Other variants designed for this model have capacities ranging from 37 to 46 passengers.
- Hyperloop L (Large): this is the largest version, which would allow for the transport of approximately 60 passengers. This model offers the best comfort and space for passengers but involves higher tube construction costs due to its larger diameter (approximately 4.3 metres).

The interior design of the capsules is generally comparable to that of a single railway carriage or a passenger aircraft cabin. The capsule can therefore accommodate a very limited number of people, especially when compared to a traditional train.

The Hyperloop system, therefore, focuses on high departure frequency to achieve the goal of high network capacity. Some service scenarios predict a departure frequency of one capsule every 120 seconds under normal conditions, which can drop to one every 30 seconds during peak hours. Thirty seconds is considered the absolute maximum limit necessary to ensure safety and avoid collisions in the event of emergency braking by the previous pod (Kurstjen, van Haken and van Mil 2022).

Various consulted sources provide a corridor capacity estimate (or rather a target) of 20 000 passengers per hour per direction (Dabrowska, et al. 2021) and (Hardt Hyperloop 2022)) referring to this number as a base for financial sustainability. This figure, however, is largely optimistic considering the operational constraints that literature itself suggests. A normal service scenario with 40 seats per pod and a headway of 120 seconds would allow a transport capacity of **1 200 passengers per hour per direction, which is substantially lower than rail**, compatible with just one high-capacity train per hour per direction. To reach higher capacity the operational constraints should be relaxed.

The reduction of headway to 30 seconds would rise to no more than 5 000 passengers per hour per direction (i.e. 3 360 per hour, (Rumin, et al. 2025)), which is again perfectly compatible with a rail system. Only the combination with the platooning of 4 pods every 30 seconds would give 20 000 pax per hour, but this encompasses technical, acceptance and safety issues (Rumin, et al. 2025). In conclusion, **commonly quoted estimates of 20 000 seats per hour per direction are**

overoptimistic and cannot be used as a reference. More likely capacity levels under safety conditions stay around **1 200–1 500 seats per hour per direction, which is lower than a normally used rail system.**

An additional element must be considered, even if not mentioned in literature. **Critical capacity points are the switches** between main line and off ramps, whose efficiency may reduce substantially the overall capacity (i.e. the feasibility of the mentioned headways of 30–120 seconds), and the secondary branches where pods are accumulating waiting for embarking operations like in an airport taxiway.

Energy and consumption

Again, energy consumption estimates are quite broad, as actual working applications are still unavailable. Hardt Hyperloop (Hardt Hyperloop 2022) estimates the energy consumption of a complete Hyperloop system at 38 Wh per pax-km at a speed of 700 km/h. The value is similar to the ones reviewed by (Rumin, et al. 2025), ranging from 10–50 Wh per pax-km. The US Department of Energy (Department of Energy 2021)) is more precautionary, ranging from 91 to 182 Wh per pax-km (converted from BTU/passenger-mile) in function of expected load factors (i.e. 30–70%). The Hyperloop Development Program provides an estimate of 29 kWh per km, equal to 34 Wh per km (assuming that it is referred to a pax-km).

The expected higher efficiency obtained by reduction of friction of wheels and air in the tube can be further improved if the tubes are used as energy generators through photovoltaic panels mounted on them. Using 50 Wh per seat-km (a relatively conservative estimate), the pod would consume 2 kWh/km.

We can elaborate a very rough estimation to verify the claim (Musk 2013) that Hyperloop is self-sustainable from the energetic point of view. Imagining mounting solar panels on the entire length of a tube, we can hypothesise 3 000 horizontal m² per km of tube.³³ Assuming production of ~1 700, ~1 250 and ~1 000 kWh per m² per year for South, Central and Northern European strips respectively,³⁴ we obtain a production of energy per km of tube of 687 000–954 000 kWh (South), 507 000–702 000 kWh (Centre), and 405 000–561 000 kWh (North). Dividing by 2 kWh/km driven by a pod, this power corresponds to the consumption of hundreds of pods-km per day. Then, if consumption estimates are correct, we can affirm that **an overground tube covered by solar panels can produce the energy needed for the traction of a number of pods compatible with the maximum system capacity.**

Towards a European strategy

In the previous sections, we have summarised the main features of Hyperloop technology considering the current state of development. The bulk of literature consulted focuses on technical issues, while sources discussing Hyperloop from a strategic/planning viewpoint are relatively few (among them: (Kurstjen, van Haken and van Mil 2022), (Hyperloop Development Program 2022b), (Hyperloop Development Program 2023b), (Kang 2026) (Vesjolijs, Stukalina and Zervina 2025a) and (Vesjolijs, Stukalina and Zervina 2025b)). Nevertheless, Hyperloop technology is already mentioned

³³ This must be used as an order of magnitude: if horizontal, the insulation would be constant but probably more complex from the engineering point of view. If adherent to the tube, the panel would be longer, but the insulation would be worse because of different orientations.

³⁴ South: ≈ 35–44°N, Centre: ≈ 44–54°N and North: ≈ 54–66°N. Global Horizontal Irradiation (GHI) for horizontal panels obtained from Photovoltaic Geographical Information System (PVGIS) by JRC (consulted February 2026). GHI is multiplied by a panel efficiency of 18–22% and a performance ratio of 0.75–0.85 including all losses.

in some relevant official European documents ((Draghi 2024) and (European Commission 2024) and included in EU General Budget for 2025.

In this section we will point out opportunities, issues and suggestions to setup a sounder European strategy on Hyperloop development and deployment.

Opportunities, challenges and issues to be considered

Hyperloop represents an innovation from three distinct points of view: it is a new technology, a new transport concept and network, and its development grounds on an innovative business model. On both the first layers, we can see it as a hybrid between high-speed rail and air transport: a land transport, potentially integrated with rail and air, whose speed, demand an organisational configuration is more like a point-to-point plane.

The system has some distinctive features that make it a potential game changer:

1. The top-speed sections (between 700 and 1 200 km/h) can be complemented with sections at lower speed for distribution and switching, avoiding building a system that suffer from the same first/last-mile inaccessibility of air transport.
2. If consumption estimates are correct, it is potentially self-sufficient from the energetic point of view.
3. Under some conditions, the investment cost could be slightly lower than high-speed rail. It can then be useful as an alternative where high-performance rail does not exist yet, integration is less necessary and potential demand is lower.
4. Operational costs could be lower due to energy efficiency and expected automation.

On the other side, significant challenges and structural limits must be carefully considered:

1. The technology is still at a relatively low stage of development, with some components at earlier stages (TRL2). This makes the moment in which the first commercial lines could be opened rather uncertain. Also, it must be considered that the model of decentralised R&D based on different Hyperloop enterprises working in parallel has the advantage of increasing the chances to develop the technology at its best but may pose the problem of lack of standardisation after the first lines are built.
2. The expected capital cost that is not significantly lower than a high-speed rail line (around € 30 million per km or more), especially where high-capacity is required (i.e. multiple tubes, many interconnections and switches). The capital cost per seat (see also following point) is then much higher than high-speed rail.
3. Despite often presented in non-technical documents as capable of transporting 20 000 pax per hour per direction, this estimate is today cannot be considered as realistic, because it assumes a number of developments that are not yet at stake: generalised use of platooning, operational headway of 30 seconds, super-efficient switches capable of not interrupting the flow of pods, and sufficient capacity at docking stations and deceleration segments to manage such flow. More reasonable estimates suggest maximum capacity levels at 1 500–5 000 pax per hour per direction, which is significantly lower than high-speed trains (at a similar capital cost). Consequently, Hyperloop does not look like *an alternative* for high-demand corridors, but at best *an option* for missing links and low-demand corridors, or *a competitor* of high-speed and air transport.
4. The urban integration of Hyperloop is often presented as an opportunity through catchy renderings, but the reality is that an overground tube with large stations (to accumulate pods in the docking phase) is not necessarily easy to implement in European cities. Of course, underground options exist, but at a higher cost, comparable to that of a metro system (so around €100 million per km or more, especially due to stations).

5. The above point makes the integration with existing rail stations challenging. Of course, integration is not necessarily occurring at central stations, but the interface rail/Hyperloop must be carefully analysed case by case and not oversimplified.
6. High-speed generates a trade-off with territorial coverage. Typical station distance for higher speeds is, according to sources, not less than 100-200 km, but probably more to benefit from higher speeds. Consequently, Hyperloop remains a substitute of high-speed rail and air transport *among large cities only*. In a continent where middle-sized cities and intermediate territories host a significant part of the total population (e.g. 60 % in Italy), Hyperloop is not a natural solution for the "left behind territories".
7. In communication campaigns the Hyperloop infrastructure is often presented as "modern" and with low visual and environmental impact. However, the visual impact of a couple of elevated 4-metre wide tubes in the landscape should not be neglected.

Elements for a sounder strategy definition

The development of Hyperloop concept is ongoing, and a significant effort is spent by various actors to develop the technology up to commercial readiness. At the same time, European institutions have considered the opportunity of being leaders in this race.

At the same time, Europe has some distinctive characteristics that must be carefully considered in defining a strategy, first the fact that it is the only continent, together with China, that has already an extensive network of fast rail connections. While the US is basically a greenfield, with no passenger long-distance public transport except airplanes and limited coaches, **Europe has been investing billions in the development of the high-speed rail network**, electrification, doublings and connections with airports. Therefore, the first decision on Hyperloop's role, if any, is whether it is an independent, commercially operated system (as in the original Musk's vision) or an integrator of rail transport. **The second case means that at a certain point it must be centrally planned by states and not left to developer's choices.**

From a planning and strategic point of view, then, the first necessary step is to define a European strategy, in particular clarifying the role of Hyperloop versus the rail and the actors that are more adapted to take the legacy of "early birds" independent developers.

The use of Hyperloop **to complete the missing links of the European HS network** is probably correct, **stressing the slightly lower capital cost, but accepting the significantly lower capacity offered**. Eastern Europe and Balkans could respond to the characteristics of not having yet fast rail lines and requiring huge investments to develop them in a context of limited demand. However, it must be clear that this means that the priority is not to develop Hyperloop between the strongest Western European urban poles, where traffic is the highest and commercial viability is easier, but starting from the fringes as a subsidised non-commercial system.

In the transitory period, say 20 years or more, it is likely that some Hyperloops will appear independently and unconnected, for example between strong city-pairs and to connect some airports. **This is the most logic option if the development is left to the market, which is an option, but the outcome could be a patchwork of subsystems** supporting or challenging rail case by case.

Urban integration, as repeatedly mentioned in this text, is a crucial issue that must be considered since the beginning. It is not an abstract aspect, that can be faced with visions and renderings, but a mix of engineering and urban planning aspects, involving huge trade-offs between capital cost, accessibility and impacts. While stations have been occasionally dimensioned in preliminary studies, the sizing of deceleration and taxi tubes is crucial.

Last, but not least, two political issues must be mentioned.

The concept itself of Hyperloop assumes that travellers need to travel at 1 200 km/h. That a cross-Europe door-to-door trip should require 2 hours instead of the 6 needed today. While moving faster and cheaper is universally desirable, policymakers should be careful in assuming that this is a need for the broader population. If the market can fulfil the mobility needs of hypermobile elites there is no larger political consideration, but if this requires billions of public expenditures, the distributive aspects must be carefully weighted.

Secondly, Hyperloop replicates the idea that Europe, and European transport planning, is a matter of connecting strong urban poles. **However, Europe is a continent of continuous development, where significant shares of population live, work and create richness independently from strong hubs.** While rail is intrinsically more capable, although not perfect, of serving also these intermediate territories through operational flexibility, developed legacy networks and lower speed services, this is yet to be demonstrated by Hyperloop systems. Of course, it is possible to decide that main urban hubs merit to upgrade (thanks to significant public expenditure) to very-high-speed systems, while intermediate territories must continue to rely on existing conventional rail. But again, given the amounts of investments needed and the option to distract it from conventional rail, this choice must be very carefully assessed.

This study examines the possible long-term trajectories of the European railway system by analysing the trends, drivers, and uncertainties shaping its evolution towards 2050. It explores how emerging technological, regulatory, economic and societal developments may influence the role of rail within a sustainable, resilient, and competitive European transport system. The analysis considers a range of plausible future configurations for the sector, assessing their implications for mobility, energy use, climate objectives, territorial cohesion, and infrastructure needs. Attention is given to the potential relevance of innovative transport solutions, including hyperloop and maglev, within different development pathways, considering their technical feasibility, regulatory requirements, and system-level impacts.

The study draws on scientific and grey literature and integrates insights from relevant stakeholders to capture diverse perspectives on the future of rail. By identifying policy options, the work aims to support long-term transport planning and investment decisions at EU level. The findings are intended to inform ongoing policy discussions on the transformation of the European rail sector and its contribution to the Union's wider competitiveness, sustainability, and connectivity goals.

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